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Memory

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Memory is a capacity that enables an agent's behavior to be modified and shaped by its past experience. Given this characterization, two central questions arise. First, what are the mechanisms by which such behavioral modifications are produced—that is, how does memory function? Second, should memory be treated as a unitary capacity, or are there fundamentally different kinds of memory that should be distinguished? These two questions have been central throughout the long history of philosophical inquiry into memory and the shorter but rich history of empirical memory research. Researchers have debated, on the one hand, the nature of memory mechanisms and processes and, on the other hand, the merits of rival taxonomies of memory. As memory is widely recognized as playing a central role in shaping human experience and cognition, this research is essential for advancing both theoretical knowledge and practical applications across domains as diverse as mental health, education, and artificial intelligence.

History

Although memory was already an object of philosophical inquiry in ancient Greece (Herrmann & Chaffin, 1988), modern empirical memory research traces its history to Hermann Ebbinghaus (1885/1964), who was the first to apply the experimental methods of natural science to memory. Measuring the amount of time or the number of repetitions it took to learn a series of simple units such as nonsense syllables, Ebbinghaus described processes relating to learning, retention, and forgetting that have stood the test of time. In doing so, he drew explicitly on the ancient metaphor of storage, describing experiences as being "inscribed" in the mind and as leaving traces that are "read off" during remembering. Inspired by the same metaphor, Richard Semon (1921) later coined the term *engram* to refer to the physical substrate of memory traces. Reluctant to speculate about the biological basis of memory, Semon posed the question whether engrams are localized in particular cells or brain regions or whether they are more widely distributed. That question would come to the fore in the mid-twentieth century, as Karl Lashley's experiments involving cortical lesions lent support to distributed models of storage (Lashley, 1950). In a seminal contribution, Donald O. Hebb (1949) hypothesized that memories are stored in populations of functionally connected neurons, an idea that has profoundly influenced modern memory neuroscience.

In the early decades of memory research, both William James (1890) and Henri Bergson (1896/1911) proposed distinctions among kinds of memory they took to be importantly different. The idea that memory is not a unitary capacity but rather a collection of distinct systems would nevertheless only take hold in the 1960s and 1970s, when researchers distinguished first between short-term and long-term memory (Atkinson & Shiffrin, 1968) and then among different long-term memory systems (Tulving, 1983), leading to the emergence of the multiple memory systems view.

Core concepts

Encoding, storage, and retrieval

According to a widely accepted model, memory processing involves three essential stages: encoding, storage, and retrieval. *Encoding* is the acquisition of information and its transformation into a form suitable for storage. The effectiveness of encoding depends on the *level of processing*: information that is processed more deeply—that is, in terms of its meaning rather than surface features like visual appearance or sound—is typically remembered better than information processed more shallowly (Craik & Lockhart, 1972). *Storage* is the maintenance of this information over time. It includes *consolidation*, a process through which memory traces are strengthened and made more stable and long lasting. *Retrieval* is the process of accessing or recovering stored information. These stages are generally understood by psychologists to be interdependent and frequently overlapping.

Forgetting

Forgetting is the loss of or inability to retrieve information from memory. Psychologists believe it occurs because of a variety of factors, including gradual information decay, interference from other information, and unavailability of memory cues—external or internal triggers (e.g., smells, sounds) that help access stored information. Although often seen as a failure of memory, forgetting can be beneficial, enabling organisms to prioritize relevant information and conserve cognitive resources (Schacter, 2021).

Memory systems

According to the multiple memory systems view, memory is not a unitary capacity but is rather composed of multiple neurocognitive systems characterized by distinct kinds of representation, principles of operation, and neural substrates (Squire, 2004). Memory systems constitute the basic kinds of memory. They interact to enable learning, retention, and retrieval across different domains of knowledge. Long-term memory systems are typically categorized into *explicit (declarative) memory*, which involves conscious recollection of events and facts (e.g., episodic and semantic memory) and *implicit (nondeclarative) memory*, which operates without conscious awareness (e.g., procedural memory and conditioning). Short-term memory systems, such as working memory, support the temporary maintenance and manipulation of information needed for reasoning and goal-directed behavior. The precise relationship between working memory and short-term memory is a subject of theoretical disagreement; some models characterize short-term storage as a component of a complex working memory system, whereas others posit short-term stores that are not part of working memory (see Cowan, 2017).

Episodic memory

Episodic memory is a memory system that enables the recollection of personally experienced events. It involves the storage and retrieval of information about specific events (e.g., one's tenth birthday party) and a distinctive sense of "re-experiencing" or "reliving" the personal past (Tulving, 1983). It thus bears an essential connection to the self, to the sense of subjective time, and to the form of consciousness that enables individuals to be aware of their own continued existence.

Semantic memory

Semantic memory is a system responsible for storing and accessing general knowledge about the world, including the meanings of words and concepts [see Concepts]. It supports a wide range of cognitive activities, including object recognition, reasoning, and future planning. Semantic memory interacts closely with episodic memory as well as with other sensory, perceptual, and motor systems (Kumar, 2021).

Procedural memory

Procedural memory is a memory system underlying a variety of motor, perceptual, and cognitive skills. It supports the know-how involved in performing activities like riding a bicycle or playing a musical instrument. Procedural knowledge is typically acquired gradually through repeated practice, eventually becoming automatic and requiring little or no conscious effort to access (Squire, 2004).

Working memory

Working memory is a memory system enabling the short-term storage and manipulation of information for goal-directed processing [see Working Memory]. It operates on timescales measured in seconds and has a very limited capacity (Cowan, 2012). According to one influential view, working memory consists of multiple distinct components, including a central executive responsible for attentional control and manipulation and several subsidiary components that store and maintain phonological (speech- and sound-based) and visuospatial information (Baddeley, 2007).

Questions, controversies, and new developments

Particularly notable is the renewed search for the neural bases of storage and retrieval. Researchers have employed a variety of novel methods to capture, manipulate, and artificially reactivate populations of *engram neurons* (Josselyn et al., 2015). Engram neurons are localized in specific brain regions (e.g., the hippocampus or the amygdala) but are embedded in broader brain networks, challenging the traditional dichotomy between localized and distributed memory storage.

Also notable is the emergence of neuroimaging and clinical evidence revealing a close connection between episodic memory and imagination [see Episodic Future Thinking]. This evidence has inspired a class of theories that posit a common neurocognitive system underlying both capacities (Hassabis & Maguire, 2007; Schacter & Addis, 2007). According to such theories, remembering the past and imagining the future amount to two forms of *mental time travel* (Michaelian, 2016).

Recent work has also deepened the understanding of the relationship between memory and sleep. A wealth of evidence shows that sleep plays a critical role in memory consolidation, facilitating the reorganization of memories and their integration into the network of preexisting memories, while selectively strengthening those that are most salient or relevant (Rasch & Born, 2013).

Broader connections

An important line of research concerns the relation between memory and the self, grounded in a prominent theory that characterizes memory as providing an autobiographical database for the self (Conway, 2005) [see Self]. Another line of research concerns memory in nonhuman animals, with a debate about whether nonhuman animals have episodic memory attracting particular attention (Suddendorf & Corballis, 2010). Most recently, rapid advances in generative artificial intelligence have inspired new lines of inquiry that compare memory in biological organisms and artificial agents and explore more biologically inspired memory architectures for future artificial intelligence systems (Rolls, 2024).

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