proceedings

MDPI

Proceeding Paper

Towards Beneficial AI: A Biomimicry Framework to Design Intelligence That Cooperates with Biological Entities †

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† Presented at the 1st International Online Conference of the Journal Philosophies, 10–14 June 2025; Available online: https://sciforum.net/event/IOCPh2025.

Abstract

This paper proposes biomimicry as a paradigm for helping to overcome both the conceptual and technological limitations of current AI systems. It begins by outlining three key challenges faced by modern AI and then proceeds to introduce the concept of biomimicry, offering examples of how biologically inspired approaches have informed technical solutions. Furthermore, this paper presents a framework for integrating biomimicry principles into AI research and development. The three central challenges identified here are the energy challenge, the gap challenge, and the conceptual challenge. This paper also presents a case study on beneficial AI to illustrate how a biomimetic approach can be applied to address some current shortcomings in AI technology.

Keywords: biomimicry; beneficial AI; AI paradigm; symbiotic AI

Academic Editor: Gordana Dodig-Crnkovic

Published: 15 September 2025

Citation: Polak, P.; Niewiarowski, P.; Huss, J.; Krzanowski, R. Towards Beneficial AI: A Biomimicry Framework to Design Intelligence That Cooperates with Biological Entities. *Proceedings* **2025**, *126*, 7. https://doi.org/10.3390/proceedings2025126007

1. Introduction

The rapid development of artificial intelligence and its growing social impact have sparked various discussions about the challenges of developing this technology. We indicate three main challenging areas and propose adopting a biomimetic (For the purposes of this paper, we treat biomimicry, bioinspired design, bioinspiration, and biomimetics as being synonymous.) approach as a means for designing AI in a way that addresses these challenges.

2. Challenges of AI Development

Based on our own research and that contained in the literature, we begin by highlighting three challenges that relate to specific philosophical issues at the foundations of AI technology [1]:

1. The challenge of energy efficiency in information-processing systems;
2. The gap between living and artificial agents, where the metaontologies of living and artificial agents differ due to their structure and operation [2,3];
3. The conceptual challenges of AI, namely the unclear and problematic conceptual foundations of AI (e.g., [4,5]).

These challenges suggest a need to redefine the conceptual (or philosophical) foundations of contemporary AI technologies. We selected beneficial AI for a case study to demonstrate how a biomimetic approach could contribute to such a redefinition.

Our aim was to create and analyze an AI paradigm based on cooperation between artificial and living entities. To this end, we propose a biomimetic framework that incorporates Gordana Dodig-Crnkovic's concept of natural computing [6] and her ideas for a unifying framework for anthropogenic, biogenic, and abiotic cognition and intelligence [7]. This framework brings together the broad concepts of agent cognition and computation, thus bridging the gap to AI technology. The proposed biomimetic framework and symbiotic AI (see Section 6.3) represent solutions to the above challenges in the context of the computing nature concept.

3. Biomimicry for Philosophy

Biomimicry, also known as biomimetics, has been a source of technical inspiration for centuries, such as in the designs of Leonardo da Vinci. The late 20th century marked the beginning of the modern era of biomimetics as it became an academic subject. From a philosophical point of view, biomimicry can be viewed from three perspectives [8,9]:

- Nature as a Model (Poetic principle), a discipline that "imitates or takes inspiration" from nature's models;
- Nature as a Mentor (Epistemological principle), which is based "not on what we can extract from the natural world, but on what we can learn from it";
- Nature as a Measure (Ethical principle), which "uses an ecological standard to judge the 'rightness' of our innovations."

We refer to all these methods, but this current study focuses on the third one. Benyus described the role of nature as a measure as follows [8]: "After 3.8 billion years of evolution, nature has learned: What works. What is appropriate. What lasts".

4. How Is Biomimicry Achieved?

A biological system can serve as an inspiration for "how" to achieve some desired functionality, which usually means solving some problem of interest.

In the famous example of Velcro, the biological system being mimicked is the burdock seed. This has stiff hooks that enable it to attach to the hair or fur of many animals, but this attachment is also reversible. Thus, the seed can be potentially transported away from the source plant, so it can later detach from the animal and germinate in a new location. For birds, the shape of their wings creates lift when air flows over them. When this is mimicked by an airplane's wings, the aircraft generates enough lift to overcome the force of gravity and fly.

