PAPER • OPEN ACCESS

Conceptual Basis of Cognitive Mimetics for Information Engineering

To cite this article: Pertti Saariluoma *et al* 2021 *J. Phys.: Conf. Ser.* **1828** 012004

Conceptual Basis of Cognitive Mimetics for Information Engineering

Pertti Saariluoma*, Antero Karvonen, and Tuomo Kujala

Cognitive science, Faculty of Information Technology, University of Jyväskylä, Finland

*Email: ps@jyu.fi

Abstract. Intelligent information processing is topical in modern technology design and development. The fundamental idea was developed by Turing as he made the first conceptual models of information-processing computers. Though it has practically never been noticed, Turing's work was a model of how to mimic human intelligent information processes and generate technologies, which can carry out intelligent tasks. The design method can be called cognitive mimetics as it imitates human information processes to design technologies and their applications. One can use cognitive mimetics even in solving techno-ethical problems. This is why we think that cognitive mimetics are vital as a method to generate intelligent information processes.

1. Introduction

Alan Turing [1-3] invented a model of the mathematical machine. To analyze the problem, he designed a conceptual, abstract, and mathematical machine for making computations of all kinds very practical. As is well known, this M-machine was to become a model for a computer, and thus it has had an enormous influence on our society, everyday life, and culture. One of the most promising consequences of Turing's work is the development of modern robotics, AI, and autonomous technologies [4].

During the Second World War, Turing applied his thinking and created a physical computational machine that was able to decipher German military codes [5]. In doing so, he showed that mathematical thinking could be physically realizable, and consequently, Turing's theoretical thinking acquired a technological form. Such physical computing machines are naturally a necessary precondition for all further developments.

Turing [2] was very aware of the similarities between his machine and human thinking. Defiantly, in one of his papers, he asked if machines could think (like human beings). In a puzzling manner, Turing then called the very question of whether "machines can think" a meaningless one, only to predict that by the end of the century, public opinion would shift so that the idea of machines "thinking" would not seem contradictory to an educated person [2]. Turing's challenging idea that computers could think like people was accepted by Newell and Simon [6,7], and they made a very important addition to Turing's [1-2] way of thinking. They studied empirically how people such as chess players solve problems and modelled the outcomes of their experiments with computers. The contribution of Newell and Simon [6] was not only to think about how people process information but also how to objectively and empirically analyze these processes [6,8]. Their models were simultaneously implementations. Their approach has been called cognitive simulation [6,9].

However, the consequences of Turing's [1,2] brilliant insights did not end with cognitive simulation. From a practical standpoint, it has never been acknowledged that Turing's [1] thinking itself was an ideal model for a constructive design thinking process. Being himself a mathematician, Turing [1] empathically but introspectively analyzed how mathematicians think when they compute. Turing's machine was designed on the basis of his analysis [1]. This means that Turing studied human thinking—or in more modern terms, human information processing—and used his analysis in designing the M-Machine. Turing did not only create an information processing machine based on his analysis; he analyzed an aspect of the human mind and designed a model of a mental process to be realized by the machine.

The idea that people design new technologies by imitating existing natural phenomena is not new. Clothes, for example, were presumably made to imitate animal furs. Airplanes were developed by the Wright brothers and other pioneers to imitate how birds fly. Finally, the forms of modern streamlined locomotives imitate birds such as the kingfisher. Such imitations of the structural properties of nature are normally called biomimetics.

However, the Turing machine is different from biomimetics. It does not imitate any biological structures. Rather, it imitates how mathematicians process information. Later models of the mind, whether theoretical or practical, have their origins in imitating how people process information. Cognitive information processing models describe how people process information. Thus, they are models of information processing minds.

What is the difference between a model of an information process and a system that *realizes* the information process? Turing demonstrated two things: first, the Turing machine shows the possibility of multiple realizability (of some mathematical thinking). This means that in some sense the process and the system can be decoupled. Second, it also shows the necessity of bringing the two together. Indeed, the Turing machine is an abstract description of both an information process as well as the operating principles of the physical system which implements it. From a mimetic perspective, the key idea is that a Turing machine can be realized with many different implementations, thus showing a proof of concept that the type of information processing Turing was outlining is multiply realizable. This is the ground concept of cognitive mimetics [10]. The power of the Turing machine lies in its generality. Why? Because the generality of the information process Turing modelled is the most abstract form of information—mathematics—further reduced to an atomic binary form that can be realized on a simple physical principle, namely, on and off.

