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The Problem of Context for Similarity: An Insight from Analogical Cognition

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Abstract: Similarity is central for the definition of concepts in several theories in cognitive psychology. However, similarity encounters several problems which were emphasized by Goodman in 1972. At the end of his article, Goodman banishes similarity from any serious philosophical or scientific investigations. If Goodman is right, theories of concepts based on similarity encounter a huge problem and should be revised entirely. In this paper, we would like to analyze the notion of similarity with some insight from psychological works on analogical cognition. Analogical cognition compares two situations or objects in order to find similarities between them. In doing so, the analogical process sorts the different features of the two situations or objects and determines the most important ones. The analogical process is also highly sensitive to context. Context-sensitivity is desirable at some level, but it is also problematic as it leads to a computational explosion. To answer this problem, we would like to consider salience as a possible heuristic in the analogical process. We will distinguish three forms of salience: Sensory, categorical, and operational. By taking salience into account, we can introduce a shortcut into the computation of similarity and circumvent computational explosion.

Keywords: analogical cognition; similarity; salience; context-sensitivity; concept

1. Introduction

Similarity is central for the definition of concepts in several theories in cognitive psychology. Rosch and Mervis [1] prototype theory considers that an object belongs to a concept based on how similar it is to its prototype. The exemplar theory [2] rests upon similarity as well, with the difference that one takes into account similarity relations to several exemplars instead of one prototype. Peter Gärdenfors' theory of conceptual spaces [3] proposes a middle ground by computing a prototype in a similarity space delimited with Voronoi tessellations.

However, similarity encounters several problems which were emphasized by Goodman in 1972 [4]. Among his structures against similarity Goodman stresses the importance of the respects upon which two things are considered similar. He makes a strong argument to state that, without respects, similarity is meaningless. He also examines the example of a baggage at an airport to outline the context-sensitivity of similarity, which is for him a major failure of similarity. The same baggage, from the point of view of the pilot, the owner or a spectator, has a different representation depending on what is important for each of them (weight, destination or color). At the end of his article, Goodman banishes similarity from any serious philosophical or scientific investigations. If Goodman is right, theories of concepts based on similarity encounter a huge problem and should be revised entirely. On the other hand, some of these theories have achieved well-established results.

Goldstone and Son [5] survey several theories of similarity (many thanks to an anonymous reviewer of *Philosophies* for mentioning this reference). They distinguish four major families of models:

Geometric models, featural models, structural alignment models and transformational models. We can unite, as suggested in their article, the two first families of models into one [3,6], which focuses on unstructured representations: A list of unrelated features or dimensions. The authors also mention some attempts [7] to link the last two families, both of which highlight the underlying structure of the representation and relations between several properties.

Mainly it is the first two families of models that have been taken into account in discussion of similarity [8]. They propose to consider similarity as a function of the features or dimensions shared by two objects. However, they don't solve the main problems of similarity as proposed by Goodman, because they integrate features or dimensions without considering any order or structure between them. They don't tackle the problem of the respects of similarity, without which similarity is meaningless according to Goodman.

Rather than giving up on similarity, we would like to examine some advantage of the structural alignment models, which have been mainly overlooked in the recent philosophical discussions [9]. This family of models rests upon works on analogical cognition. We would like to examine the particularity of the analogical process to consider it as a potential complement for featural/dimensional accounts of similarity. We suggest that the two approaches (featural and structural) are not opposed, but complementary. Similarity can integrate both featural properties and relational properties.

The notion of analogical cognition refers to the cognitive process (we will call it the analogical process) which compares two situations or objects in order to find similarities between them and particularly relational similarities (common relations between two pairs of objects). In doing so, the analogical process sorts the different features of the two situations or objects and determines the most important ones. In this sense, the analogical process assesses the respects upon which two things are similar. This gives a first answer to Goodman's criticism.

The analogical process is also highly sensitive to context, in particular the goal of the subject and his knowledge of the situation. Context-sensitivity is highly desirable as it reflects our intuition about similarity. However, context sensitivity also creates a problem for the analogical process. It undermines the analogical process which needs to take into account a huge number of possible features and parameters for the computation of similarity.

To answer this problem, we would like to consider salience as a possible heuristic in the analogical process. Salient properties are the properties which stand out among others, which are deemed as more important "at first sight". We will distinguish three forms of salience: Sensory, categorical, and operational. By taking salience into account, we can introduce a shortcut into the computation of similarity by the analogical process. Therefore, we explain why similarities are most often easily identified, while keeping the fluidity and context-sensitivity provided by the analogical process.

This paper offers a theoretical contribution which attempts to provide useful analyses of the notion of similarity through a distinction between several forms of salience. The aim is to present a model to integrate the different factors which influence the analogical process in determining the importance of features. We hope these preliminary analyses will be beneficial for modelling the analogical process.

2. Strictures on Similarity

2.1. Respects of Similarity

In 1972 [4], Goodman presents several arguments against similarity which leads him to dismiss the notion entirely. His rebuttal is mainly addressed to Carnap's geometrical model [10] of similarity. Nevertheless, some of his objections are also problematic for featural models of similarity and any other account of similarity, particularly his focus on the respects in which two things are similar.

