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J. L. McClelland

Cognitive Psychology: History

Since the beginning of experimental psychology in the nineteenth century, there had been interest in the study of higher mental processes. But something discontinuous happened in the late 1950s, something so dramatic that it is now referred to as the 'cognitive revolution,' and the view of mental processes that it spawned is called 'cognitive psychology.' What happened was that American psychologists rejected behaviorism and adopted a model of mind based on the computer. The brief history that follows (adapted in part from Hilgard (1987) and Kessel and Bevan (1985)) chronicles mainstream cognitive psychology from the onset of the cognitive revolution to the beginning of the twenty-first century.

1. Beginnings

From roughly the 1920s through the 1950s, American psychology was dominated by behaviorism. Behaviorism was concerned primarily with the learning of associations, particularly in nonhuman species, and it constrained theorizing to stimulus–response notions. The overthrow of behaviorism came not so much from ideas within psychology as from three research approaches external to the field.

1.1 Communications Research and the Information Processing Approach

During World War II, new concepts and theories were developed about signal processing and communication, and these ideas had a profound impact on psychologists active during the war years. One important work was Shannon's 1948 paper about *Information Theory*. It proposed that information was communicated by sending a signal through a sequence of stages or transformations. This suggested that human perception and memory might be conceptualized in a similar way: sensory information enters the receptors, then is fed into perceptual analyzers, whose outputs in turn are input to memory systems. This was the start of the 'information processing' approach—the idea that cognition could be understood as a flow of information within the organism, an idea that continues to dominate cognitive psychology.

Perhaps the first major theoretical effort in information processing psychology was Donald Broadbent's *Perception and Communication* (Broadbent 1958). According to Broadbent's model, information output from the perceptual system encountered a filter, which passed only information to which people were attending. Although this notion of an all-or-none filter would prove too strong (Treisman 1960), it offered a mechanistic account of selective attention, a concept that had been banished during behaviorism. Information that passed Broadbent's filter then moved on to a 'limited capacity decision channel,' a system that has some of the properties of short-term memory, and from there on to long-term memory. This last part of Broadbent's model—the transfer of information from short- to long-term memory—became the salient point of the dual-memory models developed in the 1970s.

Another aspect of Information theory that attracted psychologist's interest was a quantitative measure of information in terms of 'bits' (roughly, the logarithm to the base 2 of the number of possible alternatives). In a still widely cited paper, George Miller (1956) showed that the limits of short-term memory had little to do with bits. But along the way, Miller's and others' interest in the technical aspects of information theory and related work had fostered mathematical psychology, a subfield that was being fueled by other sources as well (e.g., Estes and Burke 1953, Luce 1959, Garner 1962). Over the years, mathematical psychology has frequently joined forces with the information processing approach to provide precise claims about memory, attention, and related processes.

1.2 The Computer Modeling Approach

Technical developments during World War II also led to the development of digital computers. Questions soon arose about the comparability of computer and human intelligence (Turing 1950). By 1957, Alan Newell, J. C. Shaw, and Herb Simon had designed a computer program that could solve difficult logic problems, a domain previously thought to be the unique province of humans. Newell and Simon soon followed with programs that displayed general problem-solving skills much like those of humans, and argued that these programs offered detailed models of human problem solving (a classic summary is contained in Newell and Simon (1972)). This work would also help establish the field of artificial intelligence.

Early on, cross-talk developed between the computer modeling and information-processing approaches, which crystallized in the 1960 book *Plans and the Structure of Behavior* (Miller et al. 1960). The book showed that information-processing psychology could use the theoretical language of computer modeling even if it did not actually lead to computer programs. With the 'bit' having failed as a psychological unit, information processing badly needed a rigorous but rich means to represent psychological information (without such representations, what exactly was being processed in the information processing approach?). Computer modeling supplied powerful ideas about representations (as data structures), as well as about processes that operate on these structures. The resultant idea of human information processing as sequences of computational processes operating on mental representations remains the cornerstone of modern cognitive psychology (see e.g., Fodor 1975).

