第十讲

脑与认知科学

脑与认知加工：记忆与学习

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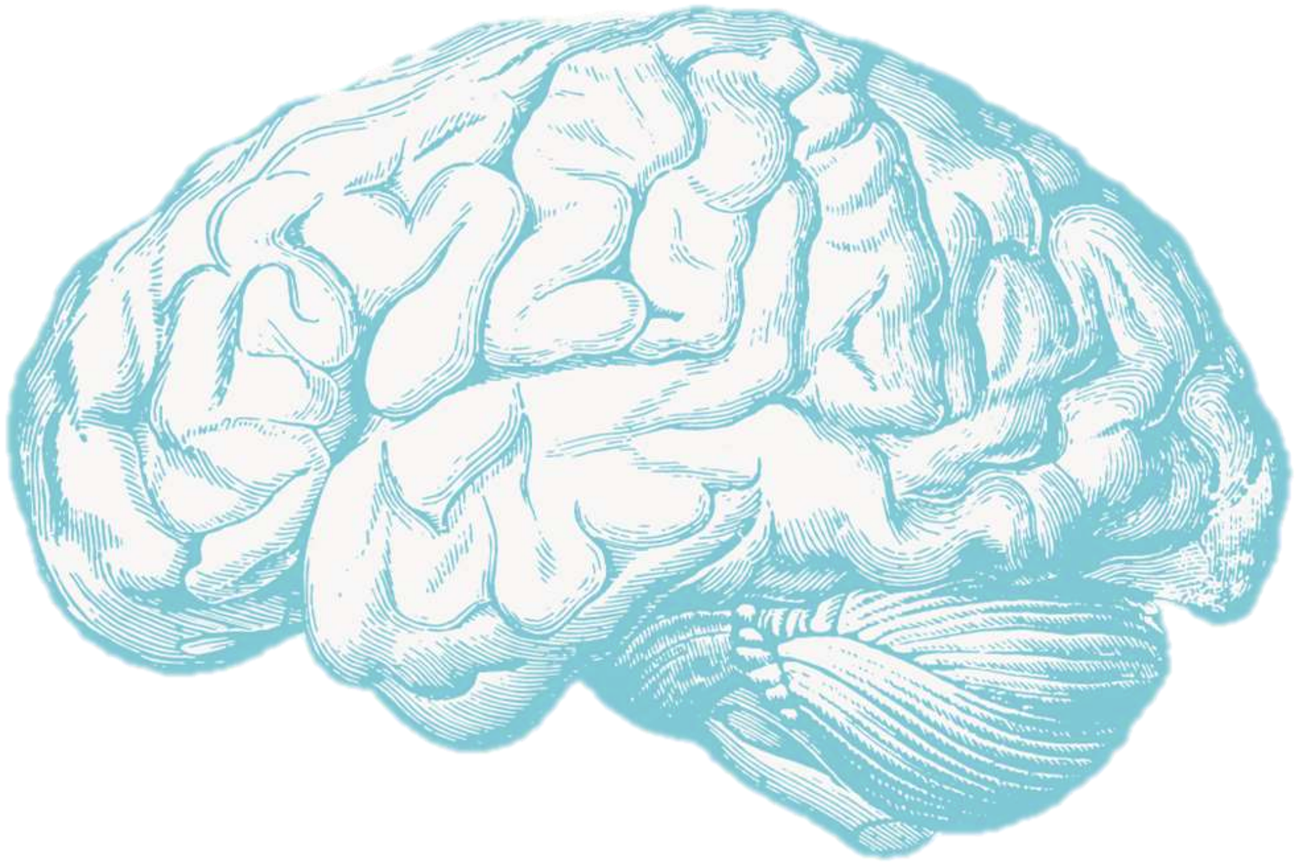

教师介绍

甄宗雷，男，北京师范大学心理学部教授，博士生导师，中科院自动化所计算机应用技术博士，长期在认知神经科学方向开展工作采用磁共振/脑磁图，神经编解码模型和人工智能等多种方法研究人脑视觉和运动的认知神经机制及其发展发育，并基于人脑认知神经新发现开发类脑计算模型。研究结果已发表在Nature Neuroscience, Nature Communications, PLoS Biology, eLife, The Journal of Neuroscience等领域高影响力期刊。

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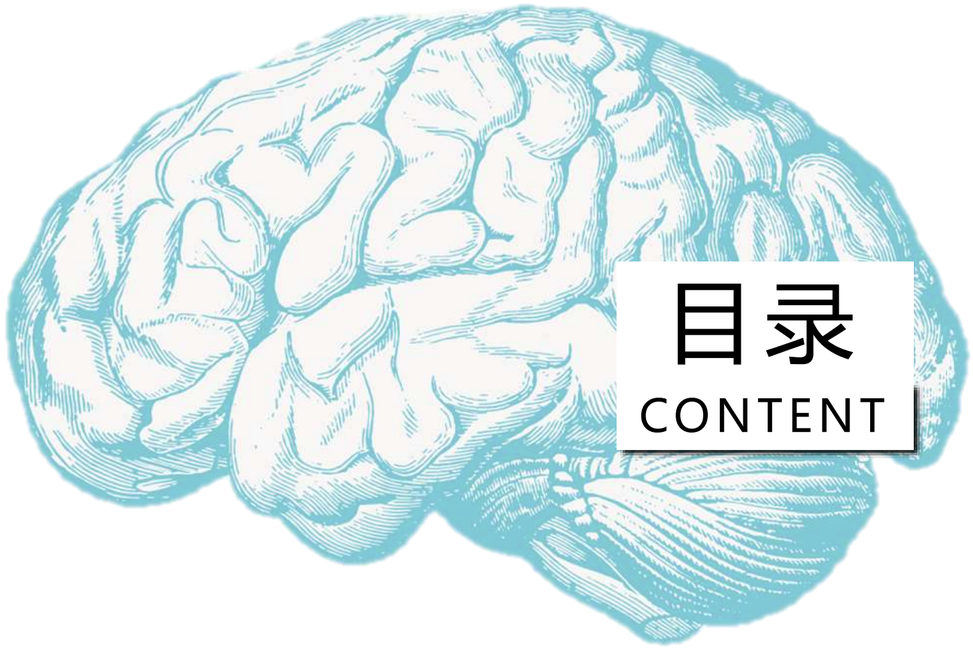

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记忆的定义和类型

按照传统心理学观点：记忆是过去的经验在人脑中的反映，表现为个体对过往经验的识记、保持、再现；按照信息加工理论的观点：记忆是人脑对输入的信息进行编码、储存和提取的过程。

