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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 that 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 range of backgrounds. The field draws from a number of disciplines including philosophy, linguistics, psychology, computer science, anthropology, sociology, and the neurosciences. The upshot of the varied nature of the enterprise is that convergent findings often arise out 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 that uses 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 can be productively viewed as a complex system involved in the acquisition, storage, transformation, and transmission of information. Though cognitive scientists differ in their interest in the biological substrate of intelligent behavior, most are committed to the thesis that the 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 that 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. Indeed, there is a daunting explanatory chasm between our conception of the brain and our conception of the mind. However, describing cognitive phenomena in terms of formal systems helps to bridge these epistemological gaps. Although the questions of which formal system is most adequate, and, indeed, whether *any* formal system is completely adequate, are hotly contested, the tendency towards the use of formal models persists.

What follows is (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 that have long been considered by philosophers. Perhaps the most notable 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.

The majority of 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 representations 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, 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.

In fact, the role of the computer in cognitive science is two-fold. First, it serves as an inspiring metaphor for mind. Second, it serves 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 behaviorism, the reigning theory of psychology in the 1950s. 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 phenomena 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 that intervene between the environmental input to a 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, memory organization, 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 is the way individuals' cognitive abilities change over the course of development. Besides attempting to characterize the mechanisms that underlie adult cognitive abilities, cognitive psychologists also describe the changes that those abilities undergo from birth to death. This includes the many changes that occur in the child's cognitive abilities as a result of maturation, differences due to experience (such as those between novices and experts in a given domain), as well as differences due to aging, as in the decline in memory in the elderly population.

Moreover, one of the biggest areas in developmental psychology concerns the question of language acquisition. Though this research has chiefly focused 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 she or 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 (1992) 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 (2004) 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 to explore the close relationship 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 that 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 (Sinha, 2000).

## 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 use of concepts from automata theory in computer science and in approaching natural language as a string of symbols that 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 behaviorist 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 focused more on the connection between form and meaning. Developments over the past 30 years in 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 Fauconnier 1985 or Fauconnier 1997 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 structure across discourse domains. Work in this vein has included investigations revealing the important role that metaphoric and metonymic mappings play in lexical semantics. This includes work done by Reddy (1979), Lakoff & Johnson (1980), Radden (1996), Kovecses (1996), Sweetser (1990), and Talmy (2000), 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 Neuroscience

Cognitive neuroscience concerns the identification of the biological structures and events involved in the acquisition of information from the environment (sensation), its interpretation (perception), its storage (memory) and modification (learning). Other issues address how we use information to predict the consequences of our actions (decision making), to guide our behavior (motor control), and to communicate (language) (see Albright & Neville 2003 for review). Early work in this area focused on the issue of localization of function, as neurologists and neuropsychologists correlated the areas of their patients' brains damaged by stroke or tumor with their resultant cognitive deficits. Perhaps the most famous example is provided by Paul Broca, who argued that the left frontal lobe is responsible for speech production. Other work in neuroscience has concerned the electrochemical basis of

neural function that has helped elucidate the mechanisms that underlie learning and memory formation.

While most early work in cognitive science proceeded independently of neuroscience research, the widespread availability of non-invasive brain imaging technologies has led to an increasingly synergistic relationship between psychology, linguistics, and neuroscience. A great deal of neuroimaging research is aimed at brain mapping, or describing the brain regions involved in various sorts of cognitive processing, including perceptual, memory, and language tasks. Moreover, cognitive scientists have used neuroimaging data to address longstanding debates about the representational basis of mental imagery (Kosslyn, et al. 2003), the locus of attentional selection (Kanwisher 2000), and the organization of semantic memory (Chao & Martin 2001). Neuroimaging studies of language function have confirmed the role of classically defined language regions such as Broca's area and Wernicke's area, and point to the importance of other regions as well (Bookheimer 2002). Additionally, neuroscientists have begun to consider how the principles of neural function might be used to explain word meaning and syntactic organization (see e.g. Pulvermüller 2003).

