A Review of Memory Theory

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Abstract

Memory is a term applied to numerous biological devices by which living organisms acquire, retain, and make use of skills and knowledge. It is present in all forms of higher order animals. The most evolutionary forms of memory have taken place in human beings. Despite much research and exploration, a complete understanding of human memory does not exist. This paper reviews briefly several significant topic areas of memory theory. Topics discussed herein include foundations of memory theory, learning versus memory, coding processes, artificial intelligence, and recent research into memory systems.

Key Words: artificial intelligence; coding processes; learning; memory; memory theory; memory systems.

1. Introduction

Despite much research, the human brain is a nebulous, complex entity. Literalism via emotional functions and cognitive functions occur within the human brain (He, et al., 2016). Memory represents a "biological process" incorporating a variety of cognitive attributes (Parkin, 1993, p. 22). Memory is the current knowledge about something that was known previously (Rubinstein, 1988). Human memory has been examined from a variety of perspectives, ranging from psychology to engineering (Miller, 1956; Murata, Uchimoto, Ma, & Isahara, 2001). Human memory is fallible and unreliable depending upon circumstances (Doss, Glover, Goza, & Wigginton, 2015; Rubinstein, 1988). Memory involves two forms of recall: perfect and imperfect. Perfect recall involves a conjunction between memory of previous actions and memory of previous knowledge (Van der Hoek, 2005). Imperfect recall involves some knowledge imperfection within the context of the human ability to process information (Rubinstein, 1988). Some of the early memory studies involved these notions, such as Miller's 1956 study involving chunking and the human ability to process information (Miller, 1956).

After the time of Miller's investigations in the 1950s, memory continued to be the subject of study by various and sundry researchers. However, despite over half a century of examination, the complexities of the human mind and the nebulousness of memory remain mysterious. A complete understanding of human memory does not exist during modern times. Therefore, this article provides a brief literature review regarding human memory with respect to the foundations of memory theory, learning versus memory, coding processes, and research concerning memory systems.

1. Design and Methodology

Remenyi (2012) indicates that qualitative research designs may involve less depth than historiography, and may be used within a topical context. The methodology for this research incorporated a qualitative approach necessary for generating a review of memory and learning concepts. Pertinent research concerning memory and learning concepts was located by searching EBSCO and Proquest databases as well as the Google search engine. These sources were queried for literature items that encompassed a period of 40 years.

As a method of including relevant materials, the search terms were broad. Examples of search terms employed within this research consisted of "memory," "memory theory," "memory research," "memory systems," "learning," "learning theory," and "learning styles." Articles were constrained to the areas of memory and learning. Researchers in the areas of higher education and criminal justice from Belhaven University and the University of West Alabama were polled for specific, additional topic areas and article recommendations.

2. Foundations of Memory Theory

At one time, the dominant view considered memory as a unitary capability. That is to say, memory was considered a one-channel process. Today, the memory processes are viewed as taking many different kinds and forms of organic operations. Memory is considered to take multiple forms and types of brain operations. Major issues of concern have to do with identification of these different forms and kinds of memory, classification of memory forms, and determination of the similarities and differences of these memory forms (Baddeley, 1997). The most evolutionary forms of memory have taken place in human beings (Baddeley, 1997).

A major contrast in the study of memory involves differences between the input-output methods versus the output-only method. When employing the input-output method, the researcher knows the input and how it has affected the output. In other words, the researcher knows what the subject originally witnessed and what the subject thinks he could have done or not done in the absence of the input. The input-output method characterizes laboratory studies of memory in which the subject is given specific training on a certain task, or stimulus materials and subsequently tested on the performance of the task or on the retention of the material (Baddeley, 1997).

In the output-only method, the input is unknown and the output is used either to make inferences about what the input might have been or as a measure of the individual's memory abilities in relation to that of other members of a particular population. The output-only method is used in situations in which the observer or examiner does not know what the relevant input into the memory system was and which the output is used for making inferences about what the input might have been. The individual's recollections of a past event are assumed to be highly accurate. Research has shown that the output from memory depends not only on the input but on other equally important factors, and that therefore direct inferences from the output to the input are not always justified. The output-only method is also used to measure the extent of an individual's knowledge of a given kind, general facts for example, where actual input need not be known (Baddeley, 1997). Baddeley (1997) also indicates that the most evolutionary forms of memory have taken place in human beings. The output-only method historically came before the input-output method. A primary contribution of Ebbinghaus, the father of the modern study of memory, was the adoption of the input-output approach (Baddeley, 1997).