Some time ago, we began to call upon the active attention of designers and suggested that they could use human information processes in designing intelligent technologies. The name of this design paradigm could be called cognitive mimetics to differentiate it from biomimetics. The idea of human information processing and its empirical analysis provides much support to the mimetic design. Nevertheless, it is one thing to scientifically analyze and model in a simulative manner how people think, but it is another matter to use human thinking as a model for development. The former refers to showing how things are and the latter to how things should or could be. Here, we outline cognitive mimetics and its basic concepts for further development.

2. Information Processing

In the late fifties, psychologists began to reconsider their basic concepts and procedures. For half a century, they had wanted to consider people as causal objects. They studied how people behave, i.e., how earlier events and the properties of those events affected subsequent behavior. This research generated a good understanding of learning, but in time the research went past behaviorism. For example, Rosenbleuth, Wiener, and Bigelow [11] differentiated behavioristic from functional analysis, the latter seeking to describe the *intrinsic* properties of the entity studied. Turing's [1,2] insights changed the game. Internal processes became important to understand, and the new interest in human information processing (i.e., cognition) opened revolutionary new visions to researchers. The psychology of human information processing, later called cognitive psychology, took over behaviorism [12,13].

In the early fifties, Turing [2] began to call attention to the similarities between machine and human information processes. At the same time, Claude Shannon worked with the amount of information that could be moved across the Atlantic by wire. Thus, he was able to raise the idea of information and information processing with Turing [2] in focus [14]. Interestingly, both called attention to the intimate connection between information and thinking as they suggested that human and machine thinking could be studied using chess players and chess playing. The first ideas about people as information processing systems were created by these two important researchers. Later, these ideas redesigned all of psychology and human research.

People could be seen as information processing systems, i.e., computers. The immediate idea was to study the capacity of systems as Shannon had studied the capacity of telephone cable [12-14]. Human beings could be seen as limited-capacity channels. This new way of thinking has since been very important in engineering and HTI psychology [15], but capacity is not a content-specific ground concept, and for this reason, it is not a very effective tool when human thinking is studied [16].

Herbert Simon with his collaborators took on the challenge of thinking machines in their research [6]. They focused on the analysis of human problem solving and the conceptual analysis of this process. The output of their research was partly theoretical and included different computational ways to model how people solve problems [6]. Several researchers have developed this approach further [9,17]

The core concept in the psychology of human information processing is information. This has been a difficult problem in research. Wiener [18] for example, defined it by arguing that information is neither matter nor energy. Information is thus not a physical concept. Or, rather more accurately, information is not expressible in physical concepts alone. However, information is a multisided phenomenon and can be considered under different perspectives.

As mentioned above, the most popular analysis of information is based on quantity. People have asked how much information or how much new information some systems or messages have. One can call these quantitative approaches to information originating directly or indirectly with Shannon and Weaver's [14] analysis ‘capacity-based analysis’ [16]. A capacity-based analysis is not the only possible approach. One could also focus on what the messages say, i.e., the information content. Alan Allport [19] for example, analyzed the mind as a collection of neuro-modular information processing systems which are content specific. Color vision would be a good example of such a system as it is neurally hardwired and content specific. Thus, content-specific neural systems such as color processing generate some content aspects of human experience.

However, we focus here on an even stronger concept of information than the one committed to specific neural systems. We want to look at information as mental content [20]. In our thinking, mental content is seen as representational information content. All analysis and explanation in this approach is focused on the information contents of thought. The focus is not on schemas, or representations at the abstract level, but on contents *as contents*. By relying on such a strong concept of contents, it is possible to mimic human thinking.

3. Modeling the Mind – Methods for Mimetics

One cannot mimic human information processing and thinking without an idea of what happens in the minds of thinking people. There are several ways that designers can get an idea about what happens when people solve some concrete intelligence-demanding tasks. The main goal of the analysis is a picture of what happens in the mind. The main conceptualization is a description of human mental representations and manipulation processes which alter the representations [6]. The knowledge of mental representations and their transformation has been collected in several ways. Here we present philosophical and phenomenological analysis, thinking aloud, and other techniques, such as focus groups. All of the methods have their strengths and limitations, and for this reason it is wise to study them briefly.

3.1. Philosophical and Phenomenological Analysis

The human experience is a core phenomenon when we investigate human thinking. People observe their thinking and derive their design ideas on the grounds of information collected in this way. This method is traditional and perhaps the most widely used. Such giants of the philosophical analysis of human thinking as Plato, Aristotle, Descartes, Locke, and Kant have used this practice. The analysis of phenomena or how people experience in their minds the world, physical or mental, is the foundation of analysis and argumentation.

