Cognitive Science

An Introduction

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implications of genetic engineering, cognitive scientists must confront the implications of knowledge technology. The potentially controversial applications of cognitive science research range from the possible development of a new generation of intelligence tests, which might be misused, to the large-scale introduction of intelligent robots in manufacturing industries, which might cause a massive loss or displacement of jobs. As with other sciences, the less and the more controversial applications often flow from the same underlying theoretical research. For example, results in computer vision might be used to design either a visual prosthesis for the blind or the control system of a cruise missile carrying a nuclear warhead. We hope that this book will provide the basic understanding of cognitive scientific theory that is needed to think about the policy issues posed by new information-processing technologies. We also strongly recommend the study of relevant aspects of history, social science, and the humanities, because the perspective of cognitive science, although crucial, must be supplemented by other perspectives.

1.5 The Interdisciplinary Nature of Cognitive Science

The Five Disciplines

As noted earlier, cognitive science is an interdisciplinary field that has arisen from the convergence on a common set of questions by psychology, linguistics, computer science, philosophy, and neuroscience. The five contributing disciplines will undoubtedly retain their separate identities because each of them involves a much larger set of concerns than the focus on a basic science of cognition. A more interesting question is whether cognitive science will become a distinct academic discipline in its own right, within which the contributions of the five converging disciplines become so thoroughly intermingled and transformed that they are no longer identifiable. This book presents cognitive science in its current form. The distinctive contributions of each of the five disciplines are highlighted, particularly in chapters 2 through 8. The topics selected for discussion, however, are those where the disciplines have shared the most common ground. Chapters 9 through 12 present several examples of research areas in which the interdisciplinary collaboration has been particularly close and has begun to obscure some of the differences among disciplines.

Obviously, no one of the five contributing disciplines encompasses the entire subject matter of cognitive science, and each discipline brings to the field a focus on particular areas. Neuroscientists are primarily concerned with the organization of the nervous system. Linguists are concerned with the structure of human language and the nature of language acquisition. Philosophers are concerned with logic and meaning, and with clarifying the fundamental concepts of cognitive science, such as information and knowledge. Psychologists are concerned with general human mental capacities, such as attention and memory. Computer scientists are concerned with the possibilities for AI. Cognitive science encompasses all of these concerns. Cognitive scientists, although they usually specialize in one or two of the contributing disciplines, benefit greatly from the cross-fertilization of all of them.

The most important differences among the five disciplines are in the research methods that they use to address the nature of mind. Psychologists emphasize controlled laboratory experiments and detailed, systematic observations of naturally occurring behaviors. Linguists test hypotheses about grammatical structure by analyzing speakers' intuitions about grammatical and ungrammatical sentences or by observing children's errors in speech. Researchers in AI test their theories by writing programs that exhibit intelligent behavior and observing where they break down. Philosophers probe the conceptual coherence of cognitive scientific theories and formulate general constraints that good theories must satisfy. Neuroscientists study the physiological basis of information processing in the brain.

The Five Disciplines Consider a Three-Letter Word

To get some of the interdisciplinary flavor of cognitive science, let us consider the following simple example: How does the word *the* figure in the information processes involved in understanding English? Speakers of English spend considerable time processing this little word. It is the most frequent word in the language. In a careful sample of one million words of printed English, one out of every fourteen words was *the* (Francis and Kucera 1982). Cognitive science ought to have something to say about it.

Linguistic methods have revealed quite a bit about *the*. To begin with, there is a nontrivial problem with correctly pronouncing and hearing *the*, because it is not always pronounced the same way. The vowel that is spelled "e" is pronounced either (roughly) like the vowel in *eat* or (roughly) like the vowel in *up*. Compare the two occurrences of *the* in the spoken sentence *The problem was tough, and the answer was two.* Although you probably never realized it before, you hear these two pronunciations as the same word, and you selectively pronounce the word in one of the two ways even in new contexts. If you learn a new high-tech word *erxel*, you are able to say *the* *erxel* correctly without thinking about it and without being told. So is a three-year old child, even though the child's parents could never have taught the child the rule, since they were unaware of it. It appears that humans can unconsciously learn finite *phonological* rules that apply to an unlimited number of cases. Chapter 6 shows how a formal theory of phonological rules can be developed.

