

Stages of Memory

The following text borrows extensively from Wikipedia, which offers a helpful synopsis of stages of memory.

Perception

Perception (from the Latin perceptio, percipio) is the organization, identification, and interpretation of sensory information in order to represent and understand the environment. All perception involves signals in the nervous system, which in turn result from physical or chemical stimulation of the sense organs. For example, vision involves light striking the retina of the eye, smell is mediated by odor molecules, and hearing involves pressure waves. Perception is not the passive receipt of these signals, but is shaped by learning, memory, expectation, and attention.

Perception involves these "top-down" effects as well as the "bottom-up" process of processing sensory input. The "bottom-up" processing transforms low-level information to higher-level information (e.g., extracts shapes for object recognition). The "top-down" processing refers to a person's concept and expectations (knowledge), and selective mechanisms (attention) that influence perception. Perception depends on complex functions of the nervous system, but subjectively seems mostly effortless because this processing happens outside conscious awareness.

Since the rise of experimental psychology in the 19th Century, psychology's understanding of perception has progressed by combining a variety of techniques. Psychophysics quantitatively describes the relationships between the physical qualities of the sensory input and perception. Sensory neuroscience studies the brain mechanisms underlying perception. Perceptual systems can also be studied computationally, in terms of the information they process. Perceptual issues in philosophy include the extent to which sensory qualities such as sound, smell or color exist in objective reality rather than in the mind of the perceiver.

Although the senses were traditionally viewed as passive receptors, the study of illusions and ambiguous images has demonstrated that the brain's perceptual systems actively and preconsciously attempt to make sense of their input. There is still active debate about the extent to which perception is an active process of hypothesis testing, analogous to science, or whether realistic sensory information is rich enough to make this process unnecessary.

The perceptual systems of the brain enable individuals to see the world around them as stable, even though the sensory information is typically incomplete and rapidly varying. Human and animal brains are structured in a modular way, with different areas processing different kinds of sensory information. Some of these modules take the form of sensory maps, mapping some aspect of the world across part of the brain's surface. These different modules are interconnected and influence each other. For instance, the taste is strongly influenced by its odor.

Sensory Memory

During every moment of an organism's life, sensory information is being taken in by sensory receptors and processed by the nervous system. The information people received which is stored in sensory memory is just long enough to be transferred to short-term memory. Humans have five main senses: sight, hearing, taste, smell, touch. Sensory memory (SM) allows individuals to retain impressions of sensory information after the original stimulus has ceased. A common demonstration of SM is a child's ability to write letters and make circles by twirling a sparkler at night. When the sparkler is spun fast enough, it appears to leave a trail which forms a continuous image. This "light trail" is the image that is represented in the visual sensory store known as iconic memory. The other two types of SM that have been most extensively studied are echoic memory, and haptic memory; however, it is reasonable to assume that each physiological sense
has a corresponding memory store. Children for example have been shown to remember specific "sweet" tastes during incidental learning trials but the nature of this gustatory store is still unclear.

SM is considered to be outside of cognitive control and is instead an automatic response. The information represented in SM is the "raw data" which provides a snapshot of a person's overall sensory experience. Common features between each sensory modality have been identified; however, as experimental techniques advance, exceptions and additions to these general characteristics will surely evolve. The auditory store, echoic memory, for example, has been shown to have a temporal characteristic in which the timing and tempo of a presented stimulus affects transfer into more stable forms of memory. Four common features have been identified for all forms of SM:

1. The formation of a SM trace is independent of attention to the stimulus.
2. The information stored in SM is modality specific. This means for example, that echoic memory is for the exclusive storage of auditory information, and haptic memory is for the exclusive storage of tactile information.
3. Each SM store represents an immense amount of detail resulting in very high resolution of information.
4. Each SM store is very brief and lasts a very short period of time. Once the SM trace has decayed or is replaced by a new memory, the information stored is no longer accessible and is ultimately lost. All SM stores have slightly different durations which is discussed in more detail on their respective pages.

It is widely accepted that all forms of SM are very brief in duration; however, the approximated duration of each memory store is not static. Iconic memory for example has an average duration of 500 ms which tends to decrease with age. The SM is made up of spatial or categorical stores of different kinds of information, each subject to different rates of information processing and decay. Genetics also play a role in SM capacity; mutations to the brain-derived neurotrophic factor (BDNF), a nerve growth factor, and N-methyl-D-aspartate (NMDA) receptors, responsible for synaptic plasticity, decrease iconic and echoic memory capacities respectively.