There are many methodologies and practices for biomimetic design, but they all come down to analyzing the structure and behavior of elements comprising a biological system of interest, combined with a knowledge of how the structure and behavior produce a function (purpose). Translating a biological Structure (S) and Behavior (B) into a human design should produce something analogous to Function (F). This FBS paradigm/model was developed by John S. Gero in the field of design research (see, for example, his seminal paper [10]). The biological system, therefore, serves as an analogy, which, when transferred with legitimate implementations of structure and behavior, delivers a desired function. In the Velcro example, plastic hook-like structures become entangled with plastic fibers to achieve an easily reversible adhesion, something that is desirable for a reusable fastener. The FBS framework is flexible and can be applied across a range of biological systems and scales.

5. Framework for Biomimetics in AI

The biological inspiration for intelligent artificial agents can be applied to many areas, such as the following:

- An expansion of AI's sensory capabilities by mimicking echolocation, chemical sensing, or distributed tactile sensitivity;
- Swarm intelligence and other multi-agent systems inspired by collective behavior;
- Alternative/hybrid computational architectures;
- Strategies for data regulation and adaptation;
- The representation and interpretation of biological knowledge (biosemiotics);
- Accurate simulations of neurons' information-processing functions, although not equivalent to neurocomputing;
- The mass storage of information, like with DNA and RNA;
- Homeostasis, such as mechanisms for self-regulating AI systems.

As we can see, biological systems are a very important source of inspiration for AI development. Nevertheless, it is worth emphasizing that the aim is not to reproduce typical human intelligence or to create an "artificial human." Indeed, biological inspiration can be drawn from a broad range of species, with many useful solutions being found in non-human organisms.

6. Using Biomimetics to Address the Challenges of AI

6.1. The Energy Challenge

A primary argument for adopting the biomimetic approach is that biological systems solve complex problems with impressively low energy requirements. For example (see [11]), the human brain is incredibly efficient, with it consuming only 20 watts of energy to perform complex tasks. Moreover, unlike always-on digital systems, neurons fire only when needed, and massive parallelism spreads the work across many simple units. Localized memory and learning also reduce costly data movement. Neuromorphic chips, therefore, mimic brain circuits to achieve significant energy savings (on bioinspired electronics, see, e.g., review article [12]; on example of energy-efficient bioinspired in-sensor computing see, e.g., review article [13]).

The problem of AI's growing energy consumption is becoming an increasingly important challenge. According to the International Energy Agency (https://www.iea.org/energy-system/buildings/data-centres-and-data-transmission-networks (accessed on 8 September 2025)) global data center electricity consumption was estimated in 2022 at 240–340 TWh, which is around 1–1.3% of the world's total electricity consumption. In US data centers alone, energy consumption reached 176 TWh in 2023, about 4.4% of total US electricity consumption [14]. Further developing AI techniques under the current paradigm will therefore be very challenging due to the necessary energy intensity. This may significantly constrain future development of the technology and become a major environmental challenge [15–17].

6.2. The AI–Human Gap Challenge

The AI–human gap refers to the differences between the world of humans and the world of AI artifacts. Roman Krzanowski described it as follows [18]:

- "AI systems and humans operate in different ethical, metaphysical, and ontological universes";
- "AI systems differ from us in their ethical assumptions, value systems, objectives, and conceptualization (ontology) of the world";

- "This difference, or gap, in the conceptual suppositions is well recognized, yet it has not been systematically studied, with its significance being brushed aside by most AI researchers."

This conceptual gap suggests that we should exercise caution when interpreting AI and its role in human life and society. Indeed, our tendency to anthropomorphize AI technology could potentially lead to all sorts of abuses and obscure how the technology should be developed for humanity's long-term benefit.

6.3. The Conceptual Challenge

In AI, many concepts are intuitive. While some may be exaggerated, they can still serve an ideological purpose, such as artificial human consciousness. Problems in the conceptual foundations of AI can lead to "AI winters" [5], cause misunderstandings, or even transform the technology into an ideological program.

We propose biomimicry as a way to formulate and clarify the fundamental concepts of AI based on biology. Rather than searching for the ill-defined concept of "artificial general intelligence," we believe it is more fruitful to refer to established biological solutions and consider how humans integrated them into their society. Symbiotic relationships exemplify the beneficial relationships between humans and non-human species from an evolutionary point of view. Studying interactions between these species can help us understand what we want to achieve with AI, as well as how to do so, seeing as AI is considered an evolving and adapting entity participating in a coevolutionary relationship. Symbiotic relationships provide an excellent model for consciously developing AI for humanity's long-term well-being rather than short-term corporate enrichment. We refer to this model as *symbiotic AI*.

