Cognitive mimetics – Main ideas

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Abstract - *The modern era of emerging intelligent technologies necessitates the development of technology-specific design methods. Artificial intelligence (AI), robots, and autonomous systems are expected to replace humans in many intelligent information-processing tasks. To develop such systems, however, designers need to understand what happens in the minds of the people completing such tasks today. Designers also need methods to develop intelligent technological solutions. In the present paper, we discuss cognitive mimetics as a possible tool for designers of intelligent technologies. Like biomimetics, cognitive mimetics is an analogy-based method; however, instead of looking for structural and material analogies between natural and technological solutions, cognitive mimetics searches for analogies and similarities between existent human and animal information processes and technical solutions. Thus, cognitive mimetics can be useful as an idea-generating method for designers developing intelligent technological solutions.*

Keywords: Mimetic, Design science, Cognitive mimetic

1   Introduction

Technology improves the quality of human life. Thus, it is logical to begin designing new artefacts to analyze how people live and the properties new technical artefacts should include to improve the quality of this life. This kind of life-based design is a good addition to designers' traditional technology-driven design and development paradigms [10, 17]. Instead of merely looking at how one can use existent technical artefacts, live-based design encourages designers to also study in detail what kinds of requirements new artefacts should fill. Thereafter, they can think about how to construct the required artefacts.

Modern technology development focuses on intelligent technologies. Several societal tasks have historically been completed by individuals because they presuppose intelligence [7, 16]. Today, advancements in AI and autonomous systems are making it possible to replace humans in many of these tasks. However, before it is possible to design intelligence-demanding tasks using computers, it is important to understand what people really do when they complete such task tasks. Thus, it is essential to develop sense-making design methods for constructing intelligent technologies.

One of the challenges in design thinking is finding new ideas. New ideas that can be used to develop intelligent technologies to replace human work through automatic and even autonomous systems are needed to foster societal development. Thus, it makes sense to investigate the nature of design thinking to develop effective processes. Finding means to design systems that can handle tasks that could historically only be completed by humans is beneficial on a societal level [7].

Designing technologies always requires human thinking. Designers must set goals and find means to reach these goals [12, 19]. Well-known sources of ideas are analogies and analogical thinking [8]. An example of analogy-based human thinking is mimetics, or when a person uses a certain process or system as model or paragon to generate a solution [2].

The most well-established example of mimetic thinking is biomimetics. The core idea of biomimetics is clear: Designers study relevant natural systems and use their knowledge to solve design problems [22]. A classic example of such thinking is the construction of airplane wings. Leonardo da Vinci and, later, the Wright brothers observed birds flying and used their knowledge to develop the concept for the airplane and the first real airplane, respectively. Thus, knowledge of bird flight served as a model for the technical device of the airplane.

Another interesting example of biomimetic thinking that has had a significant impact on the evolution of computation, artificial intelligence, and cognitive science is neural networks. Inspired by the work of Nicolas Rashevsky in the 1930s [5], McCulloch and Pitts [11] cast the idea of neural networks in Boolean terms. This concept was later meshed with the thinking of Turing [20, 21] and von Neumann [3]. Together, these works influenced the development of the digital computer.

The soundness of the basic ideas of biomimetics has been well established by numerous innovations in different sectors of technology design, ranging from clothing to aviation [4]. Biomimetics also plays a role in the development of robotics, as many researchers have used different types of animals to construct robots' bodies. For example, insects, bats, snakes,

and fish have often been used as paragons for constructing the bodies of prototype robots. Of course, humanoid models have also been common. Thus, the properties of existing biological structures have inspired designers to solve the problem of designing robotic bodies.

Nevertheless, structural issues are not the only similarities that can be used in search for new ideas. Animals have also developed complex information processing systems. They can create highly sophisticated men tal representations to control their actions. Thus, it is possible to mimic animal and human information processing methods to create, design, and develop effectively intelligent technologies. It is also possible to imitate intelligent information processes and, thus, develop a new branch of mimetic thinking. We have termed this branch of mimetics cognitive mimetics.

2   Information and its processing

Information has always been a somewhat mysterious concept. Norbert Wiener [23], the father of cybernetics, defined information in a rather puzzling manner by saying that it is neither matter nor energy. Information can also be defined in a straightforward manner as systems of signs. This definition comes close to Shannon's [18] classic formulation of information in his theory of communication. However, whereas Shannon [18] concentrated on quantitative aspects of information, for our purposes, it is important to consider signs and information from a more qualitative point of view: that is, to see information as content. This raises two questions: What is the content of a given set of information, and how can understanding information content be used in mimetic thinking?