Carnap [10] proposed a geometrical account of similarity which has been central to discussion of similarity in the twentieth century [8]. The geometrical model describes similarity in a geometrical space characterized by its properties: Minimality, symmetry and triangle inequality. Similarity is defined as the inverse distance between two objects: The closer two objects are in the space, the more similar they are. Goodman criticizes this approach on several points. One of his major points is the insensitivity to context: The appreciation of similarity depends highly on who makes the judgement and in which circumstances. Several studies in psychology [6,11] have shown that the properties of the geometrical space (minimality, symmetry and triangle inequality) are often transgressed when people make judgement of similarity.

Tversky [11] suggests another model to account for the context-sensitivity of similarity: The featural model. Similarity is defined as a function of shared and distinctive features, weighted with parameters which are influenced by context. Those parameters emphasize the shared features in some context or the distinctive features in some other. This model explains why judgements of similarity are not symmetric: North Korea is more similar to China than China is similar to North Korea, because the features of the subject of the comparison are weighted more heavily. As China has more distinctive features than North Korea, the distinctive features overweight the shared features when it is the subject of the comparison. On the contrary, North Korea has very few distinctive features and most of its features are shared with China, therefore amplifying their judged similarity.

However, if this account resolves the context-sensitivity of similarity, it doesn't answer Goodman's other objection against Carnap's account of similarity: The aspect in which two things are similar. Attributing a distance between two objects as a measure of similarity treats all features as having equal weight in assigning similarity. This is a characteristic of Tversky's model. Goodman, by contrast, argues that different properties vary in their importance for similarity. Goodman proposes for consideration, but dismisses just afterwards, a qualitative definition of similarity in place of a quantitative definition: Similarity corresponds to the respects in which two things are similar. He states:

> *"More to the point would be counting not all shared properties, but rather only important properties—or better, considering not the count, but the overall importance of the shared properties. Then a and b are more alike than c and d if the cumulative importance of the properties shared by a and b is greater than that of the properties shared by c and d."* [4] (p. 444)

We propose this formalization of Goodman's suggestion:

$$\left(\sum_{i=1}^{n} p^{C}{}_{x_i}\right) > \left(\sum_{i=1}^{m} q^{C}{}_{y_i}\right), \tag{1}$$

where p is the importance of a property x, shared by two objects a and b, depending on a context C, q the importance of a property y, shared by two objects c and d, and n and m the number of properties shared by a and b, and c and d respectively.

However, Goodman rejects immediately this definition of similarity. As Medin et al. sum up: "Goodman's argument against similarity as an explanatory construct is that the "with respect to" specification is doing the explanatory work, and not similarity itself." [12] (p. 258) Goodman holds therefore a reductionist view on similarity: Similarity has no explanatory power by itself, therefore it should be dismissed from any serious philosophical or scientific investigation.

We propose to consider the above definition (expanded from Goodman's proposition) as an answer to Goodman's very own argument. Goodman's view oversimplifies the role played by similarity. The respects of similarity do not hold all the explanatory power, because similarity itself also determines the importance of those respects. Similarity is more than a list of important properties, it is a list all the properties shared by two objects (which is open and not limited to a small number of properties) sorted and weighted by their importance. The process by which similarity determines the importance of each property is even more important than the property themselves.

Furthermore, Medin et al. highlight the importance of keeping the list of possible commonalities open:

> *"It is actually quite important that similarity judgements typically involve multiple properties. If the "with respect to" clause is filled in with a specific property, then similarity statements are of little*

> *use. If Items X and Y are similar with respect to only a single property, then very few inferences can be made about Y, even if a great deal is known about X. By having a similarity judgement that encompasses several properties, inductions can be made with more confidence. If X and Y are similar with respects to many properties, then what is known about X may well transfer to Y. In fact, one reason to say "X and Y are similar" instead of "X and Y are similar with respect to properties* P_1*,* P_2*, and so forth" is that one may wish to leave open the possibility that unknown properties are shared by X and Y. By making a nonspecific similarity claim about X and Y, one explicitly creates an expectation for new commonalities to be discovered (Gelman and Wellman, 1991; Medin and Ortony, 1989; Wellman and Gelman, 1988)."* [12] (p. 258)

The definition presented above has also the positive effect of offering a potential limit to the number of properties taken into account for the calculus of similarity. Each property does not have the same impact on the result: The properties that weigh the most dwarf the others, making them insignificant. For example, if we compare three glasses to determine which two are the most similar, we can take into account their shape, height and color, by attributing a weight to each characteristic on a scale of 0 to 1, depending on our evaluation of their importance: Respectively 0.85, 0.9 and 0.75. The three glasses have the same shape and height, but two are blue and one is green. Then the two blue glasses have a similarity score of 2.5 and the third has a score of 1.75 with the other two.

However, adding a new property, like the presence of a small chink on the green glass and one of the blue glass, which is quite irrelevant to our judgement, with a weight of 0.05, we have a similarity of respectively 2.5, 1.75 and 1.8, which does not significantly change our representation of the three glasses. We could even say that the attributed similarity of the three glasses is the same with or without the added characteristic of the chink. Therefore, if the computation of similarity is restricted to the few most important properties, a good approximation of the similarity value is obtained, even though it is open to potential new properties.