1.3 The Generative Linguistics Approach

A third external influence that lead to the rise of modern cognitive psychology was the development of generative grammar in linguistics by Noam Chomsky. Two of Chomsky's publications in the late 1950s had a profound effect on the nascent cognitive psychology. The first was his 1957 book *Syntactic Structures* (Chomsky 1957). It focused on the mental structures needed to represent the kind of linguistic knowledge that any competent speaker of a language must have. Chomsky argued that associations *per se*, and even phrase structure grammars, could not fully represent our knowledge of syntax (how words are organized into phrases and sentences). What had to be added was a component capable of transforming one syntactic structure into another. These proposals about transformational grammar would change the intellectual landscape of linguistics, and usher in a new psycholinguistics.

Chomsky's second publication (1959) was a review of *Verbal Behavior*, a book about language learning by the then most respected behaviorist alive, B. F. Skinner (Skinner 1957). Chomsky's review is arguably one of the most significant documents in the history of cognitive psychology. It aimed not merely to devastate Skinner's proposals about language, but to undermine behaviorism as a serious scientific approach to psychology. To some extent, it succeeded on both counts.

1.4 An Approach Intrinsic to Psychology

At least one source of modern cognitive psychology came from within the field. This approach had its roots in Gestalt psychology, and maintained its focus on the higher mental processes. A signal event in this tradition was the 1956 book *A Study of Thinking*, by Bruner, Goodnow, and Austin (Bruner et al. 1956). The work investigated how people learn new concepts and categories, and it emphasized strategies of learning rather than just associative relations. The proposals fit perfectly with the information-processing approach—indeed, they were information processing proposals—and offered still another reason to break from behaviorism.

By the early 1960s all was in place. Behaviorism was on the wane in academic departments all over America (it had never really taken strong root in Europe). Psychologists interested in the information-processing approach were moving into academia, and Harvard University went so far as to establish a Center for Cognitive Studies directed by Jerome Bruner and George Miller. The new view in psychology was information processing. It likened mind to a computer, and emphasized the representations and processes needed to give rise to activities ranging from pattern recognition, attention, categorization, memory, reasoning, decision making, problem solving, and language.

2. The Growth of Cognitive Psychology

The 1960s brought progress in many of the above-mentioned topic areas, some of which are highlighted below.

2.1 Pattern Recognition

One of the first areas to benefit from the cognitive revolution was pattern recognition, the study of how people perceive and recognize objects. The cognitive approach provided a general two-stage view of object recognition: (a) describing the input object in terms of

