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# Cognitive science

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## 1. Definition

Cognitive science, the interdisciplinary study of cognitive phenomena, has its origins in philosophy and can be viewed as the empirical pursuit of age-old questions in the philosophy of mind. Perhaps the word which best captures the field of cognitive science is diversity. Cognitive scientists study a broad range of cognitive phenomena, including attention, perception, memory, language, learning, and reasoning. Moreover, researchers in cognitive science come from a wide set of backgrounds. The field draws from a number of disciplines including philosophy, linguistics, psychology, computer science, anthropology, sociology, and the neurosciences. However, one upshot of the varied nature of the disciplinary backgrounds of cognitive science researchers is the production of a number of complementary research methods.

Unifying the diversity in cognitive scientists' topics, backgrounds, and methods is a set of core questions and a shared approach which utilizes notions of computation and information processing as motivating metaphors and as explanatory concepts. All cognitive scientists are committed to the belief that the human mind is a complex system involved in the acquisition, storage, transformation, and transmission of information. Further, most cognitive scientists are committed to the thesis that an explanation of cognitive phenomena involves an account of formal structures and processes, their representational significance, and their physical implementation. The principal characteristics of the field, then, include commitment to some species of mental representation and the tendency to employ formal systems, especially computational models, in their descriptions of cognitive phenomena.

The overarching goal of cognitive science is to develop models of cognitive processes which link the disparate levels of analysis tackled by the field's eclectic set of researchers. It is no easy feat to link events noted by cognitive neuroscientists to events reported by cognitive anthropologists. Moreover, there is a daunting explanatory chasm which exists between our conception of the brain and our conception of the mind. However, description of cognitive phenomena in terms of formal systems helps to bridge these epistemological gaps. Although the questions of which particular formal system is most adequate, and, indeed, the question of whether any formal system is completely adequate, are hotly contested, the tendency towards the use of formal models persists.

Below follows (i) a brief history of cognitive science broken down by its contributing fields; (ii) an account of the multifarious methods of cognitive science; (iii) a discussion of some of the main issues in the field to date; and, finally, (iv) a short section on the relationship between pragmatics and cognitive science.

## 2. History of contributing fields

### *2.1 Philosophy*

Cognitive science involves an empirical approach to questions which have long been considered by philosophers. Perhaps the most notable of these is the mind/body problem concerning the relationship between mental characteristics of mind and physical characteristics of the brain. Whereas the philosophical problem involves consideration of whether and why such disparate phenomena might (or might not) be connected, the problem in cognitive science is to characterize the relationship between mind and body for any given phenomenon.

Most cognitive scientists have adopted, at least implicitly, one of two positions on the mind/body problem. The first is materialism, and is favored especially by people working in neuroscience. Materialism involves the belief that the only adequate characterization of mental states is in terms of their reduction to physical states of the brain. The second position is functionalism, and is popular among cognitive scientists pursuing questions in psychology and artificial intelligence. Functionalism, although compatible with materialism, differs from the latter in the belief that the essential characteristics of mental states are their informational properties, rather than their physical characteristics.

Whereas the materialist characterizes cognitive phenomena in terms of the physical phenomena with which they are seemingly identical, the functionalist characterizes cognitive phenomena in terms of their function in the cognitive system. Thus for the functionalist, the chief characteristics of cognitive phenomena are not the physical characteristics of the systems in which they occur, but their role in the information processing system. This includes the relationship between inputs to the cognitive system, the relationship between different mental states, and the consequent output of the system.

Other philosophical issues tackled by cognitive scientists include the question of intentionality (how it is that words, actions, and mental representation in general can have content); the issue of whether human knowledge should be characterized as innate or learned; rationalism versus empiricism (the relative importance of the mind as opposed to the external environment in determining our conception of reality); and epistemology (what it is to know something: in cognitive science, this debate has centered on the possibility of building intelligent computers).

As noted above, cognitive science has branched off from its philosophical roots, abandoning the thought experiment for the empirical methods of the natural and social sciences. To some extent, one can conceptualize artificial intelligence (AI) as an extension of philosophy, where the philosophers' logical tools have been automated. Nonetheless, philosophy continues to have a strong influence on cognitive science in forcing clarity of concepts and the explanatory adequacy of its theories.

### *2.2 Artificial intelligence*

Perhaps more than anything else, cognitive scientists have been inspired by the invention of the computer and its attendant theoretical constructs, such as information theory and symbol processing. The movement in the 1950s in computer science towards construing computers as symbol processors rather than mere number crunchers led some of AI's founders to a new way of thinking about the mind. The use to which cognitive scientists put the computer is two-fold: first, the computer is employed as an inspiring metaphor for mind. That is to say, cognitive scientists have used the metaphor of mind as a computer to inspire their work. Second, the computer has been used as a tool for building formal models of intelligent behavior.

The beginnings of the field of artificial intelligence is generally put at 1956, the date of an academic conference at Dartmouth College in which the topic was the production of computer programs capable of intelligent behavior. From the very inception of the field then, artificial intelligence researchers were committed to the tenet that intelligent behavior could be characterized in a formal manner and simulated on computers. However, the attempt to build formal models of the brain dates back even earlier. McCulloch & Pitts (1943) proposed a mathematical model of neural mechanisms with an eye toward exploiting their models in the explication of cognitive phenomena. Their work, although long ignored, was paradigmatic of cognitive science efforts, first, in its interdisciplinary character resulting from the collaboration between a mathematician (Pitts) and a neuroscientist (McCulloch); and, second, its attempt to provide a formal mechanism for theorizing about cognitive phenomena.

## *2.3 Psychology*

The field of cognitive psychology began mainly as a reaction against the reigning theory of psychology in the 1950s, behaviorism. Profoundly committed to controlled experimentation and the study of observable phenomena, behaviorists considered mental phenomena such as thoughts, images, and ideas to be vague categories whose ontological status was questionable. Because mental phenomena were not directly observable, they were deemed unfit for scientific investigation. However, the development of the computer and concomitant theoretical developments in information theory (Shannon 1949) offered psychologists a new way of discussing mental phenomena.