This definition also supports the flexibility of context. Suppose we are not in a neutral context, but in a goal-oriented one, where we want to choose which glass to throw away. Then we ascribe a weight of 0.9 to any crack or chink in the glass, which gives us a similarity of 2.5 between A and B, 1.75 between A and C and 2.65 between B and C. The glasses B and C are then considered more similar than A and B, because we have changed the value of p for one element in the new context. The new property which was unimportant before becomes central in this context.

Therefore, we claim that this definition of similarity defeats most of Goodman's objections against similarity. Similarity can't be restricted to one shared property or a list of properties, because it also integrates differing degrees of importance to each of those properties. Similarity sorts and weights properties and determines the most important in a context. A good approximation of similarity can be obtained by computing the few most important properties while keeping the open aspect of similarity stressed by Medin et al. [12] as a one of the most important characteristics of similarity. We will see in Section 3 how the analogical process can be used to provide a way of sorting the important properties and attributing a weight to each of them.

2.2. The Problem of Context

However, basing similarity on importance gives rise to a second difficulty, due to the fickle nature of importance. In the same article, Goodman argues that "importance is a highly volatile matter, varying with every shift of context and interest, and quite incapable of supporting the fixed distinctions that philosophers so often seek to rest upon it." [4] (p. 444). His main argument is what we will refer to as "the problem of context":

- Similarity is meaningless if we do not determine which properties the two objects have in common.
- Determining under which aspects two objects are similar is dependent on the context, which is itself highly variable.

- Because of this variation, similarity can say nothing stable about two objects: Therefore, similarity, for Goodman, is meaningless.

The problem of context is not so much about the high variability of context, the fact that it shifts every few seconds, but about the fact that this shifting reveals the many possibilities among which each context selects a few properties. Let's consider Goodman's example of a baggage:

> *"Consider a baggage at an airport check-in station. The spectator may notice shape, size, color, material, and even make of luggage; the pilot is more concerned with weight, and the passenger with destination and ownership. Which pieces of baggage are more alike than the others depends not only upon what properties they share, but upon who makes the comparison, and when."* [4] (p. 445).

The list of properties associated with the baggage stretches out each time a new context is considered: Shape, size, color, material, make, weight, destination, ownership, etc. If we consider other contexts we could add: Makeshift quality, resistance, volume for someone buying a new baggage, contents for customs officers, or even smell for security dogs trained to detect drugs. The list seems to go on forever, as we have only considered a few contexts and already come up with 13 properties. Some of those properties are complex ones which can be distributed into sub-categories like "content": Dangerous contents (which includes weapons, knifes and water bottles), forbidden contents (drugs, furs, seeds and sometimes cheese), spilling contents (creams, shampoo, perfumes), valuable contents (jewels, computer), personal contents (clothes, books), etc.

Among all those properties, which are to be considered in which context? The answer should be easy enough and be solved by pragmatic aspects: The most important properties are the ones associated with the goal at hand. However, some may appear important, because of some link with the goal at hand which is not foreseen. For example, smell is important for a police officer searching for drugs as his dog is able to detect drugs through its highly sensitive sense of smell. Similarly, color is important for the owner of the baggage as it is often the easiest way to identify one baggage among others. So, the determination of the set of properties in a given context depends on pragmatic aspects and other parameters like knowledge about the relation between several properties.

As Medin et al. put it:

> *"The argument is as follows: Similarity is assumed to be based on matching and mismatching properties or predicates. Two things are similar to the extent that they share predicates and dissimilar to the extent that predicates apply to one entity, but not the other. However, any two things share an arbitrary number of predicates and differ from each other in an arbitrary number of ways (see Goodman, 1972; Watanabe, 1969). The only way to make similarity nonarbitrary is to constrain the predicates that apply or enter into the computation of similarity."* [12] (p. 255).

Therefore, we need some way to sort the properties so that we only take into account the properties that are relevant for a particular situation.

3. Analogy as a Sorting Function

In 1993, three psychologists, Medin, Goldstone and Gentner [12] propose to solve the problem of context through the reference to the analogical process: The cognitive process in charge of analogical reasoning. It determines the important properties, i.e., the respects upon which the two objects or situation are similar. They argue that the analogical process is even more remarkable: It is also able to transfer knowledge from the source situation to the target situation. The analogical process is then able to identify important features that are not visible in the target situation. Similarity is a source of knowledge.

The analogical process is the cognitive function that deals with comparisons between two objects or situations, based on perceived similarity between them, in order to transfer information from the well-known situation to the new and unknown one. The key aspect of the process is to determine the relevant properties shared by the two situations, in order to solve the problem at hand (interacting with some objects, understanding new notions, etc.). We propose to make an analogy between categories and situations to understand the notion of similarity and how the important features are determined. For our study, the two notions are interchangeable, and we will use one or the other depending on their standard usage in the literature.

One of the most famous examples in psychological studies on analogical reasoning is the analogy made by Rutherford between the atom and the solar system [13,14]. In this analogy, the nucleus of the atom is associated with the sun and the electrons with the planets on the basis of the shared relation of attraction which causes the revolution of the later around the former. There is a great number of properties shared by the two systems: The spherical representation of the components, their relative mass, their relative distances, their relative length, their decomposition into some more elemental elements and their overall schema of the system. However, they also have a great number of differences, like their respective length, mass, distances which are distinct from 10^{21} factor for their length. The analogical process is therefore dealing with the problem of determining which properties are the more important to understand the analogy. A subject who would only see the common spherical shape of all the elements would miss the most interesting aspects of the analogy. They would therefore be unable to learn the causal relation between the attraction of the nucleus on the electrons and the revolution of the electrons around the nucleus.