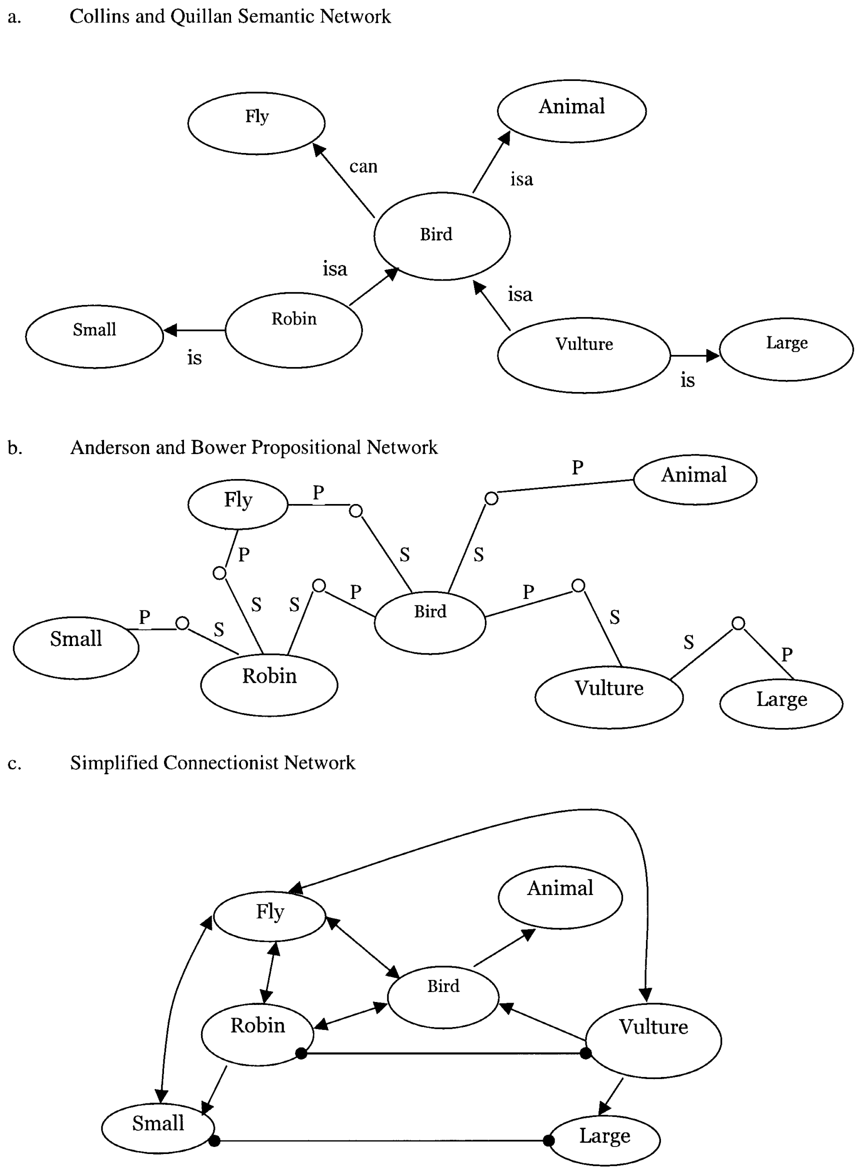

Figure 1
(a) Part of a Collins and Quillian (1969) semantic network. Circles designate concepts and lines (arrows) between circles designate relations between concepts. There are two kinds of relations: subset–superset ('Robin is a bird') and property (e.g., 'Robins can fly'). The network is strictly hierarchical, as properties are stored only at the highest level at which they apply. (b) Part of an Anderson and Bower (1973) propositional network. Circles represent concepts and lines between them labeled relations. All propositions have a subject–predicate structure, and the network is not strictly hierarchical. (c) Part of a simplified connectionist network. Circles represent concepts, or parts of concepts, lines with arrowheads depict excitatory connections, and lines with filled circles designate inhibitory connections; typically numbers are put on the lines indicate the strength of the connections. The network is not strictly hierarchical, and is more interconnected than the preceding networks

relatively primitive features (e.g., 'it has two diagonal lines and one horizontal line connecting them'); and (b) matching this object description to stored object descriptions in visual memory, and selecting the best match as the identity of the input object ('this description best matches the letter A'). This two-stage view was not entirely new to psychology, but expressing it in information-processing terms allowed one to connect empirical studies of object perception to computer models of the process. The psychologist Ulrich Neisser (1964) used a computer model of pattern recognition (Selfridge 1959) to direct his empirical studies and provided dramatic evidence that an object could be matched to multiple visual memories in parallel.

Other research indicated that the processing underlying object perception could persist after the stimulus was removed. For this to happen, there had to be a visual memory of the stimulus. Evidence for such an 'iconic' memory was supplied by Sperling in classic experiments in 1960 (Sperling 1960). Evidence for a comparable brief auditory memory was soon provided as well (e.g., Crowder and Morton 1969). Much of the work on object recognition and sensory memories was integrated in Neisser's influential 1967 book *Cognitive Psychology* (Neisser 1967). The book served as the first comprehensive statement of existing research in cognitive psychology, and it gave the new field its name.

2.2 Memory Models and Findings

Broadbent's model of attention and memory stimulated the formulation of rival models in the 1960s. These models assumed that short-term memory (STM) and long-term memory (LTM) were qualitatively different structures, with information first entering STM and then being transferred to LTM (e.g., Waugh and Norman 1965). The Atkinson and Shiffrin (1968) model proved particularly influential. With its emphases on information flowing between memory stores, control processes regulating that flow, and mathematical descriptions of these processes, the model was a quintessential example of the information-processing approach. The model was related to various findings about memory. For example, when people have to recall a long list of words they do best on the first words presented, a 'primacy' effect, and on the last few words presented, a 'recency' effect. Various experiments indicated that the recency effect reflected retrieval from STM, whereas the primacy effect reflected enhanced retrieval from LTM due to greater rehearsal for the first items presented (e.g., Murdock 1962, Glanzer and Cunitz 1966). At the time these results were seen as very supportive of dual-memory models (although alternative interpretations would soon be proposed—particularly by Craik and Lockhart 1972).