During the last century, phenomenologists such as applied phenomenological analysis in their thinking. However, the development of the Turing machine, which we see as the first example of cognitive mimetics, was based on introspective phenomenological work in how mathematicians think. Consequently, one should not underestimate the importance of intuitive phenomenological work. As an additional example, formal logic began with how people experienced their thought processes and their information structures [21].

The problem with philosophical analysis lies in its subjective and difficult-to-verify nature. The experiences of one person may be also difficult to generalize. The latter problem can be solved to some degree, as in linguistics, in that when ideas such as the laws of logic have generally been accepted, they can be seen as argumentatively confirmed. Thus, accepting the weaknesses, one can apply phenomenological analysis in cognitive mimetics.

3.2. Thinking Aloud

An alternative to phenomenological analysis can be thinking aloud. In this method, people are asked to relate aloud everything that comes to mind when they solve problems and other thinking-related tasks. This method has been used quite frequently in the psychology of thinking [22,6]. The strength of thinking aloud is that researchers and designers can move from internalism and introspection to a more objective methodology.

In a thinking-aloud analysis, generalizability and confirmation processes are clearer than in phenomenological analysis. The results are also more objective than for introspective methods as they provide researchers with an idea about subconscious processes involved in human information processing. The analysis and comparison of objective data make it possible to study—as clinical psychologists do—the vast information processing undertaken by the conscious and also the subconscious mind [23].

On the other hand, it should be noted that in design, a single thinking-aloud protocol that shows, for example, a technically useful information processing method, can be more valuable than some more common patterns of thinking. Thus, in cognitive mimetics, the effectiveness of a human information process is measured also against its applicability in the computational domain. Copying and pasting information processes is not likely to yield optimal results, and thus the designer also becomes implicated in how they can implement ideas gleaned through mimetic means.

3.3. The Document, Social Research Knowledge, and Focus Groups

Thinking-aloud protocols are not the only sources of information on human thinking. Surveys, interviews, and documentary analyses can also yield objective knowledge about what happens in human minds when they think. The outputs such as documents, laws, machines, and histories of real-life thought processes can thus provide a rich source of knowledge.

In practice, it may be difficult to test models of mental processes generated on the basis of documents. One cannot make any experimental designs which could alternate documentary information for purposes of testing. A way to look for further confirmation is to use focus groups. These are groups of discussing experts who can analyze the presented interpretations of given empirical data.

3.4. Using the Knowledge of Thinking in Mimicking

None of the presented methods is absolute. There is no way to confirm the given knowledge [24,16]. On the other hand, in mimetics, the analysis of human information processing is not the end but the beginning. The end of the process can be seen in the actual intelligent applications. Even slightly mistaken analysis can sometimes lead to excellent results. Turing [2], for example, made a partly false analysis of human thinking as he neglected the information contents of thought and concentrated only on the formal aspects of the mind [25]. Nevertheless, the Turing machine opened new ways for mankind to develop human life.

The ultimate goal of mimetics is to develop intelligent technological applications. Their validity is tested in practice. The criterion is how the new intelligent technologies can improve the quality of human life, and thus the validation should be derived not from the absolute truth of the analysis of thinking but from the function of the analysis in designing intelligent applications.

Mimetics are not built on the idea of precise similarity between model and product. Airplanes mimic bird wings; however, airplanes do not fly like birds. But airplanes and birds obey the same laws of aerodynamics. Similarly, mimicking human information processes and thinking does not mean that intelligent applications should be identical to human processes. For example, chess-playing computers do not process information similarly to people. Yet, they can follow the laws and regularities of information processing and thus free people from many practical tasks [6].

4. Ethical Thinking – A Practical Model

An important question in developing intelligent technologies is whether ethical machines are possible. Machines shall take over many tasks in our lives, and many of these tasks have ethical dimensions. One may also ask whether machines can develop new ethical principles by mining large portions of data [26]. A major obstacle of ethical technologies appears to be the well-known ethical principle called Hume’s guillotine, which states that values cannot be derived from facts. Thus, computing machines operating with facts could not be used to process ethical information.

Cognitive mimetics could be used to solve such principal issues. One can use philosophical analysis to study how one could construct computational models with ethical capacities. Such analysis presupposes solving Hume’s aporia. Here, the argumentation can be based on the analysis of the basic conceptual properties of human ethical actions.

Ethics is concerned with actions. Ethics define how people should act in order to act morally. The grounding concept is thus human action. Human actions are controlled by mental representations, which have both emotional and cognitive aspects. The importance of the two aspects of the mind was also noticed by Hume. However, he argued that emotions could not dictate what facts should be, and thus values, which are closely linked with emotions, could not be derived from facts (i.e., one could not say whether things are how they should be).