## *2.6 Current directions*

In early cognitive science, much emphasis was placed on mental representation and thought in a single individual. In recent years, however, greater emphasis has been placed on how representations are built, shared, and updated by multiple individuals during interaction. A key finding is that people naturally establish common ground — a mesh of knowledge from past experiences, their immediate surroundings, and shared culture, and that they rely on it to achieve understanding and complete joint tasks (Clark 1996). Some research on interaction focuses on how people align linguistic representations during conversation (e.g., Pickering & Garrod 2004). Other research focuses on the role of gesture during spoken interaction, including its utility in completing joint tasks (Clark & Krych 2004), narratives and story re-telling (McNeill 1992), and (c) explaining or remembering relatively abstract phenomena, such as math (Goldin-Meadow 2003).

This move towards the study of interaction is consistent with the field's growing appreciation of cognition as emerging from our interactions with the material,

social, and cultural world. In neuroscience, this is marked by two research trends: first, the study of the interdependence of perceptual and motor mechanisms; and, second, the study of social cognitive neuroscience, aimed at identifying the neural mechanisms that subserve the perception of affective and socio-emotional cues. In artificial intelligence, this trend is marked by the growth of machine learning, the field of computer science that explores techniques in which a machine acquires knowledge from its previous experiences. In addition, the importance of the social world has been modeled computationally using the modeling paradigms of artificial life. In these models, whole populations of autonomous, interacting agents are simulated so that researchers can examine the conditions that lead to coordinated activity. In robotics, this philosophy is extended even further, as researchers examine how intelligent behavior can arise from the dynamic interaction between the robot's physical capabilities, its cognitive system, and its external physical and social environment (see Clark 2001).

Indeed, with the internet boom and the ubiquity of electronic devices such as laptops, cell phones, and personal digital assistants, cognitive science is even moving out of the ivory tower and into the work place. High-technology companies and many laboratories in academic settings have established research groups to study and evaluate how people interact with technology and how they work with each other using various media, such as the internet, video-conferencing systems, and instant-messaging systems. Cognitive scientists in this setting use many different methods to study human behavior in the work environment, ranging from discourse analysis to ethnography to eye-tracking (see Hollan, Hutchins & Kirsh 2000). In keeping with cognitive scientists' increasing interest in emotion, some of this work has focused on affect, and the emotional impact of technology on its users (Norman 2004; Picard 2000).

### 3. Methods

#### 3.1 Methods for investigating behavior

##### 3.1.1 Psychological experiments

A key contribution of psychology to cognitive science is the practice of conducting controlled experiments. Experiments test a particular hypothesis about the relationship between two or more variables: the variables the experimenter manipulates, termed the *independent variable*; and the variable 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 the cognitive system changes its behavioral output. Conducting experiments allows the cognitive scientist to reject hypotheses that 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 that must be explained, and, a means to evaluate theories of cognitive processes. However, traditional experimental methods have been criticized for the tendency to overemphasize cognitive phenomena that are easily addressed by experiments and a corresponding under-emphasis on efforts to integrate experimental findings into unified theories of cognition (see especially Newell 1973).

Further, the more 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 experimental methods of psychology are not necessarily relevant or applicable to cognition in everyday situations (Cicourel, 1996). The laboratory is said to be an impoverished setting that 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 of 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 and ethnography

One alternative to experimental techniques is the anthropologist's method of naturalistic observation and ethnography. This method involves the observation and recording of intelligent behavior in the setting in which it normally occurs (Hutchins 1995). For instance, the investigation of child language acquisition has included naturalistic study of children in the process of acquiring a language. Such an investigation requires the observer to be as non-intrusive as possible, or reflecting on the manner and extent of 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 that 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 performing experiments in naturalistic settings themselves. While this approach precludes the experimenter from exerting complete control over the setting, participants are less likely to employ atypical strategies induced by the conditions in the laboratory. This helps insure that the investigator is observing cognitive processes that govern agents' normal behavior.

### 3.1.3 Linguistic methodologies

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 that manipulate the form of sentences. 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. Whereas the syntactic methodology relies upon judgments of grammaticality, cognitive semantics involves judgments of the plausibility of a range of inferences evoked by a given sentence/utterance. Further, these investigations often explore the impact of varying background assumptions and contextual circumstances.