3. Memory versus Learning

Memory and learning are two closely related concepts, although the relation between the two cannot be specified. Memory and learning are not identical. There are three ways in which learning and memory differ. One has to do with the nature of the activity. If individuals acquire a new skill or new knowledge slowly with much labor they are said to be engaging in learning. For instance, an individual may learn via job experience or by experiencing failure and learning from past mistakes to improve future performance (Doss, Sumrall, McElreath, & Jones, 2013; McElreath, et al., 2013). If acquisition occurs instantly individuals are said to be making use of memory. A second difference separating learning and memory is acquisition versus expression of a skill or knowledge. Acquisition is thought of as learning whereas expression is thought of as memory. A third distinguishing sense between learning and memory is concerned with the subdivision of the biological versus psychological domain in which scientists organize topical areas of presentation. This has as much to do with tradition and current fashion than it does with a disciplined separation of organized thought (Schacter, 1996).

4. Coding Processes

Memory processes permeate all cognition and most all forms of behavior. Researchers break the continuity of memory into entities called memory tasks. A typical memory task begins with encoding, getting the information about the witnessed event into the memory store. The task ends with retrieval which is making use of the stored information in some select manner. It is widely accepted that typical memory tasks involve many different kinds of memory and many different kinds of memory processes (Schacter, 1996).

One major distinction between memory tasks is based on individual's conscious awareness of what they are retrieving. If individuals are aware they are remembering an earlier experience they are said to be retrieving information explicitly. If they are not aware that their current behavior has been influenced by a particular past event, their retrieval of the stored information is said to be implicit. An extensively researched form of implicit memory is perceptual priming. Perceptual priming is the enhanced ability in identifying and naming perceptual objects. Presently, a distinction cannot be made between explicit and implicit memory in nonverbal people or animals (Schacter, 1996). Another fundamental division in human memory is that between memory and conception. William James described this distinction in the1890s. Today, this dichotomy is expressed as the difference between episodic memory and remembering on the one hand, and semantic memory and knowing on the other. Remembering consists of the explicit retrieval of stored information while knowing consists of the retrieval of implicit information (Schacter, 1996).

For the first three quarters of a century in the history of the scientific study of memory, most knowledge about memory and its underlying processes was gained through behavioral research. Since the early 1970s, clinical and experimental study of memory disorders induced by brain damage has added significantly to the knowledge base. Starting in the early 1990s, the uses of neuro-imaging techniques, positron emission tomography (PET), and functional magnetic resonance imaging (fMRI) have become increasingly helpful in the study of memory (Baddeley, 1997). All mental processes are represented by neural activities in the brain. Therefore, they are neural codes representing mental experiences. Coding processes are those sensory, perceptual, and higher cognitive processes whose function is to transform objects and events from the outside world into their coded representations in the brain/mind (Baddeley, 1997).

Some ways of representing an event lead to better memory for that event than other possible ways. For example, if a person encodes a word in terms of its sound or its visual appearance, this will be less beneficial for later memory than if the word had been encoded in terms of its meaning or implications. The study of memory encoding is concerned with the different ways in which events can be represented, the consequences for later memory of these different ways and, how the different representations may be achieved. One important distinction in this respect is between stimulus-driven encoding and strategically mediated encoding. If the recipient presents a concept such as "chair" in the form of a picture of a chair, as opposed to the word "CHAIR," it will drive different encoding operations. The differences are determined by the physical nature of the stimulus. The same physical object can be encoded in a variety of ways depending on the perceiver's strategic goal. This is what allows individuals to read a sentence in a text for meaning versus comprehension or to proofread for spelling or errors. These different encoding strategies have different consequences for later memory, even in cases where the reader is not attempting to memorize the material in any sense (Schacter, 1996).

Two further related terms are decoding and recoding. The concept of decoding refers to changing the coded representation back into its original form. Recoding refers to a situation in which some encoded information is changed into a form that is more compact and more meaningful and easily remembered (Schacter, 1996). Since 1960, cognitive psychologists have found it useful to think of the brain as an information processing device. They have identified memory and attention as components of this complex information handling system. Within this framework, memory was thought of as a series of stages or stores. First, the modality-specific sensory stores were considered to hold relatively raw sensory information. A second stage or store of memory was the capacity to hold a limited amount of short-term or primary memory. The third memory store was the long-term or secondary memory. Information in the sensory stores decays quickly unless it is selected by additional useful processing. This selection entails recoding processes such that the codes are transformed into short-term memory codes representing the chosen features. Further processing typically recodes the short-term information into semantic or conceptual information that can be retrieved minutes or years later from the long-term stores (Baddeley, 1997).

