arts

The Machine as Art/ The Machine as Artist

Edited by

Frederic Fol Leymarie, Juliette Bessette and G.W. Smith

Printed Edition of the Special Issues Published in *Arts*

www.mdpi.com/journal/arts

MDPI

The Machine as Art/
The Machine as Artist

The Machine as Art/ The Machine as Artist

Editors

Frederic Fol Leymarie
Juliette Bessette
G.W. Smith

MDPI • Basel • Beijing • Wuhan • Barcelona • Belgrade • Manchester • Tokyo • Cluj • Tianjin

MDPI

Editors
Frederic Fol Leymarie
University of London
UK

Juliette Bessette
Sorbonne University
France

G.W. Smith
Space Machines Corporation
USA

Editorial Office
MDPI
St. Alban-Anlage 66
4052 Basel, Switzerland

This is a reprint of articles from the Special Issues published online in the open access journal *Arts* (ISSN 2076-0752) (available at: https://www.mdpi.com/journal/arts/special_issues/Machine_Art and https://www.mdpi.com/journal/arts/special_issues/Machine_Artist).

For citation purposes, cite each article independently as indicated on the article page online and as indicated below:

LastName, A.A.; LastName, B.B.; LastName, C.C. Article Title. *Journal Name* **Year**, *Article Number*, Page Range.

ISBN 978-3-03936-064-2 (Hbk)
ISBN 978-3-03936-065-9 (PDF)

Cover image courtesy of Liat Grayver (www.liatgrayver.com).
A detail of her robotically-assisted painting “LG02”.

Contents

About the Editors

Frederic Fol Leymarie is a professor with the Department of Computing at Goldsmiths, University of London, where his focus has been on creative applications of computing. In this role, he has been instrumental in establishing Masters' degree programs in Arts Computing and Computer Games (in Programming as well as Art and Design); he has established collaborations with artists including Brower Hatcher, William Latham, Patrick Tresset, Rui F. Antunes, Carol MacGillivray, Daniel Berio, Memo Akten, and Terrance Broad; and he has also launched two related entrepreneurial ventures: London Geometry Ltd. (together with Prof. William Latham) and DynAIkon Ltd. (together with Prof. Stefan Rueger). Frederic received his Ph.D. from Brown University, Engineering Division, with a focus on 3D shape understanding.

Juliette Bessette is a researcher in art history (Sorbonne University, Centre André Chastel). Her research focuses on the impact of technical and scientific changes on artistic creation and history of ideas in the post-World War II era in Europe and the USA. She is also part of the project "Mass Media/Transmedia/Postmedia: research at the interface between arts and technologies" (DFK – Paris). She is a lecturer at Sorbonne University and at the Ecole du Louvre.

G.W. Smith is an English Literature major turned software engineer turned kinetic sculptor; the creator of the BLAST (blocked asynchronous transmission) data communications protocol; the founder of Space Machines Corporation, a kinetic sculpture and motion display consultancy; a contributor, as a techno-art theorist, to journals such as *Arts* and *Leonardo*; and the holder of two patents in the field of electro-mechanical display systems.

Foreword

In 1843, the renowned mathematician Lady Ada Lovelace, often known as the world's first computer programmer, published her famous "Notes" (Lovelace 1843), and which, remarkably, included some insightful visions on computational art.

The "Analytical Engine" was a mechanical computer designed by the inventor Charles Babbage in 1837. It was only partially built in that time, but this did not stop Lovelace from designing programs for it and theorizing on its potential. She had the insight to see that it could perform beyond just acting on numbers to solve equations, but could also conduct symbolic manipulation to perform true general purpose computing. She also had the vision to foresee that the Analytical Engine could be used to compose generative music:

> Supposing, for instance, that the fundamental relations of pitched sounds in the science of harmony and of musical composition were susceptible of such expression and adaptations, the engine might compose elaborate and scientific pieces of music of any degree of complexity or extent

or even that it could create generative imagery, "We may say most aptly, that the Analytical Engine *weaves algebraic patterns*, just as the Jacquard loom weaves flowers and leaves."

However, it is another of her rather controversial statements that I would like to recall:

> The Analytical Engine has no pretensions whatever to *originate* anything. It can do whatever we *know how to order it* to perform. It can *follow* analysis; but it has no power of *anticipating* any analytical relations or truths. Its province is to assist us in making *available* what we are already acquainted with.

Almost two centuries later, we are still grappling with this statement and still trying to understand our relationship with the machine. Is it simply assisting us to make available what we are already acquainted with? Or can it originate anything? Can it anticipate any analytical relationships or truths?

We are not the first to revisit these questions. In 1950, over a century after Lovelace published her "Notes", the famed computer scientist Alan Turing addressed these topics in his seminal paper "Computing Machinery and Intelligence" (Turing 1950). He reframed the question in the context of surprise, asking whether a machine could ever surprise us. He added, "Machines take me by surprise with great frequency". However, his main proposition—echoing his collaborator Douglas Hartree—was that in order for a machine to really create something original, it should have a property that would not have been available to Lovelace or Babbage. That property, he concluded, was the ability to learn, "Instead of trying to produce a programme to simulate the adult mind, why not rather try to produce one which simulates the child's? If this were then subjected to an appropriate course of education one would obtain the adult brain."

This idea, now known as machine learning, is the very concept that underlies the recent surge in the fields known as artificial intelligence (AI) and AI art (though this latter label has not been adopted by everybody, including myself, for reasons which will soon become apparent).

The academic field of artificial intelligence is rooted in computer science but spans many other disciplines such as psychology, neuroscience, statistics, and philosophy. Since the 1950s, AI researchers have been thinking about the properties required to be able to create 'intelligent' machines, and they have been designing and building computational models of such systems.

For a similar amount of time, artists have been independently investigating the role of computers in art, creating many overlapping subgenres such as computational art, generative art, (new) media art, etc. As early as the 1960s, artists such as Harold Cohen were already engaging with AI (McCorduck 1990), and as early as the 1980s, artists were using machine learning (such as evolutionary algorithms) for their artwork.

However, just as the mainstream emergence of the internet in the 1990s produced a new era in computational art known as net art, the last few years mark a new era in computational art. As I previously mentioned, this new wave is colloquially referred to by some as AI art. Since it only refers to very specific recent technologies, it would probably be more accurate to describe it as (the much less catchy) 'deep learning art'.

Deep learning is a form of machine learning based on large artificial neural networks and massive amounts of data. The algorithms date back to the 1980s (or even earlier depending on who you ask), but only recently has the technology been broadly accessible and practically useful at scale. This is due to the vast increases in computing power that we have recently developed, and the massive amounts of data now available required to train these huge neural networks. The underlying reason for this recent explosion in deep learning is the political and social climate that requires, supports, and funds this research; the primary purveyors of deep learning research are also the primary purveyors of the data economy and mass surveillance—both state-sponsored and commercial—such as Google, Facebook, Amazon etc.

This situates deep learning, whether as a medium, tool, or subject matter, in a very unique position, and with very particular challenges and opportunities for artists.

Any topic surrounding big data immediately raises questions regarding privacy and ownership. On one end of the spectrum, we have organizations infringing on the rights of their customers by stealthily harvesting, selling, and otherwise exploiting their data. On the other end of the spectrum, we have individuals (such as artists) creating work using data belonging to others. In between, we have combinations that present more complicated ethical and legal challenges, such as the use of a neural network designed by one person or group, implemented by a second person, modified by a third person, trained by yet a fourth on data owned by a variety of individuals and collected by a fifth person, and using scripts written by a yet a sixth (true story). This highlights that our old concepts of ownership or even authorship, and our legal and economic systems built on these concepts, are becoming obsolete in these new digital ecosystems.

Given that deep learning can be thought of as a technology that attempts to extract meaningful information from vast amounts of big data, any progress in deep learning thus has the potential to impact any enterprise that is big-data-driven. Currently, practically all of our enterprises are big-data-driven, from physics, chemistry, and biology to finance, psychology, and even politics.

These deep learning algorithms are notoriously inscrutable. Often referred to as black boxes, they are incredibly difficult to decipher and meaningfully control or correct if they give undesired outcomes. As Alan Turing himself said in his 1950 paper, "An important feature of a learning machine is that its teacher will often be very largely ignorant of quite what is going on inside." This is also why they are so powerful. This is precisely what makes these big-data-driven learning algorithms both terribly exciting but also desperately terrifying. We are already seeing the unexpected negative consequences of for-profit companies using closed-source, closed-data, proprietary software to make critical decisions affecting thousands, if not millions or billions, of lives. We already have algorithms in use deciding which job adverts to show people, and not only that, but actually learning from current salary schedules to be sexist, by showing higher paid jobs to men only. We already have platforms, such as YouTube or Facebook, algorithmically spreading targeted misinformation and increasingly extreme propaganda. Extrapolating into the future, the potential damage these algorithms can inflict does not require a vivid dystopian imagination.

However, these are also the technologies that will allow us to see beyond what we would otherwise be capable of seeing, just as the telescope allowed Galileo, quite literally, to look at the sky and see the solar system in a new light. By helping us see and understand patterns and meaningful information in vast amounts of data, these big-data-driven learning algorithms can contribute to breakthroughs in many different fields, from helping us cure our most awful diseases, to early warnings for earthquakes or other natural disasters, to suggesting solutions for the ecological crisis we are facing. Some of these breakthroughs are likely to be unimaginable by our current norms, like houses that can grow organically or cars that can photosynthesize!

The future is not yet written; it is up to us to write it. Ultimately, technologies are not separate entities that are external to us. They are part of us. They are extensions of our bodies, extensions of our minds, and extensions of our values. They are embedded within us, and we are embedded within them—the users who use them, the researchers that develop them, the organizations that fund them—they cannot be totally separated from the motivations behind their development and the values of those who support and promote them.

As artists, we are in a unique position to help shape, or at least envision, potential futures. As artists, we try to trod untrodden paths. We try to imagine alternative realities and futures. We try to see and share different perspectives. We even try to feel those different perspectives and enable others to feel them as well. To quote Golan Levin, Professor of Electronic Art at Carnegie Mellon University, we try to create art that "comforts the afflicted or afflicts the comfortable".

I myself, as a computational artist practicing for almost two decades, have been thinking about such topics for many years, and I have decided to focus specifically on these big-data-driven learning systems, with meaningful human control, for my Ph.D. The authors of the essays in this book, collectively, have centuries of experience between them in computational art and creativity. We realize that we are together entering a new chapter in this area of inquiry, and, in the context of machines that can learn from vast amounts of data, that revisiting the relationship between artists and machines, and between humans and machines, is more urgently needed than ever.

Memo Akten

www.memo.tv

References

Lovelace, Ada A. 1843. Notes by the Translator [of Luigi F. Menabrea's "Sketch of the Analytical Engine"]. In *Scientific Memoirs*. London: Richard and John E. Taylor, 3. Available online: https://www.fourmilab.ch/babbage/sketch.html (accessed on 4 April 2020).

McCorduck, Pamela. 1990. *Aaron's Code: Meta-Art, Artificial Intelligence, and the Work of Harold Cohen*. New York: W.H. Freeman & Company.

Turing, Alan. 1950. Computing Machinery and Intelligence. Mind, LIX (236): 433–460. Available online: https://academic.oup.com/mind/article/LIX/236/433/986238 (accessed on 4 April 2020).

arts

MDPI

Editorial

Trends and Anti-Trends in Techno-Art Scholarship: The Legacy of the *Arts* "Machine" Special Issues

Juliette Bessette [1,2,*], Frederic Fol Leymarie [3,*] and Glenn W. Smith [4,*]

1 Centre André Chastel, Sorbonne Université, Galerie Colbert, 2 rue Vivienne, 75002 Paris, France
2 DFK Paris, 45 Rue des Petits-Champs, 75001 Paris, France
3 Department of Computing, Goldsmiths College, University of London, London SE14 6NW, UK
4 Space Machines Corporation, 671 Startouch Dr., Eugene, OR 97405, USA
* Correspondence: bessette.juliette@gmail.com (J.B.); FFL@gold.ac.uk (F.F.L.); gsmith@space-machines.com (G.W.S.)

Received: 3 September 2019; Accepted: 11 September 2019; Published: 16 September 2019

Abstract: With the goal of casting a spotlight on the posture of the creative community at this crucial moment in human technological history, we present herein a thematic overview of the 23 articles published in the recent *Arts* Special Issues "The Machine as Art (in the 20th Century)" and "The Machine as Artist (for the 21st Century)". Surprisingly, several of the themes that had been suggested in our two introductory essays as representing shared and positive points of departure—in particular, (a) the visual arts as a longstanding touchstone of human culture, (b) the visual arts (with the example of John James Audubon) as having a unique ability to rally the public to the environmental cause, and (c) computer and robotic proficiency in the arts as leading to a friendlier artificial intelligence—received less than the expected amount of attention. Instead, it was another of the suggested themes (albeit also of a positive and forward-looking nature) around which our authors coalesced, as expressed in the following phrase: the "vast expansion of the creative sphere" which technology has made possible, or in other words, the idea that technology is not only providing new horizons for the professional artist but is also providing new avenues for the non-professional to discover his or her creative potential. In light, furthermore, of the marked enthusiasm for this theme, we suggest in our conclusion the need for a corresponding expansion of the venues available to both professional and non-professional techno-art practitioners.

Keywords: algorithm; artificial intelligence; computer-generated art; embodiment; emergent phenomenon; environmental crisis; GAN; generative adversarial network; machine art; neural network; techno-art

---

1. Introduction

The two *Arts* Special Issues "The Machine as Art (in the 20th Century)"[1] and "The Machine as Artist (for the 21st Century)"[2] ran nearly simultaneously (with the "Machine as Artist", in fact, launching three months before "The Machine as Art", in April 2017, and with a final shared submissions deadline of December 2018); and they were coordinated, as well, in respect to both (1) their coverage areas—the former addressing that period starting roughly in 1950, during which the machine became a legitimate artistic medium (as in the works of Nicolas Schöffer and Jean Tinguely), and the latter addressing the contemporary period during which the modern machine, the computer, actually began to participate in the creative process—and (2) their editorial approach, with the inaugural article in

1 Available online: https://www.mdpi.com/journal/arts/special_issues/Machine_Art.
2 Available online: https://www.mdpi.com/journal/arts/special_issues/Machine_Artist.

each Special Issue being an essay by the guest editor or editors setting out its scope and suggesting some potential themes as representing shared and positive points of departure.

Given, moreover, the interdisciplinary and speculative nature of the subject, a special effort was made to reach out beyond the art history community and to transcend the bounds of the typical research article. The results were most gratifying: the two Special Issues attracted a total of 23 articles, essays, and interviews by a variety of artists, art historians, engineers, and scientists, with many of them being notable individuals in their respective fields.[3] As such, the topics that they chose to pursue throw a spotlight on the posture of the creative community at this crucial moment in human technological history, and so, there follows a straightforward thematic overview of the two Special Issues. It must be stressed, however, that this should in no way serve as a substitute for a reading of the individual articles themselves, each of which—and to whatever extent our subject themes have been dealt with—reflects its author's or authors' hard-won insights.

2. Suggested Themes

With the understanding that humankind finds itself in an unprecedented situation—facing a technological future which is at once beckoning and frightening but at the same time sustained for the foreseeable part of that future by planetary ecosystems under grave threat[4]—it seemed advisable to us

---

[3] In alphabetical order by lead author.

Agüera y Arcas, B. Art in the Age of Machine Intelligence. Available online: http://www.mdpi.com/2076-0752/6/4/18.
Audry, S.; Ippolito, J. Can Artificial Intelligence Make Art without Artists? Ask the Viewer. Available online: https://www.mdpi.com/2076-0752/8/1/35.
Ballet, N. Survival Research Laboratories: A Dystopian Industrial Performance Art. Available online: https://www.mdpi.com/2076-0752/8/1/17.
Bessette, J. The Machine as Art (in the 20th Century): An Introduction. Available online: http://www.mdpi.com/2076-0752/7/1/4.
Broeckmann, A. The Machine as Artist as Myth. Available online: https://www.mdpi.com/2076-0752/8/1/25.
Carter, R. Waves to Waveforms: Performing the Thresholds of Sensors and Sense-Making in the Anthropocene. Available online: https://www.mdpi.com/2076-0752/7/4/70.
Edmonds, E. Algorithmic Art Machines. Available online: http://www.mdpi.com/2076-0752/7/1/3.
Edmonds, E. Communication Machines as Art. Available online: https://www.mdpi.com/2076-0752/8/1/22.
Gülzow, J.M.; Grayver, L.; Deussen, O. Self-Improving Robotic Brushstroke Replication. Available online: https://www.mdpi.com/2076-0752/7/4/84.
Hertzmann, A. Can Computers Create Art? Available online: http://www.mdpi.com/2076-0752/7/2/18.
LaViers, A.; Cuan, C.; Maguire, C.; Bradley, K.; Brooks Mata, K.; Nilles, A.; Vidrin, I.; Chakraborty, N.; Heimerdinger, M.; Huzaifa, U.; McNish, R.; Pakrasi, I.; Zurawski, A. Choreographic and Somatic Approaches for the Development of Expressive Robotic Systems. Available online: http://www.mdpi.com/2076-0752/7/2/11.
LaViers, A. Ideal Mechanization: Exploring the Machine Metaphor through Theory and Performance. Available online: https://www.mdpi.com/2076-0752/8/2/67.
Lijn, L. Accepting the Machine: A Response by Liliane Lijn to Three Questions from *Arts*. Available online: http://www.mdpi.com/2076-0752/7/2/21.
Lomas, A. On Hybrid Creativity. Available online: http://www.mdpi.com/2076-0752/7/3/25.
Moura, L. Robot Art: An Interview with Leonel Moura. Available online: http://www.mdpi.com/2076-0752/7/3/28.
Mazzone, M.; Elgammal, A. Art, Creativity, and the Potential of Artificial Intelligence. Available online: https://www.mdpi.com/2076-0752/8/1/26.
Nechvatal, J. Before and Beyond the Bachelor Machine. Available online: https://www.mdpi.com/2076-0752/7/4/67.
Rolez, A. The Mechanical Art of Laughter. Available online: https://www.mdpi.com/2076-0752/8/1/2.
Simmons, S. Drawing in the Digital Age: Observations and Implications for Education. Available online: https://www.mdpi.com/2076-0752/8/1/33.
Smith, G.W.; Leymarie, F.F. The Machine as Artist: An Introduction. Available online: http://www.mdpi.com/2076-0752/6/2/5.
Smith, G. W. An Interview with Frieder Nake. Available online: https://www.mdpi.com/2076-0752/8/2/69.
Still, A.; d'Inverno, M. Can Machines Be Artists? A Deweyan Response in Theory and Practice. Available online: https://www.mdpi.com/2076-0752/8/1/36.
Tosa, N.; Pang, Y.; Yang, Q.; Nakatsu, R. Pursuit and Expression of Japanese Beauty Using Technology. Available online: https://www.mdpi.com/2076-0752/8/1/38.

[4] As we are reminded by Teilhard de Chardin (1969), we still have "feet of clay".

as editors to go beyond a mere posing of the question, "Where do we stand, artistically and otherwise, vis-à-vis our machines?", by suggesting some themes in our respective introductory essays which would convey not only the gravity of the situation but also the possibility of positive action:

- The visual arts—and, by implication, the performing arts—as longstanding touchstones of human culture and thus of inestimable value as we face a flood tide of technology;
- The visual arts, amidst this same flood of technology, as having a unique ability to rally the public to the environmental cause;
- Computer and robotic proficiency in the arts as leading to a friendlier technology in general and, in particular, to a friendlier artificial intelligence, i.e., a technology informed by the cultural and human-centric approach of artists;
- Technology as fostering a "vast expansion of the creative sphere", i.e., as providing new creative opportunities for both professional and non-professional artists.

Surprisingly, the first three of these themes (Table 1)[5] received less than the expected amount of attention from our authors; and indeed, we as editors cannot avoid expressing some disappointment at their relative neglect. As society searches for some footing amidst the onslaught of technology, for example, one might suppose that the visual arts, which have existed in recognizable form for some 30 centuries (Gombrich 1996), would receive more notice on that account. Similarly, and amidst this same flood of technology, an apparent reluctance to embrace the utility of the visual arts in celebrating the natural world is likewise a mystery, although we might have done well to have used Ansel Adams as an example (Figure 1)—he of Sierra Club fame—in addition to John James Audubon. Even more puzzling was the following question: why is there not more interest in the idea that learning how to build aesthetic pathways into software (e.g., a sense of harmony and balance, attention to detail, and a concern also for the "big picture") is also a vital step in the creation of a human-friendly artificial intelligence?

Table 1. Major themes of the two *Arts* Special Issues "The Machine as Art (in the 20th Century)" and "The Machine as Artist (for the 21st Century)".

Theme	Number of Articles	
Expansion of the creative sphere via technology	20	××××××××××××××××××××
Human/machine partnership in art production	14	××××××××××××××
The algorithm as a significant factor	11	×××××××××××
Artificial intelligence as a significant factor	11	×××××××××××
Aesthetics as leading to a friendlier technology	8	××××××××
Algorithmization/technification of society as a concern	8	××××××××
Traditional visual arts as a phenomenon of long duration	5	×××××
Emergent phenomenon as a significant factor	5	×××××
Embodied experience as critical to our understanding	5	×××××
Machine as medium (in traditional sense of the word)	4	××××
Machine art as healthy challenge to human imagination	4	××××
Machine as producing legitimate art	4	××××
Art as contributing to protection of the environment	3	×××

Yet, such concerns are all but swept away in considering the outpouring of thought and enthusiasm given by our authors to the theme expressed in the following phrase: the "vast expansion of the creative sphere" which technology has made possible.[6] As set forth, for example, in a pair of definitive essays by two of our most prominent contributors, the technology of photography was initially seen as a threat

[5] The complete "Machines Special Issues Thematic Analysis" on which Table 1 is based and consisting of an article-specific breakdown of addressed themes, has been made available in the Supplementary Materials; however, it must be emphasized again that this beakdown was done on a discursive rather then rigorously logical basis, and that, in any event, all such systems of categorization are inherently problematical.

[6] Or—in the original French—"une large ouverture de la sphère créative" (Bessette 2018).

to the visual arts; and indeed, it did have a negative impact on portraiture and landscape painting. In the long run, however, the scope of the visual arts was in fact enlarged by this new technology, and in more or less obvious ways: with respect to the latter, the challenge posed to representational painting pushed artists in new directions and thus helped give rise to abstraction and expressionism; and in a more obvious manner, photography itself is now recognized as one of the fine arts, and in which capacity it has allowed a huge new cadre of individuals to discover themselves as artists, at both the professional—e.g., the aforementioned Ansel Adams—and amateur levels. This process, moreover, can be expected to repeat itself, and here, we refer in particular to neural net-based image generation: another of our flagship essays, for example, describes a generative adversarial network (GAN) system which might allow a new generation of individuals to discover their creative potential by empowering them to curate image collections beyond our current power of imagining.

In truth, such was the enthusiasm accorded this theme—with no less than 20 of our 23 articles touching upon it in some fashion—that, in retrospect, it must be admitted that this was a subject that our authors were ready to take up even in advance of our introductory essays. We are obliged, in turn, to inquire as to what deeper intuitions on their part might be thereby represented; and an answer readily presents itself: while perhaps ignoring a technologically-mediated environmental crisis, have not our authors chosen to weigh in on a parallel crisis, namely, the challenge posed by the machine to the human psyche? In choosing to emphasize the positive side of the equation—i.e., the idea that technology could help each of us reach our full creative potential (or, to use a term employed by author Blaise Agüera y Arcas, the idea that technology will at last "democratize" artistic production, such that it is no longer the province of an elite few (Agüera y Arcas 2017))—have they not also implicitly acknowledged its opposite (and this is perhaps something to keep in mind as we contemplate the unrest being experienced in some of our industrialized Western countries): the fear felt by many that they will be increasingly in competition with computers and robots for their respective positions within society?

Figure 1. *The Tetons and the Snake River*, by Ansel Adams, 1942 (Public domain image).

3. Other Themes

Returning now to Table 1 (and with the understanding that this is a discursive rather than a logically rigorous categorization), it can be seen that there are several other themes that gained a significant degree of traction among our authors, as elucidated in several noteworthy articles:

- The idea that human–computer partnerships can yield impressive artistic results (this is a subset of the "expansion of the creative sphere");

- The algorithm as a significant factor in current techno-art production, it being understood that, from a purely technical standpoint, this is what we are really talking about in most discussions involving the computer and/or artificial intelligence;
- Artificial intelligence as a significant factor in current techno-art production (and which, for the purposes of these Special Issues, might have been better referred to as "machine intelligence");
- The algorithimization/technification—or, to put it more bluntly, the de-humanization—of society as a concern;
- Emergent phenomenon—i.e., the ability of relatively simple systems to exhibit relatively complex behaviors, as with robot swarms or the current crop of AI algorithms—as another significant factor in current techno-art production;
- Embodied experience as critical to our understanding, i.e., the idea that the efficient organism—or robot—is best modeled as a system in which sensation, computation, and action are treated as a continuum rather than according to a Cartesian body–mind duality, and hence the utility of bringing the embodied arts such as dance into the picture when designing complex systems;
- The machine as a medium in the traditional sense of the word;
- Machine art as posing a healthy challenge to the human imagination (this is also a subset of the "expansion of the creative sphere");
- The machine as able to produce legitimate art.

The last of these, in that it represents the theoretical crux of our two Special Issues, demands some additional commentary; and in fact, at least two of our contributions describe systems for which the claim is made that they are capable, and on an essentially independent basis, of producing original and not-insignificant works of art. These, to be sure, are in both cases abstract paintings—on the one hand, produced by micro-robot swarms via the aforementioned (and quite real) phenomenon of emergence and, on the other, by the similarly aforementioned GAN system, as a function of it having pre-digested multiple works by human abstract artists; and the results—to the eye, at least (i.e., without rehearsing the several technical and philosophical discussions that our Special Issues have been fortunate enough to have attracted)—are truly impressive.

4. Conclusions

We would like to dedicate our conclusion to a single topic, as justified by its gravity: if we accept the idea that technology will continue to "expand the creative sphere"—and that this is an antidote to its disruptive tendencies—then it would seem to behoove us to advocate for the parallel expansion of opportunities for artists, both professional and non-professional, to exhibit works of techno-art. Or, more generally, it would seem to behoove us to advocate for much more exposure in the world art scene for the emerging category of what we could call "machine art": art practices that clearly and deeply engage with machines, including the design and use of software by and for human artists. If we as a society were to follow through with such a program, we might not only discover that the healing influence of artistic creation has in fact been significantly democratized but also that our own machines, in their continued evolution, have been given the opportunity to become friendlier and more human-aware entities.

Supplementary Materials: Machines Special Issues Thematic Analysis (http://www.mdpi.com/2076-0752/8/3/120/s1).

Acknowledgments: The authors would like to express our deep appreciation to all of our contributors.

Conflicts of Interest: The authors declare no conflict of interest.

References

Agüera y Arcas, Blaise. 2017. Art in the Age of Machine Intelligence. *Arts* 6: 18. [CrossRef]
Bessette, Juliette. 2018. The Machine as Art (in the 20th Century): An Introduction. *Arts* 7: 4. [CrossRef]
de Chardin, Pierre Teilhard. 1969. *The Future of Man*. New York: Harper & Row, p. 242.
Gombrich, Ernst. 1996. The Miracle at Chauvet. *The New York Review of Books*, November 14.

arts

MDPI

Essay

The Machine as Art (in the 20th Century): An Introduction †

Juliette Bessette

Centre André Chastel, Université Paris-Sorbonne, Galerie Colbert, 2 rue Vivienne, 75002 Paris, France; bessette.juliette@gmail.com

† Inasmuch as Paris was the epicenter of much of the history reviewed herein—as noted in the text, for example, the two leading machine sculptors of the 20th century, Jean Tinguely and Nicolas Schöffer, had moved there from, respectively, Switzerland and Hungary to launch their careers—*Arts* is pleased, via the link following, to make available as Supplementary Material the original French version of this essay: www.mdpi.com/2076-0752/7/1/4/s1.

Received: 2 November 2017; Accepted: 6 December 2017; Published: 23 January 2018

Abstract: The machine, over the course of the 20th century, progressively integrated itself into all fields of human activity, including artistic creation; and indeed, with the first decades of that century having established a surprisingly vital and wide-ranging series of perspectives on the relationship between art and the machine, certain artists in the wake of the Second World War no longer felt compelled to treat the machine as a mere theme or source of inspiration: the machine itself becomes art—unless it is art which seeks to become mechanical? The artist mutates into "artist-engineer"; and this transition, resonating within a specific historical context, leads not only to a questioning of the nature of the work itself, but also to a broader questioning which places us within the realm of anthropology: what is this art telling us about the actual conditions of contemporary human society, and what is it telling us about the future to which we aspire? It is the goal of this special issue of *Arts* to stimulate an historically conscious, protean, and global (re)thinking of the cultural relationship between man and machine; and to this end, we welcome contributions falling anywhere within the nearly infinite spectrum represented by the prismatic period during the middle of the last century in which the machine became a legitimate artistic medium.

Keywords: art; machine; science; technology; machine aesthetics; systems aesthetics; 20th century art history

---

As humankind finds itself afloat in a sea of technology, it is with newly attentive eyes that we look back to the pioneer machine artists of the middle of the last century—and we do so both to understand their vision, and to wonder what has become of it. What does the machine mean after the Second World War? The drama of the conflict, in which the machine was a central element, put an end to the techno-scientific utopianism that had been dominant in the Western world for several decades. Yet to this trauma is opposed a contrary force—that of the astonishing hope of reconciliation between man and machine; and it is amidst this tension that the proposition of "the machine as art" comes to occupy us here. If the current sense of the machine, that is, its association with modern technique, and indeed technology (as in speaking of the cybernetic machine), appears rather late, the word is originally derived from the Latin *machina*, which means an invention but which is also used in the sense of "work made with art"[1]. In the post-war period, this link with artistic creation is more ardent

---

[1] The technical meaning of the word "machine" is attested from the 16th century. It is then associated with the mechanism, and subsequently with automation. (Rey 1992).

than ever, when, despite the troubled relationship between man and machine, there has also emerged in the midst of its scientific and technological discoveries a huge expansion of the creative sphere.

This path was opened at the beginning of the century, and then unceasingly appropriated by later artists. John McHale, himself an artist, theorist and researcher, highlighted in the 1960s the artistic frontier so revealed:

> ... reacting more swiftly and intuitively to changes in his immediate environ, and being less hampered by academic specialization and professional commitment, [the artist] has been more attuned to new forms and technological potentials of our period. If Dadaism, Surrealism, Constructivism, and their later variants have sensitized the contemporary vision to the metamorphosis of cultural values, often through a savage and corrosive irony, they have also provided a usable mythology of the machine and an insight into its creative potentialities. (McHale 1969, p. 38)

The reflections developed during the interwar period by the Bauhaus, and as part of a larger formal inquiry corresponding to an epoch defined by the machine, find clear expression in the agenda that Walter Gropius described, in the mid-1920s, in these words: "Believing the machine to be our modern medium of design, we sought to come to terms with it" (Gropius [1925] 1965). The pivotal period of the 1950s tinged these reflections with a new color. It is clear that, in retrospect, this was a period of transition between a vision of the machine as an element external to man (the machine, or the representation of the machine, may well then exert an influence on the creative process—but from the outside—and thus giving rise to a discrete *machine aesthetic*), and our contemporary period, in which humankind, surrounded on all sides by technology, has established with it an unprecedented conceptual relationship.

This transition is clearly illustrated in the London of post-war reconstruction where, for example, the 1954 exhibition *Artist versus Machines*, organized by the group of English Constructivists,[2] "was important because it explored, in a vey positive way, the possible uses of machine-made materials and industrial techniques by abstract artists" (Grieve 2005). The British critic and historian of architecture Reyner Banham nevertheless delivers an acerbic comment[3], blaming them for remaining restricted to a formal approach with the machine, which is not approriate anymore to the contemporary period Banham designates, at this time, as a "Second Machine Age"[4]—a second industrial era in which the machine is, this time, fully integrated into the domestic sphere, and thus becoming omnipresent. The relationship between society and the machine takes on a new form: inviting us to plunge into the atmosphere of the time, and as always in his colorful and picturesque style, Banham remembers that "what appeared to be a second machine age as glorious as the first beckoned us into the 'Fabulous Sixties'—miniaturization, transistorization, jet and rocket travel, wonder drugs and new domestic chemistries, television and the computer seemed to offer more of the same, only better" (Banham 1980).

A number of artists, through initiatives sometimes individual, sometimes collective, give birth to a broad trend, protean in nature, and with Paris as the epicenter: the two big names of machine art, Swiss-born Jean Tinguely and Hungarian-born Nicolas Schöffer, had moved there to launch their careers, and it is in Paris as well that the early and important exhibitions of their work are held. But initiatives are also being launched from other artistic centers and will develop rapidly in the 1950s

---

2 *Artist versus Machine*. Building Center, Store Street, London, 19 May–9 June 1954. Exhibition organized by Victor Pasmore, Kenneth Martin, Robert Adams and John Weeks. John McHale also presents works. Re this exhibition, see Alastair Grieve's comprehensive article, (Griev 1990). One might also mention the important Paris exhibition, one year later, dedicated to kinetic art: *Le Mouvement*, Galerie Denise René, Paris, April 1955.

3 (Banham 1954), cited in Alastair Grieve, *Constructed abstract art in England, op. cit.*, pp. 29–30. He writes: " ... the welcome insistence on the virtue of new materials is sterilized and compromised by an all-too-frequent reliance on Simple-Simon geometrics which the Abstract Art of the twenties inherited from nineteenth century academic theory ... ".

4 (Banham [1960[1967). He writes: " ... we have already entered the Second Machine Age, the age of domestic electronics and synthetic chemistry, and can look back on the First, the age of power from the mains and the reduction of machines to human scale, as a period of the past." (introduction to the edition of 1967, New York, Praeger, p. 10).

and 1960s. It is precisely the various trajectories of this "machinic" renaissance of the middle of the century that this special issue of *Arts* proposes to explore.

One of the focal points for an analysis of this theme is New York's Museum of Modern Art during the winter of 1968–1969, in the form of an exhibition that takes place under the revealing name of *The Machine as seen at the end of the Mechanical Age*, and the catalog for which, with its famous metallized cover, remains an important resource for art historians[5]. Directed by exhibition curator Pontus Hultén (Figure 1), this catalog reviews the history of the relationship of Western artists to the machine, documenting various theoretical axes that are then developed in their relationship to technology, and illustrating many newly established forms of convergence between art and machine.

Figure 1. Pontus Hultén during the installation of the exhibition *The Machine as Seen at the End of the Mechanical Age*, Museum of Modern Art, New York, 1968. Around, works by Claes Oldenburg and Thomas Shannon. Photograph: Shunk-Kender © J. Paul Getty Trust. Getty Research Institute, Los Angeles (2014.R.20).

Despite the richness of the work, the initiative of Pontus Hultén can not be exhaustive. The number of artists who participated in the 1950s and 1960s experiments with the machine itself—namely, art involving actual mechanical articulation—far exceeded the scope of his exhibition, and represents a remarkably diverse group: Giovanni Anceschi, Marina Apollonio, Roy Ascott, Fletcher Benton, Davide Boriani, Martha Boto, Robert Breer, Pol Bury, Enrique Castro-Cid, Gianni Colombo, Lin Emery, Edward Ihnatowicz, Harry Kramer, Liliane Lijn, Heinz Mack, Kenneth and Mary Martin, Charles Mattox, Nam June Paik, Julio Le Parc, Bruno Munari, Robert Rauschenberg, George Rickey,

5 (Hultén 1968), 27 November 1968–9 February 1969, catalog under the direction of Pontus Hultén. (See here for photo of catalog cover: http://www.fondation-langlois.org/html/e/page.php?NumPage=1716).

Nicolas Schöffer, James Seawright, Thomas Shannon, Jesús Rafael Soto, Joël Stein, Takis, Jean Tinguely, Grazia Varisco, Gerhard von Graevenitz, David von Schlegell, Wen-Ying Tsai and Robert Whitman. If there is one name, for example, that of Robert Rauschenberg, which jumps out at us as not belonging in this listing, we will be perhaps astonished to discover that he not only created as soon as 1959 a wheeled sculpture—his "Gift to Apollo"[6]—but also, in 1963, a Tinguely-like motorized sculpture—his wire-framed "Dry Cell"[7]. Thereafter, the work he will complete with the collective *Experiments in Art and Technology* (E.A.T.), for which he is, in 1967, one of the founding members together with the artist Robert Withman and two engineers, Billy Klüver and Fred Waldhauer, will constitute a substantial contribution to the initiative we are discussing here[8].

At this stage is revealed the complexity faced by anyone who would venture to present a definition of "the machine as art", "machinic art", or "art as machine"—and which task is made even more daunting by the many new roles that art has been attempting to take on, and especially during the tumultuous 1960s. In the catalog for the exhibition *Metamatic Reloaded* at the Museum Tinguely, art historian Andres Pardey has nonetheless advanced these quite insightful designations: "Art is an interaction generator, process condenser, happening machine, adventure producer"[9]; and although it is of course beyond the scope of this brief introduction to address each of these functions, it becomes clear that it is not only the relationship between the artist and the work that is deeply modified and redeveloped, but also that between spectator and work, and between whom a real interaction takes place.

How can one understand such an upheaval when the machine as a medium does not correspond to anything in the framework of the canons of so-called "traditional" art? The criteria for judgment of this art must also be revisited: the machine is certainly neither painting nor sculpture, but can not, either, fall into the category of "minor art"; it belongs, in part, to a sphere external to the world of art, and its acceptance as such is therefore problematic. One must remember, furthermore, the historical context, which is that of the Cold War and a profound questioning as to the equilibrium between the human being and the forces of the machine. The experience of a "war of machines" and the nuclear disasters of 1945 gave rise to a feeling of helplessness in the face of a technology that had revealed itself capable of annihilating humankind. Playing with this truly human feeling, the Swiss artist Jean Tinguely ironically emphasizes that the machine is also capable of provoking its own annihilation: in the early 1960s, he designed works devoted to self-destruction, or "suicide machines". The most celebrated of these, entitled *Homage to New York*, was programmed to self-destruct during a 17 March 1960 performance in the MoMA sculpture garden. For French curator Henry-Claude Cousseau, "it is the triumph of the machine itself, capable of production and conception until its dismantling, and to control until then its existence and destiny" (Cousseau 2015).

The incisive work of Jean Tinguely (Figure 2) cannot be thought of as representing a single "spirit" guiding the artist in this era of the machine. On the contrary, the diversity of propositions regarding the machine as art is such that it would be difficult to grasp here the complete picture. The machines of Jean Tinguely, these moving sculptures, belong to the world of mechanics. In other cases, the machine is electronic, as with the hypnotic devices of Nicolas Schöffer, and about whom the art historian Arnauld Pierre observes that "in a time when humans had already entrusted to the machines so many other more delicate functions—notably cognitive and cerebral", his work tends to be nothing less than an "industrial production of the material of the dream" (Pierre 2015), that is to say, a penetration of the machine into the consciousness of the spectator. The drift towards this invisible machine also takes

6 See here for details on the work *Gift for Apollo*: https://www.rauschenbergfoundation.org/art/artwork/gift-apollo.
7 See here for details on the work *Dry Cell*: https://www.rauschenbergfoundation.org/art/artwork/dry-cell.
8 Robert Rauschenberg and Billy Klüver also initiated, in 1966, the *9 Evenings: Theatre and Engineering* program, supporting the establishment of interdisciplinary projects conciliating art and new technologies. As part of the same approach, one should also mention the *Art and Technology Program* established by Maurice Tuchman at the Los Angeles County Museum of Art.
9 (Pardey 2013), 23 October 2013–26 January 2014.

place through the advent of cybernetics[10], its conception of the world being based on *systems* of control and communication. Therefore, and in this context, there occurs a paradigm shift in the apprehension of the role and of the nature of the machine, "whose objective is no longer the accomplishment of work, of a mechanical task, but the processing of information" (Quinz et al. 2015).

Figure 2. Jean Tinguely with an early example of his "Eos" series. Photograph licensed under Creative Commons © ErlingMandelmann.ch.

This dematerialization of the machine is already identified by Pontus Hultén, who actually speaks, in the title of his 1968 exhibition, of the "end of the mechanical age". This tension is highlighted very early in the introductory text: the mechanical age lives fully its culminating phase but sees already the symptoms of its near end—this at the threshold of the 1970s, and which decade will see this phenomenon confirmed—as the importance of mechanics is progressively eroded by advances in electronics, electromechanics, chemistry, biotechnology and, in particular, *software*. For theorist Jack Burnham, this exhibition of Pontus Hultén draws a line of demarcation between "the earlier 'machine art' and what could be defined as 'systems and information technology'"[11].

In fact, that same year 1968 saw the publication by Burnham of his memorable article "Systems Aesthetics" (Burnham 1968b), in which he describes the transition—already prefigured in the development of cybernetics—from a culture of the object to a culture oriented towards systems: as the machine moves in the direction of dematerialization and ephemeralization[12], artists, in a corollary manner, show a growing interest in the system, and to the detriment of the object. In short, this trend can be considered as one of the symptoms of the end of the "golden age" of the art-machine as represented by Tinguely and Schöffer. In particular, an opening is created for more "conceptual" initiatives, as well as for many forms of artistic performance, but also for "virtual" art, and which can

10 In 1968, both John McHale and Jack Burnham expressed a great deal of interest in the exhibit *Cybernetic Serendipity* (ICA, London, 2 August–20 October 1968; Corcoran Gallery of Art, Washington D.C., 16 July–31 August 1969; Exploratorium, San Francisco, 1 November–18 December 1969), catalog under the direction of Jasia Reichardt (Reichardt 1968). The discipline itself was formally established in 1948 by Norbert Wiener (Wiener 1948).

11 (Burnham 1980). Burnham distinguishes between "the earlier 'machine art' and what could be defined as 'systems and information technology'", and he then goes on to elaborate: "The latter includes artists' use of computer and online display systems, laser and plasma technology, light and audio-sensor controlled environments, all levels of video technology, color copy duplicating systems, programmed strobe and projected light environments using sophisticated consoles, and artificially controlled ecological sites".

12 This artistic transition between the mechanical and the digital (computer art) also generates a geographical dispersion: digital art pioneers such as Frieder Nake, William Latham and Harold Cohen work, respectively, from Stuttgart, London and California.

be considered as both funeral director (in the sense of total dematerialization) and heir (in the sense of technology as interface) to the art machine.

Burnham will soon showcase some of these new developments in a 1970 exhibition entitled *Software: information technology: its new meaning for art*[13], and which is focused on a data-intensive approach to art. Originally to be entitled, in an obvious reference to Hultén's show, "The Second Age of Machines", the name under which the show was actually held places much more emphasis on the immateriality of information based processes.

For Burnham, what these new artistic forms have in common is that the focus is no longer on *things* (the art object) but rather on *process.* In a landmark book of the same period, *Beyond Modern Sculpture: The Effects of Science and Technology on the Sculpture of This Century* (Burnham 1968a), he describes how, in the context of systems art, the development of the relationship between art and technology is resolved within the larger culture and not specifically within the field of art. That is to say, this new relationship between the artist and the machine ends not in the creation of works of art, but in the creation of a *lifestyle*[14].

Nor is Burnham isolated in this approach; it is common to a variety of thinkers who are at the time connected to each other and whose attention is focused on the state of art brought about by the new information environment[15]. John McHale, for one, writes:

> The future of art seems no longer to lie with the creation of enduring masterpieces, but with defining alternative cultural strategies. But in destroying the formal divisions between art forms, and in their casual moves from one expressive medium to another, individual artists do continue to demonstrate new attitudes towards art and life. As art and non art become more interchangeable, ... the artist defines art less through any intrinsic value of the art object than by furnishing new concepts of life style.[16]

It is interesting to note that Hultén himself, in choosing to end his introduction to *The Machine as seen at the end of the Mechanical Age* with this quotation from McHale, also wishes, it would seem, to have his exhibition seen from a perspective which includes a focus on this new concept of lifestyle. According to this conception, in which new technological means are at the service of new forms of art, the arts—and it is again McHale speaking—"are no longer a canonical form of cultural communication restricted to specific elites and conducted according to specified rules and procedures ... The promise within the newer media is of a greater interpenetration and interaction of life-art-culture rather than the forms-objects-images that preserved and isolated social life (McHale 1969, p. 339)."

Yet even beyond this transformation of art into lifestyle—as, for example, in the vitality of conceptualism to which we have been a witness—the underlying presence of the machine as mechanical entity does not seem to have dissipated. We are realizing, in fact, that there is a strong symbiotic relationship between the mechanical machine and the electronic machine, and which in combination—as with the electronically enabled automobile—occupy such an important place in our daily lives. The machine, in other words, continues to have an ever-increasing physical footprint; but it was actually during the middle of the 20th century—the golden age of machine art—that humankind first becomes aware of the extent of the invasion of the environment[17] by technology. Moreover, for the

---

13 (Burnham 1970), New York, Jewish Museum, 16 September–8 November 1970; Washington D.C., Smithsonian Institution, 16 December 1970–14 February 1971; catalog under the direction of Jack Burnham.

14 This same term, "life-style", is used by Jack Burnham in his text "Art and Technology: The Panacea That Failed" (Burnham 1980, p. 213): "Nevertheless, avant garde art during the past ten years has, in part, rejected inert objects for the 'living' presence of artists, and by that I am referring to Conceptual Art, Performance Art, and Video Art. In the case of such artists as Chris Burden, Joseph Beuys, Christian Boltanski, James Lee Byars, and Ben Vautier, art and life activities have become deliberately fused, so that the artist's output is, in the largest sense, *life-style*."

15 This intellectual world also included at the time some other leading figures as, for example, John Brockman, Gene Youngblood, Douglas Davis, and Billy Klüver.

16 John McHale, as cited by Pontus Hultén in (Hultén 1968, p. 13). Probably derived, with some slight modifications, from (McHale 1967).

17 See, in particular, (McHale 1970).

first time, the undeniable vulnerability of humankind to these increasingly advanced technologies induces actual vertigo: the French anthropologist André Leroi-Gourhan remarks in 1983 that "what is happening in our world is without doubt grave, but the privilege of living during the generations that have been chosen to know the moment when man would find himself naked before his machines must command confident reflection (Leroi-Gourhan 1983)."

In the same way, we believe that the privilege of being able to participate in an investigation of a subject as fundamental as that to which this special issue of *Arts* is dedicated calls for a spirit of inquiry on the part of our contributors which, if not confident, is at least vigilant and conscientious. This inquiry, moreover—ongoing since the second decade of the 21st century—will make sense for us only to the extent that it corresponds to the development of our sense of rapport with the machine. A retrospective look at those who, half a century ago, included the machine in their creative activity seems now essential to writing the history of art; but more to the point, the present inquiry also represents a vital contribution to the question of a humanity seeking to navigate with assurance upon its ocean of technology.

Supplementary Materials: As noted above, the original French version of this essay is available at www.mdpi.com/2076-0752/7/1/4/s1.

Acknowledgments: The author would like to thank (1) Arnauld Pierre for encouraging me to take on this editorship, and (2) Glenn Smith for his support during the writing of this introductory essay.

Conflicts of Interest: The author declares no conflicts of interest.

References

Banham, Reyner. 1967. *Theory and Design in the First Machine Age*. New York: Praeger, p. 10. First published 1960.

Banham, Reyner. 1954. Match Abandoned. *Art News and Review* VI: 7.

Banham, Reyner. 1980. *Preface to the First Paperback Edition MIT Press*. Cambridge: MIT Press, p. 10.

Burnham, Jack. 1968a. *Beyond Modern Sculpture: The Effects of Science and Technology on the Sculpture of This Century*. New York: George Braziller.

Burnham, Jack. 1968b. Systems Aesthetics. *Artforum* 7: 30–35.

Burnham, Jack. 1970. *Software: Information Technology: Its New Meaning for Art*. New York: Jewish Museum.

Burnham, Jack. 1980. Art and Technology: The Panacea That Failed. In *The Myths of Information*. Edited by Kathleen Woodward. Madison: Coda Press.

Cousseau, Henry-Claude. 2015. Digressions sur les machines: Ingénieurs, bricoleurs et poètes. In *L'Art et la Machine*. Lyon: Lienart éditions, p. 46.

Griev, Alastair. 1990. Towards an Art of Environment, Exhibitions and Publications by a Group of Avant-Garde Abstract Artists in London 1951–55. *The Burlington Magazine* 132: 773–81.

Grieve, Alastair. 2005. *Constructed Abstract Art in England after the Second World War. A Neglected Avant-Garde*. New Haven and London: Yale University Press, p. 27.

Gropius, Walter. 1965. *Die Neue Architektur und das Bauhaus (The New Architecture and the Bauhaus)*. Translated by P. Morton Shand. Cambridge: MIT Press, p. 75. First published 1925.

Hultén, Pontus. 1968. *The Machine as Seen at the End of the Mechanical Age*. New York: Museum of Modern Art.

Leroi-Gourhan, André. 1983. Le fil du temps. In *L'illusion Technologique*. Paris: Fayard, p. 127.

McHale, John. 1967. The Plastic Parthenon. *Dot Zero 3* Spring: 4.

McHale, John. 1969. *The Future of the Future*. New York: George Braziller.

McHale, John. 1970. *The Ecological Context*. New York: George Braziller.

Pardey, Andres. 2013. From Méta-Matic to 'Métamatic Reloaded'. In *Métamatic Reloaded*. Heidelberg: Kehrer Verlag, p. 25.

Pierre, Arnauld. 2015. 'I am the Dream Machine'. Les écrans hypnogènes de Nicolas Schöffer. *Les Cahiers du Musée National d'Art Moderne*, 53, Winter 2014–2015.

Quinz, Emanuele, Jack Burnham, and Hans Haacke, dirs. 2015. Préface. In *Esthétique des Systèmes*. Dijon: Les Presses du Réel, p. 12.

Reichardt, Jasia. 1968. *Cybernetic Serendipity. The Computer and the Arts*. London: Studio International, Available online: https://monoskop.org/images/2/25/Reichardt_Jasia_ed_Cybernetic_Serendipidity_The_Computer_and_the_Arts.pdf (accessed on 17 January 2018).

Rey, Alain, dir. 1992. *Dictionnaire Historique de la Langue Française*. Paris: Dictionnaires Le Robert, entry for "Machine". p. 2082.

Wiener, Norbert. 1948. *Cybernetics: Or Control and Communication in the Animal and the Machine*. Cambridge: MIT Press.

arts

Editorial

Accepting the Machine: A Response by Liliane Lijn to Three Questions from *Arts*

Liliane Lijn

Independent artist, 93 Vale Road, London N4 1TG, UK; liliane@lilianelijn.com

Received: 4 June 2018; Accepted: 6 June 2018; Published: 11 June 2018

Abstract: Celebrated techno-art pioneer Liliane Lijn—whose participation in the landmark 1970 London "Kinetics" exhibition at the newly opened Hayward Gallery was but a waypoint in a long and adventurous career, and whose work is represented in the collections of Bern's Kunstmuseum, MoMA, and Tate—has prepared this essay on the evolution of machine art in response to three questions from G.W. Smith and Juliette Bessette of *Arts*.

Keywords: art; technology; electric motor; kinetic art

---

1. The Question of the Electric Motor

Arts:

As you know, Ms. Lijn, the thesis of our special issue is that a society which has now found itself afloat in a sea of technology must look back at the work of the techno-artists of the 1950s and '60s with renewed attention, and what we would like to focus on in this conversation is the apparently unlikely subject of the *electric motor*. And we use the ironic term "apparently," because even in the 1950s and '60s, the electric motor was at the heart of our civilization, powering our pumps and elevators and ventilation systems, and at this point in history—2018—we are, in truth, on the verge of the "golden age" of the electric motor, which will do no less than save our planet by replacing the internal combustion engines in hundreds of millions of automobiles! Even more to the point vis-a-vis this conversation, however, is the fact that you are among the earlier members of the second wave of 20th-century artists (Mellor 2005) to have employed the electric motor in their work (Table 1), and apparently the first woman.

We must not forget, furthermore, that it was this second wave of artists who achieved for machine art its own first "golden age," albeit under the banner of kinetic art, culminating in the landmark *Time* and *Life* magazine articles of 1966 (*Time* 1966; Fincher 1966). Could you, therefore, Ms. Lijn, honor our readers by painting a picture, within this context, of your own use of electric motors in your historic 1962–65 series of "Poem Machines" (Figure 1)?

LL:

I should begin by stating that my *Poem Machines* were not the first works in which I used electric motors. From 1960 through 1963, I lived both in New York and in Paris, and, as is the case when one changes habitat, there comes with this constant movement a feeling of temporal discontinuity. I spent much of 1961 and 1962 in New York, and in 1961, I worked on a series of kinetic tableaux that I called *Reflection Tableaux* (1961), in which I used small electric motors to revolve Plexiglas cylinders on which I had injected acrylic lenses. These led to the more complex *Echo-Lights* (1962), for which I devised small projectors in which light passed through a turning lens illuminating acrylic lenses on the surface of thick Perspex blocks, creating reflections that appeared to double and triple themselves. In these early works, I imagined that I was capturing photons, particles of light.

Table 1. A provisional chronology of electric motor use by early- to mid-20th-century artists.

Year	Artist(s)	Work(s)
1919	Naum Gabo	*Kinetic Construction (Standing Wave)*
1920	Vladimir Tatlin Marcel Duchamp	*Monument to the Third International* (model) *Rotative plaques verre (Optique de précision)*
1925	Constantin Brancusi	*Leda* (with integrated turntable base)
1930	László Moholy-Nagy	*Light-Space Modulator*
1931	Alexander Calder	*Pantograph* (one of a 1931–34 series)
1953	Pol Bury	*Plans Mobiles*
1954	Nicolas Schöffer Jean Tinguely	*Tour spatiodynamique cybernétique et sonore* *Element Detache Meta-mechanic Relief*
1959	Davide Boriani Gianni Colombo	*Superficie Magnetica* series *Strutturazione Pulsante*
1960	Harry Kramer	*Klingelmaschine*
1961	Takis	*Ballet Magnetique*
1962	Julio Le Parc Liliane Lijn Charles Mattox Grazia Varisco	*Continuel-Lumière-Cylindre* *Get Rid of Government Time* (one of the 1962–65 series *Poem Machines*) *Untitled* (*also referred to as Kinetic Sculpture)* *Schema luminoso variabile R.R. 66*
1963	Giovanni Anceschi Heinz Mack Robert Rauschenberg	*Strutturazione cilindrica virtuale* *Light Dynamo* *Dry Cell*
1964	Fletcher Benton Enrique Castro-Cid Joël Stein	*Trapeze Bobbie* (one of a series) *Anthropomorphic I* *Boîte lumière*
1965	Martha Boto Robert Breer Ken Cox Lin Emery Horacio Garcia-Rossi François Morellet Nam June Paik James Seawright Wen-Ying Tsai Gerhard von Graevenitz	*Essaim de Reflets* *Self-Propelled Styrofoam Floats* *Moving Letter Board* *Fledgling* *Structure P-N à lumière instable n. 8* *Wave Motion Thread* *Robot K-456* *Watcher* *Multi Kinetic Wall* *19 schwarze Punkte auf Weiss*
1966	Thomas Shannon David von Schlegell	*Squat* *Radio Controlled Sculpture*

Living in Paris from late 1958, I was able to experience a wide range of early kinetic art, as well as optical and pop art. In each area, there were artists who used movement. I did see Duchamp's spinning bicycle wheel and quite a few Calders, although the latter used air currents to induce motion. I don't think I have ever seen a work of Gabo's that uses an electric motor, and at the time, I had only seen illustrations of Tatlin's works and László Moholy-Nagy's wonderful *Light-Space Modulator* in books. I was present at the 1959 opening of Jean Tinguely's "Drawing Machines" at the Iris Clert Gallery, and saw numerous Pol Bury slow-motion works and a number of Takis's exhibitions and events, such as his *Fire Works* sculptures, shown on the square of Saint-Germain-des-Près. Takis's *Fire Works* sculptures did not use electric motors; instead, he used the explosions of the fireworks to spin the tops of his *Signals*. In New York, I saw electric motors used in Robert Rauschenberg's works, and Tinguely's self-destructive *Homage to New York* at MoMA certainly had any number of motors in its complex and very humorous structure. Like other materials, electric motors were available and already used by artists. I wasn't particularly drawn to their use by what I saw; that is, kinesis for and in itself did not particularly excite me.

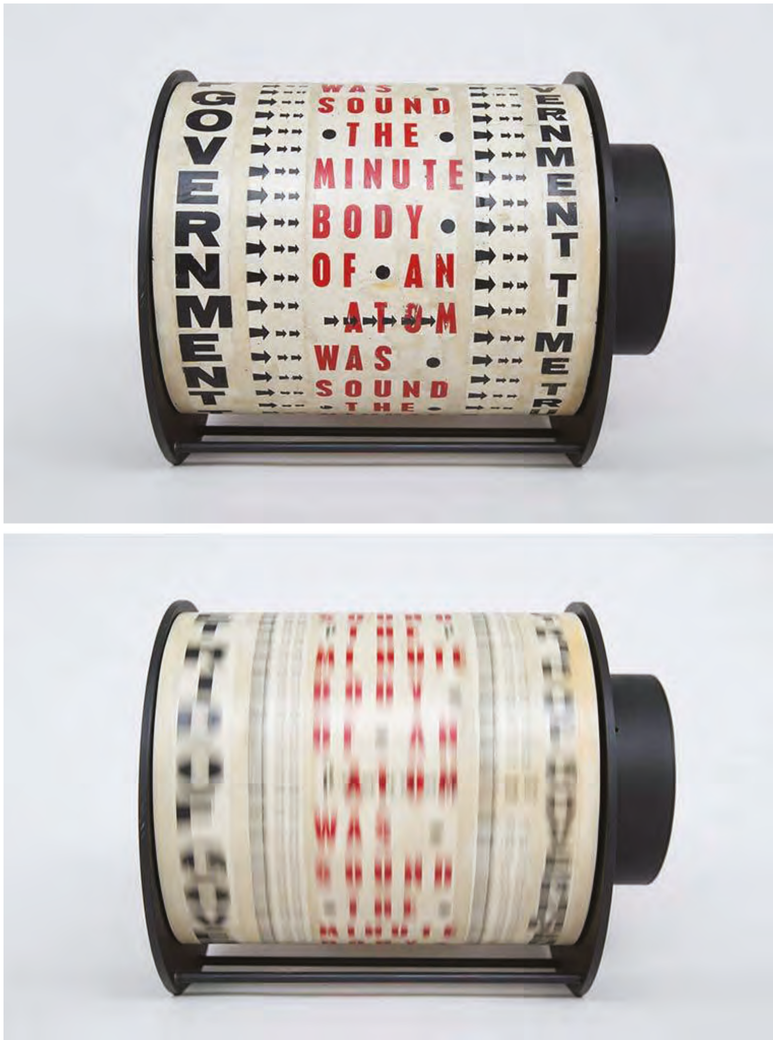


Figure 1. *Get Rid of Government Time* by Liliane Lijn, 1962; frame modified in 1965. Letraset on painted metal drum, plastic, painted metal, motor, 29.5 cm × 38 cm × 30 cm. Words from a poem by Nazli Nour. Photographs by Richard Wilding (2014) and used by permission. Collection of Stephen Weiss.

I did not come from a particularly technical background. There were a number of artists in my family; aunts and cousins who were painters, my father's cousin Stefan Temerson was a filmmaker and both a writer and a publisher, another cousin was second violinist with the New York Philharmonic orchestra. My father had an import-export business of watches and was later one of the first agents for Japanese transistor radios and the earliest Walkmans, but he was more interested in design and had no idea how they worked.

As I said, my *Poem Machines* were not my first use of electric motors. I had always been fascinated by the movements of reflected light, and in the summer of 1960, on a boat with Takis from Venice to Greece, I was delighted by the droplets of water that formed on the porthole window of our cabin. The luminous drops of water would throw flares of light across the glass of the porthole as the air currents altered their form, new ones being splashed on the glass and then slowly or even quickly spread and erased. I wanted very much to try to create a work that would give the same sensation of luminosity and creation, evanescence, dissolution and renewal. Then, in the autumn, when I returned to New York, I found a way to work with acrylic monomer, a clear viscous liquid plastic that, at first, I splattered across a sheet of Perspex. Then I did the same using clear Perspex cylinders, painting the inside white. I wanted these to turn, to create a visual effect something like the water on the porthole. I think that may well have been the first time I used a small electric motor.

More interesting perhaps was the first time I had to take a motor apart. It was sometime in 1963. Takis and I were sharing the very small maid's room atelier on the sixth floor of a house in rue Saint-André-des-Arts. Takis was in New York and I had the studio to myself. I was preparing works for my first solo exhibition at La Librairie Anglaise on the Rue de Seine, and Takis's assistant Raymondos was helping me. I had designed a small projector with a turning lens to light the works I called *Echo-lights*. Raymondos was helping me make this, but for some reason, on that day he was not in a good mood. The small motor I was using did not work, and he started to take it apart. After a while, thinking that he would break the motor, I complained that he was too rough. This infuriated him, and dropping all the bits down on the workbench, he told me in his inarticulate French that if I didn't like the way he handled things, I could just do it myself. With this, he walked out. I found myself with a motor that was now just a pile of small gears and pins, all the inner workings that I had never really examined before. At first I despaired and cursed my own impatience, but then I started carefully looking at each bit and, as with a puzzle, began to get a sense of pleasure in discovering how each part functioned. Eventually, I put them all together and the motor worked again.

Most of my works in motion were spinning or rotating like planets; wind would have been possibly less reliable. Although in 1970, I designed *Whirling Wind Koan*, a huge outdoor wind-driven conical and slatted sculpture that would also supply a small town with electricity. I think the reason I used motors, as opposed to wind, in the *Poem Machines*, *Poemcons*, and *Liquid Reflections* (Figure 2) was because I needed precise RPMs (rotations per minute).

Most of the first motors I used were bought secondhand. My earliest *Poem Machines*, like *Young Universe* and *Get Rid of Government Time* (1962), rotated extremely fast, so fast that the poems, the words, became blurred vibrations. I found that very exciting. As to the subject of whether they were left running or were viewer-activated when first exhibited in 1963, I am not entirely sure, but I think that for the first show of the *Poem Machines* I had them continuously spinning. As I've said, I was very excited by the energy that emanated from these verbal vibrations. I also remember that Nazli Nour was at first upset that people couldn't read her poems.

However, not all the *Poem Machines* had high-speed motors. There were some that revolved slowly enough to allow the text to be read and some that allowed the viewer to alter the speed. Most of my works at the time were made using secondhand drive systems. I was just beginning to work with motors, and at the time, I was interested in interactions between the work and the viewer. In 1965, I did buy a number of new record turntables and used these for the Poemcons that I began to make at that time. Since these vinyl turntables had four speeds, by moving a small switch left or right, the viewer could change the speed of rotation and observe the effect of this change on the words. I felt I was looking at the sound of the poems, *seeing sound*, as I wrote in my *Poem Machine* manifesto in 1968. Using record-player turntables also seemed conceptually fitting, since they played the sounds that had been physically transcribed on the vinyl surfaces, discs that then spun, sounds encoded in their fine concentric circles.

I am not sure whether there was a mystique about motorized art in the 1960s. On the whole, I would say kinetic art was distrusted by curators and art dealers, with only a very few enterprising gallerists, such as Denise René and Howard Wise, taking the bold and risky step of exhibiting art that was motorized. Movement implied change and disruption of the way things had been and were; demanded attention and care or maintenance. There was certainly a distinction between artists who created static works that depended on the movement of the viewer to create certain optical effects and artists who used mechanical means to introduce motion. The works of the former were usually spoken of as "op art" as opposed to the latter, "kinetic art." I don't think the term "machine art" was used, except perhaps by E.A.T. (Experiments in Art and Technology) in the US. I may be very wrong here, because I am not adept at cataloguing groups and movements. I have never much liked the "kinetic" moniker.

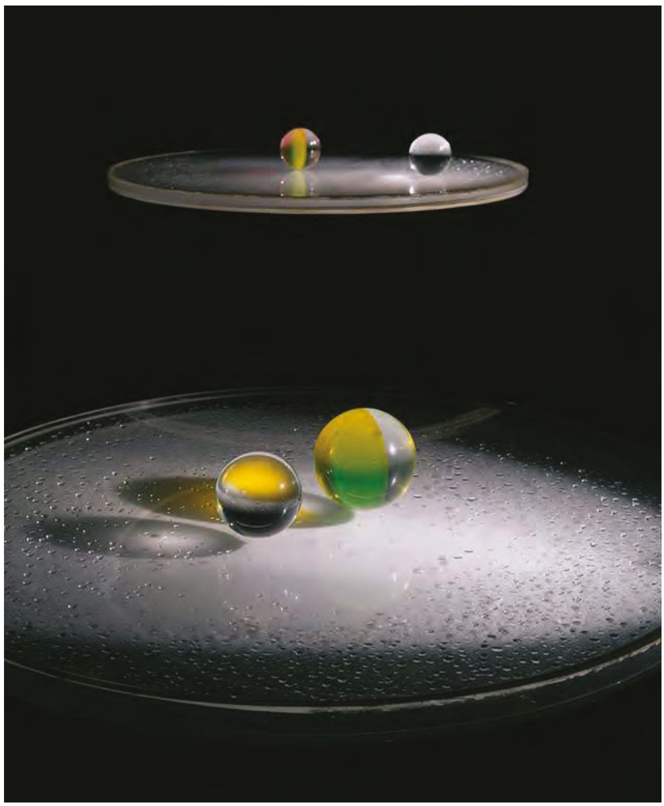


Figure 2. *Liquid Reflections*, one of a 1968 series by Liliane Lijn. Acrylic drum containing water, turntable and projector lamp, acrylic balls. Photo used by permission.

2. An Unconsummated Marriage?

Arts:

With thanks, Ms. Lijn, for this marvelous recreation of the artistic milieu of the 1960s, we hope now, with your continued help, to penetrate even more deeply into the 20th-century use of the motor for artistic purposes—and we will begin with Alexander Calder. With a degree in mechanical engineering, Calder was the first to create, in the early 1930s, an entire series of motorized sculptures—but he more or less abruptly broke off these experiments to pursue the wind-driven mobile. The noted techno-art historian Jack Burnham has explained this remarkable turnabout by reference to the *determinism* of the machine (Burnham 1968)—that it must repeat, over and over, its series of movements—and thus the appeal to Calder of random wind currents; and indeed, when we look at the artists of your generation who began once again to employ the electric motor, we can see various stratagems for "softening" the relentless aspect of the machine. Tinguely, for example, built his motorized pieces from worn, discarded parts, and so there is no shortage of random movement; the more typical approach, as with Joël Stein, has been to depend on various optical effects; and even with your own work of the early 1960s, can we not say that the poetry aspect is to some extent a way of ameliorating the Sisyphean aspect of the machine? And if we accept this hypothesis—that machine artists have tended to focus, so to speak, on ways of "dressing up" the machine, or making it more "entertaining"—must we not also accept the corollary, that there has, as of yet, been no kinetic sculptor who has established a major reputation by building upon the native energy and precision and organization of the machine? Or, in other words, must we not accept the fact that the celebrated marriage between art and machine, said to have occurred at some point in the 20th century, has in truth never been consummated?

LL:

There is no point in "dressing up the machine." The machine may be "deterministic," but it is also a tool and not necessarily an end in itself. I can cite examples from different aspects of my own work to describe the way I have used or played with machines—not always motors—and, of course, here one would have to define the machine. I prefer to think of it in its largest and most open definition, as per Wikipedia: "A *machine* uses power to apply forces and control movement to perform an intended action" (Wikipedia 2018).

My *Poem Machines* (1962) were named "machines" as a provocation of the elite glass tower of poetry. Machines were dirty, noisy, and related to both industry and manual work, in contrast to the intellectual. Machines were thought of in opposition to the organic, natural, emotional context of poetry. I like machines and value the innovative thought and creativity that has gone into inventing and making them. It is almost unnecessary to agree with Marcel Duchamp that a turbine is an object of beauty. It is often the precision of the machine that creates its beauty; it is an absolute dictate of function with no frills. Even tools made for injection-molding toothpaste caps can be beautiful objects. Well before using motors, I collected odd bits of machinery thinking I would use these in my work. But when I made *Poem Machines* (1962), I was not interested in beauty, I was interested in energy, the power latent in words.

Another aspect of a work of mine that I mentioned earlier, *Echo-Lights* (1962), used motors, in projectors that I designed and made, to rotate lenses. In that way, I enabled the reflections of tiny lens-shaped plastic drops that I had formed on seven- to nine-centimeter-thick blocks of Perspex to appear to split and double or triple themselves. The motor, like one's heart, was important in the creation of the work but was not the aim or focus of attention. In *Liquid Reflections* (1967–1968), made some years later in 1967, the machine or mechanism—motorized turntable, transformer, spotlight—is concealed beneath the water containing a Perspex disc or thin drum, which sits upon it and is rotated and lit by it. One might say that the machine gives the work its life, but in this work, it sets in motion a combination of natural forces, centrifugal and centripetal, with the important addition of angular momentum due to a slight altering of the level of the disc, and finally unplanned changes wrought by atmospheric pressure. These varied forces, some due to the motorized rotation of the disc and others nonmechanical, cause the two clear Perspex balls to slide at random across the surface of the turning disc in slowly changing patterns. There is also a small amount of water inside the disc that condenses into lens-like droplets, creating patterns of points of reflected light and shadows, a lunar landscape magnified inside the clear balls as they glide across the surface of the disc.

In the 1980s, I began to create works that represented female archetypes or goddesses. Apparitions of feminine power and inner energy, *Woman of War* (1986) and *Lady of the Wild Things* (1983) (Figure 3), are pure machine art come alive. They perform a six-minute drama that includes movement, sound, and light. They are interactive and automated. They both contain and are themselves machines.

However, they do not appear to be machines; one could even say they do not appear "deterministic" or even repetitive, no more than a piece of theater or a film watched over and over might seem. They do not appear to be machines, because of their complexity and because I have given my human voice to the *Woman of War*. The *Lady of the Wild Things* listens to that voice and transforms the sound into light, 250 LEDs flickering in red and green through a feathery pair of wings made of steel and PVC fibers, responding to the volume and pitch of my recorded voice.

There are further surprises, a sense of unpredictability that, combined with complexity, transforms the machine into something more organic. In making these larger-than-life figures, I wanted to combine animal, plant, mineral, and machine, drawing together our mythic past with an imagined future.

Figure 3. *Conjunction of Opposites: Lady of the Wild Things and Woman of War* by Liliane Lijn, 1983–86. Mixed media, 400 cm × 800 cm × 400 cm. Photo used by permission.

3. Looking to the Future

Arts:

And now, in closing, let us look to the future, in respect to which we will find no shortage of young artists who will tell us that the classical machine is passé and that we should now be focused on computer art, virtual art, database art, and so on. There is, however, a strong argument to be made for the idea that art must continue its engagement with said machine: first, there can be no doubt that the computer is itself a machine, and no less deterministic in its own way than, say, a steam locomotive—and so if art has not yet consummated its relationship with the classical machine, what hope can there be at present for a truly thoroughgoing computer art? And second, there is a quite powerful symbiotic relationship between the computer and the classical machine, as per the automated factory, the robot, and so on; i.e., there will be more, rather than fewer, machines in our future—and so an art that has not yet come to terms with even the classical machine will find itself less and less relevant. As an artist who has been engaged with the machine since 1962, what is your response to these arguments? Is it time to lay down our wrenches and screwdrivers—or is there more to be done?

LL:

It is quite evident that machines are even more thoroughly a part of our environment than ever before: driverless cars, satellites in space, drones, and a couple of new tools for artists, laser-cutting and

3D printing, not to mention the near-future advent of quantum computing. I believe that there are no rules in art, and for that reason, predictions of what may be considered art in the future seem a bit spurious to me. However, I see a strong tendency for collaborative art, whether between artists or across disciplines. Scientists are more interested now in opening their doors to other disciples, artists, composers, philosophers. In the last year, I have been asked to be part of a group called Universe 2.0, initiated by Professor Pierre Binétruy of the Centre for Astro-Particle Physics in Paris, who sadly passed away last April. He believed that the recent detection of gravitational waves had begun a new paradigm in astronomy and human thought, and that this implied too great a change and could only be understood by an openness of thought, thus the necessity for cross-fertilization between disciplines.

In order to detect a minute deformation of space-time, on the order of 10^{-18} m, that was generated by two colliding black holes nearly 1.3 billion light years away, scientists must use larger and larger arrays of machines and instruments. On my recent visit to the Virgo European Gravitational Observatory in Pisa (Figure 4), the sight of these extraordinary machines, these tools that men and women have made collaboratively to see far into space-time, made me feel that perhaps artists could also pool their individual creativity and imagination to visualize an infinite inner universe.

Figure 4. Aerial view of the Virgo European Gravity Observatory near Pisa, Italy. Photo courtesy Wikipedia (https://commons.wikimedia.org/wiki/File:VirgoDetectorAerialView.jpg) under the Creative Commons CC0 1.0 Universal Public Domain Dedication.

Conflicts of Interest: The author declares no conflict of interest.

References

Burnham, Jack. 1968. *Beyond Modern Sculpture: The Effects of Science and Technology on the Sculpture of This Century*. New York: George Braziller, p. 234.

Fincher, Jack. 1966. Sculptures in Motion. *Life*, August 12, 40–45.

Mellor, David Alan. 2005. *Liliane Lijn: Works 1959–80*. Warwick: Mead Gallery, University of Warwick.

Time. 1966. Styles: The Movement Movement. January 28, 66–69.
Wikipedia. 2018. Machine. Available online: https:/en.wikipedia.org/wiki/Machine (accessed on 7 June 2018).

arts

MDPI

Essay

Before and Beyond the Bachelor Machine

Joseph Nechvatal

Independent Artist, 93, Blvd Raspail, 75006 Paris, France; jnech@thing.net

Received: 28 September 2018; Accepted: 15 October 2018; Published: 18 October 2018

Abstract: This paper will examine the importance of Marcel Duchamp's *La Machine Célibataire (The Bachelor Machine)* on Art and Technology in the 20th and 21st centuries.

Keywords: art theory; bachelor machine; sexual politics; identity; gender studies; cultural studies; art; machine aesthetics; 20th century art history; generative art; post-conceptual art; Marcel Duchamp

1. Bachelor Machines

Dada's liberation of mechanamorphic sexual imagery has long been tarnished by the fact that male artists have historically been licensed to explore the rapid repetitions in lust and love, while women, for the most part, have inspired and represented them. Central to this naïvely gendered *démodé* dialogue is Marcel Duchamp's flamboyant and sexually subversive suggestion of onanistic *machine célibataires* (bachelor machines, Figure 1), with which he converted the principle of autoeroticism into one of the greatest masterpieces in the history of art.

Figure 1. *The Large Glass (The Bride Stripped Bare by Her Bachelors, Even)* by Marcel Duchamp, 1915–1923; 2nd version 1991–1992. Oil on lead sheet, lead wire, dust and varnish on broken glass plates, glass plates, aluminum foil, wood, steel, 277.5 cm × 175.9 cm. *Moderna Museet*, Stockholm. © succession Marcel Duchamp/ADAGP, Paris 2014 and used by permission.

In this paper, I view early Duchamp as essentially a provocative dandy: a self-conscious, self-constructed young man who dedicated himself to the resistance of convention by trafficking in elegant indifference and cool ascetic aloofness. Through his attitude of depersonalization, he freed himself of hackneyed artistic good 'taste', and in so doing deconstructed the concept of romantic sexual roles, replacing them with something much more frenetic, technological, phantasmagorical, and impersonal. I will additionally investigate the young bachelor Duchamp's mechanical sex machine, as its resistance to the needs of procreative insemination have moved both Art and Technology well beyond his male gaze towards complex and ambiguous hermaphrodite-like conceptions of bi- and pansexual cyborg bodies and a-sexual artificial life.

Indeed, imaginary pansexual bachelor machines will be theorized here as a philosophical space of transversal viral contamination obsessed with examining conceptual linkages, connectivity, and the intersection of genders. My contention is that cultural identity-politics practitioners and other gender theorists today would do well to put themselves in the fancy pants of algorithmic bisexual artificial lifeforms that ebb and flow between fluid understandings of masculine and feminine and the a-sexual viral (Parikka 2007). Such a sexually ambivalent art theory, based in sex farce, could be valuable to "all those interested in the question of dual-sexuality, whether in the domains of psychoanalysis, gay, or gender studies, the history of medicine or zoology, the history of ideas, or even the history of art" (Brisson 2002, p. xiii).

2. Marcel Duchamp: The Large Glass

Marcel Duchamp first made reference to the machine célibataire apparatus in 1913, when he wrote notes in preparation for *La mariée mise à nu par ses célibataires, même (The Bride Stripped Bare by Her Bachelors, Even)*, also known as *Le Grand Verre (The Large Glass)* (1915–1923), now permanently displayed in the Arensberg Collection at the Philadelphia Museum of Art. Though well-known, *The Large Glass*, made of two large panes of glass, seems inexhaustible in terms of its larger meaning and thus infinitely mysterious and useful (Henderson 2005). Conceiving it as an eroticized corpulent machine, Duchamp in his notes used such terms to describe its parts: 'sex cylinder', 'desire gear', 'reservoir of love gasoline', and 'general area of desire magneto'. Within the notes, Duchamp also identifies the specific bachelor machine's component parts as a water paddle, scissors, a chocolate grinder, a sledge, and nine malic molds. Technically, he employed a toy cannon to shoot paint-dipped matches at the glass ground of this work to determine the positions of these nine malic molds that were intended to represent nine job types, into which males are molded as men (all middle class or lower): a priest, a delivery man, a gendarme (military police), a cuirassier (cavalry soldier), a police officer, an undertaker, a go-fer sycophant, a busboy, and a railroad stationmaster.

Any prurience aroused by the title is not gratified by looking at either the bride or the bachelors, who are linked together, like a daisy chain of mechanical implements or schematic diagrams. They sit well below the looming bride (who scarcely looks naked and hardly looks female), hovering wasp-like in the upper panel, sealed off by a segmenting metal strip. Duchamp imagined in the lower Bachelor Apparatus section these nine bachelor bootlickers cock-blocked: trapped in a chain of repetitive emotional states that flutter between hope, desire, and fear.

I find this emotional chain (or cycle) prescient, as this fearful-hopeful-yearning state has now become emblematic of Art *writ large*, due to the rhizomatic (Deleuze and Guattari 1987) internet condition of art as spectacle, endlessly flowing in attention-seeking circularity (Debord 1976). Like the net, Duchamp's *Large Glass* as a mental masturbation machine contains the two great mythic spaces so often explored by western imagination: space that is rigid and forbidden—that requires a circular quest and return (for example, the trail of the Argonauts)—and the space of polymorphic confused borders, of strange affiliations, of magical spells, and of symbolic replacements (the labyrinth space of the Minotaur).

While waiting for the bride's gratifying attention, the sexually frustrated bachelors below are enacting an enigmatic fantasy drama of competing passion (or aggression), suggested by the phrase "stripped bare" in the full title of the piece. All the bachelors hope and strive to bed the bride, but fear of vague consequences holds them back in a state of frustration, which introduces the important psychosexual function of the chocolate grinder, that nearly dominates the Bachelor Apparatus zone. This important form was transferred to *The Large Glass* from Duchamp's delicious painting *Chocolate Grinder (No. 1)* (1913). The grinding machine in the Bachelor Apparatus area signifies how the bachelors, frustrated with their inability to mate with the bride machine, may achieve some sweet satisfaction by repeatedly sexually stimulating their own genital apparatus, thus demonstrating a sort of faux dual-sexuality that can be described as the "simultaneous or successive possession of both sexes by a single individual" (Brisson 2002, p. 1).

This feverish theme of onanistic dual-sexual circularity in *The Large Glass* presents us with a model of gender grandeur: a theoretical imaginative bisexual machine that functions independently of "the other", thereby pulling faux dual-sexual passion into a developmental logic of its own, leading to a transcendental infinite. It is here, in the faux dual-sexual self-pleasuring chocolate grinder, where I detect some spiritual implications of the nine male types, who Duchamp has virtualized and sprayed into their discrete zone of remote presence. Their endless faux dual-sexual self-pleasuring (that smoothly shrivels into asexuality or explodes into pansexuality) implies two polymorphic viewpoints: that of asexual and pansexual bachelor machines.

Crucial to the imaginative fantasy powers of a pansexual bachelor machine is the implementation of a theory of the variegated virtual (Shanken 1997). This theory assumes the existence of preposterous and imaginatively configured subjects able to ford human anthropocentric sexual frontiers. Duchamp's use of post-humanist chance in the making of his bachelor machine implies that the artist relinquishes, to a greater or lesser degree, the power to close down the final interpretation of a work, i.e., keeping it open to interpretation (Eco 1989), which facilitates all sort of imaginative and fluid mental processes in the viewer. Thus, for me, a spiritual implication of *The Large Glass* is the denial of sexual determinism in favor of the potency of apparent pansexual fluidity in circularity *ad infinitum*. This means an implicit refutation of the assumption that the 'neutral' body is always white and straight and masculine. Thus, the circular implication of faux dual-sexuality has directed my focus in theorizing and coding post-bachelor hermaphrodite, artificial life, and viral art projects as early as 1992 (Gruson 1993), as well as computer-robotic painting pansexual bachelor machine images (Lewis 2003), with Duchamp's male bachelor machine as starting point.

3. Marcel Duchamp: The Bride

The cold impersonality of technology and the heat of dual (or dueling) sex is a curious alliance. Prior to *The Large Glass*, Duchamp produced a few cherished images depicting mechanized sexuality. Among them the drawing *Vierge, No. 1 (Virgin No. 1)* (1912), and the paintings *Le Passage de la Vierge à la Mariée (The Passage from the Virgin to the Bride*) (1912) and *La Mariée (The Bride)* (1912, Figure 2). Intriguingly, he painted both of these the year he proclaimed the end of painting, the same year he visited an aeronautical exhibition with Fernand Léger as they were admiring an elegant airplane propeller. Particularly in the wonderful *Bride*, who appears as the bride in *The Large Glass*, the elaborateness of her repeatedly pumping machine gear suggests an excess of sexual bliss attainable through circular, auto-sexual, and faux bisexual autonomy. Such body politics contains an admixture of romantic ideals and auto-mechanical sensations, where the psyche may become lost in a throbbing spiral of labyrinthine extensions, duplications, and repetitions. Although arrived at by chance (twenty-five notes randomly picked from a hat), Duchamp's first musical endeavor, the 1913 *Musical Erratum: La mariée mise à nu par ses célibataires, même* (for piano) (Duchamp 2008) makes the same circular point by stubbornly repeating only two up-and-down notes for the first 43 s. Listening to these masturbatory repetitions in *Musical Erratum* while contemplating the pumping mechanics of *The Bride* introduces a trance element into Duchamp's aesthetic and casts his bachelor machine into the dizzying activities of the impersonal but ingenious dandy (Huysmans 1973). However, I also think of this pumping trance-state as Duchamp's definitive desire when he is in an uninhibited bachelor machine mode: a detached, depersonalized, and mystical state of being (Stace 1960).

Figure 2. *La Mariée (The Bride)* by Marcel Duchamp, 1912. Oil on canvas, 89.5 cm × 55.6 cm. *Philadelphia Museum of Art, The Louise and Walter Arensberg Collection, 1950*. © Artists Rights Society (ARS), New York/ADAGP, Paris/Succession Marcel Duchamp and used by permission.

It is curiously true that this depersonalized dizzying circularity is comparable to how algorithms now run automatically behind the technological scene (Johnston 2008). Thrusting away in cellular automaton artificial life is something so astoundingly pregnant with auto-bachelor machine circularity that it excites and stimulates creativity, as I discovered with my cellular automaton-based *Computer Virus Project 2.0* (2002) (Nechvatal 2011, p. 252), a resultant series of pansexual paintings created in the early-2000s (Lewis 2003).

In art, the patriarchal construction of woman as other and the female body as object, though contested (Betterton 1996), is deeply rooted in the supposed duality (opposites) of the (two) sexes. Most feminist theory questions this patriarchal construction of sex and gender, suggesting that sex is expressed through a continuum, rather than as an opposing couplet based on heterosexist male/female polarities (Butler 2004). Accordingly, within dual-sexual hermaphroditic auto-bachelor machines, containments designed for womanhood/manhood are subverted by the mutable image of pansexuality. Gender here is theorized as an act of becoming. Consequently, art fails to sustain sex oppression in culture by ceasing to draw the boundaries of the Other.

Going a step further, hermaphroditic-sexual bachelor machines are a provocation not only to male/female constructions of heterosexuality, but also to homosexual constructions of identity. I discovered this while working on my hermaphroditic painting series for the New York City exhibitions *ec-satyricOn* (2000), *vOluptuary: an algorithic hermaphornology* (2002), and *Real Time* (2004). For all three shows I melded images of the sex organs of both sexes into a chimera field of virtuality that went under viral attacks scripted in C++ as artificial life. The results yielded many quixotic transformations, where all sort of pan-sex orders arose (Nechvatal 2011, p. 246). But as digital bachelor machines are immaterial pure information spaces, it is neither surprising nor coincidental that the immense perspective of algorithmic auto-bisexual bachelor machines requires a questioning of the legitimacy of common sexual organ arrangements and familiar forgone conclusions concerning theoretical issues around sexual politics, gender studies, and the farther-reaching heterogeneous philosophical critique of the cultural mechanisms of representation (Foucault 1970) that have preceded it.

Of course, Duchamp set the stage by countering bourgeois ideals of masculinity. Duchamp considered himself to be counter-type, *un artiste désœuvré* (an idle artist), after he temporarily abandoned the production of traditional art objects. While the 19th century dandy was a masculine figure, his masculinity had a lot in common with artificial and constructed femininity. Indeed, in late-19th century French culture, the dandy was often considered decadent and effeminate in a vague way that verged on the homosexual. Regardless, the travestying heterosexual Duchamp staged himself in bisexual dandy drag as Rrose Sélavy for a series of *femme fatale* photos done in 1921 by Man Ray. When read out loud pronouncing both "r"s, Rrose Sélavy can sound like *Eros, c'est la vie* (Eros is life). In an artwork called *Belle Haleine. Eau de voilette* (Beautiful Breath: Veil Water) (1921), Duchamp first incorporated his Sélavy drag portrait on the label of a perfume bottle, effecting a bisexual metamorphosis into a cross-dressed alter ego seemingly lost in the scent of gender-masked maneuvers. But what are some earlier dandy-era precedents of self-transcending pansexual bachelor machines *avant la lettre*?

4. Raymond Roussel and Auguste Rodin

Along with Guillaume Appollinaire, Francis Picabia, and Gabrièle Buffet-Picabia, Duchamp attended a 1912 performance of *Impressions d'Afrique (Impressions of Africa)*, a wacky play by Raymond Roussel based on his 1910 book of the same name (Roussel 2001), which was written according to formal constraints based on homonymic puns. This play was a revelatory intellectual experience for Duchamp, to the extent that he would credit it with helping inspire *The Large Glass* (Henderson 2005). Clearly, its punning delirium pushed Duchamp's bachelor machine idea towards celebrating exhaustive circularity and its effects of intransigent obliqueness and mechanical dizziness. For this reason, Duchamp's faux dual-sexual self-pleasuring grinding machine is always a potentially transgressive proposition, as regards to bourgeois ideals concerning the difference between the sexes.

Salient to this circular connection is Michel Foucault's analysis of Roussel's invention of dreamy language machines, which produced texts through repetitions and combination-permutations. Foucault explains how a machine-like logic provides Roussel's writing with a seemingly endless variety of textual combinations, flowing in grinding circular form. Roussel's technique of endless grinding lent itself to the creation of unforeseen, automatic, and spontaneous invention, which gives the reader a feeling of being pulled into an onanistic eternity. By grinding and grinding, and through his use of labyrinthine extensions, doublings, and duplications, Roussel transmits to the reader the sense of an altered, circular, and exalted state of mind (Foucault 1986). Foucault's revealing analysis of Roussel's final deliriousness book, *Comment j'ai écrit certains de mes livres (How I Wrote Certain of My Books)* (Roussel 2005), contains and repeats all the mental-machines Roussel had formerly put into motion, and by doing so, evidencing the master-grinding-machine that produced his text-machines. Here I grasped the stylistic mood of grinding gamesmanship associated with Duchamp's bachelor machine—an extravagant, intricately hermetic, elaborate, and mechanical-morphism that is conceptually consistent with Duchamp's exuberant and preposterous faux dual-sexual desires. Like Duchamp's dazzling bachelor machine, Roussel's themes and procedures involved isolated and frustrated stereotypes that were reflected in his writing method, with its inextricable play of double images, repetitions, and impediments, all of which created a feeling of an altered, exalted, and orgasmic state of mind.

But I discovered another self-stimulating onanistic bachelor machine precedent in Auguste Rodin's well known sculpture *Le Monument à Balzac (The Monument to Balzac)* (1898, Figure 3). Duchamp's bachelor machine, like all bodies, is inscribed with the values and beliefs of the culture from which it emerged. As evidenced in Rodin's *Balzac, second nude study F* (1886, Figure 4), the sculptor secretly formed an autoerotic bachelor machine model of artistic self-stimulation. The finished work that stands on boulevard Raspail (also at the Rodin Museum, at MoMA, and elsewhere) replicates the pose of the *Balzac, second nude study F* to a tee, with the cloak covering the busy bulge. The backward lean in this study is the definitive posture of the Balzac monument.

Rodin's objective for this bachelor machine was to depict a ballsy Balzac at the moment of conceiving the idea for a work of art through onanistic imaginative gazing. That Rodin chose to furtively depict Balzac as an onanist is far from ludicrous, as Balzac used masturbation (without climax) to intensify his writing sessions, drinking many cups of coffee, again masturbating just short of orgasm, halting, writing, and repeating, like a well-oiled machine.

Figure 3. *Monument to Balzac* by Auguste Rodin, 1898. Bronze, 282 cm × 122.5 cm × 104.2 cm. Photo by the author.

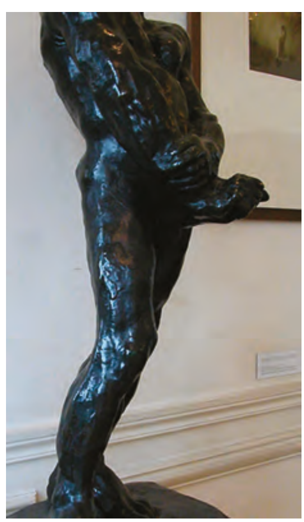


Figure 4. *Balzac, second nude study F* by Auguste Rodin, 1886 (detail). Bronze, 93.1 cm × 43.5 cm × 35 cm. *Musée Rodin*, Paris. Photo by the author.

In his 1954 book, *The Bachelor Machines*, Michel Carrouges points out that all bachelor machines share the signification of such autoerotic circularity (Carrouges 1954). All bachelor machines are mental sex machines, the imaginary workings of which suffices to produce real movements of mind-body. Although curator Harald Szeemann revisited and expanded Carrouges's argument in a 1975 traveling exhibition, also entitled *The Bachelor Machines* (Clair and Szeemann 1975), he left out some historical Modern figures that I would like to add here before moving on to theorize the current complex pansexual bachelor machines of the mind.

5. Fernand Léger, Francis Picabia, André Masson and Oskar Schlemmer

Gender-fluid bachelor machines are already detectable in some of Fernand Léger's earliest artworks. What particularly interests me about Léger is how his imagery enters the oily slipstream of the bisexual cyborg, where distinctions between sex, the body, and robotics blur in the density of speeding political networks (Terranova 2004). We see this in the best painting Léger ever made: his rich, velvety textured, pre-war composition, *La Noce (The Wedding)* (1912, Figure 5), completed the same year Duchamp painted *The Bride*.

Figure 5. *La Noce* by Fernand Léger, 1912. Oil on canvas, 206 cm × 257 cm. *Collection Centre Pompidou, Paris Musée National d'art Modern*, Paris. Donation of M. Alfred Flechtheim in 1937. Used by permission.

The Wedding is so jam-packed with crunchy cubist incident that it is difficult to decipher at first glance. It has a nonchalant, silky, falling feel to it. Like a fine, nuanced, and balanced wine, this painting exhibits the bachelor machine intensity without metallic heaviness. It draws the eye to the full rhythmic structure of the kaleidoscopic space where smaller, interlocking elements lure the gaze into deeply opulent repetitions of machine-like (and implicitly sexual) exploits. The painting's male and female couple fuse into gyrating repeats in a complex and cryptic way, lending the work a vivacious and sleek visual texture that is delightfully seductive. The couple and surrounding multitude procreate into a repetitive orgy-machine, pulling the mind into an infinite mechanical pan-logic that is almost transcendental. Their post-flesh machine unanimity is set flowing in jerks and spasms across the surface of the canvas.

Léger has imposed on gender here a vibrating restlessness of Rousselian proportions. Again we fall into a labyrinthine of repeats, extensions, and stutter doublings. In *The Wedding,* Léger paints the idea of gendered flesh undergoing a cascade of annihilation. Yet the composition's flickering staccato repetitions create the impression of a rolling bacchanalia, where human forms also transcend that annihilated fleshiness and extend themselves through motorized re-embodiment into a kind of pan-transubstantiation. With *The Wedding*, Léger seems to suggest that the glory of artificial life is to be found in the technological apparatus of mixed bodies, tumbling into a field of circuits (Weibel 1990). Likewise, in his painting *Le Cirque Medrano (The Medrano Circus)* (1918), exuberant performing figures are put through Léger's mechanical meat grinder and expelled into the hyperreal dominion of entertainment simulacrum.

Léger, though not himself a Dadaist, would, like the Dadaists, make much of the machine; unlike them, however, he would make little of sex farce. He did not mock sex as machinic the way Francis Picabia did during his machinist period, when he too blended a machine aesthetic with representations of the human-machine body, as in *Parade amoureuse (Love Parade)* (1917). Still, both artists paint the interface between sex and the machine.

Undoubtedly, when in his Dada tecnomorphic period, Picabia illuminated such spatialized sexual paradigms by mixing implied human bodies with mechanical schematics. Again, like in Léger's *The Wedding* and Duchamp's mental-mechanical sex machine, the sexual body is endowed with ecstatic transcendent capabilities through the endless repetitions of oiled machinery. So it is not surprising that Picabia, like Léger, was also a member of the *Section d'Or* (Golden Section) group that was associated with Marcel Duchamp and his brothers.

Like Duchamp and Picabia, Léger also distributed and blurred disparate body parts and mechanical elements in his paintings, in what looks to be a turbulent and haphazard fashion, challenging the 'humanist' conceptions of 'man', similar to Duchamp's man-mechanical approach. This is most evident in Léger's paintings of the mustachioed *Le mécanicien (The Mechanic)* (1918) and the *L'Homme à la pipe (Man with Pipe)* (1920), with their tin man-like volumes. In these two proto-robotic *tour de forces*, Léger clearly sets up Picabia-like tensions between the human narrative and the mechanical spectacle that points in the direction of neuro-computing wetware, bio-robotics, and all of the AI-charged automatization humming away in the space between the mechanic, the digital, and the organic. This humming is why these Modernist bachelor machines sing to us as a mythic oracle.

But the other great construct of tipsy bachelor machine automatization, and I think Léger's paramount work, features Kiki de Montparnasse. Léger co-directed her, with American film director Dudley Murphy, in their nourish flicker-film chef-d'oeuvre, *Ballet mécanique (Mechanical Ballet)* (1924, Figure 6), where Kiki is cast fluctuating between figuration and abstraction. *Mechanical Ballet* is a Dada masterpiece of early-experimental film, stringing together a reeling mechanic-mental river of sensations both flashy and frustratingly repetitive. Like Duchamp's bachelor machine, *The Large Glass*, which was declared definitively unfinished the year before the film was made, *Mechanical Ballet* is a bid at eliminating our sense of linier time. Through the construction of its repeats, the film gives me the fantastic feeling of prolongation into an erotic eternity.

Mechanical Ballet, much of it shot by Man Ray, smartly transmits an altered, exalted, and orgasmic state of mind that is perfectly complimented by George Antheil's noise music soundtrack: his 30 min long *Ballet mécanique (Mechanical Ballet)* (1924). This pummeling composition recalls the beginning of Duchamp's *Musical Erratum* for piano, and was originally conceived of as the musical accompaniment to the film, but due to length differences, eventually the filmmakers and composer chose to let their creations evolve separately (although the film credits always included Antheil). Nevertheless, Antheil's *Mechanical Ballet* premiered as concert music in Paris in 1926 and is majestic in and of itself. But when included in the film, as it now is, everything is permutated with a pulsating and flickering energy of go/stop/go/stop/go/stop/go—depicting a hyperactive current of techno machine forces on the body. The film, with an insistent flicker, is flush with discontinuous, fragmented, and kaleidoscopic sensations that remind me of *The Wedding*. The screen pulsates with the hot energies of modern life and its dull repetitions.

Mechanical Ballet is a stunning spasmodic display of stutter-and-flicker-and-looped concentration, where relationships between the protoplasmic body and mechanical repeats invite meditation on the self-prosthesis of pansexual bachelor machines. In this flickering metamorphic ballet, the human body is at the center of traditional narrative subjectivity and again undone by a visual noise it cannot contain.

Figure 6. *Le Ballet mécanique* by Fernand Léger & Dudley Murphy, 1924 (two stills showing Kiki de Montparnasse). 19′50″ 35 mm black & white film acquired 1997, inventory number AM 1997-F1388. *Centre Pompidou, Musée national d'art modern*, Paris. © Centre Pompidou, MNAM-CCI/Service de la documentation photographique du MNAM/Dist. RMN-GP Â© Adagp, Paris, 2017 and used by permission.

Made the same year as *Mechanical Ballet*, and relevant to auto-sexual bachelor machines, is the speeding, automatic, ritualistic, and revelatory mode of iconographic mark-making André Masson devised for *Automatic Drawing* (1924, Figure 7). In this jittery automatic drawing, a conflict or antagonism is set up between the 'feminine' litheness of curves and the 'male' hard angles. Up against the supple curves of a centered naked woman, aggressive lines cut through her like a knife. Slow looking reveals that the image calls to mind not only *Mechanical Ballet*, but Marcel Duchamp's *Nu descendant un escalier n° 2 (Nude Descending a Staircase, No. 2)* (1912). Beyond that, there is at work an automatic artistic method, which plays in the area of chaotic control/non-control, aiming towards constructing a capricious alliance that associates discourses of mechanic grinding with organic sexuality, an association that opens up both notions to mental connections that enlarge them. Here the coming cyborg woman of Fritz Lang's *Metropolis* (1927, Figure 8) and Donna Haraway (Haraway 1991) are already undone by overwhelming complex disturbances they cannot contain.

That immersion into visual noisy disturbance (Nechvatal 2011) is essential to theorizing pansexual bachelor machines.

Masson's likewise intense *Dessin automatique (Automatic Drawing)* (1924–1925, Figure 9) strikes hard as an example of the divinatory practice of finding subconscious desires within vague cues. It is a neurotic network of bachelor machine lines that seem fluid but hectic, and, at times, staccato-like. In what seems to appear gradually is a standing, plugged-in burial casket, surrounded by phantasmagorical figure motifs that may include object parts merged with anatomical fragments typical of bachelor machines. The sum total gives off a feeling of occultist ferment and whimsy that alludes to potential auto-sexual bachelor machines.

Figure 7. *Automatic Drawing* by André Masson (1924). Ink on paper. Photo courtesy Galerie Natalie Seroussi and used by permission.

Figure 8. *Robot* by Walter Schulze-Mittendorff from Fritz Lang's film *Metropolis*, 1927. Copy created by the Louvre in 1994, painted resin, 190 cm × 74 cm × 59 cm. Cinémathèque française and used by permission.

Figure 9. *Automatic Drawing* by André Masson (1924–1925). Ink on colored paper. Photo courtesy Galerie Natalie Seroussi and used by permission.

Moreover, Oskar Schlemmer's paintings, drawings, choreography, and costume/set design flamboyantly depict the mechanic post-flesh. The coming asexual bachelor machine is most obvious when Schlemmer inserts his dancers into svelte geometric-based outfits and puts them to work, repeating spectacular sequenced motions machine-like in their repetitions (Figure 10). Again, we have entered the sexually ambivalent android realm.

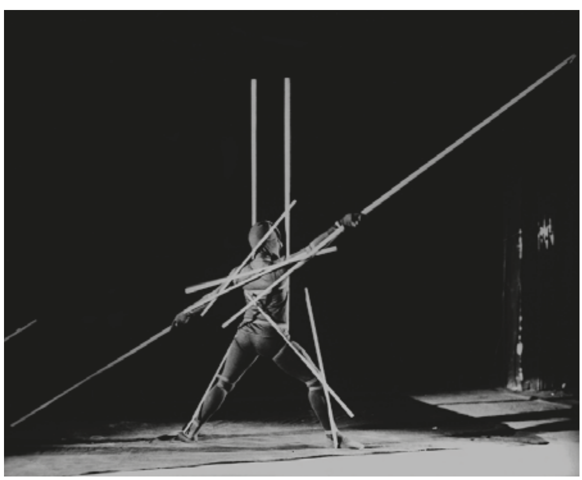


Figure 10. *Danse des batons* by Oskar Schlemmer, 1928. © 2016 Oskar Schlemmer, Photo Archive C. Raman Schlemmer and used by permission.

Schlemmer theorized a serene, classical, and monumental approach to the human form based on the tensions between anthropological narratives and mechanical simulacrums, a tension typical of our period's electronic contours. His personal-impersonal amalgamate may have even predicted the spectacle of moral aridity we have come to expect within certain technological elites today. Schlemmer's flair for an asexual robotic approach in the automated figure embodies the theorized notion of aesthetic synthesis, which is intended to symbolize social synthesis within a benevolent emerging techno-society. As such, he attempted to depict the human form as pansexually spiritual through an abstract geometric consistency of form, in service of a social totality. This idea led Schlemmer to create a proto-robotic pansexual art by virtue of a relocation of body/machine/consciousness, typical of the telematic embrace (Ascott 2003). Following this theoretical thread, as can be seen in his *Tanz Figurinen* sketchbook, Schlemmer points the mind towards churning pansexual bachelor machines: that is, cyborg sequencing merged with dematerialized flesh.

This is most obvious in Schlemmer's *Les signes de l'Homme (Dématérialisation) (Signs of Man (Dematerialization))* (1924/1986, Figure 11), where he raises the hyperreal issue of virtual dematerialization as interface between the human body and an abstracting, universalizing machinery. This is also obvious in his extremely delicately drawn lithograph *Figurenplan (Figure Plan)* (1919), which offers up an index of his costumes within a grid scenario. As with his choreography of repetitive simple motions, it is a telltale hint at what American Minimalism will successfully create in the 1970s with *Einstein on the Beach*, a four act opera by Philip Glass and Robert Wilson. The opera features task-based, quasi-robotic choreography by Lucinda Childs, where dancers' bodies seem already spliced into a cybernetic-technomorphic circuit. This spliced sense is enhanced through the use of stiff repetition and a dismemberment of traditional narrative subjectivity. Here, the notion of the human body receives a strange, almost ecstatic, capability through trance-like, pansexual bachelor machine repetitions. In the brilliant costume *Le Ballet triadique, Figure de fil de fer, Série noire (The Triadic Ballet, Wire Figure, Black Series)* (1922)—made for his masterwork *The Triadic Ballet*—Schlemmer seems interested in moving robotic-like trans-crystalline bodies in space towards the formational effects of pansexual bachelor machines. He does so by constructing a space of imaginative accommodation for an intensely connected and immersed circulate (Nechvatal 2009), suggestive of biomorphic machines as an artistic source of self-transcendence.

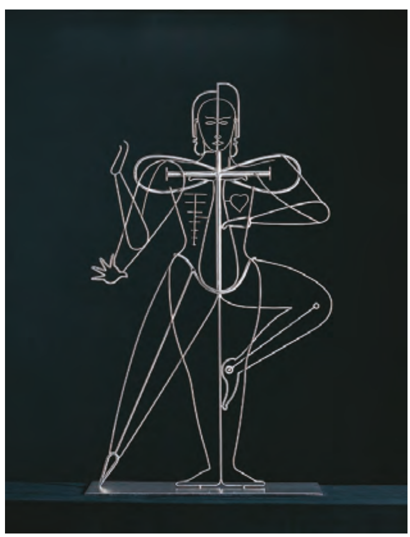


Figure 11. *Les signes de l'Homme (Dématérialisation)* by Oskar Schlemmer, 1924/1986. © 2016 Oskar Schlemmer, Photo Archive C. Raman Schlemmer and used by permission.

6. Pansexual Bachelor Machines and Oögenesis

The conceptual pansexual bachelor machine theory I am sketching out while dropping historical precedents is re-configurative and trans-figurative in intention. Based on the capacity of connected electronic media's immeasurable intermixture, it nudges the current cultural context away from a biologically determinist reading of femininity and masculinity. The point is that within pansexual bachelor machines, all sexual signs are subject to boundless semiosis. This is to say that these signs are translatable into other signs of other sex arrangements, in order for art to articulate new sexual combinations.

Certainly, the male Modernist bachelor machine propositions mentioned above—sleek, coolly impersonal, and sexually confused—point towards needs to expand on the range of current slippery situations between fleshy embodiment and connective circumvention. By mixing abstracted bodies with mad mechanical repeating geometrics, Modernist bachelor machines suggest to me a pansexual robotic sensibility that at least temporarily refutes the sour feeling that we are living in an epoch of identity click-bait art fueled by predatory virtual capital. At least it challenges the imagination of many current cultural producers whose work has been looking dismally identity-reductive, parochial, and ethnocentric.

Privileging pangender conceptual machines suggests that we cannot be satisfied with identity-based vanity culture as art lauded by chatting memes that repeat and repeat themselves in search of bigger and bigger audiences. Clearly theorizing pansexual bachelor machines as a form of virtual art (Popper 2007) cracks open representational boundaries between human beings and other human beings and their digital machines. These leaky boundaries—or schematas—are the reason that ideas of phantasmagorical bachelor machines (or butch machines, if you like) are interesting *as art* today. The creation of mad mental sex machines has to do with an abiding conviction that cold code may be brought to a-life through the correct application of art and programming. While learning is a property almost exclusively ascribed to self-conscious living systems, AI-based a-life computer programs can now learn from past experiences and improve their operative functions to the point of surpassing human capabilities. Such post-human transcendence raises both aesthetic and ethical concerns for Art and Technology.

Much art, whether machine art or media art, has become almost indistinguishable from popular cultural commodities. Freaky a-life pansexual bachelor machines stand out as a reasonable alternative, a comparatively unpopular art approach that values farcical camp humor, transcendental metaphysics, conceptual construction, and clandestine mysticism over common human-centric assumptions for art as entertainment. The concept of a self-churning pangender machine suggests ways to think of life outside of the normal longwinded explanations and closer to Speculative Realism's anti-anthropomorphic transcendental materialism (Meillassoux 2008).

That is why, from beginning to end, I have appreciated avant-garde interests in an artistic-philosophical spirituality of bachelor machines (Clair and Szeemann 1975). The idea of mad a-life pansexual bachelor machines points art away from the humanist niceties of a human-centric world and towards non-humanist modes of pangender expression that is both flamboyantly poetic and technologically terse, evoking an aesthetic that is simultaneously alchemical, cosmic, ancient, and uncannily new as artificial life.

Undoubtedly, past art theories have been unequivocal in their urge towards closure, embellished with a sort of self-significance, and, often, fallacious universalism, which I wish to avoid. If what I have said about pansexual bachelor machine theory sounds metaphysical (or a parody of metaphysics), it is so only in so far as it is early pre-memory—which takes us to oögenesis.

