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Cognitive science

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Cognitive science is the interdisciplinary study of the mind. Its focus is on the nature of cognition: thinking, learning, problem solving, language and its interactions with conceptual structure, and other aspects of mental life. It embodies a convergence of cognitive psychology, cognitive development, artificial intelligence, linguistics, cognitive anthropology, cognitive neuroscience, and philosophy. What brings these disciplines together is the central tenet that a broad range of mental processes are computational in nature and that these processes operate on mental representations.

Differences from Cognitive Psychology. There is considerable overlap in topic matter between cognitive psychology and cognitive science. Both disciplines aim to model human knowledge and mental processes. However, cognitive science is more inclusive in the methodologies it brings to bear on these issues. In addition to the laboratory experimental methodology traditionally used in cognitive psychology, cognitive science draws on other methodologies: from artificial intelligence, simulations that provide explicit models of human representation and processing; from linguistics, analyses of the structure of language; from cognitive anthropology, ethnographies that reveal the variety of human systems of belief; from cognitive neuroscience, investigations of how the brain connects with the mind; and from philosophy, arguments as to how these currents link with each other and with the great issues of western thought.

Cognitive science is thus more inclusive than cognitive psychology in that its methods include those of the other disciplines as well as those of cognitive psychology. There is also a subtle difference in focus. Cognitive science focuses chiefly on higher-order cognitive processes such as causal reasoning, planning and analogical mapping; it is less concerned with low-level processes such as attention and priming in memory than is cognitive psychology.

History. Questions about the nature of the mind have been asked throughout human existence: how ideas are represented in the mind, whether different kinds of concepts are stored in different parts of the brain, whether the capacity for language is innate, and how perception, language and thought are interrelated. Yet the study of cognition as an empirical field did not become established until the nineteenth century. Paradoxically, the first step in the development of cognitive science was one of division. Around the beginning of the twentieth century, the component disciplines of psychology, linguistics, anthropology, and neuroscience split off from the parent field of philosophy and emerged as empirical fields. A general hiatus in cognitive studies occurred during the behaviorist period, roughly 1920 - 1950 (See Cognitive Psychology). Nonetheless, during this period certain events took place that combined to form the foundations of cognitive science. One of these was the rise of computational theory. Norbert WEINER and John VON NEUMANN put forward cybernetics and Claude SHANNON invented information theory. Alan TURING set out the central notion of a simple finite state machine that could, with enough steps, carry out any conceivable calculation. He also proposed what is now called the Turing test to decide whether a computer can really think. If a human interviewer, allowed to question the computer at will, cannot distinguish it from a human on the basis of its answers, then the computer has passed the Turing test.

The new field of artificial intelligence developed from these roots, with John McCARTHY, Marvin MINSKY, Allen NEWELL, and Herbert SIMON as its early leaders. Its importance lay not only in the idea that machines might be programmed to think like humans, but also in the equally bold idea that by explicitly describing the content and processes of thinking, we can make them available to empirical study.

Cognitive psychology emerged as a subfield of psychology in the late 1960's. Psychology and philosophy discovered the idea that human thinking could be modeled as programs in a symbolic language carried out on computational devices. In linguistics, Noam CHOMSKY applied these ideas to human language and demonstrated that simple non-recursive finite-state models (such as might have been compatible with the behaviorist's stimulus-response chains) could not account for the generativity of human language. Psychologists like George Miller and Ulric Neisser applied these ideas to the description of human cognition.

In the ensuing decade, linguistics, psychology and the other disciplines progressed along their separate tracks. However, among many researchers there was a growing belief that none of the separate disciplines was by itself adequate to the problem: that understanding the complexity of the human mind requires a combination of different methodologies. The Cognitive Science Society and its journal, *Cognitive Science,* were founded in 1979 and 1977, respectively. Donald Norman, Roger Schank and Allan Collins were instrumental in both endeavors.

Cognitive science is now well-established internationally, with societies in Europe and Asia as well as in North America. Most researchers do not consider cognitive science a replacement for its subdisciplines. Specialized methodologies continue to be necessary. However, the cognitive science approach of interdisciplinary collaboration is leading to fruitful interpenetration of the subfields.

Major themes and topics of study. The assumption that there are mental representations and computational processes that operate over them is close to a universal tenet within cognitive science. The analogy between humans and computers has been very influential and has served to establish certain ground assumptions. One assumption is that, although knowledge of the brain may prove highly informative for gaining knowledge of the mind, it is not strictly necessary: explanations at the level of representations and processes acting on them are legitimate descriptions of cognitive phenomena. Further, the representational paradigm allows a rich vocabulary of internal processes that operate over these representations: *accessing* mental representations, as in memory retrieval; *transforming* a representation, as in problem-solving; *aligning* representations, as in analogy and similarity; *concatenating* representations, as in conceptual combination, and so on. This common vocabulary facilitates cross-disciplinary interaction, which often takes the form of applying converging methodologies with the goal of decoding the representations and processes that characterize a particular cognitive domain.

One example of synergy is the convergence of psychology, artificial intelligence and anthropology in the investigation of mental models of complex systems. Using a combination of protocol analysis (a kind of structured interview technique) and experimentation and task simulation, researchers aim to discover how people represent and reason about devices such as thermostats, puzzles and games such as tic tac toe or chess, and natural phenomena such as heat flow or electricity. Some researchers have tried to capture very general problem-solving techniques, such as theorem proving or deductive reasoning. Others have argued that much of human intelligence lies in our rich domain knowledge and in our ability to apply previous knowledge to the current situation through processes of *analogical mapping* or *case-based reasoning.* Most researchers favor a combination of analogical reasoning and general-purpose logical rules for modeling thinking. as this approach is sometimes called, is a central topic within cognitive science.