This three stage information processing model of memory has been very influential. One of its variants was proposed by Atkinson and Shiffrin (1971), and it is still a useful framework. However, the three stage model also has drawbacks. For example, it encourages a rather stable view of short-term (primary) memory. Empirical studies show that the encoding, capacity, and forgetting characteristics of primary memory are anything but stable. As an alternative, Craik and Lockhart (1972) have proposed a levels-of-processing view (LOP), which suggests that incoming stimuli are processed to different levels or depths in the cognitive system ranging from shallow sensory levels to deep levels of meaning and implications.

In this framework, memory is not information held in a store, but is rather the product of processing operations carried out primarily for the purposes of perception and comprehension. According to the LOP approach the deeper the processing (determined either by greater attention, effort or highly meaningful stimuli), the better the subsequent memory. The LOP view stresses the crucial importance of encoding processes of memory. Clearly, retrieval processes are equally important and a more complete framework would marry the LOP view of encoding with the transfer appropriate processing view of retrieval. Once encoding processes have determined the qualitative nature of the stored trace, the optimal retrieval cue will be one whose qualitative nature reflects these same qualitative characteristics (Schacter, 1996).

One crucial point concerning encoded information is that mentally encoded knowledge must reflect all aspects of the outside world if the internal mental model is to be useful as a guide to the external environment. Therefore, humans must have mental codes that represent smells, tastes, sounds, and touch information as well as the more commonly studied verbal and pictorial codes. It seems reasonable to assume, in fact, that all sensory modalities first store relatively unprocessed literal copies of the sensory input, and that further processing reveals the associations and implications for action of this sensory information. One can think of the cognitive system as hierarchical, with lower levels representing the surface aspects of stimuli which merge into progressively higher levels whose representations become gradually less concerned with the specific sensory details of the current stimulus, and more concerned with general, amodal, categorical, and conceptual aspects of the input. It seems likely that these higher levels of representation can be generated from within more easily than can the lower sensory levels, which in turn are more easily driven by stimuli coming through the senses. Normal processing involves some mixture of top down (conceptually driven) and bottom-up (stimulus-driven) processing, with the mixture depending on such factors as the strength of the perceiver's expectations and the clarity of the sensory input (Bower, Clark, & Lesgold, 1969).

Important concepts in this area are elaboration, organization, and distinctiveness. Elaboration refers to the richness or extensiveness of an event's encoding. An example would be noting a person, his surroundings, and actions very carefully, as opposed to merely glancing at the person. The general finding is that greater degrees of elaboration support higher levels of subsequent memory. Organization refers to the linking together of individual representations to form larger units, usually on the basis of their meaning. For example, a list of unrelated words is hard to remember, but if the list is made up of common groups of words it is much easier to recollect. Perhaps the participant would organize the words into common headings and then into specific words under each heading.

Distinctiveness refers to the situation where an encoded item stands out from its background, similar to the way a brightly colored object stands out perceptually from a drab background. Hunt and McDaniel (1993) have argued that both organization and distinctiveness are important for good recollection with organization providing the structural background, and distinctiveness rendering an item salient against this background. Therefore, an excellent way to encode an event is to process it deeply and elaborately, emphasizing its distinctive characteristics, but also noting how it fits into some well-known piece of structured knowledge (Baddeley, 1997).

The role of prior knowledge is crucial for an understanding of memory-encoding processes. Individuals remember items and events that are readily interpretable in terms of our own specific sets of expertise. For example, a professional mathematician can remember a new equation; a master chess player can remember a new board position after studying it for a few seconds because it is in his particular area of expertise. These well-learned, highly structured knowledge systems are known as schemas. They are effective for many of the same reasons that a well-organized library is effective. The reason is that the previously set-up or organization provides a precise place for encoding each new acquisition and the same organization provides the structure to support later retrieval. The notion of expertise and prior knowledge explain why pictures and self-related events are particularly well remembered. Humans are all experts when it comes to our personal schematic knowledge of ourselves (Schacter, 1996).

Most memory research has dealt with either language codes or picture codes. Some researchers (Paivio, 1971) have claimed that the manner in which the brain processes pictures or visual imagery is categorically different from the manner in which the brain processes verbal information. These researchers posited two codes by which information can be represented. One code is an analogue code that preserves the main physical features of the object being represented. The other code is a symbolic code that stands for the external event but does not resemble it perceptually.

