Cognitive Science

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THE CROSSROADS OF COGNITIVE SCIENCE

The monograph *Cognition, Meaning and Action. Lodz-Lund Studies in Cognitive Science* collects papers written by the members of two Cognitive Science Departments: of Lund and of Lodz. It presents a range of issues currently examined in both centers. Some texts are written in collaboration as the result of collective research.

The opening article "Cognitive science: From computers to ant hills as models of human thought" (Peter Gärdenfors) offers an introduction to the history of ideas in cognitive science as it has been developing throughout last decades. Much of the contemporary mind theories derive from Descartes' *res cogitans* and *res extensa* distinction, and to some extent they may be seen as a continuation of rationalist-empiricist debate. The dawn of computer science is kept in quite rationalist fashion. The fundamental concept of computer science is the theoretical construct of Turing's machine. Inspired by Turing's concept, John von Neumann proposes a general architecture for modern computer based on logic circuits. The transfer of these findings to a theory of how the mind works was only a matter of time. Soon after von Neumann's proposal, McCulloch and Pitts interpreted neurons as a logic circuits combining information from other neurons according to some logical operations. This leads directly to one conclusion: the entire brain is a huge computer – and so the foundational metaphor for cognitive science was born.

Cognitive science can be said to emerge in 1956, the year in which Noam Chomsky, in response to the behaviourist concept of language, presented his proposition of *transformational grammar*. His central argument is based on the claim that processing the grammar of natural language requires a sort of algorithm as used in Turing machine. Also in 1956 Newell and Simon demonstrated the first computer program constructing logical proofs from a given set of premises and, finally, the concept of Artificial Intelligence was used for the first time. The philosophical assumption of the AI approach to cognitive processes is that the representation of mental content and processing is essentially *symbol manipulation*: only logical relations connect different symbolic expressions in a mental state of a person. The meaning of symbols is not part of the process of thinking, since they are manipulated exclusively on the basis of their form.

This quite rationalist manner of representing the cognitive process gave rise to several forms of criticism. One of them – derived from empiricism – was a new model of cognition called connectionism. Connectionist systems, also called *artificial neuron networks*, consist of large number of simple but highly interconnected units ("neurons"). According to the connectionists' point of view, thinking is not manipulation of meaningless symbols run and controlled by a central processor computer-like program, but it rather occurs in parallel neuronal processes distributed all over the brain, which is seen as a *self-organizing system*.

However, as it is claimed in the first paper, there are aspects of cognitive phenomena for which neither symbolic representation nor connectionism seems to offer appropriate "modelling tools". Those aspects include: mechanisms of concept acquisition, concept learning, and the notion of *similarity*. They turned out to be problematic for the symbolic and associationist approaches. To deal with them, a third form of representing information was proposed based not on symbols or connections between neurons, but rather on *geometrical* or *topological* structures. These structures generate mental *spaces* that represent various domains, and allow for modelling similarity in a very natural way as, for example, with the function of distance in such a space.

The topics of all other papers oscillate around the eponymous subject from the point of view of communication and its efficiency. The philosophical perspective of thinking, typical for the research on cognition, meaning, and action, is here replaced by psychological as well as neurophysiological benchmarks. The concept of the meaning of natural language expressions presented in "Two procedures expanding a linguistic competence" (Piotr Łukowski) is the result of two approaches, of the logical and of the one known in the cognitive psychology as *exemplary theory of meaning*. It employs *model example*, *function of sufficient similarity*, *accidental* and *essential similarities* and *zone of proximal development*. From such a perspective, the meaning inevitably appears to be a social, dynamic, and temporal phenomenon. Furthermore, since cognitive psychology is firmly founded on neuroscientific research, the properties of the presented understanding of *notions* can be partially linked to their neurophysiological correlates, as outlined in the following chapter: "Neurobiological basis for emergence of notions" (Konrad Rudnicki).

Comparative studies of *feature lists*, (dynamic) *frames*, and *conceptual spaces* as models for the representation of scientific conceptual knowledge is the aim of "Similarity as distance: Three models for scientific conceptual knowledge" (Frank Zenker). It is shown that the concepts arising from and giving rise to the exact measurement – mainly scientific ones – are properly represented in conceptual spaces. Also in the paper "The Approximate Numbers System and the treatment of vagueness in conceptual spaces" (Aleksander Gemel, Paula Quinon) the advantages of this model are successfully confirmed for the representation of concepts whose character is far from being scientific, i.e. vague concept of number.

Interpersonal communication defines the context of analyses for the next two papers: "To tell and to show: the interplay of language and visualizations in communication" (Jana Holsanova, Roger Johansson, Kenneth Holmqvist) and "Communication, cognition, and technology" (Peter Gärdenfors, Jana Holsanova). The main topic of both texts concerns various kinds of visualization with particular focus on how they influence communicational effectiveness. *Structuralist semiotics* and naturalistic, *computational concepts of language* are traditionally considered as being in conflict. Yet, closer analysis reveals their complementarity. In the paper "Semiotics, signaling games and meaning" (Aleksander Gemel, Bartosz Żukowski) some reconciliation of these two paradigms is proposed, which results in a coherent model preserving the advantages of the both concepts. The hybrid model requires, however, a formal tool to organize the semantic structure of the cultural system. To this aim *content implication* is introduced.