Oögenesis is a moment of bisexual or a-sexual development of the pre-fertilized human egg cell where both female and male potentiality exists simultaneously. It is the place and time prior to the differentiation of the ovum into a cell capable to further develop and divide as fertilized by the male seed. This moment of sexual potentiality exemplifies the transcending pansexual bachelor machine concept brilliantly, and it suggests the truth that in life somethings can be both one thing and its opposite at the same time. Two opposites can exist simultaneously and not cancel each other out.

Such peacefully sustained conflict is the agent of transformation that can engage art ideas in a play of contradictory excess (Bataille 1985), encouraging pleasurable critical creativity (Drucker 1996). That is why I myself have made post-conceptual generative art based on an a-life viral model as connected to the subject of the hermaphrodite (Lewis 2003). After establishing a coded viral project in

1992 (Gruson 1993), I became interested, around the year 2000, in oögenesis (Nechvatal 2009, p. 66), a hermaphroditic-like pre-bifurcation moment in human development.

Pansexual bachelor machine theory investigates, through the imaginative powers of art, ways in which our sense of one-gendered self has a fluidity that defies spatial containment. As such, it opens gendered thought up to new spaces of malleable and combinatory sites, hence a perpetual multiplication of significance. Meaning in art (and in life) then advances by seeing more clearly into its own underlying assumptions of superfluity, by facing up to the radical implications of those oögenesis assumptions, and by purging itself from conventional ways of thinking by making no recourse to imagined exterior principles or *a priori* assumptions.

What is important in auto (or pan) sexual bachelor machines is their intentional enigma. They need to be obscure to the degree that their gender codes cannot be easily discerned (and politically used). This oögenesis obscurity (and mystery) is increasingly desirable in a world that has become progressively data-mined, identity-mapped, and sex preference quantified, in a straight-forward matter-of-fact way.

To be sure, each era has its own redundancies and compliances, so the chaotic excess of oögenesis bachelor machines works well with today's connected cravings for unlimited information and access. Which is as it should be: the definition of artistic activity occurs, first of all, in the fields of seduction and social distribution. With pansexual bachelor machines hovering above common distinctions, conceptual transmission is already the endpoint. Fitting to today's reality of globalization-digitization, the non-linearity of pansexual oögenesis bachelor machines propose a space of visual hyper-thought where the encountering of contradictory realities is bound only by the next thought and driven by the last.

Funding: This research received no external funding.

Acknowledgments: The author would like to thank Jane Prophet, Wayne County & the Electric Chairs, Genesis P.-Orridge, Association pour l'Étude de Marcel Duchamp, Bill Seaman, Bradley Eros, L. Brandon Krall, Elena Filipovic, Juan Antonio Ramírez, and Divine for their additional inspiration during the writing of this essay. He also acknowledges the sagacious encouragement of Hrag Vartanian's *Hyperallergic* and especially thanks Yves Fall and Françoise Gaillard for graciously lending their bungalow on the Mediterranean Sea where the final writing ensued in August 2018.

Conflicts of Interest: The author declares no conflicts of interest.

References

Ascott, Roy. 2003. *Telematic Embrace, Visionary Theories of Art, Technology and Consciousness*. Berkeley: University of California Press.

Bataille, Georges. 1985. *Visions of Excess*. Minneapolis: University of Minnesota Press.

Betterton, Rosemary. 1996. *An Intimate Distance: Women, Artists and the Body*. London: Routledge.

Brisson, Luc. 2002. *Sexual Ambivalence: Androgyny and Hermaphroditism in Graeco-Roman Antiquity*. Berkeley: University of California Press.

Butler, Judith. 2004. *Undoing Gender*. New York: Routledge.

Carrouges, Michel. 1954. *Les Machines Célibataires*. Paris: Arcanes.

Clair, Jean, and Harold Szeemann, eds. 1975. *Le Macchine Celibi/The Bachelor Machines*. New York: Rizzoli.

Debord, Guy. 1976. *The Society of the Spectacle*. Detroit: Black and Red.

Deleuze, Gilles, and Félix Guattari. 1987. *A Thousand Plateaus: Capitalism and Schizophrenia*. Minneapolis: University of Minnesota Press.

Drucker, Johanna. 1996. Critical Pleasure. In *Joseph Nechvatal: Retrospektive*. Edited by Frank Berndt and Caroline Fuchs. Köln: Galerie Berndt, pp. 10–13.

Eco, Umberto. 1989. *The Open Work*. London: Hutchinson.

Foucault, Michel. 1970. *The Order of Things*. London: Tavistock.

Foucault, Michel. 1986. *Death and the Labyrinth: The World of Raymond Roussel*. New York City: Doubleday.

Gruson, Luc, ed. 1993. *Joseph Nechvatal: Computer Virus Project*. Arc-et-Senans: Fondation Claude-Nicolas Ledoux.

Haraway, Donna. 1991. *Simians, Cyborgs and Women: The Reinvention of Nature*. New York: Routledge.

Henderson, Linda Dalrymple. 2005. *Duchamp in Context: Science and Technology in the "Large Glass" and Related Works*. Princeton: Princeton University Press.

Huysmans, Joris-Karl. 1973. *Against Nature*. Harmondsworth: Penguin.

Johnston, John. 2008. The Allure of Machinic Life: Cybernetics, Artificial Life, and the New AI. Cambridge: MIT Press.

Lewis, Joe. 2003. Joseph Nechvatal at Universal Concepts Unlimited. *Art in America*, 21 February–27 March. 123–24.

Meillassoux, Quentin. 2008. *After Finitude: An Essay on the Necessity of Contingency*. London: Continuum.

Nechvatal, Joseph. 2009. Fast and Beautiful: The A-Life Undeadening of Painting. In *Towards an Immersive Intelligence: Essays on the Work of Art in the Age of Computer Technology and Virtual Reality (1993–2006)*. New York: Edgewise Press.

Nechvatal, Joseph. 2011. *Immersion into Noise*. Ann Arbor: Open Humanities Press.

Parikka, Jussi. 2007. *Digital Contagions: A Media Archaeology of Computer Viruses*. New York: Peter Lang.

Popper, Frank. 2007. *From Technological to Virtual Art*. Cambridge: MIT Press.

Roussel, Raymond. 2001. *Impressions of Africa*. London: John Calder.

Roussel, Raymond. 2005. *How I Wrote Certain of My Books*. Cambridge: Exact Change.

Shanken, Edward. 1997. Virtual Perspectives and the Artistic Vision: A Genealogy of Technology, Perception and Power. In *Proceedings of the Seventh International Symposium on Electronic Art*. Rotterdam: ISEA 96 Foundation.

Stace, Walter. 1960. *The Teachings of the Mystics*. New York: The New American Library.

Terranova, Tiziana. 2004. *Network Culture: Politics for the Information Age*. London: Pluto Press.

Weibel, Peter. 1990. Virtual Worlds: The Emperor's New Bodies. In *Virtuelle Welten*. Edited by Gottfried Hattinger, Morgan Russel, Christine Schöpf and Peter Weibel. Linz: Veritas-Verlag Linz, pp. 9–38.

arts

MDPI

Essay

The Mechanical Art of Laughter

Anaïs Rolez

Art College of Nantes, 2, allée Frida Kahlo, 44000 Nantes, France; anais.rolez@beauxartsnantes.fr

Received: 6 December 2018; Accepted: 19 December 2018; Published: 21 December 2018

Abstract: Our aesthetic experiences are today conditioned by machines, which operate at multiple levels: at the moment of conception of a work, at the moment of conservation and distribution of the work, and at the moment of its contemplation. For art today, it is no longer a theoretical question of asking whether the machine can act with freedom in the sense of a game that remains as of yet open-ended—or if humans themselves can still so act in a world entirely conditioned by technology—because the brute fact is that machines are becoming ever more autonomous, and humans ever more dependent upon them. For some artists, therefore, the ideas of autonomy and sacralization are best addressed, not in the posing of serious questions, but rather through the subversive activity of enticing the machine to reveal its comic nature—and wherein we discover, with Bergson, the essentially rigid and mechanical nature of the humorous.

Keywords: Henri Bergson; Collectif Obvious; comedy; Simone Giertz; humor; laughter; machine art; Niklas Roy; Sunspring; Jean Tinguely

---

1. The Omnipresent Machine

If one were to be allowed a somewhat impressionistic description of the role of the machine in modern culture, one might begin by noting that it is nearly everywhere, and especially in the production of sound and image, as with photography, cinema, video (considered as a distinct art), and television. The means of cultural production and distribution have long since been rationalized and made autonomous: images are produced, reproduced, and diffused through numerous mechanical, electronic, and algorithmic procedures. Images are in turn becoming less representation than artificially produced simulation. A relay of automated reproduction is set off: from literature to theatre to cinema to television, and back again to the printed page in the form of reviews, take offs, and send ups. At the center of it all is the machine in its role of institutionalized automatism, and operating at several levels: at the moment of preparation of a work, at the moment of conservation and distribution of the work, and at the moment of its contemplation. These devices can be understood as organs, as extensions of our senses, and human perception as a system, using models taken from cybernetics, and conceived of on the basis of computations, actions, and feedback loops.

Since the mid-20th century, in short, the automatic processing of information has brought about a major shift in the nature of the work of art; but even before then, the purely mechanical machine had become inseparable from our own aesthetic experiences, as with the sensation of speed and the rapid change of scenery when traveling by train, automobile, or airplane. Likewise, when considering the intimate emotional spaces in which the machine acts upon us, our current awe at witnessing, for example, the precision of the surgical robot (Ancarani 2012) is simply an addition to the emotions we have long felt in the presence of certain historically impressive machines. The machine has now given us the tools, furthermore, to experience phenomena inaccessible with our basic human senses. For instance, the phenomena of the behavior of certain materials in the experiments of the artists Evelina Domnitch and Dmitry Gelfand (Domnitch and Gelfand 2018) would be completely unknown to us without the technology that allows us to see at such a level; technology is similarly essential in the sonification of electromagnetic activity (Kubisch 2003) or tidal flow (Eacott 2008);

and the machines of Felix Luque-Sanchez even allow us to experience a sense of the infinite (Luque-Sanchez 2015). In a world composed of information, machines translate, transpose, code, decode, and transcode phenomenon on our behalf. Indeed, we can enter a universe in which everything is calculated—reference points, forces, illumination, structures, textures, behaviors—and where, lacking mass and without up or down, we can even pass through walls: a so-called 'virtual reality'.

2. The Subversive Machine

In October 2018, a series of murky but also compelling portraits in a style reminiscent of the 18th century—but generated almost entirely by computer—were offered for sale at Christie's by the Paris collective Obvious (Fautrel et al. 2018). The portraits were produced using the GAN (Generative Adversarial Networks) technique developed by AI researcher Ian Goodfellow and his team of engineers at the University of Montreal, with human intervention limited to selecting in the first place the large set of existing portraits fed into the system and used by it as examples of the expected output. This marked the first offering of AI-generated art at a major auction house, and with the lead such work selling for $432,500—this a piece entitled *Portrait of Edmond Belamy*, which was signed in the lower right corner with the equation guiding the entire process, as if by an artist with the charming name of $min_g\ max_d\ E_x[log(D(x))] + E_z[log(1-(D(G(z)))]$ (Elgammal 2018; Schneider 2018).

The work of this Paris collective has as one of its precedents the late 1950s *Méta-matics* of Jean Tinguely. These were painting machines, to be sure, but the paintings produced were an unpredictable result of the co-action between the device itself (with characteristically imprecise drive belts), the audience member's choice of colored marker, and the amount of time the sheet of paper was left exposed to the machine's scribblings. The source of whatever creativity that could be said to be involved was thus not obvious, and this was in fact where the real interest in the *Méta-matics* resided. While each drawing, moreover, was unique, they were not presented as legitimate works of art inasmuch as this would have undercut one of Tinquely's principle goals with the exercise: in 1959, Tachism was at the forefront of the Parisian art scene, and Tinguely wished to mock the subjective excesses and overly serious discourse of these artists. There was, as well, an implicit denunciation of over-consumption and commercialism:

> The drawing machine needed to be cool, funny. The child playing with it had no problem at all, whether it was a work of art or not. And when it began to move, I really liked it, it built up to a certain speed where everything became ridiculous. It became burlesque.[1]

The Obvious collective, in turn, seems to be mocking the feeding frenzy which characterizes not only the speculative art market but also the community of technophiles; and there is also an inherently subversive quality in the hint that objects produced by artificial intelligence can take on some of the attributes of the ready-made.

In other words, we can trace here the evolution, over a period of sixty years (or more than one hundred years if we go back to Duchamp's 1913 *Bicycle Wheel*), of what must now be seen as an alternate artistic strategy—this in contrast to those previously mentioned artists who have embraced the possibilities provided by the machine—for dealing with the brute fact that machines are becoming ever more autonomous, and humans ever more dependent upon them: rather than posing theoretical questions as to whether the machine can act with freedom in the sense of a game that remains as of yet open-ended, or whether humans themselves can still so act in a world entirely conditioned by technology, there is an obvious potency in enticing the machine to reveal its subversive and/or comic nature.

Such an approach can even be placed in the service of a certain cynicism, as with the *Cloaca* series of ten works, dating from 1992, by Wim Delvoye (Regine 2018): huge, assembly line-like machines

1 Tinguely as quoted in *Tinguely et le Mystère de la roue manquante* (Keller 1992). Thomas Thümena (2012) has not hesitated to point out the shabby quality of Tinguely's first kinetic and meta-matic reliefs and their associated joking, gag-like character.

which digested a carefully prepared mixture of ingredients in order to produce quite real-seeming feces (up to 80 kg of fecal material produced daily) as an example of technological development always more ‘driven’ (or, if you prefer, ‘pushed’). The output of these systems was actually vacuum packed and sold to the public as a further commentary on our modern industrial economy, and with both scientists and chefs employed as consultants in order to optimize the overall process.

Artists have not lost their sense of humor. Far from falling in line behind a tendency towards monumentalization and stylization that one finds among the worshipers of science and technology, there is to be found a derision with respect to the monumental and its associated aesthetic claims. The machines of these artists continue to probe subjects which, though not serious, are very profound.

3. Towards a Practice of Mechanical Subversion

Some of these works seem to come straight out of Jacques Carelman’s *Catalogue of Unfindable Objects* (Carelman 1997). Such is certainly the case with the work of Simone Giertz, who presents on *YouTube* and elsewhere (Giertz 2017) her nutty, do-it-yourself robotic creations. A prime example is the robot that serves breakfast (Giertz 2015). Very approximate both in form (it seems to be held together with tape) and action (the cereal is poured beside the bowl instead of in it, as is the milk), the articulated arm moves in a way that is seemingly deliberate (it identifies the objects to be manipulated, and makes appropriate gripping and tilting motions), but ultimately abrupt and clumsy (the spoon is not dipped quite low enough to actually reach into the bowl and so arrives empty, and only in the general vicinity of the mouth of the inventor, who must therefore stretch her head awkwardly to the side to meet it). The humor of the situation—a technically advanced object which is in fact pathetically inept—is further heightened by the apparent aplomb of its inventor, who continues throughout to read a book without glancing up from it. A similar stoicism is exploited in the video of a makeup machine that scribbles lipstick all over her face; and again, we must be reminded, albeit now it in robotic form, of the machines conceived of in the last century by Jean Tinguely.

In the same vein, *My little piece of privacy* by Niklas Roy (Roy 2010) centers on a curtain installed in a storefront window, and meant to prevent the occasional sidewalk passerby from looking in. It is much too small for the job, however—reminding one of the tiny handkerchiefs behind which exotic dancers pretend to hide their dainties—and so must be robotically shuttled back and forth along its curtain rod (this in fact accomplished with a quite sophisticated system consisting of a surveillance camera, computer, and servo drive mechanism) in order to attempt to continuously block the view of said occasional pedestrians as they pass in front of the window. The behavior of the curtain, in turn, evokes a reaction from them, who notice that its movement follows theirs. The interaction sometimes becomes playful, with the goal of the game being to move faster than the curtain, or to find strategies which will trip it up. Once again, there is a disparity: on the one hand, between a task calling for subtlety and discretion, and, on the other, the mechanical system to which it has been assigned. The curtain thus sometimes ends up being jerked back and forth in a frantic and hilarious manner—and we are thus reminded of the crucial connection that Bergson has made between mechanical rigidity and the comic [italics mine]:

> Consequently, it is not his sudden change of attitude that raises a laugh, but rather the involuntary element in this change—his clumsiness, in fact. Perhaps there was a stone on the road. He should have altered his pace or avoided the obstacle. Instead of that, through lack of elasticity, through absentmindedness and a kind of physical obstinacy, as a result, in fact, of rigidity or of momentum, the muscles continued to perform the same movement when the circumstances of the case called for something else. That is the reason of the man’s fall, and also of the people’s laughter.[2]

[2] From Henri Bergson’s *Laughter: An Essay on the Meaning of the Comic*, which was first published in French in 1900; the English translation here is from the 1911 Macmillan edition (Bergson 1911).

Or in summary, "the mechanical plastered onto the living", to use Bergson's phrase, is the true source of laughter.

The literary realm, likewise, has its examples of algorithmic subversion, and these are clearly Oulipian in spirit. Such is the case with the email novel *Rien n'est sans dire* (Nothing is without saying) by Jean-Pierre Balpe (Balpe 2001), and the 'Pipotron' by the collective Cyber!Campus (Cyber!Campus 1997), an automatic generator of random sentences, hollow phrases, and other gibberish which, at the end of a long day, one might use to plump up the introduction or conclusion of a serious report. Comic and ironic at the same time, the Pipotron produces results not unlike those of a certain all-knowing politician; and here again, the humor stems from the rigid and wooden quality of phrases that do fit into the discourse. More recently, director Oscar Sharp has given us his *Sunspring* (Sharp 2016), a short science-fiction film whose dialogue was automatically generated by an AI program of the type originally designed to predict, for example, what word one is attempting to type when sending a text message—but trained instead on the scripts of dozens of science fiction films. A movie so generated will of necessity remain utterly directionless and incoherent, and without depth and meaning; but the viewer is nonetheless surprised by some improbable effects. In the first place, one is shocked to discover the extent to which properly formatted but ultimately nonsensical language can arouse in us an anticipation of meaning; but one is also shocked to realize that we have become almost accustomed to such language via the formulaic speech of advertising and politics. Indeed, we are all but startled to discover that our own understanding has perhaps been in an automatic mode as well. In keeping with our theme, furthermore, this surprise ultimately turns into laughter—i.e., the *dipositif*[3] stands exposed—at the beautifully constructed gibberish we have been taking so seriously.

4. Postscript: Unproductive Expenditure and the Free Laugh

In his *The Notion of Expenditure* (Bataille 1933), Georges Bataille reminds us of the importance to society of what he calls "unproductive expenditure", and hence it is with the comic machines we have been examining here.

From their derision are born unstable images apt to trigger reflections on the meaning of existence. These so-called "useless" machines do not produce anything except laughter, dreams, and even dread. They are machines of theatrics, machines for communication. Yet they do not willingly admit their madness: as with any robot working in a world where order is disorder, they obey.

Decidedly unlike humans in their form and appearance, yet extremely close in their attitudes, paradoxes, complicity, and the humor they provoke, these mechanical works are sufficiently like us so that in a moment of recognition, the regard of each spectator can be turned back on itself. In this, they allow us to go beyond the appearance of the indivisible and the permanent in favor of a mobile, heterogeneous multiplicity of the identities we give to them.

These games thus allow for the appropriation of a symbolic space where the work of art is, in part, unencumbered by the weight of social constructs. In this sense, the artist builds a space of experimentation where the experiment feeds fictions, and these fictions in turn feed reality.

Funding: This research received no external funding.

Conflicts of Interest: The author declares no conflict of interest.

References

Ancarani, Yuri. 2012. *Da Vinci*. Regione Toscanna Film Commission. Available online: http://yuriancarani.com/works/da-vinci/ (accessed on 17 June 2018).

[3] This, of course, is Foucault's term for the entire apparatus of control, articulated by him finally in his 1977 interview "The Confession of the Flesh" (Foucault 1980), but implicit in much of his social criticism.

Balpe, Jean-Pierre. 2001. Rien n'est sans dir: Mail-roman de Jean-Pierre Balpe. Available online: http://www.ciren.org/ciren/productions/mail-roman/index.html (accessed on 17 June 2018).

Bataille, Georges. 1933. *The Notion of Expenditure*. Paris: Éditions Lignes (2011).

Bergson, Henri. 1911. *Laughter: An Essay on the Meaning of the Comic*. Translated by Cloudesly Bereton, and Fred Rothwell. New York: Macmillan, p. 5.

Carelman, Jacques. 1997. *Catalogue D'objets Introuvables*. Paris: Le Cherche Midi.

Cyber!Campus. 1997. Le Pipotron. Available online: http://lepipotron.com/ (accessed on 17 June 2018).

Domnitch, Evelina, and Dmitry Gelfand. 2018. Portablepalace. Available online: http://portablepalace.com/ (accessed on 17 June 2018).

Eacott, John. 2008. Flood Tide. Available online: https://www.youtube.com/watch?v=kBAvGMH9UJg (accessed on 11 September 2018).

Elgammal, Ahmed. 2018. What the Art World Is Failing to Grasp about Christie's AI Portrait Coup. *Artsy*. October 29. Available online: https://www.artsy.net/article/artsy-editorial-art-failing-grasp-christies-ai-portrait-coup (accessed on 28 November 2018).

Fautrel, Pierre, Hugo Caselles-Dupré, and Gauthier Vernier. 2018. Creativity Is Not Only for Humans. Available online: http://obvious-art.com/ (accessed on 17 June 2018).

Foucault, Michel. 1980. The Confession of the Flesh. In *Power/Knowledge: Selected Interviews and Other Writings, 1972–1977*. Edited by Colin Gordon. New York: Pantheon Books, pp. 194–228.

Giertz, Simone. 2015. The Breakfast Machine. Available online: https://www.youtube.com/watch?v=E2evC2xTNWg (accessed on 17 June 2018).

Giertz, Simone. 2017. Simone's Robots. Available online: https://www.youtube.com/channel/UC3KEoMzNz8eYnwBC34RaKCQ (accessed on 17 June 2018).

Keller, Jean-Pierre. 1992. *Tinguely et le Mystère de la roue manquante*. Paris: Ed. Zoe, p. 98.

Kubisch, Christina. 2003. Electrical Walks. Available online: http://www.christinakubisch.de/en/works/electrical_walks (accessed on 11 September 2018).

Luque-Sanchez, Felix. 2015. Different Ways to Infinity. Available online: https://www.felixluque.com/D-W-I (accessed on 17 June 2018).

Regine. 2018. Wim Delvoye: Cloaca 2000–2007, We Make Money Not Art. *Regine*. January 19. Available online: http://we-make-money-not-art.com/wim_delvoye_cloaca_20002007/ (accessed on 28 November 2018).

Roy, Niklas. 2010. My Little Piece of Privacy. Available online: http://www.niklasroy.com/project/88/my-little-piece-of-privacy (accessed on 11 June 2018).

Schneider, Tim. 2018. The Gray Market: How Christie's So-Called 'AI-Generated' Art Sale Proves That Records Can Distort History (and Other Insights). *Artnet*. October 29. Available online: https://news.artnet.com/opinion/gray-market-obvious-portrait-1381798 (accessed on 28 November 2018).

Sharp, Oscar. 2016. Sunspring: A Sci-Fi Short Film Starring Thomas Middleditch. *End Cue*. Available online: https://www.youtube.com/watch?v=LY7x2Ihqjmc (accessed on 11 June 2018).

Thümena, Thomas. 2012. *Tinguely*. Zürich: Frenetic Film.

arts

Article

Survival Research Laboratories: A Dystopian Industrial Performance Art

Nicolas Ballet

ED441 Histoire de l'art, Université Paris 1 Panthéon-Sorbonne, Galerie Colbert, 2 rue Vivienne, 75002 Paris, France; ballet.nicolas@sfr.fr

Received: 27 November 2018; Accepted: 8 January 2019; Published: 29 January 2019

Abstract: This paper examines the leading role played by the American mechanical performance group Survival Research Laboratories (SRL) within the field of machine art during the late 1970s and early 1980s, and as organized under the headings of (a) destruction/survival; (b) the cyborg as a symbol of human/machine interpenetration; and (c) biomechanical sexuality. As a manifestation of the era's "industrial" culture, moreover, the work of SRL artists Mark Pauline and Eric Werner was often conceived in collaboration with industrial musicians like Monte Cazazza and Graeme Revell, and all of whom shared a common interest in the same influences. One such influence was the novel *Crash* by English author J. G. Ballard, and which in turn revealed the ultimate direction in which all of these artists sensed society to be heading: towards a world in which sex itself has fallen under the mechanical demiurge.

Keywords: biomechanical sexuality; contemporary art; destruction art; industrial music; industrial culture; J. G. Ballard; machine art; mechanical performance; Survival Research Laboratories; SRL

1. Introduction

If the apparent excesses of Dada have now been recognized as a life-affirming response to the horrors of the First World War, it should never be forgotten that society of the 1960s, 70s, and 80s was laboring under another ominous shadow, and one that was profoundly technological in nature: the threat of nuclear annihilation. Hence, we must give serious consideration to the industrial culture of the 1970s and 80s—and with the word "industrial" implying an intimate, but also wary relationship with technology. In particular, England in the 1970s witnessed the emergence of industrial music bands involved in a counterculture that operated as a platform of exchange between the arts. The visual productions of industrial musicians, who were initially performers, revealed a global artistic phenomenon operating at the intersection of a multitude of media. The industrial movement involved an elaborated thinking between film, graphics, music, performance and video art in an experimental framework, and under the increasing influence of technology. Genesis P-Orridge theorized this movement encapsulated through the slogan "Industrial Music for Industrial People", borrowed from a conversation s/he had with Californian performer Monte Cazazza and then adopted for the band Throbbing Gristle. These artists intended to construct a new model of socialization from within the post-industrial ruins in which they operated. They exploited the decadence of urban landscapes, and created an aesthetic of dystopia, revealing disturbing hybridizations that questioned the negative—but perhaps also inevitable—effects of technology on the human psyche. Through destruction and trauma in art, these artists asserted a resistance to a new form of power that threatened control over their daily lives, their present, and their future.[1] The idea of "progress" thus became a

[1] This new form of power was identified by the concept of biopolitics by Michel Foucault, who examined here the theoretical effects of the technology over the body (Foucault 1976).

producer of trauma examined in light of the machines created by the Survival Research Laboratories (SRL): a post-apocalyptic iconography with destruction as its necessary focus. This paper examines how the mechanical performances of this collective have anticipated different contemporary issues about the relationship between men and machines, while referring to specific concepts and references (those formulated by several industrial bands, and by J. G. Ballard).

2. Destruction, Survival, and Robotics

In his work *The Destruction of Art* (Gamboni 1996), Dario Gamboni underlines the fact that the tools chosen for destruction are also the ones used for construction. Ruins constitute an ideal space within which to contemplate the recurring theme of destruction—a subject that had attracted a considerable number of artists by the middle of the 1970s. Art historian Kristin Stiles, focusing on performance art, highlights the fact that "destruction art is exhausting. It requires not only consideration of the most urgent and often overwhelming conditions of life, but also constant vigilance so that the dissociative desires to escape into numbed acquiescence do not prevail."[2] An ideal theme having thus been discovered by the industrial music rebellion, there is also a general embrace of the corollary phenomenon of survivalism. According to Stiles, "destruction art bears witness to the tenuous conditionality of survival. [. . .] It is [. . .] one of the few cultural practices to redress the general absence of discussion about destruction in society" (Stiles 1992). The tendency towards an art of destruction reveals, above all, how these artists apprehend the consumer society in which they have evolved, and the prominent role played therein by technology.[3] The re-appropriation of that same technology for radical and violent ends hence questions the pat formulas of an "information society", and control is re-asserted over it as well by making that technology available as a set of tools for the individual. In a summary statement, Stiles evokes the fashion in which artistic appropriation of the machine can address the twin issues of destruction and survival:

> Certain kinds of presentational art forms have demonstrated a predisposition for and an ability to convey the ontological effects of the technology, phenomenology, and epistemology of destruction and the ways in which individuals and the collective negotiate the resulting crisis of survival. These performances and/or public events often feature advanced technology and/or use the body or body surrogates. Robots and other mechanized body substitutes sometimes serve as the aesthetic site for the representation of the conjunction of social and political practices and in interrelationships that collude in destruction. (Stiles 2016, pp. 29–30)

If the author then goes on to argue that the work of artists who merely subject the body (mechanical or biological) to destructive influences cannot in itself constitute an artistic movement, it still seems possible to evoke the emergence of a serious artistic trend, manifested by technological hijackings of a most extreme sort. The machines designed by the American artist Mark Pauline, and remotely controlled during the disquieting performances of the SRL[4], offer a prime example of destruction as survival. Kristine Stiles relates the extent to which "destruction art is the visual corollary to the discourse of the survivor: it bears witness to the tenuous conditionality of survival—survival itself being the fundamental challenge posed by humanity in the twentieth century and to humanity in the twenty-first century. Destruction art is the only attempt in the visual arts to grapple seriously with both the technology of actual annihilation and the psychodynamics of virtual extinction" (Stiles 2016,

[2] From *Concerning Consequences. Studies in Art, Destruction, and Trauma* (Stiles 2016, p. 30). Stiles adds that "destruction art is the kind of performance art where conditions of human emergency are most vividly displayed" (Stiles 2016, p. 42).

[3] For the link between consumerism and technology, see "Swing Low, Sweet Chariot: Kinetic Sculpture and the Crisis of Western Technocentrism", wherein is documented the fact that a great portion of 20th century consumer goods were machines of some sort (Smith 2015).

[4] Officially formed in 1978, the name of the collective—Survival Research Laboratories—stems from an advertisement published in the far-right magazine *Soldier of Fortune*.

p. 31). The witnesses of SRL's performances were faced with the annihilating effects of armed devices that exploded and self-destructed, as seen in *Noise*, a performance held at San Francisco's Golden Gate Park in 1979 (Figures 1 and 2).[5]

Figure 1. Poster for *Noise*, a mechanical performance by SRL, 21 September 1979, Golden Gate Park Bandshell, San Francisco. © Survival Research Labs (www.srl.org).

Figure 2. Scene from *Noise*, a mechanical performance by SRL, 21 September 1979, Golden Gate Park Bandshell, San Francisco. © Survival Research Labs (www.srl.org).

In 1983, the "first industrial performer" explained the relevance of resorting to machines: "The intervention of human performers limits the performance because there are many preconceptions at stake. By using machines, this problem can be avoided altogether; you can trouble people by throwing a whole bunch of very precise ideas and images at them."[6] This strategy was at the center of the event *Terrifying Scenes From The Battlefields of Tomorrow* (1980) and its machinery, and whose goal was the questioning of the very nature of images and of their survival. The machines, which the members of

[5] As an example of the connection between industrial music and mechanical performance art of this kind, members of the British industrial band Throbbing Gristle were present for the occasion. Jean Tinguely, of course, had not only created in 1960 his self-destructing *Homage to New York*, but also, in 1962, had staged a series of explosions in the deserts of Nevada entitled *Study for an End of the World No. 2* (Museum Tinguely 2013).

[6] Mark Pauline as quoted in the *Industrial Culture Handbook* (Vale and Juno 1983, p. 27).

SRL designed for the occasion, were indeed targeted at portraits of armed individuals, with the said portraits subsequently being the victims of rockets launched in their direction (Figures 3 and 4).

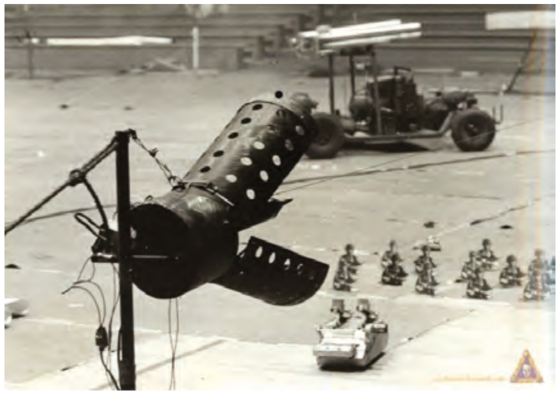


Figure 3. Scene from *Terrifying Scenes from The Battlefields of Tomorrow*, a mechanical performance by SRL, 6 December 1980, Kezar Pavillion, San Francisco. © Survival Research Labs (www.srl.org).

Figure 4. Scene from *Terrifying Scenes from The Battlefields of Tomorrow*, a mechanical performance by SRL, 6 December 1980, Kezar Pavillion, San Francisco. © Survival Research Labs (www.srl.org).

The futuristic paramilitary aesthetic on display here attempted to imagine the technologic conflicts in a multimedia and post-apocalyptical world, and with the assistance of the screening of several short films.[7] This confluence of genres has as its focus an announcement of the death of Western society, foreshadowing Friedrich Kittler's theory, according to which the increasing materiality of the media ultimately leaves the subject itself out of the equation (Kittler 1995, 1986). Mark Pauline's work, however, is not exclusively concerned with mechanical elements, inasmuch as he sometimes includes animal carcasses—a rabbit for *Rabot*, a hog's head for *Piggly-Wiggly* (Figure 5)—and also collaborates with industrial musicians such as Monte Cazazza.[8] One of the works designed by Pauline and Cazzaza, and exhibited during the Factrix "Night of the Succubus" concert at the Ed Mock Dance Studio in San Francisco (6 June 1981)[9], was an animated sculpture made of the body of a pig arranged

[7] Among these, one has to mention *Letters to Dad* (1979) by Scott & Beth B.

[8] The work *Terrifying Scenes from The Battlefields of Tomorrow* already showed these kinds of collaborations with interventions by Factrix, Monte Cazazza, Tana Emmolo and Cole Palme.

[9] The performance was recorded on a VHS tape on the same year. Several excerpts from the video were used in the film *True Gore* (1987), directed by Matthew Dixon Causey and Monte Cazazza (credited as "creative consultant"). According to Jack

on a robotic structure and targeted by Monte Cazzaza's dart gun (Figure 6). We, thus, witness in the industrial culture of that time a foreshadowing of the interpenetration of the organic and mechanical, which has become such a large part of current discourse.

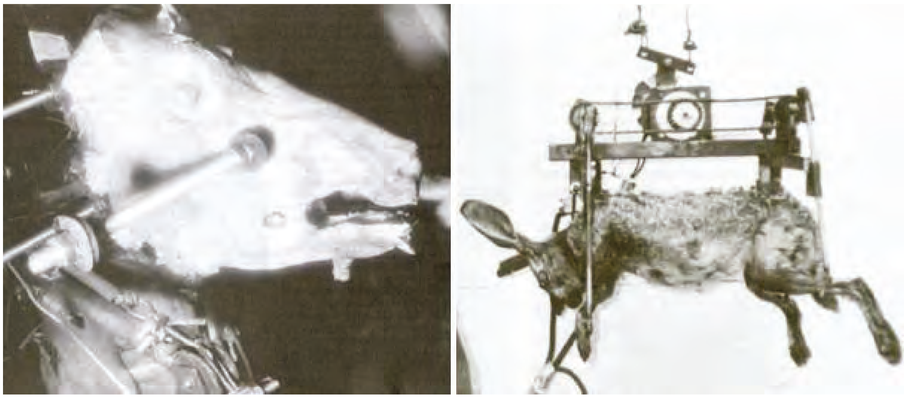


Figure 5. *Piggly-Wiggly* (**left**) and *Rabot* (**right**) by Mark Pauline, 1981. Hog's head, rabbit, and mechanics. Courtesy of the artist. © Survival Research Labs (www.srl.org).

Figure 6. Animated sculpture for *Night of the Succubus* by Mark Pauline and Monte Cazzaza, 6 June 1981, Ed Mock Dance Studio, San Francisco. Pig, robotic structure. © Survival Research Labs (www.srl.org).

3. *Man-Amplified*.[10] The End of the Natural Body and Postmodern Cyborgs

This diversion of organic elements calls into question the very nature of the body, of "its *naturalness*, according to Isabelle Queval. The new pharmacology, transplants and prosthesis imply a plasticity of the *human* which the body emblemizes, and whose fusion with technique remains problematic. Thus, the techniques of health, training, enhancement, and 'augmentation' announce their hold over a work-body suffused with the artificial, and indefinitely perfectible. The advance of knowledge entails, by its very inevitability, an increasing reification of the body. The contours of human identity, just like the notion of the *natural body*, are called into question"[11]. To this conversation regarding hybrid

Sargeant, *True Gore* is "a film which gleefully depicts what many would consider polymorphic sexual dysfunction as home movie [. . .]. The extract presented in *True Gore* depicts Cazazza digging at a sore on his penis with a metal scalpel, and Smith letting a gigantic black centipede scuttle over her labia" (Sargeant 1999).

10 From the title of the album composed by the members of Clock DVA in 1991.

11 From the introduction to the article "Corps Humain" by Isabelle Queval (Queval 2015, pp. 40–41).

machines and the thoughts which they arouse of the end of the natural body, Donna Haraway adds the figure of the postmodern cyborg, and which can be distinguished from the way in which the Dadaists "symbolized the different aspects of the machine and industrial life."[12] If the opposition of "organisms [and] machines, [has been] blurred" since the end of 20th century, Haraway writes, the "distinctions between the natural and the artificial, the body and the mind, self-development and external creation"[13], which should be obvious, keep arousing the interest of industrial artists. The phenomenon which Haraway raises is linked, in particular, to an effect of reversal, in which the machine "is debased to the stage of a means of expression of carnal pleasure", while man transforms himself into "a muscular machine that turns away from pleasure and pursues production", according to the culture studies specialist Klaus Theweleit (Theweleit 1977). Mark Pauline's performances with the SRL exemplify these artistic questions through the prism of robotics. If robots can be traced back to the imaginings of the ancient myths, Gottfried Hattinger explains that the presence of androids in contemporary art began in 1964 with Nam June Paik's sculpture *Robot K-456*. The art historian holds that, "in artistic intents, the machine as a tool, traditionally balancing ends and means, does not play a great part, as opposed to its use as a tool through which artificial works are produced or as an invention which is not oriented towards use, but towards the representation of an intellectual construct, towards the creation of a sculpture or of a spatial or kinetic event" (Hattinger 2014, pp. 61–62). This understanding of robotic installation can be seen in Mark Pauline's hybrid machines, conjuring up the ambivalent relationship between flesh and robot, between the organic and of the mechanical, and which can be found as well in the "repetition principle" of cut-up[14], a core process of industrial culture. These extreme stagings were accompanied by massive explosions, destroying, as designed, the installations themselves. The goal of the American performer was also to explore the mechanisms of thought, of his own reflections as a human being. This intention he materialized during the performance *Mysteries of the Reactionary Mind* (1981), in which, as an example of an entity reacting to a stimulus, machines gradually destroy monumental paintings created by members of the SRL (Figure 7).

The noisy mechanical claws of the machines, as well as the missiles launched against the canvases, place the destruction of art in a soundscape that also emphasizes the theme of alertness, and, in fact, an alarm echoes throughout the various actions as a call to these workshops of artistic destruction. The devices of *Mysteries of the Reactionary Mind* and its "exploration of the mechanics underlying reactionary thought"[15] once again foreshadow an entire current of contemporary philosophy since, according to Jean Baudrillard, "if men dream of original and brilliant machines, it is because they are disheartened by their own originality or because they would rather surrender it and enjoy it through machines. For what machines can offer is the very spectacle of thought, and men, when manipulating them, can indulge in the spectacle of thought rather than in thought itself" (Baudrillard 1990). This "spectacle of thought" takes shape through mechanical reactions whose mental exploration is reversed in the field of contemporary cinema when Cameron Vale (Stephen Lack), protagonist of *Scanners* (David Cronenberg 1981), infiltrates a computer's circuits via a telephone network. After having been examined by Doctor Ruth (Patrick McGoohan), who leads a psychic research program

12 From "Technologie et sexe dans la science-fiction. Note sur l'art de la couverture" (Alloway 1956, p. 45). See also Matthew Biro's *The Dada Cyborg: Visions of the New Human in Weimar Berlin* (Biro 2009).

13 Donna Haraway as quoted in *Manifeste cyborg et autres essais: sciences, fictions, féminismes* (Allard et al. 2007, p. 35). The authors add that "our machines are strangely alive while we are appallingly inert."

14 "Through cut-up, the principle of repetition reaches a degree of systematization which transforms it into a mechanical process. One can talk about a technique of cut-up. [. . .] Cut-up can both operate a mechanical (repetitive) and technical writing (a writing that requires a *technè*, a practice which stems from a kill). Yet, initially, the mechanical is opposed to the organic: cut-up can help conceive the deconstruction of this binary opposition and refashion the links between writing and the mechanical" (Hougue 2014). One should recall the fact that Mark Pauline met William S. Burroughs in the beginning of the 1980s, along with Matt Heckert. For Burroughs' influence on industrial culture, see "Révolution bioélectronique. Les musiques industrielles sous influence burroughsienne" (Ballet 2017).

15 Mark Pauline as quoted in the *Industrial Culture Handbook* (Vale and Juno 1983, p. 27).

named “scanners” that aims to explore the subjects noted for such abilities, Vale becomes aware of his faculty for both manipulating the minds of individuals and controlling machines at a distance: the nervous system here navigates through the printed circuits of the various targeted machines.

Figure 7. Scene from *Mysteries of the Reactionary Mind*, a mechanical performance by SRL, 5 April 1981, Fort Mason Center, San Francisco. © Survival Research Labs (www.srl.org).

This biotechnical fantasy of minds connected at a distance holds several analogies with the utopias of industrial performers, with their interest in cyberspace and the synthesis of organic and mechanical bodies. Gilbert Hottois, in highlighting this phenomenon of hybridization and commingling, notes that it is “often violent, gloomy, wild and unregulated. The typical mixture includes the cyborg, the individual plugged into cyberspace, and an infinity of prostheses whose city is the sum total. The technique is also *immediate* because it physically penetrates human bodies and brains, either to manipulate, amplify or interconnect them” (Hottois 2012). Indeed, this train of thought, under the influence of J. G. Ballard’s works, goes so far as to question the basic tenets of sexuality itself.

4. *Crash* Biomechanical Sexual Hybridization

> Ballard explores in perverse detail the twin leitmotifs of the 20th century: sex and paranoia. [. . .] With a ruthless and sadistic/masochistic honesty, he “reduces the amount of fiction”, forcing us to come face to face with our own ambiguous attitudes. [. . .] What we are forced to realize is that science has become equivalent to pornography in its aim of isolating objects analytically from their context in time and space. [. . .] The obsessions are subjective—the only key in a world deprived of objectivity able to unlock the reality/fiction surrounding each of us.
>
> Graeme Revell[15]

Crash, J. G. Ballard (1973) novel, exhibits a major strength in the expression of an unrestrained “industrial sexuality”, sometimes revealed as an extreme violence inflicted upon bodies in certain works. If the radical content of the novel lies in extraordinary sexual desire, where adepts can only be satisfied through car accidents, the story also exhibits the hold of technology over the human body—an aspect which the section “Technology and Pornography” of the exhibition “J. G. Ballard. Autopsy of the New Millennium” (Costa et al. 2008) displayed. Marianne Celka and Bertrand Vidal show how Ballard precisely describes the paradox of controlled societies in which “consumerist practices can be compared to a phenomenon of sensorial deprivation, through the ever renewed and renewable

[15] Mark Pauline as quoted in the *Industrial Culture Handbook* (Vale and Juno 1983, p. 27).

satisfaction of desires. Thus, only extreme practices, however meaningless and purely gratuitous, can bring new meaning in the world" (Celka and Vidal 2011, p. 43). The technological pornography of *Crash*—foreshadowed by the literary images of the catalogue/novel *La Foire aux atrocités*, which "transmutes pop culture in a neurotic and obscene nightmare" (Mavridorakis 2011, p. 24)—amplified the "cultural libido" of the Independent Group Pop pioneers who had inspired Ballard.[17] His clinical studies of human impulse were eagerly consumed by industrial bands, inclined as they were to present a violent reality without filters. The fantasized violence of the automobile accident reflects the growing power of machines: technology has become so essential in the everyday life of the human species that it now occupies a place of potentially fatal intimacy. This fascination for crinkled iron could already be seen in Michael Rothenstein's "Crash Box" series and in Warhol's "Car Crashes". This latter series, in particular, in which Warhol drew upon archived photographs to create *White Burning Car III* (1963), *Saturday Disaster* (1964) and *Ambulance Disaster* (1963), thus contributes to the establishment of a legitimate motif: that of violent death.

If Neil Printz holds that this series "[constitutes] some of the most violent imagery in the history of art" (Printz 1988, p. 14), the aesthetics developed by the industrial collectives under the influence of Ballard's science fiction amplifies still further the brutality of "mechanical" crashes, and to the extent that the deleterious transformations of the postindustrial model cannot escape notice. That the author's universe has indeed had an impact on the industrial movement becomes truly evident on 19 October 1984, the date of a series of performances organized by RE/Search Publications as an homage to Ballard's novel. V. Vale conceived, during the same year, the event "Crash: A Unique San Francisco Spectacle" in San Francisco's Fort Mason for the release of his book dedicated to the British author, and which book includes articles, interviews, the first chapter of *Crash*, and some of Ballard's short stories and collages (Vale and Juno 1984). The evening was divided into three parts, with installations and performances by Boyd Rice, Mark Pauline, Eric Werner and Monte Cazazza. The first was an intervention by Kristine Ambrosia who, hanging by her feet, was whipped by Boyd Rice in a police uniform. She in turn was holding a chain which passed through a hoop piercing Noni Howard's clitoris, and who was laying among the victims of car crashes tied up on the blood-stained ground. The second phase of the event, an installation designed by Mark Pauline, featured two damaged cars manipulated remotely, thanks to a hydraulic system invented for the occasion. The report of the fanzine *Hello! Happy Taxpayers* mentions the presence of "cars [having] very slow sexual intercourse (like insects). There were four victims in the cars, splattered with blood, covered in gaping and very real looking slashes (made by Monte Cazazza). [...] Exploding blood bags were attached on the victims' bodies and burst one at a time. [...] One of the victims was dressed as a housewife and had obviously been run over when going back home with her trolley: her groceries were scattered on the pavement" (*Hello! Happy Taxpayers* 1985). Four monumental paintings showing bodies maimed by car crashes, as well as a series of documents from the RE/Search book devoted to Ballard (quotes, collages, drawings, pictures) enriched the soundscape of Matt Heckert's installation for the SRL. The four paintings hung in the back of the space next to the photograph of an explosion, a monumental portrait of Ballard, and a selection of his works, among which figured the dystopian novel *Why I Want to Fuck Ronald Reagan* (Ballard 1968). These pieces were accompanied by the screening of two films brought by Monte Cazazza, *Red Asphalt* and *Signal 30*, which documented car crashes and thus completing an extensive multimedia environment meant to immerge the viewer in the gloomy reality of *Crash*. Finally, at the end of the evening, SRL member Eric Werner repeatedly launched "his car, equipped

---

[17] Valérie Mavridorakis deals with the impact of the Independent Group, especially with its part in the 1956 international exhibition "This is Tomorrow" (London, Whitechapel Art Gallery), in Ballard's work. This influence partly stems from "a lack of desire" felt by Pop artists during the 1950s, who attempted to restore "a form of 'cultural libido' [by resorting to] the themes of the ideology of abundance, linked with consumption and technology and which promised a cultural renewal" (Mavridorakis 2011, p. 16).

with a steel spur and decorated with coats of arms on its missile shaped frame, at two crashed vehicles" (*Hello! Happy Taxpayers* 1985; Figure 8).

Figure 8. *Ram Car* by Eric Werner, 1984, San Francisco. © Survival Research Labs (www.srl.org).

These repeated assaults end the performance, recalling the ways in which machines can affect the body, whether psychologically or physically: the fantasy of self-harm by accident. Through the prism of an all-encompassing artistic expression, the influence of Ballardian fiction on 1980s American subculture is thus made manifest. A subsequent Mark Pauline performance, *An Unfortunable Spectacle of Violent Self-Destruction* (1981), had as its setting a car park with several damaged machines—this by way of focusing on the bodily changes generated by mechanical shock, and as underlined, in the promotional poster, by an image of a half-naked man suspended amidst smoking wreckage (Figure 9):

> I'd been thinking all along that this should be a show about accidents. That's kinda what it was about. There was a lot of equipment there that had accidents; a lot of equipment was destroyed. I tried to make sure that the things that were destroyed were as helpless as possible. Things were really tied down, roped up, like the big skeletal man, Flippy Man, that got hauled way up in the air and then crashed . . . and the robot thing whose heads kept blowing up . . . and the catapult firing at the huge face. Just all these things, like the guy getting hit in the head with a rock who tried to sue me . . . breaking the girl's windshield with the ball-bearings that got thrown into the blower . . . accidents. I emptied a five-pound bag into this big blower; the bearings went past where people were and broke the windshield of a car.[18]

The imagery of *Crash* thus rubbed off on both the specific devices of artists and their imaginations, now imbued with the idea of a biomechanical sexuality in which the human body is an integral part of the machine. This implied hybridization is evoked throughout the film *Tetsuo: The Iron Man* (1989), in which director Tsukmoto Shin'ya (塚本晋也) shows Kafkaian transformations of the human body under the grip of industrial waste. The grafting of technological scrap onto human flesh gives rise to the hybrid figure of the man-machine, and suggests, as an example of the way in which humankind tends to evolutively adapt to its own creations, a new, omnipresent, and indispensable form of sexuality.[19]

---

[18] Mark Pauline as quoted in the *Industrial Culture Handbook* (Vale and Juno 1983, p. 27).

[19] Tsukamoto Shin'ya's themes are also exploited by Shozin Fukui (福居ショウジン) in the films *964 Pinocchio* (1991) and *Rubber's Lover* (1996). Shozin Fukui had already directed two short films by the end of the 1980s: *Gerorisuto* (1986), as well as *Caterpillar* (1988), designed by the Japanese filmmaker when he worked on the filming team of *Tetsuo*. The two directors then resorted to the same film techniques: depth animation, handheld camera and hyperactive editing.

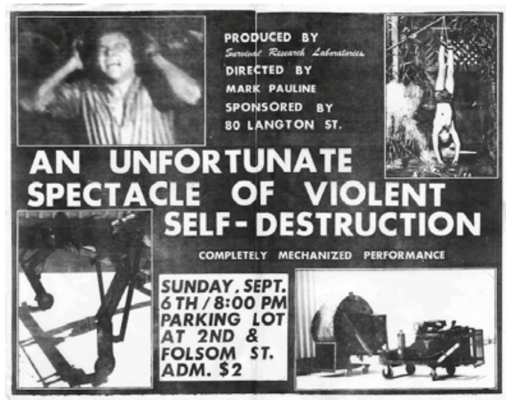


Figure 9. Poster for *An Unfortunate Spectacle of Violent Self-Destruction*, a mechanical performance by SRL, 6 September 1981, Metro Park parking lot, San Francisco. © Survival Research Labs (www.srl.org).

This libidinal connection, in which the biological systems and daily life of the individual become integrated into his tools, had already made its presence known in the title that Mark Pauline had chosen for his inaugural installation *Machine Sex*, in 1979. This title, in turn, had shared origins with the text of a poster that his partner at the time had in fact distributed on the streets of San Francisco, "Machine sex is a bore", a phrase which evoked not only Pauline's obsession with his own machines, but also the boredom which she felt when the American artist devoted long hours to his robots, and thus questioning the presence that the machine occupies in the lives of individuals (Figure 10). Pauline's creations even seem to bear a form of a danger to his own life: "During the show his eccentric machines ran into each other, consumed each other, and melded into broken heaps" (Kelly 1994).

The lure of technological fascination also leads SRL members to conceive a 1988 "Misfortunes of Desire" performance, punctuated by impressive pyrotechnic effects (Figures 11 and 12).

This love of gadgetry once again testifies to the close link between SRL and the industrial movement in general. At a 1982 SPK concert in San Francisco, its leader Graeme Revell was equipped with "a homemade flamethrower designed by Mark Pauline, [which he] pointed at the audience, setting the clothes of a member of the audience on fire" (Duboys 2009, p. 133; Figure 13). If the audience member was not thereby wounded because of this action—and which could have gone incredibly wrong—the warlike attitude embodied by the members of SPK, equipped as they were with lethal weapons, confirms the ambivalence with which these extreme technological hijackings were regarded.

Figure 10. Poster for *Machine Sex*, a mechanical performance by Mark Pauline, February 1979, Chevron station, Columbus & Green, San Francisco. © Survival Research Labs (www.srl.org).

Figure 11. Scene from *Misfortunes of Desire: Acted Out at an Imaginary Location Symbolizing Everything Worth Having*, a mechanical performance by SRL, 17 May 1988, parking lot of Shea Stadium, Queens, New York. © Survival Research Labs (www.srl.org). Photography Credit: mxcandless/adams.

Figure 12. Scene from *Misfortunes of Desire: Acted Out at an Imaginary Location Symbolizing Everything Worth Having*, a mechanical performance by SRL, 17 May 1988, parking lot of Shea Stadium, Queens, New York. © Survival Research Labs (www.srl.org). Photography Credit: mxcandless/adams.

Figure 13. Graeme Revell with a homemade flamethrower designed by Mark Pauline during a performance of SPK, 17 April 1982, Russian Center, San Francisco. © SPK.

The main goal of these performances, however, remains that of alerting the public to the various transformations underway in a postindustrial world, and wherein sexuality is becoming, first and foremost, a mechanical affair. Ballardian metaphors thus appear as recurrent references in the works of an entire generation of artists at the margins of culture. This is evidenced by Graeme Revell's statement that Ballard "hinted towards the fact that the dynamics of post-industrial culture were that of seduction, or some kind of sexual pathology. We were driven by our own consent to take part in postmodern pathologies rather than controlled, from the outside, by some kind of devilish structure (the government or a military-industrial complex)".[20] In SPK's productions—which bring Ballard's solutions back into the field of entertainment, playing with many concepts albeit a singular aesthetic—the display of violent images combined with pornographic iconography attempts to act in the manner of electroshock therapy. The author Éric Duboys states that "for Ballard as for the SPK, violence pre-exists because of the very organization and functioning of society and remains a constitutive phenomenon. Behind its apparent functional coldness, death and self-harm impulses, sexual-machinic deviances proliferate in the individual's subconscious, creating an inorganic subconscious (a concept which Revell borrowed from Deleuze and on which he had wished to write a book)" (Duboys 2009, p. 126). All of these impulses, under the provenance of Lyotard's "activity of life"[21], manifest themselves here as a relationship between sex and technology, while generating an aesthetic and theoretical tendency specific to the industrial genre. Thomas Thorn, an industrial musician writing in the illustrated article "Machine Sex" (Figure 14), thus concludes that "it is only a matter of time before technology renders sex between humans obsolete" (Thorn 1985). This observation appears in the experiments conducted by the SRL members when they question the representation of the subject by staging its own death in a dystopian world featuring aggressive and uncontrollable robots. This aspect leads these performers to explore survivalist reflexes—which are deeply rooted in American culture—through a disturbing paramilitary imagery that aims to fight against the most noxious effects of new technologies. This concern was already apparent, as we have just seen, in Ballard's novels that influenced a whole generation of artists who changed the usual protocols of performance art, while being aware of issues that will be at the center of transhumanism. Indeed, the questions raised very early by the SRL reveal how much scientific research can come initially from the field of experimental art, a field that has a significant impact on new multimedia art practices today.

20 Graeme Revell in correspondence with Éric Duboys. (Duboys 2009, p. 108).
21 "The activity of life always covers that of death impulses." (Lyotard 1977).

MACHINE SEX

TECHNOLOGY CONTINUALLY REVOLUTIONIZES OUR ENVIROMENT. IT CHANGES NOT ONLY THE WAY WE LIVE, BUT THE WAY WE ACT...AND THE WAY WE THINK. OUR WORLD IS DOMINATED BY MACHINES. WE SHARE OUR WORKSPACES WITH THEM, OUR HOMES ARE FILLED WITH THEM. THE HUMAN MUST ADAPT OR BE RENDERED OBSOLETE. AS THE WORLD INDUSTRIALIZES, SO DO THE PEOPLE. INTERPERSONAL COMMUNICATION IS LARGELY DEPENDANT ON MACHINERY. AS A RESULT, INTERACTION BETWEEN PEOPLE BECOMES MORE AND MORE MECHANICAL. EMOTION IS SACRIFICED TO EFFICIENCY. THIS ONLY SERVES TO ISOLATE THE INDIVIDUAL TO A GREATER DEGREE. MEANWHILE, THIS BEING A SOCIETY BASED ON THE CONSUMPTION OF USELESS GOODS & INFORMATION, WE ARE CONSTANTLY ASSAULTED BY BOTH BLATANT AND SUBLIMINAL SUGGESTIONS THAT AFFECT THE BASEST OF HUMAN INSTINCTS: THE SEX DRIVE. THE USE OF SEX IN ADVERTISING HAS PROVEN EXTREMELY EFFECTIVE. HOWEVER, THE RESULT OF THIS PSYCHOLOGICAL ABUSE IS A DISTORTED SENSE OF LUST WITH A STRANGE CONNECTION TO MATERIAL GOODS. IT HEIGHTENS THE ALIENATION FROM HUMANITY WHILE INVOKING A DESIRE FOR SEXUAL CONTACT. THE ANSWER TO THIS DILEMMA HAS BEEN FOUND IN THOSE OBJECTS THAT OFFER SUCH COMPLETE SECURITY: MACHINES. THIS IS ILLUSTRATED BY THE RECENT RISE IN POPULARITY OF PHONE SEX AND COMPUTER SEX SERVICES. WITH A CREDIT CARD IN HAND, SATISFACTION CAN BE ACIEVED SIMPLY BY PUSHING BUTTONS. IT SEEMS ONLY FITTING THAT, IN LIGHT OF THEIR DOMINANT ROLES IN OUR LIVES, MACHINES SHOULD HOLD A SORT OF EROTIC ATTRACTION. THEIR SHAPES ARE OFTEN DRAWN FROM THE SUBCONSCIOUS, MADE IN THE IMAGE OF THAT WHICH WE FIND TRULY BEAUTIFUL. THE PRECISION WITH WHICH THEY EXECUTE THEIR TASKS IS ABSOLUTE. THEY ARE ETERNAL...BEYOND CORRUPTION, BEYOND DECAY. WITH SEXUALLY TRANSMITTED DISEASES REACHING EPIDEMIC PROPORTIONS, IT IS NO SURPRISE TO SEE PEOPLE TURNING TO THE SAFETY AND STERILITY OF MACHINE SEX. IT IS THE ULTIMATE IN SEX WITHOUT GUILT OR RESPONSIBILITY. COMPLETELY ANONYMOUS. IT IS ONLY A MATTER OF TIME BEFORE TECHNOLOGY RENDERS SEX BETWEEN HUMANS OBSOLETE.

Here are 3 devices that offer a novel approach to your feelings

Figure 14. "Machine Sex" by Thomas Thorn, U-Bahn, No. 2, 1985. © Magazine and collages by Thomas Thorn.

Funding: This research received no external funding.

Conflicts of Interest: The author declares no conflict of interest.

References

Allard, Laurence, Delphine Gardey, and Nathalie Magnan, eds. 2007. *Donna Haraway, Manifeste Cyborg et Autres Essais: Sciences, Fictions, Féminismes*. Paris: Exils Editeur, p. 35.

Alloway, Lawrence. 1956. Technologie et sexe dans la science-fiction. Note sur l'art de la couverture. In *Art et Science-Fiction. La Ballard Connection*. Edited by Valérie Mavridorakis. Geneva: MAMCO, pp. 45–50.

Ballard, James Graham. 1968. *Why I Want to Fuck Ronald Reagan*. Brighton: Unicorn Bookshop.

Ballard, James Graham. 1973. *Crash* London: Jonathan Cape.

Ballard, James Graham. 1984. What I Believe. In *RE/Search #8/9: J. G. Ballard*. Edited by V. Vale and Andrea Juno. San Francisco: RE/Search Publications, pp. 174–75.

Ballet, Nicolas. 2017. Révolution bioélectronique. Les musiques industrielles sous influence burroughsienne. *Les Cahiers du musée National d'art Moderne* 140: 74–95.

Baudrillard, Jean. 1990. *La Transparence du Mal. Essai sur les Phénomènes Extrêmes*. Paris: Éditions Galilée, p. 58.

Biro, Matthew. 2009. *The Dada Cyborg: Visions of the New Human in Weimar Berlin*. Minneapolis: University of Minnesota Press.

Celka, Marianne, and Bertrand Vidal. 2011. "Le futur, c'est maintenant". L'imaginaire dystopique dans l'œuvre de James Graham Ballard. *Sociétés* 3: 39–47. [CrossRef]

Costa, Jordi, Rodrigo Fresán, Vicente Luis Mora, V. Vale, and Simon Sellars. 2008. *J. G. Ballard. Autopsy of the New Millennium*. [Exhibition catalog., Barcelona, Centre de Cultura Contemporània de Barcelona, 22 July–2 November 2008]. Barcelona: Centre de Cultura Contemporània de Barcelona.

Duboys, Éric. 2009. *Industrial Musics. Volume 1*. Rosières-en-Haye: Camion Blanc.

Foucault, Michel. 1976. *Histoire de la Sexualité, vol. 1: La Volonté de Savoir*, 2013th ed. Paris: Gallimard, p. 183.

Gamboni, Dario. 1996. *The Destruction of Art: Iconoclasm & Vandalism Since the French Revolution*. London: Reaktion.

Hattinger, Gottfried. 2014. L'artiste et le robot. Brève histoire d'une relation. In *Robotic Art = Art Robotique*. [Exhibition catalog., Paris, Cité des sciences et de l'industrie, 8 April 2014–4 January 2015]. Translation from the German by Valentine Meunier, in Olivier Carriguel (dir.). Paris: Art Book Magazine, pp. 56–62.

Hello! Happy Taxpayers. 1985. No. 4/5 April. Bordeaux: Hello Happy Taxpayer.

Hottois, Gilbert. 2012. Modernité et postmodernité dans l'imaginaire des sciences et techniques au xxe siècle. In *L'idéologie du Progrès dans la Tourmente du Postmodernisme*. [Conference proceedings 9–11 February 2012]. Edited by Valérie André, Jean-Pierre Contzen and Gilbert Hottois. Brussels: Académie royale de Belgique, p. 142.

Hougue, Clémentine. 2014. *Le Cut-Up de William S. Burroughs. Histoire d'une Révolution du Langage*. Dijon: Les presses du réel, p. 357.

Kelly, Kevin. 1994. *Out of Control: The New Biology of Machines, Social Systems and the Economic World*. New York: Basic Books, p. 29.

Kittler, Friedrich. 1995. *Aufschreibesysteme 1800–1900*, 3rd ed. Munich: Wilhelm Fink Verlag. First published 1985.

Kittler, Friedrich. 1986. *Grammophon Film Typewriter*. Berlin: Brinkmann & Bose.

Lyotard, Jean-François. 1977. *Rudiments Païens. Genre Dissertatif*, 2011th ed. Paris: Klincksieck, p. 23.

Mavridorakis, Valérie, ed. 2011. Is There a Life on Earth? La SF et l'art, passage transatlantique. In *Art et Science-Fiction. La Ballard Connection*. Geneva: MAMCO, pp. 9–44.

Museum Tinguely. 2013. *Museum Tinguely Basel: The Collection*. Heidelberg: Kehrer Verlag.

Printz, Neil. 1988. Painting Death in America. In *Andy Warhol: Death and Disasters*. [Exhibition catalog, Houston, The Menil Collection, 21 October 1988–8 January 1989]. Directed by Walter Hopps. Houston: Houston Fine Art Press, pp. 11–22.

Queval, Isabelle. 2015. Corps humain. In *Encyclopédie du Trans/Posthumanisme. L'humain et ses Préfixes*. Directed by Gilbert Hottois, Jean-Noël Missa, and Laurence Perbal. Paris: Vrin, pp. 40–48.

Revell, Graeme. 1984. Essay on J. G. Ballard. In *RE/Search #8/9: J. G. Ballard*. Edited by V. Vale and Andrea Juno. San Francisco: RE/Search Publications, pp. 144–45.

Sargeant, Jack. 1999. *Cinema Contra Cinema*. Berchem: Fringecore, p. 134.

Smith, Glenn. 2015. Swing Low, Sweet Chariot: Kinetic Sculpture and the Crisis of Western Technocentrism. *Arts* 4: 75–92. Available online: http://www.mdpi.com/2076-0752/7/2/15 (accessed on 8 November 2018). [CrossRef]

Stiles, Kristine. 1992. Selected Comments on Destruction Art. In *Book for the Unstable Media*. Edited by Alex Adriaansens, Joke Brouwer, Rik Delhaas and Eugenie den Uyl. Bois-le-Duc: Foundation V2, p. 44.

Stiles, Kristine. 2016. *Concerning Consequences. Studies in Art, Destruction, and Trauma*. Chicago: The University of Chicago Press.

Theweleit, Klaus. 1977. *Fantasmâlgories*. [*Männerphantasien*, 2016 Translation by Christophe Lucchese]. Paris: L'Arche, pp. 381–82.

Thorn, Thomas. 1985. Machine Sex. *U-Bahn*, No. 2. 13.

Vale, V., and Andrea Juno, eds. 1983. *RE/Search #6/7: Industrial Culture Handbook*. San Francisco: Re/Search Publications.

Vale, V., and Andrea Juno, eds. 1984. *RE/Search #8/9: J. G. Ballard*. San Francisco: RE/Search Publications.

arts

MDPI

Article

Communication Machines as Art

Ernest Edmonds

IOCT, Leicester Media School, De Montfort University, The Gateway, Leicester LE1 9BH, UK; ernest@ernestedmonds.com

Received: 30 December 2018; Accepted: 4 February 2019; Published: 9 February 2019

Abstract: The paper presents a personal history of making machines as artworks. The particular kind of art machines that have been made since around 1970 are communication machines: ones that enable humans to interact with each other. However, they do not provide communication in the normal sense, but use a small bandwidth for relatively complex connections, making the experience of the interactions the art experience. The paper concludes by explaining how it later became possible to use computer networking and the Internet to make artworks that were more complex and, in part, autonomous generative machines whilst retaining the earlier communication machine functions.

Keywords: art; computer; communication; machine

1. Introduction

The paper follows an earlier one in this journal in which I described my personal development in relation to art made by algorithmic machines (Edmonds 2018a). For completeness, I will repeat a few of the points made in that earlier description. However, this paper deals with a different aspect of that personal development. In this case, I will review my art that is about human-to-human communication through machines. So the algorithm in the machine, that is central to that other stream of work, is not the point here. Instead, machines have been constructed as artworks through which people communicate with one another. The forms of communication are not linguistic, or meaningful in that explicit sense, but nevertheless what one person sees or hears in the machine is determined by the actions of others. These art works are communication machines, machines that, when operated at least, are art. I presented a paper at a 1970 Computer Graphics conference, Computer Graphics '70, together with Stroud Cornock. It was titled "The Creative Process where the Artist is Amplified or Superseded by the Computer". We discussed the implications of the computer for art and for the role of the artist. We asked: would this machine become the artist of the future? Would the artist of the future have any role at all? The paper was later published in Leonardo (Cornock and Edmonds 1973). Although not discussed in that paper, I was also asking a closely related question: would the machine become the art? The context in which I was asking this last question was communication. As I will explain, I had become interested in human-to-human communication processes and I saw one route forward in my exploration of the computer and art in communication machines. The paper will show how this began using purpose-built logic circuits rather than computers as such and how it has developed into Web-based art machines.

This paper discusses a certain path in the history of interactive art and discusses the context of that history. Whilst considering the works reported, a number of other, non-historical, research questions come to mind. Some of these have been investigated and such work is briefly introduced in Section 5.

2. Machines (as Art)

A machine can be defined as "a piece of equipment with several moving parts that uses power to do a particular type of work"[1]. Today, the notion of "equipment with several moving parts" is taken to include electronic devices, such as the computer. There is expected to be a clear task that a machine should undertake and normally its operation is deterministic: it will always operate in the same way. Another important characteristic of a machine is that it needs a human operator who, at the very least, sets it going. Until it is "going" a machine has little meaning. If we take an interest in the aesthetics of a machine, then that can only be considered when the machine is in action (Edmonds 1987). As Werner Gräff said of the 1925 Berlin bus, " ... the shape of a vehicle must be preserved above all when it is in motion ... OUR NERVES demand PNUMATIC TYRES ... And our aesthetic sense too" (Gräff 1926).

A machine that is art is a working machine that is doing something. We might argue, taking this point further, that the art in an art machine is in what it does much more than in how it looks. Perhaps how it looks is of little concern at all. One perspective on machines as art is to consider them doing something that creates the aesthetic experience that defines the art. It is this view that informs the kind of machine as art that I am reporting here. The machines that I have built and that I describe below are electronic machines, sometimes using computers. Their appearance is often not material. It is primarily the experiences that they facilitate in the audience that is at the core. In this case the audience consists of the operators of the machines, so we would normally call them the participants. The art forms of my machines discussed in this paper are particular cases of interactive art, forms in which the interaction is between different participants through the machines.

3. The Communications Game Concept

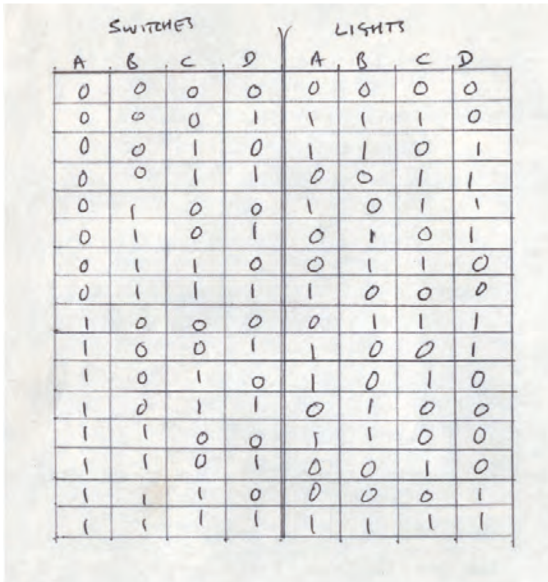
At the same time that Stroud Cornock and I were discussing what became the Computer Graphics '70 conference paper referred to above, I was following psychological research about language and learning. I was most influenced by the work of T.G.R. Bower. He neatly described the key points in a book a little later (Bower 1974). As I have described elsewhere, my focus was on a notion of communication that "was one of meaningful interaction in the sense of, for example, the ways that T.G.R. Bower found that newborn infants explored the world around them. They took actions, observed what happened and, in a very real sense, seemed to form theories that could be tested. They began learning how to communicate through the exploration of actions purposefully taken." (Edmonds 2016). The exploration of interactive art using computers, that was at the heart of the Cornock and Edmonds paper, informed my thinking about this early infant behavior: about the early communications with the world that a newborn makes. Perhaps I could make interactive art, in some sense, that explored these psychological findings about learning to communicate?

My concept was to build an art machine that in itself had no aesthetic, or other, interest but that facilitated some kind of low bandwidth exchange between people, where the involvement in that exchange was the art work experience. The machine I devised was called a *Communications Game*. I used the label "game", not because there was any "computer game" or party aspect to it but so as not to stress my intention to make "art" and so risk participants putting barriers up.

The idea was to provide very simple communication networks between participants who could not see one another. Each participant would access *Communications Game* through their own unit or station. A way of adding a small amount of complexity, that to me seemed to be a vital part of the real world, was to have at least three participant units and for the networks to cross over, so that there was only ever a partial direct link. Thus each unit was to be equipped with an input switch for turning on lights in units of the same network and a single light for output. For each participant, the lights provide the stimuli and the switches, the means of action or response. As I indicated, screens would

[1] Machine, definition, Cambridge Dictionary: https://dictionary.cambridge.org/dictionary/english/machine (accessed on 28 December 2018).

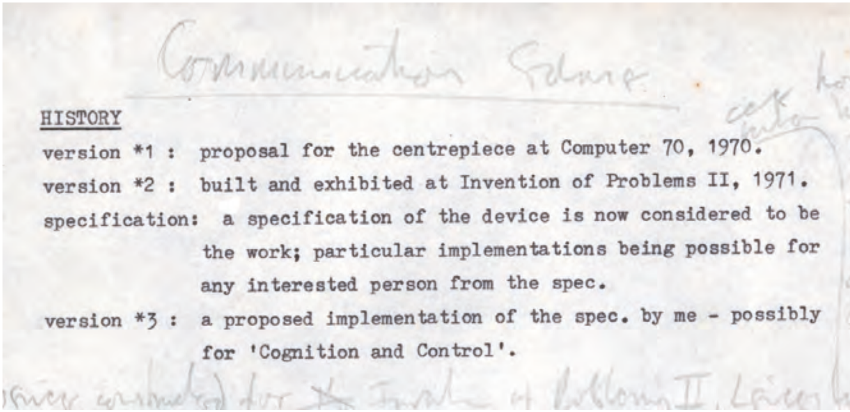
keep participants from seeing each other. The illumination of a light on one unit is controlled by the other participants by opening or closing their switches. The truth table shown in Figure 1 shows how I planned one configuration to work, where for example a person at A can control switch A and sees light A.



SWITCHES A	B	C	D	LIGHTS A	B	C	D
0	0	0	0	0	0	0	0
0	0	0	1	1	1	1	0
0	0	1	0	1	1	0	1
0	0	1	1	0	0	1	1
0	1	0	0	1	0	1	1
0	1	0	1	0	1	0	1
0	1	1	0	0	1	1	0
0	1	1	1	1	0	0	0
1	0	0	0	0	1	1	1
1	0	0	1	1	0	0	1
1	0	1	0	1	0	1	0
1	0	1	1	0	1	0	0
1	1	0	0	1	1	0	0
1	1	0	1	0	0	1	0
1	1	1	0	0	0	0	1
1	1	1	1	1	1	1	1

Figure 1. Truth table drawing, *Communications Game* (c. 1970), © Ernest Edmonds.

The *Communications Game* machine was not defined as any particular physical object. I defined it functionally but was very clear that it could be realized in many different ways. See my note from that time, for example, the "specification" remark in Figure 2. I was emphatic that this was not to be an aesthetic physical object. It was not a crucial issue that it should look a particular way, be in a particular color or be made of a particular material. In a sense, the art was conceptual but the point was that the art was the machine in action, providing the interchange between people that I termed, perhaps rather grandly, "communication". The concept of this work was of a particular machine that was the art, at least once it was in action. By definition, however, there was never meant to be only one physical object. As with most machines, it could be copied, varied and reproduced, as I will describe below.



HISTORY

version *1 : proposal for the centrepiece at Computer 70, 1970.

version *2 : built and exhibited at Invention of Problems II, 1971.

specification: a specification of the device is now considered to be the work; particular implementations being possible for any interested person from the spec.

version *3 : a proposed implementation of the spec. by me - possibly for 'Cognition and Control'.

Figure 2. Notes about *Communications Game* (c. 1971). © Ernest Edmonds.

4. Realizing Communications Games

The first *Communications Game* that I constructed was shown in the *Invention of Problems II* Exhibition at the City of Leicester Polytechnic in 1971. The work has six stations and there are three networks of three units. Screens kept the participants apart. The general physical arrangement is shown in Figure 3.

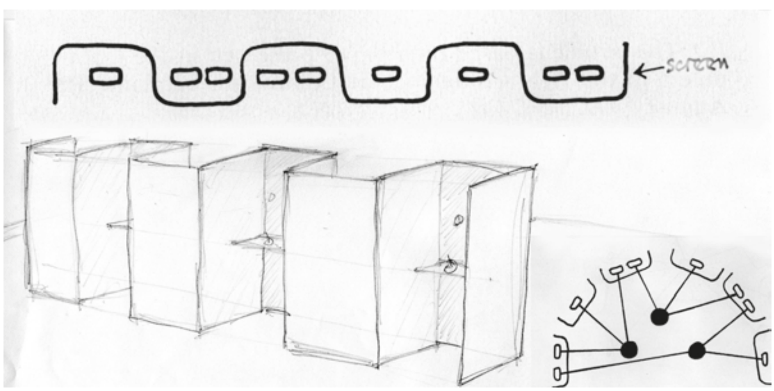


Figure 3. Sketches of the *Communications Game* layout (c. 1971). © Ernest Edmonds.

I designed electronic circuits to implement the connection logic of the networks, along the lines of the truth table in Figure 1. The actual construction of the connection logic, at that time, involved the use of a soldering iron rather than software, as is more convenient today.

In 1972 I was invited to show in the exhibition organized in Nottingham by Stephan Willats, *Cognition and Control* at the Midland Group Gallery (Edmonds 1972, 1975). For this, I constructed a second version that accommodated three, rather than six, participants. My informal evaluation of the first version was that it was rather over complex and I felt that reducing the number of stations, whilst retaining the rest of the design as before, improved the work. See Figure 4.

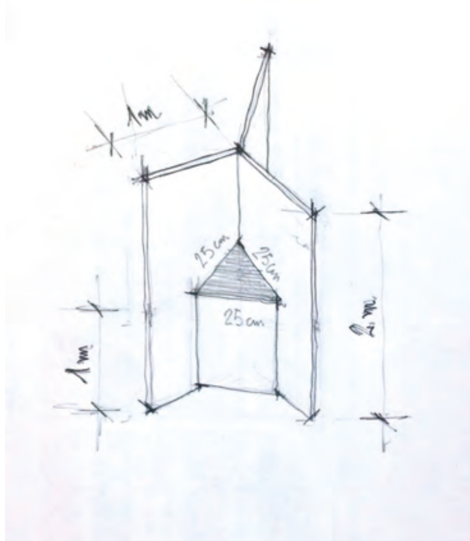


Figure 4. Sketch of *Communications Game version 2* (c. 1972). © Ernest Edmonds.

A little later, I made a three-station version which used sound output rather than lights. Three boxes were installed in different parts of an informal exhibition, also at Leicester Polytechnic. Figure 5 shows part of the circuit diagram used in this version.

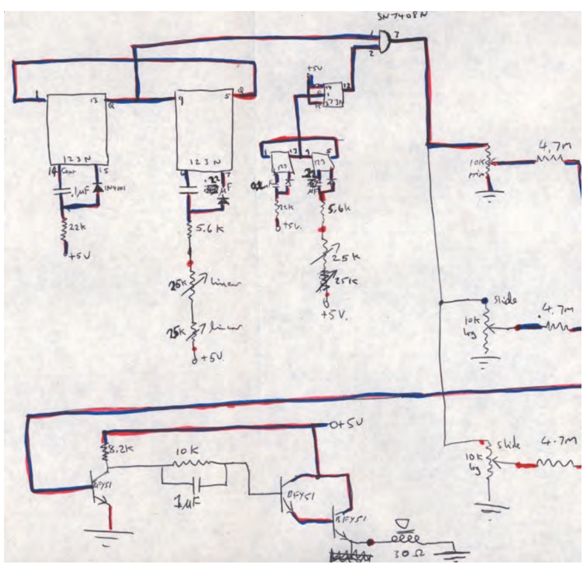


Figure 5. Circuit diagram (detail) of *Communications Game* with sound output (c. 1972). © Ernest Edmonds.

I left my work on communication art machines aside for quite some time, until 1990, when Willats invited me to show in his *Art Creating Society* exhibition at what was then called the Museum of Modern Art, Oxford. By now, I could build networks in software, of course, and I built a new version in which each participant saw a screen rather than lights. The screen showed a sequence of images based on my *Fragment* video construct. See Figure 6 and more about *Fragment* in Edmonds (2018a). The operations performed by other participants changed the image sequence. The network, in this version, contained a number of computers as shown in Figure 7. I had intended to make the stations remote by using wide area network connections to a VAX computer in Oxford, but the collaboration was not sealed in time and that aspect was not realized. The use of wide area networks had to wait until the next phase, as described in Section 4.

Figure 6. Fragment 1984–5, still from the exhibition 'Duality and Co-existence' Exhibiting Space, London, 1985. Photo Ernest Edmonds, © Ernest Edmonds.

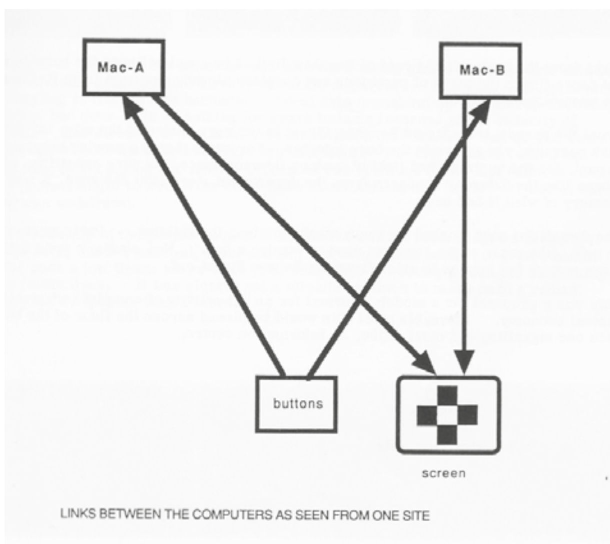


Figure 7. Diagram of one unit of *Communications Game* in the 'Art Creating Society' exhibition, 1990. Illustration from Edmonds (1990).

Much later I started to hold retrospective exhibitions of various kinds and it became useful to construct new implementations of *Communications Game*. I used the second, *Cognition and Control*, version for these reconstructions. The first was shown in 2015 in the *Códigos Primordiais* (Primary Codes) exhibition at Oi Futuro Flamengo, Rio de Janeiro (Poltronieri and Menezes 2017). The electronics was reproduced to function exactly as in 1971, but this time implemented in software on Arduino computers. Visually, it looked very similar to the earlier version, see Figure 8.

Figure 8. *Communications Game* in the 'Primary Codes' exhibition. 2015. Photo Ernest Edmonds. © Ernest Edmonds.

A very similar reconstruction was shown in 2017 at a one-person retrospective, *Constructs Colour Code: Ernest Edmonds 1967–2017* in The Gallery, De Montfort University, Leicester.

5. Communications Game Machines and the Internet

Historically, the time when I first developed my *Communications Game* machines was just as the the first working version of ARPANET, the Internet's predecessor, was put together, in 1969 (Leiner et al. 1997). Of course, the idea of an electronic, computer-based network had been under discussion for some time but the Internet itself awaited the key concepts published in 1974 (Cerf and Kahn 1974). Although *Communications Game* was a machine concept developed before Internet art, it was natural to think about implementing it on the Internet once it was available. However, I never considered making a simple direct version.

I reflected on my Oxford experience of making the computer-based version that employed a local area network and worked towards an extension of the concept. Eventually I started to make a series of works, called *Cities Tango,* that were distributed widely over the Internet (Edmonds and Franco 2013). Briefly, images from remote location are dynamically shown within an otherwise abstract colour structure. The images are treated as abstract objects within the work. The colours used and the pace of the work are influenced by a combination of the audience behaviours at the various locations.

Cities Tango is not a simple machine like *Communications Game*. It incorporates a different interaction paradigm drawn from my *Shaping Form* pieces. These are individual works, first exhibited in 2007 in Washington, DC (Jennings 2007). In these, images are generated using rules determining the colours, the patterns and the timing. The generative works are also changed by inputs from the environment: movement is detected and causes continual changes to the rules, so that changes are made to the generative process. Thus, many of the changes are only apparent over time. A first viewing followed by another weeks or months later will reveal noticeable developments in the colours and patterns. The *Shaping Form* works might be considered machines, but they are not machines in the sense focused upon in this paper. Therefore, by combining *Communications Game* with *Shaping Form, Cities Tango* demonstrates a more complex machine form.

In one example of *Cities Tango*, the cities, Belfast and Sydney, interacted with one another (Edmonds 2009). The colours, shapes and timings used at one location were driven by movements at the remote one. Sometimes, real-time images from the remote location are shown. Immediate responses to movement in the remote location are seen by participants in their own location. See

Figures 9 and 10. Further developments have been made in collaborative projects (Edmonds and Clark 2016).

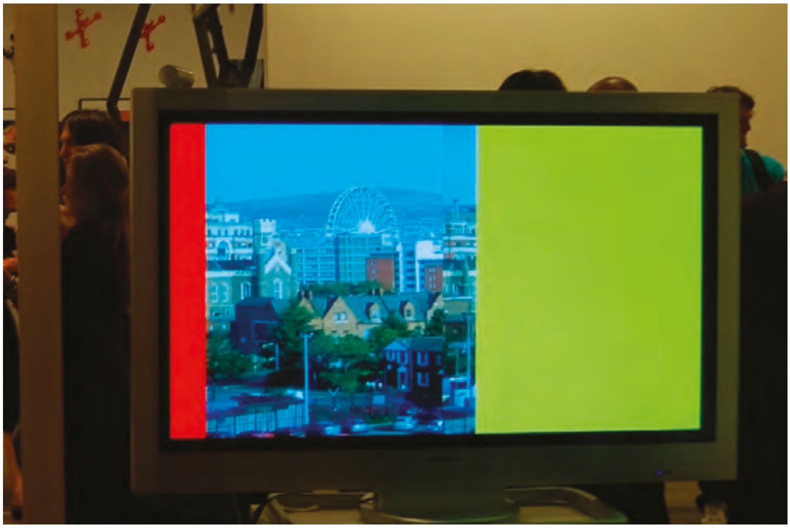


Figure 9. *Cities Tango* in Sydney. 2009. Photo Ernest Edmonds. © Ernest Edmonds.

Figure 10. *Cities Tango* in Belfast. 2009. Photo Ernest Edmonds, © Ernest Edmonds.

These works include the communication machine functions discussed above but they are overlaid on a generative process that is independent of any "operator" (participant) action. The *Cities Tango* works are still machines, so "machines as art", but they have partial autonomy and so are more complex than the machines I made in the 1970s.

6. Research Questions Arising from this History

The primary contribution of this paper is historical but, as the new art forms described above were invented and explored, various research questions arose. Indeed, as I have explained, the initial impetus arose from research in psychology. However, the questions that the work gave rise to, were from the practice-based research viewpoint (Candy and Edmonds 2018) and related more to computer–human interaction than to psychology itself. A full review of such research, from a broader context, is the subject of a recent book that emphasizes how much computer–human interaction research can learn from interactive art research (Edmonds 2018b). I will now give a flavor of research relevant to the art reported in this paper.

Specific issues relating to the artwork *Communications Game* and its developments, technical matters aside, include two main classes of research question: (1) what are the experiences of and influences on the artist, and (2) what are the experiences of the participating audiences?

In relation to the first class of question, I have documented my reflections in the classic practice-based research manner. As yet, most of that research has not been published but, briefly, the key points to note are:

- The early (1970s) concentration on interaction between participants clarified and strengthened an inclination to see the artwork as a conceptual object.
- It became impossible to complete such artworks without seeing versions of them in action, in the field. This led to the development of a beta-testing element in the art-making process and to the *Beta_Space* initiative, as described for example in Candy and Edmonds (2011), in which interactive artworks were shown and evaluated in a live museum exhibition setting.
- The use of the Internet to build distributed communication artworks (art systems) introduced new concerns such as dealing with time, climate and cultural shifts within a single work.

In relation to the second class of question, I should first emphasis that the intended experiences are aesthetic, art, ones. Hence they do not relate to any task or purpose, which would be expected in a more typical computer-human interaction case. The methods used for these studies are those described in two books (Candy and Edmonds 2011; Candy and Ferguson 2014). Those books include various examples of those methods in use together with descriptions of the results.

A specific relevant case of such research was an empirical study of an interactive public installation of an early element of *Cities Tango* (Bilda et al. 2017). The interactions (driven by sound pickup up by a microphone) were quite abstract and participants were at times inclined to "think of sound waves, sunshine and the horizon. Other participants felt happiness, liveliness, a festive or party feel; while still others thought of rhythm and music or a discotheque". A small number of "participants stated that they would have engaged more comfortably if it was in a museum/art gallery context, and that they would prefer an enclosed space with a feeling of an individual experience rather than an open and social one", and "one stated he became self-conscious when he thought he was being monitored". These last two concerns relating, in one way or another, to privacy are of on-going and increasing interest. The future of art of the kind described above must address such concerns, which can indeed become one of the subjects that the art addresses.

The art history described in this paper is one that has led to a particular stream of research about artist and audience experience that is increasingly strong. To review it would require a second paper, at the very least, and here I simply wanted to acknowledge that outcome and point to some of the resulting work.

7. Conclusions

I have presented a personal history of the making of machines as art. The particular machines that I have made, I have termed "communication machines". The term "communications" has only been used to indicate that participants interact with one another through the machines. There is no suggestion or intention that meaningful communication in any deep sense takes place. The interaction is aesthetic. It is the art experience. These machines are not of any particular aesthetic interest as objects, only as machines whose operation is being used by the participants. *Communications Game* was a pre-Internet concept but, in the later part of the paper, I indicate how I developed the idea to both employ the Internet over large distances and incorporate generative, autonomous, approaches from my *Shaping Form* works, thus making the *Cities Tango* series. A full discussion of my work is available in Francesca Franco's book (Franco 2018).

Acknowledgments: I am grateful to Sean Clark for his help in reconstructing *Communications Game* for the 2015 and 2017 exhibitions. As I was preparing the final version of this paper I discovered that Stroud Cornock had sadly passed away. His collaboration and many conversations inspired much of the work that I have done over the fifty years since we first met.

Conflicts of Interest: The author declares no conflict of interest.

References

Bilda, Zafer, Ernest Edmonds, and Deborah Turnbull. 2017. Interactive experience in a public context. In *Proceedings Creativity and Cognition 2007*. New York: ACM, pp. 243–44.

Bower, T.G.R. 1974. *Development in Infancy*. San Francisco: Freeman.

Candy, Linda, and Ernest Edmonds, eds. 2011. *Interacting: Art, research and the Creative Practitioner*. Oxford: Libri Press.

Candy, Linda, and Ernest Edmonds. 2018. Practice-based research in the creative arts: Foundations and futures from the front line. *Leonardo* 51: 63–69. [CrossRef]

Candy, Linda, and Sam Ferguson, eds. 2014. *Interactive Experience in the Digital Age: Evaluating New Art Practice*. London: Springer.

Cerf, Vinton G., and Robert E. Kahn. 1974. A protocol for packet network interconnection. *IEEE Transactions on Communication Technology* 22: 627–41.

Cornock, Stroud, and Ernest Edmonds. 1973. The creative process where the artist is amplified or superseded by the computer. *Leonardo* 16: 11–16. [CrossRef]

Edmonds, Ernest. 1972. Communications game. *Control Magazine* 6: 14.

Edmonds, Ernest. 1975. Art systems for interactions between members of a small group of people. *Leonardo* 8: 225–27. [CrossRef]

Edmonds, Ernest. 1987. Good software design: What does it mean? In *Human-Computer Interaction: INTERACT '87*. Edited by Hans-Jörg Bullinger and Brian Shackel. Amsterdam: Elsevier, pp. 333–35.

Edmonds, Ernest. 1990. Video construct communication systems. *Control Magazine* 14: 14.

Edmonds, Ernest. 2009. Cities Tango: Between Belfast and Sydney. In *Catalogue ISEA2009*. Coleraine: University of Ulster, p. 66.

Edmonds, Ernest. 2016. Network art from the birth of the internet to today. *Acoustic Space* 15: 80–87.

Edmonds, Ernest. 2018a. Algorithmic Art Machines. *Arts* 7: 3. [CrossRef]

Edmonds, Ernest. 2018b. *The Art of Interaction: What HCI can learn from Interactive Art*. San Rafael: Morgan and Claypool.

Edmonds, Ernest, and Stroud Clark. 2016. Tango Apart: Moving Together. In *CHI EA'16 Extended Abstracts on Human Factors in Computing Systems*. New York: ACM, pp. 3663–66.

Edmonds, Ernest, and Francesca Franco. 2013. From communications game to cities tango. *International Journal of Creative Computing* 1: 120–32. [CrossRef]

Franco, Francesca. 2018. *Generative Systems Art: the work of Ernest Edmonds*. London: Routledge.

Gräff, Werner. 1926. On the form of the motor car. *Die Form* 1: 195–201. Translation in Tim Benton. 1975. In *Form and Function*. London: Crosby Lockwood Staples, pp. 242–44.

Jennings, Pamela. 2007. *Catalogue: Speculative Data and the Creative Imaginary*. Washington: National Academy of Sciences Gallery.

Leiner, Barry M., Vinton G. Cerf, David D. Clark, Robert E. Kahn, Leonard Kleinrock, Daniel C. Lynch, Jon Postel, Larry G. Roberts, and Stephen Wolff. 1997. Brief History of the Internet. Available online: https://www.internetsociety.org/internet/history-internet/brief-history-internet/ (accessed on 18 December 2018).
Poltronieri, Fabrizio, and Caroline Menezes. 2017. *Primary Codes*. São Paulo: Caosmos.

arts

MDPI

Essay

The Machine as Artist: An Introduction

Glenn W. Smith [1] and Frederic Fol Leymarie [2,*]

[1] Space Machines Corporation, 3443 Esplanade Ave., Suite 438, New Orleans, LA 70119, USA; gsmith@space-machines.com
[2] Department of Computing, Goldsmiths College, University of London, SE14 6NW London, UK
* Correspondence: FFL@gold.ac.uk

Academic Editor: Annetta Alexandridis
Received: 2 March 2017; Accepted: 28 March 2017; Published: 10 April 2017

Abstract: With the understanding that art and technology are continuing to experience an historic and rapidly intensifying rapprochement—but with the understanding as well that accounts thereof have tended to be constrained by scientific/engineering rigor on the one hand, or have tended to swing to the opposite extreme—it is the goal of this special issue of *Arts* to provide an opportunity for artists, humanists, scientists, and engineers to consider this development from the broader perspective which it deserves, while at the same time retaining a focus on what must surely be the emerging core of our subject: the state of the art in mechatronics and computation is such that we can now begin to speak comfortably of the *machine as artist*—and we can begin to hope, as well, that an aesthetic sensitivity on the part of the machine might help lead to a friendlier and more sensitive machine intelligence in general.

Keywords: art; science; technology; artificial intelligence; aesthetics; empathy; embodiment

---

The Machine as Artist: An Introduction

If we can accept the 1967 founding of the journal *Leonardo* [1] and the 1968 publication of Jack Burnham's *Beyond Modern Sculpture* [2] as milestones—and the latter of which had an extensive chapter on "Robot and Cyborg Art"—it must come as a shock to realize that the study of electronic techno-art has been established as a formal discipline for half a century, and which study since placed in brackets with the appearance of at least two comprehensive surveys [3,4]. It continues to be the case, however, that there has also been constant and now breath-taking progress, and to the extent that *we can at present begin to think of the machine, not as the artist's subject matter or medium, but as creator or co-creator*. Indeed, it is this subject to which the current special issue of *Arts* is dedicated; and we begin by noting that the literature bears ample witness to this emergence, and with the contributions documented therein falling into several major sub-fields:

1. The kinetic or robotic art works whose movement and/or behavior has become so sophisticated that we are entitled to regard them as performance artists in their own right [5–8].
2. The algorithmic studio assistants set loose to embellish computer-mediated graphic or sculptural works of art, and which work is then output via large-format ink-jet printer or additive manufacturing system, or as video [9–14].
3. The autonomous and cleverly-designed painting robots which, drawing upon the emergent properties of minimally-intelligent systems, are nonetheless able to create striking abstract works [15,16].
4. The far more computationally-intensive anthropomorphic robots (Figure 1) able to create sensitive and imaginative portraits of their human subjects, or engage in other forms of graphic virtuosity [17–23].

5. The purely computational/AI systems which qualify themselves as aesthetically competent entities, if not actual artists, by their ability to predict the style period and/or author of existing works of graphic art [24–28].
6. The purely computational/AI systems capable of isolating and capturing the style of a given work of graphic art and applying it in an aesthetically-pleasing manner to an arbitrary image [29–37].
7. The purely computational/AI systems capable of generating striking imagery based on otherwise mundane or even random visual input fields [38–42].

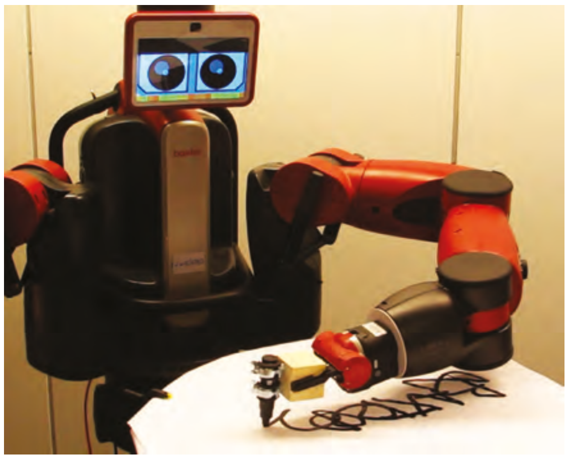


Figure 1. Baxter Signing His Name in Graffiti Style [22].

It is of particular interest and significance, moreover, that these sub-fields tend to overlap within the genre of the traditional *graphic arts*—the physical robotic systems producing sophisticated portraits, and the purely computational systems generating sophisticated analyses and transformations of historic and well-known paintings—for we have here a coming-together of a number of critical threads.

This overlap is due, in the first place, to the fact that graphic art can of course be represented by two-dimensional arrays of pixels, and is thus ideally suited for computational analysis. Indeed, virtually all of the important results reported under categories 5, 6, and 7 above have been achieved with that same family of computational techniques—the "deep neural network", or DNN—that has also been responsible for the recent and unprecedented victories of computer over human in master-level Go and Poker tournaments. In other words, *the graphic arts have emerged as a vital research arena for the artificial intelligence community, and to some extent as a replacement for the board game*—and along with this circumstance comes the opportunity for our own contributors to address the larger questions associated with AI.

And the ultimate question at this point is no longer whether or not artificial intelligence will be capable of achieving some real degree of autonomy [43]; the question, rather, is the degree to which such an autonomous or semi-autonomous intelligence can be designed to operate in a consistently humane and responsible manner [44], and with "responsible", in this day and age, understood to include an environmental dimension.

But of course it is not merely the status of the graphic arts as a computer-friendly medium that should encourage its various practitioners to take on the question of a humane AI: the far larger point is that the graphic arts represent a creative and non-competitive and distinctly human activity—an activity, in fact, intimately associated with the emergence of humankind from a preoccupation with mere survival [45,46]—and an activity as well in which the entire focus is on sensitivity of observation and execution.

In short—and if we can thereby conclude with Herbert Marcuse that "the aesthetic values are the non-aggressive values par excellence" [47]—then *the addition of aesthetic capabilities to the machine intelligence armamentarium would perhaps bring us an important step closer to the addition, as well, of a sense of empathy and responsibility*—and it is this possibility that we would like to propose as the focus of our special edition on "The Machine as Artist".

But let us emphasize here—and as strongly as possible—that it is not only those who have been involved with the computational graphic arts who are making, or who are in a position to make, an important contribution to the genesis of a "friendly AI". In particular, the artists and scientists and engineers who have worked to bring the robot out of the factory and into public gallery and exhibition spaces are playing a critical role in introducing machine intelligence as a physical as well as mental presence, and we are eager to hear more of their work; and to the extent that our basic thesis is correct, most such contributions will tend to have at least some bearing on the question, "Can there be a humane intelligence apart from the sense of balance and harmony and attention to detail that we normally associate with aesthetics?"

Given, however, the speculative and cross-disciplinary nature of this question, it is anticipated that many of the submissions to this special edition will take the form of scholarly *essays* or even *communications* (albeit still subject to peer review); i.e.,—and at the risk of repeating ourselves—we hope to provide here an opportunity for specialists in the fields of computer science, neuroscience, anthropology, and art history to share their thoughts on a more open-ended basis.

In this context—and we rush here to our conclusion, and by way of returning to our central theme—the status of the graphic arts is given a powerful boost by the fact that so distinct is the emergence, and so invariant over time the performance and reception of certain of its styles, that we are entitled to regard it as a *phenomenon*—a phenomenon as yet imperfectly understood, but no less worthy of study, and potentially no less rewarding, than the phenomenon of a certain mineral ore able to fog unexposed photographic plates. Or in other words, we have here a near-ideal venue for interaction between the humanities and the sciences in respect to the question of a humane machine intelligence; and in support of this claim we exhibit following a group of drawings from the Chauvet Cave created some 32,000 years ago (Figure 2)—and the freshness and clarity and sensitivity of which must instill in us a deep wonder:

Figure 2. Group of Chauvet Cave Drawings. By Nachosan - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=32316562.

And given, finally, that no modern intellectual enterprise can be complete without a reference to the very real environmental threat facing our planet, we note that here also the graphic arts have a critical role to play, and as likewise deeply embedded in our culture and history—and there is perhaps no better example than Audubon's depiction of the Swallow-tailed Kite (Figure 3).

A computational analysis of the exquisite lines thereof (refined, as we must note, by the master engraver Havell) would almost certainly reveal, from a human factors standpoint, some noteworthy, if not indeed uncanny, qualities; but what should strike us as most uncanny is the fact that the collected set of such images—the graphic art created by Audubon under humble circumstances as he trekked through the wilds of North America—has been responsible for an outpouring of public commitment to environmental preservation to which no modern public relations campaign can bear comparison; i.e., we have here an example of the fact that art has a very real and unique power, and a greater appreciation and understanding of which has now become a vital matter.

Figure 3. *Swallow-tailed Kite* by John James Audubon.

Acknowledgments: The authors would like to thank the hard-working artists, scientists, and engineers who have made this special issue a possibility.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. *Leonardo: Journal of the International Society for the Arts, Sciences and Technology*. Cambridge: The MIT Press.
2. Burnham, Jack. *Beyond Modern Sculpture: The Effects of Science and Technology on the Sculpture of this Century*. New York: George Braziller, 1968.
3. Shanken, Edward A. *Art and Electronic Media*. New York: Phaidon Press, 2009.
4. Broeckmann, Andreas. *Machine Art in the Twentieth Century*. Cambridge: MIT Press, 2016.
5. Ghedini, Fiammetta, and Massimo Bergamasco. "Robotic Creatures: Anthropomorphism and Interaction in Contemporary Art." Paper presented at the 19th International Symposium in Robot and Human Interactive Communication, Viareggio, Italy, 13–15 September 2010, pp. 731–36. Available online: https://www.researchgate.net/publication/301899556_Robotic_creatures_Anthropomorphism_and_interaction_in_contemporary_art (accessed on 13 February 2017).

6. Penny, Simon. "Robotics and Art, Computationalism and Embodiment." In *Robots and Art: Exploring an Unlikely Symbiosis*. Edited by Damith Herath, Christian Kroos and Stelarc. Singapore: Springer, 2016, pp. 47–65.
7. Rinaldo, Ken. "Trans-Species Interfaces: A Manifesto for Symbiogenisis." In *Robots and Art: Exploring an Unlikely Symbiosis*. Edited by Damith Herath, Christian Kroos and Stelarc. Singapore: Springer, 2016, pp. 113–47.
8. Velonaki, Mari, and David Rye. "Designing Robots Creatively." In *Robots and Art: Exploring an Unlikely Symbiosis*. Edited by Damith Herath, Christian Kroos and Stelarc. Singapore: Springer, 2016, pp. 379–401.
9. Rees, Michael. "Rapid Prototyping: Realizing Convoluted Form and Nesting in Sculpture." *Prototipazione e Produzione Rapida* (1997).
10. Xu, Songhua, Francis C. M. Lau, and Yunhe Pan. *A Computational Approach to Digital Chinese Painting and Calligraphy*. New York: Springer, 2009.
11. Sikora, Stéphane. "Balancing Art and Complexity: Joseph Nechvatal's Computer Virus Project." *THE THING*, 2012. Available online: https://post.thing.net/node/3569 (accessed on 13 February 2017).
12. Holmes, Kevin. "Quayola and Memo Akten Translate Athletic Movements into Abstract Animations." *Creators*, 6 March 2012. Available online: https://creators.vice.com/en_us/article/quayola-and-memo-akten-translate-athletic-movements-into-abstract-animations (accessed on 13 February 2017).
13. Lambert, Nicholas, William Latham, and Frederic Fol Leymarie. "The Emergence and Growth of Evolutionary Art: 1980–1993." *Leonardo* 46 (2013): 367–75. [CrossRef]
14. Roniger, Taney. "Review of "VORTEX: Recent Animations and Works on Paper by Carter Hodgkin"." *Caldaria*, 13 February 2013. Available online: http://www.caldaria.org/2013/06/exhibition-review-carter-hodgkin-by.html (accessed on 13 February 2017).
15. Moura, Leonel. "A New Kind of Art: The Robotic Action Painter." Paper presented at the X Generative Art International Conference, Politecnico di Milano University, Milano, Italy, 2007. Available online: http://www.generativeart.com/on/cic/papersGA2007/16.pdf (accessed on 13 February 2017).
16. Doepner, Stefan, and Urška Jurman. "Robot Partner—Are Friends Electric? " In *Robots and Art: Exploring an Unlikely Symbiosis*. Edited by Damith Herath, Christian Kroos and Stelarc. Singapore: Springer, 2016, pp. 403–23.
17. Calinon, Sylvain, Julien Epiney, and Aude Billard. "A Humanoid Robot Drawing Human Portraits." Paper presented at the 5th IEEE-RAS International Conference on Humanoid Robots, Tukuba, Japan, 5 December 2005, pp. 161–66. Available online: http://lasa.epfl.ch/publications/uploadedFiles/calinon-humanoids-161.pdf (accessed on 13 February 2017).
18. DiPaola, Steve. "Exploring a Parameterised Portrait Painting Space." *International Journal of Arts and Technology* 2 (2009): 82–93. [CrossRef]
19. Tresset, Patrick, and Frederic Fol Leymarie. "Portrait Drawing by Paul the Robot." *Computers & Graphics* 37 (2013): 348–63.
20. Tresset, Patrick, and Oliver Deussen. "Artistically Skilled Embodied Agents." Paper presented at AISB, Goldsmiths, University of London, UK, 1–4 April 2014. Available online: https://kops.uni-konstanz.de/handle/123456789/27046 (accessed on 13 February 2017).
21. Lindemeier, Thomas, Jens Metzner, Lena Pollak, and Oliver Deussen. "Hardware-Based Non-Photorealistic Rendering Using a Painting Robot." *Computer Graphics Forum* 34 (2015): 311–23. [CrossRef]
22. Berio, Daniel, Sylvain Calinon, and Frederic Fol Leymarie. "Learning Dynamic Graffiti Strokes with a Compliant Robot." Paper presented at 2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Daejeon, Korea, 9–14 October 2016, pp. 3981–86. Available online: http://publications.idiap.ch/downloads/papers/2016/Berio_IROS_2016.pdf (accessed on 13 February 2017).
23. Kluszczyński, Ryszard, ed. *Patrick Tresset, Human Traits and the Art of Creative Machines*. Gdańsk: Centre for Contemporary Art LAZNIA, 2016.
24. Johnson, C. Richard, Ella Hendriks, Igor J. Berezhnoy, Eugene Brevdo, Shannon M. Hughes, Ingrid Daubechies, Jia Li, Eric Postma, and James Z. Wang. "Image Processing for Artist Identification." *IEEE Signal Processing Magazine* 25 (2008). [CrossRef]
25. Shamir, Lior, Tomasz Macura, Nikita Orlov, D. Mark Eckley, and Ilya G. Goldberg. "Impressionism, Expressionism, Surrealism: Automated Recognition of Painters and Schools of Art." *ACM Transactions on Applied Perception (TAP)* 7 (2010): 8. [CrossRef]

26. Karayev, Sergey, Matthew Trentacoste, Helen Han, Aseem Agarwala, Trevor Darrell, Aaron Hertzmann, and Holger Winnemoeller. "Recognizing Image Style." *arXiv* (2013). arXiv:1311.3715.
27. Van Noord, Nanne, Ella Hendriks, and Eric Postma. "Toward Discovery of the Artist's Style: Learning to Recognize Artists by Their Artworks." *IEEE Signal Processing Magazine* 32 (2015): 46–54. [CrossRef]
28. Tan, Wei Ren, Chee Seng Chan, Hernán E. Aguirre, and Kiyoshi Tanaka. "Ceci n'est pas une pipe: A Deep Convolutional Network for Fine-art Paintings Classification." Paper presented at 2016 23rd IEEE International Conference on Image Processing (ICIP), Phoenix, AZ, USA, 25–28 September 2016, pp. 3703–7. Available online: https://www.researchgate.net/publication/305402238_Ceci_nest_pas_une_pipe_A_Deep_Convolutional_Network_for_Fine-art_Paintings_Classification (accessed on 13 February 2017).
29. Gatys, Leon A., Alexander S. Ecker, and Matthias Bethge. "A Neural Algorithm of Artistic Style." *arXiv* (2015). arXiv:1508.06576.
30. Gatys, Leon A., Alexander S. Ecker, Matthias Bethge, Aaron Hertzmann, and Eli Shechtman. "Controlling Perceptual Factors in Neural Style Transfer." *arXiv* (2016). arXiv:1611.07865.
31. Li, Chuan, and Michael Wand. "Combining Markov Random Fields and Convolutional Neural Networks for Image Synthesis." Paper presented at the IEEE Conference on Computer Vision and Pattern Recognition, Seattle, WA, USA, 27–30 June 2016, pp. 2479–86. Available online: https://arxiv.org/abs/1601.04589 (accessed on 13 February 2017).
32. Ulyanov, Dmitry, Vadim Lebedev, Andrea Vedaldi, and Victor Lempitsky. "Texture Networks: Feed-forward Synthesis of Textures and Stylized Images." Paper presented at the International Conference on Machine Learning (ICML), New York, NY, USA, 19–24 June 2016, pp. 1349–1357. Available online: http://jmlr.csail.mit.edu/proceedings/papers/v48/ulyanov16.pdf (accessed on 13 February 2017).
33. Alex J., Champandard. "Semantic Style Transfer and Turning Two-bit Doodles into Fine Artworks." *arXiv* (2016). arXiv:1603.01768.
34. Denzler, Joachim, Erik Rodner, and Marcel Simon. "Convolutional Neural Networks as a Computational Model for the Underlying Processes of Aesthetics Perception." In *Computer Vision–ECCV 2016 Workshops, Part I*. Lecture Notes in Computer Science, vol. 9913. Edited by Gang Hua and Hervé Jégou. Switzerland: Springer, 2016, pp. 871–87.
35. Güçlütürk, Yağmur, Umut Güçlü, Rob van Lier, and Marcel A. J. van Gerven. "Convolutional Sketch Inversion." In *Computer Vision–ECCV 2016 Workshops, Part I*. Lecture Notes in Computer Science, vol. 9913. Edited by Gang Hua and Hervé Jégou. Switzerland: Springer, 2016, pp. 810–24.
36. Johnson, Justin, Alexandre Alahi, and Li Fei-Fei. "Perceptual Losses for Real-time Style Transfer and Super-resolution." In *Computer Vision–ECCV 2016, Part II*. Lecture Notes in Computer Science, vol. 9906. Edited by Bastian Leibe, Jiri Matas, Nicu Sebe and Max Welling. Switzerland: Springer, 2016, pp. 694–711.
37. Li, Chuan, and Michael Wand. "Precomputed Real-time Texture Synthesis with Markovian Generative Adversarial Networks." In *Computer Vision–ECCV 2016, Part III*. Lecture Notes in Computer Science, vol. 9913. Edited by Bastian Leibe, Jiri Matas, Nicu Sebe and Max Welling. Switzerland: Springer, 2016, pp. 702–16.
38. Mordvintsev, Alexander, Christopher Olah, and Mike Tyka. "Inceptionism: Going deeper into Neural Networks." *Google Research Blog*, 17 June 2015. Available online: https://research.googleblog.com/2015/06/inceptionism-going-deeper-into-neural.html (accessed on 13 February 2017).
39. Yosinski, Jason, Jeff Clune, Anh Nguyen, Thomas Fuchs, and Hod Lipson. "Understanding Neural Networks through Deep Visualization." *arXiv* (2015). arXiv:1506.06579.
40. Berov, Leonid, and Kühnberger Kai-Uwe. "Visual Hallucination for Computational Creation." Paper presented at the Seventh International Conference on Computational Creativity, Paris, France, 27 June–1 July 2016. Available online: https://www.researchgate.net/publication/304932129_Visual_Hallucination_For_Computational_Creation (accessed on 13 February 2017).
41. Nguyen, Anh, Jason Yosinski, Yoshua Bengio, Alexey Dosovitskiy, and Jeff Clune. "Plug & Play Generative Networks: Conditional Iterative Generation of Images in Latent Space." *arXiv* (2016). arXiv:1612.00005.
42. Tan, Wei Ren, Chee Seng Chan, Hernan Aguirre, and Kiyoshi Tanaka. "ArtGAN: Artwork Synthesis with Conditional Categorial GANs." *arXiv* (2017). arXiv:1702.03410.
43. Amodei, Dario, Chris Olah, Jacob Steinhardt, Paul Christiano, John Schulman, and Dan Mané. "Concrete Problems in AI Safety." *arXiv* (2016). arXiv:1606.06565.
44. Russell, Stuart, Daniel Dewey, and Max Tegmark. "Research Priorities for Robust and Beneficial Artificial Intelligence." *Ai Magazine* 36 (2015): 105–114.