Historical and comparative linguistics, that is, investigation of how a given language changes over time and how it compares to other languages, also provide useful information for cognitive science by revealing the impact of basic cognitive processes in conventionalized language use. For instance, words often take on new meanings via metaphorical extension, as when verbs of perception come to mean ‘understanding’ or ‘knowledge’ (Sweetser 1990). Tracking the development of words that grammaticalize can provide insights into the more salient aspects of conceptualization, especially when parallel diachronic developments show up in unrelated languages or when they mirror patterns in conceptual development (Gibbs 1992). The Old English predecessor of *may* (*magan*) changed over time from a meaning that referred to one’s physical ability to the more epistemic meaning of the modal *may* in modern English. This pattern of subjectification, in which word meaning changes from an objective characterization of reality to one that reflects the speaker’s understanding or estimation of reality, is a major process in language change (Langacker 1990).

### 3.1.4 Eye tracking

A variety of techniques are available for measuring people’s eye movements, and consequently eye-tracking studies have become increasingly popular in cognitive science. Eye movements during reading are typically used to index processing difficulty, where the assumption is that the longer a reader fixates a word, the more difficult that word was to process. Psycholinguists use eye-tracking during reading to test various hypotheses about the relative processing difficulty of different

syntactic constructions and how supportive semantic and pragmatic context affects processing difficulty (Rayner & Liversedge 2004). While eye-movement registration techniques used to monitor reading are relatively constraining, recent years have witnessed the development of head-mounted eye-tracking systems that can be used to monitor eye movements during more natural communicative situations.

Eye movements during or preceding the production and comprehension of speech are thought to index visual attention and have been used to test hypotheses about the time course of these language processes. In the visual world paradigm, listeners sit in front of a display of real or pictured objects, and their eye movements are tracked as they carry out actions on those objects. In production studies, speakers typically fixate objects approximately 900 ms before referring to them (Griffin 2004). In comprehension studies, listeners shift their gaze to indicate how they understand the unfolding speech signal (Tanenhaus et al., 1995). This paradigm has been used to investigate the time course of processing linguistic phenomena such as anaphora, ambiguity, and thematic roles (Tanenhaus 2004). Cognitive scientists have also tracked eye movements during collaborative tasks to study interactive strategies, such as how speakers establish common ground (Keysar et al. 2000; Metzing & Brennan 2003).

Eye-tracking has also been used to study relatively complex behavior in naturalistic settings such as interacting with web browsers. In such studies eye movements can provide a marker of people's visual attention as well as revealing the strategies they use to solve complex, multi-step problems. In some cases, eye movements suggest the existence of low-level strategies not available to the subject's conscious awareness. For example, in driving, rapid task swapping is observed between multiple subtasks (Land 1992). In a natural hand eye task in which subjects had to reproduce a design made of blocks, eye-tracking measures suggested that rather than storing task-relevant information in working memory, people broke the task down into simpler sub-tasks that allowed them to postpone the gathering of task-relevant information until just before it was needed (Ballard, Hayhoe & Pelz 1995). These unconscious measures of people's behavior reveal a far greater reliance on information in the external environment than indicated by their self-reports. For review of eye tracking methods and findings, see Richardson & Spivey (2004).

### *3.2 Neuroscience techniques*

#### *3.2.1 Neuropsychology and lesion studies*

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 the 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 research 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 tasks.

In any group of brain damaged patients there is bound to be substantial variability in the exact location of the lesion site, thus making it difficult to form generalizations that relate damaged structure to damaged function. This problem is somewhat attenuated by recent advances in brain imaging that allow neuropsychologists to record the lesion locations of a large number of patients onto a standard map of the brain. The particular lesion locations can then be correlated with patients' performance on various behavioral tests. Known as voxel-based lesion symptom mapping, this technique produces color-coded pictures of the brain that indicate the degree of correlation between injury to specific regions of the brain and any particular cognitive deficit (Bates, Wilson, Saygin, Dick, Sereno, Knight, and Dronkers 2003).

However, interpretation of lesion studies is not as straightforward as it might, at first, seem. Brain damaged patients vary in the extent to which their brain is able to reorganize and recover lost functions (a phenomenon known as plasticity). Plasticity 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 that are actually 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*

As noted above, 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 (CAT), positron emission tomography (PET), and magnetic resonance imaging (MRI) provide the cognitive scientist with images of the patient's brain that can be interpreted with respect to that patient's performance on behavioral tests of cognitive function. Noninvasive imaging techniques can also complement neuropsychological techniques by providing us with images of healthy brains.

