<u>Cognitive Psychology</u>

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History of Cognitive Psychology

Cognitive psychology in its modern form incorporates a remarkable set of new technologies in psychological science. Although published inquiries of human cognition can be traced back to Aristotle's ''De Memoria'' (Hothersall, 1984), the intellectual origins of cognitive psychology began with cognitive approaches to psychological problems at the end of the 1800s and early 1900s in the works of Wundt, Cattell, and William James (Boring, 1950).

Cognitive psychology declined in the first half of the 20th century with the rise of "behaviorism", the study of laws relating observable behavior to objective, observable stimulus conditions without any recourse to internal mental processes (Watson, 1913; Boring, 1950; Skinner, 1950). It was this last requirement, fundamental to cognitive psychology, that was one of behaviorism's undoings. For example, lack of understanding of the internal mental processes led to no distinction between memory and performance and failed to account for complex learning (Tinklepaugh, 1928; Chomsky, 1959). These issue led to the decline of behaviorism as the dominant branch of scientific psychology and to the "Cognitive Revolution".

The Cognitive Revolution began in the mid-1950s when researchers in several fields began to develop theories of mind based on complex representations and computational procedures (Miller, 1956; Broadbent, 1958; Chomsky, 1959; Newell, Shaw, & Simon, 1958). Cognitive psychology became predominant in the 1960s (Tulving, 1962; Sperling, 1960). Its resurgence is perhaps best marked by the publication of Ulric Neisser's book, ''Cognitive Psychology'', in 1967. Since 1970, more than sixty universities in North America and Europe have established cognitive psychology programs.

At the beginning of the 21st century, cognitive psychology is a broad field concerned with memory, perception, attention, pattern recognition, consciousness, neuroscience, representation of knowledge, cognitive development, language, thinking, and, human and artificial intelligence. But contemplation about the source of knowledge, how people think, solve problems, and perceive their world is as ancient as human history and has occupied a venerated position in the musings of philosophers, theologians, mystics, and scientists for as long as we can tell. These notions started to be tested empirically during the latter part of the nineteenth century and throughout the twentieth century and became known in the history of science as cognitive psychology.

The history of cognitive psychology can be parsed into four periods: philosophical, early experimental, the cognitive revolution, and modern cognitive psychology.

Assumptions

Cognitive psychology is based on two assumptions: (1) Human cognition can at least in principle be fully revealed by the scientific method, that is, individual components of mental processes can be identified and understood, and (2) Internal mental processes can be described in terms of rules or algorithms in information processing models. There has been much recent debate on these assumptions (Costall and Still, 1987; Dreyfus, 1979; Searle, 1990).

Philosophical Period

Ancient Egyptian hieroglyphics suggest that thoughtful people were concerned with processes such as thought, memory, and most of all the “ka”, or soul, Great energy was directed toward preserving the soul but also some theorized that knowledge was localized in the heart. Greek philosophers were obsessed with knowledge and cognitive matters and current models of cognition often have some ties to ancient Greece. Aristotle’s views on the locus of knowledge were similar to the Egyptians. However, Plato postulated that the brain was the true locus of knowledge. Renaissance scholars considered thinking, logic, and the nature of the soul and, although divergent views were expressed, the locus of the knowledge and rationality was thought to be in the brain.

During the eighteenth century, philosophic debate over the source of knowledge took place between the empiricist and the nativist. A British empiricist believed knowledge came from experience. However, the nativist believed knowledge was innate and based on structural characteristics and properties inherent in the brain. Modern cognitive psychologists continue to argue these matters, although usually with scientific data.

The philosophic period provided a context for understanding the mind and its processes. In addition, these early thinkers identified some major theoretical issues that would later be studied empirically using scientific research methods.

Early Experimental Period

Cognition has been studied scientifically since the end of the nineteenth century. In 1879, the philosophical aspects of mental processes gave way to empirical observations when Wundt founded the first psychological laboratory in Germany in 1879. Psychology began to break away from philosophy and form a discipline based on objective science rather than on speculation, logic, and conjecture. Many forces propelled the break with moral philosophy, but certainly the development of new methods that allowed for the examination of mental events changed the way cognition was studied. Introspection, or looking within, was one such method that allowed the observer to examine consciousness and the structure of mental representation by breaking down an experience into sensations and images. By detecting patterns within introspective reports, the mind’s contents were presumed to be revealed.

Theories of knowledge representation became divided between introspectionists who studied observable sensations, and act psychologists, led by Brentano, who studied the activities of the mind. Brentano considered internal representations meaningless to psychology and chose to study mental acts of comparing, judging, and feeling physical objects.

Despite interest in overt behavior, cognitive process were not totally neglected. During the early 1900s Donders and Cattell were conducting perception experiments on imageless thought using brief visual displays to examine the time required for mental operations to take place and using reaction time data as dependent measures.

In several laboratories in America interesting research was being done on memory, attention, perception, language, concept formation, and problem solving that was the preformal stage of cognitive psychology. In addition to these efforts within psychology, several forces outside of traditional experimental psychology helped shape cognitive psychology. Among these forces are the considerable influence of the Swiss psychologist, Jean Piaget, whose central idea was that there are distinctive cognitive stages through which children develop. In Russia, the brilliant young savant, Lev Vygotsky, suggested a model of development psychology in which learning precedes development. Another important influence was the work of Frederic Bartlett, from England, who investigated memory from a naturalistic viewpoint and was particularly concerned with the re-membering of stories. From recall of stories, Bartlett hypothesized that memory is largely determined by schemata, or the way knowledge is organized and represented in the brain. Even some animal studies were beginning to embrace cognitive themes. In 1932, Tolman, a well-known behavioral psychologist, observed that rats learned a cognitive map of their environment while learning to run a maze.