45. Mellars, Paul. "The Impossible Coincidence: A Single-Species Model for the Origins of Modern Human Behavior in Europe." *Evolutionary Anthropology Issues News and Reviews* 14 (2005): 12–27. [CrossRef]
46. Gombrich, Ernst. "The Miracle at Chauvet." *The New York Review of Books*, 14 November 1996 43 (1996).
47. Marcuse, Herbert. *Art and Liberation: Collected Papers of Herbert Marcuse*. New York: Routledge, 2007, vol. 4, p. 118.

arts

MDPI

Essay

Art in the Age of Machine Intelligence †

Blaise Agüera y Arcas

Research and Machine Intelligence, Google Seattle, 601 N 34th St, Seattle, WA 98103, USA;
blaisea@creativemachine.org.uk

† Although the following essay has already been published by Medium (https://medium.com/artists-and-machine-intelligence/what-is-ami-ccd936394a83), it is being re-published here by an agreement between the author himself and the editorial staff of both Medium and MDPI, and on the grounds that a work dealing in such a clear, comprehensive, and compelling manner with the critical social issue of a rapidly emerging machine intelligence deserves widespread dissemination; furthermore, given that the essay is also thoroughly grounded in respect to the histories of both art and science—and with appropriate citations—such a dissemination might well include academic publication; and given still further that its focus is the advent of machine intelligence as a mighty new factor in the arts, the current Special Issue of Arts on "The Machine as Artist (for the 21st Century)" would seem to be an ideal venue, and wherein it will stand as an important complement to our own introductory essay.

Received: 7 September 2017; Accepted: 14 September 2017; Published: 29 September 2017

Abstract: In this wide-ranging essay, the leader of Google's Seattle AI group and founder of the Artists and Machine Intelligence program discusses the long-standing and complex relationship between art and technology. The transformation of artistic practice and theory that attended the 19th century photographic revolution is explored as a parallel for the current revolution in machine intelligence, which promises not only to mechanize (or democratize) the means of reproduction, but also of production.

Keywords: art; science; technology; machine learning; artificial intelligence; aesthetics; photography

---

Art in the Age of Machine Intelligence

Art has always existed in a complex, symbiotic and continually evolving relationship with the technological capabilities of a culture. Those capabilities constrain the art that is produced, and inform the way art is perceived and understood by its audience.

Like the invention of applied pigments, the printing press, photography, and computers, we believe machine intelligence is an innovation that will profoundly affect art. As with these earlier innovations, it will ultimately transform society in ways that are hard to imagine from today's vantage point; in the nearer term, it will expand our understanding of both external reality and our perceptual and cognitive processes.

As with earlier technologies (Figure 1), some artists will embrace machine intelligence as a new medium or a partner, while others will continue using today's media and modes of production. In the future, even the act of rejecting it may be a conscious statement, just as photorealistic painting is a statement today. Any artistic gesture toward machine intelligence—whether negative, positive, both, or neither—seems likelier to withstand the test of time if it is historically grounded and technically well informed.

Figure 1. An American daguerreotype from 1839—amateur chemist and photography enthusiast Robert Cornelius in Philadelphia taking, as far as we know, the world's first selfie. Image permission: this image is in the public domain. United States National Archives, Washington, DC, USA.

Walter Benjamin illustrated this point mordantly in his 1931 essay, "Little History of Photography" (Benjamin 1999), citing an 1839 critique of the newly announced French daguerreotype technology in the Leipziger Stadtanzeiger (a "chauvinist rag"):

> To try to capture fleeting mirror images," it said, "is not just an impossible undertaking, as has been established after thorough German investigation; the very wish to do such a thing is blasphemous. Man is made in the image of God, and God's image cannot be captured by any machine of human devising. The utmost the artist may venture, borne on the wings of divine inspiration, is to reproduce man's God-given features without the help of any machine, in the moment of highest dedication, at the higher bidding of his genius. (Benjamin 1999, p. 508)

This sense of affront over the impingement of technology on what had been considered a defining human faculty has obvious parallels with much of today's commentary on machine intelligence. It is a reminder that what Rosi Braidotti has called "moral panic about the disruption of centuries-old beliefs about human 'nature'" (Braidotti 2013, p. 2) is nothing new.

Benjamin (1999) goes on to comment:

> Here we have the philistine notion of "art" in all its overweening obtuseness, a stranger to all technical considerations, which feels that its end is nigh with the alarming appearance of the new technology. Nevertheless, it was this fetishistic and fundamentally antitechnological concept of art with which the theoreticians of photography sought to grapple for almost a hundred years, naturally without the smallest success. (Benjamin 1999, p. 508)

While these "theoreticians" remained stuck in their thinking, practitioners were not standing still. Many professionals who had been making their living painting miniature portraits enacted a very successful shift to studio photography; with those who brought together technical mastery and a good eye, art photography was born, over the following decades unfolding a range of artistic possibilities latent in the new technology that had been inaccessible to painters: micro-, macro- and telephotography, frozen moments of gesture and microexpression, slow motion, time lapse, negatives and other manipulations of the film, and so on.

Artists who stuck to their paintbrushes also began to realize new possibilities in their work, arguably in direct response to photography. David Hockney interprets cubism from this perspective:

> cubism was about the real world. It was an attempt to reclaim a territory for figuration, for depiction. Faced with the claim that photography had made figurative painting obsolete, the cubists performed an exquisite critique of photography; they showed that there were certain aspects of looking—basically the human reality of perception—that photography couldn't convey, and that you still needed the painter's hand and eye to convey them. (Quoted in (Weschler 2008, p. 294))

Of course, the ongoing relationship between painting and photography is by no means mutually exclusive; the language of wholesale embrace on the one hand versus response or critique on the other is inadequate. Hockney's "joiners" explored rich artistic possibilities in the combination of photography with "a painter's hand and eye" via collage in the 1980s, and his more recent video pieces from Woldgate Woods do something similar with montage.

Hockney was also responsible, in his 2001 collaboration with physicist Charles Falco, for reigniting interest in the role optical instruments—mirrors, lenses, and perhaps something like a camera lucida—played in the sudden emergence of visual realism in early Renaissance art.[1] It has been clear for a long time that visual effects like the anamorphic skull across the bottom of Hans Holbein's 1553 painting The Ambassadors (Figure 2) could not have been rendered without clever optical tricks involving tracing from mirrors or lenses—effectively, paintbrush-assisted photography. Had something like the Daguerre-Niépce photochemical process existed in their time, it seems likely that artists like van Eyck and Holbein would have experimented with it, either in addition to, in combination with, or even instead of paint.

Figure 2. The Ambassadors by Hans Holbein, 1533. Oil on oak, 207 x 209.5 cm. *The National Gallery*, London. Image reproduced with permission (left). Digitally reprojected image of the anamorphic skull in the bottom center of the painting. The imperfections evident in the left eyesocket may have been due to the need to move or refocus the optics halfway through. Image permission: courtesy Thomas Shahan, https://commons.wikimedia.org/wiki/File:Holbein_Skull.jpg. (right).

[1] The Hockney-Falco thesis is explained at length in Hockney (2001) book *Secret Knowledge: Rediscovering the Lost Techniques of the Old Masters*. While critiques of their methodology and expository approach have been made, both by scientists and by art historians (see, for example, Tyler (2004)), the basic point, that the Old Masters used what was at the time state-of-the-art optical technology to render effects in painting, is not in serious dispute.

So, the old European masters fetishized by the Leipziger Stadtanzeiger were not reproducing "man's God-given features without the help of any machine", but were in fact using the state of the art. They were playing with the same new optical technologies that allowed Galileo to discover the moons of Jupiter, and van Leeuwenhoek to make the first observations of microorganisms.

Understanding the ingenuity of the Renaissance artists as users and developers of technology should only increase our regard for them and our appreciation of their work. It should not come as a surprise, as in their own time they were not "Old Masters" canonized in the historical wings of national art museums, but intellectual and cultural innovators. To imagine that optics somehow constituted "cheating" in Renaissance painting is both a failure of the imagination and the application of a historically inappropriate value system. Yet even today, some commentators and theoreticians—typically not themselves working artists—remain wedded to what Benjamin called "the philistine notion of 'art'", as pointed out in an article in *The Observer* from 2000 in response to the Hockney-Falco thesis:

> Is [the use of optics] so qualitatively different from using grids, plumb-lines and maulsticks? Yes—for those who regard these painters as a pantheon of mysterious demigods, more than men if less than angels, anything which smacks of technical aid is blasphemy. It is akin to giving scientific explanations for the miracles of saints. (Marr 2000)

There is a pungent irony here. Scientific inquiry has, step by step, revealed to us a universe much more vast and complex than the mythologies of our ancestors, while the parallel development of technology has extended our creative potential to allow us to make works (whether we call them "art", "design", "technology", "entertainment", or something else) that would indeed appear miraculous to a previous generation. Where we encounter the word "blasphemy", we may often read "progress", and can expect miracles around the corner.[2]

One would like to believe that, after being discredited so many times and over so many centuries, the "antitechnological concept of art" would be relegated to a fundamentalist fringe. However, if history has anything to teach us in this regard, it is that this particular debate is always ready to resurface. Perhaps this is because it impinges, consciously or not, on much larger issues of human identity, status and authority. We resist epistemological shock. Faced with a new technical development in art it is easier for us to quietly move the goalposts after a suitable period of outrage, re-inscribing what it means for something to be called fine art, what counts as skill or creativity, what is natural and what is artifice, and what it means for us to be privileged as uniquely human, all while keeping our categorical value system—and our human *apartness* from the technology—fixed.

More radical thinking that questions the categories and the value systems themselves comes from writers like Donna Haraway and Joanna Zylinska. Haraway, originally a primatologist, has done a great deal to blur the conceptual border between humans and other animals;[3] the same line of thinking led her to question human exceptionalism with respect to machines and human-machine hybrids. This may seem like speculative philosophy best left to science fiction, but in many respects, it already applies. Zylinska, in her 2002 edited collection *The Cyborg Experiments: The Extensions of the Body in*

---

2 Even works that eschew modern technology are often enriched owing to that choice—whether through new perspectives on traditional techniques, as with the analog techno ensemble Dawn of Midi (https://dawnofmidi.bandcamp.com/), or through an aesthetic or even ethic of renunciation, as with Amish furniture made entirely by hand. These artistic or design choices are of course not "wrong"; on the contrary, their "rightness" exists in relation to the technology of the culture in which they are embedded, and they would be diminished without that context. We can be as awed by contemporary renunciatory art as the artists of the past would be by today's "normal".

3 From an evolutionary point of view, it is clear that other primate brains are closely analogous to those of humans, hence the widespread use of macaques for electrophysiological experiments. Many of Haraway's contributions are, however, focused on behavioral and sociological studies, domains where she shows how the cultural priors of the research community inform which questions are asked, which observations are made, and which conclusions are drawn. There is an element of subjectivity and observer bias in every branch of science, but it's especially pronounced in research areas that rely heavily on narrative and statistical observations.

the Media Age, interviewed the Australian performance artist Stelarc, whose views on the relationship between humanity and technology set a useful frame of reference:

> The body has always been a prosthetic body. Ever since we evolved as hominids and developed bipedal locomotion, two limbs became manipulators. We have become creatures that construct tools, artefacts and machines. We've always been augmented by our instruments, our technologies. Technology is what constructs our humanity; the trajectory of technology is what has propelled human developments. I've never seen the body as purely biological, so to consider technology as a kind of alien other that happens upon us at the end of the millennium is rather simplistic. (Zylinska 2002, p. 114)

As Zylinska and her coauthor Sarah Kember elaborate in their book *Life after New Media* (2012), one should not conclude that anything goes, that the direction of our development is predetermined, or that technology is somehow inherently utopian. Many of us working actively on machine intelligence are, for example, co-signatories of an open letter calling for a worldwide ban on autonomous machine intelligence-enabled weapons systems (Future of Life Institute 2015), which do pose very real dangers. Turkle (2011) has written convincingly about the subtler, but in their way equally disturbing failures of empathy, self-control and communication that can arise when we project emotion onto machines that have none, or use our technology to mediate our interpersonal relationships to the exclusion of direct human contact. It is clear that, as individuals and as a society, we do not always make good choices; so far we have muddled through, with plenty of (hopefully instructive, so far survivable) missteps along the way. However, Kember and Zylinska (2012) point out,

> If we do accept that we have always been cyborgs[4] ... it will be easier for us to let go of paranoid narratives ... that see technology as an external other that threatens the human and needs to be stopped at all costs before a new mutant species—of replicants, robots, aliens emerges to compete with humans and eventually to win the battle ... [S]eeing ourselves as always already connected, as being part of the system—rather than as masters of the universe to which all beings are inferior—is an important step to developing a more critical and a more responsible relationship to the world, to what we call "man," "nature" and "technology". (Kember and Zylinska 2012, p. 193)

Perhaps it is unsurprising that these perspectives have often been explored by feminist philosophers, while replicants and terminators come from the decidedly more masculine (and speculative) universes of Philip K. Dick, Ridley Scott and James Cameron. On the most banal level, the masculine narratives tend to emphasize hierarchy, competition, and winner-takes-all domination, while these feminist narratives tend to point out the collaborative, interconnected and non-zero sum; more tellingly, they point out that we are already far into and part of the cyborg future, deeply entangled with technology in every way, not organic innocents subject to a technological onslaught from without at some future date.

This point of view invites us to rethink art as something generated by (and consumed by) hybrid beings; the technologies involved in artistic production are not so much "other" as they are "part of". As the media philosopher Vilém Flusser put it, "tools ... are extensions of human organs: extended teeth, fingers, hands, arms, legs" (Flusser 1983, p. 23). Preindustrial tools, like paintbrushes or pickaxes, extend the biomechanics of the human body, while more sophisticated machines extend prosthetically into the realms of information and thought. Hence, "All apparatuses (not just computers) are ... 'artificial intelligences', the camera included" (ibid., pp. 30–31).

That the camera extends and is modeled after the eye is self-evident. Does this make the eye a tool, or the camera an organ—and is the distinction meaningful? Flusser (1983) characterization of the

4 "Cyborg" is short for cybernetic organism, meaning a hybrid of machine and biology.

camera as a form of intelligence might have raised eyebrows in the 20th century, since, surrounded by cameras, many people had long since reinscribed the boundaries of intelligence more narrowly around the brain—perhaps, as we have seen, in order to safeguard the category of the uniquely human. Calling the brain the seat of intelligence, and the eye therefore a mere peripheral, is a flawed strategy, though. We are not brains in biological vats. Even if we were to adopt a neurocentric attitude, modern neuroscientists typically refer to the retina as an "outpost of the brain" (Tosini et al. 2014)[5], as it is largely made out of neurons and performs a great deal of information processing before sending encoded visual signals along the optic nerve.

Do cameras also process information nontrivially? It is remarkable that Flusser was so explicit in describing the camera as having a "program" and "software" when he was writing his philosophy of photography in 1983, given that the first real digital camera was not made until 1988 (Wikipedia 2017a). Maybe it took a philosopher's squint to notice the "programming" inherent in the grinding and configuration of lenses, the creation of a frame and field of view, the timing of the shutter, the details of chemical emulsions and film processing. Maybe, also, Flusser was writing about programming in a wider, more sociological sense.

Be this as it may, for today's cameras, this is no longer a metaphor. The camera in your phone is indeed powered by software, amounting at a minimum to millions of lines of code (Information is Beautiful 2017). Much of this code performs support functions peripheral to the actual imaging, but some of it makes explicit the nonlinear summing-up of photons into color components that used to be physically computed by the film emulsion. Other code does things like removing noise in near-constant areas, sharpening edges, and filling in defective pixels with plausible surrounding color, not unlike the way our retinas hallucinate away the blood vessels at the back of the eye that would otherwise mar our visual field (Summers 2011). The images we see can only be "beautiful" or "real-looking" because they have been heavily processed, either by neural machinery or by code (in which case, both), operating below our threshold of consciousness. In the case of the software, this processing relies on norms and aesthetic judgments on the part of software engineers, so they are also unacknowledged collaborators in the image-making.[6] There is no such thing as a natural image; perhaps, too, there is nothing especially artificial about the camera.

The flexibility of code allows us to make cameras that do much more than producing images that can pass for natural. Researchers like those at Massachusetts Institute of Technology (MIT) Media Lab's Camera Culture group have developed software-enabled nontraditional cameras (many of which still use ordinary hardware) that can sense depth, see around corners, or see through skin (http://cameraculture.media.mit.edu/); Abe Davis and collaborators have even developed a computational camera that can "see" sound, by decoding the tiny vibrations of houseplant leaves and potato chip bags (Davis et al. 2014). So, Flusser (1983) was perhaps even more right than he realized in asserting that cameras follow programs, and that their software has progressively become more important than their hardware. Cameras are "thinking machines".

It follows that when a photographer is at work nowadays, she does so as a hybrid artist, thinking, manipulating and encoding information with neurons in both the brain and the retina, working with muscles, motors, transistors, and millions of lines of code. Photographers are cyborgs.

What new kinds of art become possible when we begin to play with technology analogous not only to the eye, but also to the brain? This is the question that launched the Artists and Machine Intelligence (AMI)

---

5 "A remarkable piece of tissue, the retina is a true outpost of the brain, peripheral only for its location on the back of the eye" (Tosini et al. 2014, p. 3).

6 Similar aesthetic judgments (and impressive engineering feats to support them) were in play by the end of the film emulsion era. Kodacolor II had "as many as 12 emulsion layers, with upwards of 20 different chemicals in each layer" (Wikipedia 2017b). This chemical programming embodied aesthetic judgments, just like the software that eventually replaced it. Aesthetics imply normativity, and therefore are not neutral with respect to subject matter; so for example, photo processing explicitly favored white people until late in the film era. Some digital camera software still reflects racial bias (see Cima 2015).

program (https://ami.withgoogle.com/). The timing is not accidental. Over the past several years, approaches to machine intelligence based on approximating the brain's architecture have started to yield impressive practical results—this is the explosion in so-called "deep learning" or, more accurately, the renaissance of artificial neural networks. In the summer of 2015, we also began to see some surprising experiments hinting at the creative and artistic possibilities latent in these models.

Understanding the lineage of this body of work will involve going back to the origins of computing, neuroscience, machine learning and artificial intelligence. For now, we will briefly introduce the two specific technologies used in our first gallery event, Deep Dream (in partnership with Gray Area Foundation for the Arts in San Francisco, http://grayarea.org/event/deepdream-the-art-of-neural-networks)[7]. These are "Inceptionism" or "Deep Dreaming", first developed by Alex Mordvintsev at Google's Zurich office (Mordvintsev et al. 2015), and "style transfer", first developed by Leon Gatys and collaborators in the Bethge Lab at the Centre for Integrative Neuroscience in Tübingen (Gatys et al. 2016). It is fitting and likely a sign of things to come that one of these developments came from a computer scientist working on a neurally inspired algorithm for image classification, while the other came from a grad student in neuroscience working on computational models of the brain. We are witnessing a time of convergences: not just across disciplines, but between brains and computers; between scientists trying to understand and technologists trying to make; and between academia and industry. We do not believe the convergence will yield a monoculture, but a vibrant hybridity.

These are early days. The art realizable with the current generation of machine intelligence might generously be called a kind of neural daguerreotype. More varied and higher-order artistic possibilities will emerge not only through further development of the technology, but through longer term collaborations involving a wider range of artists and intents. This first show at the Gray Area is small in scale and narrow in scope; it stays close to the early image-making processes that first inspired our Art and Machine Intelligence (AMI) program. We believe the magic in the pieces is something akin to that of Robert Cornelius's tentative self-portrait in 1839.

As machine intelligence develops, we imagine that some artists who work with it will draw the same critique leveled at early photographers. An unsubtle critic might accuse them of "cheating", or claim that the art produced with these technologies is not "real art". A subtler (but still antitechnological) critic might dismiss machine intelligence art wholesale as kitsch. As with art in any medium, some of it undoubtedly will be kitsch—we have already seen examples—but some will be beautiful, provocative, frightening, enthralling, unsettling, revelatory, and everything else that good art can be.

Discoveries will be made. If previous cycles of new technology in art are any guide, then early works have a relatively high likelihood of enduring and being significant in retrospect, since they are by definition exploring new ground, not retreading the familiar. Systematically experimenting with what neural-like systems can generate gives us a new tool to investigate nature, culture, ideas, perception, and the workings of our own minds.

Our interest in exploring the possibilities of machine intelligence in art could easily be justified on these grounds alone. However, we feel that the stakes are much higher, for several reasons. One is that machine intelligence is such a profoundly transformational technology; it is about creating the very stuff of thought and mind. The questions of authenticity, reproducibility, legitimacy, purpose and identity that Walter Benjamin, Vilém Flusser, Donna Haraway and others have raised in the context of earlier technologies shift from metaphorical to literal; they become increasingly consequential. In the era where so many of us have become "information workers" (just as I am, in writing this piece), the issues raised by MI are not mere "theory" to be endlessly rehearsed by critics and journalists.

7 Brillhart (2016) piece in the DeepDream show also makes use of virtual reality which, while not neural, represents an important advance in both cameras and displays.

We need to make decisions, personally and societally. A feedback loop needs to be closed at places like Google, where our work as engineers and researchers will have a real effect on how the technology is developed and deployed.

This requires that we apply ourselves rigorously and imaginatively across disciplines. The work cannot be done by technophobic humanists, any more than it can be done by inhuman technologists. Luckily, we are neither of the above. Both categories are stereotypes, if occasionally self-fulfilling ones, perpetuated by an unhelpful cultural narrative: the philistines again, claiming that artists are elves, and technical people dwarves, when of course the reality is that we are all (at least) human. There is no shortage today of artists and intellectuals who, like Alberti, Holbein or Hockney, are eager to work with and influence the development of new technologies. There is also no shortage of engineers and scientists who are thoughtful and eager to engage with artists and other humanists. And of course, the binary is false; there are people who are simultaneously serious artists and scientists or engineers. We are lucky to have several of such among our group of collaborators.

Acknowledgments: The author would like to thank Kenric McDowell, Jess Brillhart, Alison Lentz, Matt Jones, Mike Tyka, Alex Mordvintsev, Jac de Haan and Charina Choi for their inspiring work and useful feedback.

Conflicts of Interest: The author declares no conflict of interest.

References

Benjamin, Walter. 1999. Little History of Photography. In *Walter Benjamin: Selected Writings*. Translated by M. W. Jephcott, and K. Shorter. Edited by Michael W. Jennings, Howard Eiland and Gary Smith. Cambridge: Belknap Press, vol. 2.

Braidotti, Rosi. 2013. *The Posthuman*. Cambridge: Polity Press.

Brillhart, Jessica. 2016. DeepDream VR. Available online: https://www.youtube.com/watch?v=Ahonv4cNvgc (accessed on 4 July 2017).

Cima, Rosie. How Photography Was Optimized for White Skin Color. *Priceonomics*. 24 April 2015. Available online: https://priceonomics.com/how-photography-was-optimized-for-white-skin/ (accessed on 4 July 2017).

Davis, Abe, Michael Rubinstein, Neal Wadhwa, Gautham J. Mysore, Frédo Durand, and William T. Freeman. 2014. The Visual Microphone: Passive Recovery of Sound from Video. *ACM Transactions on Graphics*, 33. Available online: http://people.csail.mit.edu/billf/publications/VisualMic_SIGGRAPH2014.pdf (accessed on 4 July 2017).

Flusser, Vilém. 1983. *Towards a Philosophy of Photography*. Islington: Reaktion Books.

Future of Life Institute. 2015. Autonomous Weapons: An Open Letter from Ai & Robotics Researchers. 28 July 2015. Available online: https://futureoflife.org/open-letter-autonomous-weapons/ (accessed on 5 July 2017).

Gatys, Leon A., Alexander S. Ecker, Matthias Bethge, Aaron Hertzmann, and Eli Shechtman. 2016. Controlling Perceptual Factors in Neural Style Transfer. *arXiv*. arXiv:1611.07865.

Hockney, David. 2001. *Secret Knowledge: Rediscovering the lost techniques of the Old Masters*. New York: Viking Studio.

Information is Beautiful. 2017. Millions of lines of code. Available online: http://www.informationisbeautiful.net/visualizations/million-lines-of-code/ (accessed on 4 July 2017).

Kember, Sarah, and Joanna Zylinska. 2012. *Life after New Media: Mediation as a Vital Process*. Cambridge: The MIT Press.

Marr, David. 2000. Portrait of the artist as a cheat. *The Observer*, February 6, p. 19. Available online: https://www.theguardian.com/theobserver/2000/feb/06/focus.news (accessed on 4 July 2017).

Mordvintsev, Alexander, Christopher Olah, and Mike Tyka. 2015. Inceptionism: Going deeper into Neural Networks. Google Research Blog. June 17. Available online: https://research.googleblog.com/2015/06/inceptionism-going-deeper-into-neural.html (accessed on 13 February 2017).

Summers, Jason. 2011. Stabilized Images and Blind Spots. Jason Summers. February 18. Available online: http://www.jasonsummers.org/stabilized-images-blind-spots/ (accessed on 4 July 2017).

Tosini, Gianluca, P. Michael Iuvone, Douglas G. McMahon, and Shaun P. Collin, eds. 2014. *The Retina and Circadian Rhythms*. Berlin: Springer.

Turkle, Sherry. 2011. *Alone Together*. New York: Basic Books.

Tyler, Christopher. 2004. Rosetta Stone? Hockney, Falco and the Sources of "Opticality" in Lorenzo Lotto's "Husband and Wife". *Leonardo* 37: 394–401. [CrossRef]

Weschler, Lawrence. 2008. *Seeing Is Forgetting the Name of the Thing One Sees*. Berkeley: University of California Press, p. 294.

Wikipedia. 2017a. Digital photograpy. Available online: https://en.wikipedia.org/wiki/Digital_photography#History (accessed on 4 July 2017).

Wikipedia. 2017b. Photographic film. Available online: https://en.wikipedia.org/wiki/Photographic_film (accessed on 4 July 2017).

Zylinska, Joanna, ed. 2002. *The Cyborg Experiments: The Extensions of the Body in the Media Age*. New York: Continuum.

arts

MDPI

Article

Algorithmic Art Machines

Ernest Edmonds

IOCT, Leicester Media School, De Montfort University, The Gateway, Leicester LE1 9BH, UK;
ernest@ernestedmonds.com

Received: 1 November 2017; Accepted: 10 January 2018; Published: 15 January 2018

Abstract: The article reviews the author's personal development in relation to art made by algorithmic machines and discusses both the nature of such systems and the future implications for art.

Keywords: art; computer; algorithm; machine

1. Introduction

The paper presents a personal narrative about my exploration of algorithmic art machines. Together with Stroud Cornock I presented a paper at a 1970 Computer Graphics conference, Computer Graphics '70 (CG70), held at Brunel University, UK. The title of the paper was "The Creative Process where the Artist is Amplified or Superseded by the Computer". In it, we discussed the advent of the computer and the implications for art and for the role of the artist. Would this machine become the artist of the future? Would the artist of the future have any role at all? The paper was later published in *Leonardo* (Cornock and Edmonds 1973). Since we first wrote that paper nearly 50 years ago, time has passed and in this article I will consider what has happened in that interval, thinking particularly about how my own work has developed in this context. I will re-visit our thoughts from 1970 and speculate on what comes next. What follows will consider algorithmic machines in the context of making art. Algorithmic machines are at the centre of modern life in almost all of its aspects and art does not stand apart from this. In this context, I again pose the question that Stroud Cornock and I addressed in 1970: is the artist amplified or superseded by the computer?

2. Background

I first used a computer in my art practice when making my relief *Nineteen*, 1968–69, see Figure 1. For this work, I wrote a program that helped me solve a problem that I had with determining the layout of the 20 constituent pieces. More important, however, was the fact that this use of programming to solve a problem alerted me to the potential significance of computer programming, of algorithms, to art. I saw that algorithms could be used to generate art and also that the underlying order that such a process implies was significant for the perception of art made in this way.

Figure 1. Ernest Edmonds, *Nineteen* (1968–69).

I became interested in algorithmic structures in two respects relevant to this article: first, the use of them is one way in which I make decisions about a work and reduce the specific choices. In making a work, the apparent freedom of the almost infinite range of possibilities is a difficulty. As, for example, Stravinsky claimed, true freedom comes with the application of constraints (Stravinsky 1942). After all, how is one to select from the infinite? This is, for example, the problem of facing the blank canvas or the clean sheet of paper. It is necessary to find a way of reducing the options to a manageable level. One way of doing this is to select a structure to which the work will conform, such as an algorithm for determining the form. In fact, the choice or design of such an algorithm is a major aesthetic decision in itself. The second respect in which I became interested is that constructive psychology, and the very existence of science, suggests that the search for order is a fundamental attribute of human perception: the face seen in the stain on the wall. See for example (Fosnot 2005). It is possible or even probable that structures in artworks are very significant in our aesthetic experience of them. This may be so even if we do not know or notice the specifics. We often say that a work has a satisfying form, such as in a final movement to a symphony, even when we cannot quite explain what caused our feeling of satisfaction. It is as if we respond to the architecture of a piece of music or a novel before we can unravel its construction. We may not know about the algorithm that generated a work, but we might at least sense its existence, as exploited by the UK Systems artists (Bann 1972).

I first explored the algorithm in drawings and paintings where the process of making was determined in advance—I designed an algorithm for the purpose—and where I followed the procedure by hand. For example, in the drawing shown in Figure 2, I decided in advance what lines should be drawn and in what order I should draw them. I then just acted rather like a computer in obeying those rules. There is more to the drawing and its structure, but this point will do for our purpose. Of course, I could have put those instructions into a computer program and had a plotter draw the image, which is fine. In this case, however, I wanted to experiment with the process of following the algorithm myself. I was interested in the act of drawing and the micro decisions that I made as I put pen to paper, as well as in the order that the algorithm gave. This approach was not possible in the next development: time-based art.

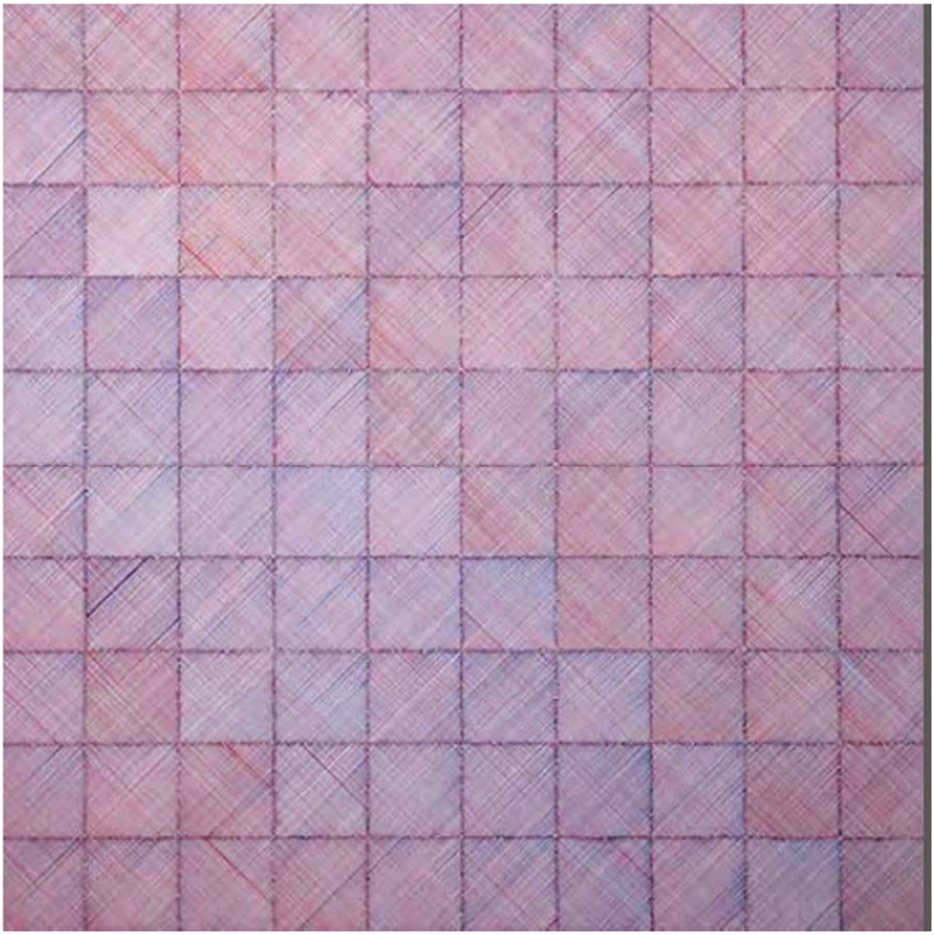


Figure 2. Ernest Edmonds, *Drawing: 7* (1975).

Algorithmic art is produced with the aid of a computer by programming it to follow some procedure that generates the art object. Much of the early work of this kind produced drawings executed on a graph plotter or was drawn by a human as in the case described above. Today, however, such processes are often associated with time-based art in which the generation of images is seen as a 'projection' over time by the audience or viewer (Le Grice 1977).

Between 1980 and 1985, I developed a system for making time based abstract artworks that were generated by computer in real time (i.e., in the time employed for projection) and recorded directly onto videotape. The first completed piece was *Fragment* which lasted an hour and was shown as part of an art exhibition in London in 1985 (Edmonds 1985). See Figures 3 and 4. The images consisted of various arrangements of black and white squares as well as pure black and pure white frames. The key point about this work was the full incorporation of the time element into the generative process implemented within the computer. Time was a concrete part of the constructed work. In *Fragment*, and other work done at that time, both the images and the timing are determined by the generative rules as the computer system works through them. The totality of the work, with the exception of its physical manifestation, is therefore completely implicit in the defining rules. For a discussion of the construction of these works see (Edmonds 1988).

Figure 3. Ernest Edmonds, still from *Fragment* (1964–65).

Figure 4. Ernest Edmonds, still from *Fragment* (1964–65).

The algorithmic system that generates a work such as *Fragment* is, of course, a closed system. That is to say, the system is entirely self-contained and has no exchange with any other system, that is, it has no exchange with the outside world. Many artists add calls to random number generators—technically pseudo random numbers (Strawderman 1965)—into their algorithms so that the resulting works are unpredictable and/or are different each time the algorithm is run. The motives vary, but include the idea of simulating 'creative' interventions and simulating interchange with a world outside the algorithm (Baggie 2008). I use another approach. After making the series of works starting with *Fragment*, I began to make works where the algorithmic system was open, where the system had exchanges with its environment taking readings from sensors, for example, and progressing in different ways depending on the values of those readings. In plain language, I was making interactive systems: something discussed in some detail in the 1970 paper mentioned at the beginning of this article, and which has been central to much of my recent work (Edmonds 2003).

We can think of the algorithms used for open systems as having a meta-logic that draws upon the exchanges with the outside world—for example reacting to the detection of movement. The meta-logic can automatically change the algorithms used to generate the artwork. The obvious case is where the algorithm is prompted to respond directly to a stimulus. However, that need not be the case. The meta-rules can change the algorithm so that its potential behaviour in the future is modified, without there necessarily being any immediate reaction to the stimulus. A person can learn without performing any observable action. A teacher might face still and blank looking students, but they might in fact be learning. I call this kind of interaction 'influence' (Edmonds 2007).

A book by Francesco Franco describing a fuller picture of my artistic journey has recently been published (Franco 2018).

3. Algorithmic Machines and Art

In the modern world the algorithm, in its various forms, is central to so much of life. From the washing machine to the car and airplane, from selecting a holiday to trading shares, from finding a book to finding a friend, algorithms control or influence the process. In the 19th century, a machine was a mechanical thing; but in the 21st century, the essence of most machines is to be found in an algorithm.

In many cases, the algorithms used in machines are relatively clear sets of procedural instructions or declarative rules: "do this, then that and on some condition do something else" or "always meet this condition and don't allow this state to arise". However, more and more we seem to be confronted with artificial intelligent (AI) machines. Exactly what an artificially intelligent machine is may not be all that clear, but one thing that is certain is that the details of how such machines work is obscure to most people. Briefly, there are two main classes of such machines, those using symbolic AI and those using connectionist AI. The algorithms that drive a symbolic AI system can be seen as explicit sets of rules, formal statements, about the subject of concern with an engine of some kind that can act on those rules, making decisions as appropriate. The algorithms that drive a connectionist AI system, on the other hand, are essentially statistically based and are developed from a learning process. Typically, large sets of examples are used to enable the system to automatically develop the ability to make correct, or appropriate decisions. For example, face recognition systems are typically of this kind. There are plusses and minuses for both kinds of AI. Connectionist AI systems have proved very successful in many recent applications. They are, however, obscure in the sense that they do not easily reveal the reasoning behind any given decision. It is somewhat easier to draw such explanations out of a symbolic AI system.

Procedural, declarative, and AI algorithms, of whatever sort, may have different implications for art. For example, a declarative algorithm could well match a set of specific composition rules that an artist wants his work to conform to. The algorithm might then embody explicit qualities that are desired. On the other hand, a connectionist algorithm might be used to recognise a face and so enable the artist to arrange that the work responds in a particular way when someone is looking at it.

4. Amplified or Superseded?

As mentioned above, in the 1970 paper, Stroud Cornock and I considered the issue of whether the computer, our algorithmic machine, might amplify or just supersede the artist. Without repeating the full argument, our basic thinking then was that "Though the computer can replace man in the production of graphic images, its function in the arts is seen as assisting in the specification of art systems and in their subsequent real-time management." In particular, we said that "The traditional role of an artist is clearly called into question by these developments ... so that when one speaks of an 'artist' one means he who is performing a kind of catalysis of creative behaviour within society and not a specialist working for a section of that society. His major function might, therefore, be to initiate."

The thinking behind these remarks was driven by the whole idea of computing. We considered the issue of where the humans, the artists, might find themselves. The answer, as we then saw it, was that the artist would become the figure who, as it were, set things up. So, whilst in some sense the computer might be left to create the artwork in detail, the artist would have defined the framework within which the situation was defined. Looking back on that position, it seems hard to take a different view. So, for the moment, I confirm that early position.

Another issue, not discussed in the 1970 paper, is the role of algorithms in the art making process. It turned out that after my making of *Nineteen* this was crucially important in my own development. As I have described above, but now re-conceptualised, the important issue of using an algorithm as an art making process was a critical advance. This idea was widespread as we know well but the particular significance in our context is the degree that it ties the invention of computation, of the general purpose computer, to a way of making art.

The underlying structures of the artwork can now be seen in computational terms. The algorithms create the work whilst, of course, the artist creates the algorithms (GV Art 2014).

5. Conclusions: The Significance of the Algorithmic Machines in Art

The thoughts that are recorded in this article were brought to a particular significance with the Algorithmic Signs exhibition in Venice (Franco 2017). In this show, I exhibited along with Manfred Mohr, Vera Molnar, Roman Verotsko, and Frieder Nake. All of us used algorithms to make our art and many of us had done that for 50 years or so. What was the incisive point about the show? For me it came from a conversation with someone who was not deeply into visual art but had been deeply into computing for very many years (Catton 2017). The point that we jointly discovered was that this exhibition of algorithmic art represented art that engaged with the key issues that are part of modern life. Very many aspects of life are conducted by—or influenced by—algorithms, from selecting a holiday to obtaining a loan. In the developed world, at least, we could argue that our lives are partly driven by algorithms and yet they remain an unexplored territory for many people. So this kind of art is engaged with contemporary life like no other. The old Cornock/Edmonds issue of "amplified or superseded" has not changed—the computer, the algorithm, the machine—is still something that the artist uses to create a framework of some kind. However, the metaphor of the algorithm, as used in art, is surely a metaphor of life itself, as we know it today. So I argue that this work is in no way on the edge of contemporary art, but is at the very core of our contemporary concerns.

Conflicts of Interest: The author declares no conflict of interest.

References

Baggie, Denis L. 2008. The use of randomness in the simulation of creativity. In *Natural Chance, Artificial Chance*. Edited by Negrotti Massimo. Bern: Peter Lacy, pp. 25–46.

Bann, Stephen. 1972. Introduction. In *Systems*. London: Arts Council, pp. 5–14.

Catton, David, and Cutthorpe, Derbyshire, UK. 2017. Personal communication.

Cornock, Stroud, and Ernest Edmonds. 1973. The creative process where the artist is amplified or superseded by the computer. *Leonardo* 16: 11–16. [CrossRef]

Edmonds, Ernest A. 1985. *Exhibition 4: Duality and Co-Existence*. London: Exhibiting Space.

Edmonds, Ernest A. 1988. Logic and time-based art practice. In *Leonardo, Electronic Art Supplemental Issue*. Oxford: Pergamon Press, pp. 19–20.

Edmonds, Ernest A. 2003. Logics for Constructing Generative Art Systems. *Digital Creativity* 14: 23–38. [CrossRef]

Edmonds, Ernest A. 2007. Reflections on the Nature of Interaction. *CoDesign: International Journal of Co-Creation in Design and the Arts* 3: 139–43. [CrossRef]

Fosnot, Catherine Twomey. 2005. *Constructivism: Theory, Perspectives, and Practice*, 2nd ed. New York: Teachers College Press.

Franco, Francesca. 2017. Algorithmic Signs. Available online: http://www.bevilacqualamasa.it/en/algorithmicsigns?uniq=f16445051ee333ea5f002352aca01f2e (accessed on 1 December 2017).

Franco, Francesca. 2018. *Generative Systems Art: The Work of Ernest Edmonds*. London: Routledge.
GV Art. 2014. *Automatic Art*. London: GV Art.
Le Grice, Malcolm. 1977. *Abstract Film and Beyond*. London: Studio Vista.
Stravinsky, Igor. 1942. *The Poetics of Music*. Cambridge: Harvard University Press.
Strawderman, William E. 1965. *Generation and Testing of Pseudo-Random Numbers*. Ithaca: Cornell University.

arts

MDPI

Article

Choreographic and Somatic Approaches for the Development of Expressive Robotic Systems

Amy LaViers [1,*], Catie Cuan [2,†], Catherine Maguire [3,4,5,†], Karen Bradley [4,6,7,‡], Kim Brooks Mata [8,9,‡], Alexandra Nilles [10,‡], Ilya Vidrin [11,12,‡], Novoneel Chakraborty [13], Madison Heimerdinger [1], Umer Huzaifa [1], Reika McNish [14], Ishaan Pakrasi [1] and Alexander Zurawski [1]

1 Mechanical Science and Engineering Department, University of Illinois at Urbana-Champaign, Champaign, IL 61801, USA; heimerd2@illinois.edu (M.H.); Mhuzaif2@illinois.edu (U.H.); pakrasi2@illinois.edu(I.P.); azuraws2@illinois.edu (A.Z.)
2 Independent dance artist/professional, Brooklyn, NY 11238, USA; crcuan@gmail.com
3 Independent dance artist/professional, Palmyra, VA 22963, USA; catmaguire@embarqmail.com
4 Laban/Bartenieff Institute of Movement Studies, New York, NY 10018, USA; kbradley608@msn.com
5 McGuffey Art Center, Charlottesville, VA 22902, USA
6 Independent dance artist/professional, Musquodoboit Harbour, NS B0J 2L0, Canada
7 School of Theater, Dance, and Performance Studies, University of Maryland, College Park, MD 20742, USA
8 Dance Program, University of Virginia, Charlottesville, VA 22904, USA; kbm2n@virginia.edu
9 Integrated Movement Studies (Certification) Program, Santa Barbara, CA 93108, USA
10 Computer Science Department, University of Illinois at Urbana-Champaign, Champaign, IL 61801, USA; nilles2@illinois.edu
11 Centre for Dance Research, Coventry University, Coventry CV1 2NE, UK; ilya_vidrin@mail.harvard.edu
12 Theatre, Dance, and Media, Harvard University, Cambridge, MA 02138, USA
13 Aerospace Engineering Department, University of Illinois at Urbana-Champaign, Champaign, IL 61801, USA; nchkrbr2@illinois.edu
14 Kinesiology and Community Health Department, University of Illinois at Urbana-Champaign, Champaign, IL 61801, USA; rmcnish2@illinois.edu
* Correspondence: alaviers@illinois.edu; Tel.:+1-217-300-1486
† These authors contributed equally to this work.
‡ These authors contributed equally to this work.

Received: 21 December 2017; Accepted: 14 March 2018; Published: 23 March 2018

Abstract: As robotic systems are moved out of factory work cells into human-facing environments questions of choreography become central to their design, placement, and application. With a human viewer or counterpart present, a system will automatically be interpreted within context, style of movement, and form factor by human beings as animate elements of their environment. The interpretation by this human counterpart is critical to the success of the system's integration: "knobs" on the system need to make sense to a human counterpart; an artificial agent should have a way of notifying a human counterpart of a change in system state, possibly through motion profiles; and the motion of a human counterpart may have important contextual clues for task completion. Thus, professional choreographers, dance practitioners, and movement analysts are critical to research in robotics. They have design methods for movement that align with human audience perception; they can help identify simplified features of movement that will effectively accomplish human-robot interaction goals; and they have detailed knowledge of the capacity of human movement. This article provides approaches employed by one research lab, specific impacts on technical and artistic projects within, and principles that may guide future such work. The background section reports on choreography, somatic perspectives, improvisation, the Laban/Bartenieff Movement System, and robotics. From this context methods including embodied exercises, writing prompts, and community building activities have been developed to facilitate interdisciplinary research. The results of this work are presented as an overview of a smattering of projects in areas like high-level motion planning, software development for rapid prototyping of movement, artistic output, and user studies that help understand how people interpret movement. Finally, guiding principles for other groups to adopt are posited.

Keywords: robotics; choreography; Laban/Bartenieff Movement System; interdisciplinary collaboration; expressivity; HRI; somatics; expressive robotic systems

1. Introduction

> ***Domin**: ...Man is a being that does things such as feeling happiness, plays the violin, likes to go for a walk, and all sorts of other things which are simply not needed. No, wait. Which are simply not needed for activities such as weaving or calculating. A petrol engine doesn't have any ornaments or tassels on it, and making an artificial worker is just like making a petrol engine. The simpler you make production the better you make the product. What sort of worker do you think is the best?*
> ***Helena**: The best sort of worker? I suppose one who is honest and dedicated.*
> ***Domin**: No. The best sort of worker is the cheapest worker. The one that has the least needs. What young Rossum invented was a worker with the least needs possible. He had to make him simpler. He threw out everything that wasn't of direct use in his work, that's to say, he threw out the man and put in the robot. Miss Glory, robots are not people. They are mechanically much better than we are, they have an amazing ability to understand things, but they don't have a soul. Young Rossum created something much more sophisticated than Nature ever did—technically at least!*
>
> —RUR (Rossums' Universal Robots) Čapek (2004)

Bringing together choreography and engineering raises a question about whether both fields are concerned with the same academic values and inquiries. That is, are they motivated by the same organizing principles and can their practices be complementary, and further mutually beneficial, when brought together? In the above excerpt from the play where the term "robot" was coined, the immediate intertwining of robotics and the arts can be observed. From the first moment the concept of a "robot" was conceived there was an idea injected that movement could be divided between its efficient, functional parts and its extraneous, expressive parts. Thus, the idea of efficiency and function has permeated robotics since the word was introduced in a 1920 play (Čapek 2004). Long before they were called robots, automatic mechanical machines, automata, have existed since antiquity and as Truitt writes "are mimetic objects that dramatize the structure of the cosmos and humankind's role in it" Truitt (2015), pointing to the long held mysticism and romance associated with complex machines. These concepts of efficiency and mysticism create a contradictory dichotomy that continues to influence the field of robotics today that may be resolved by considering the vastness of human motion as investigated through body-based methods in this paper.

At the same time, a choreographer Rudolf Laban (1879–1958) was working to establish a system for movement, now called the Laban/Bartenieff Movement System (LBMS), that helped codify learning from work in the arts and helped frame a rejection of industrialization and return to nature (Bradley 2008). Thus, both the *idea* of a robot and this somatic body-based movement system that will be leveraged heavily in the methods presented here are in part a reaction to the industrial revolution where mechanical efficiency—and its abstract ideal—was taken to hyperbolic levels not previously seen. Dancers' technique and training often reflects the ethos of developing efficiency through iteration of motor tasks, continually refined and streamlined. But, dance performance requires the use of something "more"—maybe the same thing Domin and Helena discuss as missing from the concept of a robot.

Thus, as much as physical phenomenon, the distinction between human and robot movement is a philosophical distinction. In broad, reductive strokes, we argue that both roboticists and choreographers aim to do the same thing: to understand and convey subtle choices in movement within a given context. One of the fundamental emergent questions from this categorization is about the lens through which constituents in each field methodologically approach how to generate, interpret, and reproduce different movement from the idiosyncratic to the robotic. Consider two branches of inquiry, one concerned with internal experience and the other with external measurement as a model for understanding the differences in assumptions generated from each field.

Different branches of philosophical inquiry provide critical, albeit artificial, lenses by which to address this complex question. Two such branches, rhetoric and phenomenology, are useful in understanding subjective and objective experience, though notably from different angles. Rhetoric, at least in the classical (Aristotelian) sense, investigates "the available means of persuasion" in any given situation (Kennedy et al. 2006). Outside of ancient Greek life, contemporary rhetoric can be understood as a practice to examine the function, efficiency, and efficacy of persuasive communication—starting with linguistic, and moving to the visual, bodily, energetic, posthuman, and so on (Barnett and Boyle 2016). Alternatively, phenomenology provides a lens through which to understand subjective, first-person experience. Championed by Edmund Husserl at the turn of the twentieth century, phenomenology urges a "bracketing" of experience such that an individual approaches stimuli as if for the first time (Husserl 2012). Phenomenology and rhetoric are not, strictly speaking, incongruous. One can approach the creation of rhetorical artifacts (i.e., speeches, visualizations, choreographies, etc.) phenomenologically, just as one can probe first-person experience rhetorically. These lenses are artificial constructs—they offer a way by which to view the world but their limitations are neither absolute nor universal (Hawhee 2004).

Returning to the questions of engineers and choreographers, a problem can occur when either one becomes too beholden to their value systems. For engineers, the problem occurs when valuing efficiency and function (i.e., rhetoric) trump user experience (i.e., phenomenology). Conversely, for choreographers, the problem occurs when first-person experience (of the performers) is not observable by an external viewer (and therefore, maybe one day, quantified). As with any practice, balance is imperative. To be able to address complex questions pertaining to generating, interpreting, and reproducing movement, relying too heavily on rhetorical or phenomenological aims can be limiting in a way that may be invisible or simply not salient for the agents. This is one reason, among many, to support bringing engineers and choreographers together into one shared space, and, for a robotics lab, to employ phenomenologically motivated practice in our research.

In the largest sense, the purpose of the methods presented here is to explore what human bodies can express in movement, what ideas machines can express in movement and whether they are the same things. Can a robot expressively communicate? If we assert that all movement is expressive (which we do), then can a robot express the same set of things as a human? The other big idea is to utilize the choreography of the body itself, and its expressive capabilities, to "move" engineers into an embodied experience that could inform their work both in design and context creation. Meaning making through movement—engineering through body. Thus, our approach is pragmatic: we want to understand the phenomenon of how people create such vastly varied motion profiles that communicate complex intent. This knowledge is contained inside body-based movement training and somatic practice[1] where practitioners hone their own movement capabilities by expanding their array of choices. External methods, typically employed in the sciences and in engineering such as motion capture, photography, force plates, and the like, can work to document the result of a movement pattern but do not have access to choices made by a human in focus, motivation, sensation, memory, prior muscle patterning (and re-patterning), etc. The practice of honing these choices is one of *embodiment*—a body of knowledge that cannot be *known* but only *moved*.

[1] Somatic approaches, being distinguished from a broad category of body-based approaches, allow us to extract knowledge from experience of the body from an internal perspective, which is called "soma", a distinct idea from the body itself (Eddy 2009).

1.1. Systems of Embodied Motion

There are a multitude of body-based practices (Foster 2004), including very well known ones, such as Alexander Technique (Alexander 1990), Feldenkrais Technique (Feldenkrais 1972), Body Mind Centering (Cohen et al. 2012), Pilates Method (Latey 2001) and Contact Improvisation (Pallant 2006) to name just a few, but they all share some commonalities in their approach to experiencing the body from an internal, rather than external, perspective (Hanna 1980). Indeed in philosophy and research in the arts a question can be posed of what kinds of ideas can be expressed through movement (Elgin 2010) and what kind of learning is inherently kinesthetic (Abrahamson 2004; Goldman Schuyler 2010; Lindgren and Johnson-Glenberg 2013). A field of work known as choreology (Hall 1964; Sutil 2015) defines methodology that enables deeper thinking about what defines movement. In robotics, a separation between functional, task-based movement and "expressive motion" profiles (only useful for the purposes of human responses) has been motivated. LBMS frames efficiency as the process of selecting from all that is possible, the clearest choices for the richness of human physical expression to occur. Recognize the word play that happens when one considers "the efficiency of enjoying the task and being in relationship with another" or "the expressiveness of a clear, decisive, precise movement through space". Thus, *all* movement is "expressive" *and* "functional"—and the tools honed through time spent in a dance studio will help to create more expressive robotic *systems* that have broader, more successful functionality in dynamic environments.

The LBMS system of embodied motion (Bartenieff and Lewis 1980; Hutchinson and Guest 1996; Hackney 1998; Maletic 1987; Laban and Ullmann 1966, 1971; Studd and Cox 2013) is mainly communicated through certification programs through the Laban/Bartenieff Institute of Movement Studies (LIMS) and Integrated Movement Studies (IMS), where successful participants become Certified Movement Analysts (CMAs) and Certified Laban/Bartenieff Movement Analysts (CLMAs), respectively. The emphasis on in-person training is part of the programs' philosophy: the material cannot be "understood" without bodily, or embodied, participation. A system of movement analysis taught in these programs and initiated by Laban and his student Irmgard Bartenieff, LBMS is utilized in many professional contexts, such as therapy, consulting, and research, in addition to dance and choreography. Unlike other academic disciplines, this field does not publish regularly (Groves et al. 2007) and does not offer doctoral degrees. Nevertheless, this body-based approach to research has much to offer the field of robotics.

The work in LBMS takes into account the larger patterns of human movement identified as Thematic Dualities. One such theme is Function/Expression (F/E), which clarifies that the need for expressive robotic systems is a practical, functional pursuit. It is important to note that finding patterns is in fact the primary experience of our body moving in relationship to our environment. It is a process of differentiation that ultimately allows for synthesis—understanding that while function and expression can be perceived as opposites, they are in fact inseparable. In the LBMS curriculum, these themes are described with a mobius strip topology, indicating that the ideas are one and the same. This is a primary influence on our point of view regarding expressive robotic systems.

Further, LBMS provides a series of interrelated, qualitative lenses, termed Body (answering "What?" about movement), Effort ("How?"), Space ("Where?"), and Shape ("Why?"), which contribute to notation systems, for practitioners to use in finding pattern and meaning in movement. The overlaps in these categories are explicated through Affinities (part of the theory of Space Harmony (Laban and Ullmann 1971)). The idea of Affinities is simply that there are large patterns that can be identified through relationships among Body, Effort, Shape, and Space. For example, certain kinds of expression tend to occur in particular directions in Space. This relationship is actually rooted in the body's design, (once again foregrounding the idea of body-based movement as a form of knowing) for example Light Weight Effort is linked to the Center of Levity, located in the Upper Body—(up)—and Strong Weight Effort is linked to the Center of Gravity located in the Lower Body—(down). As humans we associate particular movement expression with certain tasks and series of changes in spatial location that allows us to create and contextualize meaningful communication. Note, that this context, most generally, is comprised of the summative experience of a lived life—thus, meaning making in movement is a function of culture, prior experience, as well as immediate situational context.

1.2. Choreography as Body-Based Research

Collaboration with dance practioners brings largely universal movement principles into the coterie of source inspiration and awareness for engineers. Movement knowledge empowers lab students to find context and meaning in seemingly commonplace movements. How does a hand wave meaning "hello" differ from a hand wave of "move out of the way"? When tempo and frequency change, is the movement "the same"? Importantly, movement awareness shows how narrative is drawn from any scale of movement in space. For instance, a Roomba floor robot skids along the floor in a continuous motion. Possible assigned narratives include subservience, a snake-like creep, and a treadmill. How does this type of movement and resulting narrative affect the perception of the robot overall? The Roomba takes up space within an owner's home, and this new addition necessarily alters their daily story. How will that owner move differently or rearrange their space as a result of the robot? What feelings or moods will it impart in its human counterparts? It is critical engineers are given tools to understand the perceptions and influence that stem from human-facing machines.

The methods utilized by choreographers help create meaningful movement[2] and organize the execution of large-scale performances, which may not take on citations in academic journals, but are nonetheless important ways in which society organizes knowledge and makes sense of experience. For example, Rainer's "Trio A" initially didn't look like a dance because she used pedestrian-style movements that do not have the typical virtuousic leg extensions, etc. associated with dance (Lambert-Beatty 2008; Rainer 1966); this work was heavily influenced by the context of the larger social movements connected with her and others working at the Judson Memorial Church at the same time (Banes 1983 2011). Thus, the innovative, groundbreaking movement profiles put forth by Rainer puzzled the dance community and audiences but revealed that pedestrian movement is already expressive and masterful (Elgin 2010). Innovation in any discipline is often associated with disorientation of existing patterns; here it is specifically new movement patterns that help express a greater variety of ideas. Moreover, the philosophy embodied by her work (Rainer 2006) informed minimalism in other art forms like fashion, music, and theater (Copeland 1993; Lambert 1999).

1.3. Improvisational Technology

Improvisation is an important process used to support choreography (movement design) and dance training and utilized in performance that is distinct enough to be called out on its own. It also employs a large role in the somatic approaches taken by the RAD Lab—activities such as movement hour incorporate individual and group improvisation activities (described in Section 2). These activities are tools for improvising *in the body*, each highlighting different aspects of movement and providing important opportunities to explore and learn about movement. Just as we can improvise with external technologies—such as musical instruments or software programs—we can improvise using the body. Forsythe has worked extensively to explicate these strategies, which he employs in training, choreography, and performance (Forsythe 2012).

One improvisational technique from dance is contact improvisation. As the name suggests, this form of dance is improvised, sometimes to music, and emphasizes contact (with other humans, walls, floors, etc.) This embodied approach to studying movement improvisation can provide valuable experience to roboticists interested in the spontaneous design of movement for bodies which interact with their environment. Further, a mature improvisational practice develops deep understanding of what choices are available and which may be generated in response to an exigency or problem Goehr (2014). As roboticists, improvisational techniques are useful at two levels. First, if a human is

2 Note that meaningful movement may not necessarily be narrative.

designing robot motion (such as a gait, or the path a robot should take through a warehouse), it is useful to be able to *improvise* instructions to the robot—allowing the designer to quickly iterate on their instructions and get feedback immediately about how their instructions are interpreted on the robot platform. On the other hand, we are moving toward robots that need to "improvise" their own movement—for example, autonomous vehicles that must react to the actions of human drivers around them. One exercise in contact improvisation is to walk in a group around a room, with each person improvising their path, and gradually increasing the speed until everyone is running around the room and must manage to avoid collisions by dodging other people at the last second, or making contact with them in a way that avoids injury. As an exercise for roboticists, this helps us understand and analyze techniques for communicating intent, and using momentum to maintain control and avoid damage—techniques very relevant to problems studied by roboticists.

Another important concept from improvised dance is an embodied understanding of creative flow and an appreciation for the complexity of the human body. As most people have experienced, improvising dance is difficult. It does not feel natural at first. But with practice, it becomes easier to slip into a mental state where there is no self-consciousness and the dance is done as an instinctive reaction to music, previous movement, or the movements of other people around you. Setting an intention to move beyond known or familiar movement patterns supplements this work (Peters 2009). This embodied experience often leads to a deep appreciation of the complexity of the human body and movement: when improvising, we choose naturally from an extremely large set of possible movements. The calculations done by the human nervous system clearly outpace our best digital optimizers and controllers. A practice in improvisation also gives an appreciation for the usefulness of constraints: trying to improvise a completely unconstrained dance is much more difficult than improvising "walking forward as if you are moving through knee-high water," for example. In robotics constraints are similarly useful: general-purpose robots are much more difficult to engineer than ones which only perform or respond in specific contexts. Indeed, after careful consideration of the body the task of creating a robot which compares in expressivity begins to seem nearly impossible. Analytical models, which acknowledge the nonlinearity of something as complex as improvisation, have been used to try and describe this behavior inside structured improvisations in performance as in Özcimder et al. (2016) or to generate diverse movement through chaotic models (Bradley and Stuart 1998). Our goal in this article is to extract embodied understanding that can guide in the development of expressive tools, rather than debating the possibility of biological processes in machines.

1.4. Tools for Creators

Creativity is a varied process even within the arts (Kaufman et al. 2005). It's also a topic that computers have helped facilitate (Isaacson 2014; Lubart 2005), even in sensory fields like cooking (Pinel et al. 2015). Similarly, external technologies can augment human movement designers, providing tools such as randomness, or immediate visualization, which can inspire new creative directions as described in LaViers (2018). One well-known adopter of such external technologies to aid in motion design was Merce Cunningham (Copeland 2004). For instance, he would use coin flips and the I Ching to randomly determine the sequence of movement in his choreography, and said of this technique, "the feeling that I have when I compose in this way is that I am in touch with a natural resource far greater than my own personal inventiveness could ever be" (Cunningham 1997). Similarly, Cunningham also adopted computer technology, such as the LifeForms software (Calvert et al. 1993; Schiphorst 1993) which is a graphical tool for choreographers to compose dances using animated representations of human dancers.

Robot programming methods for inexperienced users use several techniques to make the process more approachable, with an emphasis on reconfigurability of programs for industrial applications (Rossano et al. 2013). These include visual (icon and data flow) languages, tangible interfaces (Sefidgar et al. 2017), CAD and VR interfaces (Whitney et al. 2017a), natural language instructions (Tellex et al. 2011), as well as lead-through or "learning by demonstration" (Argall et al. 2009). Research into human-robot collaboration often combines natural language commands with social cues such as direction of gaze and posturing of the body (such as pointing) (Whitney et al. 2017b) and processes from the arts (El-Jiz and Rodrigues 2017). In general, there is a trade-off between the simplicity and ease-of-use of a language or interface and its expressivity—the size of the sets of robot configurations and/or paths that it can specify.

Abstractions, such as instructions about repeating movements and modifying stored movements in time, space, and resulting style, can help increase the expressivity of a language or interface while maintaining a compact, understandable specificiation. Similarly, in choregraphic notation, there is a range of media and languages used for specifying movement—from raw video, to Motif and the more explicit full Labanotation (Guest 1977), to style modifiers such as level and Effort changes. Robot programming similarly requires a range of tools for different use cases, informed by an understanding of the choregraphic (aka movement design) context and task requirements. Somatic methods can help roboticists understand the subtleties of movement differences (for example, between a chop and a point gesture), and to help define design criteria for robotics tools (for example, the desire for a tight development loop to encourage improvisation and fast prototyping of robot motion). To this end, commercial solutions for robotic prototyping have been developed, including by a startup spin-off of the RAD Lab, AE Machines, shown in Figure 1, as well as by LabView, Google Blockly, Scratch, and Lego Mindstorms, Technic, and Boost Blocks.

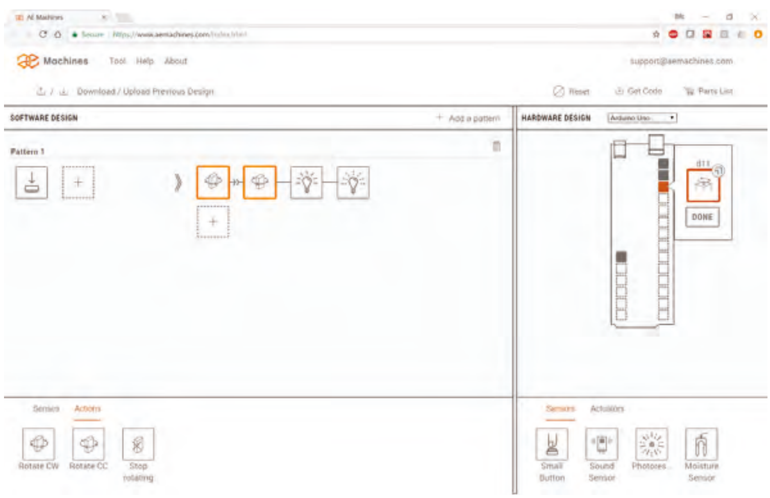


Figure 1. Easy-to-use hardware coding interface developed by AE Machines, Inc., which leverages choreographic abstractions regarding movement design and enables creators.

1.5. Expressive Robotics

Motion for robots that is termed "expressive" has been used to describe movement used in social and human-facing settings. Breazeal's Kismet (Breazeal 2004), one of the first socially expressive robots, employed imitations of facial features in order to create engaging interactions through a mechanical system. On the other hand, Knight's candy delivering systems (Knight et al. 2015) focused on engagement between human and robots can be created through contextual interaction (situated in this case around the Halloween holiday). Other work has attempted to recreate autonomous behavior around musicality (de Sousa Junior and Campos 2011; Michalowski et al. 2007; Weinberg et al. 2009; Schoellig et al. 2014) (even in functional tasks like surgery (Siu et al. 2010)). Inside social robotics, the idea of dance is a strong abstraction for connection through movement (Okamoto et al. 2014; Peng et al. 2015). Such dance-inspired motion is often described with affective labels (Breazeal and Scassellati 1999; Knight and Gray 2012; Knight and Simmons 2014) or, similar to Domin in the play that spawned the term "robot", as motion features orthogonal to function (Knight and Simmons 2015). Extensive work in animation has explored similar veins of work (Bradley and Stuart 1998; Brand and Hertzmann 2000; Gillies 2009; Liu et al. 2005; Torresani et al. 2007). For example, Etemad and Arya (2016) validates motion profiles via lay viewers under labels of "happy", "sad", "tired", "energetic", "feminine", and "masculine". LBMS has also been utilized in several such academic publications in the field of robotics (Knight and Simmons 2014, 2015; Patla 1982; Barakova et al. 2015; Huang and Hudak 2003; Knight and Simmons 2016; Lourens et al. 2010; Masuda and Kato 2010; Masuda et al. 2009; Rett and Dias 2007; Rett et al. 2008). Work in Gielniak et al. (2010) has shown that just adding *variation* to movement makes it seem more human-like to human viewers. Other work has focused on functional interpretation, termed *legibility* and *predictability*, in narrow contexts (Dragan et al. 2013).

Studies in the psychology of adoption of robotic technologies in the household outline the importance of social intelligence and perceived animacy. These studies show that by expressing character traits, a robotic system can imply levels of social intelligence that increases the likelihood of adoption. Hendriks et al. (2011) and Young et al. (2011) tell us that it is natural for humans to try and extract information from robotic actions, subsequently attributing intentionality to robot movement characteristics and decision making. In Forlizzi and DiSalvo (2006), for instance, user study participants describe the movements of a robot vacuum cleaning system, the Roomba as "cute" or "pathetic", even though such a correlation may not have been intentioned. There are also instances where people name their Roomba robot, thus giving it an added social identity. The achievement of social assimilation albeit by coincidence and not by intention, prompts the user to associate decisions made by the robot to its personality traits, as opposed to the functional algorithm that determines its movements. In Darling et al. (2015) researchers explore the relationship between empathic concern and the effect of stories in the interaction with robotic systems. This is done through a user study, where participants are asked to strike and destroy a robot insect, with a mallet. Some of the miniature robot insects are given a backstory as described to participants, and some are not. Results of the study show that people are less likely to strike the insects with a backstory, thus proposing a relationship between empathy towards robots and the existence of a priming backstory. This indicates that constructing the design, movement, and context surrounding future robots could lead to increased social acceptance. Similarly, choreographers leverage and create elements, e.g., a program note, to manipulate audience experience.

2. Methods: Embodied Practices for Roboticists Developed from Choreography and Somatics

Members of the RAD Lab are exposed to the different aspects of choreography, improvisation, and LBMS as a tool for meaning making through recognizing patterns, reconciling paradox, contexting (meaning-making), and gaining respect for the complexity of human movement. We approach these ideas through both functional and expressive movement experiences that can illuminate the body as basis for our "knowing" of the world in order to inform our engineering work. This section highlights a small subsection of the activities in the lab with choreographic tools and often a somatic perspective, which have become important, foundational *methods* for our research.

2.1. Bringing Movement to the Foreground

Humans move all day everyday. So, unless one is trained to isolate and inspect it, as dancers and choreographers and somatic practitioners are, it is invisible. This activity brings movement to the foreground, even for engineers and inexperienced movement practitioners; at the same time, participants in a new group setting will learn each others names. The activity is a good way to begin a new project or workshop on embodied methods.

The exercise is a twist on a standard, simple name game. In the classic version of this game, participants stand in a circle (as in Figure 2) and go around the circle, saying their name at the same time as making a personal movement. The first participant (usually a facilitator) will say: "Hi, I'm

Amy," and in time with their name will make a move, which can be a combination of postural and gestural change and may involve weight shift. Typically the stakes of the room and length of the workshop can determine how involved or complex this first movement is. It should both invite participants to move more than they are expecting, but also respect the boundaries implied by the context of the workshop. For example, if participants are in business suits and skirts, a large jumping jack movement will only serve to alienate participants. Typically a large gesture mixed with a more subtle postural change sets an easy tone for future participants to match—they can exaggerate and choose a more athletic movement for their name or they can use a familiar, pedestrian gesture like a wave.

Figure 2. Two images of the beginning of a movement workshop.

Next, the facilitator instructs the whole room to repeat their name and their movement in unison. This is a magical moment for group building. The facilitator sets the tone by breaking the "movement taboo" that can exist in engineering and now the whole group will follow suit. It can be helpful for the facilitator to have people in the group that they know will be comfortable with the action and join in—this will help along participants who may be resistant to such an odd request for their context. The exercise now shifts to the next participant who will repeat the actions of the facilitator. This time the group will repeat the facilitator and the first participant's name in sequence, forcing memory and building the shared movement experience of the group. This repeats until everyone in the room has had a turn, and a seemingly impossible feat has been accomplished: an entire room of engineers is dancing together.

If time allows, the twist on this exercise illuminates this feat further. Now the facilitator allows each participant to go around the room in turn and correct their fellow participants in the execution of their personal movement. To keep plausible deniability, the facilitator may not want to demonstrate, but simply choose an eager participant to go first, offering encouragement or asking questions about how the movement should be done to spur corrections. Now the participants are engaging in iterative choreography. Often, they'll need to work hard to articulate how a movement should be done, particularly as questions arise. This offers the facilitator a chance to foreground taxonomies (like LBMS) which may help in this process, e.g., by using their own expertise to highlight and articulate more nuanced differences in execution. Eventually, this provides a point of comparison that brings the focus back to an engineering perspective: how can everyone be doing the same thing if we all have different shaped bodies? Indeed, it is a high-level notion of movement that is needed to make such a claim, and the tools inside LBMS provide ways to improve and highlight successful replication.

2.2. Weight, Flow, Breath, and Group Sensing

Standing in a circle, the facilitator begins by activating weight in relationship to gravity by bouncing, jiggling, and vibrating both core and limbs standing with two feet on the ground. As the movement range increases the facilitator invites the participants to activate a conscious awareness of their breath, activating flow through sounding and allowing a connection with the others in the room.

Focusing on breath allows an Inner/Outer (I/O) relationship to be established in which participants are feeling their body's inner space in relationship to the general space. The intensity, speed, and space of the movements continue to increase by adding weight shifting from the core not only up and down, but also forward and backward and sideways. This establishes the ability to locomote and move in a shared rhythm. In doing this the group is literally "warming up"—core body temperature is raised, and mobilization and oxygenation of muscles occur. Breath support is activated and helps to establish a shared space and connection between participants. This attuning to inner sensation can be effective preparation for a shared, embodied research session.

A second exercise allows participants to go into a deeper relationship with one's own body and breath. Beginning with a partner seated on the floor back to back, participants are instructed to close their eyes and bring their attention to their breath as they sit in relationship to another person. After several breaths and a prompt to observe their natural breathing rhythms participants are asked to bring their attention to Lengthening and Shortening in their torso, investing in the Vertical dimension with their breath. After a few breaths here, they are encouraged to place their hands on their abdomens and with each breath focus on Bulging and Hollowing in the Sagittal dimension. Finally, with hands on either side of their torso, to send breath into their side space as they invest in Widening and Narrowing in the Horizontal dimension. By attending to breath in relationship to another person and with the addition of self touch for kinesthetic and proprioceptive awareness, participants begin to sense more deeply into the shaping of their torsos and the role of breath.

Another short exercise can further develop the sense of the group as a whole, bringing a sense of play as well. One participant, a volunteer, exchanges eye contact with the participant to their left. Using this eye contact as a nonverbal line of communication, the pair attempts to clap at the same time. This is trickier than it sounds because there is a tendency to lose eye contact, which can feel culturally awkward, initially, and undervaluing the complexity of simultaneous action, participants tend not to give the task their full attention. However, after passing this around the circle a few times, most participants receive the satisfaction of simultaneous action, emphasized with the sound of clapping, and the energy in the room will invariably change. The participants are ready for more. Next, to increase the complexity of the task, participants are instructed to add the possibility of locking focus with others across the circle and increasing speed of the exercise. This warmup builds shared focus, group sensing, prolonged awareness during the exercise (you never know when the focus will be directed to you). It also demonstrates how synchrony in dance is temporal, spatial, and qualitative. Dancers who synchronize well attend to many factors, can observe them, and have a range of choices in their body movement repertoire to adapt, adjust, and, thus, synchronize. This training is additive and not reductive. The abstraction of synchrony (it's an abstraction, not an absolute truth as in same physical behavior) needs additive choice in order to exist on the multiplicity of morphologies of human bodies.

2.3. Kinesphere Exploration Through Spatial Pulls

Laban defined the Kinesphere as "... the sphere around the body whose periphery can be reached by easily extended limbs without stepping away from that place which is the point of support when standing on one foot, which we shall call the stance/place." (Von Laban 1966). This idea includes more than a roboticist's notion of workspace, but it is similar. There are many ways to explore the dynamic space around which humans move. Primarily, in the study of the Kinesphere, LBMS maps an approach to Kinesphere that includes Zones, Levels, Reach Space, Pathways, Forms, and Directions. Patterns of Body Organization which are underlying movement pattern identification based on human motor development that support relationship of part to whole provide another way to internally organize movement within the Kinesphere. "Our form, with its upright vertical stance, and bilateral symmetry, is organized through relationships among upper and lower body, right and left sides of the body, front and back, core and periphery" (Studd and Cox 2013).

One exercise in particular highlights spatial organization keyed around a room versus a body reference frame—exploration through Spatial Pulls. To explore the Kinesphere through Spatial Pulls, participants, moving around in a dance studio, are instructed to move while attending to specific directions within the room, e.g., "Place High", "Place Middle", and "Place Low". Initially, these directions are the same for every participant, keyed off the room, and using the hand, or another body part available to all participants, comfortably extended, as the body part drawn to each direction. Gradually, the notion of a space centered around each mover individually, allows for instructions keyed from each participant's body, e.g., "Forward Right", which will result in more varied movement for participants with different facings. Another changing condition can be the extent to which the hand moves into the space: a shorter extension is in Near-Reach Space, while, conversely, full extension of the hand is in Far-Reach Space, which can also invite locomotion. Finally, the body part which initiates the movement can change: elbow, hip, top of the head, nose, etc. Inviting participants to debrief the exercise, e.g., answering "When do you do these actions in your daily life? or "How did different spatial prompts make you feel?", reveals commonalities and differences in experience that highlight the complexity and malleability of meaning-making through movement.

These changing conditions highlight several lessons: (1) the body is an adaptable and accommodating phenomenon to changing requests, (2) what delineates a particular body part is not always clear, and (3) space has meaning. This framework abstracts away the physical properties of the moving parts, focusing on high-level movement ideas common to all movers. "Place High" is a different place for every mover based on different heights, shoulder flexibility, and ability to rise onto the ball of the foot. Moreover, each mover has different prior experiences—maybe positive or negative or something complexly in between—with this kind of movement, which may create strong or subtle emotional responses to the components of the activity. That is why, for understanding this framework, one cannot just rely on going through the related literature that covers these details. Instead, one has to get inside a movement studio, experience the different spatial pulls, move through different spatial levels, and imagine the different spatial instructions while moving around.

2.4. Written and Embodied Movement Observation

A short exercise in movement observation might simply involve bringing up a YouTube video of some movement and having participants write descriptively about the video, communicating it to someone who has never seen it. A sentence might read as follows (this one was written about Mikhail Baryshnikov in Twyla Tharp's "Push Comes to Shove"): *The dancer enters a foggy spotlight emerging from shadows upstage. He deftly flips a tan hat into the air and pops it on his head with a nonchalant air. Holding his hands limp, softly locked in a spatial location while creating a myriad of choices with his core underneath.* This description requires participants to watch movement in great detail and make sense of the pattern. To take the exercise a level deeper, participants can write about distinct movement examples and switch samples to see if a naive reader can determine what the original movement sequence entailed.

To continue to work on participants listening and movement observation skills—from an embodied perspective—participants are placed in pairs and prompted to engage in what is often referred to as a mirroring exercise. With partners facing each other, one is directed to improvise various movements which can include pedestrian movements, weight shifts, and arm and leg movements, while their partner is working real time to mirror/imitate the exact movements that they are observing. This tool is used to hone movement observation skills and the ability to make movement choices in the moment. Replicating exactly is not possible—because both participants have different bodies (different ranges of motion different lengths of bones)—and this brings up a chance to describe strategies and choice in motion creation.

Labanotation is a well-known toolset that utilizes Laban's work to record movement sequences—mostly for archival purposes Guest (1977). A more common shorthand notation system is called Motif, which is useful in practice for applying (and learning) the tools in LBMS. While Labanotation is a precise record of a specific movement phrase, often recorded for posterity, Motif is a description of a gross movement idea or pattern. Each form utilizes its symbols in slightly different ways. Utilizing these notation schemes can clarify observations and record executions of movement.

Given the inability to perfectly recreate motion between two distinct platforms, as in the mirroring exercise described previously, our group favors use of Motif as a flexible shorthand that allows certain movement features to be foregrounded over others. The tool of Motif helps designers consider which features or broad patterns of a movement are most important for a given context; the mechanics of the tool are described through the diagrams in Figure 3.

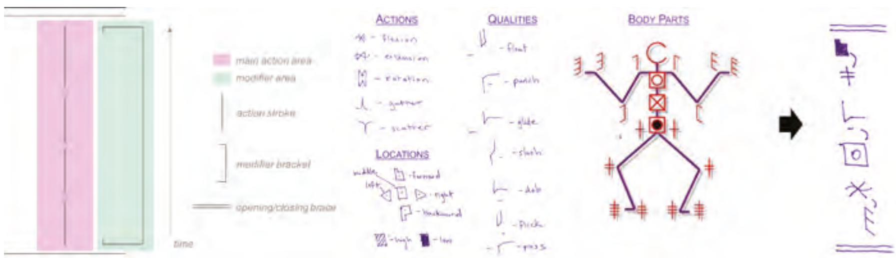


Figure 3. The diagram at left shows the structure of a vertical Motif (shown at right). The center column of a Motif denotes the main action. The length of a stroke indicates relative duration. These generic strokes may be replaced with more complex symbols (shown in center). The green area to the right, which may also be called a theme bow, allows for the main action to be modified, possibly highlighting overarching themes in the phrase. The sequence of action moves from bottom to top.

Another useful investigation revolves around the LBMS component of Effort (Laban and Lawrence 1947); Studd and Cox (2013) and reading/interpreting Effort Motifs. Effort can be simply described as the "quality" of a movement—the mover's inner attitude, motivation, and intention as revealed in observable movement. Activities designed to allow participants to explore the choices in this space can evolve as follows:

1. Engage in free movement improvisation in response to the stimuli of varying musical selections
2. Engage in free movement improvisation in response to words (adjectives) that evoke qualitative movement responses
3. Playing children's games, like Red Rover, Ring-Around-The-Rosey, and Duck-Duck-Goose, which naturally elicit playful, dynamic motion profiles (which easily produce short moments of complex Effort constellations, such as States and Drives, providing fodder for discussion)
4. Break into groups that are each given an Effort Motif, e.g., three symbols describing distinct motion quality, and have the group create a phrase of movement that uses them, explicating a context (note that it's unlikely, bordering on impossible, that two groups will come up with the same motion sequence)
5. Show movement sequences that are generated from the same Motif side-by-side
6. Discuss as a group: What is essential about the movements and their commonalities? How is this revealed through the quality descriptors in the Motif? What makes the sequences different and "mean" different things?

2.5. Establishing the Malleability of Meaning in Movement

This scale of "meaning" in movement—whether narrative ("Romeo loves Juliet"), emotional ("that part seemed sad"), or aesthetic ("that reminds me of a flower blooming")—is utilized to the choreographer's discretion and this utility impacts the audience's subjective experience and interpretation. To illustrate this, an exercise described here allows students to create mini-narratives and manipulate contexts from the pedestrian ("a shopping trip to the mall") to the surreal ("swimming through Saturn's rings") with a single gesture.

All participants sit against one wall of a large, open studio. One person is selected to begin the exercise. The person is then directed to "pick a scene, place, idea, event, dream, etc. It can be an atom floating across the universe, it can be a dragon lying in an abandoned mythical forest, or it can be a monk sitting atop a hill. There are no limitations to the who, what, where, when, why. Decide what or who you will be within this scene. Are you the heat coming off a loaf of fresh bread? Are you Cleopatra on her throne? Now when you stand up and enter the large open area of the space, you will be this. No speaking or verbal clues. You will move like it and commit to it. Go." Now this first participant, the "scene leader" goes into the space without revealing their internal image or desired role; they simply begin moving in the space. After the scene leader begins, the facilitator selects students at random and instructs them to, "Decide what you think this is. What scene/what action/what is happening? What space is being created? And then select how you will insert yourself into this." This participant now enters the space, similarly without revealing what they think is going on or talking in anyway; they simply begin moving, in earnest, their role. This continues for all of the participants until a dynamic, moving scene has been created.

In one example, the scene leader laid on their stomach with arms outstretched, holding an imaginary item, and keeping one eye closed. They rolled back and forth on their stomach with constrained breathing and bound overall flow. It was revealed later that they were a World War I soldier fighting in the trenches. Without this knowledge, other members of the class cohort decided for themselves what was happening and joined the scene. The first "joiner" began moving in a curved path, on their hands and feet with hips in the air, similar to a children's camp "bear walk". They would occasionally pause and switch their focus up from side to side. This was a labored movement pattern, with dramatic weight shifting and a strong energy. It was revealed later that the first joiner believed the scene to be a safari and inserted themselves as a large hunter-target.

In each case, the participants are told, "once you join, continue what you are doing until the exercise ends". At the end of the exercise, each participant had joined the scene and committed to their interpretation. After a few minutes, the facilitator ends the exercise and participants stop moving, and then each individual revealed what they believed the scene to be. The interpretations of one single scene can be varied: from "gas along Saturn's rings" to "children on Easter" or rather unified: "journalist reporting on war", "soldier patrolling an area", and "medic caring for the wounded". Participants altered between joining early in the scene and later in the scene. Additionally, as a further variation, a subset of participants can exit a scene once it had been "finalized", and then asked to reinterpret the scene from their original image. This creates a cycle of constantly deciding and participating based on the new visual representation, examples are shown in Figure 4.

Figure 4. The same prompt can create distinct resultant compositions; here, two very different takes on an initial seed of walking.

The lessons learned can be numerous. For example, one person is a "hunter" when another is the "buffalo". How does this change when the hunter disappears? Relationships created through movement and space are altered through perspectives, additions, and subtractions. Confirmation bias exists in performance as audience members process what may be purposefully ambiguous or unstructured. One scene leader might choose a very specific theatrical action, like the scene leader on their stomach, while the joiner may use an entirely improvisational, constant, and freeform movement pattern. This exercise illustrates the malleability of meaning in movement. In real time, participants can observe how movement patterns reorganize into new narratives, for individual performers and for the performance area as a whole.

3. Results: Progress and Principles in Developing Expressive Robotic Systems

The methods described above have been utilized in a myriad of robotic projects, in the RAD Lab and outside it. Moreover, in successful funding proposals, these methods have been explicitly touted for their potential for dramatic leaps forward inside robotic control and human-robot interaction. Through this work, a few guiding themes have emerged, which are discussed here.

3.1. Irreplaceable Body-Based Research in Robotics

The understanding gained from the exercises described in the previous section cannot be learned from a textbook. This work is of the body, not just the mind, and is necessarily passed on through embodied practice. What role does breath play in movement? As most motion capture systems ignore this aspect of motion, one way to answer is through the exercises described in Section 2.2. From this work, researchers have worked to include the notion of breath in virtual and robotic agents, including work in Pakrasi and LaViers (2018). A bodily understanding of the role of improvisation (Section 1.3) and spatial commands (Section 2.3) in movement design has led to new languages for robotic motion specification (Jang Sher et. al. 2018; Nilles et. al. 2018). Further, as seen in Huzaifa et al. (2016); Huzaifa and LaViers (2016), body-based exploration can lead to novel robot designs. Just as biomedical researchers collaborate with medical practitioners and visit hospitals to understand the activities and stakeholders within, roboticists building expressive systems for human interaction can gain much spending time in a dance studio working with and learning from choreographers and dance professionals. In our case, artistic output of the lab has stretched performance of robotic systems and helped us better understand how changing the context around a given physical machine can change perception of it (Cuan et al. 2018).

3.2. The Case for Manual Movement Design

Spending time in a dance studio with a choreographer illuminates how malleable motion interpretation can be (as in Section 2.5). For example, contrary to work where specific models are given for movement that is "happy" and "sad", our follow on work (Heimerdinger and LaViers 2017) has shown that these models are limited. Thus, tools that allow human movement designers choice in developing motion profiles, as in Huang and Hudak (2003), are critical to this intersection of work. Yet, robotics venues have balked at creative tools and methodologies as being too "ad-hoc" with reviewers offering constructive feedback like "The key postures are also manually provided for different styles—this does not sound very scientific. I think it is necessary to automate such process to claim a contribution on stylizing the movements" and "if a different designer had done the transformation, very different characters might have emerged. The design process is highly subjective and does not generalise". However, when viewed as a creative tool, these are *strengths* of such "ad-hoc" methods. Again, the many myriad of ways human motion may be translated to a set of fewer or distinct degree of freedom system guarantees choice in the process. Premature automation and restrictive optimization may end up limiting the exhibited behavior of robotic systems. On the other hand, think of the many myriad ways motion as simple as a Roomba has been interpreted in the inherently varied contexts it inhabits in human homes. Offering this choice to a human is not only the way to empower collaborators in dance but also a reasonable step toward making useful tools.

3.3. Objective, Qualitative Movement Observation (to Support Subjective Conclusions)

In pursuit of automation that is sensitive to movement expression, then, we motivate the need for a pipeline of activity which starts with observation of movement. Only through noticing the objective mechanisms at play with qualitative methods (e.g., written description) can we begin to quantify and automate aspects of expression through movement. The diagram in Figure 5 highlights this take away, motivating the need for two areas of future work: qualitative methods for the description of objective movement phenomena and quantitative methods for the analysis of subjective phenomena. The former is a way of characterizing all of the methods presented in Section 2, while the latter describes the results presented in Section 3. For example, every conversation spurred on by the embodied practices employed here is a chance for engineers and dancers to describe the experience of moving in their own bodies and viewing movement in others. On the other hand, every output of expression through movement that interfaces with some technological element or another requires quantification.

	Quantitative	*Qualitative*
Objective	Traditionally emphasized in engineering	Emphasized in exercises in movement observation, description, and generation – like the one presented in Section 2, which are designed for engineers working to produce expressive robotic systems
Subjective	Emphasized in tools for expressive robotic systems – like the ones presented in Section 3, many of which are working toward being accessible to dance collaborators	Traditionally emphasized in dance

Figure 5. Qualitative and quantitative methods are needed to explain and design objective and subjective phenomena. This diagram frames how the methods and results presented here aid in this need, bringing balance to the upper right and lower left quadrant of the diagram.

These lenses also reveal how important objective description is to seeing mechanisms in movement that can be translated to automated systems. It is tempting for engineers to watch an animate character that may serve inspiration for a robot companion and say: "I'm going to replicate this happy movement in my robot design". As seen in Pakrasi and LaViers (2018), this lacks objective explication of movement phenomena that can be translated to an engineered system. Instead engineers need to break down the behaviors that are contributing to that character's "happy" affect within its given context (Heimerdinger and LaViers 2017, 2018). In this light, an engineer can then see: "Ah, the frequency of motion in the vertical dimension is modulated when the character's internal state varies, and an increased frequency of the period of the motion correlates with a happier seeming character". This can be translated into quantitative design elements: period of oscillations. Moreover, it motivates an important separation between "style" (how a platform is moving) and "affect" (how a human responds to motion). Expressive robotic systems will have wide capacity for a range of motion styles that, when aspects of context and characteristics of a human counterpart are accounted for, can communicate a desired affect to a human counterpart.

4. Conclusions: Toward Widespread Collaboration between Dancers and Roboticists

> *...the truest creativity of the digital age came from those who connected the arts and sciences.*
>
> —The Innovators (Isaacson 2014)

There is inherent excitement around collaborations between engineering and the arts—as evidenced by the quote above. The sum of the embodied, relational work presented here implies that, no, a machine cannot express all the things a human can express, but that humans themselves *can express more things alongside and in relation to* machines. To this end, this paper has provided background on tools and techniques from choreography and somatics and how those have been used in the development of more expressive robotic systems. We've posited that a missing piece from much of the prior work in robotics is embodied practice alongside artistic practitioners. To that end, we've presented methods developed in the RAD Lab with our many collaborators to provide embodied experiences for an interdisciplinary group working in robotics. To show that these approaches can be effective and spur innovation, we've shared connections to projects that have benefited within our group. Finally, framing principles that have resulted from this work have been shared.

Robotics is at a critical point where researchers are working to bring complex mechanical machines outside of controlled factory environments, where they are walled-away from human counterparts. This demands new understanding of how humans view and create movement that experts like dance artists, choreographers, and somatic practitioners already understand. Broadly speaking, the methods highlighted in this paper work toward the production of expressive robotic systems: systems that have a greater variety of choice in the generated motion profiles. This makes it easier for humans to design movement. It makes it easier for humans to interpret movement. Is such a system more life-like? Yes, because it's more expressive. Is it dancing? No, that's the humans operating it, designing it, selecting moving patterns over time, and extending themselves through technology. Thus, as a more refined paintbrush or a camera with better dynamic range, with improved, more expressive robotic technology, the machine *extends the artist* into the 21st century.

Acknowledgments: The work in this paper was sponsored by NSF grant numbers 1528036 and 1701295, DARPA grant number D16AP00001, a grant from the Jefferson Trust, a grant from the UVA Data Science Institute, and start up funds from UVA and UIUC. We thank all of our collaborators, including those who could not contribute directly to this paper, who have helped us along the way.

Author Contributions: Catie Cuan and Catherine Maguire have helped design and conduct many activities over a sustained period in the lab and wrote one or more sections of the paper; Karen Bradley, Kim Brooks Mata, Alexandra Nilles and Ilya Vidrin contributed significant chunks of text, heavy edits, and important main ideas toward the core material of the paper. The rest of the authors have participated in activities and translated them to disciplinary work in robotics and helped contribute to the paper. The lead author organized, compiled, and wrote several sections of the paper. Please see the list in the Appendix A for further detail about author roles.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Detailed Activity List

This approach has been adopted through several diverse activities organized through the Robotics, Automation, and Dance (RAD) Lab. This lab was at the University of Virginia (UVA) from 2013–2015 and is now at the University of Illinois at Urbana-Champaign (UIUC) since 2015. In this article, the author group writes as one body (although we are from multiple perspectives and experiences) for clarity. A list of specific activities, along with the names of collaborators, is given here in order for the reader to see examples and details about author roles.

- Between 2013 and 2017 Catherine Maguire offered five workshops in LBMS for the RAD Lab. These ranged from one-on-one sessions to group sessions with all lab members and sponsored from the lab start up packages at UVA and UIUC as well as a grant from the UVA Data Science Institute.
- In Fall 2014 Kim Brooks Mata and Amy LaViers co-developed and co-taught DAN 3559/ENG 3501 Electronic Identity and Embodied Technology Atelier, cross-listed between the dance and engineering programs at the University of Virginia and funded by the Jefferson Trust.
- As part of a research project, "Choreography of Platform-Invariant Motion Primitives" Amy LaViers organized two three day training workshops at UIUC. The first, in June 2016, was co-developed and co-taught with Catherine Maguire and Karen Studd; the second, in June 2017, was co-developed and co-taught with Catherine Maguire, Catie Cuan, and Riley Watts. In addition to travel expenses covered, the facilitators were paid at one of two hourly rates (one for consulting and a higher rate for teaching). These workshops were sponsored by DARPA grant number D16AP00001.
- Karen Bradley advised Amy LaViers' CMA thesis project entitled "Preparing to Cook with Eric: Function and Expression Within Recipe", which was completed in August 2016 through the Laban/Bartenieff Institute of Movement Studies (LIMS).
- Amy LaViers organized a workshop at Robotics: Science and Systems (RSS) in 2016 entitled "Let's Move: Embodied Experience and Movement Observation for Roboticists". The workshop

featured Elizabeth Jochum, Heather Knight, and Kayhan Ozcimder as speakers. Attendees included participants from industry and academia including CMU, JPL, U Mich, Duke, WPI, Google, Sphero, UIUC, Princeton, and Aalborg University.

- Amy LaViers co-organized an invited, follow on workshop in 2017 for RSS with Kayhan Ozcimder entitled "Experimenting with Movement Observation". Attendees included participants from MIT, UIUC, Princeton, and U Mich.
- In April 2017 Amy LaViers attended Art, Tech, Psyche III at Harvard University where she also spent extended time meeting with Ilya Vidrin and Riley Watts discussing the phenomena of partnering in dance; these conversations have led to an inprogress independent study project for a master's student in mechanical engineering at UIUC.
- In June 2017 Catie Cuan, a New York based choreographer, spent a month in residence at the RAD Lab in Urbana, IL. As part of this residency she taught classes to lab members and developed an artistic piece alongside Amy LaViers, Ishaan Pakrasi, and Novoneel Chakraborty. The piece "Time to Compile", and was presented as a work in progress on 30 June 2017. This work is sponsored by the lab start up package and NSF grant number 1528036. User studies are in progress using this material to modulate perception of in home robots.
- In addition to training and education for lab members, Catherine Maguire has consulted on two research projects where her expertise in movement theory and observation have been integral parts of the technical output in the lab. In addition to co-authoring resulting papers, she has been paid an hourly consulting rate on these projects, funded by NSF grant numbers 1528036 and 1701295.
- In Spring 2017 a new course ME 598: High-level Robotic Control and Movement Representation was offered at UIUC. The course emphasized embodied movement exploration, writing, and interdisciplinary research. An "Expressivity Expansion Pack" for the Robot Design Game[3] was produced as a formal output of this class.
- Over the years two regular lab activities have been developed that support this line of work in the group in addition to the group's weekly lab meeting. We call them "writing hour" and "movement hour". In each, we take time to practice descriptive writing and embodied movement exploration (led by Amy LaViers or a guest facilitator like Catie Cuan who helped establish "movement hour") in order to supplement the traditional education students receive in engineering. Students in the group who have contributed as co-authors here are Novoneel Chakraborty, Madison Heimerdinger, Umer Huzaifa, Reika McNish, Alexandra Nilles, Ishaan Pakrasi, and Alexander Zurawski.
- Lab outreach activities also benefit from these workshops. The lab holds outreach activities for students in age ranges from elementary to high school. All of these activities work to showcase robotics in an accessible manner and feature embodied movement exploration as well as quantitative *and* qualitative objective description of movement of machines *and* humans.
- A commercial spin off of the lab, start up AE Machines, was founded by Eric Minnick and Amy LaViers. The start up has received seed funding from the NSF grant #1621861 and won Product Design of the Year at the 4th Revolution Awards in Chicago, IL.

References

Abrahamson, Dor. 2004. Embodied Spatial Articulation: A Gesture Perspective on Student Negotiation Between Kinesthetic Schemas and Epistemic Forms in Learning Mathematics. Paper presented at the Twenty Sixth Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education, Toronto, ON, Canada. October 21–24, vol. 2, pp. 791–97.

Alexander, Frederick Matthias. 1990. *The Alexander Technique: The Essential Writings of F. Matthias Alexander*. Edited by Edward Maisel. New York: Carol Publishing Group.

[3] http://radlab.mechse.illinois.edu/2017/06/14/robot-card-game/.

Argall, Brenna D., Sonia Chernova, Manuela Veloso, and Brett Browning. 2009. A survey of robot learning from demonstration. *Robotics and Autonomous Systems* 57: 469–83.

Banes, Sally. 1983. *Democracy's Body: Judson Dance Theater, 1962–1964*. Number 43. Durham: Duke University Press.

Banes, Sally. 2011. *Terpsichore in Sneakers: Post-Modern Dance*. Middletown: Wesleyan University Press.

Barakova, Emilia I., Roos van Berkel, Liang Hiah, Yu-Fang Teh, and Ceil Werts. 2015. Observation Scheme for Interaction With Embodied Intelligent Agents Based on Laban Notation. Paper presented at 2015 IEEE International Conference on Robotics and Biomimetics (ROBIO), Zhuhai, China, December 6–9, pp. 2525–30.

Barnett, Scot, and Casey Boyle. 2016. *Rhetoric, Through Everyday Things*. Tuscaloosa: University of Alabama Press.

Bartenieff, Irmgard, and Dori Lewis. 1980. *Body Movement: Coping with the Environment*. New York: Routledge

Bradley, E., and J. Stuart. 1998. Using chaos to generate variations on movement sequences. *Chaos: An Interdisciplinary Journal of Nonlinear Science* 8: 800–7.

Bradley, Karen. Kohn. 2008. *Rudolf Laban*. New York: Routledge.

Brand, Matthew, and Aaron Hertzmann. 2000. Style Machines. Paper presented at the 27th Annual Conference on Computer Graphics and Interactive Techniques. New Orleans, LA, USA. July 23–28. New York: ACM Press/Addison-Wesley Publishing Co., pp. 183–92.

Breazeal, Cynthia, and Brian Scassellati. 1999. A context-dependent attention system for a social robot. *rn* 255: 3.

Breazeal, C. L. 2004. *Designing Sociable Robots*. Cambridge: MIT Press.

Calvert, Tom W., Armin Bruderlin, Sang Mah, Thecla Schiphorst, and Chris Welman. 1993. The Evolution of an Interface for Choreographers. Paper presented at the INTERACT'93 and CHI'93 Conference on Human Factors in Computing Systems, Amsterdam, The Netherlands, April 24–29, pp. 115–22.

Čapek, Karel. 2004. *RUR (Rossum's Universal Robots)*. New York: Penguin.

Cuan, Catie, Ishaan Pakrasi, and Amy LaViers. 2018. Time to Compile: An Interactive Art Installation. Paper presented at Intersections: The Ammerman Center for Arts and Technology 16th Biennial Symposium. New London, CT, USA. February 15–17.

Cohen, Bonnie Bainbridge, Lisa Nelson, and Nancy Stark Smith. 2012. *Sensing, Feeling, and Action: The Experiential Anatomy of Body-Mind Centering®*. Toronto: Contact editions.

Copeland, Roger. 1993. Dance, Feminism, and the Critique of the Visual. In *Dance, Gender and Culture*. London: Palgrave Macmillan, pp. 139–50.

Copeland, R. 2004. *Merce Cunningham: The Modernizing of Modern Dance*. New York: Routledge.

Cunningham, M. 1997. The impermanent art. In *Vaughn, Merce Cunningham: Fifty Years*. New York: Aperture.

Darling, Kate, Palash Nandy, and Cynthia Breazeal. 2015. Empathic Concern and the Effect of Stories in Human-Robot Interaction. Paper presented at 2015 24th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN), Kobe, Japan, August 31–September 4, pp. 770–75.

De Sousa Junior, Samuel Felix, and Mario Fernando Montenegro Campos. 2011. Shall We Dance? a Music-Driven Approach for Mobile Robots Choreography. Paper presented at 2011 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), San Francisco, CA, USA, September 25–30, pp. 1974–79.

Dragan, Anca D., Kenton C. T. Lee, and Siddhartha S. Srinivasa. 2013. Legibility and Predictability of Robot Motion. Paper presented at 2013 8th ACM/IEEE International Conference on Human-Robot Interaction (HRI), Tokyo, Japan, March 3–6, pp. 301–8.

Eddy, Martha. 2009. A brief history of somatic practices and dance: Historical development of the field of somatic education and its relationship to dance. *Journal of Dance & Somatic Practices* 1: 5–27.

El-Jiz, Michael, and Luis Rodrigues. 2017. Trajectory Planning and Control of a Quadrotor Choreography for Real-Time Artist-in-the-Loop Performances. *Unmanned Systems* 1–13. doi:10.1142/S2301385018500012.

Elgin, Catherine Z. 2010. Exemplification and the Dance. In *Philosophie de la Dance*. Edited by Roger Pouivet. Rennes: Presses Universitaire de Rennes.

Etemad, S. Ali, and Ali Arya. 2016. Expert-Driven Perceptual Features for Modeling Style and Affect in Human Motion. *IEEE Transactions on Human-Machine Systems* 46: 534–45.

Feldenkrais, Moshé. 1972. *Awareness through Movement*. New York: Harper & Row, vol. 1977.

Forlizzi, Jodi, and Carl DiSalvo. 2006. Service Robots in the Domestic Environment: A Study of the Roomba Vacuum in the Home. Paper presented at the 1st ACM SIGCHI/SIGART conference on Human-robot interaction, Salt Lake City, UT, USA, March 2–3, pp. 258–65.

Forsythe, William. 2012. *Improvisation Technologies: A Tool for the Analytical Dance Eye*. Berlin: Hatje Cantz.

Foster, Mary Ann. 2004. *Somatic Patterning: How to Improve Posture and Movement and Ease Pain*. London: Pearson.

Gielniak, Michael, C. Karen Liu, and Andrea L. Thomaz. 2010. Stylized Motion Generalization Through Adaptation of Velocity Profiles. Paper presented at 2010 IEEE RO-MAN, Viareggio, Italy, September 13–15, pp. 304–9.

Gillies, M. 2009. Learning finite-state machine controllers from motion capture data. *IEEE Transactions on Computational Intelligence and AI in Games* 1: 63–72.

Goehr, Lydia. 2014. Improvising impromptu, or, what to do with a broken string. In *The Oxford Handbook of Critical Improvisation Studies*. New York: Oxford University Press, vol. 1.

Goldman Schuyler, Kathryn. 2010. Increasing leadership integrity through mind training and embodied learning. *Consulting Psychology Journal: Practice and Research* 62: 21.