However, in humans, actions are controlled by the human mind. In action, control of emotions is intimately linked with both emotions and cognitive representations of situations and the actions which have led to these situations. Emotional valence tells which situations are negative and which are positive, and it marks the actions leading to critical situations with positive and negative valences. In the human mind, the actions leading to positive situations are worth aspiring to, and situations with negative emotional valences are worth avoiding. For example, people avoid pain and pursue pleasure. Consequently, actions leading to positive situations are valuable, and actions leading to negative situations are avoided. Representations of the emotional consequences of an action can be termed as elementary ethical experience [26].

On the basis of individuals’ ethical experiences, they form guiding rules for their actions. For example, people avoid situations such as close relations with people, work communities, or tasks which they find negative. The systems of elementary ethical rules that individuals adopt have been discussed with other people on parliamentary and world levels. Finally, the discourse of right and wrong will become historical. The process of socially analyzing and unifying primitive ethical norms into socio-ethical principles can be called discourse ethics [27].

From a technological point of view, emotional and cognitive analyses of actions mustn't be separated as in Hume’s work. Actions always have emotional and cognitive aspects, and similarly, human perception always encodes borderline, figure and background, and movement simultaneously. There is no obstacle to incorporating both emotional and cognitive aspects into intelligent applications. This general notion should be extended to other acts of cognition as well. Many philosophical and practical mistakes occur when elements that are intimately encoded together are separated in the abstract and then reduced to only one dimension [28]. This may be persuasive, as the reduced dimension is indeed present in the cognition, such as facts in ethical thinking. However, it is important to seek an analysis of what is given [28] rather than starting from a constrained box—surely not always an easy task.

There are numerous ways to encode the emotional valence of people in models. Social media uses thumbs, for example. Such evaluations can be attached to respective action models. Consequently, designers have primitive ethical assessments of actions in their use. A typical example of using emotional preferences is provided by recommender systems. Grahn et al. [29] showed that a prospective thinking-aloud method applied to driving instructors can indicate information requirements and corresponding safety-relevant actions in prototypical traffic situations to enhance automated driving technologies. In any case, by unifying the emotional and cognitive aspects of action information, one can create machines with ethical properties.

As another example of using cognitive mimetics to generate ideas, Karvonen [30] examined tacit knowledge, action ontologies, and problem restructuring in the context of AI ethics. Take problem restructuring, for example. Intrinsic machine ethics, where AI is capable of some ethical information processing, easily slips into the development of an ethical calculus. This is an important problem, but it also easily distracts from a more powerful ethical thinking tool, which is illustrated in human problem restructuring. In the famous trolley problem [31] the very idea is to narrow the ethical problem into a no-win situation and to examine the consequences. In reality, most people would prefer to seek a win-win situation or a no-lose situation by restructuring the problem or solving the dilemma in a new way. An AI capable of intrinsic ethical processing should first seek to restructure problems as they occur such that no ethical calculus is needed. The calculus is rather an alarm process which calls upon the need for restructuring. This is something humans excel in, and the mimetic approach would take this very ability or the various empirically discovered restructurings as cue and content for AI development. Here, again, the key is representations and mental content.

5. The Challenge of Information Processing Machines

In this paper, we have outlined the foundations of cognitive mimetics. We call this approach cognitive mimetics. This method is intended to aid designers in working with intelligent applications. The practical example illustrates that mimetics can be used even when working with ethical information, which topic shall be important in future developments of an intelligent society.

Autonomous systems, such as autonomous machines, vehicles, and devices, require an understanding of intelligent actions and intelligent information processing. Half a century of working with human information processing has demonstrated that human information processing can be mimicked in developing new technologies. It is sufficient for designing mechanical tools such as spades or caterpillars to have a good comprehension of biomechanical processes of animals and people. A spade can be designed by mimicking how the human hand operates. The principles by which digging operates are similar to the principles a spade must follow when used.

However, if new technologies operate in the world of information, the traditional principles of biomimetics are insufficient. They cannot provide much help when machines should, for example, design tools for creative processes. To aid such processes, it is essential to understand how people think and how they create new information.

New information processing artifacts need not operate like people, but they have to follow the laws and regularities of intelligent information processing developed by human cultural evolution. This is why the analysis of human information processes can be highly valuable for developing intelligent technologies and intelligent society. Artifacts operating with information can be faster, they can have more capacity than people have, and they do not easily exhaust. However, they need to follow the laws of rational and intelligent information. They have to follow principles of formal logic, to take an example, if they are to be of real use. Nevertheless, there are numerous other principles the human mind follows. Ethical information is a good example of such information. Analyzing and implementing the many yet unknown information processes of the human mind in machines will be a challenge of our time. In this process, we think that cognitive mimetics has a role to play.