Whereas CAT and MRI yield static images of the brain, techniques such as PET and functional magnetic resonance imaging (fMRI) are used to measure dynamic changes in brain activity. In PET, for example, the patient is injected with a mildly radioactive substance and placed on a table that moves through a tube containing gamma ray detectors. When positrons emitted from the radioactive substance collide with electrons in the tissue, they give off gamma rays. PET detects those gamma rays and determines the precise location of the tissue from which they arose. PET can provide images of blood flow as well as glucose metabolism in the brain. By contrasting blood flow measures in closely matched tasks, such as silently reading nouns versus reading nouns out loud, it is possible to determine brain regions involved in various cognitive functions, such as the production of speech (Posner & Raichle, 1994).

Similarly, fMRI is frequently used to determine the brain areas that are metabolically active during different sorts of cognitive processes. The most commonly used method, blood oxygen level-dependent (BOLD) contrast imaging, takes advantage of the presence of paramagnetic deoxyhemoglobin in the blood to track changes in the amount of oxygen in the blood that result from brain activity (Kwong et al. 1992). Because fMRI scans are completely non-invasive and can be done in clinical scanners available in most hospitals (though BOLD imaging does require minor modifications to most clinical MRI scanners), fMRI has largely supplanted PET as the method of choice in cognitive neuroscience.

In keeping with its use to localize brain regions involved in various cognitive processes, the spatial resolution of fMRI is excellent. When used in the appropriate paradigms, resolution can extend down to less than a millimeter, enough to separate ocular dominance columns. However, because the change in blood oxygenation levels is not an immediate response to neural activity, the temporal resolution is considerably less than that in electrophysiological techniques such as event-related potentials.

### *3.2.3 Event-related potentials*

Another source of information about brain activity is electrical recording from the scalps of humans. By recording participants' brain waves on an electroencephalogram (EEG) and averaging across time-locked 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 ms after the presentation of a stimulus item, have been related to aspects of perceptual processing. Components occurring later, at about 300 ms 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 ms post-stimulus, has proven to be correlated with certain aspects of semantic processing. Because the ERP taps real-time processing of sentences it is ideal for testing processing models of pragmatic phenomena (see Coulson 2004 for review).

### 3.3 Computational techniques

#### 3.3.1 Computational modeling

Overall, the dominant research paradigm in cognitive science is computational modeling of cognitive processes. Computational models provide a medium for integrating knowledge of disparate cognitive phenomena gleaned from experimental studies. By the same token, modeling provides a medium for integrating knowledge of cognitive processes gleaned from multi-disciplinary studies. Moreover, cognitive phenomena are not static but dynamic processes that 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 that explain a given cognitive phenomenon. In the course of coding up a model, the cognitive scientist inevitably discovers aspects of a problem that s/he might never have encountered had s/he not endeavored to provide as explicit an account as required by a computational model.

Additionally, a sufficiently complicated model of cognitive process will often yield predictions about empirical manifestations of the phenomenon that may not have been obvious at the outset of the investigation. Used correctly, computational modeling 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.

The disadvantage of modeling 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 simplified 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 remains a challenge for cognitive science.

### 3.3.2 *Corpus research*

Another use of the computer is as a research tool, as when linguists use computers to investigate the statistical properties of electronically stored records of written and spoken text. The use of corpora allows the linguist to make objective statements about the existence of certain language phenomena, as well as their relative frequency in certain sorts of texts. Because a number of models of language comprehension suggest speakers are extremely sensitive to the frequency of different sorts of linguistic information, psycholinguists often use corpora to make predictions about processing difficulty (MacDonald, Pearlmutter & Seidenberg 1994).

Due to the availability of electronic language corpora as well as the continual increase in computers' storage capacity and processing speed, corpus linguistics is one of the fastest growing subfields in linguistics. Historical linguists use corpora to track the emergence of word senses over time, while lexicographers use them to rapidly assemble examples of a word or phrase so as to categorize and quantify its different uses. In semantics, the corpus can provide an additional source of information about meaning besides the linguists' intuitions. Though many corpora do not include the sort of contextual information needed by researchers in pragmatics, the number of context-rich corpora is bound to increase so that this tool may soon be influential in pragmatics.