Groves, Rebecca, Norah Zuniga Shaw, and Scott DeLahunta. 2007. *Talking about Scores: William Forsythe's Vision for a New Form of "Dance Literature"*. Berlin: Transcript Verlag.

Guest, Ann Hutchinson. 1977. *Labanotation: Or, Kinetography Laban: The System of Analyzing and Recording Movement*. TAB paperback, Theatre Arts Books. New York: Taylor and Francis.

Guest, Ann Hutchinson. 1996. *Labanotation, or, Kinetography Laban: The System of Analyzing and Recording Movement*. New York: Oxford University Press.

Hackney, Peggy. 1998. *Making Connections: Total Body Integration through Bartenieff Fundamentals*. New York: Routledge.

Hall, Fernau. 1964. Dance notation and choreology. *The British Journal of Aesthetics* 4: 58.

Hanna, Thomas. 1980. *The Body of Life*. New York: Knopf.

Hawhee, Debra. 2004. *Bodily Arts: Rhetoric and Athletics in Ancient Greece*. Austin: University of Texas Press.

Heimerdinger, Madison, and Amy LaViers. 2018 Modeling the Interactions of Context and Style on Affect in Motion Perception: Stylized Gaits Across Multiple Environmental Contexts. Under review.

Heimerdinger, Madison, and Amy LaViers. 2017. Influence of Environmental Context on Recognition Rates of Stylized Walking Sequences. Paper presented at 9th International Conference on Social Robotics (ICSR) Tsubuka, Japan November 22–24, pp. 272–82.

Hendriks, Bram, Bernt Meerbeek, Stella Boess, Steffen Pauws, and Marieke Sonneveld. 2011. Robot vacuum cleaner personality and behavior. *International Journal of Social Robotics* 3: 187–95.

Huang, L., and P. Hudak. 2003. *Dance: A Declarative Language for the Control of Humanoid Robots*. Technical report. Yale: Department of Computer Science, Yale University New Haven.

Husserl, Edmund. 2012. *Ideas: General Introduction to Pure Phenomenology*. New York: Routledge.

Huzaifa, Umer, and Amy Laviers. 2016. Control Design for Planar Model of a Core-located Actuation Walker. Paper presented at 6th IEEE International Conference on Biomedical Robotics and Biomechatronics (BioRob), Singapore, June 26–29.

Huzaifa, Umer, Crispin Bernier, Zachary Calhoun, Gerald Heddy, Colleen Kohout, Brett Libowitz, Anne Moenning, Jason Ye, Catherine Maguire, and Amy Laviers. 2016. Embodied Movement Strategies for Development of a Core-located Actuation Walker. Paper presented at Biomedical Robotics and Biomechatronics (BioRob), Singapore, June 26–29.

Isaacson, Walter. 2014. *The Innovators: How a Group of Hackers, Geniuses, and Geeks Created the Digital Revolution*. New York: Simon and Schuster.

Jang Sher, Anum. Umer Huzaifa, Jialu Li, Varun Jain, Alexander Zurawski, and Amy LaViers. 2018. An Embodied, Platform-invariant Architecture for Connecting High-level Spatial Commands to Platform Articulation. *Robotics and Autonomous Systems. Special Issue on Human Movement Understanding*, under review.

Kaufman, James C., and John Baer. 2005. *Creativity Across Domains: Faces of the Muse*. Mahwah: Lawrence Erlbaum Associates.

Kennedy, George A., and Aristotle. 2006. *On Rhetoric: A Theory of Civic Discourse*. Oxford: Oxford University Press.

Knight, Heather, and Matthew Gray. 2012. Acting lesson with robot: Emotional gestures. Paper presented at 2012 7th ACM/IEEE International Conference on Human-Robot Interaction (HRI), Boston, MA, USA, March 5–8, pp. 407–7.

Knight, Heather, and Reid Simmons. 2014. Expressive motion with x, y and theta: Laban effort features for mobile robots. Paper presented at the 23rd IEEE International Symposium on Robot and Human Interactive Communication, Edinburgh, UK, August 25–29, pp. 267–73.

Knight, Heather, and Reid Simmons. 2015. Layering Laban Effort Features on Robot Task Motions. Paper presented at the Tenth Annual ACM/IEEE International Conference on Human-Robot Interaction Extended Abstracts, Portland, OR, USA, March 2–5, pp. 135–36.

Knight, Heather, and Reid Simmons. 2016. Laban head-motions convey robot state: A call for robot body language. Paper presented at 2016 IEEE International Conference on Robotics and Automation (ICRA), Stockholm, Sweden, May 16–21, pp. 2881–88.

Knight, Heather, Manuela Veloso, and Reid Simmons. 2015. Taking candy from a robot: Speed features and candy accessibility predict human response. Paper presented at 2015 24th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN), Kobe, Japan, August 31–September 4, pp. 355–62.

Laban, R., and F. C. Lawrence. 1947. *Effort*. New York: Macdonald and Evans.

Laban, Rudolf, and Lisa Ullmann. 1966. *Choreutics*. New York: Macdonald and Evans.

Laban, Rudolf, and Lisa Ullmann. 1971. *The Mastery of Movement*. New York: Macdonald and Evans.

Lambert, Carrie. 1999. Moving Still: Mediating Yvonne Rainer's "Trio A". *October* 89: 87–112.

Lambert-Beatty, Carrie. 2008. *Being Watched: Yvonne Rainer and the 1960s*. Cambridge: MIT Press.

Latey, Penelope. 2001. The Pilates method: History and philosophy. *Journal of Bodywork and Movement Therapies* 5: 275–82.

LaViers, Amy. 2018. Programmed Improvisation Inspired from Autonomous Humanoids. In *Handbook on Improvisation in Dance*. New York: Oxford University Press, (to appear).

Lindgren, Robb, and Mina Johnson-Glenberg. 2013. Emboldened by embodiment: Six precepts for research on embodied learning and mixed reality. *Educational Researcher* 42: 445–52.

Liu, C. Karen, Aaron Hertzmann, and Zoran Popović. 2005. Learning physics-based motion style with nonlinear inverse optimization. *ACM Transactions on Graphics (TOG)* 24: 1071–81.

Lourens, Tino, Roos van Berkel, and Emilia Barakova. 2010. Communicating emotions and mental states to robots in a real time parallel framework using Laban movement analysis. *Robotics and Autonomous Systems* 58, 1256–65.

Lubart, T. 2005. How can computers be partners in the creative process: Classification and commentary on the special issue. *International Journal of Human-Computer Studies* 63: 365–69.

Maletic, Vera. 1987. *Body, Space, Expression*. Berlin: Walter de Gruyter & Co.

Masuda, Megumi, and Shohei Kato. 2010. Motion Rendering System for Emotion Expression of Human Form Robots Based on Laban Movement Analysis. Paper presented at 19th International Symposium in Robot and Human Interactive Communication, Viareggio, Italy, September 13–15, pp. 324–29.

Masuda, Megumi, Shohei Kato, and Hidenori Itoh. 2009. Emotion Detection From Body Motion of Human Form Robot Based on Laban Movement Analysis. Paper presented at International Conference on Principles and Practice of Multi-Agent Systems, Nagoya, Japan, December 14–16, pp. 322–34.

Michalowski, Marek P., Selma Sabanovic, and Hideki Kozima. 2007. A Dancing Robot for Rhythmic Social Interaction. Paper presented at 2007 2nd ACM/IEEE International Conference on Human-Robot Interaction (HRI), Arlington, VA, USA, March 9–11, pp. 89–96.

Nilles, Alexandra, Chase. Gladish, Mattox Beckman, and Amy LaViers. 2018. Improv: Live Coding for Robot Motion Design. Paper present at the 5th International Conference on Movement and Computing (MOCO), Genoa, Italy. June 28–30, under review.

Okamoto, Takahiro, Takaaki Shiratori, Shunsuke Kudoh, Shin'ichiro Nakaoka, and Katsushi Ikeuchi. 2014. Toward a dancing robot with listening capability: Keypose-based integration of lower-, middle-, and upper-body motions for varying music tempos. *IEEE Transactions on Robotics* 30: 771–78.

Özcimder, Kayhan, Biswadip Dey, Rebecca J. Lazier, Daniel Trueman, and Naomi E. Leonard. 2016. Investigating Group Behavior in Dance: An Evolutionary Dynamics Approach. Paper presented at American Control Conference (ACC), Boston, MA, USA, July 6–8, pp. 6465–70.

Pakrasi, Ishaan, and Amy LaViers. 2018. A Design Methodology for Abstracting Character Archetypes onto Robotic Systems. Paper present at the 5th International Conference on Movement and Computing (MOCO), Genoa, Italy. June 28–30, under review.

Pallant, Cheryl. 2006. *Contact Improvisation: An Introduction to a Vitalizing Dance Form*. Jefferson: McFarland.

Patla, A. 1982. Aspects ofthe Kinematic Simulation of Human Movement. *IEEE Computer Graphics and Applications* 2: 41–50.

Peng, Hua, Changle Zhou, Huosheng Hu, Fei Chao, and Jing Li. 2015. Robotic dance in social robotics—A taxonomy. *IEEE Transactions on Human-Machine Systems* 45: 281–93.

Peters, G. 2009. *The Philosophy of Improvisation*. Chicago: University of Chicago Press.

Pinel, Florian, Lav R. Varshney, and Debarun Bhattacharjya. 2015. A culinary computational creativity system. In *Computational Creativity Research: Towards Creative Machines*. Paris: Atlantis Press, pp. 327–46.

Rainer, Yvonne. 1966. A quasi survey of some 'Minimalist'tendencies in the quantitatively Minimal dance activity midst the plethora, or an analysis of trio A. In *What's Dance*. Edited by Roger Copeland and Marshall Cohen. London: Routledge, pp. 325–32.

Rainer, Yvonne. 2006. No Manifesto. Available online: https://conversations.e-flux.com/t/yvonne-rainer-no-manifesto/1454 (accessed on 31 October 2017)

Rett, Jorg, and Jorge Dias. 2007. Human-Robot Interface With Anticipatory Characteristics Based On Laban Movement Analysis and Bayesian Models. Paper presented at 2007 IEEE 10th International Conference on Rehabilitation Robotics, Noordwijk, The Netherlands, June 13–15, pp. 257–68.

Rett, Joerg, Jorge Dias, and Juan-Manuel Ahuactzin. 2008. *Laban Movement Analysis Using a Bayesian Model and Perspective Projections*. London: INTECH Open Access Publisher.

Rossano, Gregory F., Carlos Martinez, Mikael Hedelind, Steve Murphy, and Thomas A. Fuhlbrigge. 2013. Easy Robot Programming Concepts: An Industrial Perspective. Paper presented at 2013 IEEE International Conference on Automation Science and Engineering (CASE), Madison, WI, USA, August 17–20, pp. 1119–26.

Schiphorst, Thecla. 1993. A Case Study of Merce Cunningham's Use of the Lifeforms Computer Choreographic System in the Making of Trackers. PhD thesis, Arts and Social Sciences: Special Arrangements, Simon Fraser University, Burnaby, BC, Canada.

Schoellig, Angela P., Hallie Siegel, Federico Augugliaro, and Raffaello D'Andrea. 2014. So you think you can dance? Rhythmic flight performances with quadrocopters. In *Controls and Art*. London: Springer, pp. 73–105.

Sefidgar, Yasaman S., Prerna Agarwal, and Maya Cakmak. 2017. Situated Tangible Robot Programming. Paper presented at the 2017 ACM/IEEE International Conference on Human-Robot Interaction, Vienna, Austria, March 6–9, pp. 473–82.

Siu, Ka-Chun, Irene H. Suh, Mukul Mukherjee, Dmitry Oleynikov, and Nick Stergiou. 2010. The effect of music on robot-assisted laparoscopic surgical performance. *Surgical Innovation* 17: 306–11.

Studd, Karen A., and Laura L. Cox. 2013. *Everybody is a Body*. Indianapolis: Dog Ear Publishing.

Sutil, Nicolas Salazar. 2015. *Motion and Representation: The Language of Human Movement*. Cambridge: MIT Press.

Tellex, Stefanie, Thomas Kollar, Steven Dickerson, Matthew R. Walter, Ashis Gopal Banerjee, Seth Teller, and Nicholas Roy. 2011. Understanding Natural Language Commands for Robotic Navigation and Mobile Manipulation. Paper presented at Twenty-Fifth AAAI Conference on Artificial Intelligence, San Francisco, CA, USA, August 7–11, vol. 1, p. 2.

Torresani, Lorenzo, Peggy Hackney, and Christoph Bregler. 2007. Learning motion style synthesis from perceptual observations. *Advances in Neural Information Processing Systems* 20: 1393–400.

Truitt, Elly R. 2015. *Medieval Robots: Mechanism, Magic, Nature, and Art*. Philadelphia: University of Pennsylvania Press.

Von Laban, R. 1966. *The Language of Movement: A guidebook to Choreutics*. New York: Plays, inc..

Weinberg, Brian Blosser, Trishul Mallikarjuna, and Aparna Raman. 2009. The Creation of a Multi-Human, Multi-Robot Interactive Jam Session. Presented at theNew Interfaces for Musical Expression Conference NIME. Pittsburg, PA, USA, June 4–6, pp. 70–73.

Whitney, David, Eric Rosen, Elizabeth Phillips, George Konidaris, and Stefanie Tellex. 2017a. *Comparing Robot Grasping Teleoperation across Desktop and Virtual Reality with ROS Reality*. Technical report, Providence: Department of Computer Science, Brown University.

Whitney, David, Eric Rosen, James MacGlashan, Lawson Wong, and Stefanie Tellex. 2017b. Reducing Errors in Object-Fetching Interactions through Social Feedback. Paper presented at International Conference on Robotics and Automation, Singapore, May 29–June 3.

Young, James E., JaYoung Sung, Amy Voida, Ehud Sharlin, Takeo Igarashi, Henrik I. Christensen, and Rebecca E. Grinter. 2011. Evaluating human-robot interaction. *International Journal of Social Robotics* 3: 53–67.

arts

MDPI

Essay

Can Computers Create Art? †

Aaron Hertzmann

Adobe Research, San Francisco, CA 94103, USA; hertzman@dgp.toronto.edu
† This essay expresses my own opinions and not those of my employer.

Received: 4 February 2018; Accepted: 7 May 2018; Published: 10 May 2018

Abstract: This essay discusses whether computers, using Artificial Intelligence (AI), could create art. First, the history of technologies that automated aspects of art is surveyed, including photography and animation. In each case, there were initial fears and denial of the technology, followed by a blossoming of new creative and professional opportunities for artists. The current hype and reality of Artificial Intelligence (AI) tools for art making is then discussed, together with predictions about how AI tools will be used. It is then speculated about whether it could ever happen that AI systems could be credited with authorship of artwork. It is theorized that art is something created by social agents, and so computers cannot be credited with authorship of art in our current understanding. A few ways that this could change are also hypothesized.

Keywords: art and technology; artificial intelligence; photography; painting; computer animation; image stylization

---

1. Introduction

Artificial Intelligence (AI) research has made staggering advances recently, including many publicly-visible developments in web search, image recognition, conversational agents, and robotics. These developments have stoked fear about Artificial Intelligence's effect on many aspects of society. In the context of art, news media hype presents new image and video creation algorithms as if they are automating the creation of art. Perhaps they will empower everyday users while putting artists out of work . . . and, while they are at it, rob us of our humanity?

Beyond the hype, confusion about how technology influences art pervades serious discussions. Professional artists are often concerned that computers might put them out of work (Nicholas 2017)—a concern I have heard for decades. Some practitioners present their algorithms as themselves, potentially, artists (Colton 2012; Elgammal et al. 2017; Shein 2017), as do some journalists (Dvorsky 2017; Perez 2018; Pogue 2018). And, I was recently contacted by a prominent social psychologist who, inspired by recent results with neural networks, wished to conduct experiments to assess whether ordinary people might be willing to buy artwork made by a computer, and, if so, why. It was assumed that computers were already happily making their own artwork.

On the other hand, when I have informally asked friends or colleagues the question of whether computers can create art, the answer is sometimes a decisive "No." Art requires human intent, inspiration, a desire to express something. Thus, by definition, there is no such thing as art created by a computer, so why would anyone worry? The concepts of art and inspiration are often spoken of in mystical terms, something special and primal beyond the realm of science and technology; it is as if only humans create art because only humans have "souls." Surely, there should be a more scientific explanation.

In this essay, I tackle the question of "Can Computers Create Art?" This might seem like a simple question. Sometimes people ask it as a question about technological capabilities, like asking if a new car can go 100 miles per hour. For this sort of question, someone who understands the technology ought to be able to give a simple yes-or-no answer. But it is not a given that any computer will ever be widely considered as an artist. To date, there is already a rich body of computer-generated art, and, in all cases, the work is credited to the human artist(s) behind the tools, such as the authors or users of the software—and this might never change.

A more precise statement of this essay's question is: "Could a piece of computer software ever be widely credited as the author of an artwork? What would this require?" This is a question of the psychology and philosophy of art; I do not describe the existing technology in much detail. I also discuss the related question of "Will AI put artists out of jobs?" and, more generally, of whether AI will be beneficial to art and artists.

Before directly addressing these questions, I discuss the history and current state of automation for art. I begin with some historical perspectives: previous moments in history when new technologies automated image and film creation, particularly the invention of photography. In each case, we see that these new technologies caused fears of displacing artists, when, in fact, the new technology both created new opportunities for artists while invigorating traditional media.

I argue that new technologies benefit art and artists, creating new tools and modes of expression, and new styles of expression. Sadly, art and science are often viewed as being separate, or, even, in opposition (Snow 1959). Yet, technological development stimulates so much of the continued vitality of art, and new artistic technologies create new job opportunities. Our new AI technologies follow this trend, and will for the foreseeable future: new AI algorithms will provide new tools for expression and transform our art and culture in positive ways, just as so many other technologies have in the past.

Computers do not create art, people using computers create art. Despite many decades of procedural and computer-generated art, there has never been a computer widely accepted as the author of an artwork. To date, all "computer-generated art" is the result of human invention, software development, tweaking, and other kinds of direct control and authorship. We credit the human artist as author, acknowledging that the human is always the mastermind behind the work, and that the computer is a simple tool.

I then discuss whether this could ever change: would we ever agree to assign authorship to a computer? I argue that artistic creation is primarily a *social* act, an action that people primarily perform as an interaction with other humans in society. This implies that computers cannot create art, just as people do not give gifts to their coffee makers or marry their cars. Conversely, any human can make art, because we humans are social creatures. However, the boundaries of art are fluid, and, someday, better AI could come to be viewed as true social agents. I discuss this and other scenarios where AI algorithms could come to be accepted as artists, along with some of the dangers of too eagerly accepting software as artists.

This essay expresses my point of view, as someone who has developed various kinds of technology for art, has followed the development of new technologies affecting art and culture over the years, and, in a few instances, exhibited my own work as artworks. I have written in a style that is meant to be accessible to a general audience, since these are topics that many different people care about.

2. History and Current Practice

Before making general claims about how computer tools relate to art, I begin by first describing several useful historical examples, including the inventions of photography, film, and computer animation. These examples show previous situations in which a new technology appeared poised to displace artists, but, in reality, provided new opportunities and roles for artists. I also discuss how procedural art and computer art employs automation. In so many of these fields, outsiders view the computer or the technology as doing the work of creativity. Yet, in each of these cases, the human artist or artists behind the work are the true authors of the work.

I argue that, throughout history, technology has expanded creative and professional opportunities for artists dramatically, by providing newer and more powerful tools for artists. The advent of new technologies often causes fears of displacement among traditional artists. In fact, these new tools ultimately enable new artistic styles and inject vitality into art forms that might otherwise grow stale. These new tools also make art more accessible to wider sections of society, both as creators and as consumers. These trends are particularly visible in the past two centuries since the Industrial Revolution.

2.1. How Photography Became an Artform

> *"From today, painting is dead!"*
>
> —Paul Delaroche, painter, at a demonstration of the daguerreotype in 1839[1]

For lessons from the past about AI and art, perhaps no invention is more significant than photography.[2] Prior to the invention of photography, realistic images of the world could only be produced by artists. In today's world, we are so swamped with images that it is hard to imagine just how special and unique it must have felt to see a skillfully-executed realistic painting (Figure 1a). The technical skills of realism were inseparable from other creative aspects. This changed when photography automated the task of producing images of the real world.

In 1839, the first two commercially-practical photographic processes were invented: Louis-Jacques-Mandé Daguerre's dagguereotype (Figure 1b), and William Henry Fox Talbot's negative-positive process. They were mainly presented as ways to produce practical records of the world. Of the two, the daguerreotype was more popular for several decades, because Talbot's process was restricted by patents. Improvements to Talbot's method eventually made the daguerreotype obsolete and evolved into modern film processes.

Portraiture was a main driver for early adoption. Then, as today, people enjoyed possessing pictures of their friends, loved-ones, and ancestors. Portrait painting was only available to aristocrats and the very wealthy. In the 18th century, several inexpensive alternatives were developed, such as the silhouette, a representation of an individual's outline (Figure 2a), typically hand-cut by an artisan out of black paper. The daguerreotype offered an economical way to create a realistic portrait (Figure 2b). It was very slow and required locking the subject's head in place with a head brace for several minutes, while the subject tightly gripped their chair, so as not to move their fingers. Nonetheless, numerous daguerreotype studios arose and became commonplace as technologies improved, and many portraitists switched to this new technology. Figure 3 shows one cartoon satirizing the situation for painters. By 1863, a painter-photographer named Henri Le Secq said "One knows that photography has harmed painting considerably, and has killed portraiture especially, once the livelihood of the artist." Photography largely replaced most older forms of portraiture, such as the silhouette, and no one seems to particularly regret this loss. As much as I appreciate the mystery and beauty of looking at old etchings and portraits, I would rather use my mobile phone camera for my own pictures than to try to paint them by hand.

Another early use for the daguerreotype was to produce souvenirs for tourists: by 1850, daguerreotypes of Roman ruins completely replaced the etchings and lithographs that tourists had previously purchased. As the technology improved, photography became indispensable as a source of records for engineering projects and disappearing architectural ruins, as well as for documentary purposes, such as Matthew Brady's photographs of the horrors of the American civil war.

---

1 The historical information from this section is distilled from two texts: Scharf (1968) and Rosenblum (1984).
2 This connection has been made previously (Agüera y Arcas 2017; Hertzmann 2001), but I explore it much more thoroughly here.

Figure 1. The interplay of painting and early photography. (**a**) By the 19th century, Western painters had achieved dazzling levels of realism. (**b**) Early cameras took low-quality (though evocative) pictures. This daguerreotype took over 10 minutes to expose. (**c**) However, camera technology steadily improved, capturing greater and greater realism, in much faster exposures. (**d**) This challenged painters to create works that were *not* about hyper-realistic depiction, such as Whistler's Tonalist *Nocturne*. (**e**) The Pictorialist photographers attempted to establish photography as an art form by mimicking the styles and abstraction of painting. **Works:** (**a**) *Ophelia*, John Everett Millais, 1851; (**b**) *Boulevard du Temple*, Daguerre, 1838; (**c**) *Portrait of Sarah Bernhardt*, Félix Tournachon (Nadar), 1864; (**d**) *Nocturne in Blue and Gold: Old Battersea Bridge*, James MacNeill Whistler, c. 1872–1875; (**e**) *Morning*, Clarence H. White, 1908. *Public domain images.*

"Is photography art?" This question was debated for many decades, coalescing into three main positions. Many people believed that photography could not be art, because it was made by a mechanical device rather than by human creativity. Many artists were dismissive of photography, and saw it as a threat to "real art." For example, the poet Charles Baudelaire wrote, in a review of the Salon of 1859: "If photography is allowed to supplement art in some of its functions, it will soon supplant or corrupt it altogether, thanks to the stupidity of the multitude which is its natural ally." A second view was that photography could be useful to real artists, such as for reference, but should not be considered as equal to drawing and painting. Finally, a third group, relating photography to established forms like etching and lithography, felt that photography could eventually be as significant an art form as painting.

(**a**) (**b**)

Figure 2. (**a**) A traditional silhouette portrait. (**b**) Daguerreotype portrait of Abraham Lincoln, 1846. Photographic techniques like this completely displaced previous portraiture techniques. *Public domain images.*

Figure 3. *The Unhappy Painter*, by Theodor Hosemann, 1843, satirizes the painter, a victim of progress, made obsolete by a daguerreotype. *Public domain image.*

Photography ultimately had a profound and unexpected effect on painting. Painters' mimetic abilities had been improving over the centuries. Many painters of the 19th century, such as the Pre-Raphaelites like John Everett Millais and Neoclassicists like Ingres, painted depictions of the world with dazzling realism, more than had ever been seen before. However, cameras became cheaper, lighter, and easier to use, and grew widespread among both amateurs and professionals (Figure 1c). Realistic photographs became commonplace by the end of the 19th century. If photorealism could be reduced to a mechanical process, then what is the artist's role?

This question drove painters away from visual realism toward different forms of abstraction. James McNeill Whistler's Tonalist movement created atmospheric, moody scenes (Figure 1d); he wrote: "The imitator is a poor kind of creature. If the man who paints only the tree, or the flower, or other surface he sees before him were an artist, the king of artists would be the photographer. It is for the artist to do something beyond this." The Impressionists, who sought to capture the perceptions of scenes, were likely influenced by the "imperfections" of early photographs. In contrast, Symbolists and post-Impressionist artists moved away from perceptual realism altogether. Edvard Munch wrote "I have no fear of photography as long as it cannot be used in heaven and in hell ... I am going to paint people who breathe, feel, love, and suffer." Vincent Van Gogh, describing his artistic breakthroughs around 1888, wrote to his brother: "You must boldly exaggerate the effects of either harmony or discord which colors produce. It is the same thing in drawing—accurate drawing, accurate color, is perhaps not the essential thing to aim at, because the reflection of reality in a mirror, if it could be caught, color and all, would not be a picture at all, no more than a photograph." Photography continued to influence modern art of the 20th century; one can infer a significant influence of Étienne-Jules Marey's multiple-exposure photography on Futurism and Cubism, e.g., in Duchamp's *Nude Descending A Staircase*.

It seems likely, in fact, that photography was one of the major catalysts of the Modern Art movement: its influence led to decades of vitality in the world of painting, as artists were both inspired by photographic images and pushed beyond realism.

Meanwhile, the Pictorialist movement, begun around 1885, was an attempt to firmly establish photography as an art form. Pictorialists introduced much more artistic control over the photographs, often using highly-posed subjects as in classical painting, and manipulating their images in the darkroom. Many of their works had a hazy, atmospheric look, similar to Tonalism, that softened the realism of high-quality photography (Figure 1e). They seemed to be deliberately mimicking the qualities of the fine art painting of the time, and today much of their work seems rather affected. They pursued various strategies toward legitimization of their work as an art form, such as the organization of photographic societies, periodicals, and juried photography exhibitions (Sternberger 2001). Their works and achievements made it harder and harder to deny the artistic contributions of photography; culminating in the "Buffalo Show", organized by Alfred Stieglitz at the Albright Gallery in Buffalo, NY, the first photography exhibition at an American art museum, in 1910. Photography was firmly established as an art, and free to move beyond the pretensions of Pictorialism.

This story provides several lessons that are directly relevant for AI as an artistic tool. At first, photography, like AI, was seen by many as non-artistic, because it was a mechanical process. Some saw photography as a threat and argued against its legitimacy. Photography did displace old technologies that had fulfilled non-artistic functions, such as portraiture's social function. Some artists enthusiastically embraced the new technology, and began to explore its potential. As the technology improved, and became more widespread over nearly a century, artists learned to better control and express themselves with the new technology, until there was no more real controversy over the status of photography. The new technology made image-making much more accessible to non-experts and hobbyists; today, everyone can experiment with photography. Furthermore, the new technology breathed new life into the old art form, provoking it toward greater abstraction. Wherever there is controversy in AI as an artistic tool, I predict the same trajectory. Eventually, new AI tools will be fully recognized as artists' tools; AI tools may stimulate traditional media as well, e.g., the New Aesthetic (Sterling 2012).

2.2. The Technology of Live-Action Cinema

The story of filmmaking and technology has important lessons about how artists and technologists can work together, each pushing the other further. Most of the early photographers were, by necessity, both artists and technologists, experimenting with new techniques driven by their art or to inspire their art. But, in film and animation, this interaction has been much more central to the art form.

The history of film is filled with artist-tinkerers, as well as teams of artists and technologists. The Lumière Brothers created one of the first films, a simple recording of workers leaving their factory (Figure 4a), but also experimented with a wide range of camera technologies, color processing, and artistic ways to use them. The stage magician George Méliès filmed fantastical stories like *A Trip to the Moon*, employing a wide range of clever in-camera tricks to create delightfully inventive and beguiling films (Figure 4b). Walt Disney employed and pushed new technologies of sound and color recording, and drove other innovations along the way, such as the multiplane camera. Many of Orson Welles' innovative film techniques were made possible by new camera lenses employed by his cinematographer Gregg Toland (Figure 4c). The introduction of more portable camera and audio equipment enabled the experiments of the French New Wave, who, in turn, influenced young American directors like Francis Ford Coppola and George Lucas. George Lucas' team for Star Wars was an early developer of many new visual effects on a shoestring budget (think of Ben Burtt hitting telephone guy-wires to create the "blaster" sound effect), as well as an early innovation in digital film editing and compositing (Rubin 2005). Digital and computer graphics technology, have, obviously, revolutionized film storytelling since then, with directors like Michel Gondry and James Cameron pushing the technology further into unforeseen directions. In each case, we see technologies rapidly adopted by directors to create new storytelling techniques and styles, transforming the medium over and over.

(**a**) (**b**) (**c**)

Figure 4. Technological developments in the art of filmmaking: (**a**) the first captured film, of workers leaving the Lumiere Brothers' factory (1895); (**b**) George Méliès' 1902 *A Trip to The Moon* filmed like a stage play but with fantastical special effects; (**c**) Citizen Kane, which used numerous experimental camera and lens effects to tell the story. *Public domain images.*

2.3. 3D Computer Animation: A Collaboration

3D computer animation as an artform was pioneered by Pixar Animation Studios, and that success is due to the close collaboration of artists and engineers (Price 2008). It all began with Ed Catmull, an animation enthusiast who received a PhD in computer science in 1974. In his thesis, he invented several core techniques that every major 3D computer graphics system uses today. During his time in graduate school, he quietly set a goal for himself: to make the world's first computer-animated film (Catmull and Wallace 2014). Consequently, he founded the Graphics Group at Lucasfilm Computer Division, and hired a team of brilliant engineers to invent computer systems to be used for film-making. However, none of this group could animate, that is, bring a character to life through movement. Hence, they recruited John Lasseter, an animator trained deeply in the Disney tradition. Through tight collaboration between Lasseter and the technical staff, they were able to invent new technologies and discover together how computer animation could start to become its own art form (Lasseter 1987). This group, led by Catmull and Alvy Ray Smith, spun out as Pixar, and, over the following years, invented numerous technical innovations aimed at answering the needs set out by Pixar's artists; in turn, the artists were inspired by these new tools, and pushed them to new extremes. One of their mantras was "Art challenges technology, technology inspires art" (Catmull and Wallace 2014).

Pixar, by design, treats artists and engineers both as crucial to the company's success and minimizes any barriers between the groups. When I worked there during a sabbatical, despite my technical role, I had many energizing conversations with different kinds of artists, attended many lectures on art and storytelling, sketched at an open life drawing session, watched a performance of an employee improv troupe, and participated in many other social and educational events that deliberately mixed people from different parts of the company. This is the culture that, though it still has some flaws to address, achieved so many years of technical and creative innovation, and, ultimately, commercial and artistic success.

Computer animation is another technology that scared traditional artists. In the early days before they found Lasseter, the Lucasfilm Graphics Group made many attempts to interest Disney animators in their work (Price 2008). Smith later said: "Animators were frightened of the computer. They felt that it was going to take their jobs away. We spent a lot of time telling people, 'No, it's just a tool—it doesn't do the creativity!' That misconception was everywhere" (Paik 2007). It is a common misconception that computer animation just amounts to the computer solving everything; a programmer presses a button and the characters just move on their own. In reality, computer animation is extraordinarily labor-intensive, requiring the skills of talented artists (especially animators) for almost every little detail. Character animation is an art form of extreme skill and talent, requiring laborious effort using the same fundamental skills of performance—of bringing a character to life through pure movement—as in conventional animation (Lasseter 1987).

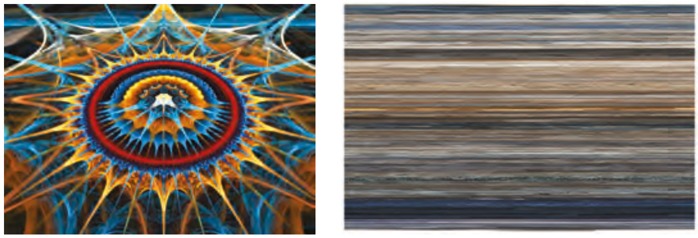
Traditional cel animation jobs did not last at Disney, for various reasons. Disney Feature Animation underwent a renaissance in the early 1990s, starting with *The Little Mermaid*. Then, following some changes in management, the Disney animation began a slow, sad decline. After releasing duds like *Brother Bear* and *Home on the Range*, management shut down all traditional 2D animation at Disney, and converted the studios entirely to 3D computer animation. Many conventional animators were retrained in 3D animation, but Disney's first 3D animation, *Chicken Little* was still a dud. Following Disney's acquisition of Pixar several years later, they revived Disney's beloved 2D animation productions. The result, a charming and enjoyable film called *The Princess and The Frog*, performed so-so at the box office, and, moreover, the animators' creative energy was focused on the newer 3D art form (Catmull and Wallace 2014). Today, traditional 2D animation at Disney is dead.[3] Today, computer animation is a thriving industry, and it thrives in many more places than cel animation ever did: at many different film studios, in visual effects for live-action films, in video games, television studios, web startups, independent web studios, and many more. There are now more types of opportunities for animators than ever before. The story here is not the destruction of jobs, but the evolution and growth of an art form through technology. This is another story that contradicts the popular notion of art and technology operating in conflict, when, in fact, the opposite is usually true.

2.4. Procedural Artwork

In the art world, there is a long tradition of procedural artwork. Jean Arp created artworks governed by laws of chance in the 1910s (or so he claimed), and, beginning in the 1950s, John Cage used random rules to compose music. The term "Generative Art" appears to have originated in the 1960s. Sol LeWitt's wall drawings are provided as lists of precise instructions; people are still drawing new versions of his paintings after his death (Cotter 2008). Starting in the 1970s, classically-trained painter Harold Cohen began exhibiting paintings generated by a program he wrote called AARON (Cohen 1995). Since the 1980s, many current artists, such as Karl Sims, Scott Snibbe, Golan Levin, Scott Draves, and Jason Salavon, create abstract artworks by writing computer programs that generate either static images, or create interactive artistic experiences and installation works (Figure 5). In Sims' and Draves' work, the artwork "evolves" according to audience input. The popularity of the Processing computer language for artists speaks to the growth of procedural art.

In each of these cases, despite the presence of procedural, emergent, and/or crowdsourced elements, the human behind it is credited as the author of the artwork, and it would seem perverse to suggest otherwise. The human has done all of the creative decision-making around the visual style, of designing a framework and process, of testing and evaluating alternative algorithms, and so on.

[3] Traditional animation styles are still vital in countries like Japan and France that, unlike America, do not believe that animation is "just for kids." Even so, their visual styles have evolved considerably due to computer technology.



(**a**) (**b**)

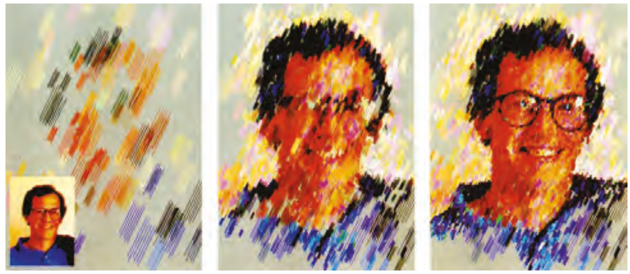
Figure 5. Procedural artworks in the fine art world of galleries and art museums. (**a**) *Electric Sheep*, by Scott Draves, evolves dazzling procedural abstract animations based on thousands of votes. *Creative Commons (CC-BY-3.0 US) image, "sheep" by BrothaLewis.* (**b**) *The Top Grossing Film of All Time*, 1 × 1 (2000) by Jason Salavon, shows the average color of each frame of the movie Titanic. *Used by permission of the artist.*

2.5. State of the Art in Computer Science Research

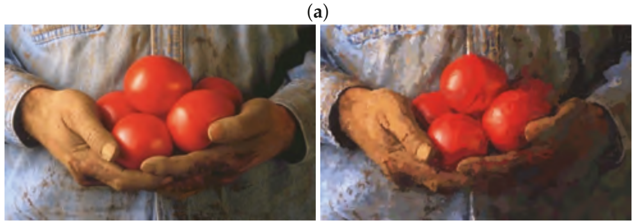
Recent developments in computational artistic image synthesis are quite spectacular. But they should not be mistaken for AI artists.

Non-Photorealistic Rendering (NPR) is a subfield of computer graphics research (Rosin and Collomosse 2013) that I have worked in for many years. NPR research develops new algorithms and artistic tools for creating images inspired by the look of a conventional media, such as painting or drawing. Paul Haeberli's groundbreaking 1990 paper (Haeberli 1990) introduced a paint program that began with a user-selected photograph. Whenever the user clicked on the canvas (initially blank), the system placed a brush stroke with color and orientation based on the photograph. In this way, a user could quickly create a simple painting without any particular technical skill (Figure 6a). In a follow-up paper, Pete Litwinowcz automated the process entirely, by placing brush strokes on a grid (Litwinowicz 1997). My own first research paper arose from experimenting with modifications to his algorithm: the method that I came up with creates long, curved strokes, beginning with large strokes that were then refined by small details (Hertzmann 1998) (Figure 6b). The algorithm was inspired by my experience with real painting, and the way artists often start from a rough sketch and then refine it.

This type of artistic algorithm design reflects the majority of computer graphics research in this area (Hertzmann 2003; Rosin and Collomosse 2013). The algorithms are automated, but we can explain in complete detail why the algorithm works and the intuitions about artistic process it embodies. This mathematical modeling of artistic representation continues the investigations begun in the Renaissance with Filippo Brunelleschi's invention of linear perspective, a viewpoint I have written about elsewhere (Hertzmann 2010).



(**a**)



(**b**)

Figure 6. Painterly rendering algorithms that process an input photograph, using hand-coded rules and algorithms. (**a**) Paul Haeberli's interactive painting system (Haeberli 1990). *Images used by permission of the ACM.* (**b**) My automatic painting system (Hertzmann 1998) processes a photograph without user input aside from selecting some parameter settings.

At some point, I found it very difficult to embody richer intuitions about artistic process into source code. Instead, inspired by recent results in computer vision (Efros and Leung 1999), I began to develop a method for working from examples. My collaborators and I published this method in 2001, calling it "Image Analogies" (Hertzmann et al. 2001). We presented the work as learning artistic style from example. But the "learning" here was quite shallow. It amounted to rearranging the pixels of the source artwork in a clever way, but not generalizing to radically new scenes or style (Figure 7). (A related style transfer method was published concurrently by Efros and Freeman (2001).) Since then, other researchers have improved the method substantially, making it much more robust (Fišer et al. 2016).

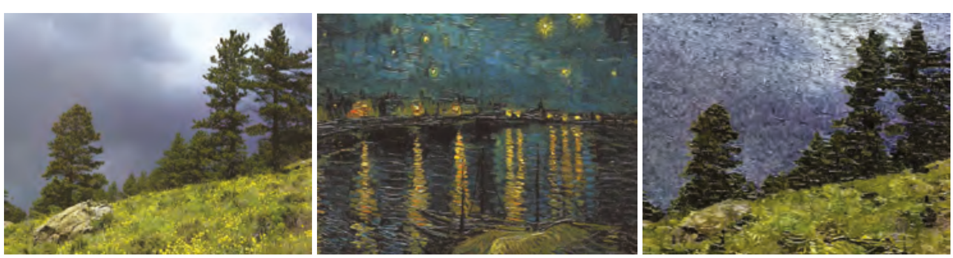


Figure 7. Our Image Analogies algorithm (Hertzmann et al. 2001), which stylizes a photograph in the style of a given artwork; in this case, Van Gogh's *Starry Night over the Rhône. Source photograph by John Shaw, used by permission; Van Gogh image in public domain.*

In 2016, Leon Gatys and his colleagues published a new breakthrough in this space, Neural Style Transfer (Gatys et al. 2016). Based on recent advances in neural networks, their method transfers certain neural network correlation statistics from a painting to a photograph, thus producing a new painting of the input photograph (Figure 8). The method is still "shallow" in a sense—there is no "understanding" of the photograph or the artwork—but the method seems to be more robust than the original Image Analogies algorithm. This paper led to a flurry of excitement and new applications, including the popular Prisma app and Facebook's Live Video stylization, as well as many new research papers improving upon these ideas. This work is ongoing today.

Figure 8. The Neural Style Transfer Algorithm (Gatys et al. 2016), which stylizes a photograph in the style of a given artwork; in this case, Van Gogh's *The Starry Night*. This algorithm has led to numerous new apps and research in stylization. *Van Gogh image in public domain; images by Leon Gatys, used by permission.*

Another development which received considerable attention in 2015 was the invention of DeepDreams by Mordvintsev et al. (2015), who, developing a visualization tool for neural networks, discovered that a simple activation excitation procedure produced striking, hallucinatory imagery of a type we had never seen before. There are many other current projects, particularly those around Generative Adversarial Networks (Goodfellow et al. 2014) and Project Magenta at Google (Metz 2017), that also show promise as new artistic tools. For example, Figure 9 shows images that we generated by visualizing trends learned by a neural network from a large collection of artistic images in different styles. A variety of related images are produced by Creative Adversarial Networks (Elgammal et al. 2017); it is a visual style that seems familiar but not the same as what we are familiar with (and is probably driven, in part, by the biases of the convolutional neural network representation).

In each of these cases, the artworks are produced by a human-defined procedure, and the human is the author of the imagery.

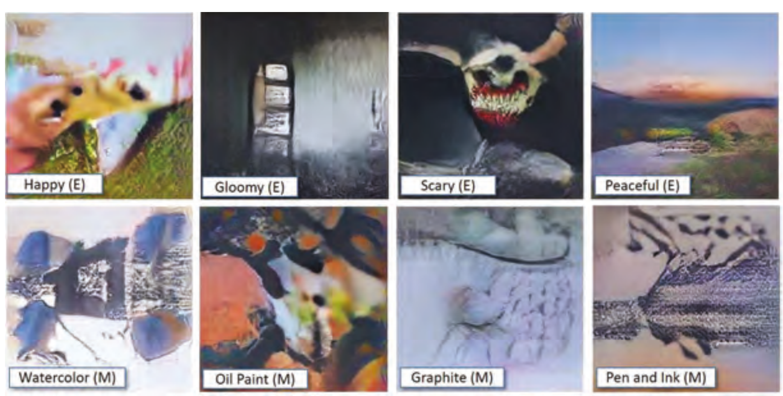


Figure 9. Images that we generated using a neural network trained on different subsets of a database of artistic imagery (Wilber et al. 2017). Each one is meant to typify a single stylistic category or a medium, though the biases of the convolutional neural network architecture are also evident.

2.6. *Artificial Intelligence is Not Intelligent*

Unfortunately, there has been a considerable amount of media hype around AI techniques. In the news media, algorithms are often anthropomorphized, as if they have the same consciousness as humans (e.g., (Wilson 2017)), and sometimes they are described as artists (Dvorsky 2017; Perez 2018; Pogue 2018). In fact, we do not really know what consciousness is (despite many theories), or what it would mean to embody it in an algorithm.

Today, the most-successful AI and machine learning algorithms are best thought of as glorified data-fitting procedures (Brooks 2017). That is, these algorithms are basically like fitting a curve to a set of datapoints, except with very sophisticated ways to fit high-dimensional curves to millions of datapoints. When we as researchers speak of "training" an algorithm, or an algorithm that "learns", it is easy to misinterpret this as being the same thing as human learning. But these words mean quite different things in the two contexts. In general, "training" a model to learn a task involves careful human effort to formulate the problem, acquire appropriate data, and test different formulations. It is laborious and requires considerable expertise and experimentation. When a new task needs to be solved, the human starts over.

Compared to human intelligence, these algorithms are brittle and bespoke. For example, image recognition algorithms have undergone breathtaking breakthroughs in the past decade, and are now widely used in consumer products. Yet they often fail on inputs that suggest bizarre misunderstandings; the existence and robustness of adversarial examples (Szegedy et al. 2014) and procedurally-evolved images (Nguyen et al. 2016) demonstrates that these algorithms have not really learned anything like human-level understanding. They are like tourists in a foreign country that can repeat and combine phrases from the phrasebook, but not truly understand the foreign language or culture. These systems have no autonomy except within the narrow scope for which they were trained, and typically fail-safes must be put in place as well, e.g., Google Photos no longer classifies anything as a "gorilla" because of one high-profile failure (Simonite 2018).

There are some fascinating parallels between human learning and machine learning, and it does seem likely that humans are, in some way, optimized by evolutionary principles (Alexander 1996; Gopnik and Wellman 2012; Koerding and Wolpert 2006; Tenenbaum et al. 2011). But going from these high-level analogies to actual machine intelligence is a problem for which the solution is not even on the horizon.

3. How Technology Changes Art

Based on this history, I now make several specific claims about how technology changes art. Far from replacing artists, new technologies become new tools for artists, invigorating and changing art and culture. These claims apply equally to current developments in AI as they did to previous developments like photography and animation.

3.1. Algorithms Are Artists' Tools

> *"my watercolor teacher used to say: let the medium do it. true that—so my sketch provides the foundation and then the network does it thing; i don't fight, just constantly tweak the #brushGAN toolkit."*
>
> —Helena Sarin (@glagolista)

In every technology that we currently employ—whether photography, film, or software algorithm—the technologies and algorithms we use are basic tools, just like brushes and paint.[4] The same is true for the new AI-based algorithms that are appearing. They are not always predictable, and the results are often surprising and delightful—but the same could be said for the way watercolor

4 This view reflects, I think, the conventional wisdom in the computer graphics research field, which is my research background. This field has always had close ties with certain artistic communities, especially computer animation and visual effects, and, based on this experience, the field is often resistant to attempts to automate creative tasks. In contrast, artificial intelligence researchers use terminology much more aspirationally, historically using words like "intelligence," "learning," and "expert systems" in ways that are far simpler than the human versions of these things.

flows on the page. There is no plausible sense in which current systems reflect “true” artificial intelligence: there is always a human behind the artwork.

Applying the same standard to the current research in neural networks and neural style transfer, it would seem equally perverse to assign authorship of their outputs to the software itself. The DeepDream software was authored by a human; another human then selected an input image, and experimented with many parameter settings, running the software over and over until good results were obtained. Indeed, in a recent art exhibition meant to promote these methods and their exploration (Tyka 2016), human artists were credited for each of the individual works.

The same process of selection of tools and inputs, adjusting settings and even modifying code, and iterating until a desirable output is produced, occurs in all current and foreseeable computer artworks. Computer-generated artworks result from considerable time and effort from human artists, from conception of the idea, to painstakingly guiding the execution, to selecting from among the outputs.

There have been a few cases where AI algorithms have been presented as artists or potential artists (Colton 2012; Dvorsky 2017; Perez 2018; Pogue 2018; Shein 2017). For the above reasons, I think this claim misunderstands the nature of procedural art.

In short, in our present understanding, *all art algorithms, including methods based on machine learning, are tools for artists; they are not themselves artists*.

3.2. New Technology Helps Art Stay Vital

Rather than being afraid of the new technologies, we should be enthusiastic about the new artworks that they will enable artists to produce. When we think of art as having external influences, we normally think of social or political influences, but ignore the effect of new tools. In contrast, I argue that, especially from the 19th century onwards, technological developments have played a pivotal role in advancing art, in keeping it vital and injecting fresh ideas. The stories I gave of photography and cinema include many examples of this. However, the effect is far more widespread.

One of the most important breakthroughs in the history of Western art was the invention of oil paint by Flemish painters such as Jan van Eyck in the 15th century (de la Croix et al. 1991). Previously, painting had been done primarily with tempera, which lacks subtle coloration, and fresco, which was very cumbersome to work with. Oil paint had existed in some form for centuries, but van Eyck and others found new techniques that gave them a very practical new medium. It was fast-drying and allowed rich colors and tones, sharp edges, and hard surfaces. The rich light and color that we associate with the Northern Renaissance and the Italian Renaissance are due to this technology (Figure 10).

In each decade since the 1950s, many of our culturally-important works used technology that had only been invented within the previous 10 years. For example, most technology used in today’s feature films did not exist 10 years ago (e.g., widespread use of HD digital cameras; facial performance capture); the same goes for artworks using smartphones and crowdsourcing; artworks involving white LEDs and Arduino controllers; DJs performing on stage behind their laptops; and so on. Even the most vérité-seeming romantic comedies frequently involve recent digital video editing and digital backdrops.

Conversely, artistic styles that fail to change become stale and lose their cultural relevance; the adoption and exploration of new technology is one of the ways that art stays vibrant. For example, the introduction of synthesizer music into 1980s pop music created a new sound that was exciting and modern. The sound diversified as the tools improved, until grunge became popular and made the 1980s synthpop sound seem superficial and old-fashioned. Nowadays, a recent revival of 1970s and 1980s instruments by bands like Daft Punk and LCD Soundsystem seems most exciting at times when they are creating new types of music using old instruments. In contrast, the swing music revival of the 1990s never went anywhere (from bands like Big Bad Voodoo Daddy and Squirrel Nut Zippers) in my opinion, because the bands mimicked classic styles with classic instruments, without inventing anything particularly original themselves.

(**a**) (**b**)

Figure 10. The development of the oil painting technology changed painting as an art form. (**a**) Fresco painting by Michaelangelo on the Sistine Chapel (ca. 1508). The fresco process was difficult and achieved limited tonal range. Today, fresco is defunct as a medium. (**b**) Oil painting by Jan van Eyck for the Ghent Alterpiece (ca. 1430). Much richer colors and lighting are possible with oil paint. *Public domain images.*

In each era, radical technological innovations are met by artists with both enthusiasm and rejection. For example, when the Moog synthesizer became popular, it was adopted by big-name bands like Emerson, Lake, and Palmer. Other bands felt that twisting knobs to make music was “cheating”: Queen’s album covers proudly state that the band did not use synthesizers. Robert Moog described one New York musician who said of the instrument “This is the end of the world” (Snowden 2012). It now seems silly to imagine that people might have ever categorically objected to synthesized music, or to the scratching and sampling of hip-hop DJs, just as it now seems silly that people once rejected waltzing, the Impressionists, and the Rite of Spring as invalid or immoral.

In addition to stimulating professional artists, new tools make art more accessible to larger portions of society. Photography was once accessible only to the most determined early adopters, but has continually become easier, faster, and more compact, to the point where nearly everyone carries a mobile phone camera in their pocket or purse. The same goes for the tools of cinematography (from hand-cranked to heavy cameras to Steadicams to handycams to iPhones), and so on. Modern computers give nearly everyone access to digital equivalents of darkrooms, mixing studios, painting studios, and so on; these were formerly highly-specialized technologies requiring laborious effort.

3.3. New Technology Does Not Cause Net Unemployment

Concerns of how technology displaces jobs have been around since at least the 19th century, when Luddite protesters destroyed mechanical weaving machines, and, in folk songs, John Henry competed against a steam drilling machine. These fears are real and understandable. Yet, despite centuries of technological disruption, we do not live in a world of massive unemployment. This is because, as old roles are erased, many more arise in their stead. But these fears keep recurring, because, at any given time, it is easy to imagine losing specific jobs but it requires superhuman imagination to forecast what new opportunities will be created by transformative new technologies. Nowadays, most of us do jobs that would be hard to explain to a 19th century worker.

The real workforce concerns should not be about the technology itself, but about whether the economic system shares the benefits of new productivity fairly across society versus concentrating wealth only among the very richest (Stiglitz 2012) and whether machine learning systems are misused to magnify existing forms of inequality (O’Neil 2016). When displacements due to new technology occur, their effects can be eased by social safety nets and better educational foundations (for employment flexibility and retraining). Conversely, a society which fails to distribute wealth and economic gains fairly has much bigger problems than just the impact of AI.

Fears of new technology seem to be human nature. I suspect many people view the "normal" state of things as being how they were when they came of age, and they view any significant change as scary. Yet, nearly all of our familiar modern technologies were viewed as threatening by some previous generation.

The fear of human-created life has been with us for a long time. Notably, 18th-century scientists discovered electricity. As they searched to understand it, they discovered the life-like effect of galvanism, that the muscles of dead frogs could be stimulated by electrical currents. Had the secret of life been discovered? This inspired Mary Shelley's novel *Frankenstein; or The Modern Prometheus*, in which an ambitious university student uses modern science to create new life (Shelley 1818). Today, the story is vivid and evocative, but, intellectually, we recognize it as preposterous. The fear of AI is essentially the same irrational fear; SkyNet is Frankenstein's monster, but with neural networks as the Promethean spark instead of galvanism.[5] At present, the Terminator's autonomous AI is only slightly more plausible than its ability to travel backwards in time.

3.4. New AI Will Be New Tools for Artists

Some general trends around the evolution of technology and art seem quite robust. As discussed above, current AI algorithms are not autonomous creators, and will not be in the foreseeable future. They are still just tools, ready for artists to explore and exploit. New developments in these tools will be enthusiastically adopted by some artists, leading to exciting new forms and styles that we cannot currently foresee. Novices will have access to new simplified tools for expression. It is possible that some tasks performed by human artists will fade out, but these will generally be mechanical tasks that do not require much creativity because they fill societal functions other than artistic expression. Some traditional arts may fade simply due to seeming old-fashioned. This is the nature of art: nothing is fresh forever, which is not to be blamed on technology. Artistic technology is an "imagination amplifier" (Cohen 2000) and better technology will allow artists to see even further than before.

Aside from general trends, it is hard to make specific predictions about the art of the future. Les Paul, who invented the solid-body guitar in the 1940s (Figure 11, himself primarily performed light pop, country, and showtunes, and could hardly have predicted how the electric guitar would be used by, say, Led Zeppelin, just as it is hard to imagine Daguerre predicting Instagram. More generally, making predictions about how AI technologies might transform society is very hard because we have so little understanding of what these technologies might actually be (Brooks 2017). Even the science fiction writers of the 1950s and 1960s completely failed to imagine the transformative power of the Internet and mobile computing (Krauss 2017); for them, the computers of the future would still be room-scale monstrosities that one had to sit in front of to operate. But they did predict moon colonies and replicants by 2018.

---

[5] In fact, *Frankenstein* is presented as a cautionary tale about the quest for knowledge in general. Victor Frankenstein tells his story as a warning when he learns that Captain Walton is himself driven by an obsessive quest for knowledge that is entirely unrelated to Frankenstein's.

Figure 11. Les Paul, inventor of the solid-body electric guitar in 1943. His technology transformed popular music in ways they could not have foreseen. *Public domain image.*

In short, we cannot predict what new inventions and ideas artists will come up with in the future, but we can predict that they will be amazing, and they will be amazing because they make use of technology in new, unpredictable ways.

4. What Is an Artist?

So far, I have described how computer technologies are currently accepted as tools for artists, not as artists themselves. Why is this? After all, computers can do other human tasks like speak, search, print, navigate, and, to some extent, drive cars. There are several obvious reasons why computers do not make art, including tradition, the incentives involved, and the relatively predictable nature of existing automation. But, still one could imagine an alternate history in which some machines or computer programs had already been called artists. I believe there is a more fundamental reason, which explains not just why this has not happened, but why it is unlikely to happen anytime soon.

In this section, I theorize about the prerequisites for an entity being an artist, focusing on my hypothesis that art is a social behavior. I will then apply this idea to AI in the next section. I also explore several alternative hypotheses for what could make an AI as an artist. Most of these alternative hypotheses identify some attribute of human artists, and then hypothesize that that attribute is needed for an AI to be an artist.

4.1. Art Is Social

> *"What an artist is trying to do for people is bring them closer to something, because of course art is about sharing: you wouldn't be an artist if you didn't want to share an experience, a thought."*
>
> —David Hockney (Hockney 1996)

Why do we create and consume art? I argue that art is primarily a social behavior: art is about communication and displays between people. For example, people often speak of art as being about personal expression, which is an act of communication.

Any human can make art, because humans are social creatures. A painter cranking out the same conventional landscapes for tourists year after year is still considered an artist. A child's drawing might only be interesting to their family, but it is still art.

I am directly inspired by the theory, going back to Charles Darwin, that art-making is an adaptive product of our biological evolution. Dutton (2009) sets out a persuasive argument for this theory, which I briefly summarize, though I cannot do it justice. Creating art served several functions for our Pleistocene ancestors. Art-making served as a fitness signal for mating and sexual selection. Art can also be used as a display of wealth and status. Storytelling, music, and dance strengthen social bonds within a group. Storytelling additionally plays a very important role of communicating information that would otherwise be hard to share.

I observe that each of these functions of art is *social*: art arose as forms of communication, displays, and sharing between people. Although art takes many different forms in different cultures today, each of these forms serves one or more of the same basic social functions that it did in the Pleistocene.

I generalize this theory beyond humans to hypothesize: *art is an interaction between social agents.* A "social agent" is anything that has a status akin to personhood; someone worthy of empathy and ethical consideration. Many of our other behaviors are interactions between social agents, such as gifts, conversation, and social relationships like friendship, competition, and romance.

In contrast, while we can get emotionally attached to our computers and other possessions, we feel no real empathy for their needs, and no ethical duty toward them. Possessions can participate only in shallow versions of these interactions. For example, we frequently talk about our possessions with statements like "The brakes on my bicycle were complaining so I gave it a new pair as a gift and now it's much happier. I love my bike." This statement indicates emotional attachment but not true empathy with the bike's feelings, despite the anthropomorphizing language. We do not live in a social hierarchy with our possessions: we do not compete with them for status, or try to impress them. We care about what other people have to say because we care about other people; we care about what computers have to say only insofar as it is useful to us. We generally treat conversational agents (like Siri and Alexa) as user interfaces to software, not like people.

Art-making does also have non-social benefits to the artist. For example, art-making can help practice skills like dexterity and problem solving. Creating art is often pleasurable or meditative in itself. But these benefits are secondary to their social benefits: they are not the reasons that evolution has produced art as a human activity. Similarly, one may also talk or sing to oneself while alone, but talking and singing are still fundamentally social activities.

Note that the evolutionary argument here is optional; one can discuss whether art is fundamentally social without it. But I believe that the evolutionary view of art gives some additional understanding.

4.2. Non-Human Authors

As we have seen, despite many technological advances, current algorithms are not accepted as artists. There are a few other existing examples where objects are created by authors or processes that are not human-driven. These give some support to this theory.

Natural processes. Natural processes, including landscapes like the Grand Canyon or the HuangShan Mountains, are not considered art, even though they may be extraordinarily beautiful and change one's perspective immensely. Beautiful structures made instinctively by animals, such as honeycombs and coral, are not considered art. This indicates that simply creating complex and beautiful outputs is not itself sufficient for art, since there is no creative social communication in these cases.

Animals. Some higher mammals, including chimpanzees, elephants, and dolphins, have been trained to paint (Desmond 2016; Dutton 2009). Many writers are skeptical of animal-made art. Typically, the animal's owner or handler steers the process, letting the animal throw paint on the canvas, then stopping the painting when they believe it is done, then selecting which works to show; the animals seem to show no interest in the artwork afterward. Animal artwork has not had any significant cultural impact or popularity; it seems to have been largely the product of media stunts. (People for the Ethical Treatment of Animals have recently tried to claim copyright in favor of a monkey, but failed (Millward 2017), as US copyright law only allows humans to claim copyright.)

The most interesting aspect of this discussion is not whether animals can create art, but *how we decide.* Discussions of whether animal-made artifacts are art are not based on *a priori* rules whether animals can be artists. Instead, they are attempts to study the evidence of the animal's behavior around the artwork, and, from that, to infer whether the artwork is some form of inner expression (Desmond 2016), or an artifact that the animal has a special appreciation for (Dutton 2009). In other words, we are open to the idea of animals creating art, because they can have social relationships with us. It is just that we have not found any other creature that satisfies our criteria for creating art, whatever they are.

4.3. Judging the Work Instead

It is tempting to judge whether a computer is an artist based solely on the merits of the work that it produces. In this hypothesis, whether or not a computer can be an artist is a judgement of the quality of the work that it produces, independent of the properties of the computer itself. If an algorithm outputs a continual stream of diverse, stimulating, beautiful, and/or skillful outputs, without many duds, we might be quite tempted to call this algorithm an artist. The better computer-generated art becomes, the more we will hear questions about whether computers are artists.

Skill is clearly not the real requirement for someone or something to be an artist. Any human can make art, including unskilled amateurs and children. Conversely, computers can already be programmed to create infinite sequences of dazzling realistic or abstract imagery, exhibiting technical proficiency way beyond the typical human capacity.

I suspect that, when we look at a computer's output and ask "is this work good enough to call the computer an artist?", we are not actually judging the quality of the work *per se*. Instead, we are really looking for evidence that the system itself is intelligent, conscious, and feeling: traits that we associate with social agents. No matter how skillful and surprising a computer's output is, we will not accept it as an artist until we infer some sort of social being inside.

4.4. An Intent Machine

Another hypothesis is as follows: in the modern art world, the role of the artist is to supply the "intent" and the "idea" for the work; it is not necessary for the artist to execute on the work, other than coordinating in its production. For humans, this is clearly true in numerous examples, such as those in Section 2.4, as well as appropriation works like Duchamp's Readymades and Richard Prince's questionable Instagram reproductions; artists can also employ helpers or crowdworkers, such as in Scott Draves' *Electric Sheep* and Aaron Koblin's *Sheep Market* (Koblin 2009). Consequently, for a computer to be an artist it simply needs to supply an intent.

It is easy to imagine designing a system that creates intent and even coordinates the labor of producing a work. For example, one could write a simple procedural algorithm to generate very basic intents (e.g., "portray ominous landscape"), or sample intents from a Recursive Neural Network trained on artists' statements scraped from the web. Or the method could randomly select some news item, photograph, or historical event, and randomly sample some attitude toward that thing. Starting from this intent, crowdworkers could be used to refine the idea and convert it into a new image, similar to systems like Soylent (Bernstein et al. 2015). One could also automate steps of the process, e.g., using GANs (Goodfellow et al. 2014) to generate entirely new starting images from scratch. Crowdworkers could also be used to rate and evaluate the outputs of the system, selecting just the best results and discarding the rest. Final steps of the process could also automatically hire professional designers, e.g., from sites like Upwork or 99Designs. This system could then run continuously, generating new images over time (with payment being automatically made to the crowdworkers involved). Workers could group images with common themes and intents, and create separate collections around these themes. Artists' statements could be generated around these themes. The system's preferences could grow and adapt over time as more data are gathered or external data streams (e.g., photography blogs) change.

Suppose someone were to build this system, calling it, say, The Intent Machine, and exhibits its work in an art show or gallery. Suppose, moreover, they convinced the curator or gallery owner to credit The Intent Machine with authorship of the works it had created, but fully disclosed the procedure by which it worked. Would people credit it as the artist who had authored its works, or would they say that the system-builder is the real artist here?

I believe that, in general, the consensus would be that the system-builder is the real artist here, and that this is really an artwork about probing the nature of computer-generated art, or the nature of the commercial artworld. Note that the procedure used to define the system is not fundamentally different than any other procedural computer-generated art algorithm (as in Sections 2.4 and 2.5). Even if the work itself ended up being quite good, viewers would ask why it is good, and it is doubtful that the computer's own contribution would be judged as significant beyond those of the humans involved.

Are artists just "intent machines"? If art is a social act, then the answer is no.

4.5. Creativity, Growth, Responsiveness, and so on

Finally, three related criteria that have intuitive appeal are the notions of creativity, growth, and responsiveness. They are important for human artists, so perhaps they should be for AI artists as well.

Several authors have proposed energy terms or criteria for *creativity* (Elgammal et al. 2017; Nguyen et al. 2016). These are often attempts to express the idea that the system's output should somehow "surpass" the human programmer and/or the training data. For example, Colton (2008) proposes that we judge the creativity of a system, in part, by whether the system's output *surprises* the system's author. I believe that this is too weak a criterion, since many mechanical or algorithmic phenomena may be surprising to their own discoverer or author at first. For example, the basic algorithm that produces Mandelbrot set images can be specified in a single sentence,[6] yet produces dazzling animations of infinite complexity.[7] The Mandelbrot set is very surprising and produces beautiful, unprecedented images, but we do not call its iteration equation creative, or an artist.

All current procedural art systems, such as the Mandelbrot set, have a recognizable style, and, after awhile, lose their novelty. I believe that the same will be true for systems specifically designed with "creativity" objectives (Elgammal et al. 2017; Nguyen et al. 2016). Unlike human artists, these systems do not grow or evolve over time.

Perhaps an AI artist would need to exhibit some form of *growth.* For example, Harold Cohen, the fine-art painter who began, in 1968, to write software to generate art, described the evolution of his views: "Ten years after [1968], I would have said 'look, the program is doing this on its own' . . . Another ten years on and I would have said 'the fact that the program is doing this on its own is the central issue here,' denoting my belief in the program's potential and growing autonomy over the whole business of art-making . . . It was producing complex images of a high quality and I could have had it go on forever without rewriting a single line of code. How much more autonomous than that can one get? . . . [But] it's virtually impossible to imagine a human being in a similar position. The human artist is modified in the act of making art. For the program to have been similarly self-modifying would have required not merely that it be capable of assessing its own output but that it had its own modifiable worldview . . . " (Cohen 2014).

In any existing system, it is easy to think of trivial ways for the system to evolve and change over time, e.g., subtly change the color palette or the training data over the years. Superficial growth is easy; meaningful growth is hard to even define for a computer AI. If someone could design a system that produces a sequence of art that is meaningful to people and also significantly evolves over time, that would be truly remarkable. Another missing piece from current systems is an artists' ability to *respond* meaningfully to their culture, experiences, world events, responses to their work, and other aspects of their environment. It seems hard to imagine achieving these goals without enormous technological advances—they may not be possible without true AI or social AI in some form.

4.6. Definitions of Art

For guidance about the nature of art, we could have also looked to existing definitions of art. However, there is no Royal Society that prescribes what is and what is not valid art. Instead, art is a

6 Color the image location (x, y) proportional to the number of steps the iteration $z_{n+1} = z_n^2 + x + yi$ requires to reach $|z| \geq \tau$, starting from $z_1 = 0$, where τ is a large constant.

7 For example: https://www.youtube.com/watch?v=PD2XgQOyCCk.

phenomenon that results from the interplay of cultural institutions and the general population that we can analyze, and it changes over time. Philosophers have attempted to devise concise definitions of art that include all existing types (music, dance, painting, etc.) and styles of art. The Institutional Definition, originated in the 1960s in response to conceptual art, states, roughly, that art is anything in a style that is broadly accepted as art (Danto 1964; Dickie 1969; Levinson 1979). A more fine-grained approach is to identify attributes common to many different types of art (Dutton 2000 2009; Gaut 2000 2005). Each of these definitions of art is an attempt to fit the data, and draw a line between those things that we call art (like theatre) and those that we do not (like spectator sports). Understandably, these definitions all assume that the artist is always human, without exploring much whether non-humans can create art, and thus do not provide much guidance for this discussion.

4.7. Attribute Theories in General

Many of the theories in this section have the following recipe: identify some attributes of human artists, and then hypothesize that AIs with these attributes will be considered artists. Artists make high-quality work; artists supply intent; artists are creative; artists grow.

The development of Cohen's thinking illustrates this. Cohen initially thought that a machine that makes high-quality art could be considered an artist. The more he observed his own software, the more something seemed to be missing. He noted that human artists grow over time, and his system did not. If he had added some form of "growth" to his system, would it then be an artist?

Maybe someday someone will develop a system with enough of these attributes to cross some intangible threshold and thus be perceived as an artist. However, it seems very hard to reason concretely about this possibility. How do we define any of these attributes precisely? How much is enough?

Furthermore, many of these attributes are not really required of human artists. Any human can make art, even if it is not very original or surprising; the artist need not grow noticeably or respond to culture or feedback. We do judge the work by these attributes, but there is no minimum requirement for humans to make art.

In contrast, the social theory makes a much more concrete statement. Art is fundamentally a social interaction, and thus can only be made by social agents. The social theory has the additional appeal of being based on a plausible evolutionary hypothesis for the reasons we create art.

5. Will an AI Ever Be an Artist?

With this background, I now turn to speculating about the future. As we have seen, authorship of all current algorithmic art is assigned to the human author behind the algorithms. Will we ever say that an AI itself created art? Will we ever recognize a piece of software as the author of a work of art?

Human-Level AI. If we ever develop AI with human-level intelligence and consciousness, by definition, it would be able to create art, since it would have the same capacity for consciousness, emotions, and social relationships. But, as discussed in Section 2.6, this scenario is science fiction and we have no idea if this is possible or how it would be achieved. Making meaningful predictions about a world with "true AI" is impossible (Brooks 2017), because we have so little idea of how specifically this AI would actually operate. Moreover, this AI would transform society so much as to make it unrecognizable to us. We may as well speculate about what kind of artwork is made by aliens from outer-space—if do we ever meet them, we will have more pressing questions than what kind of music they like.

Hence, the interesting question is whether there could be computer-authored artwork *without* human-level intelligence or consciousness.

Social AI. If, as I have argued, creating art is a fundamentally social act of expression and communication, then it follows that *AI can be granted authorship when we view the AI as a social agent, and it is performing some communication or sharing through art.*

What does it mean for us to view an AI as a social agent? We have to view the AI as deserving of empathy and ethical consideration in some way. However, the AI does not need human-level intelligence, just as we have social relationships with our pets. But we do expect that the AI has something to say socially, something that suggests an inner consciousness and feeling.

Short of true intelligence (the science fiction scenario), I think that the only way this can happen is through "shallow AI" agents. People are sometimes "fooled" by shallow AI. The classic example is Eliza, a simple text-based "psychiatrist" program developed in 1964, based on simple pattern-matching and repetition of what the user types (Weizenbaum 1966). It was meant as a demonstration of the superficiality of the AIs of the time, but, unexpectedly, many people attributed human-like emotions to the machine. Since then, there are many anecdotes of people being fooled by "chatbots" in online settings (Dvorsky 2016; Epstein 2007), including the recent plague of Twitter bots (Kessler 2014). But, once the veil is lifted, it is clear that these chatbots do not exhibit real intelligence.

Some software and robots have been designed to have relationships with their owners, including talking dolls, Tamagotchi, and Paro therapeutic baby seals. A related effect is that people behave toward their computers as if they were social agents in certain ways (Reeves and Nass 1996), even when they do not believe that they are intelligent. For example, dialogue systems like Siri and Alexa all use female voices by default, based on many findings that male and female users both respond better to female voices (Griggs 2011; Reeves and Nass 1996).

Perhaps, for many users, the system does not need to be truly intelligent, it just has to be *perceived* as a social agent, like a Siri or Alexa that you can ask to make you an artwork (Xu et al. 2017). The day may come in which these agents are so integrated into our daily lives that we forget that they are carefully-designed software. One can easily imagine the development of AI that simulates emotion and affection toward the user; it is easy to imagine, for example, a toy doll that paints pictures for its owner, as one of many behaviors designed to display companionship and affection.

Non-social AI. It seems possible that non-social algorithms could be successfully promoted as artists; there have been a few tentative forays in this direction, e.g., (Colton 2012; Elgammal et al. 2017). For the reasons given above, I am skeptical that such methods will be accepted as true artists without some plausible belief about their underlying social and/or conscious attributes.

Perhaps a curator at a well-known museum would download or otherwise acquire various artifacts from software "artists", and list the software systems as the authors. There would be controversy, and discussion in newspapers and journals. Perhaps other curators and galleries would follow suit. Perhaps people would find enough value in these computer-generated artworks, while also being convinced that no human could be rightly given credit for their works. This sort of process has happened for things like abstract expressionism, and not for chimpanzee art. Could it happen for computer art?

Suitcase words. The term "artist" could come to be used as having multiple meanings, just as words like "intelligence" and "learning" have come to mean something different for humans than they do for algorithms (Brooks 2017). A software program that, say, automatically stylizes your photos, could be called an "artist" in the same way that software applications like "calendar" and "mail" programs have replaced their physical-world namesakes. Unfortunately, the use of the same word to mean different things in different contexts causes endless confusion, as discussed in Section 2.6.

Dangers. A continual danger of new AI technology is that human users misunderstand the nature of the AI (O'Neil 2016). When we call a shallow AI an "artist", we risk seriously misleading or lying to people. I believe that, if you convince people that an AI is an artist, then they will also falsely attribute emotions, feelings, and ethical weight to that AI. If this is true, I would argue that calling such AIs "artists" is unethical. It leads to all sorts of dangers, including overselling the competence and abilities of the AI, to misleading people about the nature of art.

It seems likely that some companies will not have any scruples about this. For example, Hanson Robotics has promoted (in many contexts) a social robot as a truly intelligent being, even though it is clearly nothing more than a "chatbot with a face" (Gershgorn 2017) or, in Yann LeCun's words, a "Potemkin AI" (Vincent 2018).

A related concern is that we deprive the AI's designer(s) of authorship credit. At present, we credit the author of a piece of automatic software with the output of that software. This usually acknowledges the skill and effort required to engineer and iterate with software so that it produces good outputs. Artistic credit is important for understanding the real sources of how something was made.

Outside of science fiction, I can see no positive benefit to calling a computer an artist, but I do see dangers.

6. Conclusions

I do not believe that any software system in our current understanding could be called an "artist". Art is a social activity. I mean this as a warning against misleading oneself and others about the nature of art. Of course, the ambitious reader could take this as a challenge: I have laid out some of the serious objections that you must overcome if you wish to create a software "artist." I do not think it can be done anytime soon, but I also know that proving critics wrong is one of the ways that art and science advance.

One of my main goals in this essay has been to highlight the degree to which technology contributes to art, rather than being antagonistic. We are lucky to be alive at a time when artists can explore ever-more-powerful tools. Every time I see an artist create something wonderful with new technology, I get a little thrill: it feels like a new art form evolving. Danny Rosin's *Wooden Mirror*, Jason Salavon's *The Top Grossing Film of All Time*, 1 × 1, Bob Sabiston's *Snack and Drink*, Michel Gondry's *Like A Rolling Stone*, Kutiman's *ThruYOU*, Amon Tobin's *Permutation*, Ian Bogost's *Cow Clicker*, Christian Marclay's video installations, Íñigo Quilez's procedural renderings, and Wesley Allsbrook's and Goro Fujita's Virtual Reality paintings are a few examples of artworks that have affected me this way over the years. Today, through GitHub and Twitter, there is an extremely fast interplay between machine learning researchers and artists; it seems like, every day, we see new tinkerers and artists Tweeting their latest creative experiments with RNNs and GANs (e.g., @JanelleCShane, @helena, @christophrhesse, @quasimondo, @DrBeef_).

Art maintains its vitality through continual innovation, and technology is one of the main engines of that innovation. Occasionally, the avant garde has tremendous cultural impact: electronic music and sampling was once the domain of experimental electronic and musique concrète pioneers, like Wendy Carlos and Delia Darbyshire. Likewise, at one time, computer-animated films could only be seen at obscure short-film festivals. Today, we are seeing many intriguing and beguiling experiments with AI techniques, and, as artists' tools, they will surely transform the way we think about art in thrilling and unpredictable ways.

Acknowledgments: Thanks to Shira Katz, Alvy Ray Smith, Craig Kaplan, Shiry Ginosar, and Dani Oore for valuable comments on the manuscript. Thanks to everyone who shared discussion and/or encouragement online, including Aseem Agarwala, Mark Chen, Lyndie Chiou, Michael Cohen, James Landay, Nevena Lazic, Jason Salavon, Adrien Treuille, and many others.

Conflicts of Interest: The author declares no conflict of interest.

References

Agüera y Arcas, Blaise. 2017. Art in the Age of Machine Intelligence. *Arts* 6: 18. [CrossRef]

Alexander, R. McNeill. 1996. *Optima For Animals*. Princeton: Princeton University Press.

Bernstein, Michael S., Greg Little, Robert C. Miller, Björn Hartmannn, Mark S. Ackermann, David R. Karger, David Crowell, and Karina Panovich. 2015. Soylent: A Word Processor with a Crowd Inside. *Communications of the ACM* 58: 85–94. [CrossRef]

Brooks, Rodney. 2017. The Seven Deadly Sins of AI Predictions. *MIT Technology Review* 120: 79–86.

Catmull, Ed, and Amy Wallace. 2014. *Creativity, Inc: Overcoming the Unseen Forces that Stand in the Way of True Inspiration*. New York: Random House.

Cohen, Harold. 1995. The further exploits of AARON, painter. *Stanford Humanities Review* 4: 141–58.

Cohen, Harold. 2014. ACM SIGGRAPH Awards—Harold Cohen, Distinguished Artist Award for Lifetime Achievement. Available online: https://youtu.be/_Xbt8lzWxIQ?t=13m20s (accessed on 9 May 2018).

Cohen, Michael F. 2000. Imagination amplification. *IEEE Computer Graphics and Applications* 20: 54–55 [CrossRef]

Colton, Simon. 2008. Creativity Versus the Perception of Creativity in Computational Systems. Paper presented at the AAAI Spring Symposium: Creative Intelligent Systems, Stanford, CA, USA, March 26–28.

Colton, Simon. 2012. *The Painting Fool: Stories from Building an Automated Painter.* In *Computers and Creativity*. Berlin and Heidelberg: Springer, pp. 3–38.

Cotter, Holland. 2008. Now in Residence: Walls of Luscious Austerity. *The New York Times*, March 24.

Danto, Arthur. 1964. The Artworld. *The Journal of Philosophy* 61: 571–84. [CrossRef]

De la Croix, Horst, Richard G. Tansey, and Diane Kirkpatrick. 1991. *Gardner's Art through the Ages*, 9th ed. New York: Harcourt Brace.

Desmond, Jane. 2016. Zoos Make Money Selling Paintings Made by Animals. Are They Art? *The Washington Post*, September 8.

Dickie, George. 1969. Defining Art. *American Philosophical Quarterly* 6: 253–56.

Dutton, Denis. 2000. But They Don't Have Our Concept of Art. In *Theories of Art Today*. Edited by Noel Carroll. Madison: University of Wisconsin Press.

Dutton, Denis. 2009. *The Art Instinct: Beauty, Pleasure, and Human Evolution*. New York: Bloomsbury Press.

Dvorsky, George. 2016. Computer Science Students Fooled By Artificially Intelligent TA. *Gizmodo*, May 9.

Dvorsky, George. 2017. This Artificially Intelligent Robot Composes and Performs Its Own Music. *Gizmodo*, June 14.

Efros, Alexei A., and Thomas Leung. 1999. Texture synthesis by non-parametric sampling. Paper presented at the IEEE International Conference on Computer Vision, Corfu, Greece, September 21–22.

Efros, Alexei A., and William T. Freeman. 2001. Image Quilting for Texture Synthesis and Transfer. Paper presented at the 28th Annual Conference on Computer Graphics and Interactive Techniques, Los Angeles, CA, USA, August 12–17, pp. 341–46.

Elgammal, Ahmed, Bingchen Liu, Mohammad Elhoseiny, and Marian Mazzone. 2017. CAN: Creative Adversarial Networks Generating "Art" by Learning About Styles and Deviating from Style Norms. Paper presented at the 8th International Conference on Computational Creativity (ICCC), Atlanta, GA, USA, June 19–23.

Epstein, Robert. 2007. From Russia, with Love. *Scientific American Mind* 18: 16–17. [CrossRef]

Fišer, Jakub, Ondřej Jamriška, Michal Lukáč, Eli Shechtman, Paul Asente, Jingwan Lu, and Daniel Sýkora. 2016. StyLit: Illumination-guided Example-based Stylization of 3D Renderings. *ACM Transactions on Graphics (SIGGRAPH)* 35: 92:1–92:11. [CrossRef]

Gatys, Leon A., Alexander S. Ecker, and Matthias Bethge. 2016. Image Style Transfer Using Convolutional Neural Networks. Paper presented at the 2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), Las Vegas, NV, USA, June 27–30.

Gaut, Berys. 2000. *Art* as a Cluster Concept. In *Theories of Art Today*. Edited by Noel Carroll. Madison: University of Wisconsin Press.

Gaut, Berys. 2005. The Cluster Account of Art Defended. *The British Journal of Aesthetics* 45: 273–88. [CrossRef]

Gershgorn, Dave. 2017. Inside the Mechanical Brain of the World'S First Robot Citizen. *Quartz*, November 16.

Goodfellow, Ian J., Jean Pouget-Abadie, Mehdi Mirza, Bing Xu, David Warde-Farley, Sherjil Ozair, Aaron Courville, and Yoshua Bengio. 2014. Generative Adversarial Nets. Paper presented at the Advances in Neural Information Processing Systems, Montreal, QC, Canada, December 8–13.

Gopnik, Alison, and Henry M. Wellman. 2012. Reconstructing constructivism: Causal models, Bayesian learning mechanisms, and the theory theory. *Psychological Bulletin* 138: 1085–108. [CrossRef] [PubMed]

Griggs, Brandon. 2011. Why Computer Voices Are Mostly Female. *CNN*, October 21.

Haeberli, Paul. 1990. Paint By Numbers: Abstract Image Representations. *ACM SIGGRAPH Computer Graphics* 24: 207–14. [CrossRef]

Hertzmann, Aaron. 1998. Painterly Rendering with Curved Brush Strokes of Multiple Sizes. Paper presented at the Proceedings of the 25th Annual Conference on Computer Graphics and Interactive Techniques (SIGGRAPH '98), Orlando, FL, USA, July 19–24.

Hertzmann, Aaron. 2001. *Algorithms for Rendering in Artistic Styles*. Ph.D. thesis, New York University, New York, NY, USA.

Hertzmann, Aaron. 2003. A Survey of Stroke-Based Rendering. *IEEE Computer Graphics & Applications* 23: 70–81.

Hertzmann, Aaron. 2010. Non-Photorealistic Rendering and the Science of Art. Paper presented at the Proceedings of the 8th International Symposium on Non-Photorealistic Animation and Rendering (NPAR '10), Annecy, France, June 7–10.

Hertzmann, Aaron, Charles E. Jacobs, Nuria Oliver, Brian Curless, and David H. Salesin. 2001. Image Analogies. Paper presented at the 28th Annual Conference on Computer Graphics and Interactive Techniques (SIGGRAPH '01), Los Angeles, CA, USA, August 12–17.

Hockney, David. 1996. *That's the Way I See It*. San Francisco: Chronicle.

Kessler, Sarah. 2014. How Twitter Bots Fool You Into Thinking They Are Real People. *Fast Company*, June 10.

Koblin, Aaron Michael. 2009. The Sheep Market. Paper presented at the Proceedings of the Seventh ACM Conference on Creativity and Cognition (C&C '09), Berkeley, CA, USA, October 26–30, pp. 451–52.

Koerding, Konrad P., and Daniel M. Wolpert. 2006. Bayesian decision theory in sensorimotor control. *Trends in Cognitive Sciences* 10: 319–26. [CrossRef] [PubMed]

Krauss, Lawrence. 2017. Why Science-Fiction Writers Couldn't Imagine the Internet. *Slate*, September 11.

Lasseter, John. 1987. Principles of traditional animation applied to 3d computer animation. *ACM SIGGRAPH Computer Graphics* 21: 35–44. [CrossRef]

Levinson, Jerrold. 1979. Defining art historically. *The British Journal of Aesthetics* 19: 232–50. [CrossRef]

Litwinowicz, Peter. 1997. Processing Images and Video for an Impressionist Effect. Paper presented at the 24th Annual Conference on Computer Graphics and Interactive Techniques (SIGGRAPH '97), Los Angeles, CA, USA, August 3–8.

Metz, Cade. 2017. How A.I. Is Creating Building Blocks to Reshape Music and Art. *The New York Times*, August 14.

Millward, David. 2017. Monkey Selfie Case: British Photographer Settles with Animal Charity Over Royalties Dispute. *The Telegraph*, September 12.

Mordvintsev, Alexander, Christopher Olah, and Mike Tyka. 2015. Inceptionism: Going Deeper into Neural Networks. *Google Research Blog*, December 16.

Nguyen, Anh Mai, Jason Yosinski, and Jeff Clune. 2016. Understanding Innovation Engines: Automated Creativity and Improved Stochastic Optimization via Deep Learning. *Evolutionary Computation* 24: 545–72. [CrossRef] [PubMed]

Nicholas, Gabriel. 2017. These stunning A.I. Tools Are About to Change the Art World. *Slate*, December 15.

O'Neil, Cathy. 2016. *Weapons of Math Destruction: How Big Data Increases Inequality and Threatens Democracy*. New York: Crown.

Paik, Karen. 2007. *To Infinity and Beyond! The Story of Pixar Animation Studios*. San Francisco: Chronicle Books.

Perez, Sarah. 2018. Microsoft's New Drawing Bot Is an AI Artist. *TechCruch*, January 19.

Pogue, David. 2018. Is Art Created by AI Really Art? *Scientific American*, February 1.

Price, David A. 2008. *The Pixar Touch*. New York: Vintage.

Reeves, Byron, and Clifford Nass. 1996. *The Media Equation: How People Treat Computers, Television, and New Media Like Real People and Places*. Stanford: CSLI.

Rosenblum, Naomi. 1984. *A World History of Photography*. New York: Abbeville Press.

Rosin, Paul, and John Collomosse. 2013. *Image and Video-Based Artistic Stylisation*. Berlin and Heidelberg: Springer.

Rubin, Michael. 2005. *Droidmaker: George Lucas and the Digital Revolution*. Gainesville: Triad.

Scharf, Aaron. 1968. *Art and Photography*. Harmondsworth: Penguin.

Shein, Esther. 2017. Computing the Arts. *Communications of the ACM* 60: 17–19. [CrossRef]

Shelley, Mary Wollstonecraft. 1818. *Frankenstein; or, the Modern Prometheus*. London: Lackington, Hughes, Harding, Mavor & Jones.

Simonite, Tom. 2018. When It Comes to Gorillas, Google Photos Remains Blind. *Wired*, January 13.

Snow, Charles Percy. 1959. *The Two Cultures*. London: Cambridge University Press.

Snowden, Don. 2012. Robert Moog: 'I Wouldn't Call This Music'—A Classic Interview to Mark a Google Doodle. *The Guardian*, May 23.

Sterling, Bruce. 2012. An Essay on the New Aesthetic. *Wired*, April 2.

Sternberger, Paul Spencer. 2001. *Between Amateur & Aesthete: The Legimitization of Photography as Art in America, 1880–1900*. Albuquerque: University of New Mexico Press.

Stiglitz, Joseph E. 2012. *The Price of Inequality*. New York: Norton.

Szegedy, Christian, Wojciech Zaremba, Ilya Sutskever, Joan Bruna, Dumitru Erhan, Ian Goodfellow, and Rob Fergus. 2014. Intriguing properties of neural networks. Paper presented at the International Conference on Learning Representations, Banff, AB, Canada, April 14–16.

Tenenbaum, Joshua B., Charles Kemp, Thomas L. Griffiths, and Noah D. Goodman. 2011. How to Grow a Mind: Statistics, Structure, and Abstraction. *Science* 331: 1279–85. [CrossRef] [PubMed]

Tyka, Mike. 2016. Exploring the Intersection of Art and Machine Intelligence. *Google Research Blog*, June 18.

Vincent, James. 2018. Facebook's Head of AI Really Hates Sophia the Robot (and with Good Reason). *The Verge*, January 18.

Weizenbaum, Joseph. 1966. ELIZA—A computer program for the study of natural language communication between man and machine. *Communications of the ACM* 9: 36–45. [CrossRef]

Wilber, Michael J., Chen Fang, Hailin Jin, Aaron Hertzmann, John Collomosse, and Serge Belongie. 2017. BAM! The Behance Artistic Media Dataset for Recognition Beyond Photography. *International Conference on Computer Vision* 1: 4.

Wilson, Mark. 2017. AI Is Inventing Languages Humans Can't Understand. Should We Stop It? *Co.Design*, July 14.

Xu, Tao, Pengchuan Zhang, Qiuyuan Huang, Han Zhang, Zhe Gan, Xiaolei Huang, and Xiaodong He. 2017. AttnGAN: Fine-Grained Text to Image Generation with Attentional Generative Adversarial Networks. *arXiv*.

arts

MDPI

Article

On Hybrid Creativity

Andy Lomas

Department of Computing, Goldsmiths College, University of London, London SE14 6NW, UK; andylomas@gmail.com

Received: 2 May 2018; Accepted: 5 July 2018; Published: 9 July 2018

Abstract: This article reviews the development of the author's computational art practice, where the computer is used both as a device that provides the medium for generation of art ('computer as art') as well as acting actively as an assistant in the process of creating art ('computer as artist's assistant'), helping explore the space of possibilities afforded by generative systems. Drawing analogies with Kasparov's Advanced Chess and the deliberate development of unstable aircraft using fly-by-wire technology, the article argues for a collaborative relationship with the computer that can free the artist to more fearlessly engage with the challenges of working with emergent systems that exhibit complex unpredictable behavior. The article also describes 'Species Explorer', the system the author has created in response to these challenges to assist exploration of the possibilities afforded by parametrically driven generative systems. This system provides a framework to allow the user to use a number of different techniques to explore new parameter combinations, including genetic algorithms, and machine learning methods. As the system learns the artist's preferences the relationship with the computer can be considered to change from one of assistance to collaboration.

Keywords: art; computer; evolutionary design; machine learning; computationally assisted design

---

1. Introduction

How are we to work creatively with generative systems that computationally create results? In particular, how should we work with systems deliberately designed to encourage emergence: complex systems where results are intrinsically difficult to predict?

There is a strong analogy with plant breeding, where we are working with a medium that is naturally rich. Through experimentation and experience we can develop insights into what is possible and how to influence plants to develop in ways that give desired properties. We need to discover the potentialities of the system we are working with, as well as the limits of its capabilities. Which features can be independently influenced, and which are co-dependent? Whether art, design or architecture, this involves changing our relationship with the computer. Traditional top-down design methods are no longer appropriate. We need to be open to a process of exploration. Participating in a search for interesting behavior: selecting and influencing rather than dictating results.

Generative systems are typically based on algorithmic processes that are controlled by a number of parameters. Given a set of parameter values the process is run to create an output. Classic examples include Conway's Game of Life (Conway 1970) and reaction diffusion equations (Turing 1952). Generative systems have been used by a number of artists, from pioneering early work by Algorists such as Manfred Mohr (Mohr and Rosen 2014), Frieder Nake (Nake 2005), Ernest Edmonds (Franco 2017), and Paul Brown (Digital Art Museum 2009a) to more recent work by artists such as William Latham (Todd and Latham 1992), Yoichiro Kawaguchi (Digital Art Museum 2009b), Casey Reas (Reas 2018), and Ryoji Ikeda (Ikeda 2018).

The most interesting systems are generally those that create emergent results: genuinely unexpectedly rich behavior that cannot be simply predicted from the constituent parts. For these systems the relationship between the input parameters and the output is generally complex and non-linear, with effects such as sensitive dependence on initial conditions. This makes working with such systems particularly challenging: both fascinating and potentially frustrating.

With a small number of dimensions, such as up to three parameters, the space of results can be relatively easily explored by simply varying individual parameter values and plotting the effects of different combinations. One common technique is to create charts where all the parameters are sampled independently at regularly spaced values and results are plotted to show the results. What scientists would call a phase space plot, or in the animation and visual effects industry is commonly called a wedge sheet. This method of parameter exploration can be effective, and was used by the author for earlier work such as for his 'Aggregation' (Lomas 2005) and 'Flow' (Lomas 2007) series.

Figure 1 shows one of the charts the author created when working on his 'Aggregation' series, exploring the effect that two different parameters had on the forms created. In this example the author was taking 8 samples in each dimension. With two parameters only 64 samples were needed to complete this chart. However, as the number of parameters goes up the number of samples needed to explore different sets of combinations using this method increases rapidly. Three parameters would require 512 samples. Four parameters would need 4096 samples. If we had a system with 10 parameters then just over a billion samples would be needed. This problem is commonly called the 'Curse of Dimensionality' (Bellman 1961) (Donoho 2000), where the number of samples that need to be taken increases exponentially with the number of parameters. Even if enough samples can be taken, how to visualize and understand the space becomes a significantly difficult problem and concepts such as finding the nearest neighbors to any point in the parameter space become increasingly meaningless (Marimont and Shapiro 1979).

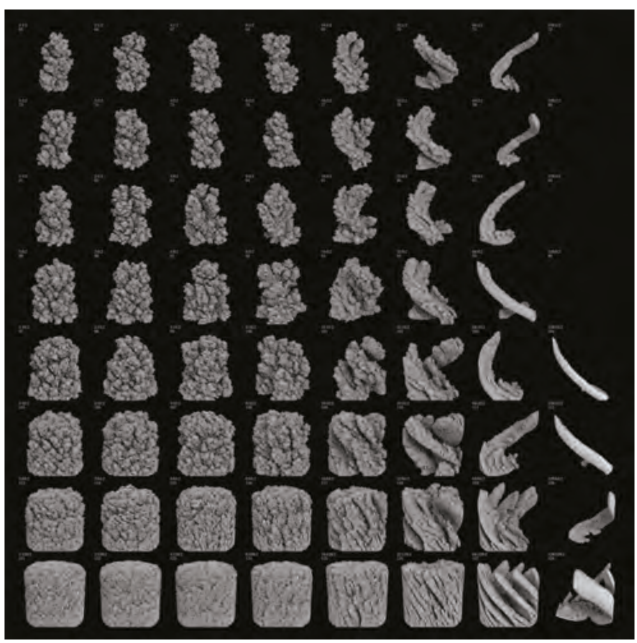


Figure 1. Phase space plot from the Aggregation series (Lomas 2005).

One approach is to simply limit the number of parameters, but this can be at the expense of overly limiting the type of system that we are willing to work with. If we are working with richly emergent system these problems are often further compounded. A direct consequence of emergence is that the parameters often work in difficult to comprehend, unintuitive ways. Effects are typically non-linear, often with sudden tipping points as the system goes from one type of behavior to another. Indeed, the most interesting results, such as those in the right hand columns of Figure 1 above, are often near regions of instability or at transitions between behaviors. In particular, in many systems the most interesting emergent behavior occurs close to the boundary between regularity and chaos (Kauffman 1996). The shape of this type of boundary can be extremely complex, a classic example being the ornately fractal shaped boundary between regularity and chaos in the Mandelbrot set (Douady and Hubbard 1984).

This raises the idea of working with the machine not merely as the medium but as an active collaborator in the process of exploration and discovery. Can computational methods be used to allow exploration of generative systems like these in ways that would not be otherwise possible? The computer becomes an active part of the process of discovery, not just as the medium used to create artefacts.

One analogy worth exploring is that of Advanced Chess: a form of the game introduced by Garry Kasparov where each human player can use a computer to assist them to explore possible moves (Kasparov 2017). In particular, computer chess programs are generally very good at quickly detecting whether a proposed move will have catastrophic results. The effect of allowing a human player to test potential moves with a computer assistant is to make the game blunder-free. By removing the stress of making easily punished mistakes the human in the collaboration is freed to approach the game in a much more actively experimental way.

Another potentially rich analogy is with fly-by-wire systems in aircraft (Sutherland 1968). These allow designs of aircraft to be created which are inherently unstable but can perform complex maneuvers beyond the performance envelope of conventional aircraft (Stein 2003). These include designs that would be difficult or even impossible for a human pilot to directly control. Through the use of digital fly-by-wire technology, where the pilot uses their controls to indicate their intent but all the data is passed through a computer before being fed to actuators on the control surfaces, such aircraft can be flown safely.

How are we to express an artistic opinion while working with a complex space of possibilities? The space of possibilities may be rich, but it can be a challenging territory to explore. How should we explore the space of possibilities to find the most interesting results when dealing with more and more parameters? There is a danger of becoming overwhelmed by too many controls. After we have tried out some initial parameter values, what values to try next? This problem, of how to choose new parameter values based on the limited number of parameter combinations we've sampled so far, is one that a computational algorithm may be able to actively help with.

We can think about the possibility for different relationships with the computer. Can using them actively in the creative process allow more fearless engagement with difficult 'unruly' generative systems, exploring spaces with more parameters and complex inter-dependence between them than would otherwise be possible? To try to address these questions, the author has created his own system, called 'Species Explorer', that provides a range of different methods to help the user select parameter combinations to try when working with generative systems.

2. Working with a Complex Space of Possibility

Most of the author's recent work involves exploration of morphogenesis: creating forms generatively through simulation of growth. The aim is to create systems that have the potential for a rich variety of different types of three-dimensional structure and form. All these come emergently from low level rules such as forces between cells, how cells split and connect to their neighbors, and how food needed for growth is created and shared between cells. The work can be considered as explorations of artificial life: inspired by, rather than trying to copy, biology. Actively exploring whether different rules create familiar or deeply alien structures.

The aim is to create systems that have the potential for a rich range of possibilities. Typically, each system has a quite large number of parameters, any of which could influence the development of the forms in potentially interesting ways. The simplest systems that the author has created as part of his Cellular Forms series (Figure 2) has 12 parameters, with more recent variations, such as Hybrid Forms (Lomas 2015) and Vase Forms (Lomas 2017), having 30–40 parameters.

A big question is how to explore a landscape with this number of parameters with a creative intent. As was previously discussed, structured sampling taking a fixed number of samples independently in each dimension would result in an overwhelmingly large number of samples to deal with. Even if we could take the required number of samples, how are we to visualize or otherwise make sense of the results? On the other hand, if we have a smaller number of less structured samples it is very difficult to make sense of what the data means and decide on new parameter combinations to try.

This is an area where computational methods, such as genetic algorithms or machine learning techniques, may be useful. In effect: allow the computer to help us make the best use of the data that has been acquired so far to decide where to next sample.

A number of authors have proposed using evolutionary methods to allow artists and designers to explore systems with large numbers of parameters. Examples include Dawkins' Biomorphs (Dawkins 1986) and Mutator (Todd and Latham 1992). A number of systems that use evolutionary selection for design are described in (Bentley 1999).

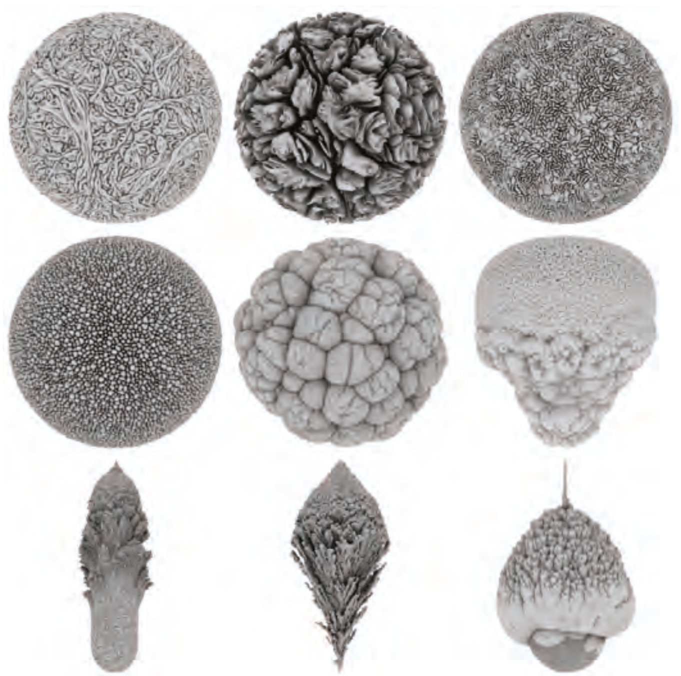


Figure 2. Examples of a range of morphologies from the author's Cellular Forms (Lomas 2014).

As demonstrated by natural processes, evolutionary methods can be effective even with extremely large numbers of parameters. One problem, though, can be that these methods generally lead to exploring a small number of paths within the space of available possibilities. The nature of these types of methods are to bias the search towards the most successful areas of the parameter space that have already been highly sampled. New samples are taken by mutation or cross-breeding of the gene codes from previous samples that are deemed fittest according to a specified fitness function. This means that previously highly sampled areas are likely to be even more highly sampled in the future as long as they contain 'fit' individuals. This is a good strategy for exploiting the best results that have been previously found, but can be seen as a bad strategy for actively finding novel solutions which may be in areas of the landscape that have had very few samples so far.

Another issue worth considering is that for creative work there is often a need for different phases of exploration. Initially we may be actively experimenting: trying to get a feel for the capabilities of the medium we are working with. Once we have done some initial experiments we may want to continue to explore broadly, but with a general focus on regions that seem to have promise. Once we have found some particularly interesting results we may wish to further refine them into presentable artefacts for exhibition, or want to switch to actively looking for novel results that are significantly different to those we have found so far. In other words, the intent of a process of exploration changes over time. If a computer is assisting us we may want it to work in different ways depending what type of result we are currently searching for.

One analogy is with journeying into an unexplored landscape looking for the particularly interesting locations. When we first go into the landscape we may go to a few random places, exploring along a single path. Once we have got an idea of the different types of terrain, we may want to go back and explore some of the most interesting locations we have found in greater detail. If we get bored with the places we have seen so far, we may want to see if we can find new distinctive types of terrain different to any of those we have seen previously.

There are at least four different phases of exploration worth considering separately: Initial Exploration, Secondary Exploration, Refined Focus, and Looking for Novelty.

2.1. Initial Exploration

Initial exploration is where the user is trying to get an initial basic understanding of how a system works and what sort of result may be possible. At this stage they typically have little or no idea what places in space may be interesting, and are effectively just randomly trying out parameter values to test if the system works as expected. They start to get a flavor for what types of behavior may be achieved, and are interested in hints of what may be possible rather than detailed exploration.

2.2. Seconday Exploration

At this stage the user has done some initial exploration. They want to use the information gathered so far to help guide the search: to be steered into broad areas of the parameter space that appear to be potentially fruitful, and away from regions that have been found to yield invalid results or are otherwise undesirable. However, the search should still be a broad one, avoiding what would be considered in optimization as becoming trapped in a local maximum by over-refining too early and in the process missing potentially even more interesting results.

2.3. Refined Focus

When the user has found some results that appear particularly interesting they may want to focus on those for further refinement. This is effectively a focused exploration within a small range of parameter values, such as to create final artistic exhibitable artefacts.

2.4. Looking for Novelty

However, once the user has found and refined some particularly interesting results, they may want to switch to looking for novelty. Are there additional rich seams in the landscape that have not yet been discovered? Can the space be searched for results unlike those seen previously, which may in turn take the exploration in fruitful new directions?

At this stage it is sensible to want to make good use of all the data that has been acquired so far, but without being overly biased towards regions that have been explored in detail. The user is willing to get results that are less 'fit' if they hold the promise for something genuinely new.

3. Evolutionary Methods and Machine Learning

As previously discussed, evolutionary methods are a commonly suggested approach for creatively working with generative systems. For the different phases of exploration, the author considers that they are particularly effective when refining previously found promising solutions, are also useful for secondary exploration, but because of their strong bias towards areas that have already been highly sampled are generally very poor for looking for novelty. With evolutionary techniques the general approach to find novel solutions is to dramatically increase mutation rates, or to simply start with a completely new population with the hope that a fresh search may explore a new path and find novel solutions. However, this is at the expense of throwing away hard-earned data about what has already been discovered in exploring the landscape of possibilities.

In more recent years a number of authors have proposed using machine learning techniques to assist human designers. In general these are for domain specific applications, such as for architectural space frame structures (Hanna 2007), structurally valid furniture (Umetani et al. 2012) or aircraft designs (Oberhauser et al. 2015). In these systems machine learning is typically used to learn about specific properties of the system. This is then used to provide interactive feedback for the user about whether an object designed by them is likely to have desired properties, such as being structurally feasible, without having to do computationally prohibitive tasks such as evaluation of structural strength using finite element analysis.

Machine learning is a potentially interesting technique when looking for novelty. In particular, it should be possible to use machine learning as a method to predict fitness at arbitrarily chosen new points in the parameter space based on all the data that has been collected so far, and conduct a search explicitly biased in favor of new samples that are a long distance in parameter space from previous samples.

4. Species Explorer

In response to these issues, the author has developed a program called Species Explorer to assist the process of generating parameter values to be used with generative systems (Figure 3). Developed out of necessity, the specific need for such a system came from the number of parameters that the author found he needed when he was developing the simulation engine for his Cellular Forms work (Lomas 2014). This program provides a framework for various methods to be used to assist exploring the landscape of possibilities.

The software is designed to be used on computers running Windows and Linux, but everything has been written in an operating system agnostic manner that should facilitate support for other operating systems. It is implemented in Python together with Qt, using the PySide Qt bindings (The Qt Company, Oslo, Norway). This has allowed rapid development and experimentation.

The software provides an interface for the user to rate and categorize the results from running a generative system with different parameter values. Various methods, including random sampling, evolutionary search techniques and machine learning, can be used to generate new parameter values to try out. Once a set of parameter values has been chosen the system writes out a 'creation script' (Linux shell script, Windows batch file or Python script) that can be executed on the computer to run the generative system with the specified values. The user can then rate and categorize the results of these new samples, and the computer in turn suggests parameter values for new places in the landscape of possibilities to try.

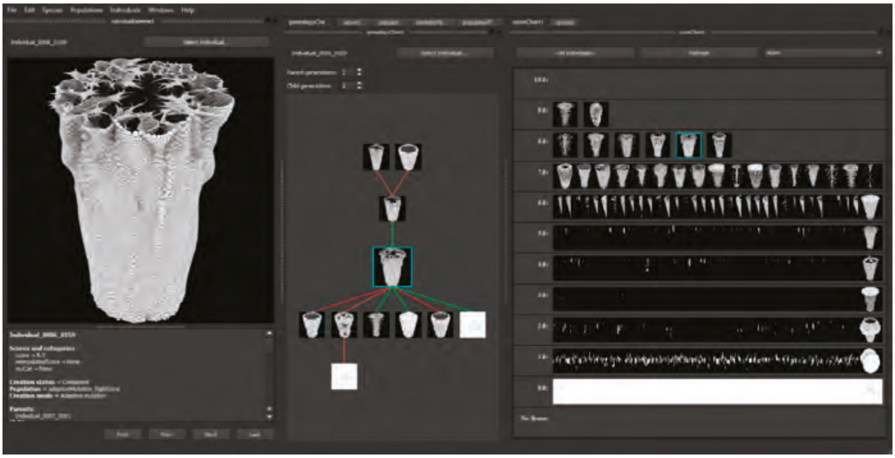


Figure 3. Species Explorer user interface.

The software allows the user to select from a number of different 'creation methods', each of which use different techniques for selection of new parameter values based on the data gathered so far. This provides the flexibility to allow the user to explore the space of possibilities in different ways depending on their intent (such as focused refinement based on some previous samples, or an active exploration for potentially novel results). The software also provides a framework for plugins to implement new 'creation methods', so the user can specify their own custom ways for how samples are chosen.

Currently the following creation methods are provided. For more technical detail see (Lomas 2016).

- Uniform random selection of parameter value
- User specified parameter values
- Wedge Test (parameter values with regular spacing)
- Standard Mutation
- Adaptive Mutation
- Cross-breeding
- Cross-breeding confined to neighbors
- Selection using lazy machine learning

These provide a flexible palette of different methods for generation of new parameter values. In the author's experience using the system, he has found that different techniques are appropriate depending on his current intent. For the initial stages of exploration the author generally uses simple random parameter selection. Once he has evaluated some results, scoring them using rating values in a range from 0 to 10, he then uses evolutionary methods such as cross breeding or estimated scores using machine learning to do 'secondary exploration' as described above in Section 2.2. When he finds results that he considers particularly interesting and he wants to refine further, adaptive mutation (where mutation rates are varied depending on the distance to the closest neighbors in parameter space) and cross-breeding confined to the neighbors both work well.