7. The Case Study of Beneficial AI: A Need to Clarify Objectives

We will now consider a case study to clarify the concept of beneficial AI, because it is rather vague. Topics typically included within it can be found in the "Foundations for Beneficial AI" course at UC Berkeley (https://philosophy.berkeley.edu/courses/detail/1277 (accessed on 8 September 2025)). These include the following: "utility theory, bounded rationality, utilitarianism, altruism, interpersonal comparisons of utility, preference learning, plasticity of human preferences, epistemic uncertainty about preferences, decision making under risk, social choice theory, and inequality." The philosophical background for beneficial AI is frequently utilitarian, perhaps due to the emphasis on beneficence. For example, the above quote explicitly states that the objectives of beneficial AI should include satisfying human preferences while remaining uncertain about what such preferences may be (more on this issue, see [19]).

We believe that a biological evolutionary perspective can shed light on such problems. In their review paper, Zybailov et al. [20] stated that "the boundary between biological and artificial entities may become increasingly blurred." They suggested that biological concepts could be adopted in the AI domain, focusing on evolutionarily inspired AI–human partnerships: "Promoting AI–human partnerships can lead to innovative solutions to global challenges and ensure the survival and adaptation of our civilization." An initial attempt at this was made by Polak and Krzanowski [21] when they introduced the concept of taming within the context of biosemiotics for AI-driven robots. These systems could be viewed from a phenomenological perspective as a specific artificial species. Here, however, we propose focusing on the more fundamental biological inspiration of symbiosis.

Biology is interpreted here as measuring what is beneficial. Ecological and evolutionary relationships between two species can involve individuals interacting closely for much of their life cycle in a way that is known as symbiosis, from the Greek word for "living together." Symbiotic relationships exist in many biological phenomena of extraordinary consequence: the origin of eukaryotes (plants, animals, fungi, and protists), the origin of algae and other plants capable of photosynthesis, and bacteria–plant cooperation in transforming atmospheric nitrogen into forms required for the survival of other organisms. Analyzing symbiosis can provide models for designing and structuring interactions between humans and AI, such that they lead to desirable and predictable outcomes. This approach would enable us to shun models that diminish one side, such as in the typical master–slave relationship exemplified in Asimov's laws [22]. Analyzing symbiotic relationships in nature is the best way to learn how to intentionally design beneficial AI. Under this approach, beneficial AI becomes part of the human ecosystem as it engages in symbiotic relationships. Indeed, more complex AIs that possess a degree of autonomy behave more like organisms than passive tools, such as a hammer or a pen.

8. Conclusions

This paper has proposed applying **biomimicry** to address several key roadblocks to AI development, namely **energy consumption**, the **conceptual gap**, and the **foundational conceptual limitations**. The proposed approach was then illustrated through the **case study of beneficial AI**.

The biomimetic approach represents a promising means for expanding the concept of AI to include non-human forms of intelligent behavior. It also clarifies the conceptual basis of AI by grounding it in biological concepts, such as evolution, natural selection, and adaptation. This approach's primary advantage lies in it being based on stable biological mechanisms that have played, and continue to play, a pivotal role in human history.

The symbiotic model shows how AI technology can be developed in a way that will be socially accepted and beneficial in the long term. Biological inspiration can also serve to identify what is beneficial in AI, thus helping to illuminate its goals and avoid the pitfalls. This proposal opens up new research directions and raises many questions for consideration in further research. Some examples include the following: How can FBS analysis be used to distinguish helpful biological analogies from facile ones? Should "beneficial" be defined locally or globally?

Author Contributions: Conceptualization, P.P., P.N., J.H. and R.K.; methodology, P.P., P.N. and R.K.; writing—original draft preparation, P.P. and P.N.; writing—review and editing, P.P., P.N., J.H. and R.K.; project administration, P.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable.

Acknowledgments: Pawel Polak wants to thank Anna Sarosiek for discussing the concept of human–AI symbiosis.

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

Abbreviations

The following abbreviations are used in this manuscript:

AI	Artificial Intelligence
FBS	Function-Behavior-System methodology
TWh	Terawatt-hour(s)

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