Although cognition was not the dominant school of psychological thought in America during this time, some experimental psychologists demonstrated that scientific methodology could be used in the study of mental events. The techniques, subject matter, procedures, and even the interpretations used by these researchers anticipated the emergence of a cognitive discipline.

Concepts such as sensation, thinking, and mental imagery were anathema under the behaviorist's influence, as they were considered subjective. Internal states were considered intervening variables and not necessary to understand human behavior. Psychology had been concentrated on observable behaviors and human subjects were largely replaced with rats and pigeons.

Gestalt psychology offered an alternative way to study sensory perception to the problematic method of introspection that diffused the research on cognition. Concurrently the behaviorists attempted to create a purely objective psychology by successfully attacking the cognitive psychologists and Gestaltists as well.

Cognitive Revolution

Cognitive psychology began to take form as a new way of understanding the science of the mind during the late 1950s. These formative events were spurred on by research discoveries in memory, learning, and attention as well as ideas outside of the mainstay of experimental psychology, such as communication theory, developmental psychology, social psychology, linguistics, and computer science, which gave cognitive psychologists additional breadth to deal with the complexity of human information processing and thinking.

The reemergence of cognitive psychology during this period is commonly referred to as the Cognitive Revolution, emerging in 1956 with a conference on communication theory at Massachusetts Institute of Technology (MIT) (Solso, 1998) in which seminal papers were presented by Noam Chomsky, Jerome Bruner, Allen Newell and Herbert Simon, and George

Miller. The coalescence of cognitive psychology during this period was probably not due to a single group of people (and certainly no precise date of a movement is possible) but was a reflection of a larger Zeitgeist in which psychologists appreciated the complexity of the thinking human. At the same time, cognitive psychologists rejected the traditional, simplistic theories of the mind, but in many cases held on to the scientific methodology as had developed in the early part of the twentieth century. The paradigm that offered a pertinent methodology and embraced a sufficiently wide latitude of intellectual topics was cognitive psychology, which enjoyed widespread acceptance and growth.

Research in verbal learning and semantic organization led to the development of testable models of memory and cognition, providing another empirical base for the study of mental processes. George A. Miller made a distinction between short-term and long-term memory and his influential paper The Magic Number Seven, Plus or Minus Two (Miller, 1956) addressed the limited capacity of short-term memory and introduced the concept of chunking—the idea that the limits of short-term memory could be extended by grouping information into larger units of information. In 1958, Peterson and Peterson in America and John Brown in England found a rapid loss or decay of memory after the study of nonsense syllables after a few seconds when verbal rehearsal was absent, thus promoting the idea of a separate stage of short-term memory. In 1960, Sperling showed that a very transitory memory (or information storage system) held information for a very brief period of time. This discovery further advanced the notion that humans were complex information-processing creatures who processed incoming information through a series of stages. That simple idea was a perfect model for researchers and theorists interested in memory, and several models appeared about this time by Atkinson and Shiffrin, Waugh and Norman, and later by Craik and Tulving.

Prior to this period, information theory was introduced by Shannon and Weaver, who used box diagrams to describe how information is communicated and transformed along a series of stages. Donald Broadbent, a psychologist at Cambridge, began applying Shannon and Weaver's ideas to selective attention processes and introduced the concept of information flow to psychology and used box diagrams to describe cognitive processes. Broadbent's information flow referred to the series of operations that analyze, transform, or change mental events such as memory encoding, forgetting, thinking, concept formation, etc. As such, Broadbent provided "a language to talk about what happened inside a man which was not a mentalistic introspective language" (Cohen, 1986, p. 23).

Elsewhere, technological advances in computer science called for reexamination of basic postulates of cognition. In 1955, Simon and Newell developed a computer capable of solving a mathematical proof. Cognitive psychologists were excited that machines could simulate human thought and computers could possibly be operating according to the same rules and procedures as the human mind. Furthermore, since computers were seen as intelligent, it required us to analyze our own intelligence so that the intelligence of a machine could be determined. As a result the hypothetical Turing test was devised to determine if observers could discriminate the output of a computer from that of human responses.

Meanwhile, the behaviorists came under attack from Chomsky, a linguist from MIT, who developed a method of analyzing the structure of language. Chomsky argued that language was too complicated to learn and produce via behavioral principles of reinforcement and postulated the existence of a cognitive structure of an innate language acquisition device.

Another influence that aided cognitive psychology's foothold was World War II. Financial support in areas of military interest became readily available during the war. Because of the military's interest in developing and using new technology, research in vigilance, creativity, and human factors was encouraged. One outcome was a seminal report in 1954 by Tanner and Swets on signal detection demonstrating that cognitive processes can have a mediating effect on sensory thresholds. Another outcome of the war was that many soldiers suffered from brain injuries. A vast amount of clinical data in perception, memory, and language was a by-product of these victims' afflictions.