The computer served as an example of a mechanism whose observable, intelligent behavior did not require an appeal to introspective knowledge. Moreover, the behavior of the computer could ultimately be attributed to physical processes. The construal of the human mind as an analogue of the computer thus had a legitimating effect on the status of mental phenomena as potential objects for scientific study. Further, it provided cognitive psychologists with a language for discussing unobservable mental phenoma in a rigorous way.

The human mind is thought of as implementing a formal system. The cognitive scientist's job, then, is to outline the symbolic representations and transformation of those representations which intervene between environmental input to a given person and his/her behavioral output. The mind-as-computer analogy has also been used to develop a vocabulary for discussing cognitive mechanisms based on that used to discuss mechanisms in the computer. For example, programs, compilers, and buffers are often invoked as analogues of human mental processes. Armed with the theoretical machinery of computer science, cognitive scientists have studied human decision making, syllogistic reasoning, reasoning under uncertainty, the organization of memory, problem solving, auditory and visual perception, planning, learning, development, and aging.

Work in cognitive psychology, besides being driven by the metaphor of the mind as an information processor is paradigmatic of cognitive science in its employment of formal models of cognitive phenomena. For example, studies of decision making were influenced by and had an impact on formal theories of intelligent decision making. Newell & Simon's early work (1965) on human problem solving was influenced by search theory, automated problem solving, and formal theories of knowledge representation.

An important component of cognitive psychology concerns the way in which individuals' cognitive abilities change over the course of development. Besides attempting to characterize the mechanisms which underlie adult cognitive abilities, cognitive psychologists also describe the changes which those abilities undergo from birth to death. This includes the many changes which occur in the child's cognitive abilities as a result of maturation, the differences which are purely due to experience (such as those which exist between novices and experts in a given domain), as well as accounting for declining memory abilities in the elderly population.

Moreover, one of the biggest areas in developmental psychology concerns the question of language acquisition. Though this research has chiefly focussed on the growth of children's syntactic knowledge, the acquisition of pragmatic aspects of language ability has also been addressed. Bates (1976) suggests that children's competence with speech acts precedes their acquisition of other aspects of language. Moreover, the child's early communicative knowledge helps pave the way for subsequent language development. Overall, such research demonstrates the centrality of communicative intention, utterance function, interactive context, and, perhaps most importantly, the adult's interpretive resources for the process of language acquisition.

A related question concerns the relationship between language acquisition and conceptual development. Language acquisition begins in the child's second year. However, traditional Piagetian accounts of development suggest that the two-year-old, although s/he has an extensive set of perceptual and motor procedures for obtaining information about the world, lacks the capacity for truly symbolic concepts. In contrast to the Piagetian dogma, Mandler (1991) suggests that, in fact, children's conceptual ability develops quite early, in the form of *image-schemas*. Image-schemas are mappings from spatial structure, abstract aspects of trajectories of objects and their interactions in space, onto conceptual structure. Mandler (1991) argues that the perceptual sophistication of very young children is sufficient to support image-schema representation; moreover, she points to the implication of image-schemas in cognitive linguistics (Johnson 1987; Lakoff 1987; Langacker 1987) and suggests that the initial stages of language acquisition involve mappings between words and image-schemas.

Another trend in developmental research involves collaboration with cognitive anthropologists in order to explore the close relationship which exists between the acquisition of language and the acquisition of cultural competence. Ochs & Schieffelin (1976), for instance, argue that cultural competence is both the raw material and the end-product of language acquisition. Researchers have begun to realize that culture is an important variable which affects the manner in which both language and cultural competence are acquired (Harkness 1992). Consequently, the field has witnessed increasing convergence on questions of the acquisition of culture and more general developmental issues.

## 2.4 Linguistics

Another key component in the rise of cognitive science was the development of generative grammar by Noam Chomsky (1957, 1965). Chomsky's approach to language was paradigmatic of cognitive science in its employment of concepts from automata theory in computer science and in approaching natural language as a string of symbols which could be described as a formal system. Chomsky's review of B. F. Skinner's *Verbal behavior* is legendary for the way in which it largely silenced behavioristic approaches to language.

Although the initial Chomskyan paradigm, in which natural language syntax is approached in a purely formal way, played a crucial role in the early development of cognitive science, subsequent movements have focussed more upon the connection between form and meaning. Developments over the past 25 years in the field of cognitive semantics have led to a research program whose results are directly applicable to cognitive science. Under this conception the function of language is to set up construals, to map between domains, and to set up mental spaces with properties such as accessing, spreading, and viewpoint. (See Langacker 1987 and Fauconnier 1985 for a comprehensive treatment of these issues).

Under this construal of language, natural languages provide us with a means to trigger the complex projection of structures across discourse domains. Work in this vein has included investigations revealing the important role which metaphoric mapping plays in lexical semantics. This includes work done by Reddy (1979), Lakoff & Johnson (1980), Sweetser (1990), and Turner (1991), among others. The extraction of abstract schemas in semantic construction has also proven to be extremely useful in the analysis of analogical thought.

## 2.5 Current directions

Current directions in cognitive science involve greater acknowledgement of the role of culture in intelligent activity. Many cognitive tasks are performed with the help of tools, or *cognitive artifacts*, such as books, calculators, and computers which the culture makes available. Moreover, the most impressive cognitive feats are generally the result of groups of people working on problems together.

One manifestation of this trend is distributed cognition analysis in which traditional concepts and analytical techniques from information processing psychology are brought to bear on cognitive systems comprised of groups of people whose actions crucially involve the use of culturally manufactured tools (Hutchins 1994). Rather than focussing on the individual as if s/he were operating in a vacuum, current analysts take seriously the notion that the social, cultural, and physical context of activity does not just factor into cognition, but, rather, that they help constitute it. By scrutinizing cognitive systems comprised of multiple actors and their cognitive artifacts with an eye towards their information processing capabilities, distributed cognition analysts simultaneously evaluate and explicate the role of collective intelligence in intelligent activity.