3.1. Overview of the Analogical Process

The analogical process aims at describing the cognitive steps through which one can reach a proper understanding of the analogy.

The analogical process interacts with four major parts of our cognitive system: Perception, long-term memory, working memory and goals (see Figure 1).

- Perception handles the stimuli given by the sensory system and feeds this information to the working memory, where the analogical process takes place.
- The analogical process seeks a source situation from the long-term memory.
- The long-term memory gives back a source situation or a category, that is, a constructed representation of some acquired knowledge.
- The analogical process compares the two situations in the working memory, mapping the various parts together.

It attributes some evaluation to the mapping and makes inferences from the source situation and applies them to the target situation. The second representation of the target situation is richer and more complex. It contains some knowledge from previous experiences.

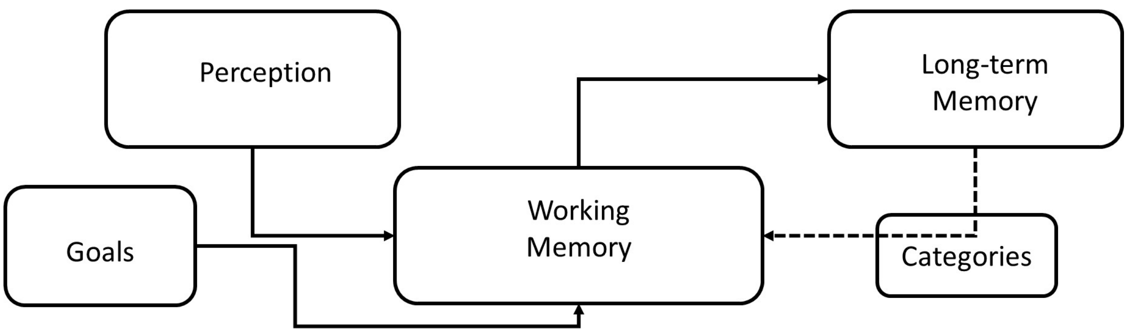

Figure 1. This figure represents how the different cognitive processes interact within the analogical process. The continuous lines represent the information which is transferred from one part of the process to another. The dotted line represents the extraction of categories from long-term memory to feed the analogical process in working memory.

Analogical reasoning or spontaneous analogical learning has been decomposed by Gentner [15] into five subprocesses:

- Retrieval in long-term memory,
- Mapping between the target and source situations,
- Inferences and transfer of properties from the source to the target situation,
- Evaluation of match and inferences, and
- Sometimes extraction of a common schema.

To this list, we would like to add the constitution of the target representation, which is one of the major part of the process as emphasized by Chalmers et al. [13]. Those six steps compose the analogical process which does not only handle complex analogies and analogical reasoning, but also literal similarities and cases of simple or complex categorization.

3.1.1. Constitution of the Target Situation

First, a representation of the target situation must be built, may it be as simple as some predicates attributed to an object. In some cases, for example Rutherford analogy between the atom and the solar system, it may require a representation which is already quite complex, composed of several superimposed relations, as pictured in Figure 2.

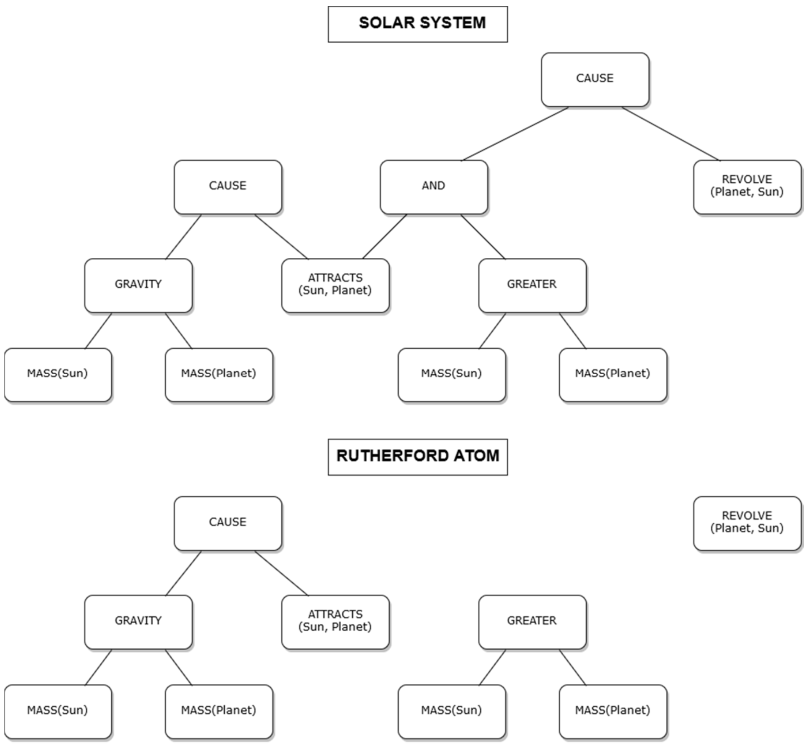

Figure 2. The Structure of Properties in source situation and target situation, from Chalmers et al. [13].