## 4. Issues

### 4.1 *The mind–body problem*

Modern cognitive science continues to explore traditional debates such as the mind–body problem, or the issue of how the relationship between the mind and the body, or brain, should be described. Indeed, a central focus of cognitive neuroscience is how the brain gives rise to mental activity. One promising avenue of research concerns the integration of social psychology and cognitive neuroscience to address the brain bases of affect and socio-emotional phenomena such as attitude change and stereotyping. On the other end of the spectrum are roboticists who study how the constraints and limitations imposed by the physical makeup of an organism's body contribute to its cognitive capacities.

Although long eschewed as an unscientific topic, the nature of consciousness has emerged in the last decade as a serious topic in neuroscience. For example, Crick & Koch (1997) suggested that conscious percepts result only when neural activity in distributed brain areas is synchronous. This suggestion was offered as a solution to the so-called *binding problem*, which results because though particular brain regions have been identified with the processing of certain aspects of visual experience (e.g. shape processing, color processing, motion processing), neuroscientists have had less success in locating brain regions in which all of this information comes together. Because oscillatory processes are found throughout the brain, Crick & Koch's suggestion that binding might occur via synchronous oscillations among multiple brain areas is an ingenious solution to this problem and has prompted a great deal of research.

Many important discoveries in cognitive science involve the importance of unconscious mechanisms in cognitive processes. For example, Milner & Goodale (1998) report a patient with damage to the temporal lobe who can perform visually guided actions without visual awareness. Analogously, damage to the medial temporal lobe produces amnesias whose explicit, declarative memory is profoundly impaired, while their performance is largely spared on implicit, nondeclarative memory tasks. Given a list of words to study, such patients perform poorly on cued recall tasks that require them to remember the experience of seeing the words, but normally on priming tasks where their better performance on studied words suggests the study task did indeed have a lasting effect on their brains (Squire & Zola-Morgan 1988). In language processing as well, most of the phonological, syntactic and semantic processes operate below the sphere of consciousness. Even high-level pragmatic phenomena such as metaphor and framing in which we are quite aware of the end product have important unconscious components (Coulson 2001; Fauconnier 1997; Lakoff & Johnson 1998).

#### 4.2 From genes to behavior

Another major axis of research in cognitive science concerns the relationship between genes and behavior, or how biology, development, and experience interact over the course of development. Like many issues in cognitive science, this controversy has its origins in philosophy but has been transformed by technological and

empirical advances in the natural and social sciences. The philosophical dispute in this case is one between the rationalists, who hold that the nature of mind itself is the main determinant of experience with reality, and the empiricists, who embrace the idea that all knowledge results from experience in the world. One formulation of this issue is the competing influence of nature and nurture on cognitive development. However, as we have learned more about genetics on the one hand and brain development on the other, it has become clear that this is an ill-posed formulation of the issue.

The problem with the traditional formulation is that biological and environmental factors are presumed to be distinct forces whose influence can be measured and compared, analogous to the hardware and software in a computer. However, the physical basis of learning is experience-dependent changes in synaptic strength that alter the ability of one neuron to influence the activity of those to which it is connected. Thus learning does not simply result in the accumulation of knowledge, but also to changes in the learning mechanism. While we often think of brain maturation as causing changes in behavioral ability, functional experience in the world is itself a causal factor in brain maturation. Further, neither the brain nor the environment is static as the developing child will attend to different aspects of the environment at different stages in the maturational process (Karmiloff-Smith 1998).

Much research in this area focuses on developmental disorders such as Williams Syndrome that can be traced to particular genetic alterations. However, because developmental pathways involve interactions between biology and experience, as well as interactions across time, modern research in this area requires modeling the way that gene deletions impact cognitive and neural development over the entire course of the lifespan. Neuroscientists seek to identify the timing of gene expression and characterize its interactions with other genetic and environmental events, while neuropsychologists study the behavioral manifestations of developmental disorders in low-level impairments as well as their impact on higher cognition (Karmiloff-Smith 1998). These processes can be modeled computationally with constructive neural networks whose architecture can be altered as part of learning (Quartz 1999).