In artificial intelligence, the acknowledgement of the role of contextual factors in intelligent behavior has resulted in a growing tendency to include these contextual elements in computational models. For example, Larkin (1989) describes a display-based problem solver which crucially relies upon perceptual representations of the external environment. Because the model can utilize aspects of its external environment (namely the display), some of its internal symbolic manipulations are simplified. Similarly, St.John (1992) reports that the task of training a connectionist network to respond correctly to verbal commands regarding the solution of a simple jigsaw puzzle was greatly facilitated when input included an updated representation of the puzzle compared to an abstract representation of the puzzle. Agre & Chapman (1987) introduce the notion of an *indexical functional representation* such as the-cup-I-am-drinking-from which are attributes of the agent's interaction with the world. Moreover, many models of reasoning processes include direct interactions between agents and the physical systems in which they operate (e.g. Greeno, Moore & Mather 1992).

Another recent trend in cognitive science is an increasing interest in evolutionary issues. Cognitive scientists have begun to look to evolutionary biology, physical anthropology, and animal psychology for clues to how human cognitive abilities might have evolved via processes of natural selection. Additionally, there is a burgeoning interest in computational modelling of the evolution of various cognitive capacities, especially natural language. Both biological and cultural mechanisms of evolution have been modelled in the new paradigm of *artificial life*. Artificial life involves the simulation of life-like behavior by systems consisting of populations of semi-autonomous entities whose local interactions with each other are governed by a set of simple rules (Langton 1988). The main thrust of this research program involves the demonstration that complex, high-level dynamics and structures are often emergent properties which develop from local interactions.

## 3. Methods

### 3.1 Methods for investigating behavior

#### 3.1.1 Psychological experiments

One important contribution of psychology to the field is the practice of conducting controlled experiments. Experiments test a particular hypothesis about the relationship between two or more variables: the variable which the experimenter manipulates, termed the independent variable; and the variable which is measured to detect the effects of that manipulation, the dependent variable. Hypotheses in cognitive science usually concern how manipulating some facet of the input to a cognitive system changes the behavioral output of that system. Conducting experiments allows the cognitive scientist to reject hypotheses which generate false predictions about how various manipulations affect cognitive performance.

Experimental studies of behavior can thus provide both the raw material for the cognitive scientist, in revealing behavioral effects which must be explained, and, a means to evaluate theories of cognitive processes. However, the experimental methodology has been criticized by people in the field (see esp. Newell 1973) for the tendency to overemphasize cognitive phenomena which are easily addressed by experiments and a corresponding underemphasis on efforts to integrate experimental findings into unified theories of cognition.

Further, the traditional methods of cognitive psychology have come under scrutiny for their lack of ecological validity. This critique consists of the charge that the cognitive phenomena addressed by the experimental methods of psychology are not relevant to cognition and behavior in everyday life. The setting of the laboratory is said to be an impoverished setting which fosters unnatural strategies. A closely related charge is that of 'decoupling' (Reitman 1970), the attempt to study the cognitive phenomenon in which one is interested in isolation from other factors. By its very nature, conducting experiments in a laboratory discounts the possibility that the context of cognition might be an important determinant of behavior.

#### 3.1.2 Naturalistic observation

One alternative to experimental techniques, is the anthropologist's method of naturalistic observation. Naturalistic observation involves the observation and recording of intelligent behavior in the setting in which it normally occurs. For instance, the investigation of child language acquistion has involved naturalistic study of children in the process of acquiring language. Such an investigation requires the observer to be as non-intrusive as possible, and/or reflecting on the manner and extent of his/her influence on the phenomenon under investigation. A language acquisition study, for instance, might involve the audio- or videotaping of a child's interaction with his primary caregiver. The investigator's observations could then be coded systematically to track or correlate the growth of the child's vocabulary, knowledge of syntactic structure, and pragmatic language ability.

The virtue of naturalistic observation is that it yields an extremely rich data set. In some cases, the sheer mass of data will far outweigh the 'mass' of theoretical framework for incorporating that data. Moreover, while observation is ideal for providing descriptive generalizations of a class of phenomena, it is less good for providing persuasive arguments for the causal relationship between elements in a theoretical framework. Because the controlled setting of the laboratory affords unconfounding the many variables which contribute to intelligent behavior, it is often useful to supplement naturalistic observations with controlled experiments performed in a laboratory.

As befitting the interdisciplinary nature of cognitive science, perhaps the best resolution of the tension between the ambiguity of field studies and the impoverished setting of the laboratory is to promote cross-talk between the two approaches. This involves extensive use of naturalistic observation to define the nature and scope of a given phenomenon, followed by more carefully controlled experimentation in the laboratory. Additionally, there is the possibility of negotiating a compromise between the ecological validity of the naturalistic setting and the control of the white room by perfoming experiments in naturalistic settings themselves. While this approach precludes the experimenter from exerting complete control over the setting, subjects are less likely to employ atypical strategies induced by the conditions in the laboratory. This helps insure that the investigator is observing cognitive phenomena which govern agents' normal behavior.

### 3.1.3 Linguistic intuitions

Traditional linguistic methods as well as the extension of those methods by researchers in cognitive semantics are a valuable tool for the cognitive scientist. Syntactic methodology is thought of as experiments which manipulate the form of sentences. In the linguist's experiments, the categories defined by syntactic theory are the independent variables, the stimuli are the sentences generated by the linguists' structural manipulations, and the dependant measure is the native speaker's intuition as to the grammaticality of the stimuli. The methods of cognitive semantics extend upon these methods in order to evaluate hypotheses about how background and contextual knowledge affect the meaning of a given utterance. Consequently, the form of the sentence is held constant while the background assumptions are varied. Moreover, while syntactic methodology relies upon judgements of grammaticality, cognitive semantics involves judements of the plausibility of a range of inferences evoked by a given sentence/utterance.

