Cognitive Mimetics – SMT Model

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Abstract
Cognitively inspired intelligent systems have recently been attracting renewed attention. However, understanding this approach in terms of design processes seems to be still in the early stages. We propose that something essential in the endeavor can understood through the lens of mimetic design, and in particular *cognitive* mimetics. We will frame the discussion through a model of mimetic design consisting of a *source,* a *target* and a *mapping relation.* At this abstract level, it provides a canvas into which different types of cognitively inspired design processes can be mapped - descriptively and prescriptively depending on purposes. It provides a starting point against which theoretical, ontological, and methodological questions, commitments, and specifications can be made explicitly.

Keywords
Cognitive Mimetics, AI Design, Intelligent Technology Design

1. Introduction

The rise of intelligent technology has been periodically making headlines and capturing the public imagination at least since the 1950s. The most recent cycle has been fueled by advances in the availability of data, development in machine learning algorithms, and computational power. More broadly, modern computers have made it possible to conduct intelligence demanding tasks with machines and consequently the problem of how to design such machine-driven processes has emerged. Recently, calls for bringing cognitive science research and AI research closer to each other in designing intelligent systems have been made [1][2].

This makes sense, given that the most evident example of intelligence in nature is human thinking. The ground of any cognitive research is the idea that such information processes can be explicated and often also modelled on computers. This means that one can find and implement an information process which can carry out complex cognitive tasks. Consequently, it makes sense to analyze human thinking to develop intelligent machines. In fact, the Turing machine was a perhaps the first example of human (mathematician's) information process to be realized by an abstract conceptual machine processing [3]. One dimension of Turing's thinking is that machines can, in some sense, think like people. A logical consequence is that machines can carry out tasks which have earlier been typical to people only.

The fundamental idea is that machines can imitate human intelligence demanding processes. Imitating nature is a standard idea in technology design and its best known as biomimetics [4]. In it, designers typically imitate the physical and biological structures in constructing technical solutions. However, biomimetics of this type is not a good approach in developing intelligent technologies, because intelligence is based on information processing. Mimicking human information processes by machines is different from biomimetic design. This new kind of mimetics we have termed cognitive mimetics. In developing cognitive mimetics, it is important to describe the structure of mimetic

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design. Designers must have an idea about how mimetics transforms the analysis of human information processing into intelligent technological applications.

2. Design – cognitive mimetics

Everything artificial is designed – including intelligent technology [5]. Although AI has often been placed somewhere "between" cognitive science (as a humanistic study) and computer science, it can be characterized more as a "science of computational intelligence" than a design science for intelligent technology. When attention shifts from artificial intelligence as science to intelligent technology as a concrete product of design processes, new types of questions relating to design emerge. Some the questions expand the scope from closed and specific technical problems to wider issues like human technology interaction, ethics and life [6] or the wider context or system in which technology is designed [7]. Another way of saying this is that intelligent technology is not semantically uncommitted (or committed to a "toy world") in the way an algorithm or logical calculi *can* be.

Lieto [1] has pointed out that two information processing systems may have either functional or structural similarity in terms of how they operate. Functionally equivalent systems succeed in the same information processing tasks, like games, but have little correspondence on *how* they do it. Functional equivalence (or surpassing) is of course a given in the whole endeavor of AI. The idea behind structurally similar systems is to make the correspondence stronger, having the AI system to correspond with (an idea or model of) human cognition. This opens interesting questions in terms of what is possible, feasible or sensible with respect to structural similarity and indeed at what level the mimetic design is operating.

From the present perspective, the endeavor does not hinge on structural similarity. A couple of reasons can be mentioned, first is that the mimetic process evolves and the process is iterative. It is to be expected that even cognitively inspired AI systems initiate their own particular problems and questions in the domain of technology, and gradually separate from their origins as they develop. This does not discount or make their mimetic origins irrelevant. Second reason is that we attempt to broaden the scope from structure (mechanisms, processes) to information content. This line has its' own equivalence issues, but the point is not to worry too much about the equivalence between the source and the target, but to open as many lenses on the source as is relevant and to conceptually be able to accommodate different perspectives. There will always be structural differences between the source and the target in mimetic design, but the crucial issue is how to achieve a mapping from a proper understanding of the source, at the proper level of abstraction [9] into the target.

