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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 Versus 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 feedforward 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 Versus 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 Lockhart (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 Versus 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 Versus 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).

Summary

The present article provides a brief overview of a few of the theoretical controversies and issues that have been the focus of theory development in cognitive psychology. In each of these areas we have shown how basic research in cognitive psychology has allowed one to distinguish between alternative theories. Cognitive psychology has made considerable progress in understanding mental activity and is now in the excellent position of taking advantage of new technologies (e.g., connectionist modeling, neuroimaging) to provide important advances in theory development.

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David A. Balota and Michael J. Cortese

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).