Psychology, linguistics, artificial intelligence and neuropsychology have joined in the study of sentence processing, inspired by theories of grammar and of language comprehension processes. Investigations of word meanings, including the interrelationships among word meanings in the mental lexicon, were seriously pursued by generative grammarians in the 1970's. This research laid the groundwork for recent cross-linguistic analyses of semantic structures. Recent linguistic research has revealed cross-linguistic differences in the way in which languages capture basic concepts such as events and spatial relations. This has led researchers to investigate whether linguistic categories influence cognitive categories, as proposed by the linguist Benjamin Whorf, or whether cognitive categories are relatively stable across the world's societies despite variations in word meanings. Inspired by Joseph Greenberg's work on linguistic universals in the 1970's, linguists, psychologists and cognitive anthropologists are currently investigating which aspects of language are universal and which vary across the world's languages.

Because the topic of representation is central in cognitive science, debates about its exact nature have occurred since the beginning of the field. Early debates concerned issues such as whether the storage of visual information was in terms of *holistic images* or *propositional networks.* Another distinction imported from artificial intelligence is that between *declarative knowledge* and *procedural knowledge.* Early in training on a complex task, people can often describe the rule they are using in fairly explicit terms. With extensive practice, automatization or proceduralization may occur, so that the ability to state the rule and to reason about it explicitly diminishes even as performance improves.

Different kinds of representational structures have been proposed, such as *schemas* (networks of related information such as the contractual structure of a business agreement), *scripts* (expected sequences of activities such as the events that take place in a restaurant or a dentist's office) and *naive physics models* (systems of beliefs about phenomena in the world, such as people's folk models of how evaporation causes cooling). Researchers have found that these kinds of representations are useful in predicting how people will respond to a given situation. For example, people tend to remember well those elements of a story that fit their schema for a situation, and that they often distort inconsistent details so as to make them match better with their long-term memory representation. There are also larger knowledge structures, such as *semantic networks* embodying knowledge about interconnected categories: for example, taxonomies of knowledge about animals and plants. Some aspects of these taxonomic category structures appear to be present across cultures, as the anthropologist Brent Berlin has shown.

Cognitive development is an important strain within cognitive science. Beginning with the work of Jean PIAGET and Lev VYGOTSKY, researchers have studied the way in which children acquire understanding of the physical world and of conceptual structure. Researchers have found that in many cases there is considerable similarity between children's early performance and the performance of adults who are novices in the domain. For example, adults who know very little science group physics problems according to their surface characteristics rather than according to physical principles, showing a classification pattern similar to that found for young children. Such results have led many researchers to take the "child as universal novice" approach to cognitive development. According to this view, the striking differences between children's and adults' thinking can best be explained in terms of a gain in knowledge rather than in terms of changing the fundamental logic of the child's thought processes.

One area in which many researchers have challenged the idea of a general-purpose learning device is that of language. They argue that ordinary learning processes cannot capture children's special ability to learn language. One line of evidence for this position is children's great facility at learning language -- e.g., the fact that while adults are better learners than children in most domains, children are better than adults at learning language. This suggests that human infants innately possess a special capacity for learning language which disappears over time. Further indirect evidence that language may have special status in human cognition comes from neurophysiological evidence suggesting that certain parts of the left hemisphere of the brain are dedicated to language. Other researchers emphasize the commonalities between language learning and other kinds of learning. The degree to which language should be considered separately from other aspects of cognition is an active research question.

Neurophysiological researchers have investigated the cognitive effects of damage to different areas in the brain. This kind of research contributes to identifying the functions of specific areas of the brain: e.g., the occipital lobes are implicated in visual-spatial memory and certain areas in the left hemisphere are implicated in different aspects of language processing. Investigations of on-line mental processing have so far been held back by a lack of sufficiently sensitive techniques. However, as new techniques are developed for real-time brain imaging, cognitive scientists will be better able to study complex mental processing in relation to brain activity.

Cognitive science has applications in education and in the workplace. In education, researchers like Jerome Bruner have stressed the social construction of cognitive models and have proposed ways to make classrooms more effective in promoting optimal ways of thinking about the world. In the workplace, the field of engineering psychology draws on research in cognitive science to identify people's typical causal mental models of devices and processes. It has been found that people can learn a new device more quickly and with fewer errors if it fits the causal pattern they expect.

The dominant computational model for most of cognitive science's history is symbolic processing, in which structural descriptions involving symbols are the medium of representation. In the classical approach, the assumption is that human thinking can be described using the same kinds of abstract language as is used to describe symbolic computer programs. Such a language includes symbols that correspond to psychologically relevant concepts and rules for combining and reasoning about symbolic descriptions. Recently, with the rise of neural nets, genetic algorithms and connectionist systems, new kinds of computational models have been applied to various aspects of human cognition... Debate continues on the merits of connectionist modeling, with David Rumelhart, James McClelland and others arguing that symbolic representations are often unnecessary and possibly even epiphenomenal, and Jerry Fodor, Xenon Pylyshyn and others arguing that the generativity and systematicity of mental processing could not be achieved without a true representational level.

Currently many researchers favor a hybrid approach that combines a neural net for modeling low-level perceptually-driven phenomena such as pattern recognition and a symbolic level for modeling higher-order knowledge and reasoning.

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