Starting from the following paper, rational action is the leading problem for all texts. The first of them, "Out of the box thinking" (Dorota Rybarkiewicz) explains in terms of the theory of metaphor how to break natural, standard borders – our typical *canyons* of thought – in order to find a better solution of a given problem. Procedures of decision making are analyzed in two papers closing the volume: "The everyday of decision-making" (Annika Wallin) and "Short- and long-term social interactions from the game theoretical perspective: A cognitive approach" (Magdalena Grothe, Bartosz Żukowski). In the former, the study of human everyday practice becomes the source of truths (information) about what a real and rational decision process looks like and of ideas about how to improve this process. In the latter, the rationality of decision making is steeped in the game theory. The well-known results established for the models of prisoner's dilemma and those with an indefinite time framework are related to the social interactions which are consistent with the cooperative equilibrium over a longer time.

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Łódź, March 2015

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COGNITIVE SCIENCE: FROM COMPUTERS TO ANT HILLS AS MODELS OF HUMAN THOUGHT

1. Before cognitive science

In this introductory chapter some of the main themes of the development of cognitive science will be presented. The roots of cognitive science go as far back as those of philosophy. One way of defining cognitive science is to say that it is just *naturalized philosophy*. Much of contemporary thinking about the mind derives from René Descartes' distinction between the body and the soul. They were constituted of two different substances and it was only humans that had a soul and were capable of thinking. According to him, other animals were mere automata.

Descartes was a *rationalist*: our minds could gain knowledge about the world by rational thinking. This epistemological position was challenged by the *empiricists,* notably John Locke and David Hume. They claimed that the only reliable source of knowledge is sensory experience. Such experiences result in *ideas,* and thinking consists of connecting ideas in various ways.

Immanuel Kant strove to synthesize the rationalist and the empiricist positions. Our minds always deal with our inner experiences and not with the external world. He introduced a distinction between the thing in itself (*das Ding an sich*) and the thing perceived by us (*das Ding an uns*). Kant then formulated a set of *categories of thought,* without which we cannot organize our phenomenal world. For example, we must interpret what happens in the world in terms of cause and effect.

The favourite method among philosophers of gaining insights into the nature of the mind was *introspection*. This method was also used by psychologists at the end of the 19th and the beginning of the 20th century. In particular, this was the methodology used by Wilhelm Wundt and other German psychologists. By looking inward and reporting inner experiences it was hoped that the structure of the conscious mind would be unveiled.

However, the inherent subjectivity of introspection led to severe methodological problems. These problems set the stage for a scientific revolution in psychology. In 1913, John Watson published an article with the title "Psychology as the behaviourist views it" which has been seen as a *behaviourist* manifesto. The central methodological tenet of behaviourism is that only objectively verifiable observations should be allowed as data. As a consequence, scientists should prudently eschew all topics related to mental processes, mental events, and states of mind. Observable behaviour consists of *stimuli* and *responses*. The brain was treated as a black box. According to Watson, the goal of psychology was to formulate lawful connections between such stimuli and responses.

Behaviourism had a dramatic effect on psychology, particularly in the United States. As a consequence, animal psychology became a fashionable topic. Laboratories were filled with rats running in mazes and pigeons pecking at coloured chips. An enormous amount of data concerning *conditioning* of behaviour was collected. There was also a behaviourist influence in linguistics: the connection between a word and the objects it referred to was seen as a special case of conditioning.

Analytical philosophy, as it was developed in the early 20th century, contained ideas that reinforced the behaviourist movement within psychology. In the 1920s, the so-called Vienna circle formulated a philosophical programme which had as its primary aim to eliminate as much as possible of metaphysical speculations. Scientific reasoning should be founded on an *observational* basis. The observational data were obtained from experiments. From these data knowledge could only be expanded by using logically valid inferences. Under the headings of *logical empiricism* or *logical positivism*, this methodological programme has had an enormous influence on most sciences.

The ideal of thinking for the logical empiricists was logic and mathematics, preferably in the form of *axiomatic systems*. In the hands of people like Giuseppe Peano, Gottlob Frege, and Bertrand Russell, arithmetic and logic had been turned into strictly formalized theories at the beginning of the 20th century. The axiomatic ideal was transferred to other sciences with less success. A background assumption was that all scientific knowledge could be formulated in some form of *language*.

2. The dawn of computers

As a part of the axiomatic endeavour, logicians and mathematicians investigated the limits of what can be computed on the basis of axioms. In particular, the focus was put on what is called *recursive functions*. The logician Alonzo Church is famous for his thesis from 1936 that everything that can be computed can be computed with the aid of recursive functions.