However, when searching for novelty the author prefers machine learning techniques over evolutionary ones. These methods use lazy machine learning to estimate scores at new positions in the parameter space. New individuals are chosen based on these estimate values using a Monte Carlo method that estimates the score at a number of candidate points, and chooses one of the candidates with a probability proportional to the estimated values. This means that parameter combinations which are expected to have high score values will be preferentially selected.

The user can also provide custom 'score expressions' to be used when selecting parents for evolutionary techniques or for the value to be estimated using machine learning. For instance a score expression can be used to raise a score to a power to bias the selection of parents even more towards those with higher score values, to combine the effects of different score values (such as if the user has rated results both on an overall 'score' and on a rating for how 'hairy' structures appear), or to deliberately bias the selection of new samples to less explored regions of parameter space by including the distance to the closest existing sample point in the score expression.

As well as providing numeric ratings, the user can group samples into categories, such as forms that look like 'brains', 'broccoli', or 'corals'. Using score expressions, the user can either restrict breeding to sets of parents in specific categories, or use the machine learning creation methods to find new parameter values that are predicted to have a high probability of being in a given category.

The author has used Species Explorer for all the work he has created in recent years, including his Cellular Forms and more recent related series (Figure 4). The key intent with the system is for the computer to act as an active assistant, helping guide users as they explore a system to discover its potential capabilities and making the best use of all the input the user has made. The user should be able to steer the search with a creative intent, refining particularly interesting results, with the computer assisting them in exploring the space for novel rich behavior.

Figure 4. Morphogenetic Creation exhibition at Watermans, 2016. All works in the exhibition were created using Species Explorer to discover parameter values for the forms presented.

This also raises the question of how the relationship between the user and the computer can change over time. The use of genetic algorithm and machine learning methods means that the system adapts through use, effectively learning about the user's preferences. The author believes that a consequence of this is that the relationship with the computer can also change over time, from one where the computer is very much in the role of purely an assistant where all creative choice is explicitly controlled by the user, to one where the computer can be seen as more of a collaborator suggesting parameter combinations that have a high likelihood of producing interesting possibilities.

Currently all aesthetic judgements when rating or categorizing results are explicitly made by the user, but one potentially interesting direction for future enhancement would be to use the system as a platform to provide training data for machine learning to model how the user is rating and categorizing. This could allow a system of interactive training, with the user rating and categorizing some initial samples, the machine making predictions about score and categories for new samples, and the user correcting the predictions if they are wrong. Using such a system we could explore whether we can reach a point where the computer can successfully predict how the user will rate and categorize.

5. Conclusions

Working with generative systems gives the potential for rich possibilities, but also presents many challenges, particularly when trying to work with a creative intent. It is natural to look towards working collaboratively with a computer as an inherent part of the process, but what is the relationship that we want to develop with the computer? Is there a way that humans and computers can work together to their mutual strengths? In the author's experience the computer can become an active assistant in the process of discovery as well as being a medium to work with, enabling creative exploration with systems that the author previously found overwhelming (due to the systems having large numbers of parameters any of which could affect the results in difficult to predict but potentially interesting ways). The process changes to one that feels like a productive active collaboration, with the computer freeing the author from anxiety when creating new systems and adding parameters that he believes may have the potential to generate unexpectedly interesting results.

In particular, as an artist it can be important to have a relationship that gives at least the plausible illusion of being relevant and provides for interaction that feels rewarding, where decisions by the artist are steering the work in ways that match their intent. The nature of using a system that adaptively changes based on the user's input is that the relationship with the computer can change over time, from one where the computer acts purely as a technical assistant to one where the computer can be seen as a collaborator in the process of creation.

Funding: This research received no external funding.

Conflicts of Interest: The author declares no conflict of interest.

References

Bellman, Richard. 1961. *Adaptive Control Processes: A Guided Tour*. Princeton: Princeton University Press.

Bentley, Peter J. 1999. *Evolutionary Design by Computers*. San Francisco: Morgan Kaufmann, ISBN 978-155860605X.

Conway, John H. 1970. The game of life. *Scientific American* 223: 4.

Digital Art Museum. 2009a. Paul Brown. Available online: http://dam.org/artists/phase-one/paul-brown (accessed on 20 June 2018).

Digital Art Museum. 2009b. Yoichiro Kawaguchi. Available online: http://dam.org/artists/phase-one/yoichiro-kawaguchi (accessed on 20 June 2018).

Dawkins, Richard. 1986. *The Blind Watchmaker: Why the Evidence of Evolution Reveals a Universe without Design*. New York: WW Norton & Company, ISBN 978-0141026169.

Donoho, David L. 2000. High-Dimensional Data Analysis: The Curses and Blessings of Dimensionality. Paper presented at AMS Math Challenges Lecture, Los Angeles, CA, USA, August 6–11; Available online: https://pdfs.semanticscholar.org/63c6/8278418b69f60b4814fae8dd15b1b1854295.pdf (accessed on 6 July 2018).

Douady, Adrien, and John Hamal Hubbard. 1984. *Etude Dynamique des Polynômes Complexes. Prépublications Mathémathiques d'Orsay*. Orsay: Université de Paris-Sud.

Franco, Francesca. 2017. *Generative Systems Art: The Work of Ernest Edmonds*. Abingdon: Routledge, ISBN 978-1472436009.

Hanna, Sean. 2007. Inductive machine learning of optimal modular structures: Estimating solutions using support vector machines. *AI EDAM* 21: 351–66. [CrossRef]

Ikeda, Ryoji. 2018. Ryoji Ikeda. Available online: http://www.ryojiikeda.com/ (accessed on 20 June 2018).

Kasparov, Garry. 2017. *Deep Thinking: Where Machine Intelligence Ends and Human Creativity Begins*. London: John Murray, ISBN 978-1473653504.

Kauffman, Stuart. 1996. *At Home in the Universe: The Search for Laws of Self-Organization and Complexity: The Search for Laws of Self-Organisation and Complexity*. London: Penguin, ISBN 978-0140174144.

Lomas, Andy. 2005. Aggregation: Complexity out of Simplicity. In *ACM SIGGRAPH 2005 Sketches*. New York: ACM, Available online: http://www.andylomas.com/sketch_0087_final.pdf (accessed on 10 March 2018).

Lomas, Andy. 2007. Flow. Available online: http://www.andylomas.com/flow.html (accessed on 10 March 2018).

Lomas, Andy. 2014. Cellular Forms: An Artistic Exploration of Morphogenesis. Paper presented at AISB-50, London, UK, April 1–4; Available online: http://www.andylomas.com/extra/andylomas_paper_cellular_forms_aisb50.pdf (accessed on 10 March 2018).

Lomas, Andy. 2015. Hybrid Forms. Available online: http://www.andylomas.com/hybridForms.html (accessed on 26 April 2018).

Lomas, Andy. 2016. Species Explorer: An interface for artistic exploration of multi-dimensional parameter spaces. Paper presented at EVA London 2016 Conference, Electronic Workshops in Computing (eWiC), London, UK, July 12–14; London: BCS.

Lomas, Andy. 2017. Vase Forms. Available online: http://www.andylomas.com/vaseForms.html (accessed on 26 April 2018).

Marimont, R. B., and M. B. Shapiro. 1979. Nearest Neighbour Searches and the Curse of Dimensionality. *IMA Journal of Applied Mathematics* 24: 59–70. [CrossRef]

Mohr, Manfred, and Margrit Rosen. 2014. *Der Algorithmus des Manfred Mohr: Texte 1963–1979*. Oakland: Spectator Books, ISBN 978-3944669168.

Oberhauser, Matthias, Sky Sartorius, Thomas Gmeiner, and Kristina Shea. 2015. Computational Design Synthesis of Aircraft Configurations with Shape Grammars. In *Design Computing and Cognition'14*. Cham: Springer International Publishing, pp. 21–39.

Nake, Frieder. 2005. Computer art: A personal recollection. Paper presented at the 5th Conference on Creativity & Cognition, London, UK, April 12–15.

Reas, Casey. 2018. Home Page of Casey REAS. Available online: http://caesuras.net/ (accessed on 20 June 2018).

Stein, Gunter. 2003. Respect the unstable. *IEEE Control Systems* 23: 12–25. [CrossRef]

Sutherland, Major J. P. 1968. *Fly-by-Wire Flight Control Systems*. Dayton: Air Force Flight Dynamics Lab Wright-Patterson AFB.

Todd, Stephen, and William Latham. 1992. *Evolutionary Art and Computers*. London: Academic Press, ISBN 978-0124371859.

Turing, Alan M. 1952. The chemical basis of morphogenesis. *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 237: 37–72. [CrossRef]

Umetani, Nobuyuki, Takeo Igarashi, and Nilroy J. Mitra. 2012. Guided exploration of physically valid shapes for furniture design. *ACM Transactions on Graphics* 31: 86–1. [CrossRef]

arts

Editorial

Robot Art: An Interview with Leonel Moura

Leonel Moura

Artist at Robotarium/Rua Rodrigues Faria, 103 Lisbon, Portugal; arte@leonelmoura.com

Received: 16 July 2018; Accepted: 16 July 2018; Published: 18 July 2018

Abstract: In the wake of his inclusion in the landmark 2018 "Artists and Robots" show at the Grand Palais in Paris, Leonel Moura reflects herein on his own work and its place within the broad spectrum of techno-art; and of particular current interest is his reliance as an artist on emergent phenomenon—i.e., the ability of relatively simple systems to exhibit relatively complex and unexpected capabilities—which has recently come back into focus with the spectacular ability of the "deep learning" family of computer algorithms to perform pattern recognition tasks unthinkable only a few years ago.

Keywords: art; technology; robots; techno-art; robot art; emergent phenomenon; emergence

1. Introduction

Arts:

As you know, Leonel, the title of our special issue is "The Machine as Artist (in the 20th Century)". Can you please give our readers an overview of how you will be approaching the subject?

LM:

Can a Machine make Art? This question, bizarre back in 2001 when I started working with artbots, is today recurrent. Why? Because robots are invading our world, artificial intelligence is a reality, and art itself, on the path of Marcel Duchamp, accepts almost anything. However, the main issues remain the same since mid-20th century pioneers started using computers and algorithms to produce a new kind of art. Are machines really creative? Or are they just another tool in the hands (and minds) of human artists? I will try to answer based on my own work.

2. Robots

Arts:

For those of us who were not lucky enough to see your installation at the Grand Palais, or who are otherwise unfamiliar with your work, could you please give us a description?

LM:

My artbots are quite simple (Moura and Pereira 2004). They are autonomous, have an onboard microchip, sensors to avoid obstacles and detect colours, and a device to actuate a colour marker pen (Figure 1). They move in a haphazard way inside an arena (Figure 2), but with each sensing the colour over which it is then passing and reacting by either raising or lowering its pen when a certain threshold is sensed, that is, when a certain amount of colour is present. This reaction to the marks left by other robots is thus an indirect form of communication known as *stigmergy*, as originally described by Pierre-Paul Grassé (Grassé 1959). The process is emergent (Whitelaw 2004): from a random start, soon randomness is replaced by a reactive mode generating patterns and clusters of colour.

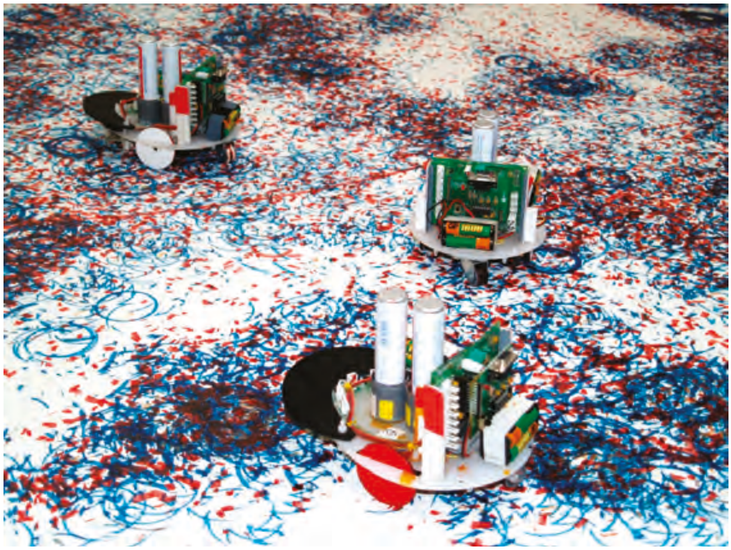


Figure 1. Three artbots at work. Photo ©2001 Robotarium and used by permission.

Figure 2. Artbot arena as installed at the Spring 2018 Grand Palais exhibition "Artists and Robots". Photo ©2018 Aldo Paredes RMNGP and used by permission.

The finalization of the work is determined by a kind of negative feedback, i.e., when robots stop reacting as a certain density of colour is achieved.

The general behaviour of my robot swarm is inspired by ants. These insects communicate among themselves through chemical messages, the pheromones, with which they produce certain patterns of collective behaviour, like following a trail. I have replaced pheromone by colour. In this way, the swarm of robots create unique paintings, impossible to anticipate, and in which an abstract composition with different levels of colour concentration can clearly be recognized by the human viewer (Figure 3).

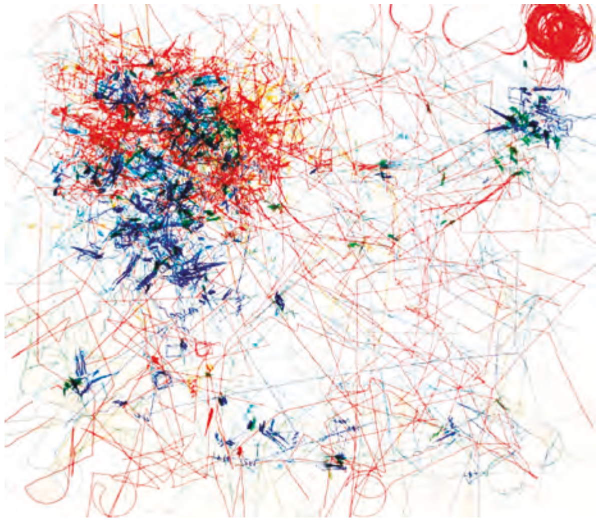


Figure 3. *RAP (Robot Action Painting)*, 2007, ink on canvas, 150 cm × 170 cm. ©2007 Robotarium and used by permission.

3. Art

Arts:

Thank you, Leonel, for this quite precise description of how your "artbots" create their output; but we come now to the inevitable question—is it Art?

LM:

Purists in respect to human uniqueness will say "no": only humans can make art. This, however, is an outdated concept. It has been understood since at least the birth of abstraction that the main issue in art is neither its production nor the individual artistic sensibility by which it is guided. The main issue of art is art itself: its history, evolution, and innovative contributions. Anything can be considered art if validated by one of the several art world mechanisms including museums, galleries, specialized media, critics, curators, and/or collectors. Only in this way has the Duchampian ready-made and most of the art produced since been accepted and integrated into the formal art realm.

Whether a work of art is made directly by a human artist or is the product of any other type of process is nowadays of no relevance. Recent art history shows many examples of art works based on random procedures, fortuitous explorations, *objets trouvés*, and arbitrary constructions. Surrealism, for example, even tried to take human consciousness out of the loop. More decisive is whether or not a new art form expands the field of art. Since the advent of modernism, innovation has become a more important criterion in evaluating artistic projects than personal ability.

Art made by robots also raises other kinds of issues. For the moment, robots and their algorithms remain human creations. In this sense, it can be said that their artistic production originates in the will and skill of the human artist. But since robots like those I use are able to generate novelty, it must also be recognized that they have at least some degree of creativity. Essential information in creating their composition, such as the detection of colour and small shapes, is gathered directly by the robots. Moreover, the emergent process implies that the resulting art works cannot be predetermined even by the person who initiates the process. Hence, the painting as a composition is the product of machines without decisive human intervention.

The algorithm and the basic rules introduced thereby via the robot microchip are not so very different, furthermore, from education. No one will claim that a given novel is the product of the author's school teacher. To the extent that the author, human or machine, incorporates new information, the art work becomes not only unique but also the result of the author's own creativity. In short, I teach the robots how to paint, but afterward, it is not my doing.

If we accept that intelligent machines can already perform many human tasks, why not accept that they can make art? Will I myself keep making paintings if robots can do it so well? Is this a menace to human creativity? No. We have plenty of other things to do.

4. Future

Arts:

And finally, Leonel, where is all of this headed? Please share with us your vision of the future.

LM:

Robots and artificial intelligence still depend on human enterprise. Soon enough, however, machines will be able to undertake their own evolution. And this is not a question of belief but rather of necessity. The autonomy of machines is essential to the best interests of humanity, as in cases such as multiple task performance, big data management, and space exploration. These developments imply the ability of the machine to solve problems, make decisions, and evolve as needed. And the result must be the capacity of machines to build new machines following their own purposes.

Does this pose a risk for mankind? Maybe. The possibility of human/machine confrontation in the future is real inasmuch as humans don't seem to be able to think and behave rationally. One example is the intense development by the military of unmanned robots with lethal capacity.

One way to avoid such an outcome is co-evolution: in a symbiotic manner, machines and humans will continue to depend on each other. In such a context, art can have an important role, teaching humans and machines how to share common goals (Figure 4).

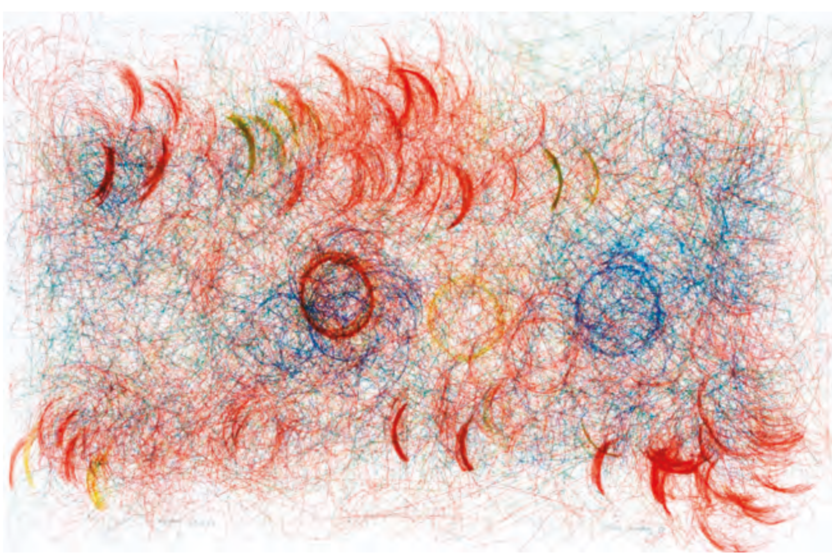


Figure 4. *Bebot*, 2017, ink on canvas, 300 cm × 470 cm. ©2017 Robotarium and used by permission.

Art-making machines are also important beyond the creation of beauty or emotional stimulation, as is typically the case in human culture, and here I refer to the fundamental process of fabricating knowledge. No knowledge, be it biological or artificial, can evolve and be perfected without exploration, experimentation, and random creativity. In fact, natural evolution is generally based on such mechanisms. Trial and error evolution can therefore be seen as an equivalent to art, since art, as opposed to science, is non-objective and non-linear. Hence, I would say that the future of robots and artificial intelligence will be artistic, or we may otherwise find ourselves in serious trouble.

Conflicts of Interest: The author declares no conflicts of interest.

References

Grassé, Pierre-Paul. 1959. La reconstruction du nid et les coordinations interindividuelles chez *Bellicositermes natalensis* et *Cubitermes sp*. La théorie de la stigmergie: Essais d'interprétation du comportement des termites constructeurs. *Insectes Sociaux* 6: 41–84. [CrossRef]

Moura, Leonel, and Henrique Garica Pereira. 2004. *Man and Robots: Symbiotic Art*. Villeurbanne: Institut d'Art Contemporain.

Whitelaw, Mitchell. 2004. Emergence. In *Metacreation: Art and Artificial Life*. Cambridge: The MIT Press, chp. 7. pp. 206–38.

arts

MDPI

Article

Self-Improving Robotic Brushstroke Replication

Jörg Marvin Gülzow *, Liat Grayver and Oliver Deussen

Fachbereich Informatik und Informationswissenschaft, Universität Konstanz, 78464 Konstanz, Germany; liat.gra01@gmail.com (L.G.); oliver.deussen@uni-konstanz.de (O.D.)

* Correspondence: marvin.guelzow@uni-konstanz.de

Received: 28 September 2018; Accepted: 10 November 2018; Published: 21 November 2018

Abstract: Painting robots, like e-David, are currently unable to create precise strokes in their paintings. We present a method to analyse given brushstrokes and extract their trajectory and width using a brush behaviour model and photographs of strokes painted by humans. Within the process, the robot experiments autonomously with different brush trajectories to improve the reproduction results, which are precise within a few millimetres for strokes up to 100 millimetres length. The method can be generalised to other robotic tasks with imprecise tools and visible results, like polishing or milling.

Keywords: robotics; painting; art; generative method; brush

1. Introduction

E-David is an automatic painting system that uses an industrial robotic arm and a visual feedback system to create paintings. It can easily be adapted to varying painting styles, tools, surfaces and paints. Based on an input photo, the system creates a set of brush strokes and executes them using the robot arm. E-David aims to approximate the human painting process (Deussen et al. 2012). A variety of painterly rendering algorithms have been developed to work within the feedback-loop, in which the robot periodically takes a photograph of its progress and determines which actions to take based on the difference between the canvas and input image Lindemeier et al. (2013). These capabilities make e-David much more than just a printer capable of reproducing flat images, as it creates unique works through the application of paint strokes that are irreproducible in terms of colour blending and materiality of their layering. The possibility of visual feedback opens up many interesting questions within the contemporary discourse on deep learning, artificial intelligence and robotic creativity. One of them is the optimization of the painting process by eliminating unnecessary strokes in order to mimic a human's efficiency when painting Lindemeier et al. (2015).

Currently, the system uses a fairly static approach to painterly rendering. Strokes are painted with a brush held at a constant distance to the canvas throughout the entire process. The application pressure is never changed and the stroke width can only be varied by switching between brushes of different sizes. Furthermore, strokes are fully computer-generated for each image. Artists working with e-David have often expressed the desire to introduce their own strokes, which the system would then replicate. Knowledge about how a certain brush movement produces a stroke is also not retained. These limitations of the robot's painting technique decreased both the artistic and scientific usefulness of the machine, because much of the finesse required for detailed painting was lacking. The new methods presented in this paper allow for a much more controlled placement of strokes and thus more detailed and varied paintings.

In order to enable e-David to precisely draw strokes, we have developed several new methods designed to mimic the human process of painting. The first method involves measuring the width of a stroke produced by a brush at a certain application pressure. This allows the creation of pressure profiles that map the distance of the brush from the canvas to the width of the stroke. We then generalised this technology to measure the width of non-overlapping strokes of nearly any shape and size, as well as the movement used to paint them. Using knowledge acquired by the these two methods, a reproduction step was developed that recreates a stroke created by a human as closely as possible. Finally, we implemented a process that automatically improves the reproduction result by correcting deviations between the target stroke and the result. Each attempt is stored in a stroke database for later use in machine learning projects or as a repertoire for future painting.

On the artistic side of the project, Liat Grayver has been collaborating with the e-David team during the past three years in order to investigate methods to redefine one of the primitive forms of art—painting—in our current technology-based era. Specifically, this includes investigating new methods for the application of paint on canvas and for using computer-assisted generation of physical images. More broadly, the work aspires to harness computers and machines to establish new and innovative avenues in contemporary artistic practices. Grayver states:

> "One of the aspects of artistic practice in general, and painting in particular, is the attempt to manifest one's own personal or intimate perspective through materials into the public and social discourse. This is not only about the form or the finished object, but also about the process, the perspective and perception of a structure—all of which is defined by our dynamic surroundings and contemplated through the tools, mediums and technology of the present time and local place."

One could claim that the history of art and culture is aligned with the history of technological innovation. The creation of painting machines is an attempt to explore and create new methods of human expressiveness; making the machine to be, in a way, more compatible to human playfulness and creativity. A painting robot seeks to achieve a result that could be experienced and felt as similar to the human way of painting. In other words, something that is aligned to the duality one can find in a work of art: a level of randomness balanced with precision and expressivity merged with a complex mathematical architecture.

In the following, we provide an overview of painting machines, from the earliest works in the 1760s up to contemporary devices, followed by a brief history of e-David and works produced by the machine. Finally, aspects of brush control and single stroke reproduction are discussed from both a technical and an artistic point of view.

2. A Brief Overview of the History of Painting Machines: From Jaquet-Droz to Other Contemporary Practices

The history of automata reaches back to antiquity, with mechanical computers like the Antikythera mechanism from around 150 BCE de Solla Price (1974) and musical automata built by Ismail al-Jazari around 1200 CE Hill (1991). The first known surviving complex painting machines first appeared during the 18th century, as people in the western world began to develop an increased interest in mechanical devices Maillardet (2017).

2.1. 18th and 19th Century

The earliest fully automated painting machine currently known is the "Draughtsman" or "Artist"—one of the three automata built by the Jaquet-Droz family between 1768 and 1774 Bedini (1964). These automata are small dolls driven by internal clockwork-like mechanisms that coordinate their movement. A central control wheel holds many plates shaped in such a way that they can act as a cam[1]. Followers are shifted to a selected wheel, reading information from the wheel as it performs one revolution. The followers then transfer the motion through amplification mechanisms to the end effectors Droz (2014).

[1] A cam is a rotating disk, on which a follower rests. The changing radius of the cam moves the follower up and down, thus translating rotational to linear motion. This is for example used in combustion engines, where a camshaft opens and closes the fuel valve.

The "Musician" is a machine that plays a functional miniaturised organ by pushing the instrument's keys. The "Writer" produces a 40 letter text by reading each letter from a reconfigurable wheel and using an ink-quill to write on a sheet of paper Mahn (2013), Schaffer et al. (2013). This automaton is interesting as it represents one of the early programmable machines and introduces the concept of encoding information in shaped metal plates—a process that was later used to store sound information in vinyl records.

The "Artist" is capable of producing four different paintings: a portrait of King Louis XV; the couple Marie Antoinette and Louis XIV; a dog with "Mon toutou" written next to it; and a scene of a butterfly pulling a chariot Mahn (2013). Each scene consists of many lines drawn with a pencil that the automaton holds in its hand. These sketches are literally hard-coded into the metal cams inside the machine and cannot be reconfigured easily. The automaton and two of its stored drawings can be seen in Figure 1. Furthermore, the painter periodically blows away the graphite dust left behind by its pencil using an integrated air pump. This feature is not found in any contemporary painting robot, despite this being potentially useful for selectively drying paint Schaffer et al. (2013).

Figure 1. The "Artist" painting automaton by Jaquet-Droz (**Left**, Rama (2005)) along with two of the four images that it can draw: a portrait of Louis XV (**Top Right**) and a drawing of a dog with "Mon toutou" written next to it (**Bottom Right**) Droz (ca. 1770).

After Jaquet-Droz's early work, Henri Maillardet constructed the "Juvenile Artist" around 1800 (Figure 2). This machine is another automaton capable of writing and drawing using a quill or a pencil and was shown at exhibitions from 1807 to 1837. The device was delivered in 1928 to the Franklin Institute in Philadelphia in a disassembled state. Upon being restored, the automaton began to produce four drawings and wrote three poems stored in the mechanism, which also revealed the forgotten name of the original creator. Alongside the final poem, it wrote "Ecrit par L'Automate de Maillardet". Like Jaquet-Droz's machine, the "Juvenile Artist" also uses brass cams to store movement information that is transferred to the arm using followers Bedini (1964); Maillardet (2017).

Figure 2. Henri Maillardet's reconstructed automaton shown here without the original shell (Left, Maillardet (2011)) and the poem that identified the original builder of the machine Maillardet (ca. 1800).

2.2. From Modern Time to Contemporary Painting Machines

From their introduction at the beginning of the 20th century up to the present, automated devices have become widespread and range from simple appliances to industrial robots. The most common machines that handle paint are industrial paint spraying robots or simple plotters International Federation of Robotics (2016). These machines, however, are different from actual *painting* robots, of which only a handful exist. A painting robot is typically a machine built to replicate or create works similar to human art. It uses multiple paints or other pigments that it deposits on a painting surface with general-purpose brushes instead of specialized tools like paint nozzles. This class contains both XY-plotter based robots as well as robotic arms, both of which can operate with brushes.

Towards the end of the 20th century, as computer use became widespread, several artists created computer programs to autonomously generate art and explore the potential of creativity in machines. While their main output medium was a printer and a not an actual painting robot, their introduction of artificial creativity into the artist community was significant. The main actor in this was Harold Cohen, who in 1973 built AARON, a computer program designed to create images intended to be both artistic and original Cohen (2016). The program is able to generate objects with stylistic consistency, which Cohen has transferred to physical paper or canvas with "turtle robots" and printers. He states that AARON is neither creative nor a thinking machine, which raises the question if the output is art or not Cohen (1995).

Hertzmann, in a recent publication, states that artificial intelligence systems are not intelligent and that "artificial creativity" is merely the result of algorithms that generate output based on rules or by combining preexisting work Hertzmann (2018). He concludes that computers cannot generate art for now, as they lack the social component that human artists posses. He does, however, state that technology is a useful tool for artists to create better artwork.

Actual painting robots mostly arose in the 21st century, as the required technology became more mature and available to a wider audience. The number of painting robots currently in existence is unknown, as it is possible for hobbyists to create a functional machine from cheap hardware. Furthermore, many artists who use automata may not publish their work outside of exhibitions, thus making it difficult to estimate the use of painting robots globally. A selection of contemporary well-known robots and their creators follows:

CloudPainter, built by Pindar van Arman, is a software system that controls XY-Plotters and small robotic arms, which are able to use brushes to paint on a canvas Arman (2017). Van Arman presented his machine as a "creative artificial intelligence" in a TED Talk from April 2016 Arman (2016). This mainly refers to a TensorFlow Abadi et al. (2015) based style transfer algorithm.

TAIDA is a painting robot at the Taiwan NTU International Center of Excellence on Intelligent Robotics and Automation Research Luo and Hong (2016). It is a custom-built arm with seven degrees of freedom (DoF) that can dip a brush into small paint containers and paint on a flat canvas in front of the arm.

A specialised group of Chinese calligraphy robots exist that aren't used to create general artwork, but rather use specialised and often custom-built hardware to produce Chinese calligraphy. Examples include *Callibot* Sun and Xu (2013) or the *CCC* (Chinese character calligraphy) robot Yao and Shao (2006). Other unnamed calligraphy machines focus on brush mechanics Kwok et al. (2006); Lo et al. (2006); Zhang and Su (2005): using measurements of brush deformation, footprints and other mechanics, they optimise the painting of calligraphic elements, which allows them to create human-like writing.

3. E-David

E-David (An acronym for "Electronic Drawing Apparatus for Vivid Image Display") is the robotic painting system that has been under development at the University of Konstanz since 2008.

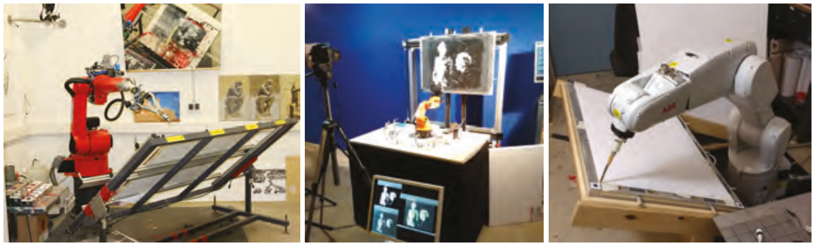
It has several features that distinguish it from other painting machines. An optical feedback system integrates information about the current canvas state into the painting process. E-David also has the ability to handle a large number of paints, to switch between brushes and to utilise sophisticated brush-cleaning methods for a cleaner result. Recent results can be seen in Figure 3. E-David is not a single machine, but rather a complex system consisting of hardware and software components.

Figure 3. Recent paintings created with e-David.

3.1. Hardware

E-David consists of a robotic arm mounted in front of a canvas. A brush is held by the arm and serves as the end effector. An accessory table holds a palette of colours that the robot dips the brush into, as well as mechanisms to clean and dry the brush before switching to another paint. A camera is positioned behind the setup such that it has a full view of the canvas, so feedback photos can be taken. These are used by the painting software described in the next section.

The main robot used by the project is a a Reis RV-20 6, which is intended for welding applications and machine tending. See Figure 4 for a photo of this device. The robot is also permanently bolted to the laboratory floor due to its weight and thus cannot be transported for events such as exhibitions. A mobile version, called "e-David Mini", was built using a small KUKA YouBot that was able to demonstrate the painting process in various locations. This setup has been demonstrated in Luzern in 2014 at the Swiss ICT award, and an upgraded version was shown in Leipzig in 2016 at an art exhibition Halle 14 (2017). A photo of the setup can be seen in Figure 4b. The YouBot turned out to be unsuitable for further work, as it lacks one degree of freedom, has no control software and developed mechanical defects after some use. Hence a new robot, the ABB IRB 1200 (see Figure 4c), has been acquired. A in-depth description of the technical aspects of the robots used can be found in Section 9.



(**a**) (**b**) (**c**)

Figure 4. The robots used for the e-David project. (**a**) Reis RV-20 6: The main robot (active); (**b**) KUKA YouBot: Mobile demonstrator (retired); (**c**) ABB IRB 1200: Mobile demonstrator (active).

3.2. Painting Software

After being given a digital image, e-David is capable of reproducing this target picture on a canvas using any paint that can be applied using a brush or a similar tool.

This painting approach is based on a *visual feedback loop*. The camera placed behind the robot provides a photograph of the current canvas state. By analysing differences between the current canvas state and the target picture, new strokes are computed and the robot is instructed to perform them. After a batch of strokes has been applied, a new feedback photo is taken and a new round of strokes is computed. This process repeats until the canvas looks similar enough to the input image. In each round, strokes are computed using a method similar to the Hertzmann algorithm Hertzmann (1998). The robot starts out with a large brush and performs several iterations. After each one, it switches to the next smaller brush, thus first generating a background followed by details layered on top.

A further benefit of the feedback loop is that it allows for error correction during the painting process. When the robot paints, inaccuracies in the painting occur due to deforming brushes, dripping paint and other hard-to-predict behaviours of the painting implements. Human painters circumvent these issues by avoiding certain behaviours based on experience, such as not keeping the brush too wet to prevent dripping, and by detecting mistakes visually after they have occurred and correcting them. While an effort is made to avoid defects in the painting through appropriate hardware design, some will inevitably occur. For example, the feedback mechanism detects a drop of paint as a colour mismatch and will draw over it using the correct colour.

The system is designed in such a way that any robot capable of applying paint to a canvas and providing feedback pictures can be used as an e-David robot. Only a driver, which translates between the e-David software painting commands and the robot, is required to be implemented for each machine. This is why there were no major redesigns required to accommodate a new robot. Today, the same software (save for the driver) operates both the RV-20 and the IRB 1200.

4. Methods

The general principle behind the current painting approach is to layer many strokes of thin paint upon each other. This allows the process to slowly converge onto the goal image. Strokes are placed according to a Voronoi-based optimization method, described in Lindemeier et al. (2015), which allows strokes to be arranged in a natural pattern and to adapt to their neighbouring strokes. The process is further extended through semi-automatic decomposition into layers for sharp corners and back-to-front painting Lindemeier et al. (2016).

The current process has several disadvantages. While up to five brushes of different size can be used by switching between them, the application pressure at which they are used is always constant. However, by varying the pressure, it is possible to achieve a continuous range of stroke width and to even vary width within a stroke. This is often used by human artists for detailing. Furthermore, the system does not take brush dynamics into account, so that brush deformation and other effects lead to the actual stroke deviating by several millimetres from the intended location. This effect becomes less visible when multiple layers of paint are applied, but makes detailing difficult.

In order to improve upon these issues, we explored new techniques for the precise placement of single strokes. The goal of the techniques described in the following sections is to develop a better robotic handling of difficult tools like brushes, and to include knowledge about their behaviour in order to achieve more precise results.

4.1. Physical Properties of Brushes and Stroke Width

When a brush is used to apply colour to a canvas, it deforms and changes its shape. This determines how colour is applied to the canvas. A human painter naturally varies the pressure of the brush hairs on the canvas in order to adjust the resulting stroke properties.

The e-David system has so far used a constant pressure for most created paintings, i.e., the brush is always kept at a constant distance from the canvas. Hence, stroke width is only dependent on the brush type and there is no variation within a stroke. A preprogrammed pressure ramp is used at the beginning and end of a stroke in order to make it look more natural, but the width remains constant for the main body of the stroke.

While brushes of various kinds are essential in many production environments, very little academic research has taken place concerning the exact prediction of brush deformation Przyklenk (2013). Many virtual brush models exist, however, with the most prominent being introduced by W. Baxter in 2004 Baxter and Lin (2004). This model treats a brush as a small set of polygonal strips that are simulated kinematically as several external forces act upon them. The resulting simulation is very useful in a virtual painting environment, but the simulated brush does not correspond to a real brush in a way that would allow predictions about the behaviour of the real brush. A realistic simulation of a brush that predicts its behaviour precisely enough for use with the robot would need to account for many parameters, for example bristle material, previous deformation, paint viscosity and so on.

Using a brush with today's industrial robots is problematic. The kinematic models used to coordinate the movement of robotic arms all require that the robot's tool has a so-called *tool centre point* (TCP). The TCP is assumed to be a static point solidly attached to the robot's end effector, which holds true for common devices like welding guns, drills or grippers—but not for brushes. Due to deformable bristles, the tip of a brush may vary in position after every stroke and the entire body of the bristles can be employed for transferring paint. Because brushes violate the assumptions of solid TCP of industrial robots, we have developed several compensation methods for e-David that account for variations in tool location. The first method accounts for stroke width as a function of pressure, while the second corrects for brush hairs dragging along the paper. The second method is described in Section 4.5.

4.2. Visual Feedback and Stroke Processing

The feedback camera is calibrated before use in order to obtain usable images for stroke analysis. The calibration process accounts for lens distortion, external lights and colour variations between cameras.

Lens distortion is corrected through a separate calibration process, during which a calibration panel of known size is placed in several locations. Using 25 or more calibration pictures a reprojection matrix is computed and the image can be rectified. This is necessary in order to obtain a canvas image in which distances between points are consistent, independent of their location in the frame.

Afterwards the canvas is calibrated for lighting, by placing a blank paper of uniform colour onto it. Differences in brightness are measured and a light map is generated, which is used to brighten dark areas in feedback images. This does not correct for glare, which can occur on wet paint and in general a soft, consistent light is still required for the feedback process to work.

The final calibration step is a colour correction. A calibration target of known colour is placed upon the canvas and a picture is taken. The resulting image is then compared to the known values and a colour transformation matrix is computed which can be used for subseqent feedback images.

Given the enhanced canvas feedback photo, a certain canvas region is specified as the input area. This subimage is thresholded in order to separate the stroke from the background. Otsu's method is used for thresholding. It automatically finds an adaptive threshold value by searching for an optimal partition of pixels in the image, based on the intensity distribution in the histogram Otsu (1979). While Otsu's method does have a certain bias and may not produce the optimum threshold Xu et al. (2011), it is sufficient for the black-on-white brushstrokes used here and even works with coloured strokes. The method has proven to be much more robust than a fixed thresholding value.

Afterwards, internal holes of the stroke are filled, as these are assumed to be defects caused by the brush running out of paint locally or even splitting.

Gaussian blurring is then applied in order to reduce the influence of certain stroke features on the result. These are small gaps within the stroke or frays caused by some brush hairs separating from the main brush body. However, the blurring may not be too strong, as this can remove thin parts of a stroke, which should be preserved. Hence the kernel size of the blurring algorithm is chosen to be 0.025 times the maximum dimension of the image. This value has been determined experimentally[2] and works well for many kinds of strokes.

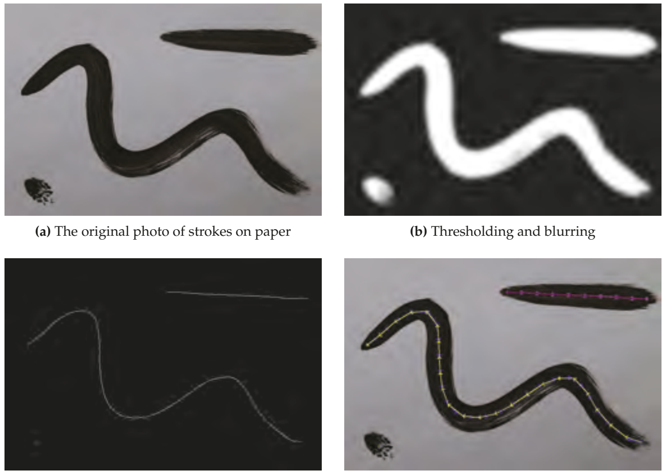
Using the thinning algorithm described in Zhang and Suen (1984), the strokes are reduced to single-pixel lines. Thinning a pixel image removes outer layers of an area until it is reduced to a topologically equivalent skeleton with a width of one pixel Baruch (1988); Hilitch (1969). The implementation of this technique has been taken from Nash (2013).

After having obtained the thinned image (see Figure 5), it is much easier to identify the beginning and endpoints of a stroke. These are simply white pixels with only one neighbour. While some cases exist where the start or end pixel can have two neighbours, for a first decomposition method it is robust enough. Beginning from the starting pixel, the line is followed by going from the current pixel to the next neighbouring one which hasn't been visited yet. This avoids getting stuck in a loop. The walk terminates if an end pixel is reached. If a pixel without unvisited neighbours is encountered but unvisited pixels exist, the algorithm backtracks, until it finds a pixel with unvisited neighbours. This corresponds to a depth-first search Tarjan (1972) and ensures that the full stroke is always explored. By doing this for every starting pixel, all possible ways to paint a stroke are found.

An example trajectory extraction can be seen in Figure 5. The original Figure 5a contains several strokes of varying shape and size. The lighting is not perfect and the centre stroke contains several defects. The hole filling and blurring (Figure 5b) removes most of them. The thinned Figure 5c exactly matches the strokes in the image, even the very noisy dot in the bottom left. Finally, Figure 5d shows the detected trajectories as a sequence of small arrows, which represent the calculated robot movements. Note that both possible directions are drawn, as the original direction cannot be reliably inferred from a stroke. Even humans cannot reliably guess whether the top right stroke was drawn from left to right or right to left without prior knowledge. In this case it was drawn starting from the right.

For use by the robot these 2D stroke trajectories in pixel space are transformed into 3D vectors in millimetres. Since both the canvas size in millimetres and the image size in pixels are known, a pixel coordinate can be transformed to its corresponding X/Y location in millimetres with a simple linear transformation.

[2] Smaller kernel sizes leave too much noise in the image, like frays. Larger sizes do not work well with thin strokes.



(a) The original photo of strokes on paper **(b)** Thresholding and blurring **(c)** Applying thinning **(d)** The detected movements along the stroke

Figure 5. Stroke detection.

4.3. Stroke Width Calibration

In order to calibrate stroke width, we first devised a technique for measuring how a brush behaves when it is applied to a canvas with varying pressure. In this case, the stroke width generated at certain pressures is of greatest interest. In the following, the term "brush pressure" is used to describe how firmly a brush is applied to the canvas by the robot rather than the physical pressure exerted on the bristles. The application is characterised by how far the robot TCP moves behind the canvas plane in millimetres. For example, at 0 mm, the tip is just barely touching the canvas and the brush is not deformed. At 2 mm the robot moves the TCP behind the canvas plane, i.e., the brush is held even closer to the canvas. Due to this collision, the brush hair deforms and the deformation increases as the TCP is moved forwards. For brevity, this is described as the "brush pressure in millimetres".

In order to control the variation of thickness within a stroke, the relationship between applied pressure and delivered thickness must be known for the current brush. Since commonly used paint brushes aren't manufactured to high precision standards[3], each brush must be measured individually. To this end a fully automatic process has been developed that determines the breadth of a stroke at a certain brush pressure.

The brush starts out 5 mm away from the canvas surface and is held perpendicular to it. The distance is reduced at a known rate while the brush is moved along a straight line at constant velocity, using the robot's linear path motion functionality. This yields a stroke on the canvas of increasing width. Within this stroke, the distance between brush and canvas is known at every point, which creates a map between pressure and resulting stroke width. By repeating this process several times, errors caused by external factors, such as clumping paint or a deformed painting surface can be minimised. The result of this procedure can be see in Figure 6.

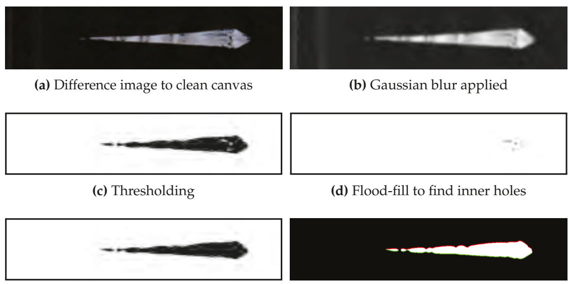
After painting the calibration strokes, a photo of the canvas is taken. Note that the calibration is robust against any background features, as only the calibration area is considered. Hence even a "noisy" canvas can be used, e.g., by placing a blank sheet of paper over it. A *difference image* is created by subtracting the resulting image from a photo of the canvas before painting the calibration strokes.

---

[3] Variations of up to three millimetres in bristle length and width have been observed during experiments.

This isolates the new strokes and makes it possible to use any colour for the calibration process, as long as it is sufficiently distinct from the background colour.

After some additional processing of the strokes, as seen in Figure 6, their width in pixels is measured in each available pixel column. The actual width in millimetres can be calculated, as the scale of camera pixels to millimetres on the canvas is already known. By collecting all these values, a table mapping pressure to width is created and stored for later use to determine the necessary Z for a desired width. A plot of measured values can be seen in Figure 7a,b.



(a) Difference image to clean canvas

(b) Gaussian blur applied

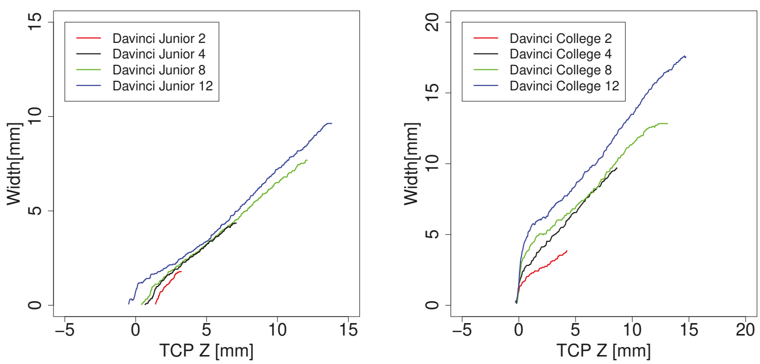
(c) Thresholding

(d) Flood-fill to find inner holes

(e) Cleaned stroke

(f) Measuring the width of the first and last white pixels encountered in each column of the image. Red and green pixels show the top and bottom stroke border respectively.

Figure 6. Pressure/Width calibration of a brush.



(a) Measurements for DaVinci JUNIOR brushes of sizes 2, 4, 8 and 12 performed on the IRB 1200 using gouache paint.

(b) Measurements for DaVinci College brushes of sizes 2, 4, 8 and 12 performed on the RV-20 using acrylic paint.

Figure 7. Measured relationships between brush pressure and stroke width.

In general, this methods yields good results: the detected widths were verified by measuring the calibration strokes with a calliper and no deviation was detected within a precision of 0.01 mm. This is in line with the camera's resolution of about 0.16 pixels per millimetre.

After a calibration run, the robot was able to draw strokes of a selected width with a precision of 0.02 mm to 1.32 mm, depending on the brush. Each brush has a range in which it performs best. For example, the DaVinci Junior 12 works well for strokes around 1 cm in width and becomes less precise for smaller widths around 5 mm, where the Junior 8 performs much better. Extremely fine strokes down to a width of 0.25 mm can be painted. The error introduced by the robot is negligible in this, as it has a positioning repeatability of ± 0.03 mm at its maximum speed of 7.9 m s^{-1} ABB (2017b).

Since the calibration is done at a TCP velocity of $100\,\text{mm}\,\text{s}^{-1}$ the robot can be expected to be more precise than the specified maximum error.

Accurate results were also obtained by using a linear model obtained from a regression on the data: the largest observed error between predicted and measured width was 0.5 mm with the largest brush. Smaller brushes, which are used to paint smaller features, show significantly lower errors. Stroke calibration is now done routinely for each new brush and stroke precision is highly repeatable, as so far no errors beyong the stated bounds have been observed.

A limitation of this method is the assumption that the painting surface starts out and remains flat throughout the painting process. However, materials such as paper are prone to warping, especially when water is applied to the surface along with paint. Another issue is the unpredictable flowing of paints such as ink, which quickly follows moisture in a paper canvas. For now, acrylic and gouache paint have been used for their predictable behaviour and limited warping of the canvas.

The data obtained here provides the basic information about brush behaviour that is required for stroke reproduction and self-improvement methods. For future work in robotic painting, this approach can be used to enable the machine to use a much more human-like approach to brush control.

4.4. Stroke Reproduction

The goal of the reproduction step is for the robot to recreate a stroke as precisely as possible when given only a photograph of the target stroke. This enables users to paint a stroke they would like to use in an image and have the robot store it for later use. Each reproduction also yields data about the difference between the target stroke and the reproduction result, which can later be used as a dataset for machine learning algorithms.

Through this feature, the robot gains the ability to produce a known stroke anywhere on the canvas. This is useful to create both patterns and details: repetition of a stroke can yield a surface with a certain structure. Placing a specific stroke in a precise location can be used by a painting algorithm to deliberately introduce detail or to speed up the painting process. This is in contrast to the current state of the art of placing strokes in a less directed way, which sometimes causes paintings to lack detail and sharp lines.

The reproduction of a stroke happens in four steps:

1. The user paints a stroke on the canvas in a given region on the canvas. This should be a non-overlapping stroke, as the method cannot handle self-intersections.
2. The robot takes a photo of the canvas and analyses the stroke by detecting its centreline. The stroke width profile is determined by using a version of the previously described width measurement, generalised for curved strokes.
3. The width profile is used to determine the Z-coordinates of the TCP along the trajectory. Since the width calibration described in Section 4.3 provides the stroke width achieved by a brush at a certain Z-coordinate, a simple lookup can be performed to determine the required brush pressure at each point in the stroke.
4. The stroke trajectory and required pressure at each point are combined into a 3D trajectory, which is then passed to the robot. It paints the stroke and takes a picture of the result for later evaluation. This yields information about the discrepancy between brush movement and resulting stroke.

Figure 8 shows an example reproduction. The chosen example is a fairly complex stroke that was painted using a brush with 12 mm long bristles, which deform significantly. Despite these obstacles, the achieved result is quite close to the original. In Section 4.5 a method is discussed that minimises these divergences. Stroke reproduction is highly repeatable, as long as the input stroke is of high enough quality. For example a "hollow" brush stroke, where the brush has run out of paint, cannot be be used or will cause the robot to attempt a reproduction of several strokes.

(a) Original with detected trajectory in red.

(b) Measured width of the stroke in each control point.

(c) Recorded reproduction result.

(d) Comparison of original and reproduction attempt

Figure 8. Reproduction of a stroke similar to the letter “b”.

4.5. Experimental Stroke Improvement

Despite working well in simple strokes, the reproduction process still suffers from inaccuracies in more complex strokes due to unknown brush dynamics. While the reproduced strokes can already be used for writing, the present deviations are an issue for other tasks. For example, if a specific detail like an eyebrow is to be painted in a portrait, even small errors can alter the overall impression. For this reason, we considered several possible solutions for e-David to increase precision.

One of these attempted to measure brush behaviour along curves in a similar fashion to the pressure-to-width calibration. The acquired data could be used to create a brush model that predicts the cornering behaviour of measured brushes. The measurement, however, would have to be made for a number of curve radii and pressure levels, which would have required an impractically large number of samples. Hence we decided not to use this approach of simulation.

Instead of virtual simulation we investigated a method for physical experimentation directly on paper. Physical experimentation has been used before in autonomous robot experimentation for biochemical research: for example, the ADAM robot, built by Sparkens et al. is a “robot scientist” that can autonomously formulate hypotheses about gene expression in yeast and then check these in a robotic laboratory, without human intervention Sparkes et al. (2010).

In our case physical experimentation is achieved by painting directly on paper and checking the result using the visual feedback system. The robot is given a *stroke prototype*, which has been painted onto the canvas by a human. The robot records this stroke using its feedback camera. Using the method described in Section 4.4, an initial *attempt stroke* is painted. Through observation of the difference between prototype and attempt, a new trajectory is computed. The experiment consists of painting this improved trajectory and recording the result. By repeating this process several times, the similarity of the attempt to the prototype stroke should increase.

Two strokes are compared by overlaying them. Their trajectories are computed and the deviation of the attempt from the prototype is determined in each point of the prototype. This is done by scanning along a line orthogonal to the prototype trajectory until the attempt trajectory is hit. Some special cases, like finding a correspondence to an unrelated part of the other stroke, must be considered. After discarding erroneous measurements, a new point is created for each control point in the original stroke. The new points are offset in the opposite direction of the measured deviation, which corrects for the deformed brush lagging behind the intended trajectory. For example, in areas of high curvature in the prototype stroke, the first attempt will commonly undershoot and be quite flat. In this case, the correction algorithm creates a more sweeping movement, bringing the brush to the correct location on the canvas.

5. Results

The work presented thus far is a step towards improving the brush handling capabilities of e-David. Fine-tuning the painting technique on a single-stroke level is an important part of producing results that is more similar to human works. The contribution here is threefold:

First, through the measurement of brush behaviour w.r.t. pressure, a primary characteristic of the utilized tool is included in the painting process. This allows adaptation to the complex dynamics of a paint brush and thus greater variation of stroke geometry. Second, stroke reproduction from visual examples is a new method for providing stroke data to the robot. It allows extending the robots capabilities via a demonstration instead of actual programming. Third, the experimental improvement of strokes as demonstrated here is the first step towards a self-teaching painting robot that can learn craftsmanship from own experimentation based on human guidance through example strokes.

5.1. Stroke Reproduction Results

An application of stroke reproduction is copying human writing, as shown in Figure 9. The example presented here was performed by the robot using only its optical systems. The prototype writing was photographed, each individual stroke was extracted and analyzed with the method described in Section 4.4. Additionally, the distance between strokes was preserved. Then the robot was able to write the presented text on a separate sheet of paper. In principle every type of writing or sketch can be reproduced with this method, as long as no self-overlapping strokes are used.

Figure 9. A reproduction of writing presented to the robot on the canvas without additional input. Human writing is shown on the **left** and the corresponding robotic reproduction on the **right**.

5.2. Stroke Improvement Results

Figure 10 shows an example of this approach producing an improved stroke.

The improvement method has approximated the stroke almost perfectly after one improvement iteration: Figure 10f is a difference image of the original stroke and the second attempt. Both strokes match very well in shape and size: the length is exactly the same and start and end points are located in the same position. The overall shape is also identical: the top loop, the long straight section and the bend at the bottom correspond precisely. Deviation can only be seen because of slight variations in stroke width. These occur since the width is not adapted between attempts, as this has proven to disturb trajectory approximation significantly. The general width profile is nevertheless still similar, as the middle part is thicker and width is smallest at the top loop. When comparing the original stroke and the improvement result without the difference image, both strokes are strikingly similar. Hence the method does successfully self-improve its painting technique.

All experiments have led to convergence between stroke prototype and the robot's attempt: while this is not always guaranteed, as random defects in the brush or paint could cause disruption of previously achieved progress, significant errors have not been observed during experiments so far. In general, the robot manages to reduce the average distance between prototype and attempt control points by approximately 14 mm each iteration, which has been achieved consistently in ten different experiments with varying stroke prototypes. The stroke in Figure 10a is about 110 mm tall for reference.

(a) Orignal human-painted stroke

(b) First attempt

(c) Comparison between attempt and original

(d) Improved stroke

(e) Comparison between original and attempt stroke

(f) Comparison between original and improved stroke

Figure 10. The steps performed for the stroke improvement method.

The main advantage of this approach is that no brush model is required to determine how to improve a stroke. The physical experiment is run with the real brush and the resulting stroke is used directly to infer an improved motion plan. As a consequence, the robot can adapt to any kind of disturbance, like a bent brush, unexpected paint behaviour, or other influencing factors. This saves a lot of effort in figuring out what parameters are relevant for the result and how they can be quantified.

The presented method has proven to work with all tested strokes: in every case improvement was observed over the initial reproduction attempt. Convergence was quickly achieved after a few attempts, because once a part of a stroke attempt matches the prototype well, that segment remains unchanged. Due to its simplicity, this model also provides a good baseline for future stroke improvement approaches.

Furthermore, as multiple experiments are run for every stroke, a lot of new strokes are gained for the stroke database. These are variations of the target stroke and can be used to analyse how a slight variation in motion changes the resulting stroke.

The main disadvantage of the experimental approach is that optimizing a stroke costs both time and material: as the robot moves slowly to avoid spilling paint, one optimization run takes at least one minute to complete and can take up to twenty. Hence time is still a major limiting factor for acquiring data about strokes. Furthermore, paper and paint are consumed and must be replenished, which as yet cannot be done automatically.

Another drawback is that only brush movement in the XY plane and pressure are considered as optimization parameters. Brush angle and twist are currently not accounted for. While most strokes can be approximated well enough using a brush being held perpendicular to the canvas, it could be necessary to include angle variation later on.

6. Discussion: Technical Implications

The feature we have developed that allows the robot to self-improve its strokes is a first step towards a painting process that can accumulate knowledge about the tools and materials being used. The inclusion of such mechanisms will allow the system to move away from the current static painting method and paves the way for more sophisticated paintings. The automatic improvement of a manufacturing process through observation of the results, as we have developed for e-David, might be transferable to industrial applications and make robots more suitable for new tasks. Current robots are able to detect internal failures Visinsky et al. (1994) or wear and tear Trendafilova and Van Brussel (2001) and some metal manufacturing machines can detect tool failure Tansel et al. (1995). These approaches all rely on motor sensor data, but in the case of tools which do not require much force to use, such a method might not be applicable. Hence visual checks of work progress can be useful.

Now that a simple method to improve strokes has been implemented, the generated data can be used in machine learning approaches. This can allow a learning system to predict brush dynamics by learning from past behaviour. Furthermore, a generalization to more complex brush movements or sequences of these can be developed in order to move from single-stroke painting to surface based approaches. Current learning approaches for style transfer Gatys et al. (2015) or artwork generation Elgammal et al. (2017) are pixel based. Moving from the pixel level to applying known discrete stroke or surface features could lead to improved results and mimic human works more closely. A prerequisite for this is to find a way to introduce the stored stroke data into such learning systems.

As a final note, because strokes were only handled as “solid” objects, methods that also consider how to develop a certain internal structure can be highly relevant as well. In conclusion, improving upon these details and including the techniques that create them into the painting process should make e-David paintings more detailed in the future.

7. Discussion of Artistic Implications: Human-Machine Interaction as a Neutral Base for a New Artistic and Creative Practice

In collaboration with computer engineers, neuroscientists and machine engineers, Grayver has been exploring new methods for the application of paint on canvas, as well as for computer-assisted generation of physical images, and has been using computers and machines in the service of exploring new aesthetic avenues in painting. This work aspires to constitute a novel venue for the establishment of new and innovative ground in contemporary artistic practices.

7.1. Artistic Motivation: The Importance of the Individual Brushstroke

The whole of artistic activity can be described as an instance of self-regulation. Order in painting is traditionally achieved through the self-regulation of the painter and by external intervention. It is necessary to distinguish between—and balance—those characteristics relevant to the realm of individual artistic perception and those that are external to the artist’s motives, intentions and preferences.

Generated data and robotic technologies are tools used in Grayver’s artistic practice to explore, retain and express visual information in relation to the digital and machine-based world we live in today. Her work with the e-David painting robot explores the different ways the body and mind perceive not only the visual objects themselves (such as painting), but also the process through which they are created—what is seen as a whole (form) and what is felt as energy (vector). Grayver states:

> "During the working process, passive materials (canvas, paper, wood surfaces, etc.) react to my active manipulation of materials upon them; both the passive and active elements are equally and reciprocally important to the process as well as to the finished work. Using and mixing different media in one work creates a rich context in which I explore the tension between marks that are made with bodily gestures and those made with different degrees of technological intervention."

Since 2015 Grayver has been exploring the general contemporary situation of painting and, more specifically, her own practice as a trained painter from a European art academy. She has dedicated herself to the exploration of the technological aspects of painting, returning to the elementary questions of painting, seeking to reflect on the relationship between image and objectness of the medium within the context of our technological era. Grayver states:

> "My engagement with the technical conditions of creating images—digital as much as traditional print- and paint-based—has greatly influenced my conceptual understanding of the painterly process in historical and contemporary practices, and has 'left a mark' on the evolution of my own artistic activities. Stimulated by the experience and by the exchange between informatics and the robotic world, I found myself to some degree compelled to challenge and reconceptualise the foundations of my painterly practice, starting with the bodily movement of the single brushstroke all the way to questions concerning control and loss of control in the creative process."

The practice of digital image-making represents a new manner by which images can be created whose sources are not derived from painting or photography, but rather arise through the writing of computer code, and are therefore not based on existing images of things. Such an approach makes it possible to deal with the cultural and psychological implications of our environment through symbols. This particular manner of creating images can of course encapsulate a huge amount of information, emanating from the most diverse sources—for example, fractal models from nature, physical phenomena and mathematical laws—that can then be translated into the visual domain. However, despite the widespread prevalence of digital image-making today, hardly any research has been conducted into the practice of translating images created via a computer simulation into the physical world using brushstrokes.

7.2. Artistic Collaboration

Since February 2016, Grayver has been collaborating with the e-David Project on the use of robotics as a painterly tool that can assist in the exploration and development of new creative and aesthetic approaches, and even in shaping our understanding of painting. The following describes her use of the robot in her private practice and interpretation of robotic arts. In this collaboration, the robot is used as a painting tool due to its nonhuman capabilities, such as very precise repetition of movements.

The focus of the collaboration has grown from more deterministic approaches of machine-based painting to dealing with contemporary questions regarding artificial intelligence (AI) and machine deep learning, and their use in the artistic domain. The interdisciplinary working platform between computer scientists and an artist can provoke a large range of questions regarding the use of robotics in the creative process of painting: How does one incorporate the use of computers and machines in the very intuitive and gestural practice of making a painting? How would we decompose the act of making a mark to a body movement (machine), taking logical decisions (computer) and emotional intentions (the artist)? Subsequently, Grayver established with the e-David team an official plan of collaboration in order to investigate human creativity through the interactive methods of computer-to-machine (simulated to real) and man-to-machine (artist working together with the machine) methodologies.

7.2.1. Composing a Painting from Individual Strokes

When Grayver first witnessed the e-David at work during a preliminary visit in January–February 2016, she was fascinated by the paths the robot chose to distribute strokes on the sheet once it began to structure a painting. To a trained painter like Greyver, the robot's stroke placement initially seemed to be illogical, strange, even arbitrary. But, it sparked a curiosity to understand the logic behind it, and illuminated an idea that the nonhuman attributes of robotic painting could cause us to rethink the practice of painting. In other words, to paint in a way that no painter would ever consider; to engage with decisions about forming and deconstructing an image; and to instigate and explore new approaches to structuring task order in the working process.

Through the collaboration, Grayver and the e-David team explored further possibilities to exploit the painting robot creatively and reflected on ideas about the ways in which these could be implemented in the form of software and hardware. A number of questions of wider impact arose as the result of the collaboration: When and why would a semantic method of defining the object in the image be used? Is it an advantage or a disadvantage to paint semantic objects without having a pre-existing cognitive understanding of them? How could we use abstract forms, grammatical structures or mathematical models to achieve more complex surfaces? How would computer language be used to express the intentions of a composition? When and why would different painting styles be used? Further, on a technical level, we had to take into consideration how different materials would react to one another. For example, how could different colours be mixed on the canvas or on the palette? How should the size of the brush be set, and when is it necessary to add glaze? We would have to develop a range of distinct, individual brushstrokes (controlling the velocity and the z-axis) whose characteristics are analogous to those made by human painters in the "real world", in order to be able to pre-define when, in which order and for which tasks each stroke is to be used. In doing so, we are basically defining and categorising singular parameters within a library of painterly "acts" and "perceptions", in order to create a grammatical structure for the "language" of robotic painting.

All of these questions—qualitative technical aspects, creative and aesthetic value, etc.—would need to be defined by the team and saved in the visual feedback of the robot as parameters or as rules. This led us to questions of control: To what degree should the robot's actions be controllable by humans? Should the robot make autonomous decisions? If so, at what stage? How would we evaluate the output of the robot (with such binary values as good/bad, or yes/no?). And how would these evaluations be saved to its memory such that the e-David would be capable of using this information "correctly", in turn enabling it to make new decisions about its actions in the next run?

7.2.2. Making Abstract Painting: Thinking in Vectors Instead of Pixels

The paintings series "Just Before it Snaps" (Liat Grayver and the e-David) is an investigation into abstract thought and experimentation with composition as energy fields that were configurations of vectors (Rudolph Arnheim's study on composition in the visual arts). Grayver was looking for the places or "border areas" in which the balance between coincidental and intentional brushstrokes created harmony on the visual surface.

From another point of view, these images were a stage for experimenting with the different painting materials used in the robot lab. Typically in human painting, the materials are controlled by the painter in a sort of interactive "ping-pong" situation. With the e-David robot, however, this is not the case as all of its actions must be predetermined and given as commands. The robot does not, for example, notice if the paint is dripping or has dried. It is exactly these limitations that are fascinating from an artistic point of view, as it stands in opposition to "normal" thinking and allows for the emergence of new, uncontrolled and surprising brushstrokes.

7.2.3. Grouping Singular Lines into Forms Using Nodes and Centre Points

In the early abstract works done with the e-David in June 2016 ("Just Before it Snaps", see Appendix A, Figure A1) individual painting operations were programmed such that the entire surface of the painting was treated equally (overall composition). Singular lines were used to construct the paintings, with each new line created according to given (programmed) variables. The first line was positioned according to a pre-determined starting point, and the location of each subsequent generated line was calculated in relation to the line painted before it. We had introduced into the system a strategy of dividing the painting into masks of colour areas using brushstroke patterns—sets of individual brushstrokes—in contrast to an approach using singular strokes. Masks were applied to fill in a section one colour at a time, according to pre-defined light and shade characteristics. In this series of paintings, the computer generates a set of strokes that are connected or related to each other due to their proximity of action, corresponding to the painter's bodily movement when performing similar tasks.

For the next step, we created a new set of paintings "Resisting Gravity" (Liat Grayver and e-David, Figure A2), using limited sets of zigzag and straight lines, as well as a grid pattern formed by intersecting brushstrokes. In order to give the patterns an organic and complex surface feel, and to break the precision and mechanical appearance of the repetitions, we defined the specific character for each set according to the following parameters: orientation of the set, curvature of individual lines within the set, centre point of the painted masks, angle of the meeting point of the two lines, number of strokes, and proximity between lines—all of which are subject to a degree of randomness.

This grouping of lines into blocks of paint enabled Grayver to incorporate the concept of a centre point as a parameter for the computer when generating a painting. This way, the brushstroke patterns are generated to be located either around or emanating from a pre-defined position.

In order to avoid the creation of a closed composition with poor visual tension, Grayver defined several centre points in a single painting. By experimenting with different colours and brushstroke characteristics (settings), the centre points can be made to support each other as visual nodes in the painting composition.

"Six Variations on Gestural Computer-Generated Brushstrokes" (Liat Grayver and the e-David, Figure A4), done in October–November 2016, is a series of computer-generated sets of brushstrokes that reflect the quality of spontaneous hand movement inspired by the practice of Japanese calligraphy. Using the e-David, Grayver repainted the same generated path again and again, each time on a new canvas, knowing that this kind of exact repetition of movement could never be achieved by a human hand. Each of the variations is an execution of the same path with an identical velocity. Nevertheless, the works are varied and can be distinguished from one other due to the use of different brushes and changes in the value of the colour, as well as variations in the viscosity of the paint and the number of times the robot was instructed to load the brush with new paint. Some of the variation applied the repetition using a layering method. Sometimes the paint didn't have enough time to dry, and so instead of the brush applying a new layer of paint, it actually scraped some of the paint off the canvas, creating some surprising and pleasing surface effects. To distinguish the layers from each other and to give the painting some visual depth, Grayver applied different painting techniques (glaze, colour variation, viscosity variation) and juggled with the information saved on the computer—for example, stopping the robot and restarting it at different points in the process or breaking and reassembling the loop action into fragments.

7.2.4. Perception of Brushstrokes Made by an Unconscious Body

Painting is a practice in which a complex architecture is constructed of separate sections that interact with each other as a whole in the form of a unified composition. While working on the e-David "Self-Portrait" (Figure A3), Grayver became aware of the need to divide the painterly process into different categories, looking into the different paths of the physical act (characteristics of individual brushstrokes) and cognitive decisions (semantic vs. abstract recognition of geometric forms) that the painter uses in the process of decomposing and reassembling visual information and material elements into a painting. More than that, the ability to save each step in the painting process and to compartmentalise and conglomerate information and action in different constellations, opens up a new field in the painting domain that explores the space between abstract and figurative painting. Grayver states:

> "Saving information in the painting process and creating, when needed, a distance between the painter and the painting (the painter is simultaneously the viewer and the executer) are two features that computer- and robotic-based painting offers the artist. As a painter and a consumer of art I wondered if I would be able to recognise brushstrokes done by a robot in a more complex, generated work. I wanted to play with this idea by generating strokes that appear gestural but are executed in a way that only a machine is capable of doing, namely, with exact repetition."

7.2.5. Traversing the Threshold of Materiality

The work "Traversing the Threshold" (see Figure A5) features a room installation of robotics-assisted calligraphic works that stretch into and expose the temporal and physical space of the artist's creative process through the mediums of robotic painting. What could have been executed as one painting constructed of thousands of brushstrokes has instead been decomposed and distributed over numerous sheets of rice paper.

The individual paper works are extracted from a complex of computer-generated particles (Simulation of a World Overview) according to Newton's Law of Gravitation. Scaled to different sizes, each can be viewed not only as an individual work but also as part of the modular wall installation. In the creation process, Grayver cropped different sections of the master particle generator and translated the individual particles into single brushstrokes (assigning parameters such as, for example, the size, length, pressure and speed variation of the strokes), before sending it to the e-David robot for the final execution.

The fragility of the ink-infused rice paper work in particular stands in sharp contrast to the industrial robot used to create them. As with Japanese calligraphy, the brush trajectories and the ink's behaviour as it penetrates the surface are of far greater importance than the perception of the object itself.

8. Conclusions

The e-David project is currently a rare fusion of technology and art. The original design goal of robots, namely to perform repetitive tasks at high speed, present limitations which we seek to circumvent through the new methods developed for e-David. Our novel techniques of brush calibration and self-improvement integrate tools that are imprecise by their nature into the framework of robotic precision. This allows e-David to be used as more than just a remote controlled brush and provides a base from which painting technique can be understood and automised.

A focus on single brushstrokes, or the painting of small features in general, allow the artists working with e-David to operate on a much higher level, and to forgo very low-level programming of the machine. The brushstroke, in its various manifestations, is the singular tool of communication that is encountered in paintings and drawings throughout all epochs. Our driving motivation in this cross-disciplinary artistic research is to study painting from the perspective of its most essential act, i.e., the process of making of a line as opposed to the study of the painting itself (the artistic object). Hence we have placed a special focus on single brushstrokes in our research.

E-David's new capabilities in the domain of painting technique and the collaboration with artists are moving the entire project closer towards producing both a robotic painter and a mechanised assistant for the human artist.

Future Work

For the future development of the project we envison three main areas of research:

We have established single strokes as primitves for the painting process so far. In next iterations of the software we will recombine these in certain patterns to fill surfaces with different structures. This will transfer yet more control of the painting process to the robot, thereby impacting the artwork created and how artists can use the machine.

The stroke experimentation creates a dataset of robot movements and the associated stroke. We will extend this dataset by enriching it with more information and by letting the robot collect new strokes for long periods of time. We will also explore how the robot can more efficiently perform its own experiments to streamline data acquisition.

The collected stroke data will form a basis for using machine learning (ML) techniques in the future. While the usefulness of ML for e-David must be evaluated closely, some promising and applicable approaches exist: Gordon et al. have developed a method that allows a learning agent to explore those aspects of a task it has very little knowledge about Gordon and Ahissar (2011, 2012). This is a natural extension of the experimentation with strokes conducted in this study, and will allow the robot to make more directed trials.

9. Additional Information: Detailed Technical Description of the Painting Setup

The current painting setup and operating principle of all e-David machines was originally designed and built by Deussen and Lindemeier, who initiated the project in 2008 Deussen et al. (2012), Lindemeier et al. (2013). The description given here contains both their previous development efforts and recent additions to it.

9.1. Painting Setup

The schematic layout of an e-David painting machine is shown in Figure 11. We place a robotic arm in front of a canvas, which acts as the workpiece. The canvas is angled such that singularities are avoided and that the working envelope of the machine is used optimally. The tool used by the robot is a brush of known length. The TCP of the robot is calibrated to lie exactly at the tip of the brush. The feedback camera is placed such that it has a full view of the canvas. Due to the placement of the robot between camera and canvas, it is necessary for the arm to move aside when a feedback photo is taken. We also set up a table for painting accessories next to the arm, where paints, exchangeable tools and a brush washing device are located. The washing device provides a water jet in which the robot holds the brush hairs to clean them before picking up a new paint which avoids cross-contamination.

Paints are held in small steel containers, which also provide an edge for the robot to wipe off excess paint. Currently there are no sensors to supervise the amount of paint remaining, but the 30 mL containers are usually sufficient for painting overnight. Paints are premixed by the operators and refreshed regularly.

The painting surface is mounted on a steel frame, which in turn is bolted to the robot's base plate. This ensures rigidity and avoids the need for frequent recalibration of the workpiece location. While the machine never applies significant force to the surface, humans tend lean on it while inspecting progress or cleaning. Previous wooden frames would move too much and even slight deviations would cause inconsistent stroke widths to appear.

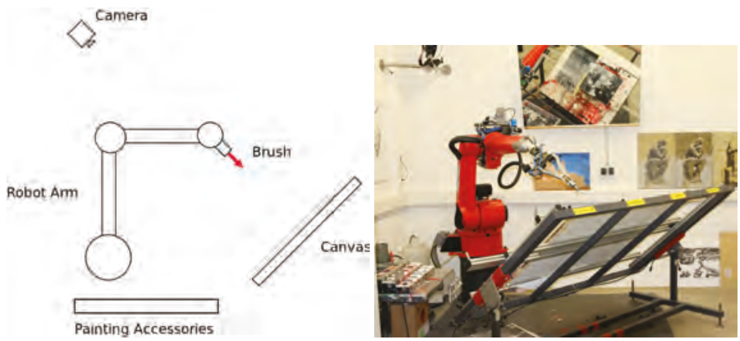


Figure 11. Schematic (**Left**) and actual (**Right**) layout of e-David.

9.2. Robots

We use six-axis industrial robots for e-David, as these provide a large degree flexibility in their use. XY-plotters have also been considered, but much more hardware effort is required to implement all necessary motions with such a machine. For example, the robotic arm is able to wipe its brush on the paint container after dipping the brush in it, in order to avoid dripping paint. This is a complex motion which has the brush follow a trajectory through dozens of points at varying tool orientations and velocities. An equivalent XY-plotter would require at least five axes to be able to perform such a motion. Furthermore, the robotic arms are a mature technology, widely used in the industry, allowing us to use common design patterns in our setup. The machines provide very good accuracy ($\pm$0.01 mm) and are very reliable.

Two robots are currently in use: The Reis RV-20 6 is a welding robot, with a range of 2800 mm and weight of 875 kg Reis (2012). It is a traditional manufacturing robot, being suitable for the production of cars or similarly sized objects. This allows the machine to work on large paintings, but makes the device unsuitable for being transported to exhibitions.

The ABB IRB 1200 is a general-purpose robot with an emphasis on a small form-factor and high speed operation. Unlike classical industrial robots, it is also suitable for medical applications or food processing. We bought this device due to its comparatively low weight of only 54 kg, as this makes moving it easy, given the right equipment ABB (2017b). The robot is attached to a 200 kg steel plate, which can be split into four pieces for transport. Figure 12 shows the robot being exhibited in Zürich.

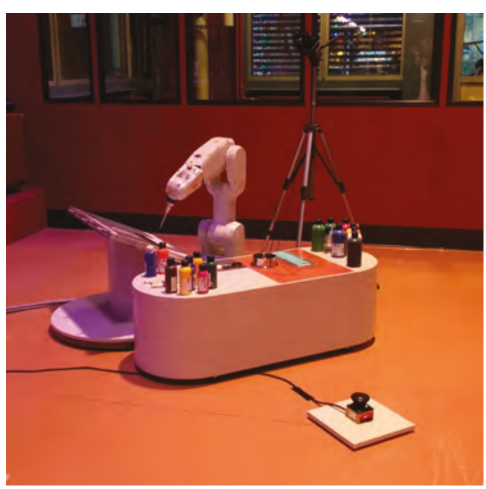


Figure 12. A mobile version of e-David being exhibited in Zürich.

Both machines need to be programmed in a manufacturer-specific programming language, which is RobotSTAR for the RV-20 and RAPID for the IRB 1200. We implement a network communication interface, which allows both machines to receive commands from a control computer.

The robot uses four coordinate systems internally: The *base coordinate system* has an origin located at the lowest point in the centre of the robots base. The *world coordinate system* serves as the basic reference point for all other coordinate systems. It can be used to define a robot working cell but in this case its origin point is set to coincide with the base coordinate system. The *tool coordinate system* has its origin point in the current tool centre point, or TCP. It defines the tool's orientation and can be used for moving a tool with constant orientation. The *work object coordinate system* defines the location and orientation of a work object onto which the tool is being applied. In the case of a painting robot, this is the canvas. Hence if the work object coordinate system is defined to be in a corner of the canvas, it is possible to reference points on the canvas by their XY-coordinate in the corresponding work object coordinate system ABB (2017a). Thanks to this mechanism, the painting software can use canvas coordinates which are easily transferable to the robot. An overview of all systems can be seen in Figure 13.

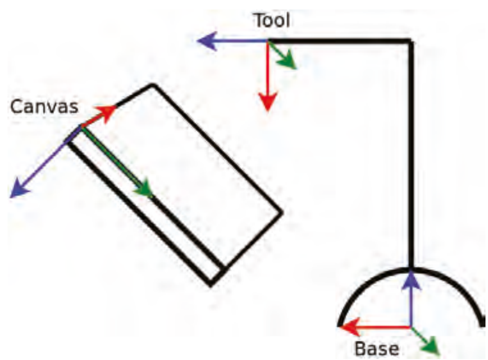


Figure 13. The coordinate systems used by e-David.

The canvas coordinate system originates in the top left corner of the canvas. The X and Y axes lie in the image plane, with the X axis being the horizontal axis. The Z axis is perpendicular to the image plane. Z is zero on the canvas surface and is positive behind the canvas. The Z axis points away from the robot and is used to control the brush application pressure. A Z value of zero causes the brush tip to barely touch the canvas and increasing Z increases the application pressure. We limit Z for each brush to a known maximum pressure to avoid inadvertently breaking the tool.

A note must be made that neither the Reis nor the ABB robot can be used collaboratively with humans. Both machines can operate at high velocities and can produce a dangerous amount of force. They cannot detect a collision with a human and are thus unable to limit forces upon a body part which is in their path. Hence the robots are kept behind light barriers which exclude humans from their working range while they operate in automatic mode. In manual mode, their speed is limited and the operator must use a dead man's switch when moving them. New collaborative robots are not planned to be included in the project, as they are expensive and there are no safety certifications for pointy tools such as brushes as of now.

9.3. Optical Feedback System

High quality DSLRs are used by the e-David system in order to acquire information about the canvas. Currently a Canon EOS 70D with a 20 Megapixel sensor and a Sony Alpha 6300 with a 24 Megapixel sensor are included in the setup. We use gphoto2 to transfer the images via an USB connection to the control computer. Transfer and analysis of a photo for feedback purposes can take up to a minute. However, since this time period allows the paint to dry, there is currently no need to optimize in this area.

Author Contributions: J.M.G. developed the new methods for brush handling and wrote this paper. O.D. initiated the e-David project and developed the painting process with Thomas Lindemeier. L.G. uses the machine for artistic purposes and wrote the section about artistic implications.

Funding: This research received no external funding.

Acknowledgments: We thank Carla Avolio for proofreading this paper. We also thank the anonymous reviewers for their feedback and Calvin Li for his assistance.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

TCP	Tool Centre Point
ML	Machine Learning

Appendix A. High Resolution Pictures of e-David Artwork

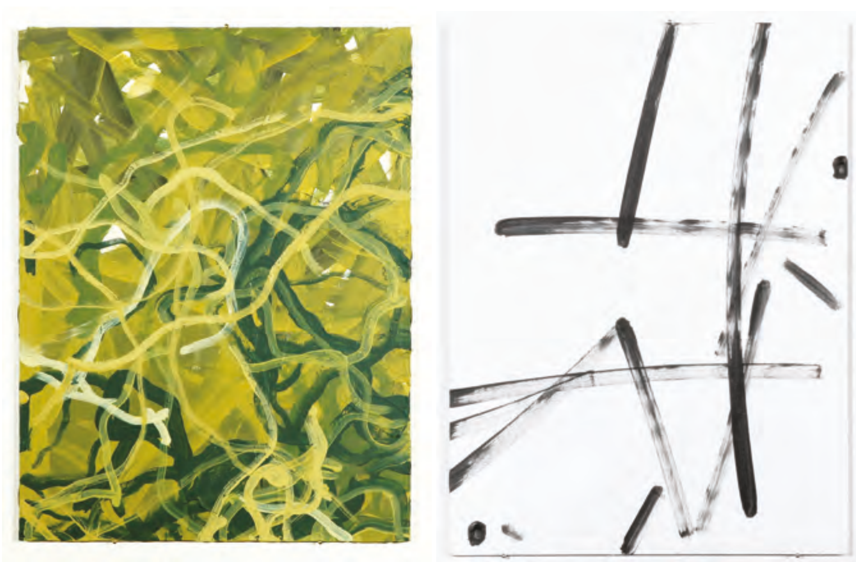


Figure A1. "Just Before it Snaps", Acrylic on canvas, 30 cm × 40 cm. 2016, ©Liat Grayver.

Figure A2. "Resisting Gravity in Blue and Red", Acrylic on canvas, 30 cm × 40 cm. 2016, ©Liat Grayver.

Figure A3. "e-David Self-portrait", Acrylic on canvas, 60 cm × 80 cm, 2016, ©Liat Grayver.

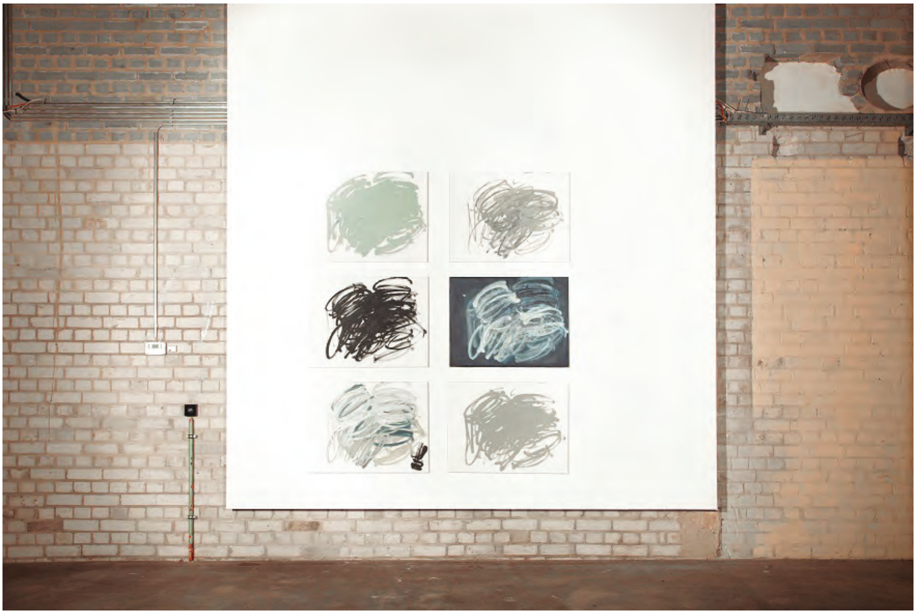


Figure A4. "Six Variations on Gestural Computer-Generated Brushstroke", six robotic paintings. Acrylic on canvas. 60 cm × 80 each. 2016. Exhibition view: "Pinselstriche im digitalen Zeitalter Interdisziplinäre Forschung in Malerei & Robotik" at the Halle 14, Februar 2017 Spinnerei Leipzig. Liat Grayver, photo ©Marcus Nebe.

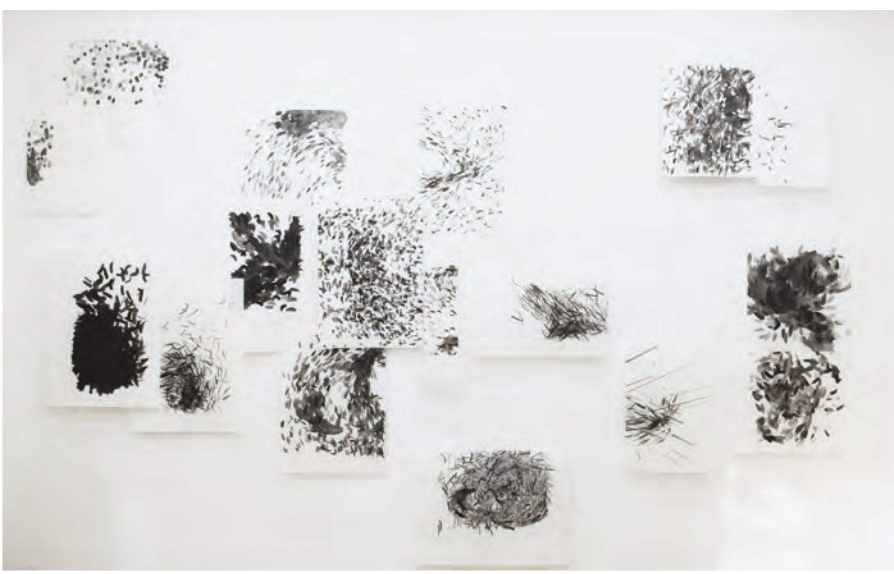


Figure A5. "Simulation of a World Overview", Exhibition view: "Traversing the Threshold" Room Installation of Robotics-Assisted Calligraphic Works and Videos in Collaboration with the e-David Project (University of Konstanz) and Video Artist Marcus Nebe. Exgirlfriend gallery, Berlin 2018. Photo ©Gabrielle Fougerousse and Exgirlfriend Gallery.

References

ABB. 2017a. Operating manual: IRC5 with FlexPendant for RobotWare 6.05. In *ABB Document ID 3HAC050941*. Zürich: ABB Download Center.

ABB. 2017b. Product specification IRB 1200. In *ABB Document ID 3HAC046982*. Zürich: ABB Download Center.

Abadi, Martín, Ashish Agarwal, Paul Barham, Eugene Brevdo, Zhifeng Chen, Craig Citro, Greg S. Corrado, Andy Davis, Jeffrey Dean, Matthieu Devin, and et al. 2015. TensorFlow: Large-Scale Machine Learning on Heterogeneous Systems. Available online: tensorflow.org (accessed on 25 August 2018).

Arman, Pindar Van. 2016. Teaching Creativity to Robots | |. TEDxFoggyBottom. Available online: https://www.youtube.com/watch?v=YYu0PdJSZcA (accessed on 21 March 2017).

Arman, Pindar Van. 2017. cloudPainter Website. Available online: http://www.cloudpainter.com/ (accessed on 21 March 2017).

Baruch, Orit. 1988. Line thinning by line following. *Pattern Recognition Letters* 8: 271–76. [CrossRef]

Baxter, William V., and Ming C. Lin. 2004. A versatile interactive 3d brush model. Paper presented at 12th Pacific Conference on Computer Graphics and Applications, Seoul, Korea, October 6–8; pp. 319–28.

Bedini, Silvio A. 1964. The role of automata in the history of technology. *Technology and Culture* 5: 24–42. [CrossRef]

Cohen, Harold. 1995. The further exploits of aaron, painter. *Stanford Humanities Review* 4: 141–58.

Cohen, Harold. 2016. Aaron Homepage. Available online: http://www.aaronshome.com/aaron/index.html (accessed on 5 September 2018).

De Solla Price, Derek. 1974. Gears from the greeks. The antikythera mechanism: A calendar computer from ca. 80 bc. *Transactions of the American Philosophical Society* 64: 1–70. [CrossRef]

Deussen, Oliver, Thomas Lindemeier, Sören Pirk, and Mark Tautzenberger. 2012. Feedback-guided stroke placement for a painting machine. In *Proceedings of the Eighth Annual Symposium on Computational Aesthetics in Graphics, Visualization, and Imaging*. Annecy: Eurographics Association, pp. 25–33.

Droz, Pierre Jaquet. 2014. The Draughtsman. Available online: https://www.jaquet-droz.tv/video/9309034/the-draughtsman (accessed on 8 January 2018).

Droz, Pierre Jaquet. ca. 1770. Paintings Produced by the Droz Automaton. Photograph by Rama. wikimedia commons, Cc-by-sa-2.0-fr. Available online: https://en.wikipedia.org/wiki/File:Automates-Jaquet-Droz-p1030415.jpg (accessed on 30 August 2018).

Elgammal, Ahmed, Bingchen Liu, Mohamed Elhoseiny, and Marian Mazzone. 2017. Can: Creative Adversarial Networks, Generating "Art" by Learning about Styles and Deviating from Style Norms. *arXiv* arXiv:1706.07068.

Gatys, Leon A., Alexander S. Ecker, and Matthias Bethge. 2015. A neural algorithm of artistic style. *arXiv* arXiv:1508.06576.

Gordon, Goren, and Ehud Ahissar. 2011. Reinforcement active learning hierarchical loops. Paper presented at the 2011 International Joint Conference on Neural Networks (IJCNN), San Jose, CA, USA, July 31–August 5; pp. 3008–15.

Gordon, Goren, and Ehud Ahissar. 2012. Hierarchical curiosity loops and active sensing. *Neural Networks* 32: 119–29. [CrossRef] [PubMed]

Halle 14. 2017. Zentrum für zeitgenössische Kunst. Pinselstriche im Digitalen Zeitalter. Available online: http://www.halle14.org/veranstaltungen/veranstaltungsarchiv/pinselstriche-im-digitalen-zeitalter.html (accessed on 11 September 2018).

Hertzmann, Aaron. 1998. Painterly rendering with curved brush strokes of multiple sizes. Paper presented at 25th Annual Conference on Computer Graphics and Interactive Techniques, Orlando, FL, USA, July 19–24; pp. 453–60.

Hertzmann, Aaron. 2018. Can computers create art? *Arts* 7: 18. [CrossRef]

Hilitch, C. Judith. 1969. Linear skeletons from square cupboards. In *Machine Intelligence 4*. Edited by Bernard Meltzer and Donald Michie. Edinburgh: Edinburgh University Press, p. 403.

Hill, Donald R. 1991. Mechanical engineering in the medieval near east. *Scientific American* 264: 100–5. [CrossRef]

International Federation of Robotics. 2016. World Robotics Report 2016. Available online: https://ifr.org/ifr-press-releases/news/world-robotics-report-2016 (accessed on 15 March 2018).

Kwok, Ka Wai, Ka Wah Lo, Sheung Man Wong, and Yeung Yam. 2006. Evolutionary replication of calligraphic characters by a robot drawing platform using experimentally acquired brush footprint. Paper presented at 2006 IEEE International Conference on Automation Science and Engineering, Shanghai, China, October 7–10; pp. 466–71.

Lindemeier, Thomas, Jens Metzner, Lena Pollak, and Oliver Deussen. 2015. Hardware-based non-photorealistic rendering using a painting robot. In *Computer Graphics Forum*. Chichester: John Wiley & Sons, Ltd., vol. 34, pp. 311–23.

Lindemeier, Thomas, Sören Pirk, and Oliver Deussen. 2013. Image stylization with a painting machine using semantic hints. *Computers & Graphics* 37: 293–301.

Lindemeier, Thomas, Marc Spicker, and Oliver Deussen. 2016. Artistic composition for painterly rendering. Paper presented at VMV 2016: 21th International Symposium on Vision, Modeling and Visualization, Bayreuth, Germany, October 10–12.

Lo, Ka Wah, Ka Wai Kwok, Sheung Man Wong, and Yeung Yam. 2006. Brush footprint acquisition and preliminary analysis for chinese calligraphy using a robot drawing platform. Paper presented at 2006 IEEE/RSJ International Conference on Intelligent Robots and Systems, Beijing, China, October 9–15; pp. 5183–88.

Luo, Ren C., and Ming-Jyun Hong. 2016. Robot Artist TAIDA. Available online: http://mjhung.wixsite.com/robotart-ntu (accessed on 14 March 2017).

Mahn. 2013. Les Automates Jaquet-Droz. Available online: http://www.mahn.ch/collections-arts-appliques-automates (accessed on 8 January 2018).

Maillardet. 2017. Maillardet's Automaton. Available online: https://www.fi.edu/history-resources/automaton (accessed on 8 January 2018).

Maillardet, Henri. ca. 1800 A picture of Maillardet's Automaton, Built Circa 1800. Photograph taken in 2011 by Daderot. Available online: https://en.wikipedia.org/wiki/File:Maillardet%27s_automaton_drawing_1.gif (accessed on 30 August 2018).

Maillardet, Henri. ca. 1800 A Picture of Drawing No. 1 of Maillardet's Automaton Created by Henri Maillardet Circa 1800. Photograph Taken in 2013. Available online: https://en.wikipedia.org/wiki/File:Maillardet%27s_automaton_drawing_1.gif (accessed on 30 August 2018).

Nash. 2013. Implementation of the Zhang-Suen Thinning Algorithm Using OpenCV. Available online: https://github.com/bsdnoobz/zhang-suen-thinning (accessed on 5 September 2018).

Otsu, Nobuyuki. 1979. A threshold selection method from gray-level histograms. *IEEE Transactions on Systems, Man, and Cybernetics* 9: 62–66. [CrossRef]

Przyklenk, Klaus. 2013. *Bestimmen des Bürstenverhaltens Anhand Einer Einzelborste*. Berlin: Springer, vol. 87.

Rama 2013. Les automates Jaquet-Droz, musée d'Art et d'Histoire de Neuchâtel. Photograph by Rama. wikimedia commons, Cc-by-sa-2.0-fr. Available online: https://en.wikipedia.org/wiki/File:Automates-Jaquet-Droz-p1030496.jpg (accessed on 30 August 2018).

Reis. 2012. Reis Roboter-Baureihe RV Technische Daten. Available online: http://reisrobotics.cz (accessed on 5 September 2018)

Schaffer, Simon, Paul Sen, and Nic Stacey. 2013. Mechanical Marvels: Clockwork Dreams. Available online: http://www.bbc.co.uk/programmes/b0229pbp (accessed on 8 January 2018).

Sparkes, Andrew, Wayne Aubrey, Emma Byrne, Amanda Clare, Muhammed N. Khan, Maria Liakata, Magdalena Markham, Jem Rowland, Larisa N. Soldatova, Kenneth E. Whelan, and et al. 2010. Towards robot scientists for autonomous scientific discovery. *Automated Experimentation* 2: 1. [CrossRef] [PubMed]

Sun, Yuandong, and Yangsheng Xu. 2013. A calligraphy robot—Callibot: Design, analysis and applications. Paper presented at 2013 IEEE International Conference on Robotics and Biomimetics (ROBIO), Shenzhen, China, December 12–14; pp. 185–90.

Tansel, Ibrahim Nur, Christine Mekdeci, and Charles Mclaughlin. 1995. Detection of tool failure in end milling with wavelet transformations and neural networks (wt-nn). *International Journal of Machine Tools and Manufacture* 35: 1137–47. [CrossRef]

Tarjan, Robert. 1972. Depth-first search and linear graph algorithms. *SIAM Journal on Computing* 1: 146–60. [CrossRef]

Trendafilova, Irina, and Hendrik Van Brussel. 2001. Non-linear dynamics tools for the motion analysis and condition monitoring of robot joints. *Mechanical Systems and Signal Processing* 15: 1141–64. [CrossRef]

Visinsky, Monica L., Joseph R. Cavallaro, and Ian D. Walker. 1994. Robot fault detection and fault tolerance: A survey. *Reliability Engineering and System Safety* 46: 139–58. [CrossRef]

Xu, Xiangyang, Shengzhou Xu, Lianghai Jin, and Enmin Song. 2011. Characteristic analysis of otsu threshold and its applications. *Pattern Recognition Letters* 32: 956–61. [CrossRef]

Yao, Fenghui, and Guifeng Shao. 2006. Modeling of ancient-style chinese character and its application to ccc robot. Paper presented at 2006 IEEE International Conference on Networking, Sensing and Control, Ft. Lauderdale, FL, USA, April 23–25; pp. 72–77.

Zhang, Kejun, and Jianbo Su. 2005. On sensor management of calligraphic robot. Paper presented at 2005 IEEE International Conference on Robotics and Automation, Barcelona, Spain, April 18–22; pp. 3570–75.

Zhang, Tongjie, and Suen Ching. 1984. A fast parallel algorithm for thinning digital patterns. *Communications of the ACM* 27: 236–39. [CrossRef]

arts

MDPI

Article

Waves to Waveforms: Performing the Thresholds of Sensors and Sense-Making in the Anthropocene

Richard Carter

Department of Media, Culture and Language, Southlands College, University of Roehampton, London SW15 5SL, UK; richard.carter@roehampton.ac.uk

Received: 1 September 2018; Accepted: 27 October 2018; Published: 30 October 2018

Abstract: This paper details the technical and conceptual background for the developing art project *Waveform*. This project is a creative-critical meditation on the role of digital sensors in monitoring and representing environmental change. It explores the origins and functioning of the global sensory architectures used to detect and assess these changes, deconstructing the connotations of omniscience, abstraction, and control associated with the 'top-down', data-driven mappings they generate. In so doing, *Waveform* enacts a speculative instance of how digital sensors can highlight the ambiguities and tensions of life in an increasingly damaged ecology. This experimental aspect involves capturing images of coastal shorelines using an airborne camera drone, and then analysing these using software that maps the outlines of incoming waves. The resulting data is then processed by software that generates text resembling free-verse poetry. These steps are not autonomous, and are subject to human intervention at each stage, with the generated poems being curated so as to engage themes concerning coast, a changing climate, and scientific knowledge-making. The outcome is an assemblage of artefacts, processes, and representations that can suggest alternative narratives of sensing and sense-making, so as to better apprehend the complexities of the present moment.

Keywords: sensors; drones; data; visualisation; computer generated text; anthropocene; machine vision; nonhuman agency; environment; poetry

---

1. Introduction

Commencing in the spring of 2017 *Waveform* is a speculative redeployment of varied technologies—airborne drones, machine vision, and automatic text generation—in search of alternative narratives of environmental sensing and sense-making (see Carter 2018). In this project, a camera drone is used to capture images of incoming ocean waves above remote coastal shorelines. These images are then analysed using a program that traces the nebulous threshold between land and ocean. The coordinates that plot this wavering boundary act as a source of variables for another program that generates text resembling free-verse poetry. The source vocabulary for this generator is curated to evoke different themes concerning the coastal environment, a changing climate, or the practices of measurement and classification in a scientific context. Each stage of this process yields distinctive visuals that are placed together in sequence, and it is this which constitutes the project's primary output.

The primary goal of *Waveform* is to generate a creative assemblage that both meditates and speculates on the role of digital sensors in environmental monitoring and representation. At one level, the project draws attention to the perceptual 'thresholds' of these systems and the outputs they generate. That is, how varied phenomena become observable and expressible as data, through the convergence of specific sites of interest, technologies of sensing, and contexts and techniques of interpretation. This is a depiction of the 'observable' not as the straightforward detection and recording of latent facts and measurements, but as emerging through a dialogue between multiple actors, both human and nonhuman. It is through this dialogue that intelligibility and significance are defined, interpretations become established, and taxonomic boundaries are drawn.

It is at this point that the project's more speculative aspects come into play. In using quantitative data to generate a form of poetic output, as opposed to a numerical graph, *Waveform* redeploys digital sensors as a framing device for modes of sense-making that fall outside their established thresholds of detection. In other words, *Waveform* adapts systems premised on sensing and representing the world in terms of the ocular, the abstract, and the quantifiable (digital cameras and machine vision software) in order to highlight their limitations, and so hinting at other, less privileged, modes of experience. These include the myriad uncertainties, critical aporia, and affective tensions of living amidst ecological crisis.

The aim of this gesture is not to suggest that these different modes of experience and sense-making are diametrically opposed, but that placing both into dialogue can help assemble narratives that are better able to capture the complexities of the present moment. That is, to recognise the multiplicity of perspectives at play, and the entanglements that exist between them. Ultimately, the aim of *Waveform*, as a creative endeavour, is to present a set of provocative artefacts to think with, whose respective histories, as will be discussed in this paper, give cause for reflection on the origins of contemporary ecological challenges, and how they might be represented.

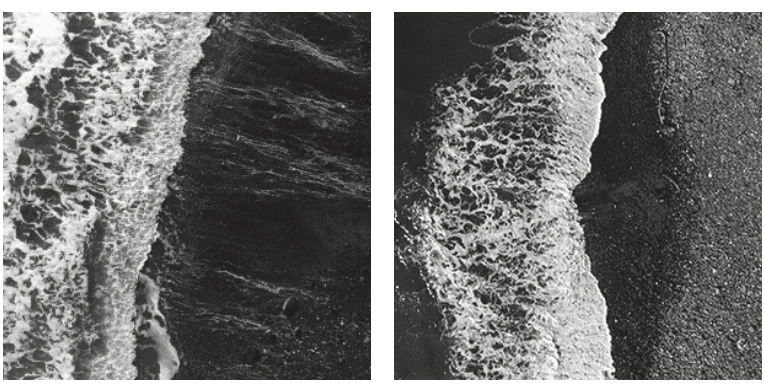
At the time of writing, *Waveform* is still at a prototypical stage in its technical and conceptual development, and is still subject to further improvements and revisions. Consequently, this paper is presented not as a final summary, but to situate *Waveform* with regard to related art works and theoretical debates. This academic background is an integral component of the project's outcomes, in its attempt at bringing into dialogue different modalities of thought, technology, and practice.

2. Technology

Prior to detailing the conceptual aspects of *Waveform*, a further word on the curatorial decisions and the technology behind the project, as these have been developed so far.

2.1. Location

The first stage of the creative process involves using a commercial camera drone to orbit at low altitudes above a coastal shoreline, taking still images of incoming waves from a top-down perspective (see Figure 1).



(**a**) (**b**)

Figure 1. (**a**,**b**) Two examples of the initial drone images, taken at approximately 45ft altitude. Source: Author.

The coastal environment itself, as a site of artistic enquiry and intervention, is a key point of reference for the *Waveform* project. In the context of contemporary climate science, the coast represents a vital domain for observing, monitoring, and experiencing the salient markers of rapid ecological transformation, e.g., rising sea levels, turbulent weather patterns, shoreline contamination, or cliffside erosion. Consequently, it represents a dynamic, liminal environment—a threshold not simply between land and ocean, but between the forces of climate, ecology, energy, technology, consumption, jurisdiction, and trade. The coast is thus a vivid site in which to observe processes that both shape and threaten the contemporary world.

All the initial photography for this project has taken place at a single location: a remote, Atlantic-facing beach in far southwest of the United Kingdom, known as 'The Strangles'. The origins of this sinister name are undocumented, but it is attributed locally to its bordering by jagged rocks and the presence of strong currents and riptides in the vicinity, making it a dangerous location for people and shipping alike.

The selection criteria behind this initial site was largely pragmatic, as dictated by flight safety requirements. The UK Civil Aviation Authority has published a 'drone code', which establishes legal minimum distances and maximum altitudes by which a drone can operate in the vicinity of people and infrastructure. Following these guidelines mean that only sparsely occupied areas can be flown over legally by unlicensed drone operators, and so ruling out many potential beach sites by default. The project itself thus required a suitably isolated location, which the challenging access conditions of 'The Strangles' provided. Nevertheless, this site also had additional attributes that resonated with certain themes of the *Waveform* project, and so further justifying its initial selection.

Just like many coastal sites facing into large oceanic currents, shoals of human generated detritus wash ashore daily at this location, and can build up substantially. The remoteness of 'The Strangles' ensures that large piles of debris are a frequent occurrence on the shoreline, offering evidence enough of the inescapable impact of human activity. Moreover, its high plastic content is a vivid indicator of the petrochemical industries that drive an energy-intensive global economy, and the excessive consumption, wastage, and pollution this generates.

A more intriguing aspect of 'The Strangles' is that it is located very near the landing sites where key submarine data cables arrive from across the Atlantic. These cables are an essential component of internet infrastructure, and their configuration traces the histories of colonisation, conflict, and multinational capitalism that underpinned its emergence in a Cold War context (see Starosielski 2015). These same histories are implicated in present ecological challenges, sitting alongside the fact the internet is now integral to the global sensory architectures which monitor them. While this site cannot claim any especial significance here, it is one of the closest such beaches in the region that can be flown over by a drone. Consequently, as an initial setting for an act of speculative sense-making, emerging out of the concerns outlined above, 'The Strangles' afforded an apposite space in which to prototype the concept.

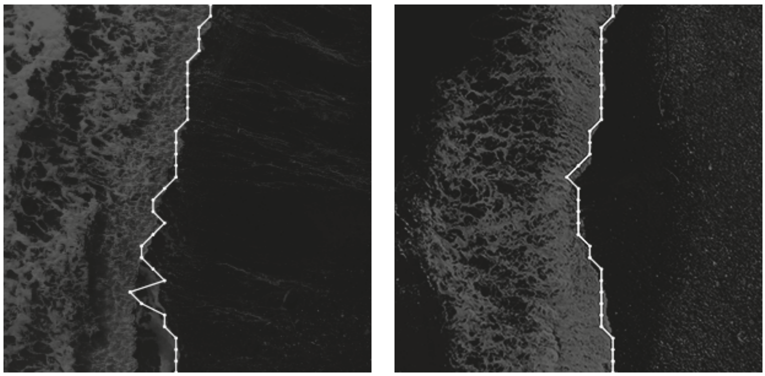
Nevertheless, it should be stressed that the future intention of this project is to document multiple sites of interest, with the aim of engaging not just the relatively high-level concerns identified here, but to interrogate sites whose social geographies provide more localised accounts of current ecological stresses.

2.2. Photography

The capturing and selection of the source imagery for *Waveform* is dictated significantly by the levels of contrast present in the scene—between the white of the incoming wave crests and the dark sands of the shoreline. This is crucial, because it is in detecting this contrast that the machine vision software attempts to delineate the threshold between land and ocean.

To explain, the image analysis software (developed using the open source *Processing* toolkit) divides a grayscale source image into a grid of 64 sampling fields. These fields are then mapped according to their overall brightness values. The modal brightness value of the sampling field is then calculated, and matched according to a predefined index pallet (16 colour, grayscale), so as to facilitate comparison with the other fields.

The comparison process involves assessing the contrast levels between a given sampling field and its surrounding neighbours. Those passing a certain threshold along a linear path are then designated as marking the edge of the incoming wave. The coordinate values generated are then stored in a two-dimensional array which is used to draw a wave outline upon the original source image (see Figure 2).



(**a**) (**b**)

Figure 2. (**a**,**b**) Wave edge detection. Source: Author.