Traditional sign theorists, such as Peirce [14] differentiated between the material bases of signs or sign vehicles and their information content. The hardware of computer memory operates using different states. Normally, when discussing computer memory, we talk of bits, words, structures, objects, or files. These different computational states have meanings outside of computer memory; thus, computer memories represent something tangible. In other words, they represent information content. As it is possible to manipulate a computer's memory contents, one may say that computers can represent symbols dynamically and manipulate them in an intelligent manner [12].

Like a computer, the human nervous system also has different representational states, and these states can stand for different external references. In human and animal minds, neural substances support an unlimited number of different information states. The contents of these states of mind can be called mental contents. Of course, the analogy between computers and minds does not mean that the systems are identical, and we are far from claiming that the human mind is a computer in any modern sense.

Nevertheless, the difference between signs or representation vehicles has the same overall structure in the two systems. Representations are material states, but information content arises from the relation between a particular state (different from other states) and some external reference [13].

One can also consider information processes independently from physical systems. It does not matter whether arithmetic operations are completed by people, a pocket calculator, or a clever horse called Hans, as long as the information process has been conducted correctly. Thus, information processing is, to some degree, independent from the processing system. This fact has traditionally been called multiple realizability [15, 9].

3   From multiple realizability to mimicking

Multiple realizability is a fundamental concept in cognitive mimicking. The purpose of cognitive mimetics is that different types of information processing systems can sometimes handle similar information processes and these similarities can be used in generating new design ideas. Cognitive mimetics does not suggest that all information processes are multiply realizable; instead, as the example of chess makes clear, though man and machine share a similar information-processing environment, neither can quite match the other in the methods by which the other succeeds in this environment. That is, humans cannot calculate hundreds of thousands or even millions of alternatives per second, and machines cannot operate by relevance.

Multiple realizability means that information processes can be independent of the processing system [15, 9]. Information processes have their own ontological status, and we need special theoretical concepts to analyze and study them in cognitive science. On the other hand, the independence of material processing systems makes it possible to build different types of physical information processing systems to realize the same information processing tasks.

Ontologically, it is not possible to reduce information to any single processing system. Computers can have a variety of programs that change their behaviors independent of hardware. The same hardware can realize unlimited numbers of programs. Therefore, the science of algorithms is related to, but different from that of computer electronics. Hardware provides a necessary platform for programs.

Similarly, human brain has plasticity and brains can thus realize mental contents of different types. Depending on the linguistic environment, a human can speak Swedish or Hindi. Brains do not explain how speakers of different languages express the same ideas; instead, this explanation is linguistic). The grammatical rules of languages are also

independent from brains. Even human skills, though built into the brain and the nervous system, are independent of brains. The same brain can learn the knowledge required for medicine or the knowledge required for engineering. Brains are open to different types of mental contents, and, for this reason, information content cannot be explained exhaustively in any brain-related terms.

The relative independence of information contents and processes from their material platform is what makes mimicking intelligent processes possible. If intelligent processes were hardware-specific, it would not be possible to mimic them using other information processing systems. In other words, it would not be possible to mimic arithmetic by means of pocket calculators or computers. Cognitive mimicking means the realization of one information process on another device. This often involves taking some human information process as the basis for developing intelligent artefacts.

4   Practical examples

Cognitive mimetics is a unique design concept based on the core knowledge of modern cognitive science. The first example of mimicking human information processing was perhaps Turing's [20, 21] model of the mathematician: the Turing machine. Turing's [20, 21] idea led to the birth of computers and information technology. Turing [20] sought to construct a model or imitation of how mathematicians process information when they solve mathematical problems. Thus, his focus was not on people's structural aspects (biology), but on their information-processing abilities. Turing's [21] insights led to several important ways of thinking that can be seen as the first examples of cognitive mimetics.

Many later simulation programs have also mimicked information processing. The field of cognitive modeling offers several examples. Symbolic production systems, known as cognitive architectures, illustrate how computers can mimic human information processing [1, 12]. The cognitive models built on these systems try to mimic the symbolic level of human information processing within the constraints of the general cognitive architecture.

Cognitive modelling and similar AI traditions have illustrated that it is important to study information processing and use the ideas learned in these studies to search for inspiration in designing intelligent technologies. Especially valuable is studying the details of people carrying out intelligent tasks. Here, mimetics is linked to cognitive task analysis. However, task analysis is only one possible mimetics approach.

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5   Behavioral and mental similarity

An observant reader will have already noted to the ambiguity of the concept of mimicking. Chess-playing computers certainly mimic people in that they can play chess. In fact, the computer Deep Blue was able to play chess better than any human being [6]. However, the system's way of processing information differed from that used by humans. Whereas people look ahead approximately 50 moves in ten minutes, computers search hundreds of millions of alternatives per second. One may say that chess computers mimic people on a behavioral level, but do not mimic all aspects of human information processing. Thus, the information contents of humans and computers differ, making it possible to differentiate between performance-level mimicry and information processing-level mimicking.