## *3.2 Neuroscience techniques*

### 3.2.1 Neuropsychology

One of the oldest techniques for investigating the brain bases of behavior is the lesion study. When the brain is damaged as a result of a stroke, an accident, a tumor, or other illness, we can observe the effect of that damage on cognitive functioning. For instance, it has long been known that damage to frontal cortex impairs planning ability, and that damage to the left hemisphere impairs one's ability to use language. The general aim of neuropsychological research is to correlate the site of brain damage to the loss of a particular sort of cognitive ability. The way this usually proceeds is to administer behavioral tests to a group of patients who have incurred similar sorts of brain lesions. For instance, a cognitive scientist interested in the role of the hippocampus in consolidating memories would compare the performance of patients with lesions in the hippocampus to normal controls on a number of memory taks.

However, interpretation of lesion studies is not as straightforward as it might, at first, seem. First, in any group of brain damaged patients there is bound to be substantial variability in the exact location of lesion site, thus making it difficult to form generalizations which relate damaged structure to damaged function. Second, brain damaged patients vary in the extent to which their brain is able to reorganize and recover lost functions. This also hinders the extent to which one can generalize over groups of patients, because the neuropsychologist never knows whether a particular patient's behavior is representative of some general facet of brain organization or of some idiosyncratic phenomenon pertaining only to that patient.

Perhaps most importantly, one cannot always conclude from a correlation between a behavioral deficit and a lesion site that there is a straightforward relationship between the two. The correlation between loss of function and lesion site (e.g. parsing ability with Broca's area) might be due to the fact that the impaired brain region is directly responsible for the cognitive ability — in this case parsing. However, another possibility is that the lesion site interrupts fibers of passage to and from areas which are really responsible for the cognitive task in question. A further possibility is that the lesion site affects a biochemical system with a widespread influence.

#### 3.2.2 Brain imaging

In recent years, a number of brain imaging techniques have been developed to supplement neuropsychological techniques by providing evidence of the precise location of the lesion site. Whereas previously, the exact site of a patient's lesion could not be ascertained until an autopsy could be performed, noninvasive techniques such as computerized axial tomography, positron emission tomography, and magnetic resonance imaging provide the cognitive scientist with images of the patient's brain which can be interpreted with respect to that patient's performance on behavioral tests of cognitive function. Moreover, noninvasive imaging techniques can complement neuropsychological techniques by providing us with images of normally functioning brains.

By positioning one's head inside a ring-shaped X-ray tube, computerized axial tomography (CAT) produces a three-dimensional picture of the brain assembled from a series of successive X-rays. It relies upon differences in the X-ray opacity of tissue between major structures and between normal and abnormal tissue. The spatial resolution of CAT is about 1mm in the plane of section, good enough to distinguish the hippocampus from the amygdala. A technique with an even higher degree of spatial resolution and which involves no conditions harmful to the subject is magnetic resonance imaging (MRI). MRI involves the use of a strong magnetic field to induce and measure the changes in the magnetic orientation of the nuclei of the hydrogen atoms in the brain. MRI maps of hydrogen density can be used to form images of the brain with a spatial resolution of about 0.1 mm in the plane of section.

Whereas CAT and MRI yield static images of the brain, techniques such as positron emission tomography (PET) afford the possibility of measuring dynamic changes in brain activity. In PET the patient is given an injection of 2-deoxyglucose, a radioactive form of glucose which is metabolized differentially by brain cells as a function of their activity. The PET scanner records the level of glucose metabolism and produces an image which is color coded to represent the differing degrees of activity in a given two-dimensional slice of the brain. Although the spatial resolution of PET is only about 10mm in the plane of section, it can be used to determine the patterns of activity in various portions of an individual's brain as s/he performs different cognitive tasks. Perhaps the most exciting development in the field of neural imaging is functional MRI. This technique involves capitalizing on the fact that the magnetic properties of glucose molecules in the blood change as a function of being metabolized. Like PET, functional MRI provides the cognitive scientist with graphical representations of the brain in action.

In spite of recent advances in the field of neural imaging, there are many experiments concerning brain function which, due to ethical reasons, cannot be performed on human subjects. This necessitates using animal models of brain processes. For instance, neuropsychologists are forced to rely on the bad luck of their patients in suffering brain damage; however, with animals it is possible for the experimenter to induce a lesion, or, even more commonly, a micro-lesion, and to test the effects of the lesion on the animal's cognitive abilities. Moreover, working with animals also affords the experimenter the possibility of studying the effects of various chemicals (e.g. agonists or antagonists of neurotransmitters) on the functioning of the brain and its cognitive concomitants.

#### 3.2.3 Event-related potentials

Another source of information about brain activity is electrical recording from the scalps of humans. By recording subjects' brain waves on an electroencephalogram (EEG) and averaging across timelocked events, the event-related potential (ERP) is obtained. The resulting waveform can be divided up into components and correlated with various aspects of the information processing required by the event. Early patterns in the waveform, occurring as quickly as 50 msec after the presentation of a stimulus item, have been related to aspects of perceptual processing. Components occuring later, at about 300 msec after the presentation of a stimulus item, are associated with the subjective perception of an improbable or surprising event (Donchin 1979). Of particular interest to linguistically oriented researchers, the N400 component, a negative-going wave with onset approximately 400 miliseconds post-stimulus, has proven to be correlated with certain aspects of semantic processing (see Van Petten & Kutas 1991 for a review). Because ERPs tap on-line processing of sentences they are ideal for addressing the sorts of questions needed for the development of processing models of pragmatic phenomena.