Thus, the essential *analytic* task in mimetic design is to discover *what makes the source an effective solution to the problem it solves or function it achieves.* The essential *design* task in mimetic design is to achieve a *mapping* from this (or these) to technology (the *target).* This is typically a relational schema, involving a capacity (in the sense of *(a) power*) and a context (or environment). Thus, one may (post hoc) see that bird flight may have served as inspiration for human flight, but the problem was not solvable by any (relatively high fidelity) copying from bird to technology. Here the realities of the *target* set important constraints in terms of the solution. Nevertheless, it is now clear that both birds and planes solve the same problems of achieving lift, propulsion, and control in the context of aerodynamics. Similarly, computers can process information although they operate on a different substrate and by different means than humans and can even surpass humans in certain well-defined tasks. When basic capacities or powers are combined with a context (or environment) a third element (or class) arises which we can call the result. In the case of birds and aeroplanes, we identify it as *flight* and associated behaviors. From a reverse engineering perspective, the *flight* is thus a design -goal and the task is to discover/construct the necessary components to achieving it. In cognitive mimetics, such reverse-engineering from some concretely operating human information processing system to its constituent cognitive elements and the context has its' role. However, it is important to note that the result (of powers and context) here is more than a design goal: it is a source in the mimetic process. The concrete information process (representations and content) that emerges as a result of elementary mechanisms in a context, forms thus an additional analytic source which merits attention. From our point of view, this third element is crucial for intelligence, since it explicates directly the level of the effective solution even though it, in turn, relies on other basic powers or capacities. This level can be explicated on its' own terms *as* information contents, rather than explained in terms of mechanisms. It could be argued that given differences between computers and humans in terms of operational mechanisms, the explication and mapping of information processes provides a fruitful line of inquiry and design, because it opens up directly the concrete information processes at play in intelligent action.

Generally defined, cognitive mimetics is about using human information processing as a source and intelligent technology (specifically digital computers) as a target. Notice, that identifying the reasons for the effectiveness of the source is not a trivial task and even less so when information processes are concerned. There simply are no "meters" or "microscopes" that would display the effective reasons at the level of information processing and so the conceptual level is highly important for enabling discovery (and mapping to technology). Here, (general) explanatory frameworks and viewpoints in cognitive science have a crucial role to play. Cognitive mimetics shares the basic idea (with cognitive science, AI and computer science) that the conceptual common ground between the domains of natural and artificial intelligence is in information processing.

Cognitive Mimetics provides an approach, a model, and methods for how to use human thinking as a mimetic source of design solutions for intelligent technology. There are accordingly four levels at which cognitive mimetics can be understood:

1. As an approach
2. As a model (of a design process)
3. As a specification and a series of commitments vis-à-vis the model
4. A set of methods vis-à-vis the specification

We turn now to the model of mimetic design: the SMT (***s* → *t*)** model consisting of a *source, a target, and a mapping relation.*

2.1. The SMT model

The SMT model outlines the form of any mimetic design process as s → t. This is simply to point out that there must always be a source (s), a target (t) and mapping process (i.e. design process) that takes something of the source in order to create some artefact (or aspect of one). What it provides for us is a framework for asking questions, which, when reaching the proper level of specification produces a type of mimetic design. Once this level of specification is reached, the very same framework (now populated with ontological and methodological commitments) can be then used to pose more specific – empirical and context-specific – questions within a concrete design process. In this context, the SMT model becomes an instance of (and within) a design process. Thus, there are two levels to discussing (and using) the SMT model: theoretical and concrete.

The skeletal form of the model can be elaborated by noting that given the fact that the source (and the target) are viewed at a level of abstraction (LoA) [8], the mapping relation involves (multiple) abstraction processes and syntheses into the conceptual design of the system (target). Moreover, the *target* is also often fixed at one level or another: at the very least one is typically looking at a *computational* system, or perhaps one seeking to build *a rational agent* or an *intelligent chemical control system* for an industrial process - or all three (or many more) as if nested Russian dolls of increasing specificity and semantic commitment. In terms both of design *processes* (instances) and theoretical specifications (types), the mapping relation is an iterative one. The questions the SMT model poses thus changes in terms of the design phase on the one hand or whether one is making theoretical specifications on the other.

This model only frames the discussion. The real content and character of (cognitive) mimetics and any cognitively inspired AI design process emerges from asking the basic questions this poses: what is our source and respective LoA? What is our target: both generally (computational systems) and specifically (an empirical design need)? What do these mean in terms of the mapping relationship? What theoretical presuppositions are brought to bear? What are the methodological implications of the commitments made with respect to the source on the one hand, and the constraints set by the target? It is this partially shifting set of commitments and needs across design phases that will give concrete character to the approach, both as an instance and as a type. Note, that a cognitive mimetic process might involve the mapping of a cognitive model, architecture, or mechanism into a technological system, which seems to be the common approach in this thematic area. As we have however intimated, there are other possible cognitively based approaches as well, for example the mapping of empirical and concrete information processes and contents into technology (possibly but not necessarily in conjunction with the previous). There is a tremendous amount of possible nuance to the issues and the basic goal of the SMT model is to facilitate discussion on these matters and enable focus and clarity.

2.2. Specification of Cognitive Mimetics

The specification (and commitments) occur at two principal levels: theoretical & foundational, and practical. Given specifications on the theoretical level, the SMT model becomes essentially a boilerplate for a design process, into which a design goal can be mapped and in terms of which the source can be (further) specified and the design process can proceed. Here we will offer very briefly four specifications: a general commitment to information processing; a specification in terms of information contents; a note on applicable methods; and a design target that emerged over our research in industrial contexts.