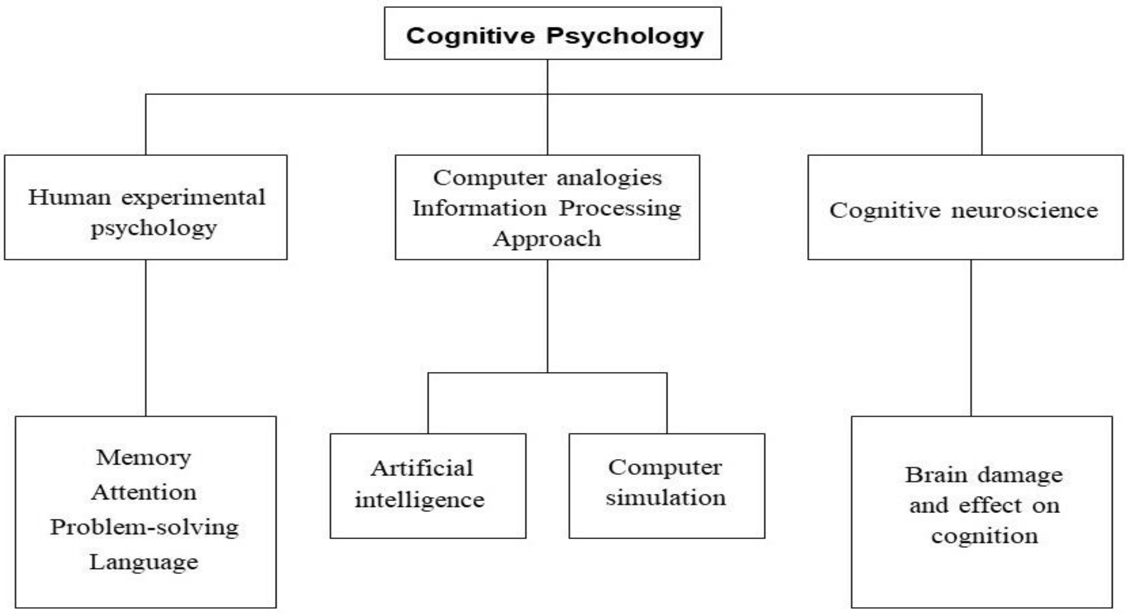
In the 1950s, interest turned to attention, memory, pattern recognition, images, semantic organization, language processes, thinking, and even consciousness (the most dogmatically eschewed concept), as well as other cognitive topics once considered outside the boundary of experimental psychology. Behaviorism and its dogma failed to account for the richness and diversity of human experience. Behaviorists could not account for the results found by Piaget's and Chomsky's developmental studies. And information theory and computer science gave psychologists new ways to conceptualize and discuss cognition.

Modern Cognitive Psychology

By the 1960s, cognitive psychology had experienced a renaissance. Cognitive Psychology, which systematized the new science, was written by Ulric Neisser and was published in America (1967). Neisser's book was central to the solidification of cognitive psychology as it gave a label to the field and defined the topical areas. Neisser used the computer metaphor for selecting, storing. Recovering, combining, outputting, and manipulating information. And in 1966 Hilgard and Bower introduced a chapter in their Theories of Learning (New York) that developed the idea of using computer programs to serve as models on theories of cognition.

The 1970s saw the emergence of professional journals devoted to cognitive psychology such as Cognitive Psychology, Cognition, Memory & Cognition, and a series of symposia volumes, including the Loyola Symposium on Cognition edited by Solso and the Carnegie-Mellon series edited by Chase and others, based on the Carnegie Symposium on Cognition. In the 1970s and 1980s cognitive laboratories were beginning to be built, symposia and conferences appeared at national and regional meetings, courses in cognitive psychology and related topics were being added to curricula, grants were awarded to people investigating memory, language processing, attention, and like topics, new textbooks were written on the theme of cognition, and universities recruited professors of cognitive psychology to replace those of traditional experimental psychology. In the 1980s and 1990s serious efforts were made to find corresponding neural components that were linked to cognitive constructs. Thus, the cerebral location for a word, like hammer, as a noun, might be far different than the location for the same word if the word were used as a verb. Furthermore, influential memory theories (such as Tulving's semantic and episodic memory theory) were manifest in cerebral localization experiments using brain imaging technology. The science of human cognition is still undergoing transformation due to major changes in computer technology and brain science. As a result cognitive psychology has converged with computer science and neuroscience to create a new discipline called cognitive science.

Finally, with the advent of new ways to see the brain (e.g. functional magnetic resonance imaging [fMRI], positron emission tomography [PET], electroencephalogram [EEG]) cognitive psychologists have expanded their operations to neuroscience, which promises to empirically display the parts of the brain involved in cognition that were hypothesized by twentieth-century psychologists.



Cognitive Psychology Theories

The primary goal of cognitive psychology is to provide an understanding of mental activity via the use of the scientific method. Because mental activity mediates between stimuli presented to a person and the person's response, and is therefore not directly observable, cognitive science is heavily theory laden. Theories attempt to provide an explanation of the results from a large number of studies and to provide predictions that can be directly tested. A good theory should reduce complex behavior to a limited set of principles that explain why some phenomena may occur in some circumstances and may not occur in others. However, there are some general limitations to theories that are noteworthy. For example, because most cognitive theory is based on experimentation, in which independent variables are manipulated and their influence is measured on dependent variables, there is always a limitation of building the model of the structures and processes intervening between the manipulations and behavior. In fact, Anderson (1976) has argued that behavioral data may not allow one to distinguish between theories that assume very different representations and processes. Theories must then be guided by other criteria such as parsimony, effectiveness, generality, and accuracy.

Given the difficulty in cognitive theory development, how does one build confidence in a theory? Converging operations is a method that has been used extensively by cognitive scientists to discriminate among alternative theoretical accounts of particular patterns of data (Garner, Hake, & Eriksen. 1956). Converging operations reflect the use of two or more experimental operations that eliminate an alternative theoretical account of a set of data. If Theory A is consistently supported after being pitted against reasonable competing theoretical accounts of a set of data, then there is increased confidence in Theory A.

In order for the reader to gain some appreciation for cognitive theories, a brief overview of some of the theoretical issues that have been addressed in cognitive psychology will presented. Obviously, it would be impossible to cover the richness of theory development in such a limited space. Therefore, we have chosen to provide a brief overview of some of the theoretical issues that have stirred controversy in the field.