Mimetics involves developing ideas for design. Though airplanes were designed based on knowledge of birds' flight, they do not fly the way birds do. Instead, they use some important principles of birds' flight, but differ from flying birds on both the material and the structural levels. A similar inspiration-based analogy is relevant in cognitive mimicking. Ultimately, we do not build birds because we cannot build birds; yet, the principles of lift and drag remain the same for both occupants of airspace. Similarly, the rules of chess define the information environment and transformation operations of the game, and this regularity allows mechanical systems to perform well in tasks that previously required human intelligence.

Mimicking, thus, requires similarity, not sameness. Chess computers can be identical to people in terms of their information processing. For example, chess computers use the same rules to move pieces and use certain identical heuristic processes. Thus, in mimicking, the ways in which technical artefacts solve problems are similar to some aspects of humans' and animals' information processes in solving the same problems.

6   Cognitive mimetics and
designing intelligent systems

Designing intelligent systems is a core challenge in developing modern technologies and societies. Current technological trends include autonomous and AI systems, machine translation, image and speech recognition systems, self-driving cars, drones, chatbots, robots, and office and industry line automation. The consequence of these new developments is that computers are increasingly replacing people in tasks that have previously required humans. This replacement presupposes an in-depth understanding of the human cognitive processes to be replaced. Therefore, it makes sense to investigate the conceptual foundations of

design thinking and mimicking in this new technological area.

An intuitive example might help to clarify our position. Let us consider how one could use mimetics to design a modern cyborg pianist. The first problem is to create the hands that play the piano. These hands should be like human hands in terms of the size and elasticity of the movements. They should have the right pressure, timing, and tempo. This is all structural and basic biomimicry, but would not even be close to what is needed to create a true cyborg pianist. To construct a master pianist, one must also design information processes that allow the piano playing to make musical sense.

In building autonomous systems, such as autonomous robots, it is, thus, not necessarily sufficient to mimic biological structures; one must also mimic sensory-motoric and even higher intellectual processes. A pianist's hand is much more than a biological structure. It is also a sensory-motor object and an emotional and intellectual artefact. To explain and mimic its processes, one must go beyond mere mechanical and sensory-motor modeling and into the realm of emotional modeling. To model a creative, skilled pianist, therefore, one must understand the artist's ways of thinking in order to understand how he or she interprets musical compositions.

Here, we could have used a common-sense example of something other than a pianist. We could have considered, for example, a surgeon, a dentist, a painter, a building constructor, a programmer, or a teacher. In fact, we could have considered any human expert at work. Our main message is that, to replace human experts, one must model and mimic many levels of intellectual work.

The ultimate goal of mimicking is to create technical systems and artefacts that can free people from certain types of tasks. A topical example is car driving; however, there are numerous other areas in which mimicking may be useful. The question we ask is whether the methods of mimicking these different levels of human performance are similar or whether designers should rely on different concepts to mimic different aspects of expert human behavior. In brief, is there only one type of mimicking, or should we rethink the concept? In this paper, we have introduced a novel concept of cognitive mimetics to refer to the mimicking of higher cognitive processes, or how people and animals process information.

Like car driving, AI and autonomous design are also topical areas of current research. One of the main challenges of future AI design is to develop systems to replace people in tasks that have previously required human involvement, thereby freeing people to engage in other kinds of tasks. In practice, the AI revolution presupposes that machines can carry out equivalently effective information processes that have been historically only been possible for humans.

Cognitive mimetics is crucial for developing design ideas that allow designers to solve such problems.

Handling any task that has previously only been possible for humans presupposes an understanding of the information processing structure of the task. This analytical process can be called cognitive task analysis, as it concentrates on cognitive requirements (i.e. the information processes required to carry out the task). For example, replacing routine aspects of radiological work requires a systematic analysis of what radiologists are supposed to see in x-ray pictures and what these natural symbols mean.

Studying human information processing in given tasks may suggest ways of using similar information processes in design. It is possible to model human information processes, and this knowledge may offer ideas about how to realize relevant mental processes by means of machines. Classic cognitive modelling may be an important tool here [1, 12]).

The main message of this paper is that biology-based mimetics differs from cognitive mimetics, or mimetics based on information processing. When developing intelligent technologies to replace people in intelligent information-processing tasks, cognitive mimetics is a natural tool. It is similar to biomimetics; however, instead of looking for structural and material analogies, cognitive mimetics searches for analogies and similarities between existent human and animal information processes and new technologies required to design intelligent technology to replace or reorganize people's work.

7   References

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