Progress during this period also involved empirically determining the characteristics of encoding, storage, and retrieval processes in STM and LTM. The results indicated that verbal material was encoded and stored in a phonologic code for STM, but a more meaning-based code for LTM (Conrad 1964, Kintsch and Buschke 1969). Other classic studies demonstrated that forgetting in STM reflected a loss of information from storage due to either decay or interference (e.g., Wickelgren 1965), whereas some apparent losses of information in LTM often reflected a temporary failure in retrieval, (Tulving and Pearlstone 1966).To a large extent, these findings have held up during over 30 years of research, although many of the findings would now be seen as more limited in scope (e.g., the findings about STM are now seen as reflecting only one component of working memory, e.g., Baddeley (1986), and the findings about LTM are seen as characterizing only one of several LTM systems, e.g., Schacter (1987)).

One of the most important innovations of 1960s research was the emphasis on reaction time as a dependent measure. Because the focus was on the flow of information, it made sense to characterize various processes by their temporal extent. In a seminal paper in 1966, Saul Sternberg reported (Sternberg 1966) that the time to retrieve an item from STM increased linearly with the number of items in store, suggesting that retrieval was based on a rapid scan of STM. Sternberg (1969) gave latency measures another boost when he developed the 'additive factors' method, which, given assumptions about serial processing, allowed one to attribute changes in reaction times to specific processing stages involved in the task (e.g., a decrease in the perceptibility of information affected the encoding of information into STM but not its storage and retrieval). These advances in 'mental chronometry' quickly spread to areas other than memory (e.g., Fitts and Posner 1967, see also Schneider and Shiffrin 1977).

2.3 The New Psycholinguistics

Beginning in the early 1960s there was great interest in determining the psychological reality of Chomsky's theories of language (these theories had been formulated with ideal listeners and speakers in mind). Some of these linguistically inspired experiments presented sentences in perception and memory paradigms, and showed that sentences deemed more syntactically complex by transformational grammar were harder to perceive or store (Miller 1962). Subtler experiments tried to show that syntactic units, like phrases, functioned as units in perception, STM, and LTM (Fodor et al. (1974) is the classic review). While many of these results are no longer seen as critical, this research effort created a new subfield of cognitive psychology, a psycholinguistics that demanded sophistication in modern linguistic theory.

Not all psycholinguistic studies focused on syntax. Some dealt with semantics, particularly the representation of the meanings of words, and a few of these studies made use of the newly developed mental chronometry. One experiment that proved seminal was reported by Collins and Quillian (1969). Participants were asked simple questions about the meaning of a word, such as 'Is a robin a bird,' and 'Is a robin an animal?'; the greater the categorical difference between the two terms in a question, the longer it took to answer. These results were taken to support a model of semantic knowledge in which meanings were organized in a hierarchical network, e.g., the concept 'robin' is directly connected to the concept 'bird,' which in turn is directly connected to the concept 'animal,' and information can flow from 'robin' to 'animal' only by going through 'bird' (see the top of Fig. 1). Models like this were to proliferate in the next stage of cognitive psychology.

3. *The Rise of Cognitive Science*

3.1 *Memory and Language*

Early in the 1970s the fields of memory and language began to intersect. In 1973 John Anderson and Gordon Bower published *Human Associative Memory* (Anderson and Bower 1973), which presented a model of memory for linguistic materials. The model combined information processing with recent developments in linguistics and artificial intelligence (AI), thereby linking the three major research directions that led to the cognitive revolution. The model used networks similar to that considered above to represent semantic knowledge, and used memory-search processes to interrogate these networks (see the middle of Fig. 1). The Anderson and Bower book was quickly followed by other large-scale theoretical efforts that combined information processing, modern linguistics, and computer models. These efforts included Kintsch (1974), which focused on memory for paragraphs rather than sentences, and Norman, Rumelhart, and the LNR Research Group (1975), Anderson (1976), and Schank and Abelson (1977), which took a more computer-science perspective and focused on stories and other large linguistic units.

As psychologists became aware of related developments in linguistics and artificial intelligence, so researchers in the latter disciplines become aware of pertinent work in psychology. Thus evolved the interdisciplinary movement called 'cognitive science.' In addition to psychology, AI, and linguistics, the fields of cultural anthropology and philosophy of mind also became involved. The movement eventuated in numerous interdisciplinary collaborations (e.g., Rumelhart et al. 1986), as well as in individual psychologists becoming more interdisciplinary.