记忆的类型

➢持续的时间长短

感觉记忆、短时记忆和长时记忆

➢表征的内容或方式

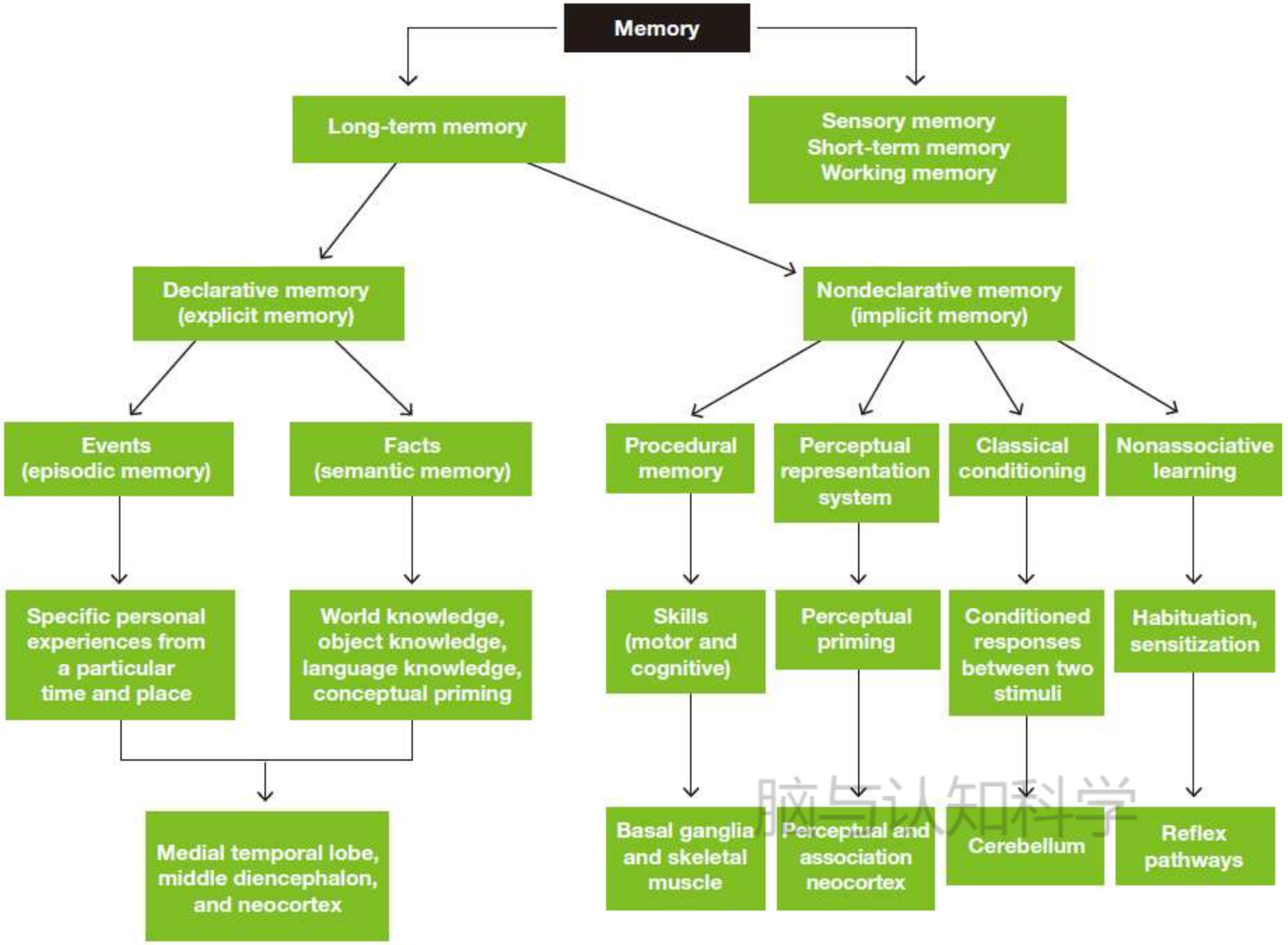
情景记忆和语义记忆

程序性记忆和陈述性记忆

情绪记忆、运动记忆

➢意识参与程度

外显记忆和内隐记忆



Sensory memory（感觉记忆）

感觉记忆是客观刺激停止作用以后，感觉信息在一个极短的时间内保存下来。

Sensory memory is a very brief storage for information from the senses.

- Duration: 0.25 to 0.5 second
- Capacity: all sensory experience
- Encoding: sense specific

触觉　　听觉　　视觉　　嗅觉　　味觉

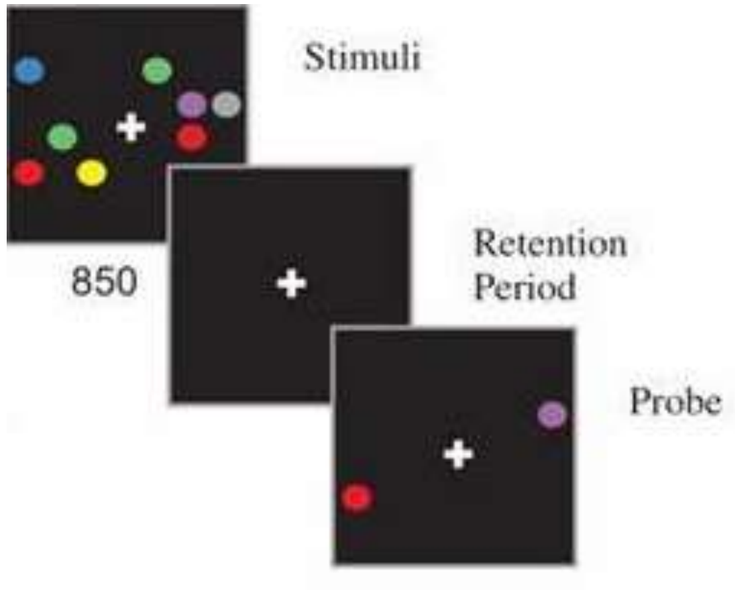
Short-term memory（短时记忆）

短时记忆指信息一次呈现后，保持时间在一分钟左右的记忆。

Short-term memory holds a small amount of information in an active, available state for a brief period.

- Duration: 15-30 seconds
- Capacity: 7±2 items.