We must assume that some elements are given first, some atomic part which cannot be decomposed into subparts. They are at the foundation of more complex representations. In this example, it would be the nucleus and the electrons, and the relations between them are to be constructed by the analogical process. Someone could nonetheless argue that those very first elements are themselves quite complex and should come from somewhere. Where do those elements come from? How many first elements are there and how much complex should they be? This is the first puzzle of the analogical process.

3.1.2. Retrieval in Long-Term Memory

Once the first representation of the target representation is determined, the analogical process seeks a source situation in long-term memory. This is the process of retrieval. The analogical reasoning uses some properties of the target representation to identify a potential source situation in long-term memory. This step is not required in the case of explicit comparison where the two compared situations are given. However, it is one of the most difficult challenge in case of spontaneous learning or natural categorization: How does the analogical process select a source situation among the thousands of situations registered in long-term memory? In very complex cases, like our example of the atom, this is required to understand spontaneous creativity.

The memory retrieval raises two questions: What is the basis of the selection of the properties from the target situation on which will be based the search in long-term memory? How is one situation selected in long-term memory among several possessing the same properties?

3.1.3. Mapping

Once the two situations are identified, the analogical reasoning compares their components to identify the properties they have in common. The analogical reasoning proposes some matches as identified in the following schema (Figure 3). For example, in the successful mapping between the atom and the solar system, the nucleus of the atom is associated with the sun, the electrons with the planets, the gravitational attraction with the electro-magnetic attraction.

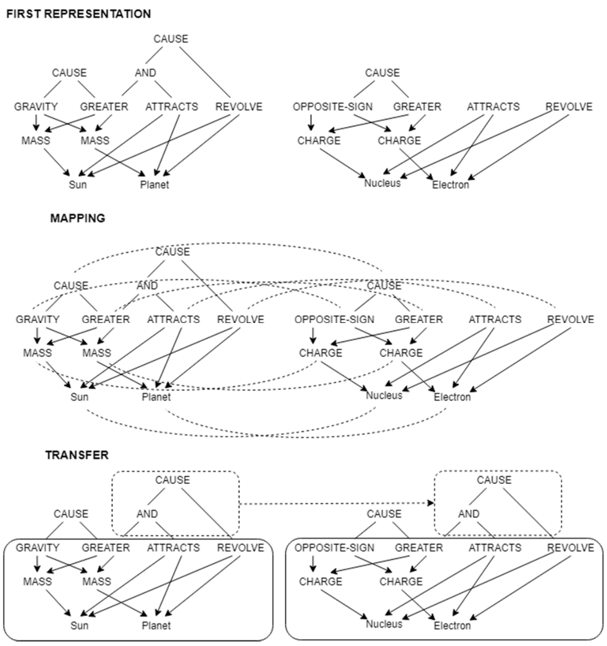

Figure 3. The analogical process: First representation, Mapping and Transfer, from Wareham et al. [16].

The difficulty in this process is to determine which elements should be paired together. The analogical process is not constrained to map together only the elements with the same labels, but is able to create matches that are not identical. In our example, mapping the nucleus with the sun and the gravitational force with the electro-magnetic force is far from evident as they are quite different. However, if there are no constraints on the mapping process, there are as many possible matches as there are elements in the two situations. More precisely, as argued by Holyoak [17] there are $m!n!$ possible matches where m represents the number of elements in the target situation and n the number of elements in the source situation.

3.1.4. Transfer

Once the matches are constructed between the two situations, some properties are transferred from the source situation to the target situation. Those are the potential inferences made from the source situation to the target situation. Analogical reasoning enables one to learn from the comparison between the two situations thanks to the process of transfer. In our example, the causal relation between the attraction force and the revolutionary movement is transferred from our representation of the solar system to our representation of the atom (see Figure 3). We could also consider that the revolutionary movement of the smallest element is also transferred. This raises the question of the selection of the potential properties to transfer: Why are some properties transferred and not others? Why don't we transfer the notion of temperature from the solar system to the atomic system?

3.1.5. Evaluation

Once inferences have been made, an evaluation of the resulting mapping and inferences. This evaluation is based on several criteria: One of the major criteria is structural alignment [18,19]. Structural alignment measures the number of connections created among the predicates. The analogical process aims at maximizing the number of connections and more importantly for Gentner, of higher-level connection. For example, the spherical shapes of the elements of the atom and solar system is an isolated property and will be dismissed for having a very low structural power. On the contrary, the relations of attraction and revolution are connected by a causal link. Therefore, the analogical process will evaluate those relations as more important, because they join more properties and reveal a common causal structure between the two systems. Another criterion is goal achievement [20].

3.2. The Three Problems of Analogical Process

The goal of the analogical reasoning is to identify the shared properties and dismiss the irrelevant differences. It must also identify the most relevant properties the two situations have in common [15]: The atom and the solar system are not similar because they have spherical elements, for example, but because the causal relation between their centers and peripheric elements is the same. Not only the analogical process dismisses irrelevant differences, it also emphasizes the most important common properties, among all properties. Therefore, the analogical process can be considered as a sorting function.