Bottom-up vs. Interactive Models of Pattern Recognition

Models of perception attempt to explain, in large part, how patterns are recognized. Our intuitions might suggest the following "bottom-up" stream of events: patterns in the environment activate sensory receptive systems (e.g. ears and eyes) and these systems provide signals that are transformed into higher-level representations that provide information regarding the identity of a stimulus pattern. For example, the pandemonium model of letter recognition (Selfridge & Neisser, 1960) is a classic example of a bottom-up feature detection model in which stimuli first activate a set of feature detectors (e.g. vertical lines, horizontal lines, oblique patterns, diagonals), and these feature detectors are combined to activate relevant letters (e.g. the letter E would be activated by the presence of three horizontal lines and one vertical line). Ultimately, the most activated letter is selected as the target to report. Interestingly, not long after Selfridge's theoretical model was introduced, results from electrophysiological studies provided some converging evidence for feature-like detectors in nonhuman species (e.g. Hubel & Wiesel. 1962).

Although evidence for feature detectors exists, and the bottom-up approach is intuitively appealing, there is also support for an alternative perspective, called the interactive model, which assumes that pattern recognition is not simply controlled by the stimulus but is aided by preexisting memory representations. For example, one of the classic findings in support of an interactive position is the word superiority effect. i.e. letters embedded within words are better perceived than letters embedded in nonwords or presented in isolation. The theoretical conundrum that this finding presents is: How can the word representation influence the letters that make up the word because the letters must have been already identified in route to recognizing the word? These findings led McClelland (1979) to propose that higher order mental representations influence recognition via a processing cascade. Specifically, early in perception before letter recognition has occurred, letter units begin receiving activation, and partial activation is transferred to higher-order representations (e.g.. words). These higher-order representations then transmit partial activation back down to the relevant letter representations, which actually helps constrain the perception of those letters.

The interactive perspective with both bottom-up and top-down processes has been very influential because it suggests that the stimulus is not the only source of information, but rather the perceiver adds information across time to the stimulus information to construct the perceptual experience. It is precisely this type of added information that provides a way of understanding perceptual illusions and potentially memories of events that never occurred. Our perceptions and memories involve an elaborate interaction between the external stimulus and preexisting knowledge.

One of the major theoretical debates that has arisen in this area is the extent to which there are interactions among distinct systems within the processing system. According to the modular approach (e.g. Fodor, 1983), there are dedicated systems that only provide feed-forward information from lower-level systems to higher-level systems. On the other hand, some theorists believe that there is almost complete interactivity across systems. For example, an area of research that has amassed a considerable amount of empirical and theoretical debate concerns the processes by which the appropriate meanings of ambiguous words are resolved in sentence contexts. The modular approach suggests that when processing an ambiguous word (e.g. the word organ can refer to musical instrument or bodily organ), a prior sentence context such as. “The musician played both the piano and organ.” does not influence which meaning becomes initially activated (i.e. both the musical instrument meaning and the body meaning of organ would become initially activated). In contrast, the interactive approach suggests that prior sentence context should control which meaning becomes initially activated (i.e. only the contextually relevant meaning becomes activated). Although the original research in this area strongly supported the modular approach, more recent work has indicated that a strong sentence context can influence the initial interpretation of ambiguous linguistic structures.

In summary, one goal of cognitive theory is to explain how patterns are recognized. Early models were primarily bottom-up processors, i.e. from the sensory systems to higher-level systems. However, the results of cognitive research and theory development suggest that pattern recognition is influenced by top-down conceptual processes that reflect the interactive nature of the processing architecture.

Attentional Selection: Early or Late

One of the most difficult issues that cognitive scientists have had to grapple with is how to empirically address and theoretically model human attention. For example, how do people at a crowded party ignore distracting information and focus on (i.e., attend to) one conversation? As in pattern recognition, we all have intuitions regarding attention, but how does one develop a theory of attention based on experimental studies? Researchers have used metaphors such as attentional filters, switches, reservoirs of capacity, spotlights, executive processors, and many others. Although attention research ultimately touches on all areas of cognitive psychology, most researchers work on specific aspects of attention such as the locus of attentional selection, its relationship to consciousness, and aspects of attentional control and automaticity.

Much of the early theoretical debate focused on the extent to which unattended stimuli are processed. Early selection models postulated that selection occurs at a relatively early level in the system, before meaning has been extracted. The initial support for this notion was classic studies using the dichotic listening task in which listeners were given a very demanding primary task to one ear (verbally repeating the information presented over headphones, i.e., shadowing), while information was simultaneously presented to the other ear (e.g., Cherry, 1953). The results suggested that participants noticed little of the information presented to the unattended ear, e.g. did not even notice a switch to a different language. However, researchers soon realized that attentional selection was not an all-or-none phenomenon. For example, if one is presented with a highly relevant stimulus in the unattended channel (such as the person's name), then in fact the person could recall information presented to the unattended channel (Moray. 1959). Returning to the crowded party example presented earlier, one would be able to tune out most of the other conversations at the party, but if one hears something that is highly relevant to the person (e.g.. his or her own name), then it is likely that the person would attend to this information. Hence, although it appears that there may be some attenuation of unattended information, it is still possible for some signal to get through, and such a signal can push highly relevant stimuli over the threshold. The topic of attentional selection has invoked rather widespread interest not, only in studies of healthy young adults, but also in the neuropsychological literature, because in some patient populations (such as attention-deficit disorders and schizophrenia), there may be a breakdown in the amount of information getting into the system (i.e., a breakdown in the attentional selection system), thereby overloading any limited capacity aspect of the processing system.

Related to the issue of attentional selection is the control of attention. Again, our intuitions would suggest that we have control over what we attend. However, researchers have become interested in situations where effects of variables are outside of the individual's attentional control. One classic example of this is the Stroop task, wherein one is asked to name the color that words are printed in. When words are printed in incongruent colors, e.g., the word red printed in blue, there is considerable slowdown in color naming, compared to naming the color of a neutral word such as run. Some researchers have argued that this interference occurs because words invoke a qualitatively distinct type of processing, referred to as automatic processing, in which words automatically activate their meaning (outside of attentional control), and this automatic processing produces conflict when the color and word information are inconsistent. Automatic processes reflect those processes that are well practiced and under consistent stimulus-to-response mappings, e.g. the processing of the meaning of the word blue is consistent and highly processed. Because these processes have in some sense been wired into the system, they are outside the scope of attentional control. Researchers have addressed theoretically interesting questions regarding the development of automaticity such as the role of conscious control, the time course, the influence of practice, and even the neurophysiological substrates. Thus, the distinction between automatic and attentional control processes has been a central theme in current theory development.