视觉短时记忆

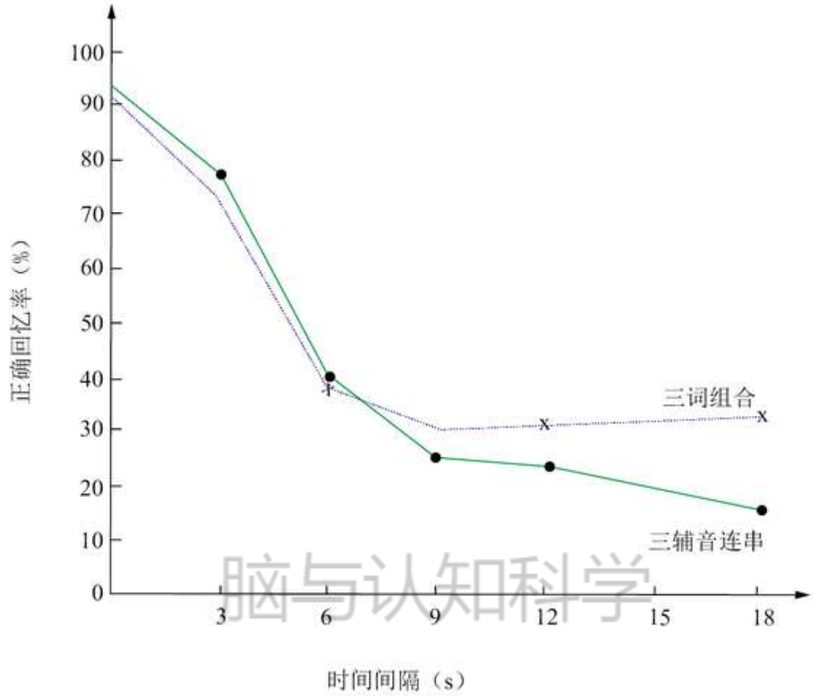


语音短时记忆

573

42189

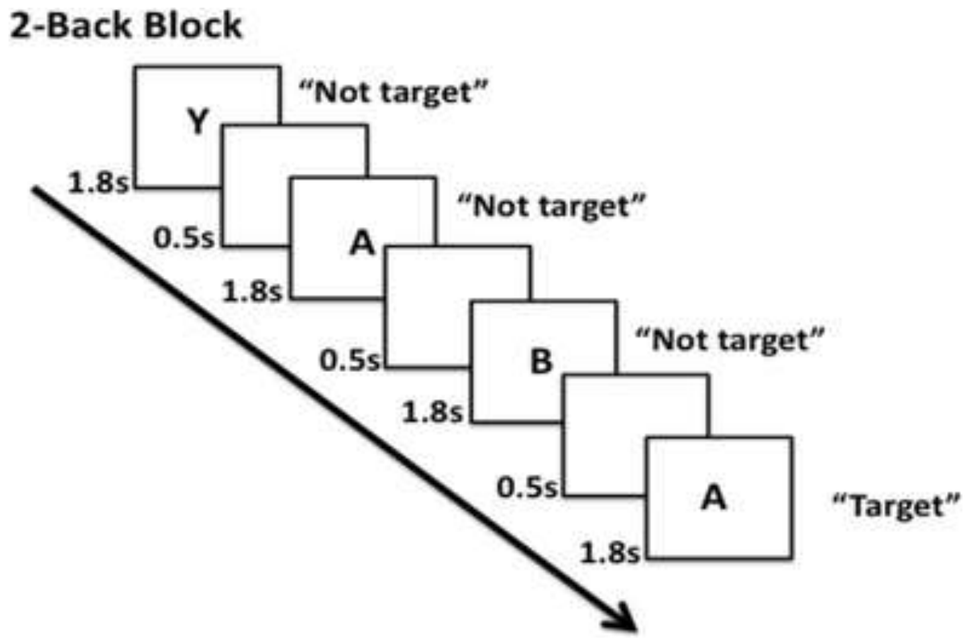
78463774

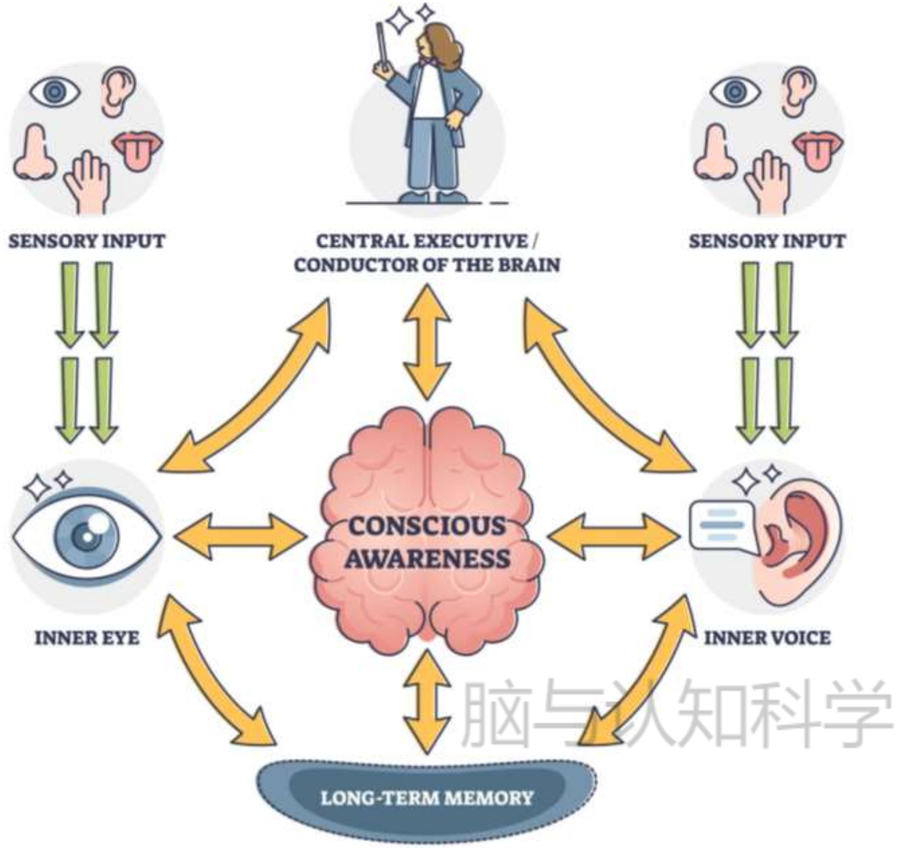


Working memory（工作记忆）

工作记忆是完成认知任务时，对信息进行暂时存储和操作的一个记忆系统。

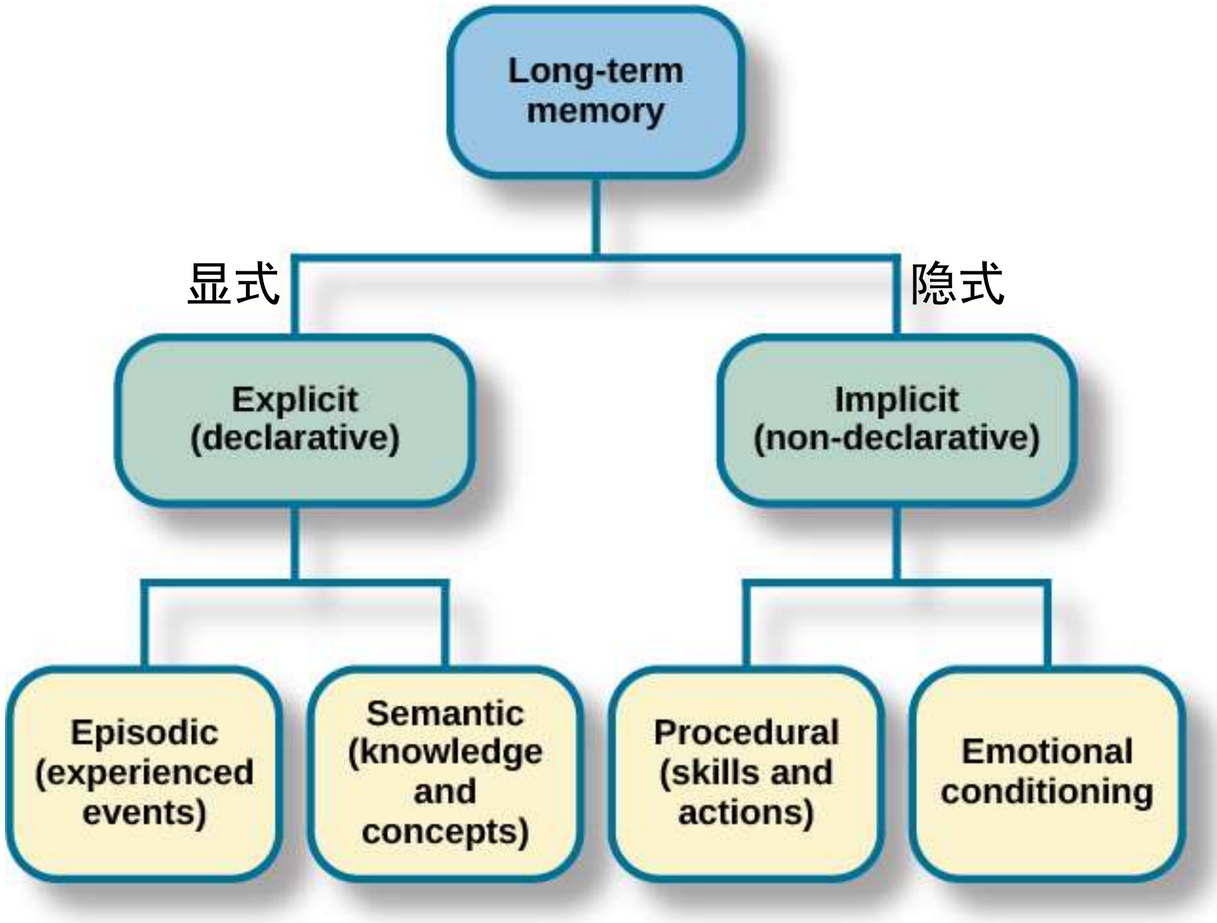
- Working memory emphasizes a wider role in cognition (reasoning, comprehension, etc.), whereas short-term memory is often taken to imply a more passive retention of material.
- Duration: 15-30 seconds
- Capacity: 7±2 items.



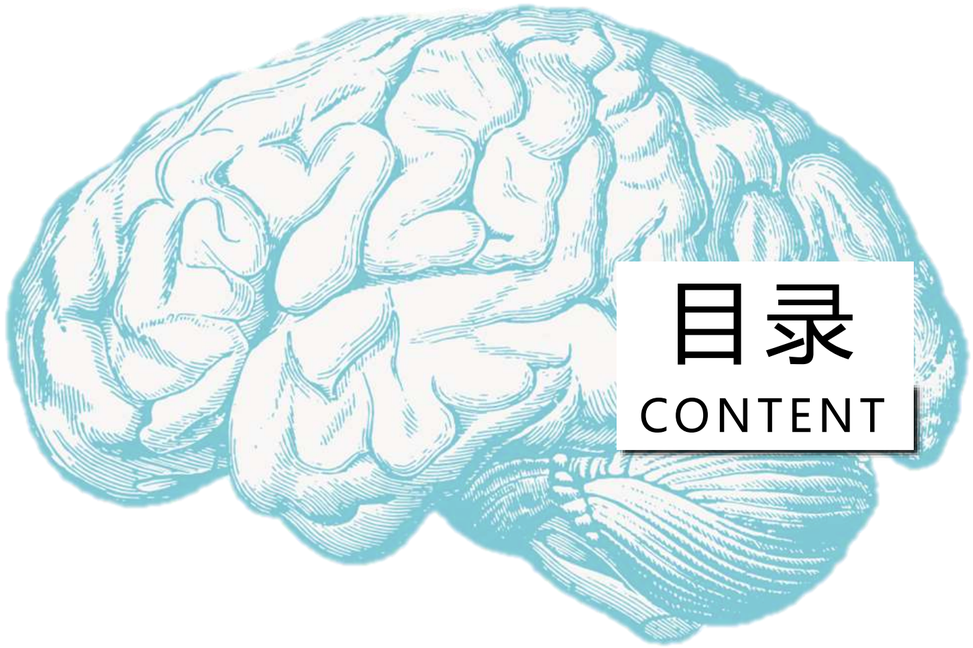


Long-term memory（长时记忆）

长时记忆是信息经过充分和有一定深度的加工后，在头脑中长时间存储的记忆。储存时间大约为1分钟以上，到许多年甚至终身。