**Iconic Memory:** The mental representation of the visual stimuli are referred to as icons (fleeting images.) Iconic memory was the first sensory store to be investigated with experiments dating back as far as 1740. One of the earliest investigations into this phenomenon was by Ján Andrej Segner, a German physicist and mathematician. In his experiment, Segner attached a glowing coal to a cart wheel and rotated the wheel at increasing speed until an unbroken circle of light was perceived by the observer. He calculated that the glowing coal needed to make a complete circle in under 100ms to achieve this effect, which he determined was the duration of this visual memory store.

**Echoic Memory:** represents SM for the auditory sense of hearing. Auditory information travels as sound waves which are sensed by hair cells in the ears. Information is sent to and processed in the temporal lobe. The first studies of echoic memory came shortly after Sperling investigated iconic memory using an adapted partial report paradigm. Today, characteristics of echoic memory have been found mainly using a Mismatch Negativity (MMN) paradigm which utilizes EEG and MEG recordings. MMN has been used to identify some of the key roles of echoic memory such as change detection and language acquisition. Change detection, or the ability to detect an unusual or possibly dangerous change in the environment independent of attention, is key to the survival of an organism. With regards to language, a characteristic of children who begin speaking late in development is reduced duration of echoic memory. In short, "Echoic Memory is a fast - decaying store of auditory information  In the case of damage to or lesions
developing on the frontal lobe, parietal lobe, or hippocampus, echoic memory will likely be shortened and/or have a slower reaction time.

**Haptic Memory:** represents SM for the tactile sense of touch. Sensory receptors all over the body detect sensations such as pressure, itching, and pain. Information from receptors travel through afferent neurons in the spinal cord to the postcentral gyrus of the parietal lobe in the brain. This pathway comprises the somatosensory system. Evidence for haptic memory has only recently been identified resulting in a small body of research regarding its role, capacity, and duration. Already however, fMRI studies have revealed that specific neurons in the prefrontal cortex are involved in both SM, and motor preparation which provides a crucial link to haptic memory and its role in motor responses.

**Working memory (Short-term)**

**Working memory** is the system that actively holds multiple pieces of transitory information in the mind, where they can be manipulated. Working memory is generally used synonymously with short term memory, but this depends on how the two forms of memory are defined. Working memory includes subsystems that store and manipulate visual images or verbal information, as well as a central executive that coordinates the subsystems. It includes visual representation of the possible moves, and awareness of the flow of information into and out of memory, all stored for a limited amount of time. Working memory tasks require monitoring (i.e., manipulation of information or behaviors) as part of completing goal-directed actions in the setting of interfering processes and distractions. The cognitive processes needed to achieve this include the executive and attention control of short-term memory, which permit interim integration, processing, disposal, and retrieval of information. These processes are sensitive to age: working memory is associated with cognitive development, and research shows that its capacity tends to decline with old age. Working memory is a theoretical concept central both to cognitive psychology and neuroscience. In addition, neurological studies demonstrate a link between working memory and learning and attention.

Theories exist both regarding the theoretical structure of working memory and the role of specific parts of the brain involved in working memory. Research identifies the frontal cortex, parietal cortex, anterior cingulate, and parts of the basal ganglia as crucial. The neural basis of working memory has been derived from lesion experiments in animals and functional imaging upon humans.

**Short-term memory** (or "primary" or "active memory") is the capacity for holding a small amount of information in mind in an active, readily available state for a short period of time. The duration of short-term memory (when rehearsal or active maintenance is prevented) is believed to be in the order of seconds. A commonly cited capacity is $7\pm2$ elements. In contrast, long-term memory can hold an indefinite amount of information. Short-term memory should be distinguished from working memory, which refers to structures and processes used for temporarily storing and manipulating information (see details below).

**Dual-store memory model:** According to Miller, whose paper in 1956 popularized the theory of the "magic number seven", short-term memory is limited to a certain number of chunks of information, while long-term memory has a limitless store.\[^1\]

**Atkinson-Shiffrin Memory Model:** According to the dual store memory model proposed by Richard C. Atkinson and Richard Shiffrin in 1968, memories can reside in the short-term "buffer" for a limited time while they are simultaneously strengthening their associations in long-term memory. When items are first presented, they enter short-term memory, but due to its limited space, as new items enter, older ones are pushed out. However, each time an item in short
term memory is rehearsed, it is strengthened in long term memory. Similarly, the longer an item stays in short-term memory, the stronger its association becomes in long-term memory.\[2\]

**Baddeley's Model of Working Memory:** In 1974 Baddeley and Hitch proposed an alternative theory of short term memory: Baddeley's model of working memory. According to this theory, short-term memory is divided into different slave systems for different types of input items, and there is an executive control supervising what items enter and exit those systems.\[3\][4] The slave systems include the phonological loop, the visuo-spatial sketchpad, and the episodic buffer (later added by Baddeley).\[5\]