Separate vs. Unitary Memory Systems

Our intuitions would suggest that there are a number of distinct types of memory systems. For example, rehearsing a telephone number until it is dialed seems to be quite distinct from recalling what one had for breakfast, which also seems quite distinct from providing the definition of the low-frequency word orb from memory. Indeed, there is a rich history of memory research that has been viewed as supporting distinct types of memory systems such as short-term, long-term, implicit, explicit, etc. Are these types of memory reflective of distinct memory systems or are they best understood in terms of a single system that utilizes different processes? The debate over memory types has had a long tradition in cognitive psychology. For example, Atkinson and Shiffrin (1968) introduced an information-processing model comprised of sensory, short-term, and long-term memory stores. However, shortly thereafter, Craik and Lockheart (1972) advanced a unitary view of memory referred to as depth of processing. The idea was that the level at which information is initially processed determines how well it will be encoded in memory. Memory for information processed at a shallow level (e.g., visual features) differs from memory processed at a deep (e.g., meaning) level. Thus, the distinction between short- and long-term memory could also be viewed as a distinction between different types of processes that vary in the quality of memory-trace strength.

In addition to the distinction between short- and long-term memory systems, distinctions have been made between declarative/explicit (directly recollecting an earlier experience) and procedural/implicit (the benefit from an earlier exposure to a stimulus on an indirect measure) memory systems. For example, manipulations of encoding condition that lead to a particular result on explicit measures (e.g., recall of a list of words) can produce opposite effects on implicit measures (e.g., perceptual identification of a visually degraded word) (e.g., Jacoby. 1983). These dissociations would appear to support distinct memory systems. However, this evidence was challenged by Roediger, Weldon, and Challis (1989), who argued that many of the dissociations that appear in the literature could also be accommodated within the transfer-appropriate-processing (TAP) framework. This approach emphasizes the match between encoding operations and retrieval operations. They noted that studies of implicit memory often emphasized data-driven processes, whereas studies of explicit memory often emphasized conceptually driven processes. They also argued that if dissociations were the criterion for separate systems, we would need many more than just two or three distinct systems.

Finally, even the dissociation between abstract category information and individual episodic experiences has been challenged. Specifically, Posner’ and Keele (1968), among others, have argued for a distinct representation for prototypes/categories (e.g., dog, which represent the common attributes of members within a category, e.g., collie, poodle. beagle). More recent work by Hintzman (1986) and Barsalou (1991) has demonstrated that the evidence in support of qualitatively distinct representations for instances and categories can be accommodated by a model that assumes only one type of instance based memory system. These theorists argue that the apparent distinction between category and instances falls quite naturally from correlations among the features across members within a category. That is, collies, poodles, and beagles all have four legs, bark, have fur, are good pets, etc. It is the similarity across these features that produces the dog category.

Although there is still theoretical debate regarding distinct memory systems versus distinct processing engaged by different tasks, it is important to note that there is evidence for some memory-system distinctions. For example, results indicate that amnesics perform poorly on explicit memory tasks, while their performance on implicit tasks is often normal. Thus, the lesion produced in these individuals would appear to be primarily affecting one system while- leaving the other system intact (Squire, 1987). Moreover, evidence from brain-imaging studies is beginning to provide evidence for distinct memory systems (Nyberg, Cabeza, & Tulving, 1996). Thus, although it is clearly the case that some memory-system dissociations are more apparent than real, it is also the case that some system dissociations are in fact real.

Analog vs. Propositional Representations of Mental Images

Humans have little difficulty imagining stimuli that are typically perceived via the senses. For example, we have little difficulty imagining a shiny red apple or a yellow school bus. The theoretical issue that has concerned researchers in this area is the form of representation to generate these images. For example, do mental images demand a qualitatively different form of representation than the representation that we use to process language?

One popular notion of imagery posits that the mental code retains the spatial and sensory properties of the external stimuli we perceive in analog form. For example, an analog representation of the neighborhood in which we live would preserve the relative distances between houses and their sizes. Accordingly, the time it takes to mentally scan between two objects in a mental image should reflect their relative distance to each other. Many experiments have demonstrated this to be the case (e.g., Kosslyn & Pomerantz, 1977). The alternative view of imagery posits that mental images are represented as abstract propositions. According to this account, mental images, language, and other information relies on one primitive code that the brain uses to process all types of information (i.e., The Language of Thought, Fodor, 1975). The generation of images occurs after this primitive code is accessed.

Recently there has been some progress in this theoretical debate. Much of the support has actually arisen from studies of the neuropsychological underpinnings of mental imagery. For example, Kosslyn, Thompson, Kim, and Albert (1995) have demonstrated, via brain-imaging studies, that not only do visual images activate areas of the brain dedicated to visual processing, but activations within neural systems across perception and imagery appear to be correlated across stimuli that vary in size. Thus, there appears to be a link between the neural systems that underlie imagery and the actual visual perception of the stimulus. Moreover, studies of individuals with brain lesions have produced dissociations between different aspects of visual imagery such as the spatial versus the visual nature of the image (e.g., Farah, Hammond, Levine, & Calvanio, 1988). Thus, it is clear that important constraints have been placed on theories of visual imagery based on both behavioral and neuropsychological evidence.