- **Episodic memory(情景记忆)** refers to memory of specific events in one's own life. The memories are specific in time and place.
- **Semantic memory(语义记忆)** is conceptually based knowledge about the world, including knowledge of people, places, the meaning of objects and words.
- **Procedural memory(程序记忆)** refers to memory for skills such as riding a bike.
- **Emotional conditioning(情绪反射)** refers to memory that links perceptual information to an emotional response.



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Three stages of memory

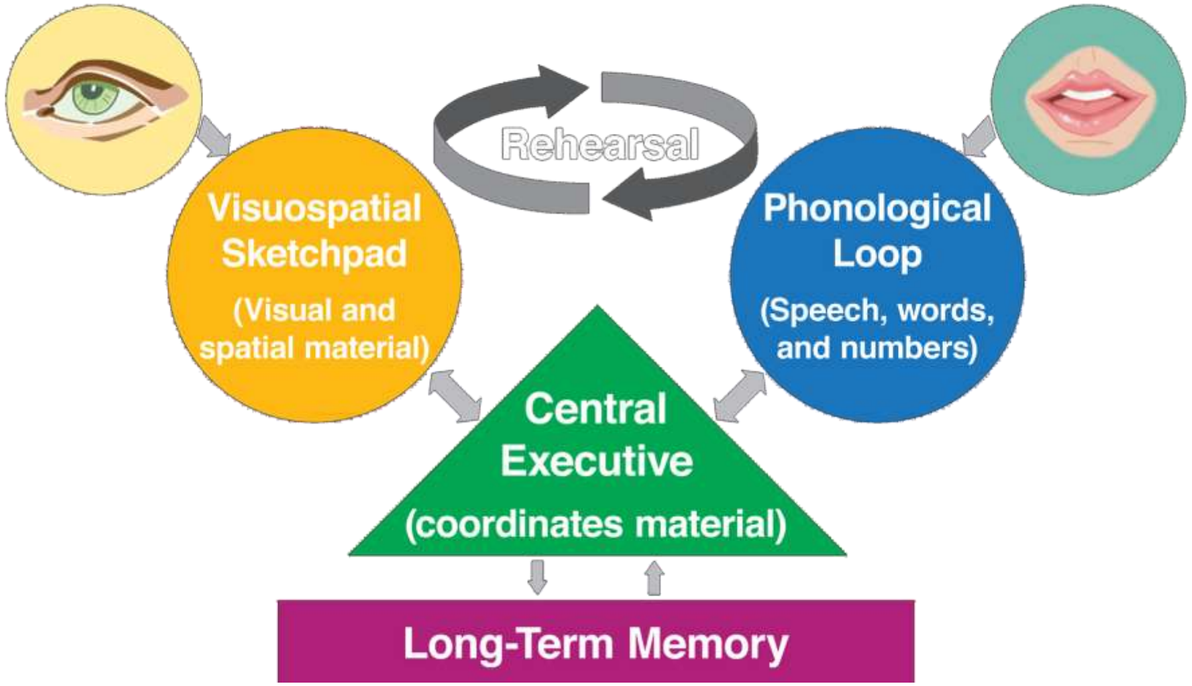
Three necessary stages in the learning and memory process: encoding, storage, and retrieval.