The concept of information processing is fundamental to cognitive science. The idiom of computational information processing in particular has been defining. It is almost obvious but discussing what is meant by it is important as the concept is notoriously multisided [9]. The fundamental commitment in terms of the entire mapping relationship in cognitive mimetics is made with respect to information processing. Namely, both the *source* and the *target* are viewed at the level of abstraction corresponding to information processing. This sets cognitive mimetics apart from considerations of, for example, the physical structures of the brain on the source side, or computer hardware on the target side. Here information is understood in a broad sense and not only in the syntactic mode. The stronger notion of information we advance turns importantly on the concept of information *contents.*

Recall that mimetic design can be characterized in terms of seeking *what makes the source an effective solution to the problem it solves or function it achieves.* It is clear, that in a general sense information processing is the basic substrate for intelligence. This by itself does not say much of course, but it provides the conceptual ground for the possibility of multiple realizability. Probably the most influential ideas in cognitive science and AI have turned on basic (universal) information processing mechanisms set against a formal background. These certainly form a part of what makes human cognition effective in general and have in a complex way influenced and been influenced by the formal-computational idiom. However, if we turn attention to a broader view of information and begin to include contents as an element in intelligent information processing, different methodological and theoretical questions arise. We can sketch out the significance by turning to the psychology of thinking. Understanding human thinking is essential for any researcher interested in developing intelligence in society, people, or machines. One can consider thinking from sociohistorical, philosophical or psychological concepts. Nevertheless, psychology of thinking opens direct links between human and machine information processing [10].

Thinking is based on mental representations. These are information states. A thought represents something and provides a "picture of the states of affairs". Intelligent actions are based on the validity and truth of these representations. However, for this reason, intelligent information systems must also represent correctly their domains. Intelligent representations in human mind are called mental representations and their information contents can respectively be called mental contents. Machines are intelligent as far as information contents in representations are intelligent [11][12][13]. Psychological thinking relies on the analysis of the properties of human mental contents and their investigation can be called content-based psychology [11][13]. The term content-based refers to the idea that the properties of mental contents are used in explaining some behavioral phenomenon. For example, the limitedness of chess players' search spaces can be explained on the ground of a small set of tacit rules which chess players use in constructing their mental representations [12]. To analyze validity, relevance, or truth of mental representations is has been essential to focus on mental content and ground both analysis of problems as well as explanation of action on the idea of contents [11].

This provides now an orienting LoA on the source. A natural question is how do we explicate our source and analyze it? Psychology of thinking and expertise studies [15] have given indispensable method and tools for surfacing and explicating mental contents. As Turing's example shows, not even "subjective" methods should be discounted, as the results can be very effective and valid. In practice, the most nuanced and intelligent representations and contents can be found in people with expertise in the domain. As our work has largely proceeded in empirical contexts, the way in which cognitive mimetics has become specified tracks some of its features. In maritime contexts we have used expert studies combined with a simulated environment, and in pulp and paper industry we conducted observational research combined with think aloud and protocol analysis [15]. These methods have worked well and have proven sufficient for our purposes.

It has become clear that having some relatively concrete target in mind is important for focusing the work and to construct a "package" that can do practical work. To this end, our work has resulted in fixing the target for industrial contexts as *human digital twins* [15]. Human digital twins (HDTs) are basically for humans what digital twins are for the physical side of industrial processes. The main idea is to use cognitive mimetic research to construct models of human thought and action vis-à-vis industrial systems (and traditional digital twins). The essential point is to base the HDTs on empirical human operators and allow through the cognitive mimetic idea (and specifications of the model) to bring cognitive research into industrial contexts and thus enable the development of the design processes of intelligent technology.

3. Conclusion

Here we have provided a general model of mimetic design to turn attention to design scientific questions in AI development that takes inspiration from human thinking. The idea has been to develop a model that is both sufficiently flexible to allow discussion and specification on the different and necessary perspectives for those engaged in this thematic area. Using the model as a guide, we briefly specified cognitive mimetics through a few key issues. In this specification, mental contents and empirical information processes become key in analysis of the source, given the overall target as intelligent technology. Two issues arise from these commitments: first are methods, dealing with how to discover information contents and processes in empirical settings. Second is the target, which we have specified as human digital twins in the industrial contexts where our work has mainly proceeded.

Looking forward, the main issue on the table is in terms of the mapping relationship. Having specified the source in terms of information contents, important foundational issues arise in terms how operationalize these in the target. The basic issue is how are representations constructed in the mapping relationship. In our thinking, formal specifications of information contents in fact have almost no contents at all, owing to the nature of formal systems (abstraction). The important result of these considerations, with respect to the SMT model, is that when the target is a computational system and the source mental contents, the mapping relation is a process of fixing semantics or translating mental contents and their implications into the formal-computational idiom. This opens interesting problems, and in a way clarifies some of the basic challenges in AI which call for solutions in the era of intelligent technology.

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5. References

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