Connectionist vs. Symbolic Representations

One issue that has recently received a considerable amount of attention is the level of description needed for models of higher-level cognition such as language processing and problem solving. For example, how might one build a theory of orthography, phonology, or syntax within a language? Based on linguistic theory, one might assume a set of rules that specify how the constituents can be combined within a language. For example, a rule might specify that the vowel that precedes the letter “e” at the end of a word, as in gave, should be elongated. Such rules provide a descriptive account of many phenomena in language processing. Unfortunately, as in most rules, there are many exceptions. For example, according to the above rule, the word have should be pronounced differently. Thus, linguistic models are often forced to provide a separate processing route for such exceptions.

Within the past decade, there has been an increased appreciation for an alternative way of modeling aspects of human cognition, i.e. connectionist modeling. Connectionist models typically assume a relatively simple set of processing units that are in distinct layers, with all the processing units within a layer connected to all the processing units in adjacent layers. These models do not assume any rules, and are mathematically specified. Knowledge of a domain is contained in the values of weighted connections linking units that are either built into the models or are adjusted according to a gradual learning algorithm that updates activation patterns based on the frequency of exposure to a given stimulus and the deviation of the correct response to the current output. Interestingly, the general principles of connectionist modeling have been used to account for many aspects of cognitive processes (i.e. pattern recognition. speech production. category learning).

Clearly there has been some tension between symbolic rule-based theories and connectionist theories (e.g. Fodor & Pylyshyn, 1988). One might argue that the symbolic models reflect the first wave of cognitive theorizing. These models are often metaphorical in nature, i.e. performance can be modeled by a specific set of stages and a specific set of rules at each stage. These models remain central in current theories of human cognition. On the other hand, connectionist models have a level of computational specificity that is quite appealing. Moreover, there is at least some sense of neural plausibility within such connectionist models (i.e. the simple processing units have some surface level resemblance to neurons. whereas rules are difficult to envisage within a neural network). Ultimately, the adequacy of such models may lie in their ability to provide new insights into understanding a set of empirical observations. Because both types of models have advantages, it is likely that both first wave metaphorical models, and second wave connectionist models will continue to be central to theoretical accounts of human cognition (Spieler & Balota. 1997).

Cognitive Psychology Research Methods

The methods used by cognitive psychologists have been developed to experimentally tease apart mental operations. At the onset, it should be noted that cognitive psychologists rely most heavily on the experimental method, in which independent variables are manipulated and dependent variables are measured to provide insights into the cognitive architecture. In order to statistically evaluate the results from such experiments, cognitive researchers rely on standard hypothesis testing, along with inferential statistics (e.g. analyses of variance) to provide estimates of the likelihood of a particular pattern of results occurring if they were occurring only by chance.

The methodological tools that cognitive psychologists use depend in large part upon the area of study. Thus, we provide an overview of the methods used in a number of distinct areas including perception, memory, attention, and language processing, along with some discussion of methods that cut across these areas.

Perceptual Methods

During the initial stage of stimulus processing, an individual encodes/perceives the stimulus. Encoding can be viewed as the process of translating the sensory energy of a stimulus into a meaningful pattern. However, before a stimulus can be encoded, a minimum or threshold amount of sensory energy is required to detect that stimulus. In psychophysics, the method of limits and the method of constant stimuli have been used to determine sensory thresholds. The method of limits converges on sensory thresholds by using sub- and suprathreshold intensities of stimuli. From these anchor points, the intensity of a stimulus is gradually increased or decreased until it is at its sensory threshold and is just detectable by the participant. In contrast, the method of constant stimuli converges on a sensory threshold by using a series of trials in which participants decide whether a stimulus was presented or not, and the experimenter varies the intensity of the stimulus. At the sensory threshold, participants are at chance of discriminating between the presence and absence of a stimulus.

Although sensory threshold procedures have been important, these methods fail to recognize the role of nonsensory factors in stimulus processing. Thus signal detection theory was developed to take into account an individual's biases in responding to a given signal in a particular context (Green & Swets, 1966). The notion is that target stimuli produce some signal that is always available in a background of noise and that the payoffs for hits (correctly responding "yes" when the stimulus is presented) and correct rejections (correctly responding "absent" when the stimulus is not presented) modulate the likelihood of an individual reporting that a stimulus is present or absent. One example of this has been a sonar operator in a submarine hearing signals that could be interpreted as an enemy ship or background noise. Because it is very important to detect a signal in this situation, the sonar operator may be biased to say "yes" another ship is present, even when the stimulus intensity is very low and could just be background noise. This bias will not only lead to a high hit probability, but it will also lead to a high false-alarm probability (i.e. incorrectly reporting that a ship is there when there is only noise). Signal detection theory allows researchers to tease apart the sensitivity that the participant has in discriminating between signal and signal plus noise distributions (reflected by changes in a statistic called d prime) and any bias that the individual may bring into the decision making situation (reflected by changes in a statistic called beta).

Signal detection theory has been used to illustratee the independent roles of signal strength and response bias not only in perceptual experiments, but also in other domains such as memory and decision making. Consistent with the distinction between sensitivity and bias, variables such as subject motivation and the proportion of signal trials have been shown to influence the placement of the decision criterion but not the distance between the signal plus noise and noise distributions on the sensory energy scale. On the other hand, variables such as stimulus intensity have been shown to influence the distance between the signal plus noise and noise distributions but not the placement of the decision criterion.

Memory Methods

One of the first studies of human cognition was the work of Ebbinghaus (1885/1913) who demonstrated that one could experimentally investigate distinct aspects of memory. One of the methods that Ebbinghaus developed was the savings-in-learning technique in which he studied lists of nonsense syllables (e.g. puv) to a criterion of perfect recitation. Memory was defined as the reduction in the number of trials necessary to relearn a list relative to the number of trials necessary to first learn a list. Since the work of Ebbinghaus, there has been considerable development in the methods used to study memory.