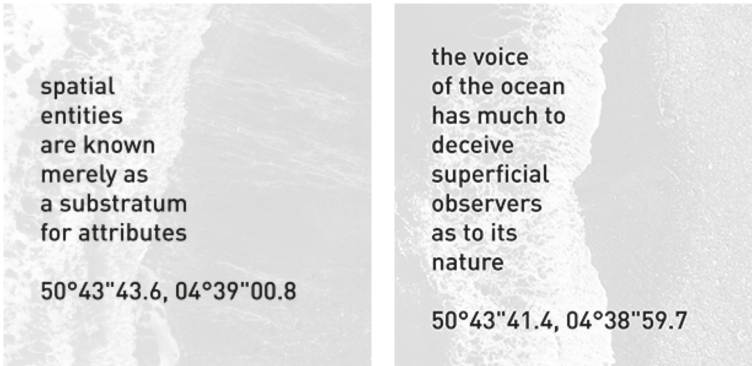
This outlining process is uncertain by design. In cases where the source image exhibits a high level of contrast between wave and shore, it is often tightly conformal. However, in cases where the shoreline is interrupted by the presence of rockfalls and patches of sea foam, the excess contrasts can make the wave outline oscillate considerably. A simple smoothing routine attempts to eliminate the worst of these outliers.

The coordinate values generated in the process of drawing the wave outline are then passed on to another program (also developed with *Processing*) that generates the final textual outputs. The relationship between these values and the texts resulting is that they constitute a supply of random variables for the generative program, providing the dynamo for its linguistic constructions.

2.3. Text Generation

The generative program itself is built around the principle of a Markov-chain. A source text is scanned to detect particular frequencies of word groupings within it, n-grams, before constructing a table recording the relative probability by which they occur in relation to one another. Selecting an arbitrary n-gram will suggest those most likely to follow, and so determining the other probable options for the next link in the linguistic chain. Making random selections from across these interlinked possibilities, weighted in accordance with their probability distribution, can result in outputs that echo the coherency of the source, but yield novel semantic juxtapositions.

It is this schema that enables the arbitrary values of wave coordinates to be used for generating coherent textual outputs. Once the initial n-gram to build the linguistic chain is chosen arbitrarily by the system, the rest are determined by the coordinate values. Nevertheless, depending on the initial choice, myriad different strings can be assembled with each execution of the program, and it is left to the artist's discretion which are finally associated with the source image. The criteria in these instances are whether the output is grammatically coherent, and whether it resonates at some level with the themes of the project (e.g., maritime, scientific, or environmental). The generated string is divided automatically into short lines of between three to six syllables each, and then overlaid finally onto the source image—along with the latter's geographic coordinates of latitude and longitude (see Figure 3).



(**a**) (**b**)

Figure 3. The final generated text. The source text for (**a**) was Alfred North Whitehead's *The Concept of Nature* (1920), and for (**b**) R. M. Ballentyne's *The Ocean and is Wonders* (1874). Source: Author.

Given the potential for many different output strings, and the consequent demands of curating only one for final display, care is necessary when selecting the source texts supplying the vocabularies used by the generative program. The choices made thus far encompass a mixture of fictive and factual works with themes relevant to those of *Waveform*, and thus likely to yield appropriate output. These texts are: R. M. Ballantyne's *The Ocean and its Wonders* (1874), which is a lyrical maritime exposition; Paul Edwards *A Vast Machine* (2003), reflecting on the evolution and politics of climate modelling; Alfred North Whitehead's *The Concept of Nature* (1920), and Annie Dillard's *Teaching A Stone to Talk* (2003), a poetic meditation on how the natural environment is variously captured in the fields of science and literature.

When generating a text to accompany each image, these literary sources are sequenced in-turn, exploring their varied possibilities of expression. Out of the above listed, those which have yielded the most coherent outputs so far, and from which the examples in Figure 3 are derived, are Ballentyne's *Ocean*, and Whitehead's *Concept*. With its frequent references to varied maritime phenomena, Ballentyne's writing style ensures that any text generated will often resonate with its accompanying coastal imagery. Moreover, being written at a time of growing interest in investigating the polar regions, *Ocean* mixes descriptions of danger and uncertainty in the face of the unknown with its framing using the tools and vocabulary of the scientific method. Whitehead's *Concept* is an extended meditation on the latter, interrogating the relationship between perception and knowledge, and thus yielding a vocabulary centred on acts of measurement and classification. However, whereas Ballantyne's text is characterised by its straightforward acceptance of scientific knowledge, Whitehead critiques its very foundations. Notably, Whitehead rejects the philosophical 'bifurcation of nature' into (subjective) sensed experience and an (objective) cause of these experiences. In its place, Whitehead posits sensing and knowing as an event in time—as concurrent, embedded, and contingent, rather than a reflection of the absolute.

Although *Ocean* and *Concept* represent very different texts for different audiences, they nevertheless bracket a period in history when the Enlightenment vision of an objectively knowable, progressive, rational universe was being complicated by new scientific discoveries and, later, the cultural disillusionment of the First World War. In this regard, the texts in Figure 3 echo the sentiments of their differing sources, with the presumed superficiality of sensed experience (3a) giving way to a recognition of the arbitrariness in separating the fundamental and perceived attributes of the world (3b).

As will be discussed in the next section, contemporary discourses surrounding climate and ecology are characterised by a similar recognition of the entanglements of scientific knowledge-making in the very phenomena under study. Such critical reflexivity takes on especial importance in this context, for the latest predictions derive from mapping events that far exceed the spatial and durational thresholds of the human senses. Whitehead's *Concept* represents an antecedent to the discussions of the present moment, and both are responding to the historical mindset seen in Ballantyne's *Ocean*. While these aspects will not be immediately present to the viewer of *Waveform*, they do, nevertheless, contribute to its critical background, and provide an apposite point of reference as it interrogates the future of sensing and sense-making in the contemporary environment.

3. Sensing the Anthropocene

The *Waveform* project first emerged in response to the varied implications of the 'Anthropocene' hypothesis developed by Crutzen and Stoermer (2000), in which the Earth is characterised as entering a new geological epoch. Here, the impact of human activity on the material ecology of the planet is seen as being irreversible and fundamental, in the form of changing climactic patterns, rapid losses in biodiversity, and the residues of nuclear technology.

Although the Anthropocene has yet to be formally ratified by international bodies (as of the time of writing) it has become a term deployed with increasing frequency in the critical and creative arts, calling for a reimagining and, indeed, a remaking of human relations with the material ecology of the planet (see, e.g., Davis and Turpin 2015). In these contexts, however, the term 'Anthropocene' is far from uncontested. Moore (2016, p. 6) is one longstanding critic, and, amongst other objections, designates the Anthropocene as a label for symptoms in isolation of their causes, suggesting in its place 'Capitaloecene': 'as a way of organising nature—as a multispecies, situated, capitalist world-ecology'. Haraway (2016) notes similarly that the conditions of the Anthropocene have emerged within the specific political, social, and technical contexts of a globalised petro-capitalism. Nevertheless, Haraway goes further in her critique, objecting to both the Anthropocene's and Capitalocene's depiction of a unitary human condition, exceptional in its agency above all other phenomena, and the consequent apocalypticism of an epoch premised on humanity rendering its environment unliveable. Haraway's alternative suggestion here is 'Cthulucene', a deliberately monstrous label, highlighting the seething interrelations that have always existed across species and processes, as well as the myriad stories and ways of seeing that emerge from these exchanges.

Although it is beyond the scope of this paper to contend for which of these labels are most useful, they reveal a desire to unearth a multiplicity of more nuanced outlooks, as compared to the sweeping narratives implied by an epochal marker. Even within the technoscientific framings that Haraway associates with Anthropocene discourse, there is a growing enquiry concerning the primacy of electronic sensors in defining its key parameters, with the consequence of bracketing anything that exceeds their thresholds of detection. In this regard, Bolen et al. (2016) note the formative role these systems have played in characterising the Anthropocene:

> [I]deas of the Anthropocene have been shaped by a technospheric net of innumerable satellites, cameras, and detectors, resulting in an aesthetic regime composed of data that has been used to narrate profound changes to climate, landscape, and biodiversity over the past 400 years.

The critical questions arising here go beyond surveying the basic functioning and deployment of environmental sensors, and include the epistemic assumptions they encode, as well as the representations they produce subsequently. It is here Bolen et al. (2016) enquire:

> If quantification, abstraction, and the logic of evidential traces have been the means by which we've largely come to recognize our purported Anthropocene condition, then the question becomes how we might proceed so that our "sensing" is less "remote," and forge aesthetics that incorporate not only the representational, but also the lived and affective experiences of various anthropo-scenes.

The chief contention here is that sensory systems, as they have been used to map epochal changes in climate and ecology, have generated representations of the world primarily in terms of the purely quantifiable—as statistical trend lines on graphs, rather than the lived experiences through which they concretely manifest. Although the utility of such actions for the modern scientific method are not disputable, the implication is that to craft a mode of 'sensing' that draws attention to these wider experiences can facilitate a more responsive ecological praxis.

To illustrate the kinds of immanent perspectives that can be missed by this data-driven episteme, Schuppli (2014, p. 60) recounts how indigenous peoples living in the Canadian Arctic have begun observing the sun setting further into the West, and the alignments of stars appearing to change:

> Sunlight is behaving differently in this part of the world as the warming Arctic air causes temperature inversions and throws the setting sun off kilter. Light is bending and deceiving eyes that have tracked the position of the sun for generations, using it as an index of place and a marker for direction. The crystalline structures of ice and snow are twisting and morphing, producing a new optical regime borne out of climate change and indigenous observations.

These stories were captured in a series of interviews with Inuit elders in the documentary film *Inuit Knowledge and Climate Change* (2010), by Zacharias Kunuk and Ian Mauro. However, Schuppli notes that it was met with some hostility by parts of the scientific community, who rejected the credibility of these indigenous accounts on the basis that they had misidentified their cause—suggesting the Earth had tilted on its axis (2014, p. 63). While such views might indeed be scientifically inaccurate, the experiences leading up to them remain cogent for understanding (and, crucially, empathising) with the far-reaching impacts of human collective agency on geophysical processes.

Cosgrove (2001) documents exhaustively the varied drives behind perspectives that emphasise the global and the absolute, over and above the kinds of uncertain, varying accounts associated with more local experiences and relations. Cosgrove (2001, p. 243) notes especially how, in a post-war environment:

> The sense of closed global space that had disturbed the strategic thinking of so many Westerners at the beginning of the twentieth century found expression in a global geopolitics of competitive imperial struggle as the frontiers of Western empires converged at the ends of the earth. Mapping the globes climates and physiography into "natural" regions could naturalize patterns of control and strategy among the imperial powers. Geopolitics suggested that unalterable geographic "realities"—the distribution of lands and seas, of landforms, natural resources, or "races"—had to be exploited if a state was to survive, compete, and prosper.

Cosgrove observes how these attitudes were facilitated by infrastructures of sensing and data collation that present a totalising, top-down view of the world—such as provided by orbiting reconnaissance satellites, and the military drive towards establishing an omniscient 'God's Eye View' over the battlespace environment. The resulting energy and resource intensive economics of geopolitical competition are seen in the key ecological and climactic markers of the Anthropocene (or, indeed, the Capitalocene), which thus becomes in-part a consequence of measuring and representing the world purely in terms of political and capitalist exchange.

It is in response to such developments that Müller-Hansen (2016) asks how we might engage in the 'process of making possible a new sensorium, one that is better adapted to the world as it is and behaves?' He notes subsequently that 'Sensing has its own politics' and that 'how we construct, train, apply, and critically engage with this new sensorium' will be vital when intervening in the structures of power that are most implicated in key ecological stressors. For Müller-Hansen, the Anthropocene thesis represents 'a call to re-forge our sensory-aesthetic practices, so that we sharpen our powers of judgment with respect to the epochal transformations currently underway [...] a call to re-forge our sensibility toward the Earth'.

4. Airborne Sensing

Evocative though such rhetoric of a 'new sensorium' may be, questions arise immediately as to what this might resemble in practice. The basic suggestion is that it will document life within a material ecology subject to accelerating change and disruption—and perhaps be reflexively aware of its own role in these transformations—but how this might be achieved is left open to speculation.

One possibility implicit within the very conception of a 'new sensorium' is the creative redeployment of existing sensory systems and platforms. That is, to reorient their established utility, the representations they generate, and the types of knowledge they crystallise.

4.1. Aerial Activism

An example of this can be found in the Aerocene Foundation of artist Tomás Saraceno (working in collaboration with many others). 'Aerocene' is a label for a speculative new epoch, a conscious response to the Anthropocene that replaces its bleak prognosis with a more hopeful array of imaginaries and practices. Concurrently artistic, activist, and scientific, this project seeks to overcome 'extractive' attitudes towards the circulation of energy and resources, facilitating instead a more collaborative, ethical relationship towards atmosphere and environment. This is achieved through freely distributing open source 'Aerocene Explorer' kits, enabling participants to construct floating sculptures whose buoyancy is achieved through entirely passive means. As described, these kits are '[d]esigned to engage participants in thinking-through-making', educating them in varied fields of physics and meteorological science, as well as inspiring their creative agency in declaring 'independence' from fossil fuels (Aerocene 2018).

Each Explorer carries multiple onboard sensors for documenting the ensuing voyage, including detectors for altitude, temperature, pressure, humidity, as well as motion trackers and cameras. It is these latter devices especially that facilitate a more creative, speculative engagement with atmospheric sensing and exploration. The motion trackers, for instance, are described as enabling digital visualisations of an Explorer's airborne trajectory—passive 'signatures' that contrast with the gridded striations of modern air travel, and the energy paradigms it embodies (Aerocene 2018). Likewise, the shaky, wind-blown output of the onboard cameras become records of the singular character of each voyage, and thus evocative of a new environmental imaginary, one that is more idiosyncratic, nuanced, and contingent upon the interplay of both human and nonhuman actors.

While there is a diverse body of critical literature surrounding the Aerocene Foundation, in the context of this discussion it can be framed as a response to the consumptive impulses and extractive infrastructures associated with the Capitalocene paradigm especially. Just as sensory architectures are integral to latter, they are equally so with Aerocene, but here become instruments of diverse communities of practice, yielding a distributed matrix of perspectives. This stands in opposition to the centralised infrastructures and 'top-down' mappings of military and commercial systems, as documented by Cosgrove.

Another sensory project conducted on a similar premise to Aerocene was *PigeonBlog* (2006) by Beatriz da Costa. *PigeonBlog* was billed as a grassroots scientific initiative, collecting localised air pollution data across the southern Californian region. The project involved fitting homing pigeons with GPS trackers and miniaturised pollution sensors, before having them fly regional circuits. The data collected was then visualised in real-time, being plotted over Google Maps for the public to observe (see Da Costa 2017).

There were multiple goals sought by the *PigeonBlog* project, but of particular interest to this discussion was Da Costa's (2017) performative approach towards airborne sensing:

> With homing pigeons serving as the "reporters" of current air pollution levels, Pigeonblog attempted to create a spectacle provocative enough to spark people's imagination and interests in the types of action that could be taken in order to reverse this situation. Activists' pursuits can often have a normalizing effect rather than one that inspires social change.

> Circulating information on "how bad things are" can easily be lost in our daily information overload. It seems that artists are in the perfect position to invent new ways in which information is conveyed and participation inspired. The pigeons became my communicative objects in this project and "collaborators" in the co-production of knowledge.

PigeonBlog thus staged an act of speculative sensing, one that entered into a collaboration with nonhuman partners so as to inspire new ways of seeing and thinking amongst its human observers. On this point, Haraway (2016, pp. 23–24) reads *PigeonBlog* as a striking instance of the exploratory kinships that are of particular import for life in the Cthulucene: 'Perhaps it is precisely in the realm of play, outside the dictates of teleology, settled categories, and function, that serious worldliness and recuperation become possible'.

4.2. Drone Art

Projects such as the Aerocene Foundation and *PigeonBlog* appear a world away from the sensory architectures built by militarism and capitalism. Such contrasts designate the latter as an especially poor basis on which to realise a 'new sensorium'. Nevertheless, it was within the conceptual spaces opened up by these art projects that *Waveform* has sought to redeploy the offspring of more established architectures. A recurrent figure of reflection here has been the 'drone': a totemic artefact that links a number of discourses surrounding machine sensing, and so offers a suggestive, if not unproblematic vehicle for creative intervention.

A cursory glance through current reports on airborne drones will yield myriad vignettes concerning their efficacy as sensory platforms—whether for filming and photography, for scientific research, or, most prominently, for surveillance, reconnaissance, and intelligence gathering. In a Western military context, the exponential growth of drone forces has been key to orienting doctrinal violence around the persistent, 'unblinking' surveillance of designated targets of interest, and so becoming a vital and seductive contributor to the aforementioned 'God's Eye View' over the contingent spaces of modern conflict. Integral to this Apollonian perspective is a presumption concerning (and a desire to pre-empt) the threatening vectors of that which is surveilled. This is demonstrated vividly through the use of drones in attacking distant figures that are constituted as 'immanent threats' in the eyes of this sensory and political assemblage (see, e.g., All-Party Parliamentary Group on Drones 2018).

Given these activities, it is unsurprising that much academic and creative work on drones interrogates their ethical and political consequences in military and policing contexts. Exemplifying such enquiry is the work of the Forensic Architecture group, which has conducted highly detailed investigations into the circumstances and consequences of specific drone strikes, using this as a means of critiquing their ultimate legality.

Turning to drone-based art specifically—in which the drone, its technologies, imagery, and impacts, feature as an irreducible aspect—this martial spectre looms large in the context of many works, which are strongly activist in focus. The photography and video art of Trevor Paglen is just such an instance here, seeking to make visible the often highly clandestine world of military drone operations, and meditating especially on the drone's sensory aspects in these contexts.

In *Drone Vision* (2010), a sequence of intercepted drone video feeds is shown in the raw, with no contextualising information or commentary. The film is grainy and uncertain, with the drone's camera turret roving across the sky around and the landscape below according to no discernible pattern or motive.

Most evident, on first viewing, is the striking presentation of a transient, uncertain drone's-eye-view, as contrasted against the smooth, unwavering focus of the popular imaginary and press release footage, which emphasises a lethal 'locked on' gaze. Amidst the arbitrary flow of imagery, Vandenburg (2016) reads into this piece a repositioning of the audience's own gaze, splicing into the unceasing streams of data that characterise the Western military episteme:

> We find ourselves on the side of the drone and its pilot, desperate to understand this torrent of collected images, the better to control and dominate—and, we realize, destroy—what and

who lies below. The unmediated flow of visual and spatial data that passes through drone eyes collapses the distance between device and operator, between American air base and Middle Eastern valley, into a single moment of seeing.

Nevertheless, an important dichotomy can be noted here, in that the very act of sensing and 'seeing' does not translate automatically into knowing. For all the myriad images presented, no clear picture emerges as to the activities depicted, either regarding the drone itself or the unwitting targets of its gaze.

A similar dynamic plays out in a related photographic series by Paglen. In *untitled* (*Drones*) (2010), the viewer is confronted by a selection of immense skyscapes, their subtle palettes reminiscent of the paintings of Agnes Martin or Joseph Turner. Only after careful scrutiny will the viewer be able to pick out a tiny fleck of shadow amidst the shifting colours. This fleck betrays the presence of a single military drone, photographed from many miles distance.

In searching for the drone, the viewer is confronted with how the entire sky can function as part of a new infrastructure of observation. The imbalance of power facing the objects of its attention is captured in the sheer challenge of observing the drone itself at work. Just as *Drone Vision* offers no clear understanding as to its actual contents or contexts, the *untitled* (*Drone*) series gives no sense as to what the photographed drones are either looking at, or indeed, for.

Even artworks that seek to detail the specifics of military drone activities are haunted by this asymmetry, as in James Bridle's *Dronestagram* (2012–2015). As the name suggests, this project appropriates the social media platform Instagram in order to document (and help make visible) the distant sites of known drone strikes, posting satellite imagery and short reports detailing each attack. Nevertheless, as Vandenburg (2016) points out: 'Instagram's very name denotes the real-time transmission of events as they happen, but nothing is ever happening in Bridle's images: they document what occurred earlier, elsewhere, far below the satellite through which we see'. In this sense, the imagery of *Dronestagram* exhibits an unsettling emptiness. The sprawling complexes of highly remote settlements become homogenised signifiers of distant violence, inaccessible to outsiders, and barely registered in the gaze of orbital infrastructures.

Uniting the work of Paglen and Bridle, then, is a depiction of the limits of sensory technologies to deliver information about the world. Inferences can be gathered, but definitive conclusions are curiously absent, and so undercutting narratives of an omniscient 'view from above'.

As a final illustration of this dynamic in drone art, and to draw this discussion back to its role in the *Waveform* project, it is worth turning to a pioneering artwork made in the late 1990s by the Bureau of Inverse Technology (the artists Natalie Jeremijenko and Kate Rich). *BIT Plane* (1997) took the form of a radio-controlled model aircraft fitted with a transmitting video sensor, and which was then flown over the no-camera zones protecting the commercial campuses of key Silicon Valley entities, including various defence contractors. The resulting footage was gathered into a video installation whose sparse, officious captions mimicked an advertisement for military hardware.

The core premise of *BIT Plane* was not, in-fact, to straightforwardly surveil the corporate nerve centres of Silicon Valley, defying their efforts at safeguarding their intellectual property, but to demonstrate the very absurdity of this idea. Unquestionably, the video footage gathered from *BIT Plane* was so grainy and low-resolution as to be useless for meaningful intelligence gathering, but in a later interview, Jeremijenko (2013) made the point that a more sophisticated conception of 'information' precludes such naïve undertakings in the first instance:

> Information is a property of people and communities and discussions, and actual work, it's not something you can just take a picture of and steal. But that was the paradigm, and it actually remains the prevailing paradigm, that information is property, that it can be stolen with cameras. So flying the BIT Plane through these no-camera zones was part of the exploration of what you could actually just see. What could you actually see? What information could you take from the plane? Of course, the answer is not much

(as contemporary drones have so aptly demonstrated)—lots of images but not much actual trustable information.

Jeremijenko's observation here is that information is not an abstract, purely cognitive phenomenon, but is expressed through, and sustained by, multiple intersecting actors and environments. A 'snapshot' video from a drone traces more the act of sensing itself, being unable to capture the enactments and exchanges that give rise to the scene being recorded—or, indeed, of any impacts caused by the drone's presence, such as the complaints of television signal interference generated by its overflights.

It is in this respect that Jeremijenko and Rich pioneered the kind of drone art practiced by Paglen and his contemporaries, revealing the 'view from above' to be not as all-encompassing as popular mythology may suggest, and demonstrating how techno-aesthetic tropes of ever-increasing sensory resolution do not translate into greater knowledge of the scene under observation.

The critical dialogue of artists towards drone technology, and the conceptions of a 'new sensorium' outlined by Anthropocene scholars, begin to converge on this point. Both share concerns regarding any implied distance and objectivity associated with sensory systems, and emphasise how they construct particular views that make sense only within particular contexts. In this regard, they both critique the limitations of viewing the world in terms of the ocular and the abstract alone, bracketing off the lived relations that enact its daily being.

It is here that *Waveform* developed into a vision of deploying an airborne drone as the basis for an alternative sensory platform. At first, it would invoke multiple fields of reference with regards to the origins and impacts of its constituent technologies, and of the 'view from above' more broadly. In this sense, it would act as both a node and an emblem of the myriad networked systems that articulate views of a global environment. Going further, it would then serve as provocative vehicle for their subsequent interrogation, highlighting the limitations and contingencies that are inherent to their operation.

5. Vision Machines

5.1. Signal Processing

Exactly how to reframe the drone as a sensory platform represented the definitive challenge for the *Waveform* project. A recurrent area of consideration was how electronic sensors are designed to minimise extraneous noise, while also separating out particular types of signal return. This filtering of signals across various thresholds of detection are foundational to the depictions of the world they generate subsequently. This suggested a point on which the varied concerns outlined above might turn, and it was here that one of the more prominent early instances of electronic sensing, radar, provided an important case study in defining the eventual shape of *Waveform*.

In Virilio's (1994) terms, radar, as with drone technology, is a species of 'vision machine'—an architecture of detection and interpretation. Here, the aim is to generate an instantaneous, noise-free depiction of the battlespace environment, and so clearly predict and engage that which crosses the thresholds from object to threat to target. Nevertheless, it is here that Virilio observes an unsettling vector, for human interpretative agency and authority becomes subject to '*a splitting of viewpoint*, the sharing of perception of the environment between the animate (the living subject) and the inanimate (the object, the seeing machine)' (emphasis original). In other words, the emergence of seeing machines, which perceive the world in ways that the human senses cannot, challenges the idea of a coherent human subject, surveying an objectively knowable world, as the preeminent basis for measuring and characterising observable reality.

The story of radar marks the moment when this 'splitting of viewpoint' became fully apparent. During the Second World War, the evolution of radar was driven by the need to more accurately determine the status of airborne contacts. This spurred the development of algebraic signal processing, which separated out moving targets from unwanted interference, such as atmospheric noise, weather formations, or terrain echoes. As Link (2016, p. 74) observes, this had a transformative impact on conceptions of what technological modes of sensing would represent, both during and after the conflict:

> The rays received from the external world allowed for the precise algebraic processing of successive waveforms, which visualised objects that had previously been imperceptible to the naked eye. [. . .] Photography and television were touted as technologies that faithfully recorded reality. Radar, however, broke the apparent unity of reality and its representation apart, because it programmatically manipulated the image. The pictures were not a faithful record of the rays received; they merely represented the initial data for filtering, that is, the algebraic calculation of the image. Slowly but surely, algorithms were beginning to determine what was considered as real.

Here lies the origin of the abstract data mappings that would later indicate a growing ecological crisis. Radar itself played a part here, in being a key enabler of the military actors engaged in a global geopolitical competition, and the cycles of excess consumption and pollution this generated.

Link goes on to observe that the arbitrary manipulation of electrical signals gave rise to the conception of the 'waveform' in scientific and engineering theory. Moreover, these processes of filtering were what allowed the pristine, discrete units of digital signals to be expressed within the confines of electronic circuitry, and so enabling the practical realisation of digital computing more broadly.

It is at this point in his account of these historical developments that Link provides an unusual vignette, describing how one of the earliest, fully electronic, programmable digital computers, the UK Ferranti Mark I, was used by mathematician and engineer Christopher Strachey for an experimental text generation program in 1952, producing a series of simple, comic love letters. Here is a typical output from this program:

> Darling Sweetheart
>
> You are my avid fellow feeling. My affection curiously clings to your passionate wish. My liking yearns for your heart. You are my wistful sympathy: my tender liking.
>
> Yours beautifully,
>
> M.U.C.
>
> (Strachey 1954, p. 26)

Despite its crude operation and evident whimsy, one of the key innovations of Strachey's generator was its use of a random number algorithm to select arbitrary words from a source vocabulary—a characteristic of many subsequent works of digital art, in their mixing of predefined primitives. Such algorithms have been subject to intensive enquiry in the computer sciences, for they are, ultimately, pseudorandom in nature: algebraic emulations that can exhibit significant levels of recursion. The need for such algorithms represents a by-product of the signal processing that is foundational to all digital computing, in that it forecloses the presence of arbitrary noise in the system. To reincorporate the latter for the purposes of calculation necessitates using a sensor that detects random signals in the ambient environment, such as atmospheric noise, and then deploying this as a source of variables.

The importance of randomness for Strachey's generator is significant not simply for the textual effects it yielded, but for the very contexts in which they were achieved. In so harnessing a digital computer, then still a highly militarised technology, to generate random variables for the assembly of non-quantifiable outputs, Strachey's generator involved the deliberate fostering of the emergent and the ambiguous back into a technical and operational context that otherwise strove for its elimination.

While Strachey (1954) developed his generator as an exercise in creative programming, his account of its functioning is part a greater reflection on the potential for computing machinery to yield just these kinds of unpredictable effects—to appear to act spontaneously, and so draw attention to its status as a distinctive agent. In this sense, his generator can be read as a creative inversion of the deterministic, martial impulses encoded within the interlinked genealogies of radar, signal processing, and digital computing. Such gestures serve to make these impulses all the more visible on reflection, and so inspire enquiry concerning their effects. Strachey's generator can thusly be regarded as a pioneering instance of digital art, revealing the expressive and self-reflexive potentialities within devices that were then closely associated, both functionally and operationally, with tasks of the gravest utility for the state.

5.2. Experimental Aesthetics

Strachey's generator was not programmed explicitly in the name of art, or to critique the troubling legacies of the Second World War, but it resonates with a longstanding tradition of using experimental aesthetics as a mode of creative resistance to modern conflicts and anxieties. Of particular note here was the Dadaist movement that emerged midway through the First World War. Dadaist practice was fuelled by its opposition to the conflict, most especially in terms of its propagandistic appeals to the defence of higher ideals. For its cofounder, Tristan Tzara, such invocations of "truth' and 'intelligence' were part of the rhetoric that had brought about the war and continued to fuel it . . . In the process, they had lost every shred of meaning' (Buelens 2015, n.p). For this end, much of the art and poetry of Dada was driven by the 'deliberate annihilation of ordinary language use and prevailing aesthetic standards' (Buelens 2015, n.p).

In pursuing disruptive new modalities of expression, such as assemblage, textual collage, and photomontage, Dadaist critique was enabled using the very techniques it placed into question, drawing on the fragmentary media landscape of newspapers, films, and advertisements. Tzara's own cut-up poems, taken from newspapers, are striking in their use of contingency to evoke the visceral chaos of machine-generated violence, and its rending apart of once coherent, believable narratives of Enlightened progress. A similar theme is captured in Raoul Hausmann's post-war assemblage *The Spirit of Our Time—Mechanical Head* (1919). Here, a crudely carved wooden head is studded with various measuring instruments, such as a watch, a tape measure, and a ruler. This assemblage suggests the naivety of the Enlightenment vision of the autonomous, rational subject, revealing instead its embedding within the attitudes and epistemes of its social environment, and its consequent vulnerability.

It is here, then, that Strachey's generator can be read in light of these earlier efforts at appropriating the tools and materials of a damaged world—sometimes themselves implicated in the disaster—as a catalyst for reflection. The work of the artists already mentioned, Saraceno, Da Costa, Paglen, Bridle, Jeremijenko and Rich, operate in a similar vein, with Saraceno and Da Costa drawing attention not just to the ecological consequences of technologies rooted in warfare and competition, but of the possibilities they might yet afford. Although such creative gestures may be limited in their ultimate impacts—Dada, after all, did not preclude the myriad conflicts that followed the Armistice of 1918—they serve the task of keeping alive a resistant, alternative imaginary to the present. *Waveform* itself, as a deliberately strange, provocative assemblage, is seeking to provide a similar legacy.

6. Waves to Waveforms

It is at this point that the varied threads of this discussion can be drawn together. Stated in concise terms, *Waveform*'s use of algorithmically processed images to generate poems represents an updating of Strachey's original creative gesture. Specifically, it meditates on the global sensory infrastructures that radar, algebraic signal processing, and digital computers gave rise to—and of which drone technology represents the latest iteration. Following Cosgrove, these infrastructures have emerged from, and are implicated within, the geopolitical struggles of recent decades, whose planetary impacts they have only detected subsequently, and thus embedding and evidencing this sense of a new ecological epoch.

By way of deconstructing the impulses driving this cycle, *Waveform* takes the form of a sensory assemblage attuned to noisy patterns in the ambient environment, using this as a source of arbitrary values for the presentation not of any clear, quantifiable data, but of poetic text. The intention here is to interrogate and unsettle the normative representations made of the world using digital sensors, to inspire enquiry as to the assumptions underpinning these practices, and to stage the kinds of reflexive alternatives to existing sensory paradigms being speculated on by various scholars.

As detailed in the opening section of this discussion, the sensory aspects of *Waveform* are supplied by an airborne camera drone, engaging directly with the top-down perspectives that have played a crucial role in constructing an image of a closed global space, ready-to-hand for human demands. In its close association with the military 'policing' of this space, in the name of establishing a secure environment for market expansion and trade, the drone serves as an especially charged instance of a sensory agent—a device that is implicated profoundly in the very changes it observes. The coastal environment it orbits, although seemingly benign from even a relatively low altitude, is being increasingly damaged by the detritus of human activity on a global scale, with rising sea levels being an implicit, and ever-growing threat.

Cumulatively, the result is a project that creatively appropriates varied technologies and practices whose genealogy is closely tied to the production of scopic regimes that deliver views of a ready-to-hand world. In so doing, the aim is to show that far from being systems of absolute precision and imposition, they operate instead as complex assemblages within an interpretive ecology, subjecting incoming signals to varied processes, and reading them across a variety of perceptual thresholds, both human and machinic. The very act of drawing a precise line where the edge of a wave might reside is ultimately nonsensical as an act of measurement, but it reveals consequently the system's functioning as it grapples with so uncertain a target. In this respect, the presence of breakdowns arising within this assemblage, where the components fail to gel, is a welcome development. Perfect wave outlines and pristine poetry are not in-fact the primary goal, for any failings expose the functional contingency of the assemblage as a whole.

This point made, however, the poems generated through this process are still curated in order to engage themes appropriate to a critical interrogation of digital sensors—although the meaning of each poem, and any relationship to the source imagery, is left open to the viewer's discretion. Nevertheless, one goal here is to draw attention to how the meanings assigned to all forms of digital sensory data, however it is rendered, arises through an intersection between human and machine, with both coming together as sensing and interpreting agents. In using devices that perceive the world in ways very different from a human observer, such data only becomes fully meaningful and actionable when understood in relation to the structures and processes through which it was derived. In cases where this is obscure or ambiguous, as in *Waveform*, the observer is tasked with attempting to establish these links for themselves. The interpretative aporia caused by the parsing of the visual into the poetic is thus an effort at challenging any sense of transparency to data representations—that they are a direct manifestation of the phenomena under study, rather than being a mediated and continually mediating vision. This in-turn shows how these aspects are still at work in more established cases, where the technologies and practices involved have been rendered normative, unremarkable, and uninterrogated, such as satellite photography or automatic image analysis.

The eventual outcome of the *Waveform* project will be an extended series of hybrid images. At the time of writing, the first set of these images are being compiled into an artists' book. This format has been chosen so that the turning of the pages will illustrate the 'transition' from image to text in each case, as well as offering space for notes concerning the vocabularies and algorithms behind their curation.

As stated in the introduction, *Waveform* is an ongoing project that is still at an experimental stage of its development. Nevertheless, it brings together diverse strands of artistic and theoretical endeavour, so as to assess diffractively their interrelations and potentialities. The goal is not to produce a definitive assessment of any one aspect involved, but to generate through practice novel vectors of enquiry, and thus bringing to light new ways of thinking through the ecological challenges of the present.

Funding: This research received no external funding.

Acknowledgments: This paper is derived from one presented at the Electronic Visualisation and the Arts (EVA) 2018 conference, and was published in its original form in *Electronic Workshops in Computing* at doi:10.14236/ewic/EVA2018.69. It is presented here in a substantially revised and expanded form.

Conflicts of Interest: The author declares no conflict of interest.

References

Aerocene. 2018. Available online: http://aerocene.org/ (accessed on 20 October 2018).

All-Party Parliamentary Group on Drones. 2018. *The UK's Use of Armed Drones: Working with Partners*. London: All-Party Parliamentary Group on Drones. Available online: http://appgdrones.org.uk/wp-content/uploads/2014/08/INH_PG_Drones_AllInOne_v25.pdf (accessed on 30 August 2018).

Bolen, Jeremy, Emily Eliza Scott, and Andrew Yang. 2016. Sensing the Insensible: Aesthetics in/and/through the Anthropocene. *Anthropocene Curriculum.* Available online: http://www.anthropocene-curriculum.org/pages/root/campus-2016/sensing-the-insensible-aesthetics-in-the-anthropocene (accessed on 30 August 2018).

Buelens, Geert. 2015. *Everything to Nothing: The Poetry of the Great War, Revolution and the Transformation of Europe*. Translated by David McKay. London: Verso. ISBN 9781784781491.

Carter, Richard. 2018. *Waveform*. Available online: http://richardacarter.com/waveform/ (accessed on 29 October 2018).

Cosgrove, Dennis. 2001. *Apollo's Eye: A Cartographic Genealogy of the Earth in the Western Imagination*. Baltimore: Johns Hopkins University Press. ISBN 0801864917.

Crutzen, Paul, and Eugene Stoermer. 2000. The "Anthropocene". *IGBP Global Change* 41: 17–8.

Da Costa, Beatriz. 2017. Interspecies Coproduction in the Pursuit of Resistant Action. *Surveillance and Art*. Available online: https://sites.tufts.edu/surveillanceandart/files/2017/11/pigeonstatement.pdf (accessed on 20 October 2018).

Davis, Heather, and Etienne Turpin, eds. 2015. *Art in the Anthropocene*. London: Open Humanities Press. ISBN 9781785420054.

Haraway, Donna. 2016. *Staying with the Trouble: Making Kin in the Chthulucene*. Durham: Duke University Press. ISBN 9780822362241.

Jeremijenko, Natalie. 2013. Interview: Natalie Jeremijenko. *Center for the Study of the Drone.* Available online: http://dronecenter.bard.edu/interview-natalie-jeremijenko/ (accessed on 30 August 2018).

Link, David. 2016. *Archaeology of Algorithmic Artefacts*. Minneapolis: Univocal Publishing. ISBN 9781945414046.

Moore, Jason, ed. 2016. *Anthropocene or Capitalocene? Nature, History, and the Crisis of Capitalism*. Oakland: PM Press. ISBN 9781629631486.

Müller-Hansen, Finn. 2016. Sensing. *Anthropocene Curriculum.* Available online: https://www.anthropocene-curriculum.org/pages/root/resources/sensing/ (accessed on 30 August 2018).

Schuppli, Susan. 2014. Can the Sun Lie? In *Forensis: The Architecture of Public Truth*. Edited by Eyal Weizman and Anselm Franke. Berlin: Sternberg Press, pp. 54–64, ISBN 9783956790119.

Starosielski, Nicole. 2015. *The Undersea Network*. Durham: Duke University Press. ISBN 9780822357407.

Strachey, Christopher. 1954. The "Thinking" Machine. *Encounter* 13: 25–31.

Vandenburg, Colin. 2016. Drone Art. *Dissent* 63: 6–10. [CrossRef]

Virilio, Paul. 1994. *The Vision Machine*. London: British Film Institute. ISBN 0253325749.

arts

Article

The Machine as Artist as Myth

Andreas Broeckmann

Institute of Philosophy and Sciences of Art (IPK), Leuphana University, 21335 Lüneburg, Germany; broeckmann@leuphana.de

Received: 4 January 2019; Accepted: 14 February 2019; Published: 20 February 2019

Abstract: The essay proposes an art–historical contextualisation of the notion of the "machine as artist". It argues that the art–theoretical tropes raised by current speculations on artworks created by autonomous technical systems have been inherent to debates on modern and postmodern art throughout the 20th century. Moreover, the author suggests that the notion of the machine derives from a mythological narrative in which humans and technical systems are rigidly figured as both proximate and antagonistic. The essay develops a critical perspective onto this ideological formation and elucidates its critique in a discussion of a recent series of artworks and a text by US American artist Trevor Paglen.

Keywords: machine; art; art history; myth; modernism; artificial intelligence; artificialism; machine realism

---

1. Machine Art

"Mechanical nature derives from human nature but will soon overtake it" (Versari 2009). When the young second generation Futurist, Fillìa, wrote this in 1927, he was at the helm of a movement that began to think about the possibility of machines becoming independent agents no longer controlled by humans, but that would instead steer human behaviour. "The people whose sensibility today doesn't adhere to modern life will find themselves weakened, nostalgic, and pessimistic, that is, practically useless, in the mechanical and intransigent organization of tomorrow" (ibid.).

A few years earlier, in 1922, Fillìa's fellow Futurist, Enrico Prampolini, had yet been less affirmative of the role of machine agency in "the new aesthetic of The Machine". Somewhat vaguely, Prampolini wrote: "The machine marks the rhythm of human psychology and beats the time for our spiritual exaltations. Therefore it is inevitable and consequent to the evolution of the plastic arts of our day" (Prampolini 1922). This inevitability became the conceptual core for an exhibition, "Machine Art", that Alfred H. Barr Jr. and Philip Johnson presented at the Museum of Modern Art in New York City in 1934. The show contained only objects from US American industrial production, polemically claiming the aesthetic superiority of designs that were determined only by functionality, rather than by artistic styles or human intention. "Good machine art", as Barr put it in his introductory text for the catalogue, "is entirely independent of painting, sculpture and architecture" (qu. Broeckmann 2016).

These instances remind us that the trope of the "machine as artist" is not germane to the age of computers and Artificial Intelligence. The idea of a supersession of humans by technics, in art and other areas of human life, runs through the 20th century and is an inherent part of a modernist understanding of technics. Another aspect of this *mythological* dimension of technics is that the presumed cataclysm of a machine takeover is always *imminent* (Fillìa says, "soon"), and that it is tied to the concern about an existential threat for humans. In Alfred Barr's words, elsewhere in the catalogue introduction: "Machines literally multiply our difficulties and point our doom. [. . .] We must assimilate the machine aesthetically as well as economically. Not only must we bind Frankenstein—but we must make him beautiful" (ibid.). The Italian, third generation Futurist Bruno Munari would, a few years later, become the first artist to build humorous, dysfunctional machine sculptures, *macchine inutile*, eager to counter the unforgiving rationality of functionalism. His motivation was a technosceptical concern similar to that voiced by Barr. In his 1938 "Manifesto del Macchinismo", Munari warns of the dangers of an all-powerful machine whose slaves people will become—"in a few years' time". Munari continues: "The machine of today is a monster! The machine must become a work of art! We shall discover the art of machines!" (ibid.).[1]

In our own time, at the beginning of the 21st century, the impact of technology on contemporary art, and on culture in general, is finally becoming a topic of general public attention. At this moment, even for the specialised technical field of Artificial Intelligence and Machine Learning,[2] every other week, a new exhibition, conference, funding program, or publication project is announced—think of exhibitions like, "I am here to learn: On Machinic Interpretations of the World" (Frankfurter Kunstverein, 2018), "Machines Are Not Alone: A Machinic Trilogy" (Chronus Art Center, Shanghai, 2018), "Entangled Realities: Living with Artificial Intelligence" (House of Electronic Arts, Basel, 2019), and "AI: More Than Human" (Barbican Centre, London, 2019); the workshop "The Work of Art in the Age of Artificial Intelligence" (Victoria and Albert Museum, London, 2018), or a panel on "art created by AI systems" (CAA Conference, New York City, 2019). Key players of the contemporary art world, like the artist Hito Steyerl (*The City of Broken Windows*, Castello di Rivoli, 2018) or Pierre Huyghe (*UUmwelt*, Serpentine Gallery, London, 2018), elicit further attention to the topic through their recent projects.

The art–historical perspective taken here seeks to underscore the relevance and urgency of a critical engagement with such technological developments. It may help to tune the conceptual framework of such a critique by pointing out that, for instance, the recent stunt of the Artificial Intelligence-based "Next Rembrandt" painting was made possible by decades of art–historical and technical research on the painter's works in the Rembrandt Research Project and could not easily be replicated for other historical artists.[3] Moreover, the topic of a concrete "machine authorship" of paintings has been virulent ever since, in the early 1970s, Harold Cohen, started his research on the computer-based cognition and creation system AARON. When we think of the status of Duchamp's Readymades and Rotoreliefs, or Warhol's Factory, or the different strands of Generative Art, we realise that questions about the artistic validity of technical products (and reproductions) form part of the bedrock of art theoretical reflection in the last 50 years.[4] The subversion of notions like artistic intention and artistic genius is constitutive of contemporary art discourses, and it has been understood throughout the 20th century to be the result of both artistic volition and of technical developments, as evidenced by Walter Benjamin's analysis of the destruction of the artwork's aura, in his essay of 1936 on "The Artwork in the Age of Its Mechanical Reproduction". Hence, some of these questions are at least as old as the discourses on photography and on modern printing techniques, discourses that date back to the 19th century. There is no need for panic.

---

1. Cf. Broeckmann, *Machine Art*, for an extensive treatment of the role of machines in the visual arts of the 20th century, as well as for specific aspects of machine aesthetics.
2. Terms like "Artificial Intelligence" and "Machine Learning" are problematic, not least due to the mixing of both descriptive and metaphorical uses of such concepts as "intelligence" and "learning"; since in this text, I only tackle the notion of the "machine" in any detail, the words are used here with upper-case letters in order to indicate their problematic, ideological status.
3. The Rembrandt Research Project (1968–2011) initiated a radical sifting of works that had previously been ascribed to the Dutch 17th-century painter Rembrandt Harmenszoon van Rijn; for a summary treatment of the project, cf. (White 2015). This thoroughly analysed corpus no doubt provided crucial material for the training of the pattern recognition systems of the "Next Rembrandt" project. Another recent example is the AI-generated image, *Portrait of Edmond Belamy* (2018), by the French artist group Obvious, cf. http://obvious-art.com (accessed on 8 February 2019).
4. Cf. also Cornelia Sollfrank's work on the digital multiplication of Warhol's *Flowers*; cf. "copyright © 2004, cornelia sollfrank". In Cornelia Sollfrank, *net.art generator*. Nürnberg, Verlag für moderne Kunst, 2004; cf. also Sarah Cook: "What would Artificial Intelligence find aesthetically pleasing? The burning question of generative art and its audience". In (Sollfrank 2004, pp. 146–55).

2. The Myth of the Artist

The notion of the "machine as artists" provokes a reflection on what is "an artist", and on the notion of "the machine". While I want to deal with the latter more extensively in a moment, I can for the former refer to the text by Aaron Hertzmann ("Can Computers Create Art?", Hertzmann 2018), elsewhere in this issue, which presents a detailed discussion of the question, "Could a piece of computer software ever be widely credited as the author of an artwork?" Hertzmann emphasises the instrumental function of computers, programs, and algorithms for people who make art, and insists that art is a social activity, an activity of social (thus human) agents.

Hertzmann's argument is based on a mostly transhistorical understanding of "art". It would benefit from a more critical understanding of the notion of "the artist" and a consideration of how this notion transforms in different historical and discursive settings. "Art" has been many different things in different cultural and historical contexts. The role of "the artist" in the Modernist art of the 20th century is far more complex than that of an intentionally acting "creative individual", and some of the key issues in this debate—which the applications of Artificial Intelligence systems now also address—concern aesthetic transformations of concepts, processes, and systems that have been addressed extensively in the contexts of conceptual art and systems aesthetics, ever since the 1960s.

Throughout the 20th century, art has—very generally speaking—been understood as a practice or a form of material production that displaces, that makes strange the sense of social artefacts and conventions; in this understanding, art thus transcends aspects of the world, of the individual, of social existence, of the existential condition of humans. The fact that art is done by an artist is as essential an aspect of modernist and postmodernist art as the very question, "what is art?". From Abstract Expressionism through Pop Art to Institutional Critique, discussions about art have been a pivot for debates on human production and creativity in the age of mass industrial production and consumption. Questioning the status of the artist is an inherent part of these considerations ever since the non-sense performances of Dada, the psychic automatisms of Surrealism, and the mathematical automatisms of Concrete Art. Of course, it is interesting to speculate about the "art" status of objects or practices which are produced or performed by non-human agents. But, as in the cases of Duchamp's Readymades and Warhol's Brillo Boxes and Sturtevant's repetitions, it is unlikely that "machine artworks" will end or destroy art. Rather, they may contribute to the continuous transformation of sense-making that we tend to categorise as "art". The question of whether they will be deemed "unethical", as Hertzmann suggests, is in direct continuation of ethical debates around the works and practices by human artists like Jeff Koons, Sherry Levine, or Richard Prince, which have deliberately put "the artist" between quotation marks.

At the same time, in addition to such conceptual challenges to art, I keep thinking of the drawings by Joseph Beuys (as an example of personal relevance—we can easily think of others), feeble, sketch-like renditions of rudimentary, existential things, or beings. These drawings are both extremely humble and they are monumental documents of a search for relations and connections with the world, with fellow humans, with animals, the Earth. How does the graphic and emotional intensity of these hurried sketches relate to art-making by machines? Quite pragmatically, consider the immense effort that goes into making such machine artworks as "The Next Rembrandt"—the research, interdisciplinary deliberations, decision making, programming, accumulation and preparing of training data, bug-fixing, 2D and 3D printing—as against the overwhelming result of a small, unobtrusive, and meaningful gesture that humans, after so many "deaths of art", continue to make for themselves, and for others.

3. The Myth of the Machine

While the "myth of the artist" is a common and well-rehearsed trope of art theoretical writing, even in more specialised discourses, the notion of the "machine" tends to be used affirmatively and quite uncritically. However, we can observe that the "machine" of, roughly speaking, the 20th century (and hence also the machine of "machine art") is based on a conception of technology in which technics is pitched against the human; the notion of the machine signifies this antagonistic construction, and the various usages of the term "machine" articulate and reaffirm this structure.

What I want to argue here is that, on the level of human communication and of culture, the machine operates as a myth—"myth" not understood in the polemical sense of an untrue story, but rather in the functional sense of the term.[5] Very generally speaking, a myth is a form of narrative that is engrained in a culture. A myth is collectively held, and repeated and affirmed, and it is powerful. Until the 1960s, the notion of myth was generally reserved for the belief systems of ancient and of non-Western cultures, whereas since the ideological critiques of semiotics and structuralism in the 1960s, and not least through the analyses of popular cultural items offered by Roland Barthes in *Mythologies*, the belief systems of Western modernity have been shown to also be based on such mythological narratives (Barthes 2009).

According to German philosopher Hans Blumenberg, myths are characterised by a narrative kernel which is both variable and, more importantly, of extended continuity (Blumenberg 1985). A myth is an articulation of ignorance, resulting in fear or hope, and a way to make sense of the world, whether in the face of the forces—and the supposed agency—of nature, or, in modernity, also addressing the agency of technics and its spiritual (or ideological) dimensions, like rationality, functionality, or necessity.

A crucial reference text for a discussion of the machine as myth is social historian Lewis Mumford's *The Myth of the Machine* (Mumford 1967–1970). Mumford claims that the conceptual power of the machine myth is not a modern phenomenon but that it harks back to human experiences in ancient and prehistoric times. For Mumford, the notion of the machine originates from an ancient order of ritual, an order which humans developed as a form of self-protection to compensate for the huge psychic pressures exerted by their hostile natural environment. In the contemporary machine myth (of the 1960s), there persist forms of unformed, unorganised phenomena of the human spirit that in the modern period have not disappeared but grown stronger by being channelled into science and technics. Mumford's passionate analysis is driven by his frustration about the fact that this myth has resulted in a continued connection of excessive power and productivity with equally excessive violence and destruction. Echoing the worries of Alfred Barr and Bruno Munari, Mumford envisions that, as a result of the emergence of the modern megatechniques, humans will not act as autonomous individuals, but they will become passive, aimless, and machine-dependent animals whose true capacities are passed over to machines, or strictly limited and controlled in favour of depersonalised and collective organisations.

Mumford is convinced that the modern technological process is neither natural nor unchangeable nor did it come about without human intervention. His goal is therefore to shrug off the myth of the megamachine and for his readers to understand and, where necessary, to change the course of contemporary technics—again an argument in which we hear the echo both of Barr and Munari's concerns, and of Fillìa's exultation.

It is now possible to identify the narrative kernel of the myth of the machine. As a comparison, consider the myth of Oedipus. Whenever the name Oedipus is mentioned, the whole complex narrative of the myth, its proponents, and tragic twists is evoked. In the same way, the whole of the myth of the machine is brought into play whenever the term "machine" is used. It goes something like this:

> This is the myth of the machine.
>
> There is a man-made object. It can be a physical device, or a symbolical representation, related to technics by association or indexicality.

[5] Cf. (Assmann and Assmann 1998), where the authors distinguish between polemical, historical–critical, and functional conceptions of myth.—This argument was first developed in a talk at the conference "Politics of the Machines—Art and After", EVA-Copenhagen, Aalborg University, on 15 May 2018, publ. by BCS/eWiC at http://dx.doi.org/10.14236/ewic/EVAC18.49 (accessed on 20 December 2018).

> It is composed of technical elements, it has moving parts, and it has a function which it performs by repetitive movement. And it exhibits a certain formal beauty.
>
> It is made to function automatically and independent of direct and continuous human intervention.
>
> Over time, the object attains an increasing degree of autonomy.
>
> It may provide interfaces for human interaction. These, however, do not determine the functionality: The human interaction can be replaced by technical elements, or by other machines. The interfaces offer the human an illusion of control which can be overridden by the machine. The interfaces are only there to appease the humans, for their play and enjoyment, or for human–machine conviviality.
>
> The autonomy of the machine becomes threatening for humans who, fearfully, struggle not for their lives, but for self-determination. The threat posed by the machine is existential, but not lethal.
>
> The narrative tends not to have an ending. If it has one, then the story ends well for the humans.

Like other myths, the *myth of the machine* can be varied, but it cannot be told completely differently. It is always this one story of something man-made being functional and then gaining a dangerous, nonlethal form of autonomy.

Consider the example of a loom. It is a technical device that is used for weaving textiles. When a person beholds the loom and says, "ah, a machine", he or she calls up the myth of the machine and at once, its particular narrative framing comes into play, its blueprint, its construction, its degrees of freedom, and the inherent threat. The ways in which the loom is then treated, in the realm of the myth, is different from how it is treated when viewed as a weaving device.

What we can learn from this *mythological* understanding of the "machine" is that the modern conception of self is imbricated with technology in this particular way. There really is no "machine" outside this narrative, and whenever the word "machine" is uttered, this figure of speech constructs the relationship between human and the technical object within that mythical structure, as binary, antagonistic, and ontologically differentiated.[6] By contrast, the proposal put forward here seeks to make it possible to, finally, speak *about* the myth of the machine, and not *in* or *through* this myth.

For our discussion of the "machine as artist", it implies that under this particular headline, even the use of these words makes us slip into a mythological realm where neither the figure of the artist nor that of the machine can easily be called into question. Instead, we automatically see them pitched against each other, struggling for supremacy and survival. The imagination of how the machine takes the place of the artist (in the phrase "the machine as artist") further charges this figure of speech.[7]

4. Images of the Automatic

If the denomination of enhanced pattern recognition systems as "Artificial Intelligence" is already occluding their epistemological reach,[8] then the subsumption of such systems under the notion of the "machine" executes even further closure and obstructs a critical and emancipatory discourse on the relation between art (or human agency and practice) and technics. Importantly, the problem is not technical but conceptual. But since human self-conception is in part shaped

---

[6] According to philosopher Martin Burckhardt's analysis of the history of the machine concept, throughout modernity and since the 18th century, the automatism of any technical system has been seen as both a condition of modern progress and as a betrayal of nature (Burckhardt 2018, p. 41).

[7] Hertzmann (2018) can be credited for using the term "machine" sparsely and for seeking precise descriptions and concepts for the technical and creative activities he analyses.

[8] The term "enhanced pattern recognition" has been proposed by artist researcher Francis Hunger as an alternative for "artificial intelligence", cf. (Hunger 2017).

by the engagement with technical systems, an assimilation of technoid concepts is predetermined. Therefore, as Hertzmann (2018) observes, "The day may come in which these agents are so integrated into our daily lives that we forget that they are carefully-designed software". Similarly, in 1950, the mathematician and information theorist Alan Turing had stated: "I believe that at the end of the [twentieth] century, the use of words and general educated opinion will be altered so much that one will be able to speak of machines *thinking* without expecting to be contradicted" (Turing 1950). Here, Turing imputes not that machines would be able to think like humans but that the conceptions of thought and computation would have converged so much that they could no longer be meaningfully distinguished (Rokeby 1995).

A recent artwork through which we can study the reproduction of the machine myth is US-American artist Trevor Paglen's image series, *Adversarially Evolved Hallucinations* (2017), created from a combination of several image recognition software systems.[9] The outcome are eerie, surreal, and mostly abstract images that contain human-recognisable elements like eyes, human limbs, or plants, positioned in nonrealistic constellations and surrounded by nonrepresentational, "painterly" modulated areas of intense colours. In the production of these images, constellations of algorithms in neural networks (so-called "generative adversarial networks", or GAN) are trained with data sets and then deployed to generate a visual output. This visual output resembles and recombines elements of the training data sets, based on the software's harvesting of what it is trained to interpret as the visual codes of human recognisability and naturalism. These are not images made by computers for themselves but tautological renditions derived from the visual training data that are themselves previously selected and tagged by humans on the basis of categories like monstrosity and uncanniness, the resulting images thus providing an algorithmically distorted mirror of the visual iconography of fear. The chilling recognisability of the output from Paglen's image-generating, enhanced pattern recognition system does, however, underscore the illusion of a "dreaming machine", an illusion that seeks to amplify fears about a potentially subjective and autonomous machine. As a subset of the myth of the machine, the myth of "artificial intelligence" is here evoked in order to affirm an existentially dangerous confrontation of human and technics.

There is a technical and an art historical genealogy to Paglen's project. The technical genealogy is closely tied to the dialectics of mathematical functionality and specific data sets in neural networks.[10] Seen from an art historical point of view, the *Adversarially Evolved Hallucinations* not only correspond to similar, GAN-based works like Constant Dullaart's *DullDream* (2015)[11] but can also be traced back to the technically more simple, yet conceptually sharp *Sorting Demon* (2003) by David Rokeby, further back to the software-based and generative works by artists like Casey Reas, Vera Molnar, or Manfred Mohr, and to the yet older, "primitive" model of Jean Tinguely's *Metamatics* automatic drawing sculptures from the late 1950s. In each of these cases, concrete image production is delegated to a technical system whose output is steered by affordances which are technically given and designed, yet which are suggestive of a machinic subjectivity and machinic volition.

In another art–historical genealogical line, the resulting images are more deliberately designed, and the human artistic intervention is more directly visible. We can think of the colourful abstractions of Thomas Ruff's *Substrat* series (2001–2002), in which the reworking of digital image details by means of software programs leads to wildly chromatic images that, although based on pop cultural models, evoke ideas of nonhuman visual pleasures and desires. The automatisms of abstract surrealist

---

9 Trevor Paglen is known for photographic works that deal with the intricate visibility of technical surveillance infrastructures like satellites and data centres. Cf. for reproductions of Paglen's works http://www.paglen.com/; examples of the *Adversarially Evolved Hallucinations* and a short promotional text are at http://www.metropictures.com/exhibitions/trevor-paglen4/selected-works (both accessed on 8 February 2019).

10 Cf. the research on GANs published in Ian J. Goodfellow, Jean Pouget-Abadie, Mehdi Mirza, Bing Xu, David Warde-Farley, Sherjil Ozair, Aaron Courville, and Yoshua Bengio. 2014. *Generative Adversarial Nets*. Paper presented at the Advances in Neural Information Processing Systems, Montreal, QC, Canada, 8–13 December (also referenced by Hertzmann 2018).

11 Cf. https://zkm.de/en/dulldream (accessed 18 December 2018).

paintings by mid-20th century artists like Max Ernst, Wols, Emmy Bridgwater, or Richard Oelze, or the results of automatic drawing and writing exercises by someone like Henri Michaux, were psychic rather than technical. But the confrontation with their visual output, emerging from the uncanny depths of the unconscious, was, we can presume, no less shocking than the discovery of supposed visual desires of AI systems.

A most striking reference example for Paglen's series are the paintings and drawings by the Czech artists Jindřich Štyrský and Toyen (Marie Čermínová), which combine abstract painterly surfaces with the placement of at times distorted, at other times clearly recognisable (partial) objects, body parts, everyday objects (Srp and Bydžovská 2007). During a joint stay in Paris in 1924–1928, Štyrský and Toyen had developed the principle, or style, of "Artificialism", conceptually framing the abstracted Surrealism of their artistic production of the following years. In their manifesto of "Artificialism" (1927–1928), they wrote:

> An artificial painting is not bound to reality in time, place and space, and for that reason it does not provide associative ideas. Reality and forms of the painting repulse each other. The greater the distance between them, the more visually dramatic is the emotiveness, giving birth to analogies of emotions, their connected rippling, echoes all the more distant and complex, so that at the moment of confrontation between reality and image, both feel entirely alien in relation to each other. (Štyrský and Toyen 2002)

What we can glean from passages like these for our reflection on machinic art is that there are complex conceptual and aesthetic decisions that lead to the realisation of such artworks, and that masking this conceptual and aesthetic framing can be part of an artistic strategy. To the same extent that it is the task of the art historian to uncover such maskings and their historical lineages, it is the task of contemporary critics of a technologically infused culture to pinpoint the technical affordances of specific systems, and to counter technological mystifications.

The artist Trevor Paglen developed the project *Adversarially Evolved Hallucinations* in order to make it possible to speak about the cultural effects of the expansive application of machine vision systems. In a recent text, he argues for a critical reading of the principles of such systems which he summarises under the title of a "Machine Realism". Paglen understands Machine Realism as a doctrine and a style which has to be unpacked analytically in order to understand its workings, and its effects.[12] Machine Realism, he writes, is "an aesthetic and interpretive mode defined by the autonomous attribution of meaning to images by machine learning and AI systems". This attribution happens though the recognition and identification of objects, followed by their association with metadata and the analysis of their relationships. Importantly, "Machine Realism operationalizes the meanings it assigns to images". It turns the results of the analysis into control data for equally automated decision-making systems to which the machine vision systems are coupled.

However, as Paglen emphasises, this automatism does not come from nowhere but is based on specific training sets of data which are used to frame and steer the parameters of analysis and decision-making—something that can, for instance, be learned from a comparison of training data and the visual outcome of artworks like those by Paglen and others.[13] The training data and the analytical parameters are the crucial aspects of such systems where political power can be exerted. As Paglen puts it: "In Machine Realism, he who controls the training sets controls the meanings of images".

---

[12] Cf. (Paglen 2018). Paglen here compares Machine Realism to the artistic doctrine of Socialist Realism, an argument that is not entirely convincing but useful in highlighting, perhaps somewhat unintentionally, the ideological baggage that Machine Realism carries. The "reality" of this Realism is limited by an information model that can handle only what is computable, and only those aspects of things which are computable. For an earlier treatment of the topic of machine vision, cf. (Paglen 2014).

[13] Cf. for instance Jake Elwes: *Machine Learning Porn* (2016), and the work by Mario Klingemann at http://quasimondo.com (accessed on 8 February 2019).

Paglen associates his analysis with a number of moral and political concerns, seeing Machine Realism in the hands of State and economic powers that seek to exploit and suppress their human subjects.[14] Let us pause for a moment at two technical aspects, which suggest that the particular aesthetics of machine vision systems also require a modified ethics, and politics.

Paglen decries that the operations of such systems are mostly imperceptible for humans and that there are no means of auditing and contradicting the interpretations made and executed upon by those systems. While this observation is not new—even in 1988, the French philosopher Paul Virilio referred to the fact that the "blind gaze" of computer-based vision systems does not make "images" but captures and analyses data patterns (Broeckmann 2016)—there are many other examples of technically based processes that may not be open to human perceptual observation but that are nevertheless democratically controlled and policed. The "imperceptibility" is a question of governance over describable and efficacious processes—not one of technically inherent ungovernability.

A second concern that Paglen voices is that the "frangibility of the meanings of images" in Machine Realism undermines the possibility for individuals to self-determine how they want to be named and represented. From a humanistic point of view, this desire is understandable, even though historically, it was the insistence on the malleability, or frangibility, of meaning in postmodern semiotics since the 1960s that made the multiplicity of self-representations Paglen defends possible in the first place. The act of self-determination always comes at the cost of acknowledging the relativity of the truth of the "who I am", and thus of the politics of its interpretation. And this is true not only in relation to historical systems of thought that seek to predetermine ideas of race or gender, and the personal consequences that follow from them, but it is also true in relation to the ideological systems that frame technics—what I take to be the essence of "technology", or "techno-logics".

On one level, therefore, the question of who determines individual representations by machine vision systems is a political challenge that must, and can, be addressed in political debates about the making, the functionality and the application of technical systems. This is by no means an easy task, but it is one that is not impossible, and this possibility should, even for strategic reasons, not be denied.

On another level, it is important to recognise the ontological difference between the social parameters of human interaction and the technical and mathematical parameters that structure the functionality of the systems at hand. Both are mutually dependent and can be seen as representations or models for one another, but they follow distinctly different operational logics, not least because of the scripted automatisms of technics. The abstraction of social facts, of body shapes and behaviours, into computable data has to be understood as a fundamental transformation of the epistemological level at which a vision system's operations are planned and executed.[15]

5. Conclusion: Machines without Engineers

The "machine" is an anthropological category that describes the relation of humans and technics as one of antagonistic proximity, and the very use of the term machine, also in Paglen's Machine Realism, tends to occlude the political dimension of dealing with technical systems, by subjectifying and thus essentialising these systems as antagonistic beings.

There is, no doubt, a certain value and usefulness in the posthumanist speculations about the potential agency, subjectivity, and sense-making by other-than-human entities. To frame such speculations in the terminology of "art" and of "machines" necessarily places them, though, in a humanist categorical framework. To speak of "machines" (without quotation marks) means to speak from within the myth. The idea of art-making machines whose products cannot be understood any more by humans is consistent with that myth, and it automatically leads to the uncanny aesthetics

[14] On the political economy of data, cf. (Zuboff 2019), and the insightful critique by Morozov (2019).

[15] A similar problematic underpins Brian House's interpretation of his situationist project, *Everything That Happens Will Happen Today* (2018) which supposedly maintains its human-ness since the data sets are derived from human behaviour.

that Paglen's *Adversarially Evolved Hallucinations* share with Mary Shelley's *Frankenstein*. The unease they exert is a function of the myth, as is the sense of human obsolescence that has haunted a culture unable to come to terms with its technical determinations, ever since the Enlightenment.

In a recent essay on the "solitude of machines", French artist Gregory Chatonsky draws our attention to the algorithmic automata that populate the electronic networks and our technical environments, unobservable and solitary, and asks whether such a solitude is thinkable without the finality of being, a solitude without a relation to the world, a solitude without anybody (Chatonsky 2013). He concludes that this speculation about "the solitude of a machine, a subject with no subjectivity and relationality that nevertheless affects us" (ibid.) serves to rethink the relation of aesthetics and ontology, of thought and perception.

Yet, what had been a rather more mechanical challenge under the moniker of the "Daughter Born Without a Mother" in the mechanomorphic drawings and paintings by Francis Picabia (*Fille née sans mère*, 1915–1917), is, a century later, being transformed into the spectre not only of the obsolescence, but of the disappearance of the human, the engineer mother, and the total independence of *machines without engineers*. This last chapter of the myth of the machine is predicated on a cybernetic and nonhuman conception of intelligence. It inherits its ideological framing from the historical discourse on Cybernetics, geared at the subjection of humans under its technological and biopolitical paradigm.[16] While the ontological speculation proposed by Chatonsky benefits from the contingent alterity of machines, the political debate on technics must address their biopolitical integration. For artists, there is no obligation to follow such a political agenda; however, they must recognise that an aesthetics of "artificialism" and "machine realism" may in fact work against the critical impetus that, as citizens and technologists, they seek to advocate.

Funding: This research received no external funding.

Acknowledgments: The author would like to express his gratitude to the anonymous reviewers for their constructive comments, to the editors for their diligent support, as well as to Francis Hunger, Leipzig, for his critical revision of an earlier version of this text.

Conflicts of Interest: The author declares no conflict of interest.

References

Assmann, Jan, and Aleida Assmann. 1998. Mythos. In *Handbuch Religionswissenschaftlicher Grundbegriffe*. Edited by Hubert Cancik, Burkhard Gladigow and Matthias Samuel Laubscher. Stuttgart: Kohlhammer, pp. 179–200.

Barthes, Roland. 2009. *Mythologies*. London: Vintage. First published 1957.

Blumenberg, Hans. 1985. *Work on Myth*. Cambridge: MIT-Press. First published 1979.

Broeckmann, Andreas. 2016. *Machine Art in the Twentieth Century*. Cambridge: MIT-Press.

Burckhardt, Martin. 2018. *Philosophie der Maschine*. Berlin: Matthes & Seitz.

Chatonsky, Gregory. 2013. The Solitude of Machines. *Art Press* 29: 81–84.

Haraway, Donna. 1991. A Cyborg Manifesto: Science, Technology, and Socialist-Feminism in the Late Twentieth Century. In *Simians, Cyborgs, and Women*. London: Free Association Books, pp. 149–81. First published 1985.

Hertzmann, Aaron. 2018. Can Computers Create Art? *Arts* 7: 18. [CrossRef]

Hunger, Francis. 2017. Artificial Des-Intelligence or Why Machines Will Not Take over the World. At Least Not Now. Available online: http://databasecultures.irmielin.org/artificial-des-intelligence/ (accessed on 18 December 2018).

Morozov, Evgeny. 2019. Capitalism's New Clothes. *The Baffler*. February 4. Available online: https://thebaffler.com/latest/capitalisms-new-clothes-morozov (accessed on 8 February 2019).

Mumford, Lewis. 1967–1970. *The Myth of the Machine*. 2 vols. New York: Harcourt Brace Jovanovich.

[16] A powerful argument about this constellation was put forward under the concept of the "informatics of domination" by Donna Haraway, in the *Cyborg Manifesto*; cf. (Haraway 1991). Haraway also provides important hints at the *gendered* aspects of the machine myth, and of the access and subjection to technology.

Paglen, Trevor. 2014. Operational Images. *E-Flux Journal*. Available online: http://www.e-flux.com/journal/operational-images/ (accessed on 18 December 2018).

Paglen, Trevor. 2018. Machine Realism. In *I Was Raised on the Internet*. Exh. catalogue. Museum of Contemporary Art Chicago. Munich and New York: DelMonico, Prestel, pp. 112–18.

Prampolini, Enrico. 1922. The Aesthetic of the Machine and Mechanical Introspection in Art. *Broom: An International Magazine of the Arts* 3: 235–37.

Rokeby, David. 1995. Transforming Mirrors: Subjectivity and Control in Interactive Media. In *Critical Issues in Interactive Media*. Edited by Simon Penny. Albany: SUNY Press, pp. 133–58.

Sollfrank, Cornelia. 2004. *Net.Art Generator*. Nürnberg: Verlag für Moderne Kunst.

Srp, Karel, and Lenka Bydžovská. 2007. *Jindřich Štyrský*. Prague: Argo.

Štyrský, Jindřich, and Toyen. 2002. Artificielismus. In *Between Two Worlds: A Sourcebook of Central European Avant-Gardes, 1910–1930*. Cambridge: MIT-Press. First published in 1927–1928.

Turing, Alan. 1950. Computing Machinery and Intelligence. *Mind* 59: 433–60. [CrossRef]

Versari, Maria Elena. 2009. Futurist Machine Art, Constructivism and the Modernity of Mechanization. In *Futurism and the Technological Imagination*. Edited by Günter Berghaus. Amsterdam: Rodopi, pp. 149–70.

White, Christopher. 2015. The Rembrandt Research Project and its denouement, review of A Corpus of Rembrandt Paintings, Vol. VI. *The Burlington Magazine* 153: 71–73.

Zuboff, Shoshana. 2019. *The Age of Surveillance Capitalism: The Fight for a Human Future at the New Frontier of Power*. New York: Public Affairs.

arts

Essay

Art, Creativity, and the Potential of Artificial Intelligence

Marian Mazzone [1,*] and Ahmed Elgammal [2,*]

1 Department of Art & Architectural History, College of Charleston, Charleston, SC 29424, USA
2 Department of Computer Science, Rutgers University, New Brunswick, NJ 08901-8554, USA
* Correspondence: mazzonem@cofc.edu (M.M.); elgammal@cs.rutgers.edu (A.E.)

Received: 2 January 2019; Accepted: 14 February 2019; Published: 21 February 2019

Abstract: Our essay discusses an AI process developed for making art (AICAN), and the issues AI creativity raises for understanding art and artists in the 21st century. Backed by our training in computer science (Elgammal) and art history (Mazzone), we argue for the consideration of AICAN's works as art, relate AICAN works to the contemporary art context, and urge a reconsideration of how we might define human and machine creativity. Our work in developing AI processes for art making, style analysis, and detecting large-scale style patterns in art history has led us to carefully consider the history and dynamics of human art-making and to examine how those patterns can be modeled and taught to the machine. We advocate for a connection between machine creativity and art broadly defined as parallel to but not in conflict with human artists and their emotional and social intentions of art making. Rather, we urge a partnership between human and machine creativity when called for, seeing in this collaboration a means to maximize both partners' creative strengths.

Keywords: artificial intelligence; art; creativity; computational creativity; deep learning; adversarial learning

---

1. AI-Art: GAN, a New Wave of Generative Art

Over the last 50 years, several artists and scientists have been exploring writing computer programs that can generate art. Some programs are written for other purposes and are adopted for art making, such as generative adversarial networks (GANs). Alternatively, programs can be written that intend to make creative outputs. Algorithmic art is a broad term that points to any art that cannot be created without the use of programming. If we look at the Merriam-Webster definition of art, we find "the conscious use of skill and creative imagination especially in the production of aesthetic objects; the works so produced". Throughout the 20th century, that understanding of art has been expanded to include objects that are not necessarily aesthetic in their purpose (for example, conceptual art), and not created physical objects (performance art). Since the challenges of Marcel Duchamp's practice, the art world has also relied on the determination of the artist's intention, institutional display, and audience acceptance as critical defining steps to decide whether something is "art".

The most prominent early example of algorithmic art work is by Harold Cohen and his program AARON (aaronshome.com). American artist Lillian Schwartz, a pioneer in using computer graphics in art, also experimented with AI (Lillian.com). However, in the last few years, the development of GANs has inspired a wave of algorithmic art that uses Artificial Intelligence (AI) in new ways to make art (Schneider and Rea 2018). In contrast to traditional algorithmic art, in which the artist had to write detailed code that already specified the rules for the desired aesthetics, in this new wave, the algorithms are set up by the artists to "learn" the aesthetics by looking at many images using machine learning technology. The algorithm only then generates new images that follow the aesthetics it has learned.

Figure 1 explains the creative process that is involved in making this kind of AI art. The artist chooses a collection of images to feed the algorithm (pre-curation), for example, traditional art portraits. These images are then fed into a generative AI algorithm that tries to imitate these inputs. The most widely used tool for this is generative adversarial networks (GANs), introduced by Goodfellow in 2014 (Goodfellow et al. 2014), which have been successful in many applications in the AI community. It is the development of GANs that likely sparked this new wave of AI Art. In the final step, the artist sifts through many output images to curate a final collection (post-curation).

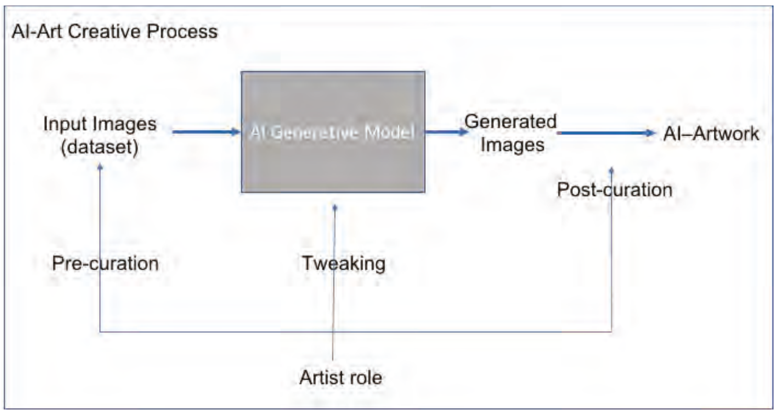


Figure 1. A block diagram showing the artist's role using the AI generative model in making art. Diagram created by author A. Elgammal.

In this kind of procedure, AI is used as a tool in the creation of art. The creative process is primarily done by the artist in the pre- and post-curatorial actions, as well as in tweaking the algorithm. There have been many great art works that have been created using this pipeline. The generative algorithm always produces images that surprise the viewer and even the artist who presides over the process.

Figure 2 is an example of what a typical GAN trained on portrait paintings would produce. Why might we like or hate these images, and should we call them art? We will try to answer these questions from a perception and a psychology point of view. Experimental psychologist Daniel E. Berlyne (1924–1976) studied the basics of the psychology of aesthetics for several decades and pointed out that *novelty*, *surprisingness*, *complexity*, *ambiguity*, and *puzzlingness* are the most significant properties in stimulus relevance to studying aesthetic phenomena (Berlyne 1971). Although there are several alternative newer theories than Berlyne's, we use it in our explanation for its simplicity as the explanation does not contradict other theories. Indeed, the resulting images with all the deformations in the faces are novel, surprising, and puzzling to us. In fact, they might remind us of Francis Bacon's famous deformed portraits such as *Three Studies for a Portrait of Henrietta Moraes* (1963). However, this comparison highlights a major difference, that of intent. It was Bacon's intention to make the faces deformed in his portrait, but the deformation we see in the AI art is not the intention of the artist nor of the machine. Simply put, the machine fails to imitate the human face completely and, as a result, generates surprising deformations. Therefore, what we are looking at are failure cases by the machine that might be appealing to us perceptually because of their novelty as visual stimuli compared to naturalistic faces. However, these "failure cases" have a positive visual impact on us as viewers of art; only in these examples, the artist's intention is absent.

Figure 2. Examples of images generated by training a generative adversarial network (GAN) with portraits from the last 500 years of Western art. The distorted faces are the algorithm's attempts to imitate those inputs. Images generated at Art & Artificial Intelligence Laboratory, Rutgers.

So far, most art critics have been skeptical and usually evaluate only the resulting images while ignoring the creative process that generates them. They might be right that images created using this type of AI pipeline are not that interesting. After all, this process just imitates the pre-curated inputs with a slight twist. However, if we look at the creative process overall and not simply the resulting images, this activity falls clearly in the category of conceptual art because the artist has the option to act in the choice-making roles of curation and tweaking. More sophisticated conceptual work will be coming in the future as more artists explore AI tools and learn how to better manipulate the AI art creative process.

2. Pushing the Creativity of the Machine: Creative, Not Just Generative

At Rutgers' Art & AI Lab, we created AICAN, an almost autonomous artist. Our goal was to study the artistic creative process and how art evolves from a perceptual and cognitive point of view. The model we built is based on a theory from psychology proposed by Colin Martindale (Martindale 1990). The process simulates how artists digest prior art works until, at some point, they break out of established styles and create new styles. The process is realized through a "creative adversarial network (CAN)" (Elgammal et al. 2017), a variant of GAN that we proposed that uses "stylistic ambiguity" to achieve novelty. The machine is trained between two opposing forces—one that urges the machine to follow the aesthetics of the art it is shown (minimizing deviation from art distribution), while the other force penalizes the machine if it emulates an already established style (maximizing style ambiguity). These two opposing forces ensure that the art generated will be novel but at the same time will not depart too much from acceptable aesthetic standards. This is called the "least effort" principle in Martindale's theory, and it is essential in art generation because too much novelty would result in rejection by viewers. Figure 3 illustrates a block diagram of the CAN network where the generator receives two signals, one measuring the deviations from art distribution and the second measuring style ambiguity. The generator tries to minimize the first to follow aesthetics and maximize the second to deviate from established styles.

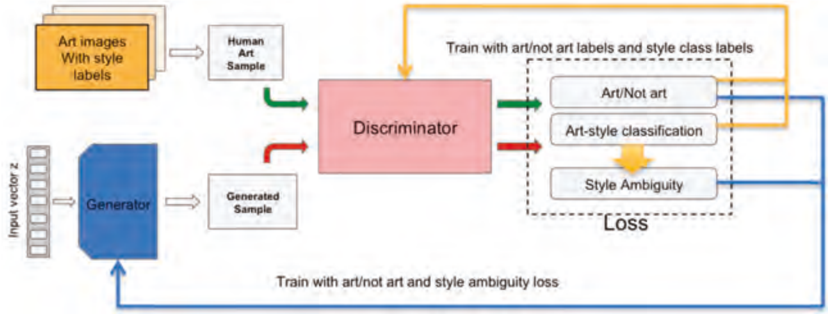


Figure 3. A block diagram of a creative adversarial network. The generator explores the creative space by trying to generate images that maximize style ambiguity while minimizing deviation from art distribution. Diagram by author A. Elgammal.

Unlike the generative AI art discussed earlier, this process is inherently creative. There is no curation on the dataset; instead, we fed the algorithm 80K images representing 5 centuries of Western art history, simulating the process of how an artist digests art history, with no special selection of genres or styles. The generative process using CAN is seeking innovation. The outputs surprise us all the time with the range of art AICAN generates. Figure 4 shows the variety of AICAN-generated art.

Figure 4. Examples of images generated by AICAN after training with images from all styles and genres from the past 500 years of Western art. Images courtesy of the Art & Artificial Intelligence Laboratory, Rutgers.

We devised a visual Turing test to register how people would react to the generated images and whether they could tell the difference between AICAN- or human-created art. To make the test timely and of high quality, we mixed images from AICAN with works from Art Basel 2016 (the flagship art fair in contemporary art). We also used a set of images from abstract expressionist masters as a baseline. Our study showed that human subjects could not tell whether the art was made by a human artist or by the machine. Seventy-five percent of the time, people in our study thought the AICAN generated images were created by a human artist. In the case of the baseline abstract expressionist set, 85% of the time subjects thought the art was by human artists. Our subjects even described the AICAN-generated images using words such as "intentional", "having visual structure", "inspiring", and "communicative" at the same levels as the human-created art.

Beginning in October 2017, we started exhibiting AICAN's work at venues in Frankfurt, Los Angles, New York City, and San Francisco, with a different set of images for each show (Figure 5). Recently, in December 2018, AICAN was exhibited in the SCOPE Miami Beach Art Fair. At these exhibitions, the reception of works was overwhelmingly positive on the part of viewers who had no prior knowledge that the art shown was generated using AI. People genuinely liked the artworks and engaged in various conversations about the process. We heard one question time and again: Who is the artist? Here, we posit that the person(s) setting up the process designs a conceptual and algorithmic framework, but the algorithm is fully at the creative helm when it comes to the elements and the principles of the art it creates. For each image it generates, the machine chooses the style, the subject, the forms, and composition, including the textures and colors.

Figure 5. Photographs from AICAN exhibition held in Los Angeles in October 2017. Photographs by author A. Elgammal.

3. AI in Art and Art History

The CAN study provoked a number of concerns about AI as a threat or rival to art made by human beings. Yes, the study is interested in the process of art creation, and the more abstract problem of what creativity is and does. However, AI focuses on developing a *machine* process and *machine* creativity, not merely aping and trying to pass as human-made. Our work is focused on understanding the *process of creativity* such that a means can be found to model that process to generate a creative result. One way to do this, and what this study has chosen, is to model the process by which art is taught and then stimulate AICAN to synthesize that style information and next create something new. To do this, the machine was trained on many thousands of human-created paintings in a process parallel to a human artists' experience of looking at other artists' works, learning by example. The AICAN system was then designed to encourage choices that deviate from copying/repeating what had been seen (the GAN function) to encouraging new combinations and new choices based on a knowledge of art styles (the CAN function). If the creation process is modeled successfully, art may result.

One barometer of whether art has been successfully created through the chosen process is whether human beings appreciate it as art and do not necessarily recognize it as AI-derived. AICAN was tasked with creating works that did not default into the familiar psychedelic patterning of most GAN-generated images as a test of its creativity function. Our inclusion of viewer surveys to gauge peoples' responses did not aim to prove that the AICAN artifacts were better than human creations, but rather to gauge whether the AICAN works were aesthetically recognizable as art, and whether human viewers liked the AI-generated works of art. It seemed most pertinent to have viewers assess the AICAN images in a group with other contemporary images rather than historical ones, hence the choice to select these from Art Basel. The objective was to learn whether AICAN can produce work that is able to qualify or count as art, and if it exhibits qualities that make it desirable or pleasurable to look at. In other words, could AICAN artifacts be recognized as quality aesthetic objects by human beings? Because we used Berlyne's theory of arousal potential, the response of human beings to the images was a necessary check to evaluate the quality level of AICAN creativity.

There may always be a number of artists and art lovers who resist the idea of AI in art because of technophobia. For them, the machine simply has no place in art. In addition, many lack understanding of what AI actually is, how it works, and what it can and cannot be made to do. There is also an element of fear at work, resulting in an imagined future in which AI will commandeer art making and crank out masses of soulless abstract paintings. However, as we discuss throughout this article, AI is really very limited and specific in what it can do in terms of art creation, and it was never our goal is to supplant the role of the human artist. There is simply and profoundly no need to do that. It is an interesting problem in machine learning to model the process of image creation and to explore what creativity might mean within the confines of computation, but these are issues separate and apart from how a human being makes art, and they are not mutually exclusive in any way. The very best outcome we can imagine is a fruitful partnership between an artist and a creative AI system. However, we are in the very early days of developing algorithms for such AI systems.

A comparison with photography is useful because both forms of technology first encountered resistance in the art world based on the use of a machine in the art-making process. This comparison has been discussed widely, including in this issue of *Arts* (Hertzmann 2018) (Agüera y Arcas 2017), so we will not elaborate on it here. A hopeful sign for AI art is that eventually, some photography was fully accepted as art. A key path towards its acceptance was the dialogue that developed between two mediums: Photographers worked to incorporate some of the formal and aesthetic characteristics of painting, while painters were closely looking at photography and shifting painting in response. Painters were inspired by the compositional flatness, capture of movement, and summary edges of the photographic viewfinder. Photographers shifted their approach to lighting, focus, and subject matter as inspired by the aesthetic criteria of painting. Thus, a feedback loop was established between the practices of painting and photography. In both cases, creators began to see *differently* based on their experiences with the other medium. Perhaps this can happen between AI and painting in turn. Currently, most AI systems are trained on thousands of paintings made by Western European and American artists over the last several hundred years. In turn, the AIs create images that speak the language of painting (color choices, form elements, arrangement of forms on a 2-D surface) and depose their elements before the eyes of viewers in a way similar to how we look at paintings. Already, we have contemporary practitioners such as Jason Salavon or Petra Cortright, whose practice demonstrates a lively exchange between the processes of painting and those of computation. Photography did threaten to supplant some of the functions of painting, particularly in those instances when a high degree of naturalistic representation was desirable, such as in portraiture or in topographical representations. Consequently, photography largely did replace painted portraits and most forms of topographical imagery, for example. We imagine that AI-produced art could usefully replace some mass-produced imagery such as decorative art or tourist scenes where repetition of a few pleasing characteristics is desirable. Consumers would be the drivers of this market, electing for the machine-derived images or preferring those created by a human.

Another sound point of comparison is the replicative process of image production employed by both the camera and the computer. Like the camera, the computer provides its user with a range of repetitive and reproductive means to generate multiple images. As noted by Walter Benjamin in the early 20th century (Benjamin [1936] 1969), the impact of the mass production and reproduction of imagery has changed how we think about the originality and the legitimacy of reproductions of works of art, and our viewing experience of art. Most people's experience of art is now soundly in the realm of reproductions, and we ascribe meaningfulness to the experience of the reproduction. Although the singular, original work of art is a paradigm still operational in painting, it is markedly less so in print making or photography, and completely absent in computational art. Computers can produce many more and varied versions of an image through parameterization, randomizing tools, and other generative processes than can nondigital photography or prints, but the theoretical principle of the multiple still applies. The contemporary art world is well able to theorize and accept multiples or reproductions as legitimate works of art, we believe even at the rate and level of complexity produced by generative computational systems.

There is, however, one profound difference between AI computer-based creativity versus other machine-based image making technologies. Photography, and the similar media of film and video, are predicated on a reference to something outside of the machine, something in the natural world. They are technologies to capture elements of the world outside themselves as natural light on a plate or film, fixed with a chemical process to freeze light patterns in time and space. Computational imagery has no such referent in nature or to anything outside of itself. This is a profound difference that we believe should be given more attention. The lack of reference in nature has historical implications for how we understand something as art. Almost all human art creation has been inspired by something seen in the natural world. There, of course, may be many steps between the inspiration and the resulting work, such that the visual referent can be changed, abstracted or even erased by the final version. However, the process was always first instigated by the artist looking at something in the world, and photography, film, and video retained that first step of the art-making process through light encoding. The computer does not follow this primal pattern. It requires absolutely nothing from the natural world; instead, its "brain" and "eyes" (its internal apparatus for encoding imagery of any kind) consist only of receptors for numerical data. There are two preliminary points to elaborate here: The first relates to issues in contemporary art, the second to the distinction from human creativity.

First, the lack of referent in the natural world and the resulting freedom and range to create or not create any object as a result of the artistic inspiration aligns AI and all computational methods with conceptual art. Like with photography, the comparison with conceptual art has frequently been made for AI and computational methods in general. In conceptual art, the act of the creation of the art work is located in the mind of the artist, and its instantiation in any material form(s) in the world is, as Sol Lewitt (Lewitt 1967) famously declared, "a perfunctory affair. The idea becomes a machine that makes the art." Thus, the making of an art object becomes simply optional. And although contemporary artists in the main have not stopped making objects, the principle that object making is optional and variable in relation to the art concept still remains. We believe this is at the heart of the usefulness of the comparison with conceptual art: The idea or concept is untethered from nature, being primarily located in the synapses of the brain and secondly disassociated from the dictates of the material world. Most AI systems use some form of a neural network, which is modeled on the neural complexity of the human brain. Therefore, AI and conceptual art coincide in locating the art act in the system network of the brain, rather than in the physical output. The physical act of an artist, either applying paint or carving marble, becomes optional. This removes the *necessity* of a human body (the artist) to make things and allows us to imagine that there could be more than one kind of artist, including *other* than human.

4. AI Art: Blurring the Lines between the Artist and the Tool

Many artists and art historians resist seeing work created with AI as art because their definition of art is based on the modern artist figure as the sole locus of art creation and creativity. Therefore, the figure of the artist is necessary to their definition of art. But understanding art as a vehicle for the personal expression of the individual artist is a relatively recent and culturally-specific conception. For many centuries, across many cultures and belief systems, art has been made for a variety of reasons under a wide range of conditions. More often created by groups of people rather than an individual artist (think medieval cathedrals or guild workshops), art is often made to the specifications of patrons and donors large and small, made to order, funded by a wide variety of groups, civic organizations, or religious institutions, and made to function in an extraordinary range of situations. The notion of a work of art being the coherent expression of the individual's psyche, emotional condition, or expressive point of view begins in the Romantic era and became the prevailing norm in the 19th and 20th centuries in Western Europe and its colonies. Although this remains a common motivation for many artists working today, it does not mean it is the only and correct definition of art. And certainly, it is not a role that any AI system will ever be able to fulfill. Clearly, machine learning and AI cannot replicate the lived experience of a human being; therefore, AI is not able to create art in the same way that human artists do. Thankfully, we are not proposing that it can in our work. Humans and AI do not share all of the same sources of inspiration or intentions for art making. Why the machine makes art is intrinsically different; its motivation is that of being tasked with the problem of making art, and its intention is to fulfill that task. However, we are asking everyone to consider that a different process of creation does not disqualify the results of the process as a viable work of art. Instead consider that without the *necessity* of the individual expressive artist in our definition of art, how we conceptualize art and art making is greatly expanded.

AI is a set of algorithms designed to function as parallel to human intelligence actions such as decision-making, image recognition, language translation/comprehension, or creativity. Elsewhere in this issue of *Arts*, Hertzmann (Hertzmann 2018) makes a point about art algorithms being tools, not artists. As we have argued, we would agree that the algorithms in AI are not artists like human artists. But AI (art generating algorithm in this case) is more than a tool, like a brush with oil paint on it, which is an inanimate and unchanging object. Certainly, artists learn over time and with experience how to better use their tools, and their tools have a role in the physical actions by which they make work in paint. However, the paintbrush does not have the capacity to change, it does not make decisions based on past painting experiences, and it is not trained to learn from data. Algorithms contain all of those possibilities. Perhaps we can conceptualize AI algorithms as more than tools and closer to a *medium*. The word medium in the art world indicates far more than a tool, a medium includes not only the tools used (brush, oil paint, turpentine, canvas, etc.) but also the range of possibilities and limitations inherent to the conditions of creation in that area of art. Thus, the medium of painting also includes a history of painting styles, the physical and conceptual restraints of the 2-D surface, the limits of what can be recognized as a painting, a critical language that has been developed to describe and critique paintings, and so on. Admittedly, we are in the very early days of the medium of AI in art creation, but this medium might encompass tools such as code, mathematics, hardware and software, printing choices, etc., with medium conditions including algorithmic structuring, data collection and application, and the critical theory needed to detect and judge computational creativity and artistic intention within the much larger field of computer science. At this time, a problem is the relatively small number of people able to work creatively in this field or judge the role of the machine in the exercise of creative processes. This will change over time as artists, computer scientists, and historians/critics all become more knowledgeable. For human artists who are interested in the possibilities (and limitations) of AI in creativity and the arts, using AI as a creative partner is already happening now and will happen in the future. In a partnership, both halves bring skill sets to the process of creation. As Hertzmann notes in his article and Cohen discovered in his work with the AARON program, human artists bring capacity for high-quality work, artistic intent, creativity, and growth/change over time. Art is a social interaction. Actually, we think we can argue that AI does a fair amount of this, and it can certainly all be accomplished in a creative partnership between and artist and his or her AI system.

Author Contributions: Conceptualization, M.M. and A.E.; methodology A.E. and M.M.; data curation A.E.; software A.E.; validation A.E.; writing—original draft preparation M.M. (abstract, introduction, Sections 3 and 4) and A.E. (Sections 1 and 2); writing—reviewing and editing, M.M.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

Agüera y Arcas, Blaise. 2017. Art in the Age of Machine Intelligence. *Arts* 6: 18. [CrossRef]

Benjamin, Walter. 1969. The Work of Art in Age of Mechanical Reproduction. In *Illuminations*. Edited by Hannah Arendt. New York: Schocken, pp. 217–51. First published 1936.

Berlyne, Daniel E. 1971. *Aesthetics and Psychobiology*. New York: Appleton-Century-Crofts of Meredith Corporation, p. 336.

Elgammal, Ahmed, Bingchen Liu, Mohamed Elhoseiny, and Marian Mazzone. 2017. CAN: Creative adversarial networks, generating "art" by learning about styles and deviating from style norms. *arXiv*, arXiv:1706.07068.

Goodfellow, Ian, Jean Pouget-Abadie, Mehdi Mirza, Bing Xu, David Warde-Farley, Sherjil Ozair, Aaron Courville, and Yoshua Bengio. 2014. Generative adversarial nets. In *Advances in Neural Information Processing Systems*. Cambridge: MIT Press, pp. 2672–80.

Hertzmann, Aaron. 2018. Can Computers Create Art? *Arts* 7: 18. [CrossRef]

Lewitt, Sol. 1967. Paragraphs on conceptual Art. *Artforum* 5: 79–84.

Martindale, Colin. 1990. *The Clockwork Muse: The Predictability of Artistic Change*. New York: Basic Books.

Schneider, Tim, and Naomi Rea. 2018. Has artificial intelligence given us the next great art movement? Experts say slow down, the 'field is in its infancy. *Artnetnews*. September 25. Available online: https://news.artnet.com/art-world/ai-art-comes-to-market-is-it-worth-the-hype-1352011 (accessed on 3 February 2019).

arts

MDPI

Article

Drawing in the Digital Age: Observations and Implications for Education

Seymour Simmons

Department of Fine Art, Winthrop University, Rock Hill, SC 29733, USA; seymoursimmons@gmail.com

Received: 11 January 2019; Accepted: 1 March 2019; Published: 6 March 2019

Abstract: This paper looks at recent examples of how drawing is advancing into the digital age: in London: the annual symposium on *Thinking Through Drawing*; in Paris: an exhibition at the Grand Palais, *Artistes et Robots*; a conference at the Institut d'études avancées on *Space-Time Geometries and Movement in the Brain and in the Arts*; and, at the Drawing Lab, *Cinéma d'Été.* These events are contrasted to a recent decline in drawing instruction in pre-professional programs of art, architecture, and design as well as in pre-K12 art education due largely to the digital revolution. In response, I argue for the ongoing importance of learning to draw both in visual art and in general education at all levels in the digital age.

Keywords: drawing; digital media; education; philosophy; cognition; robots; artificial intelligence

---

1. Introduction

In this paper, contemporary considerations of "Machine as Artist" serve as points of departure for thinking about one of humankind's oldest arts. With the earliest extant example now dating back more than 70,000 years, drawing apparently has been part of the human experience since its beginnings (Henshilwood et al. 2018). Since then, drawing has accompanied the expansion of humanity around the globe and has helped human civilization advance from the Stone Age to the Digital Age. For example, Patrick Maynard (2005) claims that, without technical drawing during the Industrial Revolution and the kinds of thinking it entailed, there simply would have been no modern era.[1] The drawing impulse is equally evident in human development as we watch children come into the world ready, as psychologist Ellen Winner (1986) says, to make their marks with any available implement on every available surface. Taken together, these facts demonstrate that the instinct to draw is innate: to be human is to draw.

At the same time, drawing, like all inborn potentials, demands cultivation for its realization. Thus, across the millennia, drawing has been taught not only to those preparing for careers in the visual arts, but equally as part of general education. In this context, drawing's virtues were praised by philosophers like Aristotle, Locke, and Rousseau; educators like Horace Mann and John Dewey; and statesmen like Benjamin Franklin and Thomas Jefferson (Efland 1990; Simmons 1988). Today, however, drawing instruction is at risk both in K12 education and in post-secondary programs of art, architecture, and design. There are many reasons for this situation including modernist reactions against 'academic' teaching methods in which drawing was the primary concern, the unprecedented pluralism of post-modern art, and the emergence of new forms of artistic expression like performance art and conceptual art. However, the principal threat comes from the power and the proliferation of digital media, which some claim makes traditional drawing instruction obsolete. In architectural

---

[1] Explaining the importance of technical drawing to the modern world, Maynard says, that without such drawings, "it is hard to see how there would be a modern world. For there would be neither the kinds of technological thinking nor the kinds of manufacture that make industrial and post industrial societies possible, nor their use and maintenance."

education, this threat was articulated as early as 1989 at the dawn of computer-aided drafting and design (CADD) by then Harvard professor of architecture, William J. Mitchell, in an article entitled: "The Death of Drawing" (Mitchell 1989). The phrase continues to resonate (Levin 2002; Yale 2013; Sheer 2014), and not just in architecture.

Here, I argue that Mitchell's dire pronouncement was, as Mark Twain said about rumors of his own death, 'exaggerated' (Twain 2018). Toward that end, I look at four examples of how drawing is being taught, researched, and applied in the 21st century: one recalling drawing's experiential origins, the others taking advantage of new technologies, including machines that draw. Doing so, however, I also take seriously the challenges new technologies pose to traditional drawing study and to the benefits it has long provided in the arts and across the disciplines, including in all four STEM subjects: science, technology, engineering, and mathematics. I will begin with some personal background. I am grateful to Frederic Fol Leymarie and Glenn W. Smith for inviting me to reflect on these topics for this publication.

Background

First, a disclaimer. Unlike many who have contributed to this issue of *Arts*, I am not an expert in robotics or technology of any kind. Far from it! My perspective on "Machine as Artist" and related subjects is as an artist and art teacher accustomed to working with traditional media like charcoal, graphite, and ink. That said, since the 1980's, I have followed with fascination advances in digital imaging and recognize its potential to take drawing, among other art forms, into the future. In fact, one of my initial forays into drawing research (at Harvard Project Zero, a center for research on the arts and cognition) involved exploring ways computers could be used to teach art, music, and social studies (Walters et al. 1988). My task was to develop lessons on linear perspective using the early Macintosh programs, Macpaint and Macdraw, a project I have pursued off and on ever since.[2]

At the same time, drawing instruction was the topic of my doctoral thesis in philosophy of education at the Harvard Graduate School of Education, which has been the basis of my continuing research. The thesis, entitled *Bringing Art to Mind: Theory and Practice in the Teaching of Drawing* (Simmons 1988), traced the history of drawing instruction from ancient times through the late 20th century, highlighting philosophical principles underlying various teaching methods. My premise was that different pedagogical paradigms represented distinct 'philosophies of drawing education.' In part, the term 'philosophy' seemed warranted because each teaching method represented a particular conception of what drawing was and what it was for, e.g., drawing as design, drawing as perception, drawing as experience, drawing as self-expression, and drawing as a graphic idiom. More important, in researching the origins of these methods, I found continuities, explicit or implicit, with prominent philosophical movements at the time. Rationalism during the Renaissance and for centuries thereafter had an explicit impact on academic art instruction where the aim of art was to capture not the actual but the ideal (Pevsner 1973). By contrast, the influence of empiricism during the Age of Enlightenment is evident in the emphasis on observational drawing based, as John Ruskin put it, on recovering the 'innocence of the eye' (Ruskin 1837). The impact of pragmatism in the late 19th and early 20th century is reflected in the emphasis on experimentation in early modernism, while the influence of existentialism is reflected in the Expressionist movement in the early to mid-20th century. Later, I came to link drawing as a graphic idiom, i.e., a visual language, with semiotics and non-representational art (Simmons 2012).

[2] Working with Winthrop University art and design students and faculty, I developed digital animations to demonstrate perspective principles like foreshortening and convergence of receding parallel lines (orthogonals). Most recently, some of these animations were included in a set of videos to teach drawing to college non-art majors as part of a research project on "Assessing and Fostering Visual Imagination Through Drawing," sponsored by the Imagination Institute. (http://www.imagination-institute.org/2018/06/06/assessing-fostering-visual-imagination-through-drawing/).

A third reason to associate drawing with philosophy is implied in the title of the thesis, where 'bringing art to mind' alludes to my concern to recall a Renaissance understanding of drawing as the 'cognitive' dimension underlying all the visual arts and connecting them to other disciplines, as mentioned above. Deanna Petherbridge at the beginning of her book, *The Primacy of Drawing* (Petherbridge 2010, p. 2), succinctly states this view in her belief "that drawing is the basis of all art and visual thinking." Further on, Petherbridge describes how that view played out in visual arts study until quite recently, saying: "before the late 20th century, learning to be an artist or architect as an apprentice in a studio or attending an academy or art school was entirely predicated on learning to draw. Drawing was conceived of as a way of learning about past and present art, about recording the everyday world and achieving control of processes of representation, as well as perfecting the conduit between hand and imagination through practice" (p. 210). What this meant for art students at the time was described to me by Professor Alf Ward, former chair of the Department of Art and Design at Winthrop University (Rock Hill, SC, USA), where I taught from 1993–2017. Ward studied at the Gravesend School of Art in the UK during the early 1960's, where, to prepare for a career that would eventually include fine arts, jewelry, metalsmithing, product design, and art education, he took required drawing classes every semester of undergraduate study. Plus, drawing was a component in other studio classes and art history (personal communication).[3]

By contrast, an increasing number of fine art and design programs today require only one or two drawing classes, typically as "foundation courses" (first, or first and second year), and some programs, including former art academies, require no drawing courses at all.[4] This paper offers a response to that situation. In addition to my thesis, I now am able to draw upon a recent body of research on drawing from various perspectives including cognitive science, neurobiology, and several branches of psychology (developmental, perceptual, cognitive, clinical, etc.). In the following sections, I will discuss how this research figured in four events I attended in the summer of 2018. Unfortunately, I am only able to highlight certain aspects of each event specifically relevant to the issues of concern in this paper. However, I will include links for those seeking more information.

---

3 Prior to enrolling full-time at Gravesend, Ward had already taken drawing classes at the school for two years on Friday's and Saturday's. Earlier still, he said he drew regularly in elementary school and took four years of technical drawing in high school. Ward is from Dartford, Kent, a largely working-class city where, he says, technical drawing was taught, not to prepare students to be architects, but to work in the local factories. Ward credits his training in drawing for his future career in fine arts, product design, and his graduate-level concentration, jewelry and metals. A biographical note about Ward for a recent lecture he gave on starting points for creativity at the Bechtler Museum of Modern Art (Charlotte, NC, USA) includes this statement: "As an internationally known designer, Ward served as consultant designer for Spink & Sons in London (by appointment to her Majesty the Queen), where he designed and produced presentation pieces for: the Royal Family, Revlon of Paris, the Royal Air Force and the United Arab Emirates, among others." (http://bechtler.org/Learn/Events/details/alfred-ward-stars-of-start-points).

4 For some descriptions of drawing instruction in the modernist era, see Goldstein (1996). Concerning 21st century trends in drawing instruction, Associate Professor Christopher Wildrick of Syracuse University surveyed 37 US foundation programs in diverse settings: large and small institutions; public and private; universities, colleges, and designated art and design schools. He found that 35% required one drawing classes, 35% required two drawing classes, and 30% required no drawing classes (personal correspondence). Regarding the UK, I am grateful to one reviewer of this paper for highlighting "the welcome rise of drawing as an autonomous subject in the early 1990's as a backlash to drawing endorsed as a 'preparatory' stage for other fine art disciplines . . . This led to the rise in drawing research and the first dedicated University level programs in the UK and in the Antipodes." By contrast, the reviewer also noted that "recent government decisions have limited the access to study drawing in the UK at secondary level . . . " To investigate these claims, I posted an inquiry on the *Drawing Research Network* website which yielded information about both issues. Equally important, the chain of responses included numerous answers to my query about examples of, and reasons for the decline in drawing instruction. Many responses, primarily in the UK, confirmed the decline with information about their own programs as well as documentation of the reasons for it, including governmental policy. Others stated that drawing instruction had not declined in their institution, but several said that the number of classes varied from program to program and the way drawing was taught varied from teacher to teacher. See: Drawing Research Network: https://www.jiscmail.ac.uk/cgi-bin/webadmin?A0=drawing-research.

2. Four Drawing Events, Summer 2018

2.1. Thinking through Drawing

In June 2018, I participated in a symposium called "Drawing Rocks," sponsored by *Thinking through Drawing* (TtD), a research group on drawing and cognition founded in 2011 by three doctoral students doing research on drawing: Angela Brew, University of the Arts London (UK); Michelle Fava, Loughborough University (UK); and Andrea Kantrowitz, Columbia University (US). Since its establishment, TtD has sponsored annual symposia and workshops at Teachers College, Columbia University; the Metropolitan Museum of Art; the University of the Arts London, etc. These gatherings, based on themes like "Drawing Rocks" and "Drawing in STEAM" (STEM plus Arts) bring together artists, designers, and art educators with researchers studying drawing from the perspectives mentioned above, as well as faculty and practitioners in fields outside the arts, such as engineering, medicine, and mathematics, who use drawing in their work. This year's theme was based on the opening experience, which began as"a Mudlarking session on the nearby Thames beach, led by Emma Fält and Michael Moore." (see Figure 1) Each participant was to find one or more rocks which they then took back to the conference room to be drawn under Moore's direction.

Figure 1. Participants in *Thinking through Drawing* Symposium, Mudlarking on the Thames and selecting rocks to be drawn in workshop. Photo courtesy of Michael Moore.

Recently retired from The Pennsylvania Academy of the Fine Arts, Moore's drawings, though usually non-representational, are evocative of experiences in nature derived from multiple modes of sensory input.[5] Similarly, Moore framed the assignment as follows: "Using any variety of tools, participants will be asked to hold and observe a rock, and to draw that rock from the inside to the outside, gradually configuring random, graphic actions toward the external, visual physicality of the rock itself." Starting from the "inside out," the task was not a scientific investigation of the particular stone as observed by eye alone. Rather, it called for an experiential response to the stone taken from its specific context involving functions of brain, eye, and hand, including tactile and haptic perception, the latter referring to touch in grasping and holding.[6]

By contrast, another part of the workshop addressed drawing from imagination. This was an interview via Skype between TtD co-director Andrea Kantrowitz and cognitive psychologist, Barbara Tversky, with comments and questions by Michael Moore and Michelle Fava. The dialogue exemplified the interdisciplinary collaboration between scientists and artists around drawing that TtD represents.

---

5 See: http://drawingdrawings.com/drawings.html.

6 Examples of rock drawings, videos of the talks mentioned below, and other aspects of the symposium may be accessed at: https://www.thinkingthroughdrawing.org/symposia--publications.html.