- **Encoding** inputs information into the memory system
  - Acoustic encoding: input of sounds, words, and music
  - Semantic encoding: input of words and their meaning
  - Visual encoding: input of images
- **Storage** is the retention of the encoded information
  - Sensory memory
  - Short-term memory,
  - Long-term memory.
- **Retrieval** is getting the information out of memory and back into awareness
  - Recall: accessing information without cues
  - Recognition: identifying previously learned information after encountering it again, usually in response to a cue

Working memory（工作记忆）

工作记忆不仅是信息的暂时存储，还包括信息的操控，包含三个从属系统。

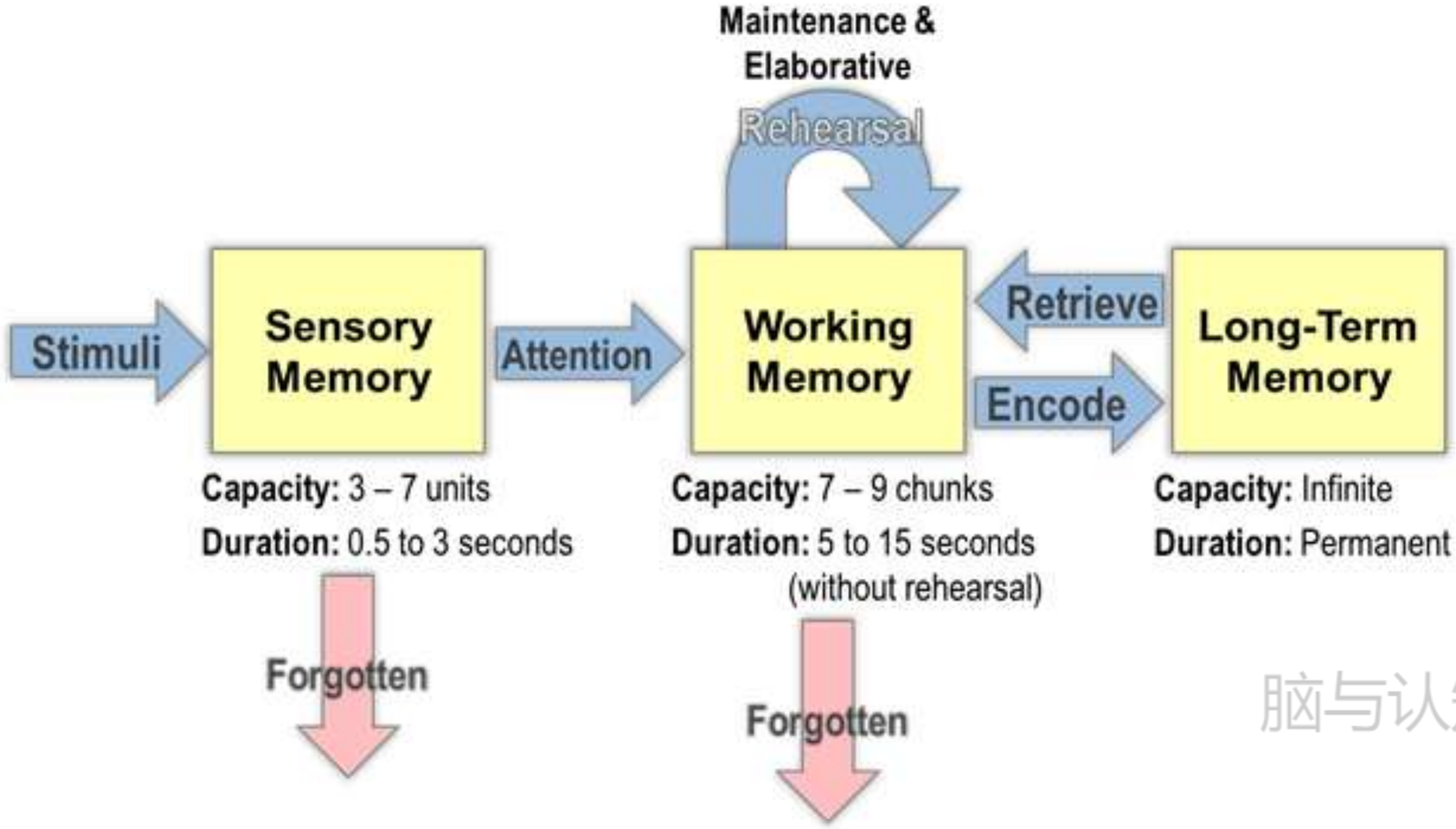
- 语音环路（Phonological Loop）： 储存和处理听觉信息。
- 视觉-空间模板（Visuospatial Sketchpad）：储存视觉和空间信息。
- 情景缓冲器（Episodic Buffer）： 整合来自不同感官的输入，并将其与长时记忆关联。
- 中央执行器（Central Executive）的负责负责分配注意力和协调工作记忆的运作。