3.2 *Representational Issues*

In the 1970s and early 1980s, cognitive science was much concerned with issues about mental representations. Whereas the memory-for-language models described earlier had assumed representations that were language-like, or propositional, other researchers argued that representations could also be imaginal, like a visual image. Shepard and Cooper (1972) provided evidence that people could mentally rotate their representations of objects, and Kosslyn (1980) surveyed numerous phenomena that further implicated visual imagery. In keeping with the interdisciplinariness of cognitive science, AI researchers and philosophers entered the debate about propositional versus imaginal representations (e.g., Block 1981, Pylyshyn 1981). In addition to questions about the modality of representations, there were concerns about the structure of representations. While it had long been assumed that propositional representations of objects were like definitions, researchers now proposed the representations were *prototypes* of the objects, fitting some examples better than others (Tversky 1977, Mervis and Rosch 1981, Smith and Medin 1981). Again the issues sparked interest in disciplines other than psychology (e.g., Lakoff 1987).

The cognitive science movement affected most areas of cognitive psychology, ranging from object recognition (Marr 1982) to reasoning (e.g., Johnson-Laird 1983) to expertise in problem solving (e.g., Chase and Simon 1973). The movement continues to be influential and increasingly focuses on computational models of cognition. What has changed since its inception in the 1970s is the kind of computational model in favor.

4. *Newer Directions: Connectionism and Cognitive Neuroscience*

4.1 *Connectionist Modeling*

The computer models that dominated cognitive psychology from its inception used complex symbols as representations, and processed these representations in a rule-based fashion (for example, in a model of object recognition, the representation for a frog might consist of a conjunction of complex properties, and the rule for recognition might look something like 'If it's green, small, and croaks, it's a frog'). Starting in the early 1980s, an alternative kind of cognitive model started to attract interest, namely 'connectionist' (or 'parallel distributed processing') models. These proposals have the form of neural networks, consisting of nodes (representations) that are densely interconnected, with the connections varying in strength (see the bottom of Fig. 1).

In 1981 Hinton and Anderson published a book surveying then existent connectionist models (Hinton and Anderson 1981), and in the same year McClelland and Rumelhart (1981) presented a connectionist model of word recognition that explained a wide variety of experimental results. The floodgates had been opened, and connectionist models of perception, memory, and language proliferated, to the point where they now dominate computational approaches to cognition. Why the great appeal? One frequently cited reason is *neurological plausibility*: the models are clearly closer to brain function than are traditional rule-based models. A second reason is that connectionist models permit *parallel constraint satisfaction*: different sources of activation can converge simultaneously on the same representations or response. A third reason is that connectionist models manifest *graceful degradation*: when the model is damaged, performance degrades slowly, much as is found in human neurological disorders (Rumelhart et al. 1986).

From a historical viewpoint, there is an ironic aspect about the ascendancy of connectionist models. Such models return to the pure associationism that characterized behaviorism. While connectionist models hardly fit with all behaviorist dictums—their representations are not restricted to stimuli and responses, and they routinely assume massively parallel processing—still their reliance on associations runs counter to Chomsky's arguments that sheer associationism cannot explain language (Chomsky 1957, 1959). This issue has formed part of the basis for critiques of connectionist models (e.g., Fodor and Pylyshyn 1988). Newell (1990), one of the founders of traditional computational models, suggested a plausible resolution: lower-level cognitive processes like object recognition may be well modeled by connectionist models, but higher-level cognitive processes like reasoning and language may require traditional symbolic modeling.

4.2 Cognitive Neuroscience

The other major new direction in cognitive psychology is the growing interest in the neural bases of cognition, a movement referred to as 'cognitive neuroscience.' There had been little interest in biological work in the research that brought about the cognitive revolution. That early work was as much concerned with fighting behaviorism as it was with advancing cognitive psychology, and consequently much of the research focused on higher-level processes and was completely removed from anything going on in the neurobiology of its day. Subsequent generations of cognitive psychologists solidified their commitments to a purely cognitive level of analyses, by arguing that the distinction between cognitive and neural levels of analyses was analogous to that between computer software and hardware, and that cognitive psychology (and cognitive science) was concerned primarily with the software. Since the early 1990s, views about the importance of neural analyses have changed dramatically. There is a growing consensus that the standard information processing analyses of cognition can be substantially enlightened by knowing how cognition is implemented in the brain.