In addressing the issue of how biology interacts with social and cultural experience, the typical formulation involves equating biological factors with hardware, and culture with software. However, because the nature of mind is so incredibly experience-dependent, this analogy is not particularly apt. Similarities and differ-

ences in the mental abilities of people in disparate cultures reflect the dynamic interplay of cognitive development in a particular culture. Related issues are also addressed by the cognitive anthropologist who studies the ways in which immersion in a culture enables intelligent behavior that would otherwise be impossible. Because cultural experience is constitutive of mind, attention to cultural factors inevitably leads to generalizations about cognition (Shore 1996).

#### *4.3 Representation and rationality*

Historically, many of the most exciting debates in cognitive science have concerned the nature of representation (Bechtel 1998). For example, cognitive scientists' initial resistance to connectionist models was that they seemed to lack the symbolic representations necessary for a compositional system (Fodor & Pylyshyn 1988). Using reasoning dating back to Chomsky's objections to behaviorism, Fodor & Pylyshyn argued that the systematic and productive character of human behavior, especially linguistic behavior, can only arise from a compositional symbol system. Connectionists have replied that although the representations in neural networks are sub-symbolic, that is, a representation in which numerous elements cooperate to represent a single symbol, their distributed character has computational advantages of its own (Smolensky 1988). These advantages include robustness to noise and the capacity to generalize from a small set of exemplars.

Another dispute in cognitive science involved the representational format of mental imagery. Based mainly on the parsimony of a single, extremely powerful representational format, some cognitive scientists have argued that propositional representations underlie all cognitive processes, including mental imagery. Others have pointed to commonalities in the properties of perceptual processes and tasks that involve mental imagery to argue for the existence of analogue representations. Although advocates of propositional representation were correct that mental images are more abstract than mental pictures, evidence from neuroscience suggests that mental imagery exploits topographically organized brain areas, and is thus analogue in character.

A related debate concerns whether conceptual representations are modal or amodal in character. Traditionally, concepts have been considered to be symbolic, and thus arbitrarily related to the things they represent. However, motivated by the

constraints of the biological underpinnings of the mind in an organ evolved to support physical and social interaction in the world, a number of cognitive scientists have proposed that conceptual representations have some of the characteristics of perceptual representations. One such proposal is that schematic representations of perceptual experience are stored around a common frame that promotes schematized simulations that recruit neural machinery activated in perceptual experience from all modalities (Barsalou 1999). One appeal of these perceptual symbols is that they help explain the *intentionality* of our concepts, or how it is that the concept of a rock is “about” a rock, by grounding concepts in perceptual experience.

While these traditional disputes over representation involve specifically mental representation, other cognitive scientists have suggested that mental representations are not sufficient for a theory of cognition. For example, 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 that 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. In a related approach, the theory of distributed cognition describes cognition as a process distributed across individuals, tools, and artifacts in the environment (Hutchins 1995).

One virtue of the distributed cognition framework is that it can help resolve the puzzle of how people are able to solve complex sequential problems with brains whose architecture seems best suited for categorization and pattern completion (Clark 2001). By using a pen, a piece of paper, culturally transmitted numeric symbols and algorithms for multiplication, it is possible to transform a difficult multiplication problem to a sequence of simpler steps that involve pattern completion and the temporary storage of information via our marks on the page (McClelland, Rumelhart, Smolensky, & Hinton 1986). Hutchins (1995: 155) notes that the use of these physical and cultural tools “permit the [users] to do the tasks that need to be done while doing the kinds of things people are good at: recognizing patterns, modeling simple dynamics of the world, and manipulating objects in the environment.”

Yet another approach to cognitive science involves no mental representations, whatsoever. Dynamic systems theory involves importing formalisms used in physics to describe multidimensional phenomena that change over time in order

to characterize cognitive processes, especially adaptive behavior that involves the interaction of neural processing, bodily action, and environmental forces. These researchers argue that representation is not a useful concept, and that cognitive scientists should instead focus on the relationship between the organism and the environment, and on the sub-representational dynamics of the system (e.g. van Gelder & Port 1995). However, others have argued that even advocates of dynamics systems theory use a notion of an information-carrying state that is tantamount to representation (Bechtel 1998; Markman & Dietrich 2000).