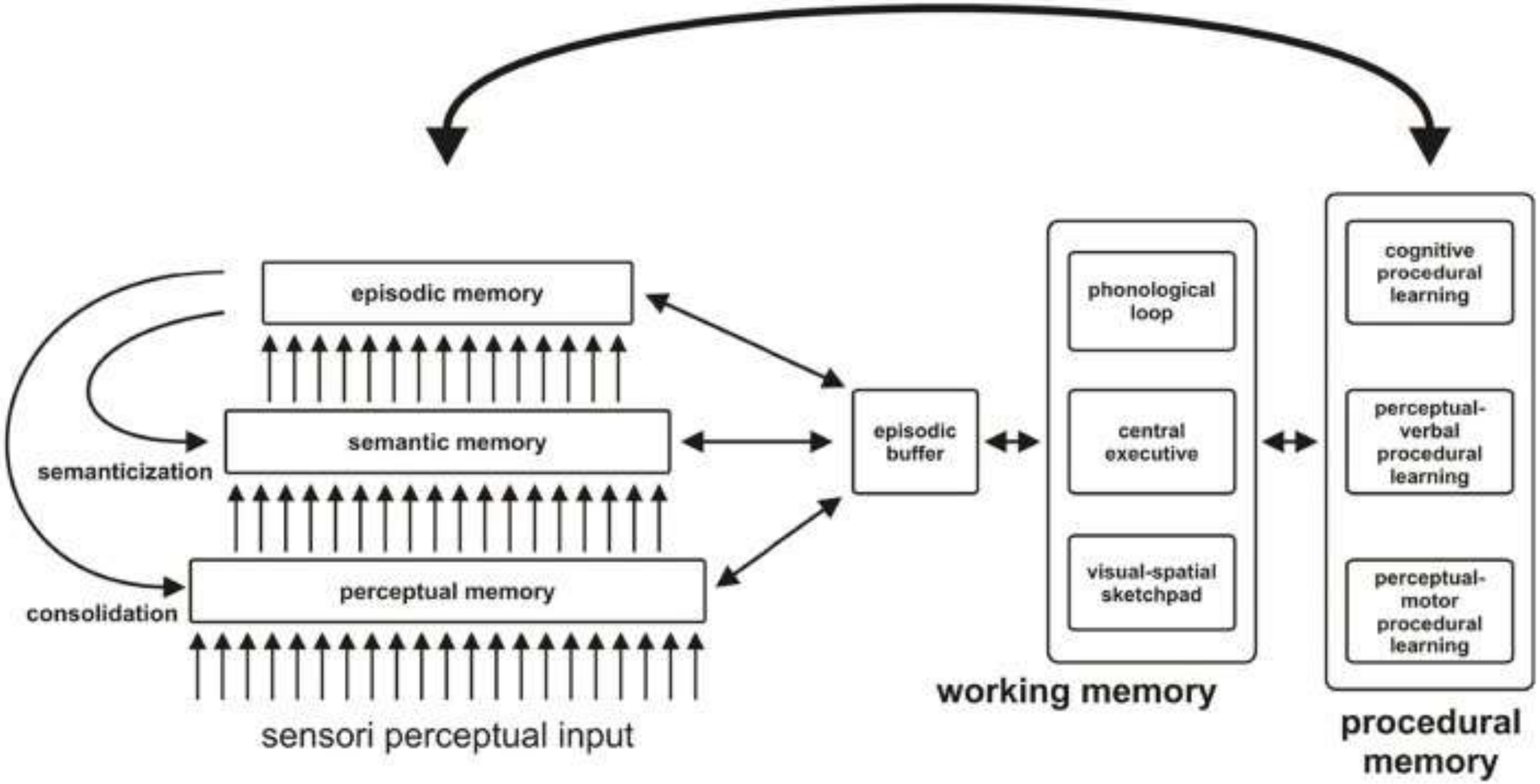
巴德利工作记忆模型

Transformation between distinct type of memory

Information processing begins in sensory memory, moves to short-term memory, and eventually moves into long-term memory. Information that you come across on a daily basis may move through the three stages of memory.

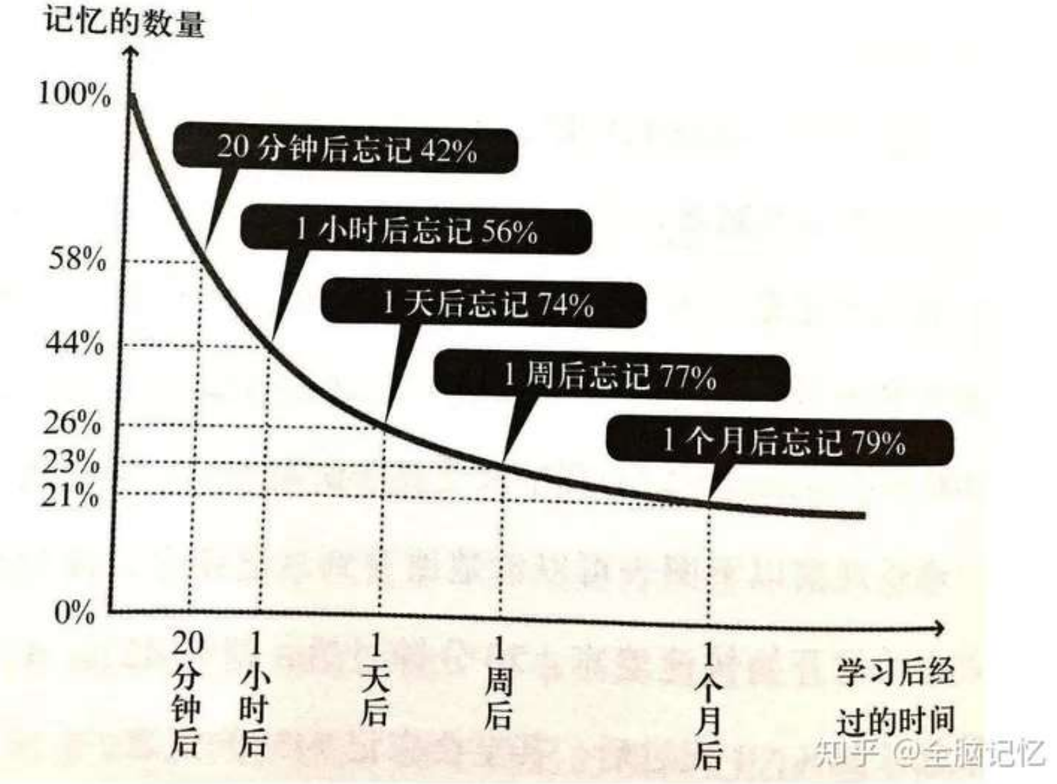


Transformation between distinct type of memory



Why we forget

1. Encoding failures - we don't learn the information in the first place
2. Decay - memories fade over time
3. Inadequate retrieval cues - we lack sufficient reminders
4. Interference - other memories get in the way
5. Trying not to remember - we deliberately attempt to keep things out of mind