### *3.3 Computational modelling*

Overall, the dominant research paradigm in cognitive science is computational modelling of cognitive processes.

Computational models provide a medium for integrating knowledge of disparate cognitive phenomena gleaned from experimental studies. And, by the same token, modelling provides a medium for integrating knowledge of cognitive processes gleaned from multi-disciplinary studies. Moreover, cognitive phenomena are not static but dynamic processes which change in response to changes in cognitive agents' external environments and internal states. Computational models are especially well-suited for capturing this dynamic aspect of cognition.

Probably the most useful reason for building computational models is that they necessitate a fully explicit account of the representations and processes which explain a given cognitive phenomenon. In the course of coding up a model, the cognitive scientist inevitably discovers aspects of a problem which s/he might never have encountered had s/he not endeavoured to provide as explicit an account as required by a computational model. Additionally, a sufficiently complicated model of a cognitive process will often yield predictions about empirical manifestations of the phenomenon which may not have been obvious at the outset of the investigation.

Another advantage of computational models is that they can be used to generate empirical predictions. Used correctly, computational modelling and empirical investigations can be employed in a symbiotic manner where data from experiments inform the original model; the development of the model leads to elaboration of the theory, which in turn yields predictions testable by empirical methods. The results of subsequent experiments are gradually incorporated into the model.

However, the disadvantage of modelling endeavours is that coding up a model usually means accepting the observation and recording of behavioral activities such that systematic and/or local sources of data are overly simplfied because of the need to obtain 'clear' or unambiguous, discrete measures. Consequently, many computational models of natural language processing are not sensitive to pragmatic aspects of language, especially subtle, situation-specific contextual clues. The incorporation of microgenetic aspects of context into computational models of language development and competence is a challenge which cognitive scientists will have to tackle in the upcoming decades.

## 4. Issues

### *4.1 Functionalism*

Given our characterization of cognitive science as the empirical pursuit of the mind/body problem, perhaps it is not surprising that one of the central issues in the field concerns the best way to characterize the relationship between psychological states and their neurophysiological instantiation. Functionalism, the traditional approach to the problem, stems from the central tenet that the mind is an information processing system. Thus the fundamental properties of the brain are not its physical properties, but rather, its informational properties.

The functionalist approach to cognitive science is historically linked with AI and draws heavily on the metaphor of the mind as a computer. Proponents of this approach often note that the same computational algorithm can be implemented on different sorts of machines, for example a PC and a Unix Machine; while the details of the physical implementation of the algorithm differ in the two cases, the formal properties of the computation do not. The functionalists' focus on algorithms and the formal aspects of information processes is due to the belief that the central component of understanding an information processing system is the knowledge of the formal rules which the system implements.

One's position on the issue of how cognitive processes are best characterized has implications for the manner in which the cognitive scientist approaches a problem and the methods which s/he employs. A commitment to functionalism, for instance, predisposes one to explain cognitive phenomena in terms of its informational properties. The functionalist, then, is concerned with what sorts of representations are involved in the phenomena and which processes operate on them. A functionalist might develop theories by building computational models of psychological processes, and later testing those theories by conducting experiments. A functionalist might also be inclined to employ the methods of linguistics, developing theories to account for linguistic facts and testing them via linguistic intuitions. Because the functionalist is less interested in the physical instantiation of cognitive phenomena, s/he will not concern him/herself with questions about the neurophysiological details surrounding that phenomenon.

By contrast, a commitment to materialism predisposes one to concentrate on the link between intelligent behavior and the neural processes which give rise to it. Materialists are more concerned with localization of function, whether and where in the brain particular sorts of cognitive phenomena occur. Materialists, then, are more likely to utilize neuropsychological methods or imaging techniques such as MRI, PET, and CAT.

### 4.2 Symbolic vs. subsymbolic architectures

A related issue concerns the sort of computational architecture which is best suited for modelling cognitive processes: traditional symbol processing architectures or the more statistical neural networks, also called connectionist nets. The debate between connectionists and the traditional physical symbol system approach to modelling cognitive phenomena can ultimately be traced back to the contrast between the functionalist answer to the mind/body problem and the materialist answer to the same. A crucial facet of this debate hinges on the importance of the physical implementation of cognitive processes. The traditional rhetoric of cognitive science involves the assumption that the details of implementation of an information processing system are irrelevant. The traditional functionalist approach to the question of how algorithms are physically implemented is to dismiss it as a largely irrelevant (peripheral) matter. In contrast, connectionists maintain that implementation is, in fact, crucially relevant. The different architecture used in connectionist models has ramifications for the way in which information is processed.

Neural networks provide a mathematical formalism and computational machinery for a multi-disciplinary synthesis of descriptions of high-level processing from neuroscience, psychology, linguistics, and computer science. They have been used to model phenomena at various levels of analysis, ranging from models of the individual neuron, to models of high-level cognitive processes, to models of collective behavior.

### 4.3 Modularity

One issue which polarized cognitive scientists in the 1980s and continues to figure prominently in psycholinguistics concerns Fodor's (1983) characterization of cognition as *modular*. Fodor's proposal is that cognition is the interaction of a large number of autonomous, highly-specialized input modules with a general purpose central processor. Input modules can be conceptualized as an array of autonomous black boxes, each of which transforms a particular sort of inputs from the world into representations which can be handled by the central processor. Input systems are referred to as black boxes because they are informationally encapsulated with respect to the central processor as well as with respect to each other. Moreover, the central processor has access only to the outputs of the input modules and not to the intervening representations in the modules themselves.

A modular approach to language processing involves the assignment of 'low-level' aspects of processing (such as parsing and word recognition) to informationally encapsulated input modules while leaving the higher level aspects such as semantics and pragmatics to the central processor. The difference between a modular account of language processing and a non-modular account chiefly concerns the time-course of processing. In the modular account, lower levels of processing occur autonomously and are integrated only later by the central processor. However, on a non-modular account, the lower levels of processing are not independent of higher levels but interact continuously with them in the processing of a sentence. Thus all parties agree that the various levels of linguistic analysis interact, while making different predictions about when the results of higher-level analyses become available. The controversy concerns whether or not higher-level contextual factors can influence processing at lower levels.