Brooks (1968) showed that visual perception interfered with the production of visual imagery but not with the mental manipulation of words and correspondingly, verbal expression interfered with word processing but not with imagery processing. Pylyshyn (1973) disagreed with the dual-code hypothesis, arguing instead that all information, whether verbal or imaginal, has the same underlying propositional form. That is, information is stored conceptually in a manner indicating the underlying relationship between concepts.

5. Memory Research

Baddeley (1997) reports on the work of Tulving in the development of a memory systems model where there are multiple dissociable memory systems, each with its own unique type of code. These memory systems are perceptual, procedural, semantic, and episodic. Tulving's model has been associated with considerable application of memory function to the education and learning process.

As mentioned earlier in this paper, scientific thinking about memory was dominated for decades by the assumption that memory is a unitary entity. Although the assumption of a unitary system has been questioned from time to time, it has been seriously challenged and convincingly refuted. Convergence lines of evidence from psychology and neuroscience have revealed multiple memory systems that can be dissociated from one another. Ledoux (1996) explained how studies of emotional memory have highlighted a special role for the amygdala, which is also thought to constitute an additional memory system specifically concerned with emotional memory. These observations strengthen and expand the fundamental insight of modern cognitive neuroscience that the concept of memory includes a variety of different ways in which the brain adapts and changes as a result of experience. Thus, memory may not be perceived as a solitary entity. Instead, it is complex.

Many researchers have distinguished among various types or forms of memory. For instance, recalling someone's name is different from recognizing it and visual memories differ from auditory memories. Recently, many researchers have distinguished between recollection of everyday experiences, explicit memory, and non-conscious effects of past experiences on subsequent behavior, implicit memory (Baddeley, Wilson & Watts, 1995). However, only some of these distinctions refer to different memory systems. Schacter and Tulving (1994) proposed that a memory system (a) is a set of interrelated brain processes that allow one to store and retrieve a specific type or class of information, (b) can be characterized in terms of lists of properties that describe its characteristic mode of operation, and (c) can be dissociated from other systems by converging evidence from psychology and neuroscience.

Although concepts of memory systems are still evolving, converging evidence from psychology and neuroscience points toward at least five major systems which include episodic memory, semantic memory (together referred to declarative memory), perceptual representation system, procedural memory, and working memory (Baddeley, 1997). As reported by Baddeley, Tulving explained in 1983 how the episodic memory stem is responsible for the explicit recollection of incidents that occurred at a particular time and place in one's personal past. Damage to the inner parts of the temporal lobes, including the hippocampal formation, greatly impairs the acquisition of new episodic memories. Individuals with amnesic syndromes produced by damage to the medial temporal region invariably have serious impairments of episodic memory. They are unable to remember ongoing events in their day-to-day lives and perform poorly on laboratory tests that require episodic memory.

Regions within the prefrontal cortex play a key role in episodic memory. Although individuals with selective damage to prefrontal regions do not develop a profound amnesia for recent events, they have great difficulty remembering when and where recent events occurred. Damage to the frontal lobes can also yield distortions of episodic memory, in which patients claim to remember events that never occurred (Cabeza, & Nyberg, 1997).

Recent neuro-imaging studies of memory, measuring regional cerebral blood flow using positron emission tomography (PET) and functional magnetic resonance imaging (MRI) have consistently revealed frontal lobe activation during episodic memory tasks. Right frontal regions have tended to show greater activation than right frontal regions during episodic encoding. Hippocampal activations have also been observed during encoding of information into episodic memory and also during retrieval of episodic memories. Somewhat surprisingly, however, quite a few neuroimaging studies have failed to report activation of the hippocampal formation, and researchers are still attempting to understand precisely why hippocampal activation is not always observed. Recent evidence suggests that the hippocampal formation tends to be most active during the actual recollection of that information, whereas prefrontal regions show maximal activation when volunteers make extensive efforts to recall recently presented information.

Thus, prefrontal and medial temporal regions both play an important role in episodic memory. However, the exact nature of their contributions remains to be determined (Cabeza & Nyberg, 1997). Semantic memory refers to general knowledge of facts and concepts not linked to any particular time and place. Whereas episodic memory is critical for remembering a specific visit to the city of Paris, for example, semantic memory is important for knowing that Paris is the capital of France. The acquisition of new semantic memories depends on the integrity of the medial temporal lobes. For instance, amnesic individuals have great difficulty acquiring new vocabulary and factual knowledge, although they can acquire large amounts of new semantic knowledge when that information is presented repeatedly (Cabeza & Nyberg, 1997). Cabeza and Nyberg report how Squire in 1987, argued that the acquisition of new episodic and semantic memories both depends on the integrity of the medial temporal region and, hence, they can be referred to collectively as declarative memory. However, episodic and semantic memory can also be dissociated from one another. An example would be individuals characterized by the syndrome of semantic dementia exhibit poor knowledge of properties of specific objects, yet show generally intact episodic memory.