As Kantrowitz's dissertation advisor, Dr. Tversky has been a frequent participant in TtD symposia where she speaks about her research on "visual-spatial reasoning, collaborative cognition, and the mapping and modeling of cognitive processes" (see, for example, Tversky 2011).

Kantrowitz began the conversation by asking: "What is the kind of thinking/reasoning that drawing allows?" Tversky responded, saying: "It's a kind of test of the idea." An idea put on the page is "never quite what you expected it to be . . . so then you work on it, and it becomes an iterative process" that influences the original idea. Kantoritz then pointed out that, "[e]ven within art and design education and among artists, [there is the view] that drawing is a way of presenting ideas that are already fully formed, but in fact what drawing allows you to do is to see the bits and pieces, and different ways of reconfiguring it . . . You coined a term in some of your studies of architects' drawing: 'constructive perception.'" To illustrate this concept, Tversky described a study she did working with architects making sketches for the design of an art museum. Explaining the process, she said the architects "would sketch out something very tentative, and then reexamine the sketch and find things they hadn't intended; in the sketch, they would see new things. Both novices and experts could make perceptual inferences—they could see patterns, things that were apparent in the sketch, but . . . experienced architects . . . could see conceptual relations, things that weren't in the sketch . . . lighting change over the year [or] traffic patterns." Like chess masters who can see many moves ahead, "it takes expertise or talent to see what isn't in the sketch but what is implied by it or might be implied by it." Moore confirmed this description based on his own drawing practice, saying: "To begin to draw, through the activity of drawing, and then to look for whatever one might have internalized having lived life on earth."

Tversky then went on to give an overview of her research: "What I first studied was how people conceive of the spaces they inhabit, the space of the body, the spaces around the body . . . how we distort them depending on our actions and how they get abstracted . . . into lines that are paths and dots that are places and . . . icons for things . . . in creating drawings, . . . diagrams, [etc.]. So, it's a bit like: 'How does space get into the mind and then how does the mind use space in the world to do more than navigate space.' It's a large agenda." In response to a question by Fava, Tversky spoke about the reasons she got into this sort of research: "When I was a graduate student, the reason I got into this whole thing, language had the hegemony in thinking, [but] it seemed to me that space came first evolutionarily and in the life of every individual. Understanding space has its own logic. We're first acting in space and language is based on that, not vice versa. [In drawing,] it becomes a conversation between the eye and the hand doing the action and what appears on the page. [In this process], language gets in the way. Articulation takes you out of the conversation. [That's] why I got into gestures. Like drawing in the air, [gestures] come before speech; to some extent they [help us] get ideas and communicate ... We think thinking happens between the ears, but the conversation with gesture is spatial motor."

Speaking about students in science learning through small group dialogue, Tversky said that when the students could refer to a visual image like a diagram, they demonstrated better comprehension than when referring only to verbal descriptions. "As a test of completeness, it's easy to see from a diagram that you have all the parts there and, as a test for coherence, you can see if it makes sense. It is a more direct mapping of thought, showing spatial, temporal, and causal relationships" (From video on TtD website).

Tversky's findings on the importance of 'constructive perception' and iterative sketching for ideation were confirmed by architects and designers in recent symposia and articles (Yale 2013; Graves 2012). As opposed to the precision required in perspective renderings and technical drawings (plans, sections, and elevations), which were once drafted by hand but are now largely produced via Computer-Aided Design software like AutoCAD and "Building Information Modeling" (BIM) software like Autodesk Revit (Revit 2018), sketches are rough, typically done by hand with pen or pencil on paper including on the proverbial napkin or envelope. As such, the process remains fluid, facilitating experimentation, correction, and communication among colleagues or with clients. Equally important, for the trained eye and hand, even mistakes may suggest unforeseen possibilities.

My presentation addressed similar practices in sketching from observation. Commonly called 'gesture drawings' and typically focused on the human figure in the context of fine arts, illustration, or animation, these involve quick poses (one to five minutes) during which time the challenge is to take in the whole figure in fluid lines intended to capture the movement, energy, or feeling of the pose. As in imaginative drawing or compositional design, reviewing the gesture during and after the pose enables artists to see if they captured the sense of unity and expressiveness in the pose while revealing errors, omissions, and aspects that need more work. From a primarily visual standpoint, gesture drawing exemplifies "active vision" (see Findlay and Gilchrist 2003; also, Brew 2015), a relatively recent field of research which challenges common assumptions of seeing as a matter of passively 'taking in' and instead defines it as a process of overt or covert searching and other intentional activities. These actions are in part evidenced by tracing eye movements, called 'saccades', between momentary stationary points, called 'fixations' (Findlay and Gilchrist 2003, p. 24).

Gesture drawing is nowhere better explained than in *The Natural Way to Draw*, a classic figure drawing text by Kimon Nicolaides first published in 1941. Explaining his title, Nicolaides says: "There is only one right way to learn to draw and that is a perfectly natural way. It has nothing to do with artifice or technique. It has nothing to do with aesthetics or conception. It has only to do with the act of correct observation, and by that I mean a physical contact with all sorts of objects through all the senses" (Nicolaides 1941, p. xiii). According to the author, gesture (p. 13) means "the function of action, life, or expression . . . " Gesture drawing thus exemplifies a 'natural,' experiential, way to draw. In this case, seeing involves a combination of visual scanning guided by kinaesthetic/proprioceptive awareness and empathy. As such, gesture is concerned less with the object's shape and more with the "energy" of the subject, including even inanimate objects. Likewise, while contour or outline drawing is done slowly and "painstakingly" in order to accurately capture an edge, Nicolaides says gesture drawing must be done fast and "furiously:"

> The model is asked to take a very active pose for a minute or less . . . As the model takes the pose . . . you are to draw, letting your pencil swing around the paper almost at will, being impelled by the sense of action you feel. Draw rapidly and continuously in a ceaseless line, from top to bottom, around and around, *without taking your pencil off the paper.* Let the pencil roam, reporting the gesture. You should draw, not what the [subject] looks like, not even what it is, but what it is *doing*. Feel how the figure lifts or droops—pushes forward here—pulls back there—pushes out here—drops down easily there. Suppose that the model takes the pose of a fighter with fists clenched and jaw thrust forward angrily. Try to draw the actual *thrust* of the jaw, the *clenching* of the hand. A drawing of prize fighters should show the *push*, from foot to fist, behind their blows that makes them hurt. (ibid., p. 14–15)

As a process of "active vision," gesture drawings distinctly resemble recordings of normal eye movement as it scans a face, figure, or object (see, for example, Noton and Stark 1974). Yet, following Nicolaides, gesture drawing is not motivated exclusively by visual interest. For example, where research on "active vision" indicates that visual attention is often attracted to elements that are similar in shape, color, etc., or to elements in proximity to one another, pursuit of the gesture involves attention to the movement of the body as a whole. Much like drawing a rock from the inside out in order to grasp its weight and density, drawing the figure often begins inside the form, for example, to capture the curve and twist of the spine, the relationship between major skeletal masses such as the skull, ribcage, and pelvis, or to follow a movement from limb to limb guided by impulse, like the boxer's punch 'from foot to fist.' As well as responding to directional lines like an arm pointing upward, attention in gesture drawing may focus on points of stress, tension, or weight, as well as features that express intention or emotion. Gesture drawing is not, however, purely intuitive. It also involves thought, but of a particular kind. As Nicolaides (p. 17) says about the process, "Let yourself learn to reason with the pencil, with the impulses that are set up between you and the model. In short, listen to yourself think; do not always insist on forcing yourself to think. There are many things in life that you cannot get by a brutal approach. You must invite them."

Relating this process to Tversky's explanation of architect's sketches, gesture drawings can be as informative or more informative when they misrepresent their subject. By looking at the drawing in process or after the fact, the artist is forced to recognize what s/he did not see or understand and so must look again, to see more accurately, more sensitively, more deeply, or more comprehensively. I have also related this process to conceptualization outside the arts based on C. S. Peirce's theory of "abductive reasoning:" reasoning by forming hypotheses and testing them out, as in the scientific method (Simmons 2017). Opposed to deduction and induction, Peirce claimed abduction was the only form of reasoning that led to truly original ideas, this in large part because even if the hypothesis being tested proves to be wrong relative to the intended outcome, it may lead to a new discovery. The same is true for the rough sketch which, by its very indeterminacy, can suggest something entirely unexpected. In contrast to the perennial pursuit in schools for the one pre-determined 'right' answer, the processes of abductive reasoning, with its always uncertain outcome and its invitation incessantly to iterate and revise, is now recognized as essential for creativity in the arts and sciences, in business, and even in education itself (Barrett 2013).[7] Like scientific experiments, gesture drawings are constantly being corrected after each new attempt, such that the final image may end up looking like "nothing but a tangle of fishing line" (p. 18) (See Figure 2).

---

[7] In this article, Barrett referenced Peirce's ideas on creativity in regard to current concerns in business and education. Speaking of "the value of creativity" in business, Barrett pointed out that: "IBM surveyed 1500 chief executives in 33 industries around the world in 2010 to gauge how much they valued characteristics like creativity, integrity, management discipline, rigor, and vision in an increasingly volatile, complex, and interconnected world. Creativity topped the list." After pointing out that ideas about creativity are widely recognized thanks to psychologists like J. P. Guilford, Barrett adds: "The philosophical antecedents [of these ideas] harken to the late 19th and early 20th centuries, when Charles Sanders Peirce, the American pragmatist, drew on the forms of inductive and deductive logic categorized by Aristotle in his Prior Analytics. Peirce added a third strain of logic, which he often called abductive. Each has its advantages. Deductive reasoning confers a high degree of certainty in its conclusions. Inductive logic works well when data are readily observable. Abductive logic, Peirce posited, relies on inference to make creative leaps in situations in which information is incomplete. It yields a large number of possible answers. The emphasis in the curriculum on Peirce's and Guilford's ideas is particularly notable given the current context. Colleges are weathering criticism that they fail to prepare students to be productive citizens and effective employees. Traditional humanistic disciplines must continually justify their relevance. The rising cost of college is adding urgency to the popular perception that colleges' main task is to train students in practical skills that will enable them to get jobs. Practically focused programs in business have been among the first to embrace creativity and design thinking in their curricula. Such efforts typically serve these programs' efforts to teach entrepreneurship and innovation, which are thought to spark new businesses, create jobs, and stimulate the economy".

Figure 2. *Man playing an Orgue de Barbarie*, ink drawing by Seymour Simmons, 2018. In this gesture drawing, which took about 5 min, the instrument being played is a hand-cranked, mechanical music box. The non-stop lines were inspired by the rapid rhythm of the music and also sought to capture the equally rapid movement of the arms: the left arm turning the crank, the right arm feeding the string of punch-cards containing the score into the music box.

2.2. Artistes et Robots

As described in a news release (https://www.aup.edu/news-events/event/2018-04-09/artistes-robots-exhibition-grand-palais), this exhibition at the Grand Palais in Paris "offers a gateway to an immersive and interactive digital world—an augmented body sensory experience that subverts our notions of space and time. In an ever more robotic society, these artists explore new technologies, including Artificial Intelligence, which is potentially revolutionising human lives and even the conditions in which artworks are produced, presented, disseminated, conserved and received." On the face of it, the exposition seemed to have little in common with the 'hands-on' experience and cognitive research perspectives of the *Thinking through Drawing* symposium. However, to me, both were explorations of different facets of drawing, given a standard definition of the term, such as: 'the formation of a line by drawing some tracing instrument from point to point of a surface; representation by lines; delineation as distinguished from painting... the arrangement of lines which determine form' (Victoria and Albert 2018).

Linear images in black and white or color were found throughout the exhibition enlivened by remarkable and diverse means of production. The exhibition began with a mid-20th century piece: *Méta-Matic no. 6* (1959) by Swiss artist, Jean Tinguely, an interactive drawing machine/sculpture that can be set up to produce an apparently endless variety of abstract images. Around the corner, more contemporary installations showed how autonomous drawing machines now can be. *Human Study #2 d La Grande Vanité au corbeau et au renard*, (2014–2017) by Patrick Tresset involved three robot artists attached to school desks surrounding a still life. The robots consisted of mobile camera "eyes" linked via computers to mechanical "arms" holding pens that were then used to draw on sheets of paper. The subject matter consisted of a taxidermied fox and raven next to a human skull, representing a fable by La Fontaine. Each robot was programmed to draw in a style similar to Tresset's. The robotic eyes looked up and focused on the subject, then the robotic arms traced initial lines, built up areas of tone, and returned to emphasize significant details, all based on what the eye took in. Although each drawing was the same in style, they all came out differently, giving the impression of students in an art class following a specific strategy of "how to draw from observation." For Tresset, these inventions provide the ultimate prosthetic. Although he himself no longer draws, his robotic surrogates can produce drawings endlessly in his style. Further, thanks to Tresset's programming, the images often suggest an almost human selectivity and sensitivity of touch.[8] (See Figure 3)

Figure 3. *Human Study #2*, installation with drawing robots and still life. Image courtesy of Patrick Tresset.

One of the more interactive exhibits was also based on drawing: Edmond Couchot and Michel Bret's, *Les Pissenlits, (The Dandelions)*, (1990–2017). Here, enormous electronically-generated drawings of colorful dandelions floated in front of a sensor into which spectators were invited to blow. As they did, and apparently depending on the force of their exhalation, the flowers exploded, scattering their virtual seeds just like the real thing. An even more expansive example of digital drawing, Peter Kogler's *Untitled* (2018) was a computer-generated image that filled a set of spaces—floors, walls, and ceilings—with an undulating linear pattern seemingly designed to disorient the visitors as they walked through the area. (See Figure 4).

8 The first prototypes of these robots were developed by Tresset as part of the AIKON-II project that he co-directed with Prof. Fol Leymarie at Goldsmiths College, University of London.

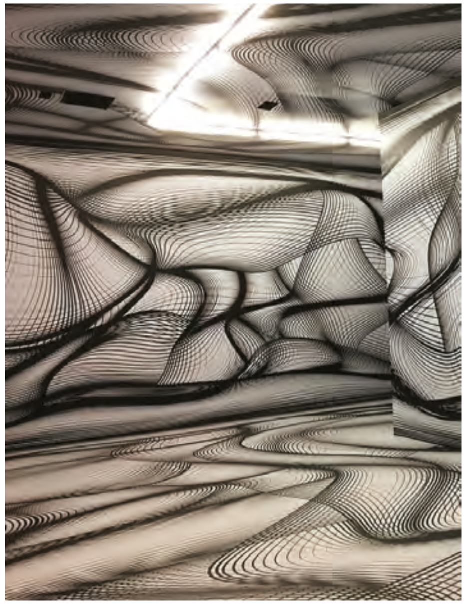


Figure 4. *Untitled* by Peter Kogler, Photo by Seymour Simmons.

Getting back to the press release, the author goes on to say: "These works contain a warning. Although Artificial Intelligence can help us, it also threatens to make itself our master by reducing humans to simple slaves to performance ... Ever more sophisticated software has given rise to increasingly autonomous works, an ability to generate infinite forms, and interactivity with audiences who permanently modify this game. This selection of works explores the questions raised by artists, which are also questions we ask ourselves: What can a robot do that an artist cannot? If it has an artificial intelligence, does a robot have an imagination? [And] What is a work of art?" The last question of course depends on how we define 'art,' a word notoriously difficult to pin down, especially in the post-modern era. Schjeldahl (2018), art critic for *The New Yorker*, recently put it this way: "Today . . . 'art' has come to mean anything that you can't think of another word for . . . " To me, whether or not the creations made by these machines can be called 'works of art,' they are, indeed, drawings as previously defined; that is, simply because they employ the basic elements of drawing: line, shape, form, space, tone, and texture. Moreover, in that these creations extend drawing beyond the limits of what a technically unaided human hand could accomplish, they immensely expand the possibilities of what drawing is and what it can do.

2.3. Space-Time Geometries and Movement in the Brain and in the Arts[9]

The description of this international conference, held at the Institut d'études avancées de Paris, highlights "the importance of understanding how the brain perceives and represents space, time and movement, and how it plans and controls our bodily movement and actions." Thus, the conference took up themes raised by Barbara Tversky, but focused on how the brain applies this kind of information both to visual and performing arts. Even in the latter, drawing figured in several presentations, such as a digital motion capture of performing violinists in the form of animated stick figures. Among

[9] From the IAS website: "International conference convened by Tamar Flash (2017–2018 Paris IAS fellow/Weizmann Institute of Science), Alain Berthoz (Collège de France) and Gretty Mirdal (Director of the Paris IAS)" https://www.paris-iea.fr/en/events/space-time-geometries-and-movement-in-the-brain-and-in-the-arts-2.

those that focused on drawing *per se*, one presentation directly related to the theme: how we process perspectival visual input using non-Euclidian geometry. However, others looked at drawing from unexpected angles.

A presentation on "The Role of Neural Circuitry in Skilled Drawing" by Emilio Bizzi, a neuroscientist from the Massachusetts Institute of Technology, began with Renaissance drawings by Michelangelo and Raphael, then concluded with works by 20th century artist Willem DeKooning, before and after he succumbed to Alzheimer's disease. While first acknowledging that neuroscience can tell us very little about the artistry in great drawings, Bizzi gave a close description of how the brain functions when transferring an image in the mind to the actions needed to produce a skilled drawing. As he explained, the production of a drawing rests upon a number of neural circuits that are organized hierarchically with feedback loops at every level of the central nervous system. He then went on to describe the neurological mechanisms underlying the formation of spatio-temporal patterns of motor activity involved in drawing and briefly touched upon the formation of motor memories that result from the intense practice that is often the daily investment of novices to skilled artists. Specifically, he pointed out that "neural signals representing skilled learning originate in the frontal areas of the brain: dorsal lateral prefrontal cortex, Motor Cortex, SMA (Supplementary Motor Area), and Parietal cortex." From there, signals go into the subcortical area, a specific region in the basal ganglia where they are segmented into 'chunks' or 'syllables' of shorter action commands that descend into the spinal cord shaped in such a way that they can produce movements. Regarding learning, he said that "practice leads to improvement in the quality of drawing by establishing memory traces through a hierarchically organized neural circuitry." Bizzi concluded by saying that fMRI technology now can make visible the more subtle and mysterious factors that lead to art, but that these studies are still waiting to be done. Afterward, a member of the audience, architect Paul Andrue, offered a clue to how a more artistic drawing might occur by pointing out that, for him, ideas often emerged through the act of drawing itself: a bottom up, rather than top down, process.

The following day, Renaud Chabrier, author, draughtsman and film director at the Institut Curie in Paris, gave a talk on the "Epistemological Role of Drawing." In it, he demonstrated animation techniques such as morphing that help us reappreciate the practice of hand drawing in history and today, both as a source of information about the space-time geometries in our brains, and as a powerful tool for cognition. His animations brought to life images of animals from the Chauvet caves, traced the stages of bladder carcinoma, and documented the birth of the brain. (See Figure 5) From an epistemological standpoint, he demonstrated the relative limitations of photography and schematic imagery compared to drawing. In an article on the topic, Chabrier and Janke (2017) explain that "[d]rawing enables the creation of images that are more abstract than photographs but have more depth and are more accurate than schematics. Indeed, drawing can provide spatial visualizations that could never be photographed or easily schematized, thus creating transitions between the different levels of abstraction." Further, working in an interdisciplinary research environment, Chabrier explained how drawings facilitate dialogue between specialists in different areas.

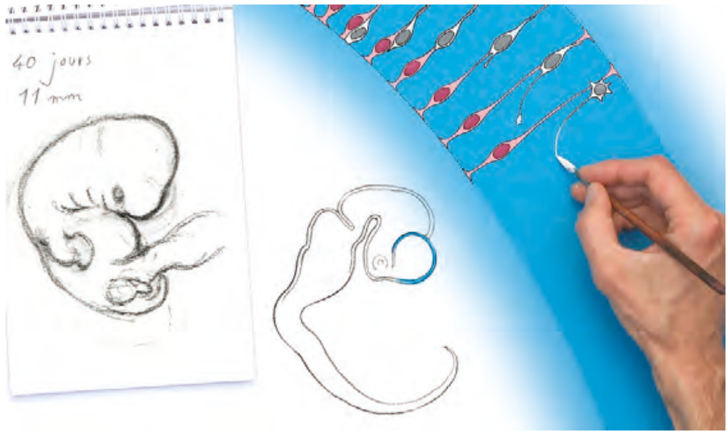


Figure 5. Sketch and color rendering for video, "Birth of the brain," documents the process of working from traditional media, pencil and brush, to digital animation. Image courtesy Renaud Chabrier.

These presentations, both in their content and their methodology, expose the complexity of the drawing process in the brain and throughout the body. Such studies challenge the popular reduction of drawing to a so-called 'right brain' visual-spatial-intuitive phenomenon necessarily opposed to and opposed by the logical-linear-linguistic functions of the left cerebral hemisphere (Edwards 1979).

2.4. Drawing Lab Paris, Cinéma d'été[10]

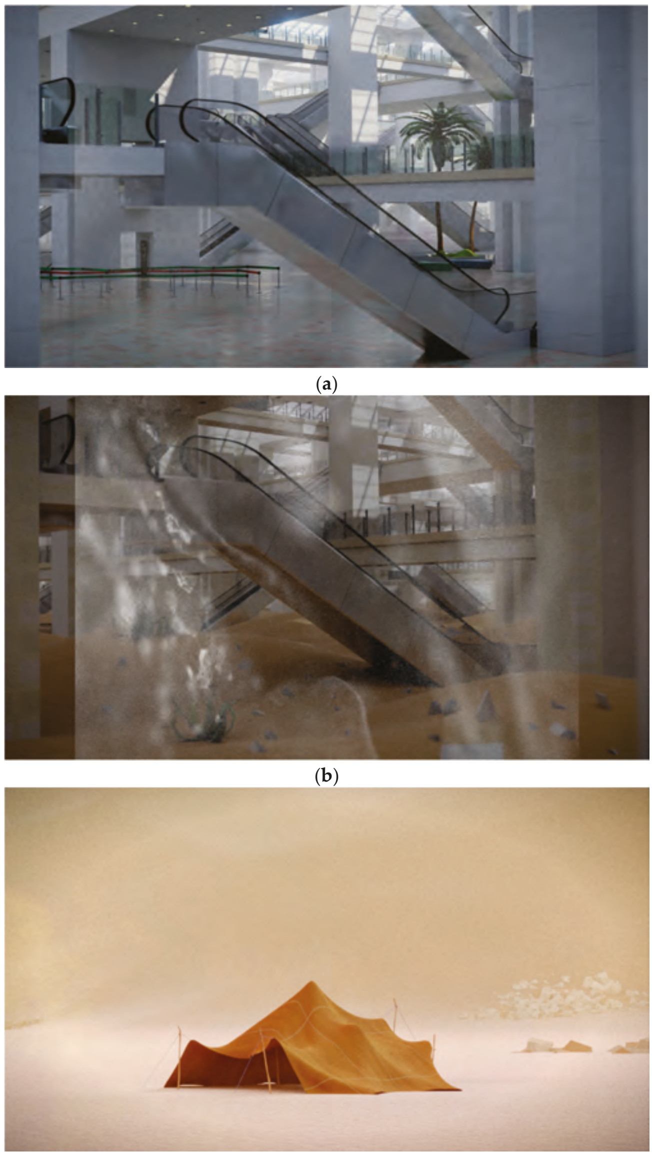
On my last day in Paris before returning to the US, I visited the Drawing Lab to see the *Cinéma d'été.* The Drawing Lab is located on the lower level of the Drawing Hotel in the "first district of Paris, near the Comédie Française, the Louvre Museum and the Musée des arts decoratifs." Its objective is "to endow contemporary drawing with enduring means for sustainable practices." Concerning specifically *Cinéma d'été*, this is described as "a programme of drawing and animated videos of the young European scene."

This summer's films featured ten short videos from seven artists. Technically, they included some made with traditional media, including ordinary pencils. Of these, Susi Jirkuff's, *Ginny* (2015), sets a disturbing childhood narrative against a background of high-rise apartment buildings drawn in pencil as if, or perhaps actually, by the child in the story, while Jérôme Allevena's *Émergence* (2007) follows the evolution of a pencil drawing, starting with thin lines drawn on a piece of paper that are then rubbed out by a finger.

By contrast, Thomas Léon's *Ecdysis* (2018), the longest film of the set, could only have been made with digital technology. According to Léon (translated from the French via Google Translate), "[t]he Greek term 'ecdysis' refers to molting in some organisms. This video installation explores uninhabitable places, designed for the management and circulation of human flows (shopping malls, airport halls, etc.) and questions their fate on the scale of geological time. The camera travels through these places of transit (escalators, walkways, elevators), crossed by ghostly silhouettes. Made using 3d software [based on] the engravings of the Series des Carceri invenzione de Piranesi (XVII s°), this impossible architecture constitutes a more than real mental space. (Figure 6a, Scene 1) As the camera progresses in this space, it is subject to climatic disturbances, and is superimposed on other images … evocation of human or reptilian bodies" (Figure 6b, Scene 2) For me, this video confirmed the potential of digital technologies (machines) to produce a genuine work of (video) art. Yet the story it

[10] https://www.drawinglabparis.com/expositions-passees/drawing-lab-cinema-dete/?lang=en.

tells is one of 'shedding' the artificial trappings of civilization and yielding a place for humanity in its most essential and enduring form. (Figure 6c, Scene 3) In this, I saw the video as a metaphor for the restoration of drawing in a world of seemingly far more sophisticated media – like grass pushing new life up through cracks in the pavement.



(**a**)
(**b**)
(**c**)

Figure 6. Scene 1 (**a**), Scene 2 (**b**), and Scene 3 (**c**). Images from Ecdysis courtesy of Thomas Léon. (To see the preview: https://vimeo.com/249929364).

3. Conclusions

To conclude, I will sum up the lessons I derive from the discussion above about drawing in the digital age and its implications for education. In the first instance, there is little evidence of drawing's demise. On the contrary, it gives every sign of being alive and thriving, and as it evolves and transforms to meet 21st century needs, it takes advantage of contemporary trends and technologies. In the second instance, however, the ongoing decline in drawing instruction means we still must make the case for drawing's potential contribution to life and learning, today. My work in that regard seeks to demonstrate how drawing's potential can be actualized by defining it as a domain of thinking in the arts and across the disciplines, and also highlighting its role in holistic development. I will end with a few preliminary points on these topics, which in turn will allow some last comments on "machine as artist."

3.1. Drawing in Contemporary Culture and Education

The four events outlined above represent a relatively recent groundswell of interest in drawing from many different quarters, the arts, the sciences, education, etc., resulting in numerous publications, research projects, symposia, and exhibitions (see DRN 2018). In terms of art, Petherbridge says that, "[a]t a time when drawing is relatively neglected in pedagogy and theory, [it is] making a vigorous comeback in contemporary art practice." (2010, p. 2). Later, (p. 412) she highlights two influences on drawing in the early 21st century that are exemplified in the discussions of drawing above: "the impact ... of digital technology and time-based practices ... [and] the major shift in the relationship of drawing to other aspects of artistic endeavour, which have expanded to become what [she calls] multi-practice, as artists tackle any number of different media and ways of working with far more freedom than in earlier decades."

Beyond the fine arts, drawing now reaches a much larger audience through the forms it takes in popular culture, including political cartoons and animations, as well as comic books and graphic novels for all ages, which often deal with significant subject matter, hence their inclusion in language arts classes at various levels.[11] Also, in general education, drawing has a potentially important role to play in current movements like "STEAM" wedding the arts to STEM subjects; "Design Thinking," teaching people in non-arts fields to think like designers; and "Graphicacy," thinking in images as a necessary complement to literacy (thinking in words) and numeracy (thinking in numbers) in the common core curriculum.[12]

In visual arts education, proponents of traditional drawing challenge the decline in drawing courses and leading figures in fields like architecture continue to argue for hand-drawing's importance. For example, at an international symposium at the Yale School of Architecture on the question, "Is Drawing Dead?", many participants just said "no!" (Yale 2013). Among them, Graves (2012) published an article in the *New York Times* entitled "Architecture and the Lost Art of Drawing" that addresses many points made in this paper. Responding to "the fashion in many architectural circles to declare the death of drawing," Graves acknowledges that "the computer is transforming every aspect of how architects work, from sketching their first impressions of an idea to creating complex construction documents for contractors." But, then he asks, "where does that leave the architectural creative process?" As an answer to that question, Graves says that "[a]rchitecture cannot divorce itself from drawing, no matter how impressive the technology gets. Drawings are not just end products: they are part of the thought process of architectural design. Drawings express the interaction of our minds, eyes and hands. This last

---

11 See, for example: https://www.edutopia.org/blog/graphic-novels-comics-andrew-miller.

12 It is interesting to note that STEAM and Design Thinking emerged largely from art/design programs, Rhode Island School of Design (http://stemtosteam.org), and the Stanford D. (for 'design') School (https://www.stanforddaily.com/what-is-design-thinking/), respectively, then penetrated into general education. It was the opposite for graphicacy. The concept and term came from geography education (Balchin 1972) and was taken up by the field of graphic design (Garner 2011). For an overview, see: http://theasideblog.blogspot.com/2015/03/what-is-graphicacy-essential-literacy.html.

statement is absolutely crucial to the difference between those who draw to conceptualize architecture and those who use the computer." In conclusion he adds, "As I work with my computer-savvy students and staff today, I notice that something is lost when they draw only on the computer. It is analogous to hearing the words of a novel read aloud, when reading them on paper allows us to daydream a little, to make associations beyond the literal sentences on the page. Similarly, drawing by hand stimulates the imagination and allows us to speculate about ideas, a good sign that we're truly alive."

3.2. Drawing as Thinking, and Drawing on the Whole

Graves' last sentence invites us to take a wider view of drawing because it applies, not only to architectural drawing, but equally to drawing in fine arts, popular culture, child development, art therapy, etc. All of these are encompassed in the phrase, 'to be human is to draw.' Besides simply highlighting the facts about drawing in human history and human development noted at the outset, the phrase from a pedagogical perspective suggests the potential role learning to draw could serve in helping us become more fully human, that is, in developing our distinctly human capacities. These include our superior ability to acquire and apply knowledge (cognition), to invent and innovate or else to find and solve problems (creativity), and to share ideas and express feelings (communication).

Another way to understand how learning to draw can help us become more fully human, related to the first, is in drawing's potential to engage and integrate the range of human attributes: body, mind, and spirit. Alongside the sensory-physical engagement of eye and hand necessary for making drawings, the role of the body is also indicated in Michael Moore's comment on how we evaluate drawings in progress by basing our judgements on "whatever one might have internalized having lived life on earth." Later, Moore suggested adding to that statement the word, "embodied," which I took to mean: "having lived an *embodied* life on earth." Embodied experience was evidently applicable when assessing work done for Moore's assignment, "Drawing Rocks," in which the object was to represent immediate tactile and haptic qualities. However, a different type of embodied experience must have helped the architects in Tversky's study to envision the effects of changing light conditions over a year as implicit in their museum designs.

Regarding the attribute, 'mind,' Graves' comments about day dreaming and speculating about ideas were echoed by Thomas Léon in a follow-up exchange about his creative process. Among other things, I wondered if, like the architects mentioned earlier, he had started with preparatory sketches in traditional media for *Ecdysis* before going digital. He said he did not, but instead "made a 3D/digital mock-up that was in fact a kind of study of the Piranesi etchings before producing the video." My question also was prompted by a visit to Léon's website where he had posted a portfolio of abstract drawings and collages that suggested imagery from the film. Léon did acknowledge that he had made charcoal drawings while working on the video but insisted that their purpose "was not to prepare something. In fact, [he said] the charcoal drawings are more a form of reverie/daydream for me. I don't use them to actively seek something."Even so, he later admitted that these drawings did have an eventual impact on the film in that they introduced "the problematic of the body in the final video process as well as some concern about an infra-human-life (insects, etc.)" (personal communication).

Such statements, which recall Paul Andreu's reference to ideas emerging out of the act of drawing and Nicolaides' point about "reasoning with the pencil," invite us to think about 'drawing as thinking:' critical, creative, and reflective. Earlier on this topic, I mentioned Maynard's reference to technical drawing as a mode of thinking essential for bringing civilization into the modern age. All these processes might be subsumed within Petherbridge's view of drawing as "visual thinking," or, more inclusively under Tversky's visual-spatial reasoning. Yet, considering the virtually innumerable forms of drawing and the diversity of functions drawing has served over the millennia, even these formulations are too limited. For one thing, they exclude drawing as thinking in fields that are usually not visual, like Richard Feynman's diagrams in quantum physics (Kaiser 2005) or Peirce's existential graphs in semiotics (Simmons 2017). On the opposite end of the spectrum are drawings in which thinking as commonly understood does not seem to figure at all. This relates to the third human attribute, spirit, both in drawing as self-expression based typically on emotion and in reference to spiritually-inspired artwork like oriental brush drawings (Sze 1959) or perhaps the images of animals on the walls of prehistoric caves (Lewis-Williams 2002). [13]

3.3. Toward a Comprehensive Model of Drawing Instruction for the Digital Age

Such considerations argue for a view of drawing as a holistic endeavor, involving the full range of human faculties: intellectual, emotional, sensory, motor, social, and spiritual. Implied in this formulation, the same basic skills (with line, tone, texture, shape, form, and space) can be applied toward a seemingly infinite array of ends: artistic and scientific, personal and professional. Combined with the unprecedented pluralism of post-modern art and the wide-open definition of the word, 'art,' already mentioned, these factors might suggest an image of drawing instruction today as a potpourri of possibilities, each as good as another. Indeed, some contemporary drawing instructional texts[14] and drawing exhibitions[15] reinforce that impression. On the positive side, these conditions open up vast new avenues for creativity, self-expression, etc., but in doing so they also make it difficult to decide how to teach drawing and assess student work.

To counter this 'anything goes' attitude while still keeping options open, I identified five paradigms of drawing instruction that address distinct but interrelated facets of drawing with applications across the arts and across the disciplines. In their most recent formulation (Simmons 2012), they include: drawing as design, drawing as seeing, drawing as experience and experiment, drawing as expression, and drawing as a visual language. These formulations are now being developed in a book entitled, *Drawing Instruction for Cognition, Creativity, and Communication across the Curriculum: The Case for Learning to Draw in the Digital Age.* (Simmons forthcoming) The concerns for cognition, creativity, and communication in the title have been discussed already. Added to these is the concern indicated in the subtitle: to determine the respective roles of traditional and digital media in regard to the applications of drawing in various spheres. Reference to 'the digital age' also implies a related issue: the need to address the challenges of teaching drawing in a social and academic climate dominated by

---

13 In both examples, the term 'painting' is commonly substituted for 'drawing,' a distinction based on the use of materials, such as pigment rather than chalk. On the contrary, many images in each instance fit well within the definition of drawing as delineation noted earlier. Needless to say, drawing in the service of spirituality and religion is restricted neither to pre-history nor to non-western cultures.

14 Among the most inclusive instructional texts for drawing at the university level is: *Drawing: A Contemporary Approach.* (Sale and Betti 2008) For example, where more traditional drawing books, especially those used at the foundation level, allow considerable space, often several chapters, to teaching linear perspective, here this topic is addressed in one chapter, called "Antiperspective: The Triumph of the Picture Plane." Before addressing linear perspective, the first section of the chapter covers "Contemporary Challenges to Traditional Perspective." Following several sections on linear perspective are sections on alternative projection systems, including: Axonometric Perspective, Multiple Perspectives, and Stacked Perspective.

15 An exhibition addressing differences between academic drawing instruction, drawing instruction under modernism, and post-modern art instruction with or without drawing was the subject of a 2015 exhibition at the École Nationale Supérieure de Beaux-Arts in Paris. The exhibit, *TRANSMISSION recréation et répétition*, juxtaposed images and artifacts from academic art training in the 17th–19th centuries and modernist art studies in the early 20th century against the work of current students and contemporary artists. Artifacts from the academic period included figure drawings, anatomical renderings, and perspective studies, as well as a cast made from a sculpture by Houdon, *Écorché au bras levé* (1776), one of thousands like it used by art students across the western world to study anatomy. The modernist tradition was represented by abstract geometric drawing exercises taught by Bauhaus-trained artist and teacher, Josef Albers, in the United States at Black Mountain College and Yale University (Goldstein 1996). Although the work of Albers and his students was itself a stark contrast to what was done in previous centuries, both parts of the historic display clearly demonstrated the rigor, relative uniformity, and explicit standards that were hallmarks of earlier art instruction. By contrast, the contemporary work reflected a vast diversity in aesthetics and media, including drawings, but also photos, videos, installations, performance art, etc. Two drawings reflect the extremes that might be found in post-modern exhibitions anywhere. One, Mladen Stilinovic's: *Bol (kriz)/Pain (cross)*, 1989, ('pain' in French means 'bread') is on a 20.6 by 29.2 cm sheet of rough beige-ish drawing paper (possibly newsprint), without a frame. In the middle of the page, single hand-drawn (in pencil) vertical and horizontal lines cross each other with the hand-written word 'BOL' inscribed at the end of each line. The other, *Air d'Olympia, dit de l'automate*, 2013, by Christelle Tea, is a complex and ambiguous mural-sized digital image, 3.20 m high × 8 m long, in which the subject, a female robot clothed in a plastic-looking white suit with black trim, is repetitively depicted whole and in parts in multiple poses and combinations against a black background overlaid in intricate patterns of white lines evocative either of circuitry schematics or city planning maps. The author of the catalogue (Basta 2015) says the work brings together drawing, photography, and (referring to the title) lyric singing, notably Offenbach's "Tales of Hoffmann."

digital media (see for example, Gardner and Davis 2013). In the final section, I will discuss how these issues play out in considering the question of "machine as artist."

3.4. "Machine as Artist" with Implications for Drawing Instruction in the Digital Age

Here, the question is whether machines (robotics, artificial intelligence, and digital technologies in general) can create what has long been recognized as among the highest forms of human achievement. That topic was broached in a sense at the *Artistes et Robots* exhibition on a wall text under the heading: "The Robot Emancipates Itself." Its opening lines addressed such mechanical potential by saying, "In 1951, mathematician Alan Turing wondered whether a digital calculator could think. Taking this thought a step further, the controversial pioneer of transhumanism, Ray Kurzweil, has predicted the emergence of an absolute form of Artificial Intelligence applicable to all social and personal fields in the near future." For me, the epitome of such an eventuality would be a machine capable of making art on the level of a Rembrandt or a Käthe Kollwitz. In the exhibition, Patrick Tresset's inventions came closest by creating accurately observed drawings, each original in its interpretation of the same subject in a style similar to, if not exactly the same as, what the artist might have done. Necessarily missing, however, is Tresset's quality of touch and emphasis resulting from what Moore would call his embodied experience based on a lifetime of living in the world. Lacking bodies with their sensitivities and frailties, lacking minds and spirits rich in memory and aspiration, machines are unlikely ever to be capable of the nuances and search for salience that humans, including young children, can infuse into their artworks, let alone well-trained, mature artists whose work, whether consciously or not, is imbued with human life deeply lived.

As an alternative to, or at least a complement to, the excitement of finding out how close we can get to creating "machines as artists," our efforts, especially as educators, might be better turned to using whatever means are available to help learners develop their *non-mechanical* human nature to its fullest. This has been the 'work of art' and the work of drawing in particular since humans made their first meaningful marks, and it continues as each child finds her or his own way to continue the tradition. In an era immersed in machinery that substitutes for seeing and for interpersonal interaction, drawing as the least mediated art medium retains the potential to reconnect us to our experiences and to one another.

Considering such conditions, the burgeoning interest in visual thinking, visual-spatial reasoning, and drawing should come as no surprise. Rather, as Barbara Tversky wrote to me on the topic, that interest may reflect a broader zeitgeist, or 'spirit of the times.' In my research, I identified similar zeitgeists when drawing, widely taught, became a skill accessible to all levels of society, from the artisans to the aristocracy and even to royalty. It is no coincidence that these eras, the Golden Age of Greece, the Renaissance, the Age of Enlightenment, and the Industrial Revolution, where among the most informed, innovative, and interconnected in history. In my view, universal drawing instruction could make a similar contribution to the present visual age. As such, it may be "an idea whose time has come," again.

Funding: This research received no external funding.

Conflicts of Interest: The author declares no conflict of interest.

References

Balchin, W. G. V. 1972. Graphicacy. *Geography* 57: 185–95. [CrossRef]

Barrett, Dan. 2013. Creativity: A Cure for the Common Curriculum. *The Chronical of Higher Education*. Available online: https://www.chronicle.com/article/The-Creativity-Cure/138203/ (accessed on 31 December 2018).

Basta, Sarina. 2015. *TRANSMISSION recréation et répétition*. Paris: Beaux-Arts de Paris Editions.

Brew, Angela. 2015. Learning to Draw: An Active Perceptual Approach to Observational Drawing Synchronizing the Eye and Hand in Time and Space. Ph.D. Dissertation, University of the Arts London, London, UK.

Chabrier, Renaud, and Carsten Janke. 2017. The comeback of hand drawing in modern life sciences. *Nature Reviews; Molecular Cell Biology* 19: 137–38. [CrossRef] [PubMed]

Drawing Research Network. 2018. Available online: http://www.drawing-research-network.org.uk (accessed on 11 January 2019).
Edwards, Betty. 1979. *Drawing on the Right Side of the Brain*. Los Angeles: Tarcher.
Efland, Arthur D. 1990. *A History of Art Education*. New York: Teachers College Press.
Findlay, John M., and Iain D. Gilchrist. 2003. *Active Vision*. Oxford: Oxford University Press.
Gardner, Howard, and Katie Davis. 2013. *The App Generation*. New Haven: Yale University Press.
Garner, Steve. 2011. Understanding Graphicacy. In *Idator Online Conference: Graphicacy and Modeling*. Edited by Eddie Norman and Niall Seery. Loughborough: Design Education Research Group.
Goldstein, Carl. 1996. *Teaching Art: Academies and Schools from Vasari to Albers*. Cambridge: Cambridge University Press.
Graves, Michael. 2012. Architecture and the Lost Art of Drawing. *New York Times*. February 9. Available online: https://www.nytimes.com/2012/09/02/opinion/sunday/architecture-and-the-lost-art-of-drawing.html (accessed on 31 December 2018).
Henshilwood, Christopher S., Francesco d'Errico, Karen L. van Niekerk, Laure Dayet, Alain Queffelec, and Luca Pollarolo. 2018. An abstract drawing from the 73,000-year-old levels at Blombos Cave, South Africa. *Nature* 562: 115–18. [CrossRef] [PubMed]
Kaiser, David. 2005. Physics and Feynman's Diagrams. *American Scientist* 93: 156–65. [CrossRef]
Levin, Helen. 2002. A Response to William Mitchell on "The Death of Drawing". *Leonardo* 35: 117–18.
Lewis-Williams, David. 2002. *The Mind in the Cave*. London: Thames & Hudson.
Maynard, Patrick. 2005. *Drawing Distinctions*. Ithaca: Cornell University Press, p. 7.
Mitchell, William J. 1989. The Death of Drawing. *UCLA Architectural Journal* 2: 64–69.
Nicolaides, Kimon. 1941. *The Natural Way to Draw*. Boston: Houghton Mifflin Co.
Noton, David, and Lawrence Stark. 1974. Eye Movements and Visual Perception. In *Readings from Scientific American: Image, Object, and Illusion*. Edited by Richard Held. San Francisco: W. H. Freeman and Company.
Petherbridge, Deanna. 2010. *The Primacy of Drawing*. New Haven: Yale University Press.
Pevsner, Nikolaus. 1973. *Academies of Art, Past and Present*. New York: De Capo.
Revit. 2018. Available online: https://en.wikipedia.org/wiki/Autodesk_Revit (accessed on 30 December 2018).
Ruskin, John. 1837. *The Elements of Drawing*. London: Smith, Elder, and Co.
Sale, Teel, and Claudia Betti. 2008. *Drawing: A Contemporary Approach*. Belmont: Thomson-Wadsworth.
Schjeldahl, Peter. 2018. Out of Time: Hilma of Klint's visionary painting. *The New Yorker*, October 22.
Sheer, David Ross. 2014. *The Death of Drawing: Architecture in the Age of Simulation*. New York: Routledge.
Simmons, Seymour. 1988. Bringing Art to Mind: Theory and Practice in the Teaching of Drawing. Ph.D. Dissertation, Harvard Graduate School of Education, Cambridge, MA, USA.
Simmons, Seymour. 2012. Philosophical Dimensions of Drawing Instruction. In *Thinking through Drawing: Practice into Knowledge*. Edited by Andrea Kantrowitz, Angela Brew and Michelle Fava. New York: Teachers College.
Simmons, Seymour. 2017. C. S. Peirce and the Teaching of Drawing. In *Peirce on Perception and Reasoning*. Edited by Kathleen A. Hull and Richard Kenneth Atkins. New York: Routledge.
Simmons, Seymour. Forthcoming. *Drawing Instruction for Cognition, Creativity, and Communication across the Curriculum: The Case for Learning to Draw in the Digital Age*. New York: Routledge.
Sze, Mai-Mai. 1959. *The Way of Chinese Painting*. New York: Random House.
Tversky, Barbara. 2011. Visualizing thought. *Topics in Cognitive Science* 3: 499–535. [CrossRef] [PubMed]
Twain. 2018. Available online: https://www.quora.com/Why-did-Mark-Twain-say-The-rumours-of-my-death-have-been-greatly-exaggerated (accessed on 31 December 2018).
Victoria, and Albert. 2018. Available online: http://www.vam.ac.uk/content/articles/w/what-is-drawing/ (accessed on 31 December 2018).
Walters, Joseph, Matthew Hodges, and Seymour Simmons. 1988. Sampling the Image: Computers in Arts Education. *The Journal of Aesthetic Education* 22: 99–110. [CrossRef]
Winner, Ellen. 1986. Where pelicans kiss seals. *Psychology Today* 20: 24–35.
Yale. 2013. Available online: https://news.yale.edu/2012/02/03/yale-school-architecture-symposium-asks-drawing-dead (accessed on 15 September 2018).

arts

MDPI

Article

Can Artificial Intelligence Make Art without Artists? Ask the Viewer

Sofian Audry * and Jon Ippolito *

New Media/School of Computing and Information Science, University of Maine, Orono, ME 04469, USA
* Correspondence: sofian.audry@maine.edu (S.A.); jippolito@maine.edu (J.I.)

Received: 1 January 2019; Accepted: 14 February 2019; Published: 18 March 2019

Abstract: The question of whether machines can make art provokes very different answers from pioneers in the field. Harold Cohen refuses to ascribe creativity to his art-making robot AARON, while Leonel Moura argues that since his "Artbots" generate pictures from emergent properties that could not have been predicted by their creator, "they have at least some degree of creativity." Although the question of whether machines can be artists seems to fall squarely on our definition of the latter, a solution to this philosophical impasse may ironically lie in redirecting the question away from the artist and toward the viewer.

Keywords: aesthetics; algorithmic art; artificial intelligence; artist; authorship; computational art; interpretation; painting robots; poststructuralism

---

1. Who Invents the Art?

Harold Cohen (1928–2016) began working with algorithmic art in 1968, decades before the art world recognized artificial intelligence as a potential artmaking strategy. During his 50-year collaboration with a computer program he dubbed AARON, Cohen gradually refined its code to produce drawings, and later paintings, of increasing interest to Cohen, and by extension, to a larger public. Over the years Cohen also redefined his own role, which shifted from a programmer who sets rules for AARON to follow to a co-producer who serves as colorist for AARON's designs. Along with his own experience as an artist, five decades of working with a computational machine to produce art made Cohen especially qualified to judge whether an artificial intelligence can be considered an artist in its own right.

Despite admitting the critical role AARON has played in his life as an artist, Cohen seemed reluctant to grant his robotic partner the status of an artist to the extent that he disqualifies a number of procedural aspects of artistry that can be modeled in computer code. As psychologist Louise Sundararajan points out, "Cohen is explicit about what creativity is not: It is not simply divergent thinking; nor is it simply algorithms and symbol manipulations." (Sundararajan 2014) Instead of talking about AARON as an individual artist, Cohen speaks about this collaboration in terms that highlight the personal nature of this human-machine relationship:

> Creativity... lay in neither the programer [sic] alone nor in the program alone, but in the dialog between program and programer; a dialog resting upon the special and peculiarly intimate relationship that had grown up between us over the years. (Cohen 2010, p. 9)

So Cohen locates the artistic potential of machines not in their instrinsic artistry but in their special collaborations with humans, as in his own relationship with AARON. He dislikes the word "creative" and considers the attempt to model human creativity on a computer a vain effort:

> AARON will never make a choice to break the rules, nor will it reflect on those constraints as something that it might want to change... AARON has no sense of continuity or sense of experience from one drawing to the next. (Buchanan 2001, p. 17)

Artist Leonel Moura (born 1948), by comparison, is a newer recruit to the machine-human boundary. Moura began experimenting with artificial intelligence and robotic art in the late 1990s and since the 2000s has produced mobile robots that make drawings based on color density. These robots look like they could be AARON's younger siblings, but their dynamic is collective rather than individual. Moura releases a swarm of them onto a plastic canvas, each armed with ink of a different color and a color sensor that helps its onboard software decide when to mark the PVC surface. The result is a multicolored drawing emerging from hundreds of such individual strokes.

To explain his preoccupation with artmaking robots, Moura points to the long-accepted tradition of artists who have explored unusual processes in order to divorce aesthetic decisions from their own received knowledge and parochial tastes:

> Whether a work of art is made directly by a human artist or is the product of any other type of process is nowadays of no relevance. Recent art history shows many examples of art works based on random procedures, fortuitous explorations, objects trouvés, and arbitrary constructions. Surrealism, for example, even tried to take human consciousness out of the loop. More decisive is whether or not new art form expands the field of art. (Moura 2018)

For Moura, whether his art is made with or without machines is unimportant, so long as it is accepted by the art world's gatekeepers. This claim might have been controversial for artists of Cohen's generation, and despite exhibiting in some prestigious venues he in many ways remained an outsider artist to his death. Moura's career, however, benefits from the expanded acceptance in the past three decades of a contextual definition of art first suggested by Marcel Duchamp:

> The main issue of art is art itself: its history, evolution, and innovative contributions. Anything can be considered art if validated by one of the several art world mechanisms including museums, galleries, specialized media, critics, curators, and/or collectors. Only in this way has the Duchampian ready-made and most of the art produced since been accepted and integrated into the formal art realm. (Moura 2018)

Moura doesn't come out and say computer programs can be an artists, but his expanded definition of art, which accepts non-human art-making processes, leaves them a place at the table. While Cohen throws a wet blanket on the possibility of art born of an autonomous machine, Moura makes room for robots to act with aesthetic free will, claiming "I teach the robots how to paint, but afterward, it is not my doing." Moura sees this as a positive, and perhaps inevitable trend, asserting that "the autonomy of machines is essential to the best interests of humanity." (Moura 2018)

If the shift from Cohen's to Moura's viewpoint can be extrapolated to the longer term, it would seem the time will come when machines could make art independent of human agency. Composer Pierre Barreau is already feeding 30,000 music scores into a neural network to generate what he judges to be a neural network's "original compositions." Barreau looks forward to a time when machines, not people, custom-tailor scores for individual listeners: "What we're working on is to make sure that AI can compose hundreds of hours of personalized music for those use cases where human creativity doesn't scale." (Barreau 2018)

2. Who Invents the Artist?

Their generational and philosophical differences aside, Cohen's and Moura's descriptions of their process offer contrasting perspectives over the question of authorship in computational art, whether it is assumed to be the human who writes the algorithms (Cohen) or an autonomous robot that has merely been educated by a human (Moura). Yet another, and in some ways more important, perspective on a work's creator comes from its viewer.

A thought experiment will explain why. Suppose proof came to light that the drawings and paintings Cohen had attributed to AARON were his sole creations all along, and that his videos of AARON in action were fictions designed to fool unsuspecting art critics. Such a revelation would not change who the true artist was, because that would have always been Cohen all along; but the revelation would have a huge impact on the reception of his work by lay and professional viewers. In a single stroke, we would look at a blue triangle no longer as the result of an inescapable algorithm but as the subjective paint stroke of a human artist. Some might switch from a judgment such as "not bad for a machine" to a judgment like "my four-year-old could do that." Others might turn from seeing the work as cold and sterile to imagining the work as the product of heartfelt emotion. In this sense, the "artist" as it matters for art history is not the actual person but the construct that lives in the minds of a work's beholders.

This is the argument of Michel Foucault's influential 1969 essay, "What Is an Author?" For Foucault, and many of the post-structuralist thinkers who followed him, an artist is not so much a body that lived in particular time and place as it is a conjecture that viewers attach to an artwork to help them make sense of it. Foucault wrote his essay in response to Roland Barthes' 1967 provocation "The Death of the Author," which denied any necessary relationship between a text and its creator. Foucault conceded to Barthes that interpreting a text might not require knowing the biography and intent of the actual author, but Foucault insisted that readers trying to interpret the text would infer the qualities of a hypothetical author nevertheless. To give a crude example, readers of Ernest Hemingway don't need to know he was an adventurous war hero because his writing is already taut and muscular; readers of Marcel Proust don't need to know he was a sickly shut-in, because his writing is already introspective and full of reverie.

3. The Meta-Artist Function

From this perspective, our central question becomes not "can machines be artists," but whether a machine can give rise to an "artist function" in Foucault's sense. Instead of the artist function disappearing when a machine makes art, it may be split in two. We might ascribe one artist function to the non-human machine–perhaps a limited one based on our understanding of the machine's finite capacity for reasoning. As of this writing, however, algorithms are still programmed by humans, and even neural networks are trained on data selected by humans. So we might ascribe a second, meta-artist function to the machine's human handler–what legal scholar Annemarie Bridy calls "the author of the author of the works." (Bridy 2011)

How is this different from simply giving both human and machine collaborators credit for the creative act, as Cohen suggests? Remember that the artist function differs from the artist because it is produced by the viewers. So yes, we might learn that Harold Cohen went to art school or that fellow algorithmic artist Jack Ox studied musicology. But we might also look at AARON's bright shards of blue, green, and orange, and imagine that AARON's creator had seen Matisse's *The Dancers.* Or we might look at the fractured abstractions produced by Jack Ox's algorithms and infer that the woman who wrote them loves rhythmic composers like Stravinsky.

In other words, the nature of the artist and meta-artist functions and their relationship may vary depending on the analogies viewers are likely to draw from their own experience. Some might see the machine as a tool, in which case they will construct a meta-artist who uses the tool in a more-or-less virtuosic or telltale fashion (as they might when examining brushstrokes in an Abstract Expressionist painting). Other viewers might imagine the machine as a child–in which case, they will construct a meta-artist responsible for educating (setting rules for) the child, but not blame the meta-artist directly for individual mistakes (and thus ally themselves with Moura's perspective). Still others might imagine the machine as a full-fledged collaborator, in which case they will picture a human artist influencing but also being influenced by the machine's choices (thus aligned with Cohen's perspective). In every case, regardless of these differences, viewers are likely to ascribe traces of "personality" in the image to the meta-artist rather than the machine.[1]

4. When Artists and Artist Functions Diverge

As historical motivation for the birth of the author function, Foucault notes that legal regimes bent on repressing writers of transgressive texts had to conjure someone to blame. During the Reformation, for example, broadsides against the Catholic church mass-printed by Protestants on Gutenberg's press did not betray the handwriting of their creators; nonetheless, readers could reconstruct the figure of the author from the tone, diction, and substance of each manifesto.

Despite the legal incentive to identify individual writers, Foucault warns us that these reconstructions are fictions, highly contingent on the nature of the text and our own station:

> Nevertheless, these aspects of an individual, which we designate as an author (or which comprise an individual as an author), are projections, in terms always more or less psychological, of our way of handling texts: in the comparisons we make, the traits we extract as pertinent, the continuities we assign, or the exclusions we practice. In addition, all these operations vary according to the period and the form of discourse concerned. A 'philosopher' and a 'poet' are not constructed in the same manner; and the author of an eighteenth-century novel was formed differently from the modern novelist. (Foucault 1992)

Foucault presumably had human creators in mind for his author function, yet we can apply his conceit equally to nonhuman agents. And as we shall see when examining hypothetical and real cases of nonhuman agents, the "projected author" may have a bearing that is both aesthetic and legal–reminding us that Foucault identified the law as a potent motivation for constructing an author function when authorship is inherently ambiguous.

A case from 2018 of such ambiguous authorship occurred after a young artist who had just graduated from high school, Robbie Barrat, posted a machine learning program he wrote to the code-sharing site GitHub. Barrat programmed this software to learn visual rules from a sample of existing, human-made paintings and generate new, digital paintings in the same style. Having downloaded Barrat's software, the French artist collective Obvious used the code to generate a new painting in the form of a physical print on canvas, which subsequently sold at auction for $432,500. Barrat later asked on Twitter, "Am I crazy for thinking that they really just used my network and are selling the results?"[2] Barrat's question suggests we should ascribe authorship to the machine learning software itself, for which he is the presumptive owner. In Barrat's case, the copyright issues are mute because he distributed his code as open-source software. However, consider a hypothetical case where authorship had more legal impact. Imagine that an AI researcher ("Harold Junior") rents time on a supercomputer owned by IBM ("Deeper Blue"). Harold Junior trains Deeper Blue in the art of digital painting, after which his silicon apprentice goes on to produce images that its human teacher could not have foreseen on his own. The complexity and aesthetic interest of Deeper Blue's evolving oeuvre attract the eye of the fashion industry, and Nike inks a 7-figure deal with IBM to display these images on t-shirts and sneakers. Not so fast, says Harold Junior, who sues them both for copyright infringement, claiming he must be the artist, since Deeper Blue is only a software agent.

As hypothetical as this example may seem, a parallel case of nonhuman artistry was debated not in a philosophy symposium but a court of law. In a national park in Indonesia in 2011, nature photographer David Slater set up a free-standing camera in such a way that a troupe of macaque monkeys could trigger the shutter and take photos of themselves. An editor at the Wikimedia

[1] Indeed, the 2006 European Copyright Term Directive defines original work as an "author's own intellectual creation reflecting his personality." (Guadamuz 2015)

[2] Source: https://twitter.com/drbeef_/status/1055285640420483073.

Foundation later posted these "monkey selfies" on the Wikimedia website, sharing them freely with the rationale that the works had no authors and were thus in the public domain. The photographer protested, building his claim to the copyright on the allegation that he had created the conditions for the "monkey selfies" to happen by setting up his equipment in such as way as to optimize the chances for the primates to capture their faces. The next year, People for the Ethical Treatment of Animals (PETA) filed a lawsuit against Slater in the name of one of the monkeys, which they called Naruto, claiming that the non-human animal had a copyright over the picture it had taken of itself.

Legal opinions and precedents for *Naruto et al. versus David Slater* were equivocal, as we might imagine would also be true of the hypothetical case *Harold Junior versus IBM*. Perhaps the clearest precedent in favor of Slater is the UK law covering computer-generated and other non-human creations, which assigns copyright to the person who sets the rules. Nevertheless even this standard admits "However, as robotic software and hardware becomes more 'cognitive' and learns and adapts from data inputs, the works created may have no relationship to the original author's software and so other factors may well come into play." (Holder et al. 2016)

Regardless of legal rectitude, from an aesthetic standpoint the arguments on both sides put too much stress on whether the monkey intended to take a photo. From Foucault's perspective, what determines the artist function in this case is the reaction viewers have to the particular photos in question. The photos show a seemingly self-possessed macaque, in one case reaching out its hand to trigger the camera, in another grinning widely as it stares into the lens. To many viewers, these images suggested a deliberate self-portrait. If, by contrast, the snapshot triggered by Slater's apparatus had showed a blurry paw rather than an expressive headshot, the would have been hard-pressed to describe the macaque as "fascinated by her reflection in the lens." (Daily Mail Reporter 2011) To take a more extreme variation, suppose a photo of a stand of trees had resulted from a branch falling on the shutter trigger after a windstorm; few would have jumped to the conclusion that one of those trees were taking a selfie, because the photo wouldn't betray evidence of its author. Unlike these hypothetical counterexamples, the actual photos precipitated a believable author function. Without access to the macaque's intentions, we have no way of proving this construct true or false, which is why our imagination is prone to fill in the gap in our knowledge. The same is true of viewers beholding works made by artificial agents.

Yet in both the cases of the monkey selfie and art produced by artificial intelligence, our imagined authors need not be limited to the being that tripped the shutter or sprayed the ink on PVC. We can also back up to the meta level and ask ourselves what Slater was trying to construct by positioning his gear in the way he did. Regardless of Slater's actual intentions, his "algorithm"—a tripod-mounted camera with a large wide angle lens, predictive autofocus, and a shutter release within reach—as well as the fact that he selected the most "selfie"-like images among the many taken by the monkeys—suggests that he was carefully crafting a revealing way to depict the primates he was studying. From this perspective, Slater was the meta-artist of those selfies—a distinction that may clarify how authorship bifurcates in the era of intelligent machines.

5. Can You Kill the Meta-Artist?

The argument made in *Naruto et al. versus David Slater* sets another obstacle in the path toward the truly autonomous artmaking machines imagined by Moura and Barreau. Apart from eliminating the human collaborator from the equation, such autonomy would also require expunging any residual meta-artist function constructed by the viewer. Viewers have been conditioned for thousands of years to apply empathy and interpretation to imagine motivations for the creators of works they view, and they are likely to ascribe personalities to the machinic producers of such works as well. Yet humans also know computers are programmed by other people; media scholar Helen Hester argues listeners put more trust in the pronouncements of a feminine digital assistant like Siri than they would an actual woman because they "imagine a male programmer" is ultimately responsible for Siri's words. [3]

Such empathic impulses may inevitably spur the viewer to construct an artistic persona for the absent creator of an art-making machine, but that hasn't stopped some AI innovators from trying to expunge any meta-artist function from the equation. Moura seems to reject the idea that a viewer would credit him for one of his ArtBot's drawings just because he "taught" them rules to make paintings. He offers the analogy that "No one will claim that a given novel is the product of the author's school teacher." (Moura 2018) This analogy may hold at some point in the future when artificial intelligences are accorded the same autonomy as human children, but given the law's focus on human versus non-human actors, they are more likely to be accorded the autonomous status of animals. And it is central to our construct of those personalities that they are highly influenced by their stewards; we are quick to blame a disobedient dog on its careless trainer.

If animals represent one possible analog for AI trained by human handlers, technology scholar Sherry Turkle has researched the embodiment of that analogy in the form of robotic pets such as Aibo, Furby, and PARO. Turkle's research into purring seals and dancing dogs reminds us that robots don't have to sit still like texts or finished drawings; in art contexts as in toy stores, they are often seen lighting up or spinning around in reaction to viewers or each other. Turkle thinks such interactions with machines raise again the question Darwin posed to his generation about whether humans are unique: "How will interacting with relational artifacts affect people's way of thinking about what, if anything, makes people special?" For his part, Moura creates opportunities for viewers to watch robots making drawings, and thus gain even more insight into the artistry of both the machines and their makers:

> "From the viewer's perspective, the main difference from the usual artistic practice is that he/she witnesses the process of making it, following the shift from one chaotic attractor to another. Even though finalized paintings are kept as the memory of an exhilarating event, the true aesthetical experience focus [sic] on the dynamics of picture construction." (Moura 2003)

Turkle calls these new technologies "relational artifacts," yet she stops short of ascribing them the complexity of human relationships.[4] While admitting that the children who play with robots form emotional attachments, she notes the same children understand their metallic companions are capable only of "a robot kind of love." For all the empathy they evoke, Turkle clearly sees computational creatures on a different level from humans: "To say all of this about our love of our robots does not diminish their interest or importance. It only puts them in their place." (Turkle 2006, p. 10) Turkle shows that even children recognize that robots aren't fully autonomous creatures. Were Turkle's research to applied to the aesthetic sphere, it might be concluded that our limited ability to empathize with artificial intelligence restricts it to "a robot kind of art."

Perhaps no artificial agent researcher strives harder to remove the meta-artist from the equation than zoologist and artificial life pioneer Tom Ray, whose project Tierra takes a more radical approach to eliminating human influence in a the act of computational creation. Tierra is a self-evolving community

---

3 Outside of the context of art, the creators of Siri and Microsoft's Cortana exploit this empathic impulse to make their devices seem more relatable:

> We spent a lot of time with the character design of Cortana. It's not about anthropomorphizing your computer, it's about these little moments of playfulness, and these moments of recognition that she's listening to what you're asking her and what's important to you. (Beres 2015)

Despite the strategic anthropomorphizing of computers to encourage users to bond with them, Hester claims the compliant female voice "can even play into people's expectations of male authority because the aren't actual women." (McNeil 2015)

4 "Relationships with computational creatures may be deeply compelling, perhaps educational, but they do not put us in touch with the complexity, contradiction, and limitations of the human life cycle. They do not teach us what we need to know about empathy, ambivalence, and life lived in shades of gray." (Turkle 2006, p. 10)

of computer viruses with no fitness function apart from survival. To create this artificial ecosystem, Ray created an environment on his hard drive filled with snippets of program code designed to copy themselves with every cycle of his computer. He further programmed this environment to introduce random mutations in the code of these tiny programs. By competing for disk space, the resulting virtual creatures evolve according to the same logic of self-replication and mutation that drives biological evolution, generating new "species" that Ray never could have predicted. These includes classes of programs that, like biological parasites, evolve to live inside host programs, some of which later evolve to be immune to such parasites. Ray himself claims that his creatures are alive by the very fact that they reproduce and evolve.

Yet as neutral and personality-less as Tierra seems, we may still wonder about the intentions of its human architect. Asked if he felt guilty turning off his machine and erasing all his digital progeny, Ray replied that he could always recreate that exact set of creatures just by resetting his Tierra program to the same initial conditions. Ray thus argued that he had created the organisms only in the sense of creating the potential for them to exist. But this clever abjuration of responsibility only offers the viewer more material from which to imagine the mastermind behind Tierra's synthetic organisms. As in any work of fiction, there will be more than one interpretation: some who hear Ray's response may imagine him a heartless psychopath, while others will judge him a principled man of science.

More important than the judgment itself is the fact that the question came up in the first place. Whether Tierra's critters are alive or inanimate, some viewers want to know the motivation behind the man who created them.[5] Even for a computational system as seemingly neutral as artificial computer viruses evolving on a hard drive, the astute viewer may be able to reconstruct the cultural assumptions of its human meta-artist. For example, anthropologist Stefan Helmreich, who analyzed the artificial life scientific movement in the late 1980s and 1990s, argues that works such as Tierra are built upon a dualistic and computationalist vision of the living enabled by a "symbolically masculine collapse of life into instrumentally useful information process." For all their seeming autonomy from their creators, Helmreich finds that such artificial ecosystems embody the historical and cultural mores of the contexts in which they were historically created, such as the Santa Fe Institute. These artificial life meta-artists were predominantly upper middle-class, Judeo-Christian white men influenced by New Age, sci-fi and Western creation stories that did not feature pregnant females. (Helmreich 2000, p. 216)

6. Conclusions

Art is not a measurable fact, like the temperature of bathwater; it is an interpreted condition, like whether bathwater feels warm or cold. As long as humans continue to infer motivations to creative acts, artists will exist as social constructs. So the question we started with—can machines be artists?—is the wrong question. We should instead be asking, what roles does machine-made art leave for artists—imagined or real, flesh or silicon—and the viewers who imagine them.

Author Contributions: S.A. and J.I. contributed equally to the concepts, analysis, drafting, and final form of this essay.

Acknowledgments: The authors would like to thank their reviewers and Wendy Seltzer for her illuminating references from the literature on robotics and copyright law.

Conflicts of Interest: The authors declare no conflict of interest.

[5] At its most abstract, it is perhaps an analogous impulse that inspires cultures to look upon nature and endow its Creator–the ultimate meta-artist–with human features such as a robe and beard. See (Ippolito 1999) for more on the extrapolation of ethical responsibility from AI experiments.

References

Barreau, Pierre. 2018. How AI Could Compose a Personalized Soundtrack to Your Life. Available online: https://www.ted.com/talks/pierre_barreau_how_ai_could_compose_a_personalized_soundtrack_to_your_life?language=en (accessed 29 Decmeber 2019).

Beres, Damon. 2015. Microsoft's Cortana Is Like Siri With A Human Personality. *Huffington Post*, July 25.

Bridy, Annemarie. 2011. *Coding Creativity: Copyright and the Artificially Intelligent Author*. SSRN Scholarly Paper ID 1888622. Rochester: Social Science Research Network.

Buchanan, Bruce G. 2001. Creativity at the Metalevel. *AI Magazine* 22: 13–28.

Cohen, Harold. 2010. *Driving the Creative Machine*. Crossroads Lecture Series. Eastsound: Orcas Center.

Daily Mail Reporter. 2011. Cheeky monkey! macaque borrows photographer's camera to take hilarious self-portraits. *Daily Mail*, July 4.

Foucault, Michel. 1992. What is an Author? In *Modernity and Its Discontents*, 1st ed. Edited by J. L. Marsh and J. D. Caputo. New York: Fordham University Press, pp. 299–314.

Guadamuz, Andres. 2015. Do Androids Dream of Electric Copyright? Ownership of Deep Dream Images. Available online: https://www.technollama.co.uk/do-androids-dream-of-electric-copyright-ownership-of-deep-dream-images (accessed on 5 February 2012).

Helmreich, Stefan. 2000. *Silicon Second Nature: Culturing Artificial Life in a Digital World*, Updated ed. Berkeley and Los Angeles: University of California Press.

Holder, Chris, Vikram Khurana, Faye Harrison, and Louisa Jacobs. 2016. Robotics and law: Key legal and regulatory implications of the robotics age (Part I of II). *Computer Law & Security Review* 32: 383–402. [CrossRef]

Ippolito, Jon. 1999. Should you feel guilty turning off the computer? *Artbyte* 1: 16–17.

McNeil, Joanne. 2015. Opinion | Why Do I Have to Call This App 'Julie'? *The New York Times*, December 19.

Moura, Leonel. 2003. Artsbot. Available online: http://www.leonelmoura.com/artsbot-2/ (accessed on 5 February 2012).

Moura, Leonel. 2018. Robot Art: An Interview with Leonel Moura. *Arts* 7: 28. [CrossRef]

Sundararajan, Louise. 2014. Mind, Machine, and Creativity: An Artist's Perspective. *The Journal of Creative Behavior* 48: 136–51. doi:10.1002/jocb.44. [CrossRef] [PubMed]

Turkle, Sherry. 2006. *A Nascent Robotics Culture: New Complicities for Companionship*. Technical report. Palo Alto: AAAI Press.

arts

MDPI

Article

Can Machines Be Artists? A Deweyan Response in Theory and Practice

Arthur Still [1] and Mark d'Inverno [2,*]

[1] Department of Psychology, University of Durham, Durham DH1 3LE, UK; stillarthur65@gmail.com
[2] Department of Computing, Goldsmiths, University of London, London SE14 6NW, UK
* Correspondence: dinverno@gold.ac.uk

Received: 9 January 2019; Accepted: 7 March 2019; Published: 19 March 2019

Abstract: To speak comfortably of the machine artist (as outlined in the call for papers for this Special Issue) makes key assumptions about what it is to be an artist. It assumes, for instance, that the experience of living as an artist, which includes the socialisation, hard work, single-mindedness, and focused energy of creative activity, is incidental rather than essential since these aspects are not comfortably applicable to machines. Instead, it supposes that what is essential is the artistic product, and it is the similarity of human and machine products that makes it possible to speak of machine artists. This definition of art in terms of products is supported by modern psychological theories of creativity, defined as the generation of novel ideas which give rise to valuable products. These ideas take place in the mind or brain, regarded as a closed system within whose workings the secret of creativity will eventually be revealed. This is the framework of what is widely referred to as "cognitivism". This definition in terms of novel ideas and valuable products has been widely assumed by artificial intelligence (AI) and computational creativity (CC), and this has been backed up through a particular version of the Turing Test. In this, a machine can be said to be a creative artist if its products cannot be distinguished from human art. However, there is another psychological view of creativity, that of John Dewey, in which a lived experience of inquiry and focus is essential to being creative. In this theory, creativity is a function of the whole person interacting with the world, rather than originating in the brain. This makes creativity a Process rather than a Cognitivist framework. Of course, the brain is crucial in a Process theory, but as part of an open system which includes both body and environment. Developments in "machine art" have been seen as spectacular and are widely publicised. But there may be a danger that these will distract from what we take to be the most exciting prospect of all. This is the contribution of computer technology to stimulate, challenge, and provoke artistic practice of all forms.

Keywords: creativity; art; art practice; AI; designing AI; John Dewey

1. Introduction

According to the call for papers for this Special Issue, the time has come when we can speak comfortably of the machine as artist. This reflects a measure of the great successes in over 60 years of work on creativity in artificial intelligence (AI) and psychology. In these disciplines, the issue of creativity in the arts, science, and everyday life has been a dominant theme since 1950, and it has been widely accepted that the essence of creativity has to do with having novel ideas in the mind or brain, which give rise to creative products. These inner processes are the focus of investigation in both cognitive psychology and AI, but it is the quality of the product that defines creativity. This focus on products and ideas is a widely held view, and it has been behind the development of the field of computational creativity (CC). This is the attempt to design machines which produce artefacts regarded as creative. It is the success in this that makes it seem appropriate to refer to such machines as artists.

But what if what we mean by "art" and "artist" is not just the making of novel products that are regarded as creative, but the way of life that accompanies this making, including the long training and socialization, and the sheer slog of preparation and effort that culminates in becoming an artist? The experience, in other words, of living and working as an artist. In the biographies of artists, much is made of this. Ideas play a part, as they do in most human activities, but it is the life and the artistic and cultural context of the artist that are distinctive in understanding the genesis of artistic work. This we take to be the view of John Dewey, and in this paper, we explore the implications of taking a Deweyan view to the idea of the machine as an artist.

We start the paper by spelling out more fully the first view, that the essential meaning of art (or science) lies in the creative *products* generated by art or science. This is the view that follows from a common and influential definition of "creativity" itself. We then set out a contrasting perspective by outlining our version of Dewey, updated to consider modern developments in AI and CC. We end with a discussion section and by outlining some systems which implement a Deweyan approach to using AI in the context of creativity.

2. Creativity in Psychology and AI: Computational Creativity

In 1950, the Psychologist J.P. Guilford gave the presidential address to the American Psychological Association, with the title "Creativity", thereby making use of a word that had been rare before the 20th century but had recently become popular in marketing circles. In this dramatic way, he introduced "creativity" to psychologists as a measurable process in the individual mind. Guilford defined the word by explaining that "the creative person has novel ideas" and "creativity refers to the abilities that are most characteristic of creative people." (Guilford 1950, p. 452).

Two other criteria were soon added—to be creative the novel ideas must be put into practice, and the products must be valuable (Stein 1953). This brought it in line with the marketing use of the word "creativity", spelled out two years before Guilford's address by the marketing executive and self-help guru, Osborn (1948), inventor of "brainstorming".

From its modern beginning in 1950, work on creativity has undergone a parallel evolution in two disciplines—cognitive psychology and artificial intelligence (AI). In both disciplines, creativity has been praised more than is usual in a scientific concept. Margaret Boden, the philosopher of AI who is also a psychologist, described creativity as "a marvel of the human mind" (Boden 2009, p. 23) and went on to define it as

> the ability to generate novel, and valuable, ideas. *Valuable*, here, has many meanings: interesting, useful, beautiful, simple, richly complex, and so on. *Ideas* covers many meanings too: not only ideas as such (concepts, theories, interpretations, stories), but also artefacts such as graphic images, sculptures, houses, and jet engines. (Boden 2009, p. 24)

A similar high valuation is expressed by the psychologists Beth Hennessey and Teresa Amabile, in a recent major review. They write that

> If we are to make real strides in boosting the creativity of scientists, mathematicians, artists, and all upon whom civilization depends, we must arrive at a far more detailed understanding of the creative process, its antecedents, and its inhibitors. The study of creativity must be seen as a basic necessity. (Hennessey and Amabile 2010, p. 570)

They go on to define it as "the development of a novel product, idea, or problem solution that is of value to the individual and/or the larger social group" (Hennessey and Amabile 2010, p. 572). For these writers, civilization itself has arisen naturally through unaided creativity by gifted individuals, but now the demands for progress and national achievement are greater, and scientific psychology and theoretical understanding are required to help it along.

3. Some Reservations about These Definitions

However, doubts have been raised about these definitions of creativity in terms of novel ideas. An early warning came from Theodor Levitt, a leading marketing academic at Harvard Business School in the 1960s. He argued that what is important in modern American creativity is innovation, and that creative ideas themselves are relatively trivial:

> The fact that you can put a dozen inexperienced people into a room and conduct a brainstorming session that produces exciting new ideas shows how little relative importance ideas themselves actually have. Almost anybody with the intelligence of the average businessman can produce them, given a halfway decent environment and stimulus. The scarce people are those who have the know-how, energy, daring, and staying power to implement ideas. (Levitt 1963)

These human attributes conventionally belong to innovators in any field. They are not inner processes in the brain but refer to activities in the social world over long periods of time, and certainly apply to the innovating computer scientists responsible for the achievements of CC. However, they cannot comfortably be applied to computers or programmes themselves; if this is the case, it is not the computers of CC which have these qualities and are creative, but the computer scientists who build them and write their programmes. More generally, if these qualities are among the distinctive characteristics of being an artist, it would be misleading to speak of the machine as an artist.

Furthermore, in many of the world's artworks, it is not novelty that is achieved and admired, but ambition in scope and perfection in execution. This is true, for instance, of much medieval art, such as illuminated manuscripts and the great medieval cathedrals; it is also true of classical Eastern art, including dance and theatre. It is the sheer beauty and manifest skill that counts. Michelangelo was admired by his contemporaries above all other artists; not because he had novel ideas, which he undoubtedly did like many others, but because of his unique skill and the energy and persistence with which he practiced them.

Some of these limitations were acknowledged early on by a few of the many writers on creativity and the meaning of creativity has been extended to include such interactive art as dance and jazz, and social factors (and not just individual brains) are now being given full weight in psychology (Glăveanu 2010). The result is that, although the definition of creativity in terms of novel ideas remains, the implementation side has been much expanded, as in the definitions given above by Boden (2009) and Hennessey and Amabile (2010). This is even clearer in a definition given in 2018 by Michael Mumford

> Creativity is not simply a matter of generating ideas. Instead, creativity is defined as the production of high quality, original, and elegant solutions to complex, novel, ill-defined problems.[1]

In this definition, although creativity may involve generating ideas, more goes on in the mind and the world than the simple generation of novel ideas and valuable products envisaged by earlier writers. This more general picture by Mumford is part of how we judge creativity. Colton makes a similar point on behalf of CC when he writes that the product alone is not enough in assessing creativity and in the case of painting "the process of creating an artefact is often a deciding factor in the assessment of that artefact." (Colton 2008). In practice, CC is by no means only a search for a creative product but has widespread applications to other fields, such as education and medical diagnosis (Wagstaff 2012; Sturm and Ben-Tal 2017).

[1] From the abstract of his paper "Creative Thinking Processes: The Importance of Strategies and Expertise" given at the Southern Illinois Creativity Conference, 2018.

Nevertheless, in spite of these reservations, the word "creativity" itself, which seems equally at home in scientific psychology, CC, marketing, and popular use, does seem to be held together by a common emphasis on novel and valuable products. The general theory behind this is that the implementation of the inner processes in the brain gives rise to great products (from nuclear weapons to space rockets as well as the works of Shakespeare, Michelangelo, and Mozart, and commercially successful products like fish fingers, jeans, and Facebook). But as it developed in psychology, the theory has become more democratic, and most writers insist that similar inner processes go on in ordinary people, and give rise to products that are novel and valuable to them, even if to no one else.

Given this general theory, the scientist's task is to discover the mechanisms that generate such novel and valuable products. As Herb Simon, himself a Nobel prize winner put it:

> The notion that creativity requires inspiration derives from puzzlement about how a mechanism (even a biological mechanism like the brain), if it proceeds in its lawful, mechanistic way, can ever produce novelty . . . for novelty is at the core of creativity. In fact, we shall define creativity operationally, in full accordance with general usage, as novelty that is regarded as having interest or value (economic, aesthetic, moral, scientific or other value). (Simon 1995, p. 945)

On this way of thinking, it is the brain that is seen as the mysterious (but mechanistic) source of creative products, which is the stance taken by many cognitive scientists who are investigating creativity. As Guilford himself wrote years before he discovered the word, "all the results of human invention and construction are creations of the human brain" (Guilford 1939, p. 486).

If, as is widely believed, brains are like computers, the way is open to treating computers as a model for investigating the brain's creative processes. To do this, it is necessary to *evaluate* the computer's power of creativity by measuring the creative value of its products. This has often involved applying a version of the Turing test of machine intelligence, but to artificial creativity rather than to artificial intelligence.

In the same year as Guilford's "Creativity", Turing published his famous paper "Computing machinery and intelligence" in which he set out a test of whether or not computers can be said to think, and a variation on this test has been widely used to evaluate whether computers can be creative. Since thinking was regarded by Turing as a process that takes place in the mind or brain, his test "has the advantage of drawing a fairly sharp line between the physical and intellectual capacities of a man" (Turing 1950, p. 455). He suggests that chess would be an appealing way (Turing 1950, p. 460) of testing the intellectual powers of machines, but his own test of thinking in what he called the imitation game is more searching. In this game, an investigator asks questions of both a machine and a human to determine which is which. The machine's task is to mislead the investigator into thinking that it is human and its success in this is taken to indicate that it is intelligent and can think.

Towards the end of the paper, he touches on creativity by introducing Lady Lovelace, the Nineteenth-century thinker whose reflections on computing machines anticipated some of the modern discussion in CC. She was the first to raise a key question for CC—whether the output of a machine could really surprise us. In her answer, she asserted, in Turing's paraphrase, that a machine can only do what we tell it to (Turing 1950, p. 454; Boden 1990).

A version of the Turing test has been used to test a machine's artistic creativity. If computers can produce works of art, music, or literature that cannot readily be distinguished from human products, then they can be said to be creative or to create. This test is very much simpler than the original and has been criticized on these grounds (Ariza 2009). The original involved probing questions from the investigator, and crafted answers from the machine, whereas this version is only a simple discrimination. Nevertheless, it has been widely used and referred to as a "Turing" test.

Probably the most famous of the early exercises in computer creativity is Harold Cohen's AARON which has been producing pictures since 1973. These can be in a variety of styles, but the choice of style is set by the programmer. Unlike a human artist, it does not learn about styles by looking at pictures or talking to other artists. A few years later, David Cope began work on programmes that compose music and published a CD in collaboration with "Emily Powell", a computer programme sometimes known as EMMY. As with AARON, styles are set by the programmer rather than through investigation and learning. Both AARON and EMMY have produced artworks that people have difficulty distinguishing from those of human artists or composers. They have therefore passed the Turing test (the non-interactive version) "at a world-class level" (Boden 2010). They are adamant that their systems are creative, though they might hesitate to call the computer itself a machine artist. After all, the artefacts depend on the programmer's instructions, and there is little about the inner processes that parallel the human artist, as their critics have pointed out (Wiggins 2008). They may occasionally surprise us, but only as a consequence doing what they are told, so they do not strictly refute Ada Lovelace's assertion that machines, "can only do what they are ordered to do" (Turing 1950, p. 454) They are similar in this respect to the well-publicized exploits of Deep Blue, the chess playing system that defeated Gary Kasparov, the world champion, in 1997. To paraphrase Lady Lovelace again, Deep Blue may have sometimes surprised Kasparov, but it was only doing what it was told to do.

This is because Deep Blue depended on what Gary Kasparov himself called "brute force": "Instead of a computer that thought and played chess like a human, with human creativity and intuition, they got one that played like a machine, systematically evaluating 200 million possible moves on the chess board per second and winning with brute number-crunching force" (Kasparov 2010). Like AARON and EMMY, it lacked independence from the programmer and was not autonomous and creative in its own right.

But the science of CC has moved on dramatically in the last 20 years, with the use of developments in statistical methods of neural networking applied to pattern recognition and learning This has made possible techniques such as style transfer, and GAN (generative adversarial networks).

In style transfer, using a form of cluster analysis, a machine extracts a common style from a set of images and imposes this style on another image. In an example widely familiar to Google searchers, Hokusai's "The Wave" ("The Great Wave off Kanagawa") is impressively reimaged in the style of Van Gogh.

GAN is a technique for rapid unsupervised learning on the part of a computer confronted by a set of images to be analysed for clusters or patterns. The programme is divided into two neural networks. One (the artist we might say) extracts patterns in the data and generates images from these. The other (the critic) compares these trial images with the originals and feeds back discrepancies to the artist. The artist then carries out another trial incorporating these discrepancies, the critic criticizes, and so on. The learning is rapid, with a structure that is identical to the original use of the phrase trial and error as a quick way of homing in on a target in gunnery practice (Hutton 1811).

GAN has been widely acclaimed as a model of imagination, and Eigemmal et al. (2017) has changed the acronym to CAN (creative adversarial networks), in a paper in which he used a classic psychological model of aesthetic appreciation based on arousal level. The critic network uses this to feedback evaluations to the artist. This has led to the development of AICAN, "an almost autonomous artist" (Mazzone and Eigemmal 2019).

GAN has had several well-publicized successes. It was used in the generation of the portrait Edmond de Belamy which fetched $432,550 at Christies in 2018, and in the development of AlphaZero, which rapidly learns a variety of games, including Chess, to a world-class level (Silver et al. 2018). In chess, it homes in on the best move through a process that seems more like human thinking than the brute force of Deep Blue. Kasparov himself has changed his mind about computers and finds creativity in the "deep thought" shown by AlphaZero (Kasparov 2018).

With such results, the idea of a machine artist is becoming commonplace. As Simon Colton, writing of his own creation The Painting Fool, puts it, "it is our hope that one day people will have to admit that the Painting Fool is creative because they can no longer think of a good reason why it is not." (Colton 2012, p. 36).

4. Dewey's Creativity

Now, we risk spoiling the party by introducing another American, John Dewey (1859–1952), whose theory of creative activity and definition of creativity are not just an alternative to Guilford, AI, and CC, but close to its antithesis, since its emphasis is on experience rather than products. It is not that Dewey (as we imagine) would be hostile to either AI or CC, but he would warn against confusing the two aims that are embedded in these fields. The first is to carry out tasks that would normally be carried out by humans, and the second to throw light on the nature of human creative activity. Just to be clear, our Dewey-based criticism of AI and CC is not about the first, but only the second. Obviously, it is not Dewey himself (he died in 1952), but our imagined Deweyan response.

John Dewey's definition of creativity appeared in 1948, two years before that of Guilford. Its publication passed unnoticed and has been largely ignored, although many of Dewey's own ideas on education have been assimilated into work on creative activity in schools (Johnston 2006). For Dewey, there is nothing marvellous or even extraordinary about creative activity. It is the natural state of being. But it is easily suppressed by teaching that is dominated by a curriculum that demands the learning of facts and theories in science and the arts at the expense of individual and group inquiry. As the humanist psychologist Abraham Maslow wrote:

> The key question isn't "What fosters creativity?" But why in God's name isn't everyone creative? Where was the human potential lost? How was it crippled? I think therefore a good question might not be why do people create? But why do people not create or innovate? We have got to abandon that sense of amazement in the face of creativity, as if it were a miracle that anybody created anything. (Maslow [1959] 2000, p. 185)

John Dewey is often regarded as America's greatest philosopher and was equally influential as an educationalist and as a psychologist. In addition, his work on thinking and inquiry formed the basis of his monumental work on artistic activity, *Art and Experience* (Dewey 1934), as well as investigations of scientific thinking. His aim in education was to move away from what regarded as the stultifying effect of learning facts and rules and towards the cultivation of habits of free inquiry and critical thinking (Rudolph 2014). The word "creative" was important in his own thinking about science, the arts, and human living in general. This emphasis on free inquiry put him at odds with standard practice in education and psychology, with its emphasis on intelligence as a fixed power in the mind. He did not like the practice of measuring human minds or the uses to which measurement was put. He did not write at length about this, but in 1917 he edited a book containing contributions from like-minded pragmatist philosophers and psychologists, notably his close friend and colleague G.H. Mead.

At that time, the measurement of intelligence was coming to the fore, first in the service of eugenics and then as a way of filtering out the mentally unfit and potential officers during World War I (Mackintosh 2011). For these purposes, the creative aspects of the Binet tests were left out (as Guilford 1950, acknowledges), and this formed the basis of the arid measure of intelligence known as IQ, as well as, much later, the concept of intelligence in "artificial intelligence". For Dewey, by contrast, thinking and intelligence both involve inquiry and are creative by their very nature. This difference is pointedly captured in 1917 by the title of his edited book, *Creative Intelligence.*

In using the word "creative", Dewey was drawing on an important tradition. At the time, the word was commonly used to qualify "imagination" as in Ribot's *Creative Imagination* (Ribot 1906). This referred to the imagination involved in creative activities like art, but it was also used more generally to refer to the activity itself. Wordsworth used it in this way when he referred to the joys of "creative agency" meaning the exhilarating focus of energy involved in all aspects of writing. This usage was taken up by later Nineteenth Century writers familiar with Wordsworth, such as Emerson's "creative reading" (Emerson 1975) and Matthew Arnold's "creative criticism" (Arnold 1914), where the word refers to the activity itself and the experience of focused energy that goes with it, irrespective of any product.

5. Whitehead's Creativity

Dewey knew Wordsworth's poetry well and wrote on both Emerson and Arnold. Drawing on them, his ideas about free inquiry and creative activity were worked out by 1920, but his later use of "creativity" derives from the use of the word by Alfred North Whitehead. During the 1920s, and independently of Dewey's use of "creative", the logician and philosopher introduced the word "creativity" as an inherent property of variation and change in a universe that is not mechanical in the Newtonian sense:

> In the abstract language here adopted for metaphysical statement, "passing on" becomes "creativity," in the dictionary sense of the verb create, "to bring forth, beget, produce." [and] no entity can be divorced from the notion of creativity. (Whitehead [1929] 1968, p. 213)

Dewey and Mead discussed Whitehead at length (Cook 1979), and later Dewey introduced the word "creativity" in his own writings. This described an individual process of change to correspond to Whitehead's more general process of change in the universe, and it reflected his own earlier use of "creative".

6. Dewey's Definition of Creativity

So, when he defined creativity in 1948, he referred to experience, and a process of full involvement, focus, zest, and mindfulness. We give this little-known definition in full, beginning with his own use of "creativity" in 1942:

> The emphasis James places upon the individual quality of human beings and all things is, of course, central in his pluralism. But the adjective "individual" is often converted into a noun, and then human beings and all objects and events are treated as if they were individual and nothing but individual. The result is that identification of human beings with something supposed to be completely isolated which is the curse of the so-called individualistic movement in economics, politics and psychology. I find the actual position of James to be well represented in a remark he quotes from a carpenter of his acquaintance: "There is very little difference between one man and another; but what there is, is very important." It is this element which is precious because it is that which nobody and nothing else can contribute, and which is the source of all creativity. Generic properties, on the other hand, are replaceable and express the routines of nature. (Dewey [1942] 1989, pp. 4–5)

Later, in a foreword to Schaeffer-Simmern (1948) *The Unfolding of Artistic Activity*, Dewey gave a definition of "creativity" in a paragraph which captures in a few words his theory of what it means to be creative. He defined creativity as

> the life factor that varies from the previously given order, and that in varying transforms in some measure that from which it departs, even in the very act of receiving and using it. This creativity is the meaning of artistic activity—which is manifested not just in what are regarded as the fine arts, but in all forms of life that are not tied down to what is established by custom and convention. In re-creating them in its own way it brings refreshment, growth, and satisfying joy to one who participates.
>
> Accompanying this principle ... is the evidence that artistic activity is an undivided union of factors, which, when separated, are called physical, emotional, intellectual, and practical—these last in the sense of doing and making. These last, however, are no more routine and dull than the emotional stir is raw excitation. Intelligence is the informing and formative factor throughout. It is manifested in that keen and lively participation of the sense organs in which they are truly organs of constructive imagination". (Dewey 1948, pp. ix–x)

Creative activity, therefore, is activity that has an impact by sustaining or changing the established order that has guided the individual to which she belongs; and is present in everyday activities, such as gardening or cooking, where there is a state of creative intelligence, active interest, and alertness. They are what Dewey called "habits of thinking" and if he ever read Guilford's 1950 paper his suggested correction would be simple: Instead of "the creative person has novel ideas", he would write "the creative person has the habits of thought that make for creative activity"; these habits of thought comprise habits of perseverance, patience, interest, curiosity, awareness, as well as those envisaged by Levitt.

He had already spelled this theory out in *Art and Experience* (though without using the word "creativity"), and he saw it in action in Schaeffer-Simmern's book, notably in the narrative with which the book begins. This is the story of Selma, a 30-year-old woman with an IQ of 49, who had been treated with great brutality until she arrived at the institution where she met Schaeffer-Simmern. At first, she was severely withdrawn and almost mute. The author describes how she was gradually encouraged to copy pictures, then to draw them in her own distinctive way, and went on to work with other women in the institution to produce a cooperative for herself. In this way, she discovered the possibility of a full life.

With this as a model, Dewey's way of bringing about a creative life that offers "refreshment, growth, and satisfying joy" would not be to train in creativity directly by encouraging novel ideas and self-expression. Instead, it would be to cultivate the habits of thought and imagination that point towards creative activity and militate against the blind following of "custom and convention". The classroom observations reported by Guy Claxton can serve here as a brief example of this approach (Claxton 2006).

A teacher, Louise, noticed that her year six pupils got reasonably good results by skimming over the surface of the learning. She found that her instruction to set them working ("Off you go!") sounded like a starting pistol in the heads of a large number of children, who immediately became competitors in a race to be the first to her desk with 'Miss, I've finished, what shall I do now?'. The habits of thought behind this classroom behaviour may make for a productive life in a competitive market, but it would not be a creative one, in Dewey's sense of creative. Accordingly, Louise attempted to change the habits of thought towards reflection and understanding, leading on to further inquiry without having to be instructed by the teacher. This change in the habits of thought was a joint effort initiated through discussions between teacher and students. As a result, Louise's

> desire that they should learn the pleasure of taking time, digging in, asking questions and challenging themselves was being more effectively communicated to the children—and they were responding. (Claxton 2006, p. 61)

7. Dewey's Brain

This is the tradition drawn upon by Dewey, but it would be a mistake to dismiss Dewey's view of creative activity as literary or humanistic. Like William James, he was well aware of the scientific psychology of his time. He had a wide knowledge of philosophy, literature, and art, but the thrust of his thinking was towards a scientific account, and he aimed for one better than that offered by the classical atomistic theories dominant at the time. His clearest statement of this is his famous reflex arc paper of 1896. There he argued that behaviour is essentially a flow and cannot be reduced to the stimulus–response reflex, in which stimulus and response are distinct units, causally connected. Instead, "stimulus" points forward to "response", and "response" points back to "stimulus", each defined in terms of the other. This led to his holistic view, which gave the brain a different role from that imagined by Guilford and Herb Simon. For them, the brain is a relatively closed system, being separated from its environment by the senses regarded as transducers. For Dewey, the brain is part of an open system, and this system is not treated as mechanistic. Nevertheless, it is materialist, and ultimately physical—in this sense, it is similar to other open systems, such as Varela et al. (1991). As Dewey himself wrote:

> An animal is... continuous with chemico-physical processes which, in living things, are so organised as really to constitute the activities of life with all their defining traits. And

> experience is not identical with brain action; it is the entire organic agent-patient in all its interaction with the environment, natural and social. The brain is primarily an organ of a certain kind of behaviour, not of knowing the world. (Dewey et al. 1917, p. 36)

It follows that thinking and intelligence for Dewey are processes that belong to the whole organism and are not confined to the brain or mind.

8. Discussion

How do we decide between these two traditions for thinking about creative activity? In the 70 years since modern "creativity" first appeared, with its standard definition connecting novel ideas with valuable products, the word has become so embedded in scientific, CC, marketing, and everyday usage that it is hard to think of a viewpoint like Dewey's being a serious scientific contender. Things may change, but for the time being, we find it helpful to think of it as a struggle for meanings around the word "creative", a struggle between the traditional dualist view of human beings, sometimes known as cognitivism or representational cognitivism (Still 1986), and the alternative represented here by Dewey, a form of process theory.

The cognitivist theory is clearly in charge at the moment. An interim result of the struggle is that the word "creativity" has changed its meaning in English. In the theories of Whitehead and Dewey, it was a group and individual process of change. But in cognitivism, represented by Guilford and AI, it has become an individual power of the mind or brain to generate novel and valuable ideas.

Of course, meanings change, often driven by technical innovation. As Paul Valery wrote, in a passage that forms the epigraph to Walter Benjamin's widely discussed essay on the impact on our notion of the art of reproduction through photography and film:

> Our fine arts were developed, their types and uses were established, in times very different from the present, by men whose power of action upon things was insignificant in comparison with ours. But the amazing growth of our techniques, the adaptability and precision they have attained, the ideas and habits they are creating, make it a certainty that profound changes are impending in the ancient craft of the Beautiful. In all the arts there is a physical component which can no longer be considered or treated as it used to be, which cannot remain unaffected by our modern knowledge and power. For the last twenty years neither matter nor space nor time has been what it was from time immemorial. We must expect great innovations to transform the entire technique of the arts, thereby affecting artistic invention itself and perhaps even bringing about an amazing change in our very notion of art. (Valery, quoted in Benjamin [1937] 1968, p. 219)

In the essay itself, Benjamin pointed out that, considered as visual art forms, photography and film differ essentially from traditional museum art, where the individual artefact has an "aura" generated by its authenticity. Reproductions are far less valuable than the unique original since they lack the aura, but this doesn't apply to photography and film; in these new art forms what we see is always itself a reproduction, and the original can be reproduced indefinitely without loss of value. He argued that it is a mistake to try to assimilate these new forms to what went before, by forcing them into a fixed category or concept of "art". Instead, the western notion of art has changed, even though we may continue to use the same word. Photography and film have joined painting and sculpture as visual art, even though the aura is lost. The old art talk about meanings and intentions and creative influences will still be there.

Therefore, the change in meaning investigated by Benjamin leaves the artistic activity relatively intact. In photography and film, the product is different in form from that of traditional museum art, but the hard work and dedication and talk remain part of the life of the artist, even if the techniques and nature of the product have changed.

This is not true of machine art or machine as an artist. Here, the products are roughly the same, but the experience behind it is totally different. None at all in one case, the same old sweat and tears in the other. Does this warrant declaring a change of meaning, or can we (*pace* Benjamin) fit the machine into the old category of artist?

This is not a question of the quality of machine products. Shifting attention to Valery's word "beautiful", it is certainly possible that autonomous computers will produce sounds or words of an exquisite beauty that we cannot yet imagine, and that will be much sought after. And, of course, an artist will learn from this, just as chess players learn by practicing against chess programmes and tennis players may one day learn by playing with robot tennis players.

Machines may serve as a resource in many other ways. The future poet, for instance, might draw on the computer's vast database and speed of search, to produce rapidly a poem that shows a mastery of language and style well beyond the reach of most human poets. Welcoming this, the human poet will use the computer as a resource to train herself, like a chess player playing against strong chess programs like Fritz. She will learn to write poems approaching the same technical excellence as the computer poet. In this way, she achieves a greater understanding and mastery over the mechanical techniques of her art. She may then draw on her human experience, and with the technical competence and self-awareness learned from the machine, become a great poet. To do this, if Dewey is right, she goes beyond the ruminating brain regarded as a closed mechanical system, to the brain as part of the body forming an open system, connected directly with the world. Turing himself put the difference starkly:

> The new problem (i.e., the Turing test) has the advantage of drawing a fairly sharp line between the physical and intellectual capacities of a man. No engineer or chemist claims to be able to produce a material which is indistinguishable from the human skin. It is possible that at some time this might be done, but even supposing that this invention available we should feel there was little point in trying to make a 'thinking machine' more human by dressing it up in such artificial flesh. (Turing 1950, p. 434)

Dewey would agree that there is no point in this, but not because living in the world and having flesh is irrelevant to human thinking, but the opposite; because it is essential to being human, and therefore to the thinking and creativity that are part of being human. On this view, Turing's "fairly sharp line" is a mistake that reflects the traditional dualism that Dewey rejected.

At present, according to Dewey's view, to be a human artist we need experience and to have human experience we need flesh. Therefore, if we really believe that machines can be artists (rather than just treat it as a metaphor), we would be changing the meaning of art and artist. This may happen, but it would be a more momentous change than the change Benjamin pointed out, which was the change in the meaning of art and artist when photography and film became assimilated into the category of art. For Dewey, such a change would entail a hardening of the traditional dualist view of what is to be human, and this is what he spent his life resisting

We take this to be a serious matter, but whatever viewpoint we adopt the really exciting prospect for us (as Deweyan), and one of the underlying goals of AI, remains the contribution of computer technology to stimulate, challenge, and provoke artistic practice of all forms. The systems we have been involved in developing and implementing reflect this belief.

9. A Deweyan Approach to the Design of AI Systems for Creativity

In recent work, we have tried to take a more Deweyan approach to the design of AI in order to support, challenge and provoke human creative activity. We are interested in designing systems that can support the ongoing moment-to-moment process of content generation over a sustained period of time. The approach has been to start with the musician and design systems based on the way in which they improvise.

One example is the system Reflexive Looper that placed the solo artist at the centre of the design process and enabled them to create new kinds of music performances (Pachet et al. 2013). In a single session (i.e., all the data the system uses about the style of a musician comes from a single performance or episode of interaction), and choosing a repeating chord sequence (of a blues or a standard, for example) as the underlying musical canvass, the musician can record themselves playing (say) a bass line (perhaps with different intensities and styles), and then chords (similarly), and then a melody, and then a series of improvisations.

Then, the solo musician can effectively play with musical copies of themselves. For example, by playing chords, the system will generate the "best fitting" bass line and improvised melody. It is important to note that the musical versions offered are not direct recordings of the original performance, rather real-time machine-created and adaptive versions based on elements such as chord or key changes, playing mode or style. The creative success of this system is that it provides a genuine sense of being able to extend the creative range of the musician and a realistic experience of interacting with alternate versions of oneself in a live musical performance.

The machine imparts a significant sense of creative agency by inheriting the output of the creative activity of the human performer with sufficient transformation to not seem like direct imitation. Its musical analyses are based solely on what the musician is doing in the moment of their sustained, ongoing moment-to-moment performance with the system. The creative activity of musicians is challenged, provoked, and stimulated—indeed, often being put considerably out of their natural comfort zone—by leading to musical creations that would not have been possible for a musician playing alone.

Another example is the SpeakeSystem (Yee-King and d'Inverno 2016). SpeakeSystem is a real-time interactive music improviser which takes as its input an audio stream from a monophonic instrument, and it produces at its output a sequence of musical note events which can be used to control a synthesizer to produce performances. The system segments and labels incoming audio from the human musician and constructs a hierarchical Markov model of the label sequence. It labels the segments with their length (after quantization), their type, either "note" or "rest", and the pitch of the note. The system then samples from the model to generate a stream of output labels that are statistically similar to the input sequence.

The BBC Radio 3 Jazz Line Up programme commissioned SpeakeSystem in 2015 for a live human and computer performance with alto saxophone player Martin Speake—one of the UK's leading jazz musicians.

A recording of the performance and the source code for the system is available in an open source repository [104]. The system is the latest in a series, including one judged as one of the "sessions of the year" when it played with flutist Finn Peters in 2009.

Again, the artist had to interact with the system in a moment-to-moment, sustained dialogue which led to genuine moments of musical ingenuity which would simply not have happened without the contribution of the machine. Taking a deliberately Deweyan approach, we actually posed the idea that the only way in which one could make judgments of the quality of the human/machine collaborating was by looking at the experiences of the musician, the audience, and the software engineer, and we used the system Music Circle in order to do this. We believe that this approach is critical in thinking about creative systems and part of our determination as we build more systems.

Whilst our systems are about music improvisation, we believe that they provide the appropriate context to explore human/machine co-creation in that interaction needs to take place in a live, moment-to-moment, embodied, and performative context over a sustained period of time. We are interested in exploring how the human or machine can take different kinds of roles spanning different notions of agency and autonomy (including who is following who) that would naturally unfold in any human/human improvised setting. Other work in this space ranges from the use of gesture analysis systems and enabling the ongoing moment-to-moment interaction of performers of using gesture recognition systems (Zamborlin et al. 2014) where there is almost no system agency up to our most recent attempts to understand the psychological flow state of performers during improvised musical interaction with machines with a great deal of musical agency and autonomy (McCormack et al. 2019).

Although the focus is mainly on music and improvisation, we believe that this space provides us with exactly the right setting in order to consider the scientific challenges of building systems that generate creative content and builds upon proposals we made in a recent paper that come through a deeper investigation in what we mean when we talk about creativity (Still and d'Inverno 2016).

Author Contributions: Conceptualisation and narrative design, A.S. and M.d.; original draft preparation, Sections 1–8 A.S. lead, Section 9 M.d. lead; overall writing, review and editing, A.S. and M.d.

Funding: This research received was not supported by external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

Ariza, Christopher. 2009. The interrogator as critic: The Turing test and the evaluation of generative music systems. *Computer Music Journal* 33: 48–70. [CrossRef]

Arnold, Matthew. 1914. *Essays by Matthew Arnold*. London: Oxford University Press.

Benjamin, Walter. 1968. The work of art in the age of mechanical reproduction. In *Illuminations*. London: Fontana, pp. 214–18. First published 1937.

Boden, Margaret A. 1990. *The Creative Mind: Myths and Mechanisms*. London: Weidenfeld & Nicolson.

Boden, Margaret A. 2009. Computer models of creativity. *AI Magazine Fall* 30: 23–39. [CrossRef]

Boden, Margaret A. 2010. The Turing test and artistic creativity. *Kybernetes* 39: 409–13. [CrossRef]

Claxton, Guy. 2006. Cultivating creative mentalities: A framework for education. *Thinking Skills and Creativity* 1: 57–61. [CrossRef]

Colton, Simon. 2008. Creativity Versus the Perception of Creativity in Computational Systems. Paper presented at the AAAI Spring Symposium: Creative Intelligent Systems, Palo Alto, CA, USA, March 26–28.

Colton, Simon. 2012. The Painting Fool: Stories from Building an Automated Painter. In *Computers and Creativity*. Edited by McCormack Jon and Mark d'Inverno. Berlin: Springer.

Cook, Gary A. 1979. Whitehead's Influence on the Thought of G. H. Mead. *Transactions of the Charles S. Peirce Society* 15: 107–31.

Dewey, John. 1934. *Art as Experience*. New York: Perigree Books.

Dewey, John. 1948. Foreward. In *The Unfolding of Artistic Activity*. Edited by Henry Schaefer-Simmern. Berkeley: University of California Press.

Dewey, John. 1989. William James and the world today. In *The Later Works of John Dewey, 1925–1953: Essays, Reviews, and Miscellany, 1942–1948*. Edited by Jo Ann Boydston. Carbonville: Southern Illinois University Press. First published 1942.

Dewey, John, Boyd Henry Bode, Horace Meyer Kallen, Addison Webster Moore, Harold Chapman Brown, George Herbert Mead, and Henry Waldgrave Stuart. 1917. *Creative Intelligence; Essays in the Pragmatic Attitude*. New York: Henry Holt.

Eigemmal, Ahmed, Bingchen Liu, Mohamed Elhoseiny, and Marian Mazzone. 2017. CAN: Creative Adversarial Networks Generating "Art" by Learning about Styles and Deviating from Style Norms. *arXiv*, arXiv:1706.07068.

Emerson, Ralph. W. 1975. The American Scholar. In *The Portable Emerson*. Edited by MarkVan Doren. Harmondsworth, Middlesex: Penguin Books, pp. 23–46.

Glăveanu, Vlad. 2010. Paradigms in the study of creativity: Introducing the perspective of cultural psychology. *New Directions in Psychology* 28: 79–93. [CrossRef]

Guilford, John P. 1939. *General Psychology*. Princeton: Van Nostrand.