However, we can identify three problems for the analogical process: The problem of retrieval, the problem of mapping and the problem of transfer. The problem of retrieval is to determine which source situation should be retrieved from long-term memory. It involves two mirror problems: Determining the more important properties of the target situation and determining which source situation is the most appropriate to make the comparison. The problem of mapping deals with determining which properties of the two situations should be mapped together. The problem of transfer deals with determining which properties should be transferred from the source situation to the target situation.

Those three problems are analogous to the problem exposed by Goodman as they arise from the sheer number of possibilities to take into account. The analogical process needs to be flexible enough to account for the various changes of context and also to be constrained in order to be manageable in a limited amount of time. The analogical process is quite flexible in the sense that it is not restricted in its mapping process: It is able to map any property with any other property. However, it follows some guidelines to estimate the appropriate mappings. One candidate is structural alignment, proposed by Gentner [21] as a factor controlling the evaluation of the correspondences and selecting the most appropriate ones. Another one is the notion of salience.

All those problems correspond to a problem of computational explosion, as already observed about Holyoak's equation. We can propose a similar equation for the problem of retrieval: $o!p!$ where o

is the number of properties in the target representation and p the number of possible source situations for each property. For the problem of transfer, we propose the equation: $q!$ where q is the number of properties in the source situation that are not mapped to the target situation.

4. Salience as a Heuristic

Salience is a heuristic inside the analogical process as it works as a shortcut for the computation. The analogical process still needs to evaluate the relevance of the result and start the computation again if necessary, but salience is used as a timesaving method.

The notion of salience is used as a heuristic during the process. Salience can be defined as the fact that some properties stand out among others. It displays "the status this information has in people's underlying representation" [22]. It is often associated with speed of processing: The salient properties are the fastest and the first to be processed. It influences the process by putting at the front some properties over others. It can be understood as a prioritizing function within the analogical process. We propose to extend this view and to represent salience as an index number attributed to a property which corresponds to its weight compared to other properties at one point in time. Each property enters the analogical process with a salient index number which is reinforced or lowered during the process.

One could argue that similarity is still meaningless without salience, that salience does all the work and that similarity should be abandoned and replaced by salience. We argue that salience and similarity fulfill different functions in the identification of a situation and an object. Salience is the capacity of objects, or properties, to appear more important in a situation. Similarity is a comparison between two situations or objects. Similarity uses salient properties as a shortcut to order properties in the comparison. Each similarity judgment is based on some saliences. But every salience does not always trigger a similarity judgment. Some salient properties are perceived, but are not compared with, a source situation, because the pragmatic aspects do not require a comparison. For example, a red dot among green dots is salient. But the red dot is not perceived as similar to anything, because the situation does not require to infer knowledge from this configuration.

We distinguish three kinds of salience: Sensory, categorical and operational saliences. We establish the distinction based on their different functions in the analogical process. Sensory salience originates in the perceptual system and is derived from our brain development. Categorical salience reflects the hierarchy inside people's knowledge structures. Operational salience refers to the ongoing salience attributed to one property during the analogical process.

4.1. Sensory Salience

Sensory salience represents the selective attention and speed of processing of the perceptual system. It grounds the analysis of similarity by calling on biological developmental and evolutionary explanations. It is very stable across time and individuals.

We make the reasonable hypothesis that some properties appear more salient, because of the structure of our sensory apparatus. This hypothesis seems a basic requirement to understand our ability to communicate with other human being. As Quine argues:

> *"[. . .] Each man's spacing of qualities is enough like his neighbor's. For the learner is generalizing on his yellow samples by similarity considerations, and his neighbors have themselves acquired the use of the word 'yellow,' in their day, by the same similarity considerations. The learner of 'yellow' is thus making his induction in a friendly world. Always, induction expresses our hope that similar causes will have similar effects; but when the induction is the ostensive learning of a word, that pious hope blossoms into a foregone conclusion. The uniformity of people's quality spaces virtually assures that similar presentations will elicit similar verdicts."* [23] (p. 47).

Sensory salience is required to ground our shared reference to the world and our ability to learn the meaning of words by ostentation. Quine's argument stands for perceptual features like colors.

However, we propose to extend this argument for other properties like shape, movement, orientation and a few others [24]. Those properties determine what we will look for first when seeing an object in a given situation.

This hypothesis seems reasonable enough based on ancient and recent studies on perception. Some studies on perception [25,26] suggest that there are some primitive features in perception which the attention focuses on. These primitives are limited to shape, movement, orientation, symmetry, color and a few others. This reduces considerably the complexity of any perceptual stimulus. Moreover, we will draw the hypothesis that some of these primitives are processed faster than others (for instance, the detection of movement is faster than the identification of forms or colors).

Sensory salient properties are not always the most important or the most relevant to solve the situation at hand, but they are the fastest and first to be handled by the analogical process. We will nonetheless draw the hypothesis that the stimuli processed the fastest were often the most important ones at some point in our biological history: There was a strong selective bias in favor of those able to process the most important stimuli with great speed and accuracy. For instance, we imagine that detecting movement is a very important feature for mammals and other species, because an object in motion is often either a predator or a prey. If an animal is able to identify and react to an object in motion more quickly than others, it has an evolutionary advantage because it is able to catch more prey or flee predators more often.