While many factors may have been responsible for the change in view, three will be mentioned here. First, the rise of connectionist models that were loosely inspired by brain function had the side effect of increasing interest in what was known in detail about brain function. Indeed, these two recent movements have become increasingly intertwined as connectionist models have increasingly incorporated findings from cognitive neuroscience. Second, in the 1970s and 1980s there were breakthroughs in systems-level neuroscience that had implications for mainstream cognitive psychology. As one example, research with neurological patients as well as with nonhuman species established that structures in the medial temporal lobe were essential for the formation of memories that could serve as the basis for recall ('explicit memory'), but not for other kinds of 'implicit memories' (e.g., Schacter 1987, Squire 1992). As another example, research with nonhuman primates showed that two distinct systems were involved in the early stages of visual perception: a 'where' system that is responsible for spatial localization, and a 'what' system that is responsible for recognition of the object (e.g., Ungerleider and Mishkin 1982). Both of these discoveries had major implications for the cognitive level of analyses, e.g., computational models of object recognition or memory would do well to divide the labor into separate subsystems.

The third factor responsible for the rise of cognitive neuroscience is methodological: the development of neuroimaging techniques that produce maps of neural activity while the brain is performing some cognitive task. One major technique is positron emission tomography (PET). In 1988, Michael Posner, Marcus Raichle, and colleagues used PET in a groundbreaking experiment to localize neurally different subprocesses of reading—PET images obtained while participants looked at words showed activated regions in the posterior temporal cortex; images obtained while participants read the words revealed additional regions activated in the motor cortex; and images obtained while participants generated constrained associations to the words revealed still additional regions in frontal areas (Posner et al. 1988). PET analyses of object recognition, memory, and language soon followed. A more recent technique is functional magnetic resonance imaging (fMRI). It is now being used to study virtually every domain of human cognition.

5. Conclusion

This article has given short shrift to important contributions that tend to fall off the mainstream of cognitive psychology. One such case is the work done by Dan Kahneman and Amos Tversky (e.g., Kahneman and Tversky 1973, Tversky and Kahneman 1983) on the use of heuristics in decision making, which can result in deviations from rational behavior. Another example is the cognitively inspired study of memory and language deficits in neurological patients (Shallice (1988) provides a review). There are other cases like these which deserve a prominent place in a fuller history of cognitive psychology.

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E. E. Smith

Cognitive Psychology: Overview

1. Meanings of the Term 'Cognitive Psychology'

Cognitive Psychology has at least three different meanings. First, the term refers to 'a simple *collection of topic areas*,' that is, of behaviorally observable or theoretically proposed phenomena that are studied within the boundaries of the field of Cognitive Psychology. Second, the term alludes to the fact that cognitive psychologists attempt to explain intelligent human behavior by reference to a *cognitive system* that intervenes between environmental input and behavior. The second meaning of Cognitive Psychology thus refers to a set of assumptions governing the operations of the proposed cognitive system. Third, Cognitive Psychology means a particular *methodological* approach to studying, that is, to empirically addressing potential explanations of human behavior. The two latter meanings of Cognitive Psychology are discussed in some depth below, after a very brief consideration of the scope of modern Cognitive Psychology and its historical roots.

2. The Scope of Cognitive Psychology

At present, Cognitive Psychology is a broad field concerned with many different topic areas, such as, for instance, human memory, perception, attention, pattern recognition, consciousness, neuroscience, representation of knowledge, cognitive development, language, and thinking. The common denominator of these phenomena appears to be that all of the phenomena reflect the operation of 'intelligence' in one way or another, at least if intelligence is broadly defined as *skill of an individual to act purposefully, think rationally, and interact efficiently with the environment*. Thus, at a general level, Cognitive Psychology is concerned with explaining the structure and mental operations of intelligence as well as its behavioral manifestations.

3. Historical Roots of Cognitive Psychology

3.1 The Term Cognitive Psychology

The term Cognitive Psychology (latin: *cognoscere*; greek: *gignoskein* = to know, perceive) is rather young. Although we do find the related term 'cognition' mentioned occasionally in the psychologies of the late nineteenth and early twentieth century (e.g., James, Spence, Wundt) where it denoted the basic elements of consciousness and their combinations, the present meanings of the term cognitive psychology owe little to the early theoretical and philosophical considerations of the human mind. Rather, the current modern meanings of the term owe much more to (a) the fact that the study of cognition emerged in opposition to the prevailing behavioristic view in the 1940s and 1950s that was trying to explain human behavior primarily in terms of its antecedent environmental conditions, and to (b) the availability of both new theoretical concepts (e.g., information theory [Shannon], cybernetics [Wiener], systems theory

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