Researchers often attempt to distinguish between three different aspects of memory: encoding (the initial storage of information), retention (the delay between storage and the use of information), and retrieval (the access of the earlier stored information). For example, one way of investigating encoding processes is to manipulate the participants' expectancies. In an intentional memory task, participants are explicitly told that they will receive a memory test. In contrast, during an incidental memory test, participants are given a secondary task that may vary with respect to the types of processes engaged (e.g. making a deep semantic decision about a word versus simply counting the letters). Hyde and Jenkins (1969) found that both the intentionality of learning and the type of encoding during incidental memory tasks influenced later memory performance.

Studies of the retention of information most often involve varying the delay between study and test to investigate the influences of the passage of time on memory performance. However, researchers soon realized that it is not simply the passage of time that is important but also what occurs during the passage of time. In order to address the influence of interfering information, researchers developed retroactive interference paradigms, in which the similarity of the information presented during a retention interval was manipulated. Results from such studies indicate that interference is a powerful modulator of memory performance (see Anderson & Neely, 1996, for a review).

There are two general classes of methods used in memory research to tap into retrieval processes. On an explicit memory test, the participants are presented a list of materials during an encoding stage, and at some later point in time they are given a test in which they are asked to retrieve the earlier presented material. There are three common measures of explicit memory: recall, recognition, and cued recall. During a recall test (akin to a classroom essay test), participants attempt to remember material presented earlier either in the order that it was presented (serial recall) or in any order (free recall). Researchers often compare the order of information during recall to the initial order of presentation (serial recall functions) and also the organizational strategies that individuals invoke during the retrieval process (measures of subjective organization and clustering). In order to investigate more complex materials such as stories and discourse processing, researchers sometimes measure the propositional structure of the recalled information. The notion is that in order to comprehend a story, individuals rely on a network of interconnected propositions. A proposition is a flexible representation of a sentence that contains a predicate (e.g. an adjective or a verb) and an argument (e.g.. a noun or a pronoun). By looking at the recall of the propositions, one can provide insights into the representation that the individuals may have gleaned from a story (Kintsch & van Dijk. 1978).

Of course, there may be memories available that the individual may not be able to produce in a free recall test. Thus, researchers sometimes employ a cued recall test, which is quite similar to free recall, with the exception that the participant is provided with a cue at the time of recall that may aid in the retrieval of the information that was presented earlier. In a recognition task (akin to a classroom multiple choice test), participants are given the information presented earlier and are asked to discriminate this information from new information. The two most common types of recognition tests are the forced choice recognition test and the free choice or yes/no recognition test. On a forced choice recognition test, a participant chooses which of two or more items is old. On a yes/no recognition test, a participant indicates whether each item in a large set of items is old or new.

A second general class of memory tests has some similarity to Ebbinghaus's classic savings method. These are called implicit memory tests. The distinguishing aspect of implicit tests is that participants are not directly asked to recollect an earlier episode. Rather, participants are asked to engage in a task where performance often benefits from earlier exposure to the stimulus items. For example, participants might be presented with a list of words (e.g. elephant, library, and assassin) to name aloud during encoding, and then later they would be presented with a list of word fragments (e.g., _le_a_t) or word stems (e.g. ele_) to complete. Some of these fragments or stems might reflect earlier presented items while others may reflect new items. In this way, one can measure the benefit (also called priming) of previous exposure to the items compared to novel items. Interestingly, amnesics are often unimpaired in such implicit memory tests, while showing considerable impairment in explicit memory tests, such as free recall.

Chronometric Methods

In addition to relying on experiments to discriminate among mental operations, cognitive psychologists have attempted to provide information regarding the speed of mental operations. Interestingly, this work began over a century ago with the work of Donders (1868/ 1969) who was the first to use reaction times to measure the speed of mental operations. In an attempt to isolate the speed of mental processes, Donders developed a set of response time tasks that would appear to differ only in a simple component of processing. For example, task A might require Process 1 (stimulus encoding), whereas, task B might require Process 1 (stimulus encoding) and Process 2 (binary decision). According to Donder's subtractive method, cognitive operations can be added and removed without influencing other cognitive operations. This has been referred to as the assumption of pure insertion and deletion. In the previous example, the duration of the binary decision process can be estimated by subtracting the reaction time in task A from the reaction time in task B.

Sternberg (1969) pointed out that the pure insertion assumptions of subtractive factors have some inherent difficulties. For example, it is possible that the speed of a given process might change when coupled with other processes. Therefore, one cannot provide a pure estimate of the speed of a given process. As an alternative, Sternberg introduced additive factors logic. According to additive factors logic, if a task contains distinct processes, there should be variables that selectively influence the speed of each process. Thus, if two variables influence different processes, their effects should be statistically additive. However, if two variables influence the same process, their effects should statistically interact. In this way, additive factor methods allow one to use studies of response latency to provide information regarding the sequence of stages and the manner in which such processes are influenced by independent variables.

Unfortunately, even additive factors logic has some difficulties. Specifically, additive factors logic works if one assumes a discrete serial stage model of information processing in which the output of a processing stage is not passed on to the next stage until that stage is complete. However, there is a second class of models that assume that the output of a given stage can begin exerting an influence on the next stage of processing before completion. These are called cascade models to capture the notion that the flow of mental processes (like a stream over multiple stones) can occur simultaneously across multiple stages. McClelland (1979) has shown that if one assumes a cascade model, then one cannot use additive factors logic to unequivocally determine the locus of the effects of independent variables.