Sensory salience is determined by our sensory apparatus. It is mostly innate and shared with every other human being. It grounds our shared reference to the world as "it is reasonable that our quality space should match our neighbor's, we being birds of a feather; and so the general trustworthiness of induction in the ostensive learning of words a put-up job." [23] Sensory salience is the ground for first-order categorization. Salient properties are handled first by the analogical process, allowing access to an initial level of knowledge. For instance, Spelke's core-knowledge theory [27] assumes that some features automatically trigger a certain kind of knowledge she calls "core-knowledge". For instance, the detection of motion activates the category 'agent', which holds interconnected expectations: Agents cause changes, have directed goals, and act efficiently toward their goals.

Salient properties constrain memory retrieval. They give direct access to some categories through the activation of identification properties. Categories include identification properties or surface features which are first activated when an object is seen. Those identification properties are not entirely incidental but are considered by our cognitive process to be a good heuristic for more essential properties. Memory retrieval therefore seeks the identification properties of a category in order to have access to deeper knowledge. Identification properties are often sensory ones, the more accessible ones for our senses, like shape or color. This allows for a fast access to previous knowledge.

4.2. Categorical Salience

Categorical salience corresponds to the structure of one's knowledge in long-term memory. It is generally highly stable across time and context even though it might vary across individuals and may change slightly or radically with new knowledge.

Categorical salience reflects the hierarchy inside people's knowledge structures. Concepts are a way to structure one's knowledge. But inside concepts, knowledge is itself structured by salient properties. For example, the concept of a chair includes several ways to use it: Sitting on it, climbing it, using it as a weapon or building a child castle. But when someone thinks about a chair, he first thinks about sitting on it. All the other uses are in his long-term memory, because he can think about them as needed, but they are not in the forefront of his mind. A chair is a seat before being a stepladder.

Categorical salience constrains memory retrieval, mapping and transfer from the source situation to the target situation. During memory retrieval, categorical salience determines which situation will be selected first. The analogical process selects first the situations which possess the desired property as a salient one. The analogical process maps together first the salient properties, with a priority given to the target situation. The analogical process does not map properties at random, but starts with the salient properties from both situations. Categorical salience also constrains the transfer of knowledge from source situation to target situation. The analogical process transfers first the salient properties of the source situation.

Vosniadou [28] notices that prior knowledge can disrupt the analogical process, in particular in children. Vosniadou [29] identifies misconceptions of the Earth in children trying to interpret the sentence "The earth is round like a ball." Even when the shared property is explicitly given, "round", children interpret the Earth as being flat, but circular like a disk, or as being round, but with a flat surface, inside on top of which we stand. She interprets this result as the effect of the salience attributed to earth flatness. Conceiving earth as flat has an important explanatory power in children's naïve physics. Because of the opposition between the roundness of a ball and the naive conception of the Earth as flat, the transfer from one to the other fails. There is nonetheless something which is transferred from one to the other, transforming the naive conception of Earth as a flat surface into the idea of a circular Earth.

4.3. Operational Salience

Operational salience refers to the ongoing salience attributed to one property during the analogical process. It is the most flexible form of salience, influenced by sensory inputs, categorical knowledge and goals. We argue that the salient properties processed by our working memory are the result of converging processes from sensory saliences, categorical salience in long-term memory, goals and some other constrains specific to the analogical process like structural alignment [19,21]. The flexibility of the system depends on all the different processes converging together. This proposal concurs with Holyoak's multiconstraint theory [17] on the multidimensional aspects of the analogical process and proposes to represent the result of the various changes with a salience index number.

First, the analogical process receives input from the sensory system, with properties varying in their salience, often due to their processing time. Sensory properties trigger the first level of the analogical process. The analogical process seeks a source situation in long-term memory and compares this source situation to the target situation by mapping the properties together. If there is a match, it transfers the salient properties from the source situation to the target situation. These new properties become salient in the target situation and overshadow the previous properties. Based on these new salient properties, the analogical process runs on and starts the process again till the system reaches the relevant information to solve the problem at hand.

The analogical process uses two strategies to find the relevant information: A heuristic we call "spontaneous categorization", which is a very fast and easy process based on sensory and categorical saliences, and a slower process that consists in breaking down the previous representation to reach less salient properties.

Modifications of Operational Salience

There are two major kinds of factors which influence the operational salience: The analogical process itself through the process of transfer and externals factors like goals.

Once the analogical process has mapped the two situations together based on sensory salience, it transfers properties from the source situation to the target situation. The transferred properties become more salient than the previous ones and erase them from working memory. Which properties will take the vacant space depends on categorical salience. We call this process "spontaneous categorization".