## 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 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 that 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, propos-

als 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. Indeed, this is the goal of researchers in the new field of experimental pragmatics that draws on methods from pragmatics, psycholinguistics, and the study of reasoning to address the relationship between language and thought in pragmatic phenomena (Noveck & Sperber 2004).

### *5.3 Issues*

Researchers in pragmatics share an interest with the rest of cognitive science in the issues described above. With respect to the mind–body problem, the neural instantiation of pragmatic processing is certainly of interest, as well as the extent to which pragmatic processing is conscious. The dynamic relationship between genes and behavior has also piqued the interest of researchers in pragmatics, as Sperber & Wilson (2002) have proposed the existence of a genetically specified meta-communicative module. Moreover, questions about the intentionality and the format of mental representations are at the heart of pragmatics and cognitive science alike. At issue is whether physical, social, and cultural aspects of context are discreet inputs to a process for the computation of meaning, or whether they constitute resources used in a continual, dynamic, interactive process of meaning construction.

### *5.4 Convergent interests*

#### *5.4.1 World knowledge and cultural 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. Cognitive scientists have suggested that background knowledge is rep-

resented in hierarchical attribute-value structures, known as frames, scripts, and schemata. The term frame is used to characterize background knowledge about objects, and includes slots which may be filled either through a slot-filling process or with default values. Default values consist generally of the most typical and/or the most frequent filler for each slot and are invoked in the absence of other information. Scripts represent stereotyped sequences of events such as going to a restaurant, and contain slots that are either filled by binding the particular fillers manifest in the situation at hand, or by instantiating the default value for any particular slot. Schemata, a similar concept in psychology, have been proposed to underlie perception, planning, and memory for events. Schemata have also 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.

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 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 providing a framework for describing the cultural assumptions essential to making the correct inferences required for reference, illocutionary force, politeness, and implicature.

#### 5.4.2 *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 1995, 1997), 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 informa-

tion, 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 play a central role in the process of meaning construction, and can be divided into four categories: 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 is 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 such as, *I was up all night reading Searle*. Third, schematic mappings involve mapping aspects of a particular situation onto more generic frames to interpret them. Schematic mapping is also involved in structuring mental spaces with frames by setting up elements in spaces that correspond to the slots in the frame. Finally, space mappings serve to link mental spaces set up in discourse.

#### 5.4.3 *Conceptual integration*

An exciting upshot of these developments is the finding that cognitive processes that 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. 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.

Fauconnier & Turner (2002) argue, similarly, that conceptual integration, or blending, processes operate in the creative construction of meaning in analogy, metaphor, counterfactuals, concept combinations, and even the comprehension of grammatical constructions. At its most abstract level, conceptual blending involves the projection of partial structure from two or more input domains and the integration of this information in a new mental space known as a *blend*. When the information in each of the inputs is very different from one another, this integration can produce extremely novel results. However, there are many cases that involve the projection of partial structure and the integration of this information that yield predictable results. Blending processes depend centrally on projection mapping and dynamic simulation to develop emergent structure, and to promote novel conceptualizations, involving the generation of inferences, emotional reactions, and rhetorical force.

Conceptual integration processes have been argued to reduce the force of classic critiques of frame-based comprehension systems (Coulson 2001). One such criticism is that viewing frames as central components of language and reasoning presents certain problems, such as the gap between the simplified nature of frames and the complex nature of the tasks for which they are employed (Brachman 1985). Similarly, there is a tension between the static nature of traditional representational structures and the flexibility and diversity evident in people's speech and behavior (Shore 1996). However, the addition of mapping, frame-shifting, and conceptual blending processes makes it possible to construe meaning construction as a dynamic process in which speakers are continuously and creatively building and blending frames and cultural models, as opposed to simply retrieving and instantiating them.

### 5.5 Conclusions

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. Investigations of meaning con-

struction reveal the centrality of conceptual integration and mapping processes to semantic and pragmatic language understanding, as well as in other verbal and non-verbal reasoning phenomena. In sum, 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.

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