Viewing English in terms of the grammatical structure, or *syntax*, of its sentences, the linguist tries to characterize where the word *the* can occur. The result, roughly, is that *the* occurs before nouns, as the first word in a *Noun Phrase* such as *the book* or *the big red book*. A small number of other words can be formally substituted for *the*, such as *a* in phrases like *a book*. Words that pass this substitution test are called *determiners*. Chapter 6 shows how linguists discover the formal syntactic rules that characterize people's knowledge of sentence structure in English and other natural languages.

Philosophers and linguists have worked together on the meaning, or *semantics*, of *the*. The word does not have any immediate semantic content in the sense that it does not refer to some object in the world, as, for example, the phrase *Mount Everest* does. Therefore, the notion of mapping symbols directly onto objects, introduced earlier for numbers, will not work for *the*. *The* is called the *definite determiner* because it seems to work together with the rest of a Noun Phrase to pick out some particular object in the world from a set of objects. A complete definite Noun Phrase, such as *the book*, still cannot be simply mapped onto a particular book in the world, however. The interpretation of *the book* depends on the *discourse situation*, that is, on who utters the phrase when, and where. The interpretation may also depend on a larger context, or *resource situation*. Suppose that Jane says to John, "The book is on reserve in the library." The interpretation of *the book* depends on the fact that Jane said it here and now and perhaps additionally on the fact that Jane and John are taking the same economics course and could not find the textbook for sale in the bookstore yesterday. Rather than being a fixed mapping, the meaning of the phrase *the book* seems to be a complex relation between situations and books. Barwise and Perry (1983) develop one philosophical theory in which the influence of situations on the interpretation of definite Noun Phrases is taken into account. Formal semantics is introduced in chapter 10 of this book.

Psychologists have investigated how people process the semantics of *the*, given the situational dependencies described by philosophers and linguists. It appears that the occurrence of a definite Noun Phrase sets off a search of the current perceptual input and of memory for an object with the correct properties. If no appropriate object is found, then the hearer tries to deduce one. Thus, Jane's remark to John sets off a search through his memory for books they have in common that might show up on reserve in the library. Next week, when Jane says, "I've got some questions about the stuff on supply and demand," John might have to deduce that she must be referring to the economics book, because he has not read the assignment. His inference bridges a gap in his memory. Cognitive psychologists have found evidence in controlled laboratory experiments that memory searches and bridging inferences are indeed triggered by the word *the* and that they take a measurable amount of time (Haviland and Clark 1974; McKoon and Ratcliff 1980).

Researchers in AI have exploited the properties of *the* in their attempts to build programs that can understand natural language. The part of a natural language processing program that figures out the grammatical structures of incoming sentences is called the *parser*. The syntactic properties of *the* are quite useful to a parser. When it encounters *the* in an input string, the parser can assume that it has entered a Noun Phrase and try to parse the next few words accordingly. This top-down process, in which the parser's behavior is guided by an expectation about what is coming, reduces the number of possibilities that have to be considered. A natural language processing program also has to construct a representation in memory of the information conveyed by the entire discourse. The discourse properties of *the* are crucial in relating the current input sentence to previous input. Thus, the programmer has to write routines that perform the memory searches and bridging inferences mentioned above. Attempts to write such programs have led to many insights about language understanding (see, for example, Winograd 1972).

It is also possible to investigate whether the syntactic and semantic properties of *the* are processed in particular parts of the brain. The potential value of *the* and similar words in the parsing process suggests that they might be preferentially processed in parts of the brain that are involved in determining grammatical structure. There are a number of other words, such as *which* and *if*, that carry information about the structure of sentences. These words are often called *function* words, because they are structurally important even though they do not convey the main content of sentences, which is the job of nouns, verbs, adjectives, and so on. It happens that there is an area of the left frontal cortex of the brain, called *Broca's area*, that seems to be involved with assigning structure to sentences. When this area is damaged, speech becomes disrupted, or *aphasic*, and the patient is said to suffer from *Broca's aphasia*. The distruption seems to interfere specifically with sentence structure. For example, people with Broca's aphasia tend to omit function words from their speech. Aphasic patients with damage to other areas do not show this pattern. In recent years there has been quite a bit of ingenious research on the question of just what kind of syntactic processing is going on in Broca's area (Bradley, Garrett, and Zurif 1980; Linebarger, Schwartz, and Saffran 1983). This research is described in chapter 7.