The most frequent way to change the salience of a property, outside of "spontaneous categorization", is through a pragmatic shift [20], when a goal differs in instant t+1 with those in instant t. For instance, you are working at your desk, sitting in your chair. But then the light goes out and your goal switches from writing to changing the lightbulb. You are too short to reach the lamp over your desk, you need a stepladder. However, you do not have one in your office. You are pacing in your office looking for a solution, and you see the chair you were sitting on a minute before. Because your goal has changed, the analogical process inhibits the salient property "seat" associated with the chair and seeks other uses for the chair, in relation with a stepladder. If you had already used a chair as a stepladder several times, the analogical process will find this previous usage very fast as a source situation and transfer this knowledge to the current situation. But if you had never climbed on a chair, the analogical process will take some more time, because it will break down the concept of chair into more basic properties, for instance "made of wood or steel" or "strong and sturdy". "Breaking down" a concept is considered in the sense proposed by Chalmers et al. [13] when describing the Copycat process, that is, deconstructed in order to access less salient information. This deconstruction takes place in working memory. From "strong and sturdy", which is shared with the stepladder, the analogical process infers that you can climb on the chair like you do on a stepladder. This process takes more time and is not always successful, because breaking down the initial representation into subparts takes cognitive effort.

5. Accounting for Similarity

We now have some answers to Goodman's dismissal of similarity. He highlighted two important aspects of similarity we ought to take into account: The respects according to which two things are similar and the context-sensitivity of similarity.

Goodman claims that any theory which reduces similarity to a distance between two objects misses its specificity. Goodman considers another definition of similarity as a list of important properties. However, he argues, this definition subdues the explanatory role played by similarity. Goodman's reductionist position leads him to dismiss the notion of similarity entirely. To counter Goodman, we analyzed another definition of similarity as "the overall importance of the shared properties", that is, the list of all the common properties weighted by their importance. Similarity is therefore more than the restricted list of important shared properties. It is a list ordered and weighted by importance, open to potential new properties which could lead to new inferences. We conclude that this definition answers Goodman's first objection against similarity.

We faced afterwards the context-sensitivity challenge of similarity. Determining for each context what the important properties are among thousands of them is a problem that needs to be solved. Goodman presents his argument through the example of a baggage at an airport: What is more important about the baggage depends on the point of view of the person making the judgement: The pilot is more interested with weight, the owner with destination and the spectator with color. Any account of similarity needs to account for such a diversity of judgements. At the same time, it poses a challenge because each new context reveals a huge number of possible properties to include in the computation. Determining what the important properties are is not trivial.

The analogical process can, though, act as a sorting function that helps to determine the importance of properties in a given context. In comparing two situations or objects, the analogical process identifies the most important properties. For example, in the analogy between the atom and the solar system, the spherical shape of the planets and electrons is less relevant than the causal relation of attraction between the center and the peripherical elements. The analogical process analyses several parameters coming from perception, long-term memory and goals, as well as internal constraints like structural alignment. This structure offers a huge flexibility to the analogical process which can make correspondence between objects that are dissimilar (like the electrons and planets).

However, this flexibility comes at the cost of a computational explosion. The more properties enter the computation, the possible paths the analogical process has to analyze, the more time it takes to come with a result. We identified three problematic steps in the analogical process: The retrieval, the mapping and the transfer.

We claim that salience is used as a heuristic during the process, a shortcut into the computation. Salient properties stand out among others and are computed first. The analogical process evaluates the solution proposed by this first computation. If the proposed solution is successful, the analogical process stops there. But if the solution is insufficient, the analogical process runs again based on other properties. Salient properties do not always lead to a successful solution, but they do often enough to be trusted most of the time. We distinguish three forms of salience based on their role in the analogical process.

When the analogical process compares item, it is influenced by several forms of salience. In any context which has to do with sensory input, in particular categorization, sensory salience puts forward some properties before others (shape before color). This effect is determined by our biological system. It builds a first representation of the target situation which guides the process of retrieval. Once a target situation is found, categorical salience plays a determining role in mapping and transfer. The analogical process maps first the properties more salient in the target situation (sensory salience) and source situation (categorical salience), with a preference for properties in the source situation. The transfer depends on categorical salience only: The transferred properties are the more salient unmapped properties in the source situation. When the analogical process is influenced by sensory and categorical salience alone, we call this process spontaneous categorization. It is very fast and works as a short cut into the analogical process. It provides an answer to the problem of computational explosion. However, in some context, operational salience will play the overriding role by breaking down previous representation to access less salient properties, which are deemed more relevant given the goal of the person doing the comparison. This process comes with a cost in time and cognitive capacity. It explains the flexibility of the analogical process, but also the complexity and difficulty of some analogies.

Therefore, salience offers an answer to the problem of computational explosion inside the analogical process while keeping the flexibility of the analogical process, emerging from the various constraints which are taken into account.

6. Conclusions

Pre-reflectively, similarity might seem to be based on matching up properties. This, arguably, is mistaken, or at least needs to be strongly qualified. Similarity judgements seem to depend on assessment about property importance. These assessments can themselves vary with context.

The analogical process provides a model for ranking properties. It integrates several aspects of context, among them knowledge and goals of the person making the judgement, as well as internal constraints like structural alignment.

But in addition, salience orients the analogical process in providing a shortcut among all the possibilities to compute. Salience is influenced by our sensory apparatus (sensory salience) and our background knowledge (categorical salience), both of which interact in complex ways with the highly context sensitive operational salience.

Similarity can therefore be seen to be central to cognition. It seems well enough defined to provide for a sound support for definitions of concepts, even if Goodman has shown that some accounts of similarity are vacuous.

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