Guilford, John P. 1950. Creativity. *American Psychologist* 5: 444–54. [CrossRef] [PubMed]

Hennessey, Beth A., and Teresa M. Amabile. 2010. Creativity. *Annual Review of Psychology* 61: 569–98. [CrossRef] [PubMed]

Hutton, Charles. 1811. *A Course of Mathematics*. London: F.C. and J. Rivington.

Johnston, James S. 2006. *Inquiry and Education: John Dewey and the Quest for Democracy*. Albany: State University of New York Press.

Kasparov, Gary. 2010. The Chess Master and the Computer. *New York Review of Books*, February 11.

Kasparov, Gary. 2018. *Deep Thinking: Where Machine Intelligence Ends and Human Creativity Begins*. London: John Murray.

Levitt, Theodor. 1963. Creativity Is Not Enough. *Harvard Business Review*, August.

Mackintosh, Nicholas. J. 2011. *IQ and Human Intelligence*. Oxford: Oxford University Press.

McCormack, Jon, Gifford Toby, Hutchings Patrick, Llano Maria Teresa, Matthew Yee-King, and Mark d'Inverno. 2019. In a Silent Way Communication between AI and improvising musicians beyond sound. Paper presented at CHI 2019 Conference on Human Factors in Computing Systems, Glasgow, UK, May 4–9.

Maslow, Abraham H. 2000. *The Maslow Business Reade*. New York: Wiley. First published 1959.

Mazzone, Marian, and Ahmed Eigemmal. 2019. Art, creativity, and the potential of Artificial Intelligence. *Arts* 8: 26. [CrossRef]

Osborn, Alex F. 1948. *Your Creative Power: How to Use Imagination*. New York: Scribners.

Pachet, François, Pierre Roy, Julien Moreira, and Mark d'Inverno. 2013. Reflexive loopers for solo musical improvisation. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. New York: ACM, pp. 2205–208.

Ribot, Th. 1906. *Essay on the Creative Imagination*. London: Kegan Paul, Trench, Trubner & Co., Ltd.

Rudolph, John L. 2014. Dewey's "Science as Method" a Century Later. Reviving Science Education for Civic Ends. *American Educational Research Journal* 51: 1058–83. [CrossRef]

Schaeffer-Simmern, Henry. 1948. *The Unfolding of Artistic Activity*. Berkeley: University of California Press.

Silver, David, Julian Schrittwieser, Karen Simonyan, Ioannis Antonoglou, Aja Huang, Arthur Guez, Thomas Hubert, Lucas Baker, Matthew Lai, Adrian Bolton, and et al. 2018. A general reinforcement learning algorithm that masters chess, Shogi, and Go through self-play. *Science* 262: 1140–44. [CrossRef] [PubMed]

Simon, Herbert A. 1995. Explaining the ineffable: Al on the topics of intuition, insight and inspiration. In *Fourteenth International Joint Conference on Artificial Intelligence*. San Francisco: Morgan Kaufmann, pp. 939–48.

Stein, Morris I. 1953. Creativity and culture. *Journal of Psychology* 36: 311–22. [CrossRef]

Still, Arthur. 1986. The biology of science: An essay on the evolution of representational cognitivism. *Journal for the Theory of Social Behaviour* 16: 257–68. [CrossRef]

Still, Arthur, and Mark d'Inverno. 2016. A history of creativity for future AI research. Paper presented at 7th International Conference on Computational Creativity (ICCC 2016), Universite Pierre et Marie Curie, Paris, France, June 27–July 1.

Sturm, Bob L., and Oded Ben-Tal. 2017. Back to music practice: The evaluation of deep learning approaches to music transcription, modelling and generation. *Journal of Creative Music Systems* 2: 1. [CrossRef]

Turing, Alan M. 1950. Computing Machinery and Intelligence. *Mind* 59: 433–60. [CrossRef]

Varela, Francisco, Evan Thompson, and Eleanor Rosch. 1991. *The Embodied Mind: Cognitive Science and Human Experience*. Cambridge: MIT Press.

Wagstaff, Kiri L. 2012. Machine Learning that Matters. Paper presented at 29th International Conference on Machine Learning, Edinburgh, Scotland, UK, June 26–July 1.

Whitehead, Alfred N. 1968. *Process and Reality*. New York: The Free Press. First published 1929.

Wiggins, Gareth A. 2008. Computer Models of Musical Creativity: Literary and Linguistic Computing. *Literary and Linguistic Computing* 23: 109–16. [CrossRef]

Yee-King, Matthew, and Mark d'Inverno. 2016. Experience driven design of creative systems. Paper presented at 7th International Conference on Computational Creativity (ICCC 2016), Universite Pierre et Marie Curie, Paris, France, June 27–July 1.

Zamborlin, Bruno, Frédéric Bevilacqua, Marco Gillies, and Mark d'Inverno. 2014. Fluid gesture interaction design applications of continuous recognition for the design of modern gestural interfaces. *ACM Transactions on Interactive Intelligent Systems* 3: 30–45. [CrossRef]

arts

MDPI

Article

Pursuit and Expression of Japanese Beauty Using Technology

Naoko Tosa [1], Yunian Pang [1], Qin Yang [1] and Ryohei Nakatsu [2,*]

1 Graduate School of Advanced Integrated Studies in Human Survivability, Kyoto University, Kyoto 606-8306, Japan; tosa.naoko.5c@kyoto-u.ac.jp (N.T.); pang.yunian.87r@st.kyoto-u.ac.jp (Y.P.); yang.qin.7e@kyoto-u.ac.jp (Q.Y.)

2 Design School, Kyoto University, Kyoto 606-8501, Japan

* Correspondence: ryohei.nakatsu@design.kyoto-u.ac.jp

Received: 2 January 2019; Accepted: 15 March 2019; Published: 21 March 2019

Abstract: We have been working on the creation of media art, utilizing technologies. In this paper, we have focused on media art created based on the visualization of fluid behaviors. This area is named “fluid dynamics” and there has been a variety of research in this area. However, most of the visualization results of the fluid dynamics show only stable fluid behaviors and a lack of unstable or, in other words, unpredictable behaviors that would be significant in the creation of art. To create various unstable or unpredictable fluid behaviors, we have developed and introduced several new methods to control fluid behaviors and created two media arts called “Sound of Ikebana” and “Genesis”. Interestingly, people find and feel that there is Japanese beauty in these media arts, although they are created based on a natural phenomenon. This paper proposes the basic concept of media art based on the visualization of fluid dynamics and describes details of the methods that were developed by us to create unpredictable fluid dynamics-based phenomena. Also, we will discuss the relationship between Japanese beauty and physical phenomena represented by fluid dynamics.

Keywords: fluid dynamics; high-speed camera; media art; fluid art; Japanese beauty

1. Introduction

We have created media art in which new technologies play an essential role. Recently, we have been interested in the usage of a high-speed camera, through which we have found hidden beauty in various natural/physical phenomena that could be revealed. In particular, we have been interested in the fluid behaviors and have been trying to create media arts by capturing fluid behaviors using a high-speed camera. Based on this methodology, we have been trying to create new types of media art (Feng Chen and Tosa 2013).

This area is considered “fluid mechanics” or “fluid dynamics” and there has been a variety of research in this area (Munson et al. 2012; Bernard 2015). As some fluid motions look beautiful, there is another research area called “visualization of fluid motion” (Smits and Tee Tai 2012). One such beautiful fluid motion is the well-known “milk crown” (Krechetnikov and Homsy 2009). However, most visualization results show only stable fluid behaviors and a lack of unstable or, in other words, unpredictable behaviors that would be significant in the creation of art. Therefore, to realize various unstable or unpredictable fluid behaviors to create artworks, it is important to introduce several new methods.

In this paper we describe two methods that have been developed and introduced by us to create new media art. In one method, we used viscous fluids such as paints with various colors, to which we applied vibration to produce upward motion and shot their “jumping-up” behaviors. It was revealed that jumping-up paints create beautiful forms that change in a very short time. Such forms were shot by a high-speed camera and then based on the editing of the obtained video, a new type of media art called "Sound of Ikebana" was created (Pang and Tosa 2015; Naoko Tosa et al. 2015).

We introduced a new method of letting color paints injected into fluid and dry ice bubbles interact to create beautiful forms of color paints, which led to the creation of a media art called "Genesis" (Naoko Tosa et al. 2017).

At the same time, we have received comments on these media arts from many Western people including art curators, art critics, etc. Interestingly, they feel that there is Japanese beauty in these artworks. Why do they feel Japanese beauty in the visualization of a natural/physical phenomenon? For this, based on our consideration, we have developed a hypothesis that one important factor of Japanese beauty is based on the extraction and expression of beauty hidden in natural/physical phenomena. As the relationship between our media arts and Japanese beauty is fundamental for the value of such arts, we will discuss what Japanese beauty is preceding the description of the media arts we have developed.

This paper consists of the following sections. In Section 2, a discussion on Japanese beauty is carried out and we make a hypothesis that one important factor of Japanese beauty is based on the visualization of hidden beauty in nature. In Section 3, the basic concept of the visualization of fluid dynamics as a method to create artworks is described. In Section 4, the detailed description of one type of media art creation method based on the fluid dynamics is described and the media art called "Sound of Ikebana" based on this method is described. In Section 5, the details of another type of art creation based on the fluid dynamics and also the created artwork called "Genesis" is described. Finally, in Section 6, we present the discussion and a conclusion is described.

2. Characteristics of Japanese Art

2.1. What Is Japanese Beauty?

What is the essence of Japanese beauty? As indicated by Bruno Taut and others, the harmony between humans and nature has always been emphasized and expressed in Japanese artworks and architecture (Taut 1958; Taut 1962). Trying to find out the root of such a basic concept, we reach the Chinese philosophers Lao-Tzu and Zhuangzi and their philosophy called "Taoism (Wong 2011)," in other words "Eastern Monism," which emphasizes the unification of humans and nature. Although Japanese beauty consists of various factors, based on this, it could be said that one factor of Japanese beauty is not beauty created by humans but beauty hidden in nature. Also, it could be said that one factor of Japanese beauty is what Japanese artists have tried to extract from nature based on their sensitivity and have expressed in the form of their artworks. This means that there is a close relationship between Japanese beauty and natural or physical phenomena. We noticed this based on our experiences described below.

We have focused on the creation of artworks based on the methodology of finding and extracting beauty hidden in natural/physical phenomena by using a high-speed camera. One of the authors, Naoko Tosa, was named as Japan's Cultural Envoy by the Agency of Cultural Affairs, the Japanese Government, in 2016 and exhibited her artworks in many cities all over the world. During such exhibitions, she received many responses from many people including art critics and art curators saying that "Naoko Tosa's artworks showing beauty hidden in nature express beauty that has not been noticed by Western people. Her artworks include the essence of Japanese sensitivity and consciousness".

It sounds a bit strange that Western people feel that there is Japanese beauty in artworks created based on natural/physical phenomena. Next, we will discuss this issue comparing Western and Eastern art history.

The creation of artworks based on beauty in nature is not an idea specific to Japan. This idea has been shared in many countries and cultures. In the West, since the Greek era, the idea that art is "imitation of nature" has long been accepted and this idea became the basis of the inventions of various art techniques such as perspective. However, since the late modern era, along with the invention of the camera, this idea was gradually replaced by another idea that art is the “expression of humans’ inner life” and this trend continues through art movements such as Impressionism, Cubism, Abstract Expressionism, and so on.

On the other hand, in the East, these theories have not been the mainstream in the art world and the basic concept of Eastern Monism that stresses the unification of humans and nature has been dominant. In contrast to Western artists, Eastern artists have neglected the concept of shadows and perspectives which play important roles in Western art. Having the idea of the unification of humans and nature deep in their minds and using their sensitivities, Eastern artists have created their artworks and also their own art world. In China, for example, monochrome ink paintings of landscapes have been popular. In such landscape paintings, based on the old Chinese philosophy of Taoism, Chinese artists tried to draw ideal landscapes—in other words, Arcadia.

As Japan used to continuously import Chinese cultures, Japanese art was deeply influenced by Chinese art. Then gradually merging this with the sensitivity of Japanese people, especially influenced by the isolation policy in the Edo era, Japanese artists began to create their own artworks without shadows, and being planar, exaggerated, etc.

As these Japanese artworks in the modern art era look very fresh to the West, who has denied the idea of “imitation of nature,” in 19th century, the movement called Japonism occurred.

Consequently, we can interpret the impressions of Western people toward Naoko Tosa’s artworks, when they say that her artworks express Japanese beauty, in the following way. As the concept of art in the West has changed from its original idea of “imitation of nature” to the modern and present one of the “expression of human’s inner life or concept,” Naoko Tosa’s artworks, that are created based on capturing and extracting beauty in nature and that are a contrast to Western art, appealed to their sensitivity and made them feel that her artworks express Japanese beauty.

Based on this experience we can make a hypothesis that “One important factor comprising Japanese beauty is based is the extraction and expression of beauty in nature.” For the extraction of such beauty, there could be several ways. One such method is based on the sensitivity or natural gifts of artists. Another method is based on the usage of technologies, which have been adopted by us.

In the next subsection, we will discuss several examples of Japanese artworks and artforms showing that one factor of Japanese beauty is based on the extraction of beauty hidden in nature and the creation of artworks containing such beauty.

2.2. Examples of Japanese Beauty in Japanese Art

In natural phenomena, such as water flow or wave forms, Japanese artists have found beauty and by expressing such beauty, they have created their artworks. One such artform is the well-known artworks by Katsushika Hokusai (Thompson and Wright 2015). Also, the specific expression of water flow, called “Korin wave,” designed by Ogata Korin is very well known (Fujiura 2018). Such artworks are typical expressions of Japanese beauty and have been welcomed by Western artists, giving them strong impressions. Figure 1 shows Fugaku sanjurokkei Kanagawa oki Namiura (the Wave off Kanagawa, from 36 Views of Mountain Fuji), a print by Katsushika Hokusai (Clark 2017). Interestingly, the dynamic waveform expressed well resembles the wave form shot by a high-speed camera. Figure 2 illustrates the fluid form created by injecting air-gun bullets into fluid with color paints. It is interesting to know the resemblance between these two.

Figure 1. "Fugaku sanjurokkei Kanagawa oki namiura (the Wave off Kanagawa, from 36 Views of Mountain. Fuji" by Katsushika. (in public domain)

Figure 2. Fluid form captured by a high-speed camera.

Another example is a basic form of Japanese "Ikebana" (flower arrangement). The basic form of Ikebana has been considered an "asymmetric triangle" (Figure 3). We have succeeded in creating a similar form by letting color paints jump up by applying sound vibration and by shooting the jumped-up color paints by a high-speed camera, which is described later (Figure 4).

What produces this resemblance between the artworks and the form expressing Japanese beauty and natural/physical phenomena? Perhaps it is that great Japanese artists, such as Katsushika Hokusai, can find beauty hidden in natural/physical phenomena using their sensitivity and talent and can create artworks using the beauty found. For now, this remains a hypothesis, but we want to reveal this by continuing the creation of artworks based on beauty hidden in nature.

Figure 3. "Basic Form" of Ikebana. (in public domain).

Figure 4. Fluid form created by sound vibration and captured by a high-speed camera.

3. Visualization of Fluid Dynamics as a Method to Create Media Art

Study of the behaviors of fluid has been a long-time research topic in physics and this area is called "fluid dynamics" (Munson et al. 2012; Bernard 2015). In physics, fluid dynamics is a sub-discipline of fluid mechanics that deals with fluid flow. It has several sub-disciplines itself, including aerodynamics (the study of air and other gases in motion) and hydrodynamics (the study of liquids in motion). Fluid dynamics has a wide range of applications including calculating forces and moments on aircraft, determining the mass flow rate of petroleum through pipelines, predicting weather patterns, understanding nebulae in interstellar space and modeling fission weapon detonation.

Determining how to explicitly show the behavior of fluid is another research area called "visualization of scientific phenomena" (Smits and Tee Tai 2012). Based on this visualization process, it became possible for people to watch the actual process of fluid behavior and it has been recognized that various beautiful fluid motions can be created depending on various conditions. As beauty is the fundamental element of art, utilizing fluid dynamics as a method to create artworks has been one of the key concepts of art creation. There are various artworks that utilize the concept of fluid dynamics. These approaches can be classified into two ways.

One approach is from a purely scientific side. Fluid motions, especially when there are obstacles in the pathway of the fluid, look beautiful and sometimes the visualized result of such fluid motion is considered art. Figure 5 shows the result of the visualization of stable flow called "laminar flow". As the ratio between inertia and viscosity, called "Reynolds number," increases, the laminar flow changes into unstable flow called "turbulence." In turbulence, frequently various types of vortex occur, some of which look beautiful. Figure 6 shows one example of such a vortex.

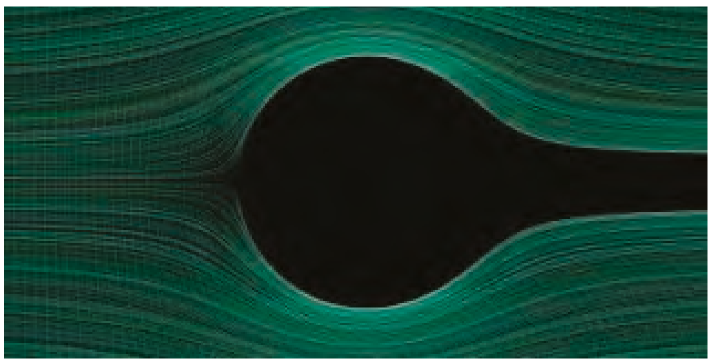


Figure 5. An example of laminar flow.

Figure 6. An example of a vortex.

Although various types of beautiful forms can be created based on such approaches, created forms based on such approaches are not considered pure art. The reason for this is that these phenomena or created forms are still based too much on physics and it is difficult to include an "intention of artists" in the form creation process. There is a clear distinction between physical phenomena and artworks and the border is how much intention of the artists to create artworks is involved in the created work. If there is no intention or the intention is too weak, the created forms are considered physical phenomena rather than artworks. In other words, forms created as physical phenomena are controlled by the laws of physics and there is little space for where something unexpected happens and this unexpectedness is a core part of artworks.

On the other hand, there is a different approach which is from an art basis. In this case, fluid usage is strongly controlled by the artists and unexpected phenomena or chance phenomena that happen in the process of fluid usage are utilized by the artists to include something unexpected into their artworks. One representative of such art creation processes is "Action Painting" (Fleck et al. 2008) led by Jackson Pollock (Landau 2010). Action painting is a form of art creation in which, instead of drawing paintings using a paintbrush, artists throw or draw paints on a canvas. Basically, artists have intentions regarding what kind of paints they use and where on the canvas they throw or draw paints. Therefore, in addition to the intentions of the artists, a kind of contingency caused by thrown or drawn paints influences the final form of the created artwork. Figure 7 shows one of the representative artworks of Jackson Pollock. Although he is now highly evaluated and appreciated in the modern history of art, a problem with his artworks is that it is difficult to find natural beauty, and, therefore, in the beginning, this confused many people.

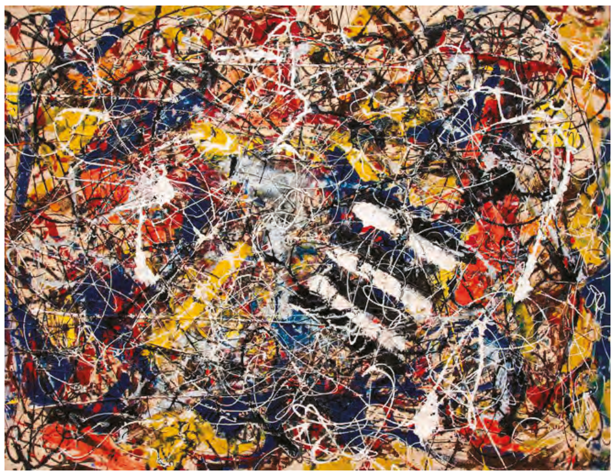


Figure 7. One of the Jackson Pollock's drawings (in public domain).

Based on the problems included in these two approaches, we think that there should be another way of new art creation somewhere in between these two approaches. We started from the former approach but tried to include more unexpectedness in created forms. In Sections 4 and 5, two methods to realize this are described.

4. Sound of Ikebana: An Example of Created Art

As one method to create artworks based on the visualization of fluid dynamics, we have developed a method to combine color ink fluid and sound vibration.

4.1. Sound Vibration System

It is well known that applying vibrations to liquids such as water creates movement in the liquid. For example, putting water on a drum and playing the drum creates a beautiful water splash form and this is frequently used as a performance. This is visible beauty based on a physical phenomenon. Inspired by this, we wanted to find invisible beauty included in this type of physical phenomenon. To realize this, we introduced a high-speed camera as key equipment and have developed a system to realize and shoot such physical phenomena called a "sound vibration system".

The sound vibration system is a new art creation method, which generates various changing shapes of materials ejected up by sound vibration (Yunian Pang et al. 2017). We used a high-speed camera with the rate of 2000 frames per second, and replayed it with 30 frames per second. This means we expand real time to 67 times. Then, the beautiful phenomenon hidden in nature is able to be seen by us directly.

The top-down view of the system is illustrated in Figure 8. First, we placed a rubber sheet over the top of a bass speaker and stretched the rubber to give it enough tension. Then, we fixed the rubber to make it stable. After that, we poured various fluid materials, with carefully controlled quantities and viscosities, onto the rubber. A rap-top computer was used to generate sound with various wave shapes and frequencies, and the generated sound was fed to the speaker. The vibration of the sound was then delivered to the rubber and to the color paints on it. The color paints were forced to jump from the rubber rapidly. A high-speed camera was used to record the changing shape and another computer connected to the camera recorded this. Also, to realize enough brightness for better quality of the shot video, we introduced two 300 W xenon lamps.

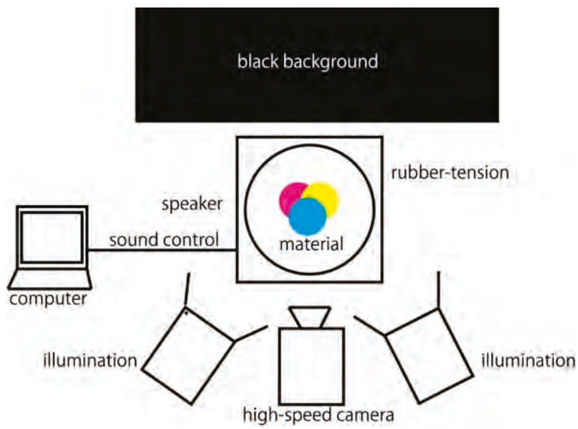


Figure 8. Top-down view of the sound vibration form system.

4.2. Sound of Ikebana: Created Art Based on SVF

By using the sound vibration system described above, we carried out various experiments by changing the type of sound, sound frequency, sound volume, liquid type, liquid viscosity, etc., and based on this, we created an artwork called "Sound of Ikebana." In this artwork, sound was used as an energy source which can eject color paint up above the speaker. Then a high-speed camera was used to capture the motion of the paints. By expanding the time of the phenomena, we can see the beautiful shape of the paint, which looks like "Ikebana," the Japanese flower arrangement. As was described in Section 2.2, it is interesting to see the similarity between various forms created by sound vibration and Ikebana, a typical traditional Japanese culture.

This artwork is a combination of the latest technology and the traditional Japanese flower arrangement culture. Sound of Ikebana consists of four short videos, each of which represents one of the four seasons in Japan. It uses specific colors to represent flowers in each season (Figure 9). By utilizing various types of color paints and liquids, we tried to express Japanese flowers in each season, such as plum and cherry in spring, cool water and morning glory in summer, red leaves in autumn, and snow and camellia in winter. Additionally, we tried to express various color variations such as prayerful colors of Buddhism, Japanese "Wabi" (austere beauty) and "Sabi" (elegant simplisity) colors, colors of delicious food, cute colors of "Cool Japan," gorgeous colors featuring the New Year season, etc.

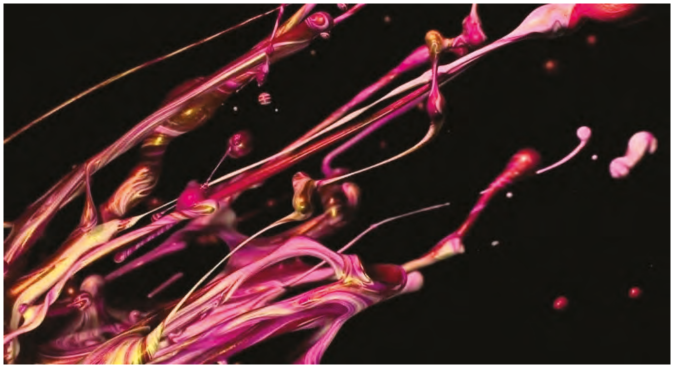


Figure 9. A scene from "Sound of Ikebana".

By watching these series of video artworks, the audience would have a feeling of wonder generated by the organic and mysterious figures of the liquid and also its unforeseeable movements. At the same time, the audience would feel the connection of the long history and traditional cultures in Asia.

To display artworks to many audiences in an effective way, a projection mapping has been frequently used. We carried out the projection mapping of Sound of Ikebana at Singapore ArtScience Museum in 2013. The moving images of Sound of Ikebana were projected on the wall of the lotus-like ArtScience Museum. The artwork became a part of the city night view, and the whole city was able to appreciate it (Figure 10). Also, the artwork was exhibited in Times Square in New York during one month in April 2017, using more than 60 digital billboards there (Figure 11).

Figure 10. Sound of Ikebana projection mapping at ArtScience Museum in Singapore.

Figure 11. Sound of Ikebana exhibited in Times Square, New York.

5. Genesis: An Example of Created Art

As another method to create artworks based on fluid dynamics, we have developed a method to let fluid and dry ice bubbles interact to create beautiful forms.

5.1. Injection of Paints into Fluid

As a basic material to observe fluid behaviors, we chose color paints. In the work described in the previous section, we chose color paints and succeeded in creating various types of beautiful and mysterious forms by applying vibrations to them (Pang and Tosa 2015; Yunian Pang et al. 2017). Therefore, we are familiar with the behaviors of color paints. This time, instead of giving them sound vibrations, we tried to inject them into water. Based on various preliminary experiments, we found that color paints injected into water from droppers can create interesting forms that resemble the phenomenon of a volcano eruption or hydrothermal vent (Figure 12).

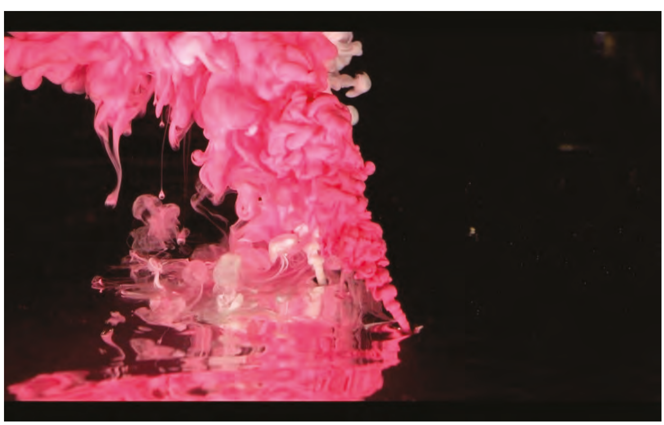


Figure 12. Injection of color paints into fluid.

There is some affinity between water and color paints, even in the case of oil-based paints; therefore, injected paints and water mingle rapidly and the water rapidly becomes a kind of "colored water". As what we want to create are the interesting behaviors of injected paints, this rapid mingling process is not preferable. Thus, we tried adding agar into water to increase its viscosity and found that, in the case of water with a certain amount of viscosity, this has the effect of delaying such a mingling process. Additionally, we found that the level of viscosity based on the amount of added agar plays an important role by changing the mingling time to some extent. This finding was important to create the interesting behavior of injected paints. However, basically behaviors of injected paints are based on the diffusing process and, as the time passes, water and paint are mixed based on a one-way process. Consequently, it is difficult to generate something unexpected based on this basic method. Therefore, some new mechanism of creating unexpected phenomena should be introduced. To realize this, we have introduced the usage of dry ice which is described in the next subsection.

5.2. Usage of Dry Ice as Obstacles in Fluid Pathways

Based on fluid dynamics study, we have learned that the existence of obstacles in the pathway of fluid motion is the key to generate beautiful and mysterious forms. At the same time, we have learned that such obstacles should not be fixed ones. Fixed obstacles give fixed effects to the behaviors of fluid and this process is not effective in generating something unexpected. Therefore, such obstacles should move around. Also, it is preferable that the moving patterns of such obstacles are unstable or even unexpected. In addition, it is preferable that forms of the obstacles unexpectedly. We carried out various kinds of experiments to determine such obstacles and finally found that the use of dry ice is very effective as obstacles interacting with injected paints.

Dry ice is the solid form of carbon dioxide. It is used primarily as a cooling agent. Its advantages include a lower temperature than that of water ice and not leaving residue. At the same time, dry ice has been frequently used as a material to create mysterious stage effects, as it creates huge amounts of fog when it is added to water. People have been focusing on the effect of fog generation when they use dry ice. However, we have focused on the early process of fog generation. When dry ice is put into water, based on the temperature difference between water and dry ice, rapid vaporization of dry ice occurs. Many small bubbles, each of which contains carbon dioxide fog, are generated as the result of vaporization and these small bubbles rise from dry ice from bottom to water surface and finally create fog. Watching this process by using a high-speed camera, we have found that such bubbles have interesting forms, with each bubble having a different form. Additionally, during the process of a bubble rising up to the water surface, the bubble always changes its form. This phenomenon gives us the impression that each bubble is a kind of living creature (Figure 13). Then, we had an idea that the combination of these bubbles and injected paints described in the previous subsection would be ideal to generate a new type of phenomenon based on fluid dynamics. Therefore, we have adopted the usage of dry ice as an obstacle material in the pathway of injected fluid.

Figure 13. Bubbles generated by dry ice.

5.3. Genesis: Created Artwork Based on the Interaction between Fluid and Dry Ice

We tried to integrate two methods described in Sections 5.1 and 5.2. Firstly, we put a small block of dry ice into water, letting it generate bubbles with carbon dioxide fog inside. Then a combination of several color paints were injected into the water. Without dry ice-based bubbles, the injected color paints quickly diffused, making the water appear as if colored water. There are two ways to avoid this somewhat uninteresting event. As described in Section 5.1, one way that we have found used agar to increase water viscosity to some extent. Based on several experiences, we found that there is a certain range of viscosity in which the diffusion of color paints into water occurs slowly. Then, under such a condition, we added dry ice into water. As described in Section 5.2, various dry ice bubbles were generated as the result of the vaporization of dry ice, where forms of dry ice bubbles are different to each other and even their forms changed continuously while rising up in water to the water surface. Then, the injected color paints interacted with these various bubbles and created various complex forms as shown in Figure 14. These created forms were beyond the forms we often see as the result of scientific visualization and look very artistic.

Figure 14. An example of the interaction between bubbles created by dry ice and injected color paints.

The created artwork called "Genesis," was exhibited in 12 cities including New York, London, and Paris, and one of the authors, Naoko Tosa, did her world tour as Japan's Cultural Envoy in 2016. One such exhibition carried out in Singapore is shown in Figure 15.

Figure 15. Exhibition of "Genesis" at Ikkan Gallery in Singapore in 2017.

6. Discussion and Conclusions

In this paper, we proposed new types of media art creation methods and described their details. We have been interested in the art creation process based on the extraction of hidden beauty in nature using technologies. We have noticed and believe that the extraction of hidden beauty is the basis of

Japanese beauty, as one of the authors, Naoko Tosa, received many comments/opinions from people all over the world including art curators and art critics saying that they feel there is Japanese beauty in the artworks developed by her and her team. In Section 2, we discussed this issue by showing several representative Japanese artworks and reached the conclusion that, in Japanese art history, the extraction of hidden beauty in nature and the expression of it as artworks has been the main stream.

We have been interested in fluid behaviors as a natural phenomenon, and have been trying to create artworks by recording fluid behaviors using a high-speed camera. As this area in science is called "fluid dynamics," in Section 3, the explanation of fluid dynamics and also the relationship between fluid dynamics and art were described in detail.

In Sections 4 and 5, two art creation methods based on fluid dynamics were described including their concepts, the methodologies and examples of created artworks. In Section 4, one method of art creation based on fluid dynamics was described. The method is based on the combination of color paints as fluid and sound vibration. We have found that jumping-up color paints, vibrated by sound and shot by a high-speed camera, make beautiful forms and we created an artwork called "Sound of Ikebana" based on the methodology. Both the methodology and the created artwork were described in detail.

In Section 5, another art creation method developed by us, which is based on the combination of two processes, was described. The first method is the effect achieved by injecting color paints into water of various viscosities. The second method is to use dry ice as obstacles that interact with the flow of the injected paints and, based on this, create surprising and mysterious liquid forms. By combining these two methods in a relevant way and also by using a high-speed camera to record and visualize the generated phenomena, we can create beautiful, noble, and inspiring forms.

We think that there are two ways of creating artworks using fluid. One is a purely scientific process and its aim is to find out beauty in the process of liquid motion as a physical phenomenon. In this case, although the created forms look beautiful, the forms do not look artistic, because there is little unexpectedness in the created forms. Another is the usage of liquid as a basic material for creating artwork. Here, the basic process of art creation is controlled by an artist. However, in the final art making process, such as paint throwing and dropping, a randomness, that is one of basic natures of physical phenomena, is included to add value to the created artwork. We have found that our proposed methods situate somewhere between these two different processes. Its feature is that, on one hand, it can keep pure beauty in physical phenomena. On the other hand, our method removes the feeling associated with too scientific phenomena. Therefore, we believe that we have succeeded in creating new type of artworks.

Of course we understand that it is not adequate to connect fluid dynamics directly to artworks including Japanese beauty. We do not want to claim that fluid dynamics-based artworks are the most adequate to express Japanese beauty. At this stage, what we want to claim is the following. We have developed several methods to create beautiful forms based on fluid dynamics. As the creation process is closely related to natural/physical phenomenon and also as Japanese sensitivity has been closely related to beauty included in natural phenomenon, it was easy for one of the authors, a Japanese artist, to include her sensitivity and aesthetics into various art creation processes such as color selection, parameter selection for sound vibration, editing of obtained video and so on. We will further pursue what is Japanese beauty and what is the essential art creation process to include Japanese beauty.

Artificial intelligence (AI) technology is progressing and there are various trials to create artworks using AI (du Sautoy 2019). So far, most of the trials are based on learning existing paintings using deep learning method and creating new paintings that are somewhat similar to the existing paintings. Such paintings are sometimes criticized as they are not new creations. On the other hand, as our art creation methodology is based on physical/natural phenomena, the combination of our methodology and AI would have a chance to create new types of art. In other words, we may have a new type of AI artists in the 21st century.

Author Contributions: N.T.—contributed to the creation of artistic concept and also the direction of the art creation. Y.P.—supported N.T. for the creation of "Sound of Ikebana." Q.Y.—supported N.T. for the creation of "Genesis." R.N.—mainly contributed to the direction of the whole project. Also he gave grounding of fluid dynamics based art.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

Feng Chen, Tomoji Sawada, and Naoko Tosa. 2013. Sound Based Scenery Painting. Paper presented at the 2013 International Conference on Culture and Computing, Kyoto, Japan, September 16–18.

Pang, Yunian, and Naoko Tosa. 2015. New Approach of Cultural Aesthetic Using Sound and Image. Paper presented at the 2015 International Conference on Culture and Computing, Kyoto, Japan, October 17–19.

Yunian Pang, Lian Zhao, Ryohei Nakatsu, and Naoko Tosa. 2017. A Study on Variable Control of Sound Vibration Form (SVF) for Media Art Creation. Paper presented at the 2015 Conference on Culture and Computing, Kyoto, Japan, October 17–19.

Naoko Tosa, Ryohei Nakatsu, Pang Yunian, and Kosuke Ogata. 2015. Projection Mapping Celebrating RIMPA 400th Anniversary. Paper presented at the 2015 Conference on Culture and Computing, Kyoto, Japan, October 17–19.

Naoko Tosa, Pang Yunian, Liang Zhao, and Ryohei Nakatsu. 2017. Genesis: New Media Art Created as a Visualization of Fluid Dynamics. Paper presented at the Entertainment Computing—ICEC2017, Tsukuba City, Japan, September 18–21; pp. 3–13.

Bernard, Peter S. 2015. *Fluid Dynamics*. Cambridge: Cambridge University Press.

Clark, Timothy. 2017. *Hokusai: Beyond the Great Wave*. London: Thames and Hudson.

Fleck, Robert, Jason Kaufman, and Gottfield Boehm. 2008. *Action Painting*. Berlin/Stuttgart: Hatje Cantz.

Fujiura, Masayuki. 2018. *KORIN: Japanese Aesthetics and Design*. West Islip: Pilkington Foundation Publications.

Krechetnikov, Rouslan, and George M. Homsy. 2009. Crown-forming Instability Phenomena in the Drop Splash Problem. *Journal of Colloid and Interface Science* 331: 555–59. [CrossRef] [PubMed]

Landau, Ellen G. 2010. *Jackson Pollock*. New York: Harry N. Abrams.

Munson, Bruce R., Alric P. Rothmayer, Theodore H. Okiishi, and Wade W. Huebsch. 2012. *Fundamentals of Fluid Mechanics*. Hoboken: Wiley.

du Sautoy, Marcus. 2019. *The Creativity Code: Art and Innovation in the Age of AI*. Cambridge: Belknap Press.

Smits, Alexander. J, and Lim Tee Tai, eds. 2012. *Flow Visualization: Techniques and Examples*. London: Imperial College Press.

Taut, Bruno. 1958. *Houses and People of Japan*. Tokyo: Sanseido Co. Ltd.

Taut, Bruno. 1962. *Refinding of Japanese Beauty*. Tokyo: Iwanami Publisher. (In Japanese)

Thompson, Sarah, and Joan Wright. 2015. *Hokusai*. Boston: MFA Publications.

Wong, Eva. 2011. *Taoism: An Essential Guide*. Boulder: Shambhara.

arts

MDPI

Article

Ideal Mechanization: Exploring the Machine Metaphor through Theory and Performance

Amy LaViers

Mechanical Science and Engineering Department, University of Illinois at Urbana-Champaign, Champaign, IL 61801, USA; alaviers@illinois.edu

Received: 4 January 2019; Accepted: 9 May 2019; Published: 23 May 2019

Abstract: Models of machines, including the increasingly miniaturized, digitally controlled machines of modern computers, inform models of human and animal behavior. What are the impacts of this exchange? This paper builds on theoretical discussion to produce an artistic exploration around this idea. The paper uses known limits on computation, previously proved by Turing, to model the process of mechanization, machines interacting with an environment. This idea was used to inform a live performance that leveraged a theatrical setting emulating an ideal mechanization machine, audience participation with their bodies as well as their personal cell phones, and readings of academic papers, which is also presented. The results of this work is a shared exploration of when human experience fits machine-based metaphors and, when it does not, highlighting distinct strengths and questioning how to measure the capacities of natural and artificial behavior.

Keywords: interactive performance; robotics; human motion; Turing Machines

1. Introduction

Computers and robots are increasingly attributed with behaviors of natural systems. The fields of machine learning and artificial intelligence often lose their synthetic modifiers: "machine learning" becomes "learning", "robotic arm" becomes "arm", and so on. From some points of view, such comparisons may be appropriate: if a computer beats a human player in chess, we may say that the computer played the game of chess successfully. However, for those outside of engineering disciplines or without knowledge, of the details of the system, it may be easy to then conclude that the computer processing used was *the same or even superior to* the human player. Moreover, in the broader scientific community, technical models become representation for analogy to biological function.

For example, the bio-inspired structure of the networks in AlphaGo that beat human Go players suggests a direct comparison of machine similarity and superiority to humans (Silver et al. 2016) and has been discussed in popular media as just exactly that (Cheng 2016; Metz 2016) without the same modifiers and subtlety used in the technical report (LaViers 2017). However, as technical readers understand, the system cannot imitate *most* features of human activity. Moreover, in controlled factory settings, robots can often outperform humans, offering greater precision, higher-payloads, and consistency in repeatable tasks (Kinova Robotics 2017; Rethink Robotics 2018; Universal Robots 2016). That is, from the point of view of Newton and mechanics, robots are superior mechanical devices—yet they cannot replicate many features of human movement. What quantitative models can explain this? One answer may come from Turing (1936) whose work has shown that machines have a limited, though infinite, set of behaviors available to them.

Increasingly, advancements in technology are used as explanatory models for biological function (Turner 2013). Neural networks have been proposed as models for brain activity (Churchland et al. 2016). Minimal coding schemes which drive data compression have also been used to model neuron communication (Spratling 2017). Logic gates have been used to describe cell function (Zah et al. 2016). Distributed control algorithms inspired from nature also have been used as explanatory models for flocking behavior (Nabet et al. 2009). Optimality has been proposed as a model for motion generation with respect to minimizing jerk along a movement trajectory (Flash and Hogan 1985) and where optimal control may provide a "unified theoretical framework" for sensorimotor systems (Todorov and Jordan 2002). These examples illustrate how our understanding of machines and mathematics forms a basis for understanding the natural world.

Imitating the movement of biological organisms, a subfield of biomimicry (Bar-Cohen 2005), using similar, continuous metrics for success, has been a topic in animation (Reynolds 1999) and robotics (Egerstedt et al. 2005; Powell et al. 2012). However despite an explosion of computing power, including cloud-based devices, robots do not thrive in dynamic environments nor can they recreate the social behaviors of humans, even under teleoperation (Yanco et al. 2015). Even for relatively simple organisms, such as fish, developing robotic counterparts has proven challenging (Marras and Porfiri 2012) with initial success in creating robotic counterparts that school with real fish (Landgraf et al. 2016; Swain et al. 2012). While these robotics fish are some of most successful robotic confederates, even simple machines such as Braitenberg's (1986) vehicles have been shown to be *expressive* to human viewers, indicating that perfect imitation is not needed for meaning-making. One of the best studied organisms, *C. elegans*, have had their 302-neuron network mapped out; moreover, a linear behavioral model describes much of the behavior they exhibit in laboratory agar plates (Stephens et al. 2010). In human tasks, movement quantification is difficult and limited to specific tasks, e.g., drawing (Del Vecchio et al. 2003).

The work of Turing (1936) and Elgin (2010) are at direct odds in their treatment of human behavior. Elgin (2010) posited that "If non-propositional items can advance understanding, then the thesis that dance advances understanding has some chance of being correct". Computers, however, rely on propositional structure to complete computation, and Turing's, and subsequent, comparisons of these models to human experience have been challenged by theorists like Godel (Gödel 1972; Shagrir 2006). Shannon (1938) showed how Boolean Logic can be implemented in circuits; similarly, modern robotics research frequently leverages Linear Temporal Logic (LTL) to produce robot behavior (Belta et al. 2007). Likewise, the structure of Turing's automatic machines is limited to systems with distinct finite states governing system behavior. This is one abstraction of many that helps us understand what computation is and what it is not. Understanding the notion of *subjective experience* is ongoing work by biologists and philosophers that is influenced by the structure and terminology of control algorithms for robots (Godfrey-Smith 2016).

Elgin (2010) wrote that dance advances understanding through variable motion profiles that exemplify ideas, both literal and abstract; moreover, the innovation of choreographers is to create new behaviors. Therefore, dance theory is a place to look for understanding about how information is carried in the motion of a moving body to a human viewer. Moreover, dance seems to imply that variation and complexity of motion profile may be important components of the biological function of movement. Indeed, many species besides humans are known to cue through complex "dances" (Soma and Iwama 2017). Thus, a way to count the number of behaviors accessible to natural systems may be an important measure of their performance, which is distinct from the mechanical measures previously listed, where the performance of robots has exceeded human abilities in the range of torque and velocity and in the precision and repeatability of movement.

A comparison by Changizi (2003) of observational studies of the complexity of behaviors exhibited by an organism and number of muscle types discovered in that organism shows a positive correlation between encephalization quotient and number of behaviors exhibited. In particular, this work plots the number of exhibited behaviors, E, against the number of muscle types, C, and finds a power law relationship between the two, i.e., $E \approx C^3$. Changizi compared this to English language where words and exhibited sentences have a power law relationship with a factor of 5; he posited that the power law factor of 3 found in his study may be higher for more complex animals, such as humans. This work shows the non-Turing behavior of animals and is related to the quantified relationships that other types of studies have been able to create, e.g., relationship between size and speed of organism (McMahon and Bonner 1983). This work suggests an evolutionary advantage to behavioral complexity—or, that expressive behavior serves a functional purpose.

The Laban/Bartenieff Movement System outlines a duality between function and expression in motion (Studd and Cox 2013). For example, consider an agent moving angrily through a living room, thrashing its arms wildly and taking heavy, sure-footed steps. On the other hand, an agent moving through a jungle may need to exhibit the same motion, but it would not be perceived as angry in this new context. The concept of *expression* is foregrounded in examples such as the agent moving angrily through a living room. Its dual, *function*, is foregrounded for the same motion profile in the jungle. However, in both examples, the opposite ideal is still occurring: in the living room, the agent is succeeding at its task of informing a counterpart; in the jungle, the agent is simultaneously communicating capability in the jungle setting to a human viewer. Thus, functional models of motion generation, where minimum energy, or maximum speed, produce motion behaviors, break down when context and communication are considered. This is analogous to function and form as abstract ideas that reinforce one another in product design where product designers have also posited the idea that physical objects communicate with human users (Crilly et al. 2004) and points to the idea that roboticists need to similarly begin factoring in the human experience of systems when designing their movement (LaViers 2019).

Artistic exploration with robotic systems (Cuan et al. 2018; LaViers et al. 2014, 2018), including cell phones (Toenjes et al. 2016) and Turing's work (Gow et al. 2014), in theatrical settings, alongside professional dancers, inform the point-of-view presented in this paper. When dancing with robots, dancers report a lack of variability in the motion of these systems; correspondingly, choreographers have found the platforms to be frustratingly limited in their expressive capacity. The *functionally efficient* approach used by roboticists to design robot movement may be part of this experience. In contrast, dancers care about *expressively rich* movement, working to create many options for movement behaviors in their bodies through extensive training. Across many classes they work to increase their range of motion, develop ability to coordinate multiple actions simultaneously and in sequence, and hone their execution of different textural qualities. By broadening and maintaining their movement options, they become more versatile instruments. Is there a limit on the options they can pursue? What is it?

In robotic systems, changes to hardware and/or software can expand the capacity of a given system to exemplify ideas. For example, efforts to bridge human notation of movement to robotic motion specification are covered in (Laumond and Abe 2016), which covers algorithmic development for humanoids based on Labanotation (Salaris et al. 2016) and where Benesh notation experts explicate the challenge, of recording and translating human motion (Mirzabekiantz 2016) and dancers lament the nuance lost in motion notation, suggesting "impossibility" (Challet-Haas 2016). On the hardware side, while a modular snake robot, e.g., (Wright et al. 2007), may not be anthropormorphic, its variable gaits provide the ability to indicate a change in internal state, which is vital for expression and communication in a theatrical context. However, known limits on machine behavior (Turing 1936) suggests we can imagine behaviors not implementable on machines. Are these "imagined" behaviors possible in natural systems? Can human bodies express more ideas than machine bodies or do limits, such as the one proved by Turing, hold?

Section 2 outlines an abstraction for mechanical motion by leveraging the Turing Machine formulation of computation. Section 3 provides a development of artistic themes and compositional questions inspired from this formulation that are put into action in a live dance performance described in Section 4. The goal of this performance is to provide embodied experiences to audience members, giving them access to an academic debate in a short amount of time. Concluding remarks and future directions for this work are given in Section 5. The contribution of this paper is not in theoretical computer science or the philosophy of dance; these are two fields from which this work is building and applying existing ideas. The contribution of this paper is presenting work from these fields—as well as biomimetics and robotics—alongside one another in a performative context. The paper uses this existing academic discourse to motivate the creation of a particular performance. This performance is only one of a myriad of creations that could happen in response to the body of literature presented. It is the aim of the paper to encourage other artistic exploration in this vein, and the paper is written for an interdisciplinary audience in order to facilitate this possibility.

2. Mechanization: An Ideal, Discrete Process with Limits

Discussion in the previous section reviews the literature on the movement of human and machine bodies. This section introduces an abstraction for systematized movement that is the inspiration for the performance described in the following two sections. The discussion in this section more explicitly outlines how movement is inherently part of computation, using a model of computation to outline an ideal process for mechanization. This discussion uses an established abstract model of computation for this exploration (a Turing Machine) and does not exhaustively review every aspect of this large field. However, it is important to note that Turing Machines are not real computers, and, thus, the model for mechanization proposed here does not describe real robots. Instead, Turing Machines are one abstract model of computation that here provides one way to *count the number of behaviors possible in a class of artificial systems.*

In (Turing 1936), Turing outlined an *a-machine*, a machine with a finitely complex mechanical head along an infinite tape where symbols can be stored. The abstract machine requires the current configuration of the head, a list of basic instructions that tell the machine what to do in that configuration, and the complete configuration (state) of the entire system.

The components of an a-machine are given by the following list, loosely following (Immerman 2016):

- a finite set of n machine states $Q = \{q_1, ..., q_n\}$;
- a finite set of m symbols $\Sigma = \{\sigma_1, ..., \sigma_m\}$, e.g., $\Sigma = \{0, 1, \epsilon\}$, where the result of machine computation, a computable number, is recorded in binary with a blank option, ϵ;
- an infinite "tape" where these symbols are recorded, comprised of cells $c_1, c_2, c_3, ...$, which is often pre-populated with a finite sequence of symbols that generate programmed behavior when the machine is in operation;
- current position along the tape, cell c_h, where $h \geq 1$; and
- a transition function $\delta : Q \times \Sigma \mapsto Q \times \Sigma \times \{-1, 0, 1\}$, which determines at a given state q_i for a given scanned symbol σ_i in c_h how to update the position of the head h, i.e., it moves left, stays in place, or moves right.

Innovations such as stored program architecture and clocking have been important to developing real, modern computers but do not change a central premise of Turing's paper. Specifically, he defines the class of numbers that can be computed by a properly formed (circle-free) machine to be enumerable (infinite but countable). That is, there are numbers that we might imagine that cannot be computed (e.g., irrational numbers without algebraic formulas for computation). This is seen through application of Cantor's diagonal process, which shows that the correspondence between natural numbers and computable numbers is one-to-one (or that the set of real numbers and computable numbers is not one-to-one) due to an inescapable recursive loop that traps an a-machine checking its own description number (this is known as the Halting Problem) (Petzold 2008). That is, we can imagine numbers that a-machines cannot compute, which means we can imagine behaviors that a-machines cannot perform. Other theoretical formulations of computation, such as Wegner's (1997) work with the abstraction of interactions, which does not change the set of computable numbers (Prasse and Rittgen 1998), are not considered in the creation of *A Machine*, where the exploration is centered around the cardinality of distinct behaviors that are enumerated by this set. New architectures that improve the swath of computable numbers, such as Siegelmann's (1995, 2013) Super-Turing formulation, and her extensions in modeling natural systems with analog devices, highlight how discrete computing devices, such as modern cell phones, where Turing's definition of a computable set of numbers is a fundamental limit, cannot capture the behavior of many natural, chaotic systems.

To establish a way of thinking about machine movement (mechanization), invert the a-machine, establishing an æ-machine. In this abstraction, the idea of a physical workspace replaces Turing's idea of "scratch paper" where computations could be worked out. An ideal mechanization machine will be able to complete tasks in the physical environment using extra workspace as needed. Here, the motion of the Turing Machine is foregrounded: its motion, which occurs in discrete units that may be called *motion primitives*, the behavior of interest. We are now focusing on the motion, right to left, of this abstraction, and we want to know: Can this device produce any arbitrary pattern of right to left movement? This is a discretized model that may be analogous to how a human or robotic artisan will use a workshop table during their work, placing part of a product off to the side while working on another element, using this tool or that to complete various steps, and increasing the size of their workshop as needed. Similarly, the tape need not be one dimensional; this machine can perform actions inside its workspace, layering simple actions in sequence to produce desired effect on the environment. Thus, we can define the components of an æ-machine as follows:

- a finite set of n' states $Q' = \{q'_1, ..., q'_n\}$;
- a finite set of m' actions, or *motion primitives* $\Sigma' = \{\sigma'_1, ..., \sigma'_m\}$, e.g., $\Sigma' = \{flexion, extension, \epsilon'\}$, where the result of machine mechanization is executed as either moving, moving in the opposite direction, or doing nothing, ϵ';
- an infinite "workspace" where these actions are executed, comprised of cells $c'_1, c'_2, c'_3, ...$, which may be pre-populated with a finite set of primitives (or tools) that generate programmed behavior when the machine is in operation;
- current position in the workspace, cell $c'_{h'}$, where $h' \geq 1$; and
- a transition function $\delta' : Q' \times \Sigma' \mapsto Q' \times \Sigma' \times \{-1, 0, 1\}$, which determines at a given state q'_i for a given motion primitive σ'_i in $c'_{h'}$ how to update the position in the workspace h, which might be envisioned as a one-, two-, or three-dimensional "tape".

What was a computation process (a sequence of logical symbols manipulated in an abstract, memory-like space) is now a mechanization process: a sequence of motion primitives executed in a discretized environment. This sequence can likewise be represented as a number—one from Turing's set of computable numbers—showing the infinite, but enumerable, action sequences possible to be executed by æ-machines. Thus, æ-machines (an idealization of robots) have the same fundamentally limited capacity as a-machines (an idealization of computers). That is, *they cannot produce all the behaviors we might arbitrarily design*. This means there are sequences of machine motion that we might imagine that are not mechanizable—those which correspond to a number in the set of uncomputable numbers, which does not include the set of real numbers. Similar to how Turing established subroutines to build his Universal Machine, we can create more complex behaviors of motion primitives that occur in sequence, acting as a *tool* in the workspace. In practice, that tool could be "software" (a stereotyped, preprogrammed gesture or action) or "hardware" (an end effector attachment as a CNC machine selects distinct cutting tools).

3. Translating Machine-Based Metaphor to Elements of Live Performance

Thus, an abstract theory in which the behavior of both computers and robots is described by the set of computable numbers has been presented. This ideal holds regardless of the specific structure of an implemented system. In computers, more transistors do not change the fundamental capacity of behavior (the set of computable numbers), and, likewise, changing the mechanical complexity of a robot may not change the fundamental capacity of behavior. The Turing abstraction is not a literal definition of how to build a computer, and it is not meant as such here. Therefore, the theatrical goal is not to set up a literal computer or a literal robot but for audience members to feel the texture of these ideal models. In doing so, the piece will explore the very real ways that humans out-perform modern day machines and vice versa.

This develops questions that are explored through artistic practice and performance: Is the machine metaphor apt for human performance? Are humans limited by the same idealized abstraction as the one Turing outlines for machines? Does non-propositional logic guide human understanding and experience? This paper does not provide a quantitative answer to these questions, but instead poses them as motivation and presents an exploration of them through art and embodied experience. Modern machines, which are in one specific, definite state at a time and take advantage of computational resources that are not spatially co-located have a form that is very unlike our own. Thus, the piece will include themes of calling from physical spaces that are not co-located with the performance, accumulating complexity and growth in our representations, and in binary logic, which underpins modern machines.

3.1. Intended Audience

It is anticipated that each audience member would bring with them a powerful, mobile discrete computing device in the form of their personal cell phone. Increasingly, we have antagonistic relationships with these devices (Jenaro et al. 2007); thus, a goal for this audience is to reframe and deepen their associations with these tools, which can be a theatrical proxy for thinking about computation more broadly, but is also a point of access to personal feelings of attachment, anxiety, and fear (Howe 2017; Mokyr et al. 2015) that many modern audience members bring with them to the start of the show.

Moreover, popular descriptions of machines frequently emphasize their human-like capabilities (e.g., Baldwin 2019; Berboucha 2018; Madrigal 2018; Mae et al. 2018). These descriptions contribute to real anxiety about the future for the public many of whom have little experience programming, an experience which affords a different perspective on how machines work to technically trained members of society. It has been estimated that in 2018 there were 23 million programmers worldwide (Garvin 2018), while 4.57 billion people were predicted to own a cell phone that same year (eMarketer 2015). Thus, the performance is motivated by the fact that as many as over half of the people in the world carry a type of re-programmable machine that they have no experience in programming. This piece is accessible in the sense that audience members do not need to pass a math test or compile a computer script to participate.

3.2. Rational for Selected Elements

Development of a dance performance began with the image of a simple system moving through an idealized, discretized workspace in which new tools, developed through compounded hardware units and nested software routines, are collected. More simply, the image can be thought of as a robot walking out into the world picking up tools, ever-increasing its own instantaneous complexity through new additions to the system. Likewise, humans are constantly developing new tools to increase our abilities. Often philosophy is locked in hard to access academic papers (specifically of interest in here is the philosophy of meaning in dance and how it may be generated through non-propositional structures (Elgin 2010) versus philosophy of decidability (Turing 1936), which relies on propositional structures), and one goal of the performance was to expose these ideas to a broad audience for examination. Three main themes were distilled as guidelines for creation of a piece entitled *A Machine*, a pun on Turing's term *a-machine*. The goal with these themes is to evoke the dark, rigidly structured internal world of computers, made visible and experiential through embodiment, transporting audiences to the quirky, unnatural innards of machines.

(1) *Workspace/Workshop Setting.* The setting of the piece would be both abstract and concrete: a representation of an idealized, discrete workspace combined with an artisan's workshop. Tape segmenting the area of a dance floor, forming a substrate onto which continuous movements may be seen as discrete *motion primitives* and an apron as a costume, referencing an article common to many

craftspeople, are two ways the performance, implemented this idea. The physical limits of modern machines and humans would be contrasted by bringing extant, everyday machines into the setting in a formal way, bridging the intimate relationship humans have with their machines, e.g., personal cell phones which were expected to be on the person of audience members attending the show. Movement composition explored the idea of finite, bodily limits and pushed to show the multiplicity of human bodily forms. The use of repetition and compositional structures that implied invisible rules were used, material which reflects an *embodied experience* of working with machines, which often leverage repetition in automated tasks and require formal instructions that *feel*, in practice, unnatural.

(2) *Rigidity of Logic-Based Statements.* The piece would explore how forced true/false statements can break down in characterizing human thinking and experience. Using statements that are hard to answer with a single bit of information, e.g., "Yes" or "No", highlights this limit of computers: while increased complexity can represent levels of gradation and many categories, at their heart "kind of" is not native to modern-day machine function. On the other hand, describing the human experience involves the notion of *subjectivity* where humans frequently exhibit indifference and multiplicity of thinking. This echoes Godel's ideas about modeling human thought with finite, discrete states. One way that this distinction can be *felt* is in the process of programming a computer, but this is a rarefied experience. As discussed in the previous section, most people alive in the world today have not written a computer program; thus, the performance would leverage theatrical techniques to provide an accessible way to *experience something such as the distinction between imparting behavioral instructions to a machine versus to a human.* Asking audience members to answer ridiculous statements with "true" or "false" similarly forces the experience of fitting into an uncomfortably finite structure, which may not be native to biology.

(3) *Segmented versus Continuous Experience.* Finally, the piece would explore rhythms and concepts native to machines versus humans. Using electronic noises throughout the performance is one way this texture was created in the soundscape. Readings from Turing's (1936) work highlight how series of numbers and letters, which are meaningful to computers and in mathematical proof, sound manic when spoken aloud and moved. The cellular segmentation of the space would be used to create a breakdown in natural gait and create contained movement phrases. Successfully stepping over tape is a discrete phenomenon, while the experience of moving a foot is continuous. This is reminiscent of a possibly familiar activity of walking without stepping on cracks in the sidewalk, but also can serve as an embodied version of the mind-bending process of creating discrete criteria for sorting numbers into arrays (for example).

4. Performance of *A Machine*

The resulting piece, *A Machine*, was performed [details redacted for review]. The live performance allowed for a physical exploration of the theoretical ideas discussed here, a chance for reflection and feedback from live human bodies, and an outreach and sharing activity. The performance was not a formal research study, but future instantiations could use this initial showing to construct response collection under differing conditions, such as demographic information. Each section of the performance is discussed in this section. Figures 1–6 present images from the performance of *A Machine* on [date redacted] throughout this section complement this discussion.

4.1. Show Advertisement

The show was advertised with the following description, which was designed to make audience members aware of the nature of the show, and possibly arrive with heightened awareness and anticipation about the type of participation that would be required of them.

> Can machines exhibit the same behaviors as humans? In what ways is your phone superior to you? How can you outperform a robot? Can you live without your tools? Are you a machine? This showing is part of an in-progress academic paper that requires embodied

inquiry. Come be a part of research on 19 December 2018 in Dance Rehearsal Krannert (DRK) in the Krannert Center for the Performing Arts at 5 p.m. Seating is limited and participation is required.

4.2. Entry and Pre-Show: Personal Machine Collection and Seating

The performance space was demarked with long strips of thick grey gaffers tape, arranged in an irregular grid. The grid points were densely packed near one end and sparse at the other. Upon 13 intersections of tape, 13 square, numbered cushions of green foam were placed. The numbering system used was base 16, or hexademical (such that 10–13 were written as "A", "B", "C", and "D"). This set up is shown in Figure 1. This choice references the numbering systems often used in assembly languages where commands correspond to directly to transistor-based hardware; moreover, the unexpected choice served to cause audience members to try and "figure out the system" even before the piece began.

Upon arriving to the performance, audience members were presented with two seating options. Either they could sit in a section of chairs behind the performance space or on the floor on numbered cushions inside the space for a participatory experience. Participants were offered these seats on a first-come, first-served basis. Several audience members did not want to sign the photo release required for this or surrender their personal property for the duration of the show. These audience members (not pictured in this paper) were seated in rows of chairs outside of the performance area.

Those who elected to participate surrendered their personal cell phones, providing their phone numbers and turning the ringers on their phone *on* and *up* as well, and filled out a photo and video release. Each of these audience members (13 in total; a number that was based on the setup of the room) were assigned a number and headed out into the space to their assigned position, corresponding to a numbered cushion (shown in Figure 1). Meanwhile, their cellphones were wrapped in correspondingly numbered foam, secured with two rubber bands, and placed in a basket. The program note (see Appendix A) was displayed on a projector for audience members to read as they entered the space (shown in Figure 1). The bright light of this mostly cool-white projection contrasted the shadowy, warmly lit performance space. Music, entitled "Black Energy" and "In the Beginning", from the album *Planetarium* composed by Sufjan Stevens, Bryce Dessner, Nico Muhly, and James Mcallister played during this time.

Figure 1. Seating audience members before the show. Low lighting and a sparse "environment" for participating audience members to sit in creates a stage that is a studio-like setting that feels lifted from the pages of a geometry textbook: natural wood grain contrasts thick industrial grey tape laid in a linear mesh; warm theatrical lights contrast cool white from a projector; and the voices of arriving audience members contrast electronic ambient noises. Photos by Natalie Fiol.

4.3. Part 1: Machine Metaphor and Workspace Setup

Once all audience members were seated, the performance began with a video of the performer writing numbers 1–13 in hexadecimal while reading excerpts of Turing's paper, outlining the properties of his "a-machine", now known as a Turing Machine (Turing 1936). These excerpts highlighted the finite properties of machines, Turing's proof that leverages a human computer writing symbols on a linear sheet of paper, and several moments where the reading of his Description Numbers created long strings of numerals and letters that provided the live performer a strange, monotone rhythm with which to move. The motion of writing the numbers was regular, informed by the predictable shape of each symbol; however, it also grated against the descriptions of the automatic machines described by Turing as the performer made irregular choices in filling in some sections of the symbols more than once, painting with a black marker on rough foam.

After the video played for several moments, the performer entered the space, stepping only into the open spaces of the grid, carrying each individually wrapped phone, and placing it in a location on the grid. The performer wore an apron and rubber bands on both wrists, placing her in a workshop environment where the rubber bands were a tool in her workbench. As each phone was unwrapped, she reinforced this image by placing the removed rubber bands onto the cadre of existing bands on each wrist. This activity has a natural, discrete propositional notion associated with it, e.g., the rubber band is off or on the wrist, and the ritual served to diversify the motion tasks, or, loosely, *primitives*, seen in this section of the piece.

Walking through the densely packed section of the grid, where human audience members were also placed with greater density, provided a physical challenge, for the performer that formed the movement composition in this section of the piece (shown in Figure 2). This composition reflects the idea that the discretization of our environment model informs possible machine behavior, in this case, the movement primitives of stepping between each grid cell. Unwrapping each phone added complexity to the workspace, providing sophisticated computers connected to network servers, at the performer's disposal and extending the workspace beyond the visible room. Moreover, the labeled numbers on each phone provided participating audience members the chance to locate where their own phone was placed in the space, giving each audience member a second point of spatial awareness—where their own personal data were being held.

Figure 2. The performer ceremoniously laying out each audience member's cell phone into the segmented space during reading of Turing's excerpts. Photos by Natalie Fiol.

4.4. Part 2: Edge Tracing and Cell Phone Sounds Solo

Once all phones were out in the space, the video cut to a blank white projection, back-lighting the performer and the audience members within the space. For a moment, the performer stood in silence in one of the larger open grid cells. Slowly, the performer began shifting weight and tracing the edges of her body with other edges of her body. This movement composition began by probing the question "How many shapes can I make in this container?" It continued by expanding the exploration to the edges of the grid cell, asking "How many things can I do in this finite section of space?" Snapshots from this are shown in Figure 3.

During this movement composition, cell phones began ringing, an action that involved sending a command to nearby cell phone towers and distant internet servers. First, three phones (numbered 1–3) encircling the performer, which were all in close sight to their owners, began ringing. The ringtones each phone had was not known prior to the show. A Python script was used to call the phones in sequence, leveraging the web service Twillo and the `TwiML` package. More phones began ringing until, eventually, all phones were called, creating an electronic cannon for the soundscape.

Anecdotally, none of the audience members on [date redacted] answered their phones. This indicates that the impoverished setting, where participating audience members were sitting in a sparse environment with choreographed distances between them, did not encourage normal, full-bodied reactions. Certainly, in a traditional audience setting, audience members respond richly to their phones ringing, and, in this performance, which was advertised to be interactive, these cues could have signaled action for the audience members since their phones were on visibly labeled cushions (and were probably also visibly familiar to each participant based on identifying features such as color). Similar to a Turing Machine, which does not describe the architecture of modern, practical computers, the performance created a lifted, abstract environment where audience members did not react as they typically would to familiar stimuli.

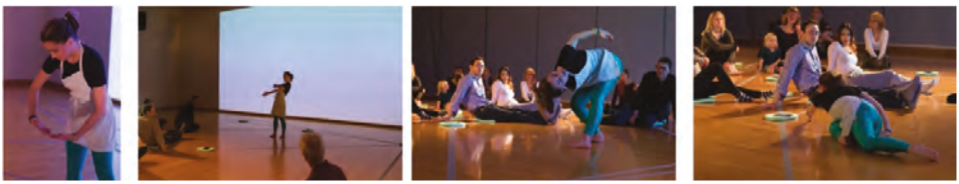


Figure 3. A movement section exploring the limits of the physical body and the segmented space is accompanied by the ringing of cell phones in a canon (one phone breaks silence and then is slowly joined by all 13 phones onstage). The performer stays inside one cell (this is a discrete statement), tracing its edges and finding unusual poses created by trying to move each joint in succession, trying out the Cartesian product of all joint angle ranges. Photos by Natalie Fiol.

4.5. Part 3: Questioning Propositional Logic Statements with "True" or "False"

The next section of the piece was demarked with distinct slide changes cued offstage such that the performer could interact with the audience members sitting in the performance space. On each slide was a phrase or symbol. A partial list of phrases is provided below and in the images in Figure 4.

- I, the performer, am a human.
- I have three arms.
- I believe I have three arms.
- We are all, at least a little, happy.
- It is not raining and I do not believe that it is not raining (Elgin 2010).
- You are answering of your own free will.
- *a black parallelogram*
- You will have a joyful reunion with your phone at the end of the show.
- I don't know the answer.

Figure 4. The performer questioning audience members with propositional statements. Each query takes on a unique tone—and often elicits answers loaded with quality that betray more than the requested "True" or "False" response. For example, "You will have a joyful reunion with your phone at the end of the show" may cause a dry, wry "False" or a sugary, sly "True", betraying the simultaneous desire to be returned to expensive personal property and the antagonistic relationship many have with their distracting portals to the Internet. Photos by Natalie Fiol.

Each of these phrases was displayed on the projected area and then performer would ask audience members "True or False?", effectuated with variable affect—as an urgent question or a playful joke or a cautious query. For slides that had a shape and no words, the performed heightened the approaching motion, catching the eye of the audience member and then creating a pronounced movement phrase before asking the question aloud. Thus, these propositions alternated between clear and concrete versus ambiguous and abstract.

This activity plays with the idea of whether all of human experience and behavior can be formulated in first-order propositional logic statements. It was also, by offloading the phrasing of the questions—some of which were completely non-verbal—to the body of the performer, an exercise in creating questions that don't quite have a clear cut answer as well as pointed statement to the audience about what binary choice, which drives the core of our digital machines today, does not capture. Another question was, "would people stick to this performative structure?" For example, an audience member could refuse to answer—or reply with a response outside of the two options given.

Anecdotally, in this performance the only audience member not to answer either "true" or "false" was a young toddler. Moreover, it was clear that every answer contained more information than the one bit that might be implied by the structure of the exercise. Some people answered only after a long pause or with a twinkle in their eye or an uptick at the end of their response that made their answer seem more like another question than a reply. These quirks communicated information, breaking the forced binary structure into something richer.

4.6. Part 4: What Does Dance Have to Offer?

The final section of the performance featured another projected video with excerpts of an academic paper read aloud. In this section, the performer read excerpts from Elgin's (2010) paper discussing exemplification in dance and began destroying the clearly written set of numbers from the previous section, creating abstract lines with varied movement qualities and rendering some symbols unreadable. The reading of the excerpt began "What, then, is dance up to? My thesis is that dance conveys understanding." and continued with Elgin's discussion of propositional ideas and the utility of dance.

Once this video had been playing for a few seconds, the performer re-entered and began walking laps of the performance space (Figure 5). This echoed the linear back and forth trips of the first section with a contrasting circularity in pathway. The performer continued stepping only in between the segmented cells, creating tiny quick steps in the densely gridded section and longer more assured strides in the less dense portion of the space.

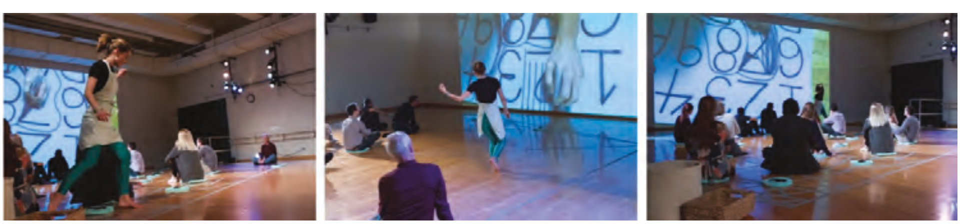


Figure 5. The closing sequence with excerpts of Elgin's writing read alongside a final, more integrated movement sequence. Still stepping to avoid the tape on the ground, the performer increases the speed and connectedness of pathways through space; rather than treating the tape like a constraint, she treats it like a rhythm that pushes the pace of the movement and creates a comfortable stride timing. Photos by Natalie Fiol.

After a few laps the performer began to exhibit a hand gesture with pursed fingers poised behind her head, which caused a focus change. This gesture built some urgency, suggesting the performer was being chased by a lingering thought or bad memory. Eventually the performer ended back in the largest cell of the grid where this hand gesture became circular, encircling the performer's head accompanied by large spinal flexion and extension in a similarly circular manner. After this built, the performer exited the space and the video finished playing, ending with Elgin's description of how dance helps us understand the world through exemplification.

4.7. Aftershow: A Descriptive, Guided Talk Back

Finally, audience members were invited to stay for a discussion. Those who stayed formed a circle for feedback and were prompted to share what they remembered and what they experienced—rather than directive points or valued judgments of the piece. This format, derived from The Fieldwork model and shown in Figure 6, allows for a more interactive discussion of the ideas explored in the piece. Audience members especially remembered the "true/false" section of the piece and a spirited conversation about binary systems, logic, and capacity ensued from this point. Audience members also felt there must be rules governing the experience that they needed to figure out, echoing the experience of computer programming. Some related feelings of anxiety and misunderstanding between themselves and their machines (specifically their phones). Finally, several were curious to learn more about the philosophical constructs of Turing and Elgin regarding the capacity and purpose of movement.

Figure 6. Audience members gathered for a post-show discussion. Photos by Natalie Fiol.

5. Conclusions

The paper has shown a relationship between mechanization and computation, pointing to an abstract model of machine behavior and extending its discussion to machines that interact with their environments. This idealized notion of a robot was then compared to the subjective experience of humans in an artistic medium. The paper has covered how these ideas were translated to a live dance performance. The goal of this work was to probe questions about the differences between humans and machines, contrasting an increasingly common practice of using machine description to describe human function.

Formalisms from computer science apply to robotics not only through explication of how the computers that control robots work; indeed, robots themselves are machines the same as computers. Thus, the ideal model for what a robot is (a machine of finite means that can interact with a segmented environment) presented here translates this idea to the articulated machines under increasing development. It also underlines the question that, if machines have behaviors, movements inside their finite form, which they cannot exhibit, do humans? Extensions of this work may consider how more advanced models of computation apply to human subjective experience. Moreover, many more artistic interpretations of these ideas may be explored, both in iterations and re-stagings of *A Machine* and in other artists' work.

Technical models derived from engineering practice may always be useful guides to dissecting the mysteries of biology. However, it is a plain, experienced and observed fact that we seem to function, qualitatively, very differently form machines. Where machines excel at repeatable execution of tasks, humans excel at variable execution of tasks; where machines excel at rapid, rote computation, humans excel at quick deduction in previously unseen scenarios; and where machines can outperform in tasks of force/torque magnitude, humans outperform machines in communicating complex ideas through motion—as in dance. As we are not yet close to a complete, formal model of human motion, metaphors such as Turing machines—and the variation introduced here—are the only way we can grapple with representations of what humans might be. Thus, exploration through artistic and experiential methods may be important fodder in the process of understanding the differences between man and machine with greater clarity. Such methods are important aspects in the discussion around the future of work, human performance, and machine development in the 21st century.

Author Contributions: A.L. prepared, researched, and wrote this paper. A.L. choreographed and performed *A Machine*.

Funding: This work was partially funded by DARPA award #D16AP00001.

Acknowledgments: The author would like to thank the Dance Department at the University of Illinois at Urbana-Champaign for providing space, Erin Berl and John Toenjes for providing technical support, Reika McNish for videography, and for Natalie Fiol for photography at the showing of *A Machine*.

Conflicts of Interest: The author declares ownership in AE Machines, Inc. and CAAII, LLC.

Appendix A. Program Note

A Machine. Presented by the Robotics, Automation, and Dance (RAD) Lab.

It is difficult to distinguish life, and non-life, on purely mechanistic criteria.

—J. Scott Turner, SUNY-ESF, via email

A Machine asks audiences to push back against the machine-based metaphors we assign to humans. Are we "programmed" to behave the way we do? Is the "mechanism" of our spine malfunctioning when a slipped disc causes lower back pain? Are we replacing ourselves with robot "arms"? Do computers "learn" from data? These metaphors which confuse the action of natural, living systems with artificial, manmade tools fill our vernacular, blurring the line between human and machine. Thus, you have deposited your phone, a machine, to enter this performance. Did this perturb you? Are you anxious? In what ways is your phone superior to you? How can you outperform a robot? Can you live without your tools? Are you a machine?

References

Baldwin, Richard. 2019. White-collar robots are coming for jobs. *The Wall Street Journal*, January 31.

Bar-Cohen, Yoseph. 2005. *Biomimetics: Biologically Inspired Technologies*. Boca Raton: CRC Press.

Belta, C., Antonio Bicchi, Magnus Egerstedt, Emilio Frazzoli, Eric Klavins, and George J. Pappas. 2007. Symbolic planning and control of robot motion [grand challenges of robotics]. *IEEE Robotics & Automation Magazine* 14: 61–70.

Berboucha, Meriame. 2018. Little sophia: A new robot citizen has entered our world. *Forbes*. Available online: https://www.forbes.com/sites/meriameberboucha/2018/11/29/little-sophia-a-new-robot-citizen-has-entered-our-world/#2f67ef503900 (accessed on 4 January 2019).

Braitenberg, Valentino. 1986. *Vehicles: Experiments in Synthetic Psychology*. Cambridge: MIT Press.

Challet-Haas, Jacqueline. 2016. The problem of recording human motion. In *Dance Notations and Robot Motion*. Berlin: Springer, pp. 69–89.

Changizi, Mark A. 2003. Relationship between number of muscles, behavioral repertoire size, and encephalization in mammals. *Journal of Theoretical Biology* 220: 157–68. [CrossRef] [PubMed]

Cheng, Jonathan. 2016. Alphago Software Storms Back to Beat Human In Final Game. *The Wall Street Journal.* Available online: https://www.wsj.com/articles/alphago-software-storms-back-to-beat-human-in-final-game-1458047121 (accessed on 4 January 2019).

Churchland, Patricia S., Terrence J. Sejnowski, and Tomaso A Poggio. 2016. *The Computational Brain*. Cambridge: MIT Press.

Crilly, Nathan, James Moultrie, and P. John Clarkson. 2004. Seeing things: Consumer response to the visual domain in product design. *Design Studies* 25: 547–77. [CrossRef]

Cuan, Catie, Ishaan Pakrasi, and Amy LaViers. 2018. Time to compile. In Proceedings of the 5th International Conference on Movement and Computing, Genoa, Italy, June 28–60. New York: ACM, p. 53.

Del Vecchio, Domitilla, Richard M. Murray, and Pietro Perona. 2003. Decomposition of human motion into dynamics-based primitives with application to drawing tasks. *Automatica* 39: 2085–98. [CrossRef]

Egerstedt, Magnus, Tucker Balch, Frank Dellaert, Florent Delmotte, and Zis Khan. 2005. What are the ants doing? vision-based tracking and reconstruction of control programs. In Proceedings of the IEEE International Conference on Robotics and Automation (ICRA 2005), Barcelona, Spain, April 18–22; pp. 18–22.

Elgin, Catherine. 2010. Exemplification et la danse. In *Philosophie de la Danse*. Rennes: Presses Universitaires de Rennes, pp. 81–98.

eMarketer. 2015. *Number of Mobile Phone Users Worldwide from 2015 to 2020 (in Billions)*. Technical Report. Hamburg: Statista—The Statistics Portal.

Flash, Tamar, and Neville Hogan. 1985. The coordination of arm movements: An experimentally confirmed mathematical model. *Journal of Neuroscience* 5: 1688–703. [CrossRef] [PubMed]

Garvin, Janel. 2018. *Global Developer Population and Demographic Study 2018*. Technical Report. Santa Cruz: Evans Data Corporation, vol. 2.

Gödel, Kurt. 1972. Some Remarks on the Undecidability Results. In *Kurt Gödel: Collected Works*. Edited by Solomon Feferman, John Dawson and Stephen Kleene. Oxford: Oxford University Press, vol. II, pp. 305–6.

Godfrey-Smith, Peter. 2016. *Other Minds: The Octopus, the Sea, and the Deep Origins of Consciousness*. New York: Farrar, Straus and Giroux.

Gow, Sherrill, Merryn Owen, Mark Bishop, Stephen Hudson, Julia Jade-Duffy, and Ian Brandon. 2014. *Mil-std-1815*. Technical Report. London: The George Wood Theatre, Goldsmiths University.

Howe, Jeff. 2017. Kentucky wants mit to stop destroying its jobs. MIT is listening. *Boston Globe*, November 14.

Immerman, Neil. 2016. Computability and complexity. In *The Stanford Encyclopedia of Philosophy*, Spring 2016 ed. Edited by Edward N. Zalta. Stanford: Metaphysics Research Lab, Stanford University.

Jenaro, Cristina, Noelia Flores, María Gómez-Vela, Francisca González-Gil, and Cristina Caballo. 2007. Problematic internet and cell-phone use: Psychological, behavioral, and health correlates. *Addiction Research & Theory* 15: 309–20.

Landgraf, Tim, David Bierbach, Hai Nguyen, Nadine Muggelberg, Pawel Romanczuk, and Jens Krause. 2016. Robofish: Increased acceptance of interactive robotic fish with realistic eyes and natural motion patterns by live trinidadian guppies. *Bioinspiration & Biomimetics* 11: 015001.

Laumond, Jean-Paul, and Naoko Abe. 2016. *Dance Notations and Robot Motion*. Berlin: Springer.

LaViers, Amy. 2017. Engineering Needs Qualitative Methods. Technical Report. Medium. Available online: https://medium.com/@alaviers/robotics-automation-and-dance-d93589d60224 (accessed on 4 January 2019).

LaViers, Amy. 2019. Make robot motions natural. *Nature* 565: 422–24. [CrossRef]

LaViers, Amy, Catie Cuan, Catherine Maguire, Karen Bradley, Kim Brooks Mata, Alexandra Nilles, Ilya Vidrin, Novoneel Chakraborty, Madison Heimerdinger, Umer Huzaifa, and et al. 2018. Choreographic and somatic approaches for the development of expressive robotic systems. *Arts* 7: 11. [CrossRef]

LaViers, Amy, Lori Teague, and Magnus Egerstedt. 2014. Style-based robotic motion in contemporary dance performance. In *Controls and Art*. Berlin: Springer, pp. 205–29.

Kinova Robotics. 2017. *Jaco2 6 Dof Advanced Specification Guide*. Technical Report. Boisbriand: Kinova Robotics. Available online: https://usermanual.wiki/Pdf/JACOC2B26DOFAdvancedSpecificationGuide.1434949807.pdf (accessed on 4 January 2019).

Madrigal, Alexis. 2018. Service workers forced to act like robots meet their match. *The Atlantic*, May 8.

Mae Ryan, Cade Metz, and Rumsey Taylor. 2018. How robot hands are evolving to do what ours can. *The New York Times*, July 30.

Marras, Stefano, and Maurizio Porfiri. 2012. Fish and robots swimming together: Attraction towards the robot demands biomimetic locomotion. *Journal of The Royal Society Interface* 9: 1856–68. [CrossRef] [PubMed]

McMahon, Thomas A., and John Tyler Bonner. 1983. *On size and life*. Scientific American Library New York: Springer Nature America.

Metz, Cade. 2016. Google's AI Takes Historic Match against Go Champ with Third Straight Win. *Wired*, March 12.

Mirzabekiantz, Eliane. 2016. Benesh movement notation for humanoid robots? In *Dance Notations and Robot Motion*. Berlin: Springer, pp. 299–317.

Mokyr, Joel, Chris Vickers, and Nicolas L. Ziebarth. 2015. The history of technological anxiety and the future of economic growth: Is this time different? *Journal of Economic Perspectives* 29: 31–50. [CrossRef]

Nabet, Benjamin, Naomi E. Leonard, Iain D. Couzin, and Simon A. Levin. 2009. Dynamics of decision making in animal group motion. *Journal of Nonlinear Science* 19: 399–435. [CrossRef]

Petzold, Charles. 2008. *The Annotated Turing: A Guided Tour through Alan Turing's Historic Paper on Computability and the Turing Machine*. Indianapolis: Wiley Publishing.

Powell, Matthew J., Huihua Zhao, and Aaron D. Ames. 2012. Motion primitives for human-inspired bipedal robotic locomotion: Walking and stair climbing. In Proceedings of the 2012 IEEE International Conference on Robotics and Automation (ICRA), St. Paul, MN, USA, May 14–18; pp. 543–49.

Prasse, Michael, and Peter Rittgen. 1998. Why church's thesis still holds. some notes on peter wegner's tracts on interaction and computability. *The Computer Journal* 41: 357–62. [CrossRef]

Rethink Robotics. 2018. *Sawyer Collaborative Robot Tech Specs*. Technical Report. Boston: Rethink Robotics.

Reynolds, Craig W. 1999. Steering behaviors for autonomous characters. In Proceedings of the Game Developers Conference, San Jose, CA, USA, March 15–19; vol. 1999, pp. 763–82.

Salaris, Paolo, Naoko Abe, and Jean-Paul Laumond. 2016. A worked-out experience in programming humanoid robots via the kinetography laban. In *Dance Notations and Robot Motion*. Berlin: Springer, pp. 339–59.

Shagrir, Oron. 2006. Gödel on turing on computability. *Churchs Thesis after* 70: 393–419.

Shannon, Claude E. 1938. A symbolic analysis of relay and switching circuits. *Electrical Engineering* 57: 713–23. [CrossRef]

Siegelmann, Hava T. 1995. Computation beyond the turing limit. *Science* 268: 545–48. [CrossRef]

Siegelmann, Hava T. 2013. Turing on super-turing and adaptivity. *Progress in Biophysics and Molecular Biology* 113: 117–26. [CrossRef] [PubMed]

Silver, David, Aja Huang, Chris J. Maddison, Arthur Guez, Laurent Sifre, George Van Den Driessche, Julian Schrittwieser, Ioannis Antonoglou, Veda Panneershelvam, Marc Lanctot, and et al. 2016. Mastering the game of go with deep neural networks and tree search. *Nature* 529: 484. [CrossRef]

Soma, Masayo, and Midori Iwama. 2017. Mating success follows duet dancing in the java sparrow. *PLoS ONE* 12: e0172655. [CrossRef]

Spratling, Michael W. 2017. A review of predictive coding algorithms. *Brain and Cognition* 112: 92–97. [CrossRef]

Stephens, Greg, Bethany Johnson-Kerner, William Bialek, Will S. Ryu, and Eric Warrant. 2010. From Modes to Movement in the Behavior of Caenorhabditis elegans. *PLoS ONE* 5: 462–65. [CrossRef] [PubMed]

Studd, Karen, and Laura Cox. 2013. *Everybody Is a Body*. Indianapolis: Dog Ear Publishing.

Swain, Daniel T., Iain D. Couzin, and Naomi Ehrich Leonard. 2012. Real-time feedback-controlled robotic fish for behavioral experiments with fish schools. *Proceedings of the IEEE* 100: 150–63. [CrossRef]

Todorov, Emanuel, and Michael I. Jordan. 2002. Optimal feedback control as a theory of motor coordination. *Nature Neuroscience* 5: 1226. [CrossRef] [PubMed]

Toenjes, John, Ken Beck, M. Anthony Reimer, and Erica Mott. 2016. Dancing with mobile devices: The lait application system in performance and educational settings. *Journal of Dance Education* 16: 81–89. [CrossRef]

Turing, Alan Mathison. 1936. On computable numbers, with an application to the entscheidungsproblem. *Jounal of Mathematical* 58: 5.

Turner, J. Scott. 2013. Biology's second law. homeostasis, purpose and desire. In *Beyond Mechanism. Putting Life Back into Biology*. New York: HarperCollins, pp. 183–203.

Universal Robots. 2016. *Ur5 Technical Specifications*. Technical Report. Odense: Universal Robots.

Wegner, Peter. 1997. Why interaction is more powerful than algorithms. *Communications of the ACM* 40: 80–92. [CrossRef]

Wright, Cornell, Aaron Johnson, Aaron Peck, Zachary McCord, Allison Naaktgeboren, Philip Gianfortoni, Manuel Gonzalez-Rivero, Ross Hatton, and Howie Choset. 2007. Design of a modular snake robot. In Proceedings of the 2007 IEEE/RSJ International Conference on Intelligent Robots and Systems, San Diego, CA, USA, October 29–November 2; pp. 2609–14.

Yanco, Holly A, Adam Norton, Willard Ober, David Shane, Anna Skinner, and Jack Vice. 2015. Analysis of human-robot interaction at the darpa robotics challenge trials. *Journal of Field Robotics* 32: 420–44. [CrossRef]

Zah, Eugenia, Meng-Yin Lin, Anne Silva-Benedict, Michael C. Jensen, and Yvonne Y. Chen. 2016. T cells expressing cd19/cd20 bi-specific chimeric antigen receptors prevent antigen escape by malignant b cells. *Cancer Immunology Research* 4: 498–508. [CrossRef] [PubMed]

arts

MDPI

Editorial

An Interview with Frieder Nake

Glenn W. Smith

Space Machines Corporation, 3443 Esplanade Ave., Suite 438, New Orleans, LA 70119, USA; gsmith@space-machines.com

Received: 24 May 2019; Accepted: 26 May 2019; Published: 31 May 2019

Abstract: In this interview, mathematician and computer art pioneer Frieder Nake addresses the emergence of the *algorithm* as central to our understanding of art: just as the craft of computer programming has been irreplaceable for us in appreciating the marvels of the DNA genetic code, so too has computer-generated art—and with the algorithm as its operative principle—forever illuminated its practice by traditional artists.

Keywords: algorithm; computer art; emergent phenomenon; Paul Klee; Frieder Nake; neural network; DNN; CNN; GAN

---

1. Introduction

The idea that most art is to some extent algorithmic,[1] whether produced by an actual computer or a human artist, may well represent the central theme of the *Arts* Special Issue "The Machine as Artist (for the 21st Century)" as it has evolved in the light of more than fifteen thoughtful contributions. This, in turn, brings forcibly to mind mathematician, computer scientist, and computer art pioneer Frieder Nake, one of a handful of pioneer artist-theorists who, for more than fifty years, have focused on algorithmic art per se, but who can also speak to the larger role of the algorithm within art.

As a graduate student in mathematics at the University of Stuttgart in the mid-1960s (and from which he graduated with a PhD in Probability Theory in 1967), Nake was a core member, along with Siemens mathematician and philosophy graduate student Georg Nees, of the informal "Stuttgart School", whose leader was philosophy professor Max Bense—one of the first academics to apply information processing principles to aesthetics. Indeed, Bense's lecture halls were the site, in early 1965, of the world's very first exhibition of computer-generated art: a dozen or so abstract, black-and-white designs produced algorithmically by Nees on the newly introduced Zuse Graphomat Z64 plotter. In April of that same year, A. Michael Noll of Bell Labs exhibited his own computer-generated graphic art at the Howard Wise Gallery in New York City (with Bela Julesz); and the world's third such exhibition was at the Galerie Wendelin Niedlich in Stuttgart in November of 1965, with algorithmically-generated Zuse Graphomat Z64 plots by both Nake and Nees (Dreher 2011).

Moreover, the work of these adherents of the Stuttgart School was from the beginning both interdisciplinary, involving (before the term became fashionable) philosophers, mathematicians, and artists, and also relatively mature in conception: identifying the algorithm with artistic *style*, they produced works in series illustrating, as with Monet's series of paintings of the facade of the

---

[1] With the understanding that the following is a simplified version of a highly complex process, it can be said that any artist with a recognizable style has developed certain patterns of working, and to which patterns the term "algorithmic" can be meaningfully applied in much the same way that other terms from computer science—e.g., "multitasking"—have found broader usage. To the extent, furthermore, that these patterns of working impart a characteristic treatment to the artist's productions—the aforementioned "style"—this latter term can also be said to imply an algorithmic tendency, and vice versa. Finally, it should be noted that an artist's style and, therefore, his or her algorithmic tendencies are typically never more on display than in a closely related series of pieces, and this because the artist's core technique can be discerned amidst systematic or random variations in the source material.

Rouen cathedral, not only the possible variations resulting from systematic or random changes to an algorithm's parameters, but also the nature of the core algorithm itself. All of this, furthermore, was accomplished and promulgated without prejudice to the possibility of some more traditional sources of inspiration, as with Nake's now iconic 1965 "Homage to Paul Klee" (Figure 1) in the collection of the Victoria and Albert Museum.

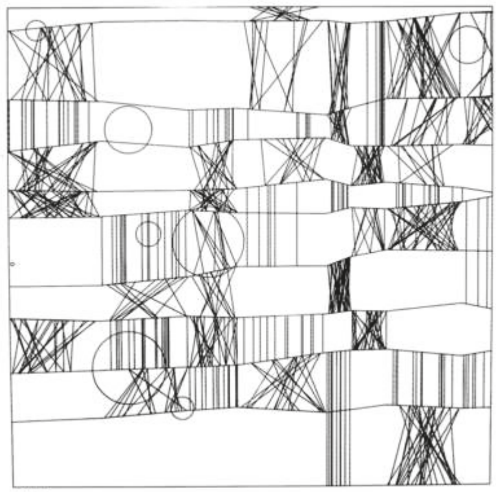


Figure 1. *Homage to Paul Klee* by Frieder Nake, 1965. Screenprint on paper, 49.2 cm × 49.2 cm. *Victoria and Albert Museum*. © Frieder Nake and used by permission.

Nake summarized his work with the algorithm in 1974 with a complete book on the subject—*Ästhetik als Informationsverarbeitung* (*Aesthetics as Information Processing*, Nake 1974)—and now, in his 80th year, has happily continued up to the present day to combine his academic career with his role as artist and algorithmic evangelist (Nake 2005, 2014, 2015, 2016). The following interview with Nake was conducted via email by artist/technologist G. W. Smith.

2. The Interview

GWS:

So now, Frieder—only 50 years after you and the other pioneers of computer art began using the term!—we find that the "algorithm" has become a hot topic in techno-art circles, and in particular the DNN (deep neural network) and its close CNN (convolutional neural network) and GAN (generative adversarial network) relatives, and we hence feel compelled to ask the following questions: first, what have been your thoughts (and feelings) as you have watched all of this unfold over the last fifty years; second, what has been missed, and/or, have there been any surprises for you, i.e., despite the fact that you yourself are a visionary computer scientist, is it not astonishing that there is now an algorithm which can "capture" Van Gogh's style and apply it to an arbitrary photograph (Gatys et al. 2015); and third, where do things go from here?

FN:

When in the mid-1960s those first drawings appeared on walls of some galleries, and soon enough, in 1968, in the two remarkable international shows in, respectively, London (Cybernetic

Serendipity: The Computer and the Arts[2]) and Zagreb (Tendencies 4: Computers and Visual Research), I thought—and was actually convinced—that something was happening that was funny, remarkable, but also destined to remain a marginal event only. I was proud of being a part of it. And, I tell you, I had reason to be. For from the first moment on, my stuff (and, perhaps, myself) was accepted by artists. Soon I got to know K.O. Götz, and he invited me to give a lecture at Kunstakademie Düsseldorf. And as a result of my second show in January/February 1966 in Darmstadt, Otto Beckmann wrote me from Vienna that we should cooperate on one of his projects.

Most likely, I overestimated the significance of what I was happy and lucky to experience. But it was great and tremendously inspiring. Now, jumping ahead several decades and, in the jump, passing my 1971 declaration that there should be no computer art (Nake 1971), we see that there are virtually no images any more that would not at least be touched to some minor degree by computer software. The image has generally become the digital image.

Such a statement is, of course, wrong. But it is correct at the same time. There are still dozens and hundreds of artists painting their canvases and preparing their printing plates. And there will be more of them forever. But the mainstream, often boring or nothing but commercial, has become "digital". This word, I should hurry to correct: the digital form of coding the image is not the important aspect. Important is that image generation is now happening, to a minor or major extent, by algorithm. The algorithm is the essence of the Algorithmic Revolution that we are witnesses of. And the essence of the Algorithmic Revolution is that all processes of society are transformed into computable form. The impact of this deep algorithmic turn-over of everything in culture we know and cherish and love is still not really understood by the masses, not even by all the experts of various kinds who currently swim with the wave of digitization.

This is the point where I want to take up your remark and question concerning van Gogh's style! Yes, there are teams of young researchers who do fantastic work in approximating a painter's style. They establish intricate systems that use given material (images in our case), analyze it, and use results of such analyses to generate new images in the "style", as they claim, of van Gogh or some other artist. That's interesting work requiring computer power and some intelligence. And it is greatly rewarding because the press will jump on it, and the public will again discuss the non-question of "who is the artist", and "is the computer an artist". It is, of course, not, and despite the nice success of such research, it has little to do with "art". Who, as an artist, would seriously copy some other artist's style? Who believes that style can be peeled off a painting? What we see in such fantastic projects is, of course, one necessary attempt at reducing some dead artist's work habits into computable form. That's difficult enough as a technical exercise. But it is not more than this.

Where do things go from here? They will go, on one hand, into the flat lands of ordinary mass culture. And they will appear as breathtaking new expressions that take as their subject matter the horrors of computability.

GWS:

Bense's information-intensive approach to aesthetics—and indeed, his preference for that term instead of "art"—clearly reflects a desire on his part to recognize within the art-making process an element of cool rationality. In your presentation to the "Art That Makes Itself" symposium (Nake 2015), you in turn specifically connect Bense's tendency in this direction with his goal of countering Hitler's raw emotional appeal; and as your very last remark in your three-part video interview with the *Generative Art Science and Technology Journal* (Nake 2005), you note that Bense was a "radical atheist", and with the implication that this was a further outgrowth of the rationalism which he hoped would shield society from future Hitlers. With an infinite degree of compassion, therefore, for Bense's motivations

[2] In her introduction to the catalog for Cybernetic Serendipity (Reichardt 1968), curator Jasia Reichardt credits Max Bense with the idea for the exhibition.

in espousing atheism, and without the slightest suggestion, furthermore, that the following remarks reflect a desire to return to a society in thrall to an unseen male deity, can we not—in addition to the rationality which it represents—also interpret the vitality of the algorithm as restoring some element of faith and hope in a benign universe? I refer, in the first place, to the fact that there is starting to be some organized resistance within academia (Nagel 2012) to the idea that it is only a matter of time before a purely *reductive* science (and note my emphasis on "reductive" as opposed to "science") will have been able to "explain everything"—and with the alternative being a science that admits the possibility of a synthetic, if not in fact creative, principle at work within the universe; and I refer, in the second place, to a concept which must inevitably arise in connection with that of the algorithm: *emergence,* or *emergent phenomenon*, i.e., the uncanny ability of relatively simple systems to exhibit relatively sophisticated behaviors. The CNN, for example, is a relatively simple algorithm when compared with, say, a mathematical model of the atmosphere, and hence its ability to be deployed by non-technical individuals on personal computer systems; but again—as with the above Van Gogh style example—must we not be astounded by its capabilities? Your thoughts, please.

FN:

That's a lot and it is heavy. Let me try to first take up the reductive science aspect. Science in my view is, and must always be, reductive. Scientists try to understand "the whole". But the whole we can only have in parts. The scientific method—as we have become familiar with it—is a success story in taking as its subject matter an isolated aspect of the world, replacing it by a formal model (mathematical to a large extent), and re-interpreting results from dealing with the model in the context of the original aspect. But what science finds out are always statements about the model. For many practical issues, that's good enough to build a machine or other systems.

Newton did not understand nature. But he prepared the ground for the world of mechanical/ energetic machines. We replace the natural by the artificial. But the artificial is so powerful that we believe we understand the natural.

Yes, we are astounded by what models run on computers are capable of producing. However, our awe should not be accredited to the computer/software system, but to the human researchers and engineers who were creative enough to bring that about. And even if the engineers successfully explain the operations of their model to us, there may be emergent behavior that goes beyond the reach of the model. We call this "emergence", and tend to believe that emerging phenomena are totally new. They are not. They were implicit in the model's computational implementation.

Algorithms, even if they are of a rather basic character, show behaviors that we did not predict or even could not have predicted. But this is not a statement about a necessary characteristic of algorithms. We are in principle able to list all explicit behaviors of a given algorithm. But pragmatically, we don't do it. We rather wait and see. As the semiotic engine, the computer is always good for a surprise.

GWS:

Inasmuch as *art* is our ultimate subject, and inasmuch as there is a sense which hovers about you that something must be left unsaid—this in accordance with Yeats' statement that "Man can embody truth but he cannot know it"—how appropriate it is, first, that you decided early in your career to pay tribute to one of your artistic forebears; second, that said artist was Paul Klee, one of the most obviously "algorithmic" of the early modern artists (e.g., "I will create a marvelous painting with nothing but tiny colored squares and triangles"), but also one of the most enigmatic and mysterious; and third, that your own tribute to him (said to have been inspired by *Highway and Byways*, but I think also *Castle and Sun* (Figure 2)) is so evocative! By way of sneaking up on this subject, could you first acquaint us with your own early exposure to modern art in general and Klee in particular—and could you then go on from there to discuss Klee as an influence?

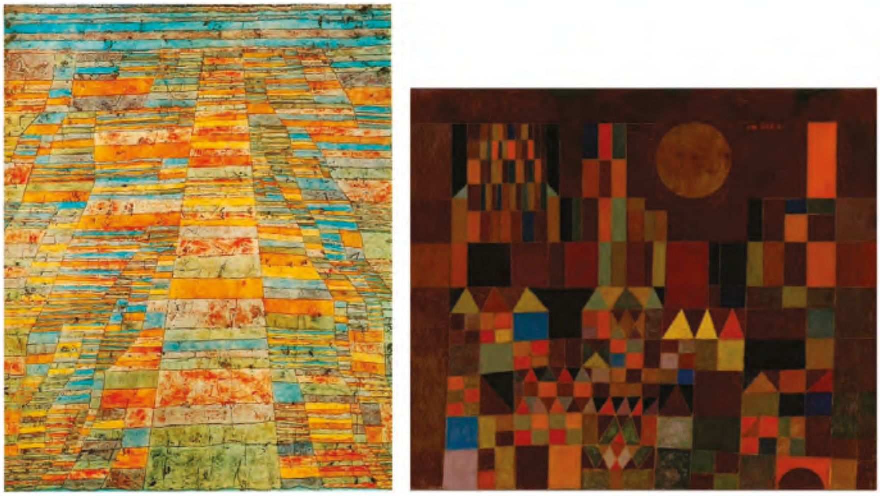


Figure 2. *Highway and Byways* by Paul Klee, 1929. Right: *Castle and Sun* by Paul Klee, 1928. Public domain images.

FN:

What a marvelous exposure, what an inspiring question! The way you characterize Paul Klee is the nicest and, at the same time, most enlightened that I may have encountered.

We are in 1965, and I possess a small little booklet of drawings by Klee. They are in black and white only, and I flip through the pages of that small collection. If I remember correctly, I felt grabbed by his drawings, and tried to analyze them in detail. Not in a technical way did I try to analyze them, but in my head. My thoughts circled around: this is so simple and basic that I must be able to program it, but, at the same time, my brain told me that any such attempt will be bound to fail. For Klee's lines are his lines, and before I will be able to simulate the stroke of his hand by algorithm, I will be doing something totally different from that which I have in mind. It will be of the utmost stupidity. In other words—so my thinking went—would it not be totally uninteresting and stupid to even try and simulate his stroke by algorithm?

And, of course, the next thought was, away from Klee's actual command of the physical line, his composition of small little elements that always in a way so surprisingly rich and light-heartedly massed up to sceneries that did not depict any real scene but that nonetheless, each one of them, could clearly be depictions. As you know, he told us so convincingly (in his twentieth century) that art does not reproduce the visible, rather it makes visible (about 1920).

Now here I was, and I had available a computer, and a drawing automaton, and I knew how to write algorithms for the computer, what else should I do but take up Klee's maxim about the invisible that should be made visible! (See the difference to the current style simulators?) So Klee during those months of August and September, 1965, became my source of inspiration.

But you have asked me about my exposure to modern art in general. I cannot answer this question in the same way that, perhaps, Michael Noll might be able to: well, my parents took me to MoMA on Sundays.[3] Instead, I went to galleries in Stuttgart that were showing contemporary art. I did not know whether I liked what I saw or disliked it. I found it interesting. Often, I did find it more than this. I stood there, studying the painting. The nice Impressionist paintings in the Stuttgart Staatsgalerie

[3] As noted in the introduction, Nake's fellow algorist Michael Noll exhibited his work in Manhattan, and he was in fact born in Newark and might very well have visited MOMA with his parents.

were nice to look at. But I did not study them, I just liked them. What attracted me was definitely different from what they had shown us in high school. But one day in school, our teacher of fine art started talking about what he liked and, obviously, had been in immediate touch with. The teacher read wonderfully absurd texts to us, told stories about those artists, and also showed their pictures. It was Berlin Dada. It became a revelation. A sensation. Yes, Picasso was there. The Blue Period. That was melancholic. The cubist stuff? Braque's guitars were great. But Picasso's shook up girls? They were not sexy. Mondrian! That was also fantastic. Pollock! Even more. But the Dadaists were a different story. And they were against the war. And against the petit bourgeois. And then Paul Klee … He gained a hidden influence on me. I don't think I discussed that with my friends who were studying painting at the fine arts school.

I became proud about my drawing "13/9/65 Nr. 2", as I called it. When in 1966 Carl Laszlo came to Stuttgart from Basel and invited me to produce a series of similar graphics that he wanted to add to a special edition of 200 copies of his *Panderma* magazine, I did it, was proud, did not take any money, and now called the first and original drawing "Homage to Paul Klee". A bit later, we produced a screenprint of 40 copies, with a few of them in white or green on pink paper (currently shown at the DAM Gallery in Berlin).

To finish this, let me add that in 2004 I did an interactive version of the algorithm. Together with Matthias Krauss and Susan Grabowski, we did a round bar table that has a screen and two pads. Two persons can manipulate the displayed drawing in various ways. The moving image is simultaneously projected onto the wall. It was fun and attracted quite a bit of attention in Kunsthalle Bremen and ZKM in Karlsruhe, and at other occasions later.

And, perhaps, I should add that I was invited to contribute in 2008 to an exhibition at Zentrum Paul Klee in Bern, Switzerland. I guess this was a recognition of some kind.

Acknowledgments: The author would like to thank Frieder Nake, and all of his fellow algorists, for their pioneering work.

Conflicts of Interest: The author declares no conflict of interest.

References

Dreher, Thomas. 2011. History of Computer Art. Available online: http://iasl.uni-muenchen.de/links/GCA-III.2e.html#Computergrafik (accessed on 16 February 2019).

Gatys, Leon A., Alexander S. Ecker, and Matthias Bethge. 2015. A Neural Algorithm of Artistic Style. *arXiv*. Available online: https://arxiv.org/pdf/1508.06576.pdf (accessed on 16 February 2019).

Nagel, Thomas. 2012. *Mind and Cosmos: Why the Materialist Neo-Darwinian Conception of Nature is Almost Certainly False*. Oxford: Oxford University Press.

Nake, Frieder. 1971. There Should Be No Computer Art. *Page, the Bulletin of the Computer Arts Society* 18: 1–2.

Nake, Frieder. 1974. *Ästhetik als Informationsverarbeitung*. Vienna: Springer.

Nake, Frieder. 2005. Interview with Frieder Nake. *Generative Art Science and Technology Hard Journal*. Available online: http://www.gasathj.com/tiki-read_article.php?articleId=50 (accessed on 16 February 2019).

Nake, Frieder. 2014. Eyeo Festival Presentation. Available online: https://vimeo.com/104315361 (accessed on 16 February 2019).

Nake, Frieder. 2015. Art That Makes Itself Symposium Presentation. Available online: https://www.youtube.com/watch?v=ICOs_8pjOIc (accessed on 16 February 2019).

Nake, Frieder. 2016. The Algorithmic Art Manifesto. In *Nevertheless. 17 Manifestos*. Edited by Andrea Sick. Hamburg: Textem Verlag, pp. 67–70. Available online: http://17.manifestos.de/ (accessed on 16 February 2019).

Reichardt, Jasia. 1968. Cybernetic Serendipity: The Computer and the Arts. Studio International Special Issue. July. Available online: http://www.studiointernational.com/flipbookCyberneticSerendipity/StudioInternationalCyberneticSerendipity-1968.html (accessed on 22 March 2018).

MDPI
St. Alban-Anlage 66
4052 Basel
Switzerland
Tel. +41 61 683 77 34
Fax +41 61 302 89 18
www.mdpi.com

Arts Editorial Office
E-mail: arts@mdpi.com
www.mdpi.com/journal/arts

MDPI
St. Alban-Anlage 66
4052 Basel
Switzerland

Tel: +41 61 683 77 34
Fax: +41 61 302 89 18

www.mdpi.com

ISBN 978-3-03936-065-9