Acknowledgement
This work has been supported by Etairos (Academy of Finland), and SEED (Business Finland) projects.

References
[1] Turing A M 1936-7 On computable numbers, with an application to the entscheidungsproblem. *Proceedings of the London Mathematical Society, 42*, 230–65
[2] Turing A M 1950 Computing Machinery and Intelligence *Mind*, **59** 433-460
[3] Petzold C 2008 *The Annotated Turing* (Indianapolis: Wiley)
[4] Russell S J, Norvig P 2014 *Artificial Intelligence: A Modern Approach* (Upper Saddle River, NJ, USA: Prentice Hall)
[5] Hodges A 1983 *Alan Turing: The Enigma* (Princeton N.J: Princeton university press)
[6] Newell A, Simon H A 1972 *Human Problem Solving* (Engelwood Cliffs, NJ: Prentice-Hall)
[7] Newell A, Simon H A 1976 Computer Science as Empirical Inquiry: Symbols and Search *Communications of the ACM* **9**(3) 113-126
[8] Chase W G, Simon H A 1973 The mind's eye in chess *Visual information processing* (Academic Press) pp 215-281
[9] Anderson J R 1983 *The Architecture of Cognition* (Cambridge, MA: Harvard University Press)
[10] Saariluoma P, Kujala T, Karvonen A, Ahonen M 2018 Cognitive mimetics - main ide-as *Proc. Int. Conf. on Artificial Intelligence (ICAI)*
[11] Rosenblueth A, Wiener N, Bigelow J 1943 Behavior, purpose and teleology *Philosophy of Science* **10**(1) 18-24
[12] Broadbent D 1958 *Perception and Communication* (London: Pergamon Press)
[13] Miller G A 1956 The magical number seven, plus or minus two: Some limits on our capacity for processing information *Psychological Review* **63** 81–97
[14] Shannon C E, Weaver W 1949 *The Mathematical Theory of Communication* (University of Illinois Press)
[15] Saariluoma P, Cañas J, Leikas J 2016 *Designing for Life* (London: Macmillan)
[16] Saariluoma P 1997 *Foundational Analysis: Presuppositions in Experimental Psychology* (London: Routledge)
[17] Polk T A, Seifert C M 2002 *Cognitive modeling* (MIT Press)
[18] Wiener N 1948 *Cybernetics: Or Control and Communication in the Animal and the Machine* (Cambridge, MA: MIT Press)
[19] Allport D A 1980 Patterns and actions: Cognitive mechanisms are content specific *Cognitive Psychology: New Directions* ed Claxton G (London: Routledge and Kegan Paul) pp 26-64
[20] Saariluoma P 1995 *Chess Players' Thinking* (London: Routledge)
[21] Husserl E 1901-2 *Logische unterschungen I-II* (Halle: Niemeyer)
[22] Ericsson,K A, Simon H A 1984 *Protocol Analysis* (Cambridge, MA: MIT Press)
[23] Beck A 1976 *Cognitive Therapy of Emotional Disorders* (Harmondsworth: Penguin Books)
[24] Popper K R 1959 *The Logic of Scientific Discover (*London: Hutchinson)

[25] Saariluoma P, Rauterberg M 2015 Turing test does not work in theory but in practice *Proc. 17th Int. Conf. on Artificial Intelligence-ICAI* pp. 433-437
[26] Saariluoma P 2020 Hume’s Guillotine Resolved *Int. Conf. on Human-Computer Interaction* (Cham: Springer) pp 123-132
[27] Habermas J 2018 *Diskursethik (Discourse ethics)* (Frankfurt am Main: Surkamp)
[28] Sokolowski R 1974 *Husserlian Meditations* (Evanston: Northwestern University Press)
[29] Grahn H, Kujala T, Silvennoinen J, Leppänen A, Saariluoma P 2020 Expert drivers’ prospective thinking-aloud to enhance automated driving technologies – Investigating uncertainty and anticipation in traffic *Accident Analysis and Prevention* In press.
[30] Karvonen A 2020 Cognitive Mimetics for AI Ethics: Tacit Knowledge, Action Ontologies and Problem Restructuring *Int. Conf. on Human-Computer Interaction* (Cham: Springer) pp 95-104
[31] Woollard F, Howard-Snyder F 2016 Doing vs. Allowing Harm *The Stanford Encyclopedia of Philosophy* (Winter 2016 Edition) ed Zalta E N URL = <https://plato.stanford.edu/archives/win2016/entries/doing-allowing/>.