One cannot consider reaction time measures without considering accuracy because there is an inherent tradeoff between speed and accuracy. Specifically, most behaviors are less accurate when completed too quickly (e.g., consider the danger associated with driving too fast. or the errors associated with solving a set of arithmetic problems under time demands). Most chronometric researchers attempt to ensure that accuracy is quite high, most often above 90% correct, thereby minimizing the concern about accuracy. However, Pachella (1974) has developed an idealized speed-accuracy tradeoff function that provides estimates of changes in speed across conditions and how such changes might relate to changes in accuracy. The importance of Pachella's work is that at some locations of the speed-accuracy tradeoff function, very small changes in accuracy can lead to large changes in response latency and vice versa. More recently, researchers have capitalized on the relation between speed and accuracy to empirically obtain estimates of speed-accuracy functions across different conditions. In these deadline experiments, participants are given a probe that signals the participant to terminate processing at a given point in time. By varying the delay of the deadline, one can track changes in the speed-accuracy function across conditions and thereby determine if an effect of a variable is in encoding and/or retrieval of information (see Meyer, Osman, Irwin, & Yantis, 1988, for a review).

It is important to note that although the temporal dynamics of virtually all cognitive processes can (and probably should) be measured, studies of attention and language processing are the areas that have relied most heavily on chronometric methods. For example, in the area of word recognition, researchers have used the lexical decision task (participants make word/nonword judgments) and speeded naming performance (speed taken to begin the overt pronunciation of a word) to develop models of word recognition. These studies have looked at variables such as the frequency of the stimulus (e.g., orb versus dog), the concreteness of the stimulus (e.g.. faith versus truck), or the syntactic class (e.g .. dog versus run). In addition, eye-tracking methods have been developed that allow one to measure how long the reader is looking at a particular word (e.g., fixation and gaze measures) while they are engaged in more natural reading. Eye-tracking methods have allowed important insights into the semantic and syntactic processes that modulate the speed of recognizing and integrating a word with other words in the surrounding text.

Researchers in the area of attention have also relied quite heavily on speeded tasks. For example, two common techniques in attention research are interference paradigms and cueing paradigms. In interference paradigms, at least two stimuli are presented that compete for output. A classic example of this is the Stroop task in which a person is asked to name the ink color of a printed word. Under conditions of conflict, that is, when the word green is printed in red ink, there is a considerable increase in response latency compared to nonconflict conditions (e.g., the word deep printed in red ink). In the second class of speeded attention tasks, individuals are presented with visual cues to orient attention to specific locations in the visual field. A target is either presented at that location or at a different location. The difference in response latency to cued and uncued targets is used to measure the effectiveness of the attentional cue.

Cross-Population Studies

Although cognitive psychologists rely most heavily on college students as their target sample, there is an increasing interest in studying cognitive operations across quite distinct populations. For example, there are studies of cognition from early childhood to older adulthood that attempt to trace developmental changes in specific operations such as memory, attention, and language processing. In addition, there are studies of special populations that may have a breakdown in a particular cognitive operation. Specifically, there has been considerable work attempting to understand the attentional breakdowns that occur in schizophrenia and the memory breakdowns that occur in Alzheimer's disease. Thus, researchers have begun to explore distinct populations to provide further leverage in isolating cognitive activity.

Case Studies

After a trauma to the brain, there are sometimes breakdowns in apparently isolated components of cognitive performance. Thus, one may provide insights into the cognitive architecture by studying these individuals and the degree to which such cognitive processes are isolated. For example, there is the classic case of H M in memory research. H M are the initials of an individual who, because of an operation to relieve epilepsy, acquired severe memory loss on explicit tests, although performance on implicit memory tests was relatively intact. In addition, there are classic dissociations across individuals with different types of language breakdowns. For example, Broca's aphasics have relatively spared comprehension processes but difficulty producing fluent speech. In contrast, Wernicke's aphasics have impaired comprehension processes but relatively fluent speech production.

Measures of Brain Activity

With the increasing technical sophistication from the neurosciences, there has been an influx of studies that measure the correlates of mental activity in the brain (Posner & Raichle, 1994). Although there are other methods that are available, we will only review the three most common here. The first is the evoked potential method. In this method, the researcher measures the electrical activity of systems of neurons (i.e. brain waves) as the individual is engaged in some cognitive task. This procedure has excellent temporal resolution, but the specific locus in the brain that is producing the activity can be relatively equivocal.

An approach that has much better spatial resolution is positron emission tomography (PET). In this approach, the individual receives an injection of a radioactive isotope that emits signals that are measured by a scanner. The notion is that there will be increased blood flow (which carries the isotope) to the most active areas of the brain. In this way, one can isolate mental operations by measuring brain activity under specific task demands. Typically, these scans involve about a minute of some form of cognitive processing (e.g., generating verbs to nouns), which is compared to other scans that involve some other cognitive process (e.g., reading nouns aloud). Given the window of time necessary for such scans, the PET approach has some obvious temporal limitations.

A third more recent approach is functional magnetic resonance imaging (fMRI). This procedure is less invasive because it does not involve a radioactive injection. Moreover, there has been some progress made in this area, which suggests that one can look at a more fine-grained temporal resolution in fMRI, at least compared to PET techniques. Ultimately, the wedding of evoked potential and fMRI signals may provide the necessary temporal and spatial resolution of the neural signals that underlie cognitive processes.

Computational Modeling

Most models of cognition, although grounded in the experimental method, are metaphorical and noncomputational in nature, e.g.. short-term versus long-term memory stores. However, there is also an important method in cognitive psychology that uses computationally explicit models. One example of this approach is connectionist/neural network modeling in which relatively simple processing units are often layered in a highly interconnected network (Rumelhart & McClelland. 1986). Activation patterns across the simple processing units are computationally tracked across time to make specific predictions regarding the effects of stimulus and task manipulations. Computational models are used in a number of ways to better understand the cognitive architecture. First, these models force researchers to be very explicit regarding the underlying assumptions of metaphorical models. Second, these models often can be used to help explain differences across conditions. Specifically, if a manipulation has a given effect in the data, then one may be able to trace that effect in the architecture within the model. Third, these models can provide important insights into different ways of viewing a given set of data. For example, as noted earlier. McClelland (1979) demonstrated that cascadic models can handle data that were initially viewed as supportive of serial stage models.