The intricacies of *the* that we have explored lead naturally to the question of when and how children begin to understand the word. Children are able to use *the* and its indefinite counterpart *a* in a syntactically correct fashion about a year and a half after beginning to talk, roughly at age three (Maratsos 1976). Remarkably, they are able to use *the* and *a* to make definite and indefinite references right from the beginning. For example, a three-year old will say "I want a cookie" when confronted with a pile of cookies and "I want the cookie" when confronted with a cookie and a carrot. Children take much longer, however, to learn how to make sure that their listeners are connected to an appropriate resource situation. It is quite common for a child to say, for example, "I broke the airplane" to an adult who has no idea what airplane the child is referring to. Apparently, children construct a good set-theoretic representation of objects in the world well before they are able to represent other people's cognitive states. Theories of cognitive development and language acquisition are discussed further in chapters 3 and 9.

The Study and Practice of Cognitive Science

The example of *the* should give a reasonable preliminary idea of the different research methods employed by the five contributing disciplines of cognitive science. Although it is clearly a circumscribed example, the problem of *the* illustrates another property of cognitive science. The cognitive scientist must cultivate a capacity to be puzzled by mental phenomena that occur without notice in everyday life. Often it is the most effortless cognitive activities, like understanding a simple word, recognizing the family cat, or planning a trip to the grocery store, that are the most complex and contain the most profound clues to the nature of cognition.

The example also illustrates one of the most attractive properties of cognitive science from the student's point of view. The diversity of methods employed in the field accommodates a wide variety of personal intellectual styles and preferences. Those who are attracted to laboratory work can pursue experimental psychology or neuroscience. Those who dislike laboratory work but who like abstract problems and careful logical analysis can pursue philosophy. Those who

love the challenge of writing computer programs can pursue AI, and those who love thinking about language can pursue linguistics. Those who are fascinated by the development of children can pursue cognitive development. This list could go on, but the general point is that cognitive science needs researchers who are motivated by many different kinds of curiosity and who like to do many different kinds of work. The field thrives on the presence of people who ask the widest possible variety of questions about mind.

Your own intellectual tastes will probably lead you to prefer some of the chapters in this book over others. It is natural to pick a specialty, but we urge you not to let your preferences lead you to neglect other chapters. Cognitive science depends on a continuing dialog among its various specialties, and the intelligence of the dialog requires people with a good grounding in the fundamentals of the contributing disciplines. Today, a new generation of cognitive scientists is learning these fundamentals as undergraduates and beginning graduate students. The resulting increase in mutual understanding will enhance the collaborative research of the future.

Suggested Readings

The nature of cognitive science is explored in depth in *Computation and Cognition: Toward a Foundation for Cognitive Science* (Pylyshyn 1984). *The Mind's New Science: A History of the Cognitive Revolution* (Gardner 1985) presents a history of cognitive science. *Mind Design: Philosophy, Psychology, Artificial Intelligence* (Haugeland 1981) is a collection of excellent essays on the foundations of cognitive science.

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2

Cognitive Psychology: The Architecture of the Mind

2.1 The Nature of Cognitive Psychology

Psychologists formulate and test theories about the human mind and behavior. The cognitive psychologist, as a cognitive scientist, views the human mind as a remarkable information-processing system that is extraordinarily powerful in most circumstances and yet impotent in others. As you read this paragraph, the meaning of each word is effortlessly activated within a mental dictionary of tens of thousands of words. But you probably do not remember the names of the seven coauthors of this book. A book-reading computer, using current technology, would have a much easier time remembering names than deploying meanings.

We begin this book with cognitive psychology for two reasons. First, cognitive psychology focuses on the human mind. In order to fully appreciate work in artificial intelligence (AI), it is necessary to have some familiarity with theories of human intelligence. Second, in keeping with the emphasis on basic science within cognitive science, cognitive psychologists have tried to develop theories of highly general cognitive capacities. They have asked what sort of general information-processing capacities a mind must have in order to do the many things it does. That is, they have tried to figure out what the overall design, or architecture, of the mind is. It is a good idea to begin the study of cognitive science by confronting some of the most basic questions about how it is possible for the mind to work as it does.

In order to maintain the focus on the most general cognitive capacities, we will delay discussion of two of the more specialized information-processing subsystems of the mind. Language will be extensively discussed in chapters 6, 9, 10, and 11. Vision will be discussed in chapter 12. Linguistic and visual information processing have many specific characteristics that require extensive and interdisciplinary investigation.