### 4.4 Nature vs. nurture

A fourth major controversy in cognitive science concerns the nature and extent to which cognitive phenomena are influenced by genetically determined biological factors as opposed to the influence of environmental factors such as one's cultural upbringing. Like many of the issues in cognitive science, this debate is rooted in a longstanding philosophical controversy. In this case the controversy is the same as that between the rationalists and the empiricists. Rationalists consider the nature of the mind itself to be the main determinant of our experience with reality. Rationalism stands in contrast to empiricism, which embraces the idea that all knowledge results from experience in the world.

The nature versus nurture debate is played out in various arenas of cognitive science research. For example, an instance of this issue concerns the question of whether general intelligence is genetically predetermined or whether factors such as diet and parenting play the major role. Similarly, the issue of heredity versus environment is central to the cultural psychologist concerned with cataloguing the similarities and differences in the mental abilities of people in disparate cultures. Related questions are addressed by the cognitive anthropologist who studies the ways in which immersion in a culture enables intelligent behavior which would otherwise be impossible.

But perhaps nowhere is the nature versus nurture issue more salient than in the field of language acquisition. Historically, the consideration of how children acquire language was Chomsky's main ammunition against the behaviorists and for the cognitivist position that an account of intelligent behavior requires an account of mental representation. It was the contrast between the apparent ease with which children acquire language with the complexity of the information processing construal of language competence as knowledge of a system of rules and representations that generates the grammar of the language which led Chomsky to posit an innate language acquisition device.

Ironically, the same construal of the complexity of language competence which led Chomsky to posit nativism led others to reject it. Many researchers found it implausible that children were innately endowed with transformational grammar, that transformational grammar could be genetically coded for. Rather than a domain-specific language organ, whose development proceeds more or less independent of environmental influences (e.g. Chomsky 1972, 1980, 1986), many cognitive scientists point to the importance of general cognitive strategies (most prominent in pragmatic phenomena) in language processing. Bates et al. (1988) reviews language acquisition data which suggest the importance of general cognitive and social competence in child language acquisition, arguing that it is the more general cognitive strategies which are innate.

### *4.5 Situated action vs. physical symbol systems*

A recent controversy in cognitive science concerns the centrality of the brain, understood as a physical symbol system, to intelligent behavior. The traditional approach to cognitive science (e.g. as represented by Newell & Simon) is focussed on the processing structures of the brain and the symbolic representations of the mind. As discussed above, an account of a cognitive process involves a thorough characterization of the perceptual inputs, the internal manipulation of representations which occurs in the brain, culminating in the outputs which lead to intelligent behavior. However, the traditional view of cognition has been questioned by researchers as overemphasizing the role of mental processes in the determination of intelligent behavior.

Advocates of situated action theory argue that intelligent behavior is less the product of internal mental processes than the interaction of those processes with external social and historical factors which constitute the context of human action. The main determinants of intelligent behavior do not involve content-independent representational processes, but, rather, embodied behavior profoundly affected by social interaction, historical influences, culture, and the environment.

## 5. Cognitive science and pragmatics

### *5.1 Definition*

The study of pragmatics has revealed the extent to which language use depends upon users' assumptions and inferences about each other, awareness of the particular context of speaking, general background knowledge, and even tacit assumptions about language use itself. The way in which speakers utilize this vast array of linguistic, non-verbal, and inferential resources constitutes an important set of cognitive phenomena. The investigation of these phenomena by researchers in pragmatics thus falls, by definition, under the rubric of cognitive science. Moreover, the close relationship between language and reasoning which is inherent in pragmatic phenomena presents a number of possibilities for fruitful interaction between researchers in pragmatics and those in other branches of cognitive science. Below we explore connections, both actual and possible, between the methods, interests, and issues of pragmatics and the rest of cognitive science.

### *5.2 Methods*

Pragmatics presents the cognitive scientist with a number of linguistic facts, a set of categories for classifying those facts, and methods for testing competing explanations of those phenomena. Proposals in cognitive science should be able to account for phenomena already identified and explained by pragmatics. Moreover, proposals in pragmatics must also be answerable to relevant critiques from other cognitive scientists.

Pragmaticists and cognitive scientists, then, might work together to account for the ways in which context constrains interpretation. The differences between them lie mainly in emphasis. For example, the pragmaticist might ask how general properties of cooperative interaction affect language structure and use, while the cognitive scientist might invert the question by asking what we can learn about general properties of cooperative interaction from language. By working together, findings from different perspectives can serve to constrain theories about language in context.

For example, cognitive scientists can look to pragmatic implicature as a species of reasoning behavior with ecological validity so often lacking in traditional cognitive psychological inquiry into reasoning. Conversely, empirical studies of interaction can be revealing for theories of implicature and pragmatic inference. Questions about the nature of representation of background knowledge as well as the content of that knowledge are germane to all sorts of cognitive scientists. Similarly, researchers from a variety of disciplinary backgrounds are interested in how knowledge about the current situation is represented and how these representations come to bear on the computation of utterance meaning.

One might consider also the possibility of adopting some of the methods from the cognitive sciences in the study of language in its social and cultural contexts. Computational modelling, for example, has proven extremely useful in AI, and might prove equally so for pragmatics. The degree of thoroughness necessary for the development of a working model has often led researchers in cognitive science to insights which might otherwise have gone unnoticed. However, a caveat is in order as a formalized theory is only as good as the theory it formalizes. It is often necessary to make simplifying assumptions in order to make models. When such simplification amounts to oversimplification the results can be disasterous.