Procedural memory refers to the acquisition of skills and habits, knowing "how" rather than knowing "that." Procedural memories are acquired gradually over time through repetitive practice. Amnesic individuals with a profound inability to remember past experiences explicitly can gradually acquire new perceptual, motor, and cognitive skills, habits that are involved in classification and categorization, and implicit knowledge of sequences or grammatical rules. These results show clearly that the acquisition of procedural knowledge does not depend on the medial temporal lobe structures, which are damaged in amnesic individuals. This conclusion is supported by research which has demonstrated that amnesic monkeys and rats with lesions in medial temporal structures can acquire new habits at a normal rate. Thus, research supports the conclusion that procedural memory depends on a different system than does either episodic or semantic memory (Baddeley, 1997).

The memory systems considered so far are all concerned with long-term retention, spanning time periods of minutes, hours, weeks and years. In contrast, the system known as working memory is concerned with short-term retention, operating over periods of seconds. The working memory system is used to hold information on-line in the service of such basic cognitive activities as comprehending, reasoning, and problem solving. The concept of working memory emerged from debates in cognitive psychology during the 1960s concerning short-term versus long-term memory. Studies of amnesic individuals revealed that they maintained intact abilities to remember immediately small strings of digits, despite their difficulties with long-term retention. However, other individual exhibited the opposite pattern. These individuals had severely impaired short-term retention of digits and related kinds of verbal information despite a relatively normal ability to acquire new long–term memories. Such individuals typically have lesions in a specific part of the left parietal lobe known as the supra-marginal gyrus. Although these finding strengthened the distinction between short-term and long-term memory, they also indicated that information could enter long-term memory even when short-term memory was profoundly impaired (Schacter, 1996).

Baddeley (1986) explained a similar pattern of findings by postulating a working memory system that consists of three components. First, a central executive or limited-capacity work space, and two "slave" sub-systems that supports it. One subsystem, called the phonological loop, allows for rehearsal or recycling of small amounts of speech-based information, but is not necessary for entering information into long-term memory. According to Baddeley, it is this subsystem that is impaired in individuals who exhibit faulty immediate retention yet show normal long-term memory. This idea has received some confirmation from recent neuroimaging research indicating that the supra-marginal gyrus is activated when people perform working-memory tasks designed to tap the phonological loop. The second slave subsystem of working memory, the visuospatial sketch pad, was held to be involved in the short-term retention of visual and spatial information. Recent evidence from brain-damaged individuals and PET scans suggests that a variety of regions in the right hemisphere of the brain are important components of the visuospatial sketch pad (Cabeza & Nyberg, 1997).

6. Memory and Artificial Intelligence

Although memory research is conducted to better understand the human mind and cognitive functions, it would be remiss to ignore the saliency of memory with respect to a perspective of its potential within the context of artificial intelligence. A long-standing goal of artificial intelligence is to craft machines that mimic indistinguishably human characteristics (Chao, 2001; Vick, 2010). Generally, progress toward this goal is achieved through the crafting of models of reasoning and thought among computer systems (Rau, 1990).

Because of its complexity, simulating human memory among computer systems tends to be problematic, and may be fraught with performance issues that necessitate some types of simplification regarding memory constructs (Pedersen & Hedberg, 2014). Simplifying the computerized memory constructs leads to profitability within real-time performance contexts (Pedersen & Hedberg, 2014).

Despite such complexities and the lack of a perfect system in which human memory characteristics are replicated completely and accurately, memory concepts are pertinent for gaming systems; visualization; user interfaces and systems functions; cognitive databases for emulating human cognition; robotics for educational purposes; criminology and policing; neural networks; and a variety of other applications (Borkin, et al., 2016; Doss, Sumrall, & Jones, 2012; Hastie, et al., 2016; Mak, 2005; McElreath, et al., 2013; Pedersen & Hedberg, 2014; Wagner & Schiller, 2013). Although artificial intelligence holds some promise of mimicking human characteristics within machines, much work is still required toward achieving the goal of exhibiting indistinguishability between humans and machines regarding cognitive processes and memory.

7. Conclusion

As previously stated, research concerning memory systems is still at an early stage despite much examination. During contemporary times, research continues into memory. The future will lead to significant contributions in the growing body of knowledge concerning memory and brain function as neuro-scientists and psychologists aggressively research this very important arena of human existence.

8. References

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