At the same time, Alan Turing proposed an abstract machine, later called the *Turing machine*. The machine has two main parts: an infinite tape divided into cells, the contents of which can be read and then overwritten; and a movable head that reads what is in a cell on the tape. The head acts according to a finite set of instructions, which, depending on what is read and the current state of the head, determines what to write on the cell (if anything) and then whether to move one step left or right on the tape. It is Turing's astonishing achievement that he proved that such a simple machine can calculate all recursive functions. If Church's thesis is correct, this means that a Turing machine is able to compute everything that can be computed.

The Turing machine is an abstract machine – there are no infinite tapes in the world. Nevertheless, the very fact that all mathematical computation and logical reasoning had now been shown to be mechanically processable inspired researchers to construct real machines that could perform such tasks. One important technological invention was the so-called logical circuits that were constructed by systems of electric tubes. The Turing machine inspired John von Neumann to propose a general architecture for a real computer based on logic circuits. The machine had a central processor which read information from external memory devices, transformed the input according to the instructions of the program of the machine, and then stored it again in the external memory or presented it on some output device as the result of the calculation. The basic structure was thus similar to that of the Turing machine.

In contrast to earlier mechanical calculators, the computer *stored* its own instructions in the memory coded as binary digits. These instructions could be modified by the programmer, but also by the program itself while it was operating. The first machines developed according to von Neumann's general architecture appeared in the early 1940s.

Suddenly there was a machine that seemed to be able to think. A natural question was then to what extent computers think like humans. In 1943, McCulloch and Pitts published an article that became very influential. They interpreted the firings of the neurons in the brain as sequences of zeros and ones, by analogy with the binary digits of the computers. The neuron was seen as a logic circuit that combined information from other neurons according to some logical operator and then transmitted the results of the calculation to other neurons.

The upshot was that the entire brain was seen as a huge computer. In this way, the metaphor that became the foundation for cognitive science was born. Since the von Neumann architecture for computers was at the time the only one available, it was assumed that the brain too had essentially the same general structure.

The development of the first computers occurred at the same time as the concept of *information* as an abstract quantity was developed. With the advent of various technical devices for the transmission of signals, such as telegraphs and telephones, questions of efficiency and reliability in signal transmission were addressed. A breakthrough came with the mathematical theory of information presented by Claude Shannon. He found a way of measuring the amount of information that was transferred through a channel, independently of which code was used for the transmission. In essence, Shannon's theory says that the more improbable a message is statistically, the greater is its informational content (Shannon, Weaver, 1948). This theory had immediate applications in the world of zeros and ones that constituted the processes within computers. It is from Shannon's theory that we have the notions of bits, bytes, and baud that are standard measures for present-day information technology products.

Turing saw the potentials of computers very early. In a classical paper from 1950, he foresaw a lot of the developments of computer programs that were to come later. In that paper, he also proposes the test that nowadays is called the *Turing test*. To test whether a computer program succeeds in a cognitive task, such as playing chess or conversing in ordinary language, let an external observer communicate with the program via a terminal. If the observer cannot distinguish the performance of the program from that of a human being, the program is said to have passed the Turing test.

3. 1956: Cognitive science is born

There are good reasons for saying that cognitive science was born in 1956. That year a number of events in various disciplines marked the beginning of a new era. A conference where the concept of *Artificial Intelligence* (AI) was used for the first time was held at Dartmouth College. At that conference, Alan Newell and Herbert Simon demonstrated the first computer program that could construct logical proofs from a given set of premises. This event has been interpreted as the first example of a machine that performed a cognitive task.

Then in linguistics, later the same year, Noam Chomsky presented his new view of *transformational grammar* that was to be published in his book *Syntactic Structures* in 1957. This book caused a revolution in linguistics and Chomsky's views on language are still dominant in large parts of the academic world. A central argument is that any natural language would require a Turing machine to process its grammar. Again we see a correspondence between a human cognitive capacity, this time judgements of grammaticality, and the power of Turing machines. No wonder that Turing machines were seen as what was needed to understand thinking.

Also in 1956, the psychologist George Miller published an article with the title "The magical number seven, plus or minus two: Some limits on our capacity for processing information" that has become a classic within cognitive science. Miller argued that there are clear limits to our cognitive capacities: we can actively process only about seven units of information. This article directly applies Shannon's information theory to human thinking. It also explicitly talks about cognitive processes, something which had been considered to be very bad manners in the wards of the behaviourists that were sterile of anything but stimuli and responses. However, with the advent of computers and information theory, Miller now had a *mechanism* that could be put in the black box of the brain: computers have a limited processing memory and so do humans.

Another key event in psychology in 1956 was the publication of the book *A Study of Thinking*, written by Jerome Bruner, Jacqueline Goodnow, and George Austin, who had studied how people group examples into categories. They reported a series of experiments where the subjects' task was to determine which of a set of cards with different geometrical forms belong to a particular category. The category was set by the experimenter, for example the category of cards with two circles on them. The subjects were presented one card at a time and asked whether the card belonged to the category. The subject was then told whether the answer was correct or not. Bruner and his colleagues found that when the concepts were formed as conjunctions of elementary concepts like "cards with red circles", the subjects learned the category quite efficiently; while if the category was generated by a disjunctive concept like "cards with circles *or* a red object" or negated concepts like "cards that do *not* have two circles," the subjects had severe