As noted above, pragmatics provides a rich set of categories as well as formalisms within which cognitive scientists can work to develop processing models of these phenomena. Because pragmatic phenomena touch on a mixture of linguistic and non-linguistic components, the development of processing models should prove fruitful for researchers interested in a wide variety of cognitive phenomena. Experimentation addressed at elucidating the details of on-line processing of pragmatic aspects of language comprehension are bound to suggest mechanisms of perception, social perception, inference and other factors of interest to researchers in all branches of cognitive science. Moreover, studying pragmatic phenomena in this manner may suggest alternatives for their characterization.

Pragmatic phenomena are also amenable to study by neuropsychologists. Evidence indicates that damage to the right hemisphere of the brain has a detrimental effect on pragmatic aspects of language comprehension. This includes metaphor, indirect speech acts, jokes, irony, and implicature (see Gardner 1985 for an overview). However, such studies have often been conducted by researchers whose knowledge of neuropsychology is far greater than their knowledge of linguistics. Neuropsychology would surely benefit from collaboration between linguists working in pragmatics and neuropsychologists studying the results of right hemisphere injury. Interdisciplinary work of this sort would enable the formulation and evaluation of sophisticated propositions linking the categories of pragmatics, the cognitive abilities which support those categories, and their neural correlates.

## *5.3 Issues*

Researchers in pragmatics share an interest with the rest of cognitive science in some pivotal issues. Perhaps the issue to which pragmatics is the most germane is the validity of the modularity thesis. Pragmatic analyses highlight the ways in which low-level aspects of processing such as parsing and meaning disambiguation both support and are supported by higher-level computations involved in the determination of reference and the evaluation of propositions which are expressed, entailed, and implicated by a given utterance. The interdependence of high- and low-level aspects of language comprehension poses problems for the modularity thesis in its strictest form.

However, it also suggests avenues for further research. For instance, psycholinguists would do well to model the interplay between implicature and the disambiguation of polysemous words in varying contexts. These would enable researchers to determine, experimentally, the precise point in time at which the results of higher-level analyses are available and postulate the processes by which those results are exploited by other language comprehension processes.

Further, it would seem that the current controversy in cognitive science between the traditional physical symbol system account of human behavior and the situated action approach is paralleled in pragmatics by linguists who view semantics as fundamental and pragmatics as extra machinery (viz. the traditional Gricean approach), and linguists who view pragmatic phenomena as central and semantics as derivative. Suchman (1987: 179), one of the chief proponents of the situated action approach, implores cognitive scientists to pursue:

> [...] a fundamental change in perspective, such that the contingence of action on a complex world of objects, artifacts, and other actors, located in space and time, is no longer treated as an extraneous problem with which the individual actor must contend, but rather is seen as the essential resource that makes knowledge

possible and gives action its sense.

Similarly, for pragmatics, one might imagine Suchman recommending a similar inversion of perspective where we view the contingence of meaning on the particulars of context as the essential resource that makes communication possible and gives language its meaning.

## 5.4 Convergent interests

Developments in cognitive semantics have, over the past 25 years, led to a research program whose results have become completely intertwined with those of cognitive science. Researchers in this school have found that the semantic and pragmatic level(s) of meaning construction also operate in other high-level aspects of thinking and communication. Because meaning construction draws upon so many different sorts of cognitive resources, investigation of pragmatic phenomena often leads to insights about processes which turn out to be involved in literal interpretation as well as in non-linguistic tasks. Conversely, the researcher whose primary interest is pragmatics might look to reasoning research in the hope that processes identified in non-linguistic contexts may be operating in meaning construction.

### 5.4.1 Background knowledge

Pragmaticists and cognitive scientists alike are interested in how background knowledge is represented and how it is brought to bear on the interpretation of utterances. Fillmore (1982) noted that some words (for example, *Tuesday*) can be defined only by providing a certain amount of background information, and proposed the term *frame* for the set of propositions which characterize that background knowledge. Moreover, Fillmore's linguistically motivated account is paralleled by similar suggestions from researchers in other branches of cognitive science; for AI, see e.g. Minsky (1975). A frame includes *slots* which may be filled through a *slot-filling* process. Frames derive great representational efficiency from the existence of *default values* for slots. Default values consist generally of the most typical and/or most frequent filler for each slot and are invoked in the absence of other information.

The idea of representing stereotyped situations which employ default values has been found to be of great value in building computer systems to understand natural language. In building their natural language understanding system, Schank & Abelson (1977) postulated *scripts* as analogous to Minsky's frames. Scripts represent stereotyped sequences of events such as going to a restaurant, and contain slots which are either filled by binding the particular fillers manifest in the situation at hand, or by instantiating the default value for any particular slot.

Moreover, cognitive psychologists have found considerable evidence that people utilize frames, or *schemata* as they are called in the psychological literature, in a variety of cognitive tasks. People use schemata in perception, planning, and memory for events. The psychological reality of schemata has been used to explain human ability to make inferences in complex situations, to make default assumptions about unmentioned aspects of situations, and to make predictions about the consequences of actions.

Schemata operate at many levels of abstraction, including everything from low-level perceptual schemas to high-level narrative structure schemas. For example, it has been proposed that because stories are typically presented in a particular format, with specifiable subparts, a story schema guides our comprehension of stories. Story schemas thus provide a set of expectations about the order in which its constituents occur. When constituents are presented in a non-canonical order, subjects' processing time during comprehension increases. Moreover, subjects tend to recall stories in canonical order, irrespective of the actual order of presentation (Mandler 1982; Mandler & Johnson 1977). Overall, story schemas constitute high-level schematic representation of narrative structure which is supplemented by appropriate generic schemas related to the content of the story.

### 5.4.2 Cultural models

Recent years have seen an increasing interest in background knowledge whose origin is primarily cultural. *Cultural models* are frames, scripts, and schemata shared by members of a given society. Cognitive anthropologists who study cultural models are engaged in elucidating the organization of this vast knowledge base and linking it to what is known about human reasoning abilities. Cultural models are used in a variety of cognitive tasks including the formulation of plans and goals, interpretation of the actions and goals of others, and talk about human activity.