**Intermediate-term memory**

Intermediate-term memory (ITM) is a stage of memory distinct from sensory memory, working memory/short-term memory, and long-term memory. While sensory memory persists for several milliseconds, working memory persists for up to thirty seconds, and long-term memory persists from thirty minutes to the end of an individual's life, intermediate-term memory persists for about two to three hours. This overlap in the durations of these memory processes indicates that they occur simultaneously, rather than sequentially. Indeed, intermediate-term facilitation can be produced in the absence of long-term facilitation. However, the boundaries between these forms of memory are not clear-cut, and they can vary depending on the task. Intermediate-term memory is thought to be supported by the parahippocampal cortex.

In 1993, Rosenzweig and colleagues demonstrated that, in rats conditioned to avoid an aversive stimulus, percent avoidance of the stimulus (and, by implication, memory of the aversive nature of the stimulus) reached relative minima at one minute, fifteen minutes, and sixty minutes. These dips were theorized to correspond to the time points in which the rats switched from working memory to intermediate-term memory, from intermediate-term memory to the early phase of long-term memory, and from the early phase of long-term memory to the late phase of long-term memory, respectively—thus demonstrating the presence of a form of memory that exists between working memory and long-term memory, which they referred to as "intermediate-term memory".

Though the idea of intermediate-term memory has existed since the 1990s, Sutton et al. introduced a novel theory for the neural correlates underlying intermediate-term memory in *Aplysia* in 2001, where they described it as the primary behavioral manifestation of intermediate-term facilitation.

**Long-Term Memory**

Long-term memory (LTM) is the final stage of the dual memory model proposed by Atkinson and Shiffrin, in which data can be stored for long periods of time. While short-term and working memory persists for only about 20 to 30 seconds, information can remain in long term memory indefinitely. According to Mazur (2006), long-term memory has also been called reference memory, because an individual must refer to the information in long-term memory when performing almost any task.

Long term memory is commonly broken down into explicit memory (declarative), which includes episodic memory, semantic memory, and autobiographical memory, and implicit memory (procedural memory).

Long-term memory encodes information semantically for storage, as researched by Baddeley.\[6\] In vision, the information needs to enter working memory before it can be stored into long-term memory. This is evidenced by the fact that the speed with which information is stored into long-term memory is determined by the amount of information that can be fit, at each step, into visual
working memory.\textsuperscript{[7]} In other words, the larger the capacity of working memory for certain stimuli, the faster will these materials be learned.

Synaptic Consolidation is the process by which items are transferred from short term to long term memory. Within the first minutes or hours after acquisition, the engram (memory trace) is encoded within synapses, becoming resistant (though not immune) to interference from outside sources.\textsuperscript{[8][9]}

As long-term memory is subject to fading in the natural forgetting process, maintenance rehearsal (several recalls/retrivals of memory) may be needed to preserve long term memories.\textsuperscript{[10]} Individual retrievals can take place in increasing intervals in accordance with the principle of spaced repetition. This can happen quite naturally through reflection or deliberate recall (also known as recapitulation), often dependent on the perceived importance of the material.

**Sleep**

Some theories consider sleep to be an important factor in establishing well-organized long-term memories. (See also sleep and learning.) Sleep plays a key function in the consolidation of new memories.\textsuperscript{[11]}

According to Tarnow's theory, long-term memories are stored in dream format (reminiscent of the Penfield & Rasmussen’s findings that electrical excitations of cortex give rise to experiences similar to dreams). During waking life an executive function interprets long-term memory consistent with reality checking (Tarnow 2003). Also, that the information stored in memory, no matter how it was learned, can affect performance on a particular task without the subject being aware that this memory is being used. Newly acquired declarative memory traces are believed to be reactivated during NonREM sleep to promote their hippocampo-neocortical transfer for long-term storage.\textsuperscript{[12]} Specifically new declarative memories are better remembered if recall follows Stage II non-rapid eye movement sleep. The reactivation of memories during sleep can lead to lasting synaptic changes within certain neural networks. It is the high spindle activity, low oscillation activity, and delta wave activity during NREM sleep that helps to contribute to declarative memory consolidation. In learning before sleep spindles are redistributed to neuronally active upstates within slow oscillations.\textsuperscript{[11]} Sleep spindles are thought to induce synaptic changes and thereby contribute to memory consolidation during sleep. Here, we examined the role of sleep in the object-place recognition task, a task closely comparable to tasks typically applied for testing human declarative memory: It is a one-trial task, hippocampus-dependent, not stressful and can be repeated within the same animal.\textsuperscript{[13]} Sleep deprivation reduces vigilance or arousal levels, affecting the efficiency of certain cognitive functions such as learning and memory.\textsuperscript{[14]}