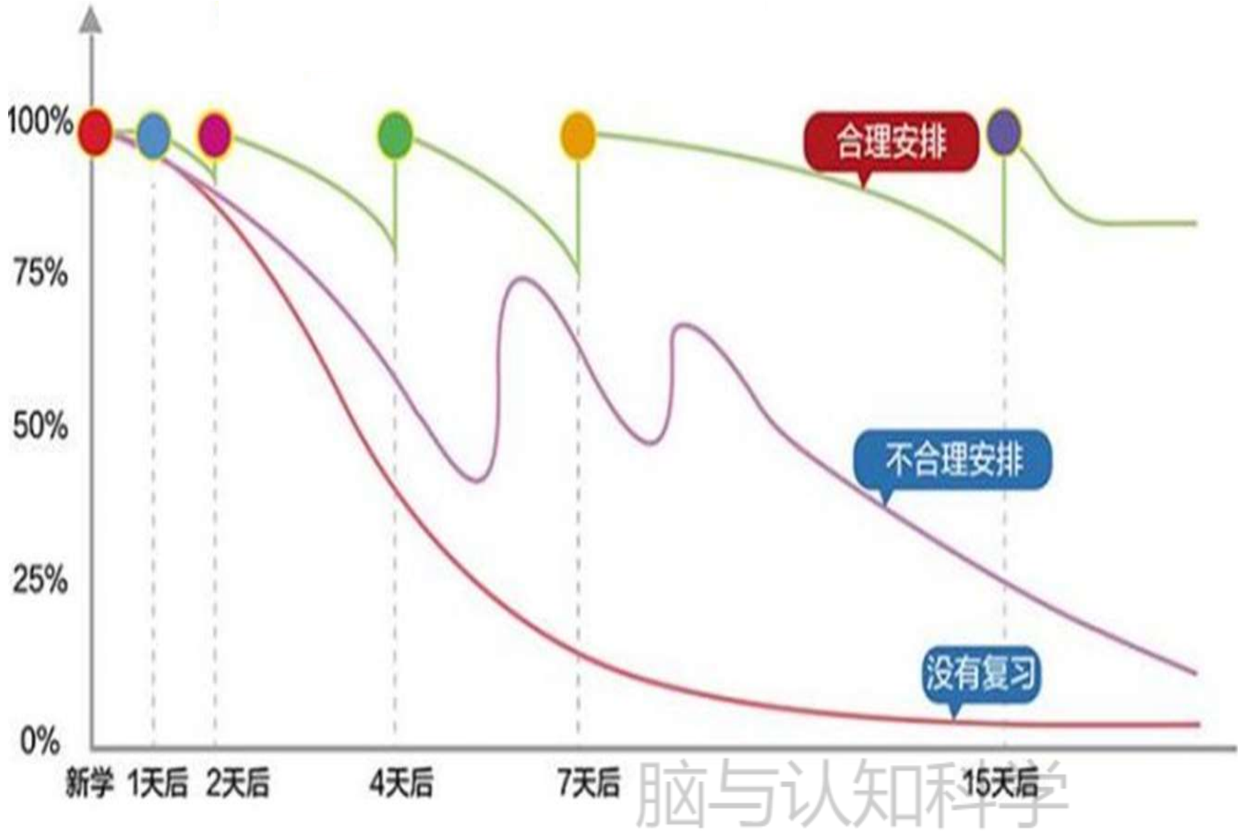


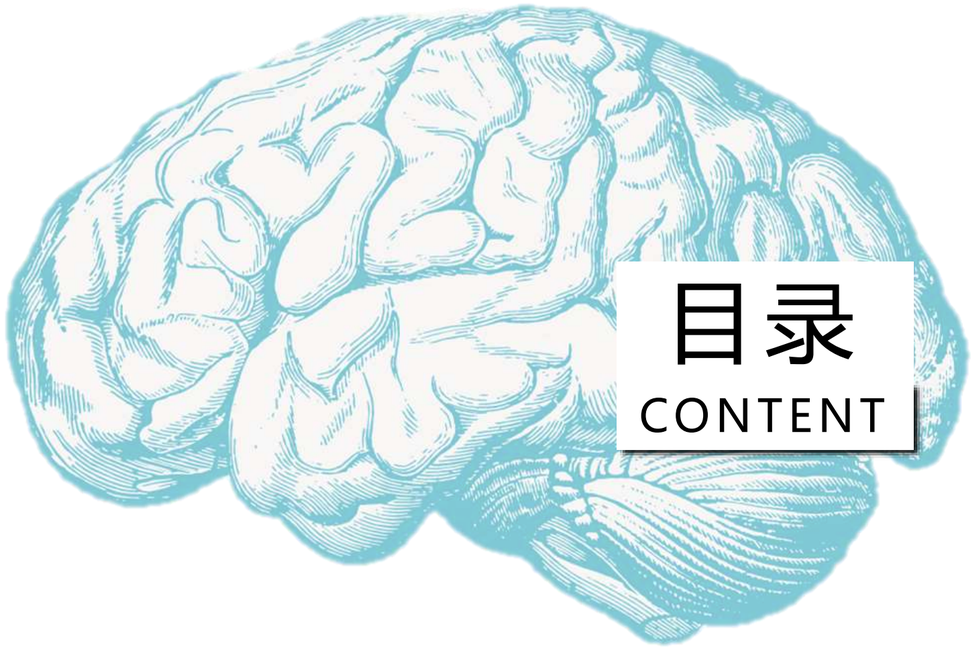
- Forgetting information from short term memory (STM) can be explained using the theories of trace decay and displacement.
- Forgetting from long term memory (LTM) can be explained using the theories of interference, retrieval failure and lack of consolidation.

Memory enhancing strategies

To help make sure information goes from short-term memory to long-term memory, we can use memory-enhancing strategies.

- Rehearse, rehearse, rehearse
- Apply the self-reference effect
- Don’t forget the forgetting curve
- Be aware of interference
- Keep moving
- Get enough sleep
- Make use of mnemonic devices