Research on cultural models has revealed the way in which speakers' assumptions about language are encoded in cultural models. Sweetser (1987) demonstrates the way in which Gricean maxims are represented as cultural models of communication and mutual assistance. Although cultural models are widely shared among culture members, they need not correspond to anything concrete in the external world. Sweetser calls her model of communication, the simplified speech act world. In this world, people speak in order to communicate information which might be helpful to one another; their beliefs are adequately justified (and, as a result, are true); finally, people say what they believe.

In spite of its idealized status, the simplified speech act world is an efficient representation for reasoners to use in the definition of speech acts that do *not* fit into the model. Sweetser shows how these models, besides functioning as a guide to everyday communication, figure in the lexical semantics of words like *lie*. Although the literal definition of *lie* is simply a false statement, understanding *lie* in the context of a culturally available taken-for-granted model of communication, makes it possible to give a unified account of the semantics of *lie*, as well as a host of other related words such as *mistake*, *white lie*, and *exaggeration* by showing how speakers employ the speech act model to note deviations from its component parts.

Quinn & Holland (1987) stress the importance for linguists and anthropologists of information about the extent to which cultural knowledge is presumed by language users. Research on cultural models has implications for theories of lexical semantics, metaphor, polysemy, hedging and other linguistic phenomena. It also has important implications for the theory of culture and the role of culture in reasoning, problem solving, and evaluating the behavior of others. Moreover, researchers in pragmatics can look to cultural models as a formalism for describing the cultural assumptions essential to making the correct inferences required for reference, illocutionary force, politeness, and implicature.

#### 5.4.3 Mappings

Besides background knowledge such as that represented in frames, schemata, and cultural models, meaning construction requires a substantial degree of mapping between cognitive domains. The importance of mapping is especially prominent in mental space theory (Fauconnier 1985), in which the process of meaning construction involves partitioning the representation of sentence meaning into *domains* or *spaces*. Although the discourse as a whole may contain contradictory information, each space functions as a distinct and logically coherent knowledge base. For example, partitioning a statement like *Six months ago John was in perfect health, but now he's on the brink of death* would start by dividing its information into two spaces: one for six months ago and one for the present time. Each space is internally coherent and together they function to represent all of the information contained in the original sentence. In contrast to traditional approaches to meaning construction, the bulk of the cognitive work involves mappings and correspondences between domains rather than the derivation of a logical representation of sentence meaning.

Mappings, which play a central role in the process of meaning construction, are of four main types: projection mappings, pragmatic function mappings, schematic mappings, and space mappings. Projection mappings involve the mapping of abstract structure from one domain onto another, as in a metaphor. In order to understand metaphoric use of language, the listener must map features of the source domain onto features of the target domain. The second type of mappings are pragmatic function mappings, such as those employed in metonymy. Pragmatic functions (Nunberg 1978) map objects from one category onto objects in another so that one term can be used to refer to the other. For example, authors are often mapped onto the books that they write, enabling us to say things like, *I was up all night reading Searle*. Third, schematic mappings involve mapping aspects of a particular situation onto more generic frames in order to interpret them. Schematic mapping is also involved in structuring mental spaces with frames by setting up elements in spaces which correspond to the slots in the frame. Finally, space mappings serve to link mental spaces set up in discourse.

#### 5.4.4 Creative vs. banal

An exciting upshot of these developments is the finding that cognitive processes which underlie meaning construction in the most banal cases are also exploited in creative thought and expression. Cognitive scientists have found that the semantic and pragmatic levels of meaning construction also operate in general reasoning, narrative structure, and other high-level aspects of communication. Rhetorical strategies may often represent extreme cases of general principles for using language. For example, Nunberg (1978) has demonstrated that 'purely denotational' utterances are most likely interpreted via strategies very similar to those used in the interpretation of indexicals. Moreover, metaphor, once thought to be a mere rhetorical flourish, has surfaced in recent decades as involving cognitive processes fundamental to language change, analogy, problem solving, scientific reasoning, concept learning as well as creative language use.

Indeed, cognitive scientists would do well to shift from logic to rhetoric as a guide to research on human reasoning. Historically, logic contrasts with rhetoric in that the former has always had more of a prescriptive, the latter more of a descriptive character. Whereas it is often necessary to undergo a certain amount of formal training in order to understand the compelling nature of a logical proof, rhetorical techniques are designed to be intrinsically compelling. The identification of semantic and pragmatic aspects of language comprehension exploited in rhetorical techniques of argumentation and articulation promises to be an excellent basis for reasoning research.

## *5.5 Conclusion*

Investigations in pragmatics and other areas of cognitive science have a shared heritage in philosophy. Besides addressing philosophical problems, this shared heritage has involved the use of analytic tools such as logic and other formal systems. However, there has been a subsequent shift towards the incorporation of socio-cultural influences on language and cognition in general. We have noted the relevance of pragmatics research to fundamental issues in cognitive science and pointed to a number of research interests shared by pragmatics and other areas of cognitive science.

The frames invoked by linguists to understand lexical semantics can also be invoked to explain non-linguistic cognitive tasks such as reasoning, problem solving, and making judgements about the behavior of others. Moreover, the cultural basis of many of these frames suggests an affective dimension which underlies their role in the formation of expectations and plans, as well as the function of cultural models as goals. Simlarly, one would expect to find the mechanisms which underlie implicature, presupposition, and other pragmatic phenomena to be invoked in reasoning which is not primarily linguistically oriented. Further, investigations of meaning construction reveal the centrality of projection, pragmatic function, schematic, and space mapping to semantic and pragmatic language understanding. Finally, explorations of the role of mapping in language and its role in other cognitive phenomena are bound to prove beneficial to researchers from a variety of disciplinary perspectives.

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