The theory that sleep benefits memory retention is not a new idea. It has been around since Ebbinghaus's experiment on forgetting in 1885. More recently studies have been done by Payne and colleagues and Holtz and colleagues.\textsuperscript{[15]} In Payne and colleague's\textsuperscript{[16]} experiment participants were randomly selected and split into two groups. Both groups were given semantically related or unrelated word pairs, but one group was given the information at 9am and the other group received theirs at 9pm. Participants were then tested on the word pairs at one of three intervals 30 minutes, 12 hours, or 24 hours later. It was found that participants who had a period of sleep between the learning and testing sessions did better on the memory tests. This information is similar to other results found by previous experiments by Jenkins and Dallenbach (1924). It has also been found that many domains of declarative memory are affected by sleep such as emotional memory, semantic memory, and direct encoding.\textsuperscript{[16]}
Holtz[15] found that not only does sleep affect consolidation of declarative memories, but also procedural memories. In this experiment fifty adolescent participants were taught either word pairs (which represents declarative memory) and a finger tapping task (procedural memory at one of two different times of day. What they found was that the procedural finger tapping task was best encoded and remembered directly before sleep, but the declarative word pairs task was better remembered and encoded if learned at 3 in the afternoon.[15]

Divisions of Long Term Memory
The brain does not store memories in one unified structure, as might be seen in a computer's hard disk drive. Instead, different types of memory are stored in different regions of the brain. Long term memory is typically divided up into two major headings: explicit memory and implicit memory.[2]

Explicit memory (declarative memory) refers to all memories that are consciously available. These are encoded by the hippocampus, entorhinal cortex, and perirhinal cortex, but consolidated and stored elsewhere. The precise location of storage is unknown, but the temporal cortex has been proposed as a likely candidate. Research by Meulemans and Van der Linden (2003) found that amnesiac patients with damage to the medial temporal lobe performed more poorly on explicit learning tests than did healthy controls. However, these same amnesiac patients performed at the same rate as healthy controls on implicit learning tests. This implies that the medial temporal lobe is heavily involved in explicit learning, but not in implicit learning.[17][18] Declarative memory has three major subdivisions:

Episodic memory refers to memory for specific events in time, as well as supporting their formation and retrieval. Some examples of episodic memory would be remembering someone's name and what happened at your last interaction with each other.[19][20] Experiments conducted by Spaniol and colleagues indicated that older adults have worse episodic memories than younger adults because episodic memory requires context dependent memory.[21]

Semantic memory refers to knowledge about factual information, such as the meaning of words. Semantic memory is independent information such as information remembered for a test.[20] In contrast with episodic memory older adults and younger adults do not show much of a difference with semantic memory, presumably because semantic memory does not depend on context memory.[21]

Autobiographical memory refers to knowledge about events and personal experiences from an individual's own life. Though similar to episodic memory, it differs in that it contains only those experience which directly pertain to the individual, from across his lifespan. Conway and Pleydell-Pearce (2000) argue that this is one component of the self-memory system.[22]

Implicit memory (procedural memory) refers to the use of objects or movements of the body, such as how exactly to use a pencil, drive a car, or ride a bicycle. This type of memory is encoded and it is presumed stored by the striatum and other parts of the basal ganglia. The basal ganglia is believed to mediate procedural memory and other brain structures and is largely independent of the hippocampus.[23] Research by Manelis, Hanson, and Hanson (2011) found that the reactivation of the parietal and occipital regions was associated with implicit memory.[24] Procedural memory is considered non-declarative memory or unconscious memory which includes priming and non-associative learning.[20][25]

Other categories of memory may also be relevant to the discussion of long term memory. For example:
**Emotional memory**, the memory for events that evoke a particularly strong emotion, is a domain that can involve both declarative and procedural memory processes. Emotional memories are consciously available, but elicit a powerful, unconscious physiological reaction. Research indicates that the amygdala is extremely active during emotional situations, and acts with the hippocampus and prefrontal cortex in the encoding and consolidation of emotional events.[26][27]

**Working memory** is not part of long term memory, but is important for long term memory to function. Working memory holds and manipulates information for a short period of time, before it is either forgotten or encoded into long term memory. Then, in order to remember something from long term memory, it must be brought back into working memory. If working memory is overloaded it can affect the encoding of long term memory. If one has a good working memory they may have a better long term memory encoding.[28][29]

**Footnotes**