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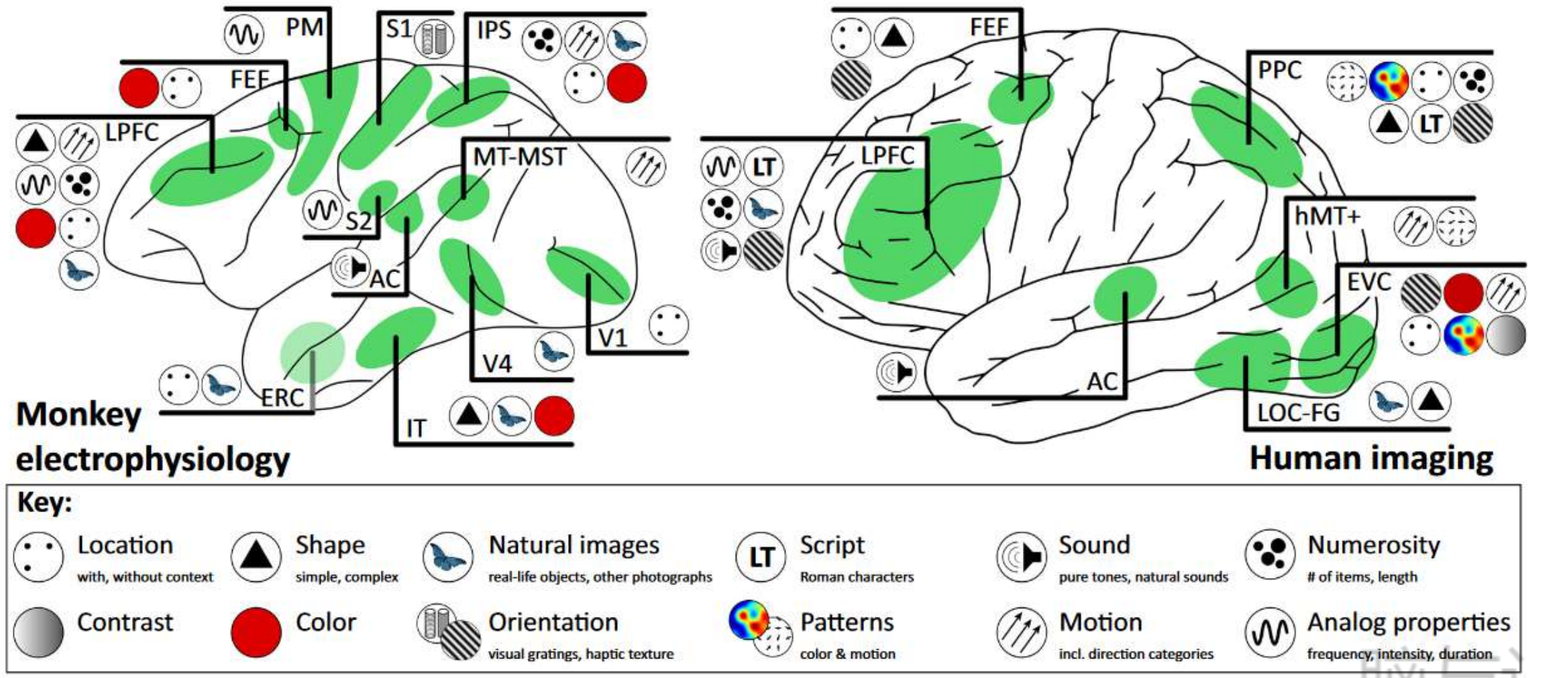
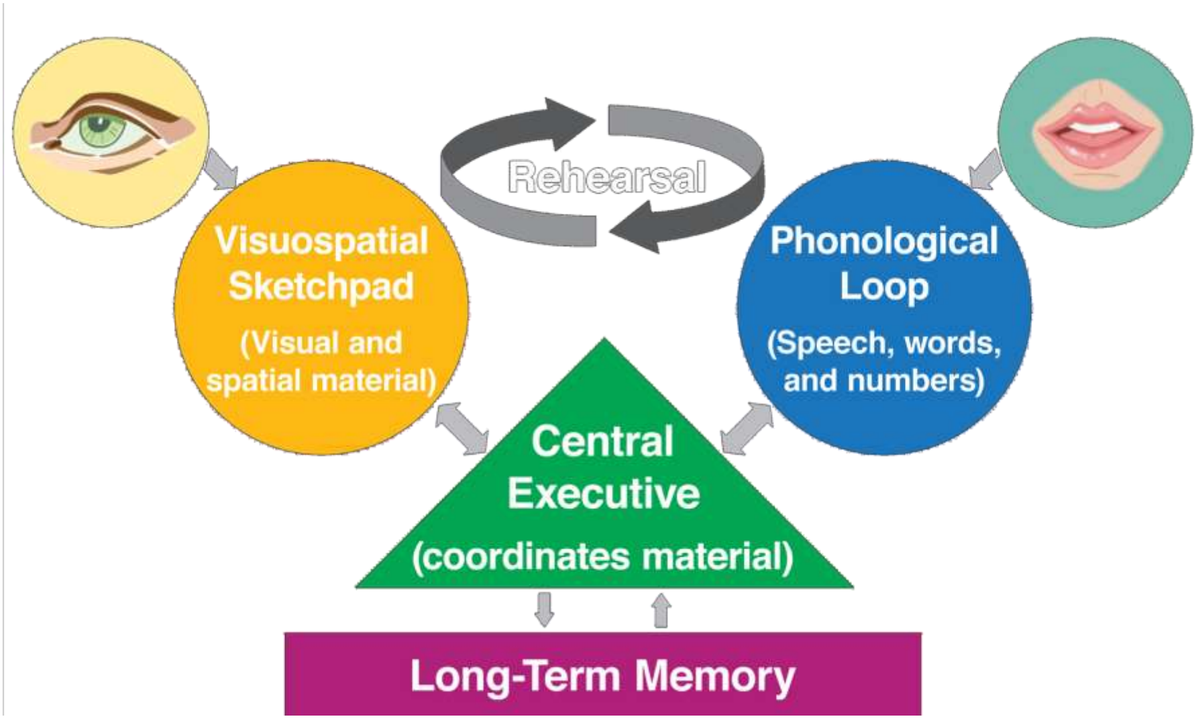
记忆的神经基础

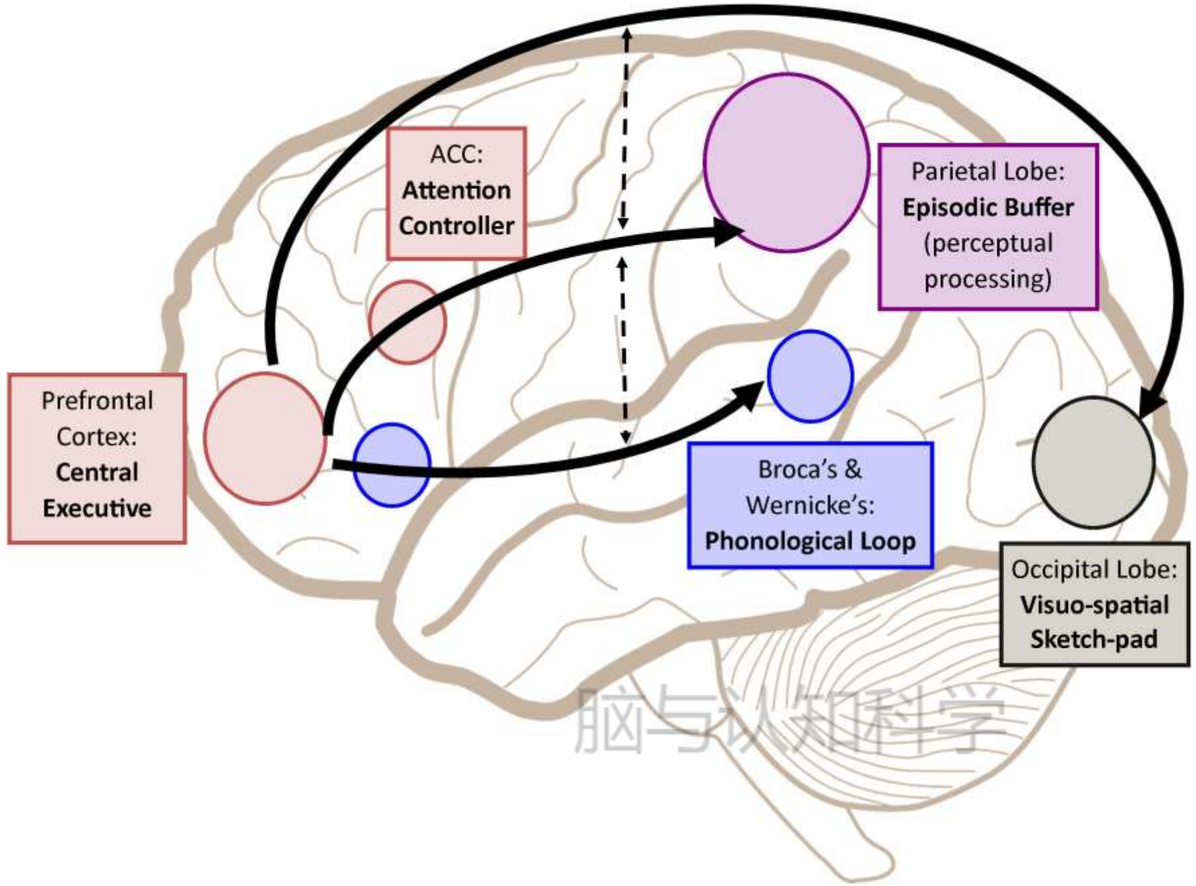
- 不同类型的工作记忆由大脑不同的区域进行表征，形成了工作记忆的分布式表征。
- 记忆不是大脑某个区域的一种专门的能力或“机构”，而是大脑整体的一种特征。



Neural basis for working memory

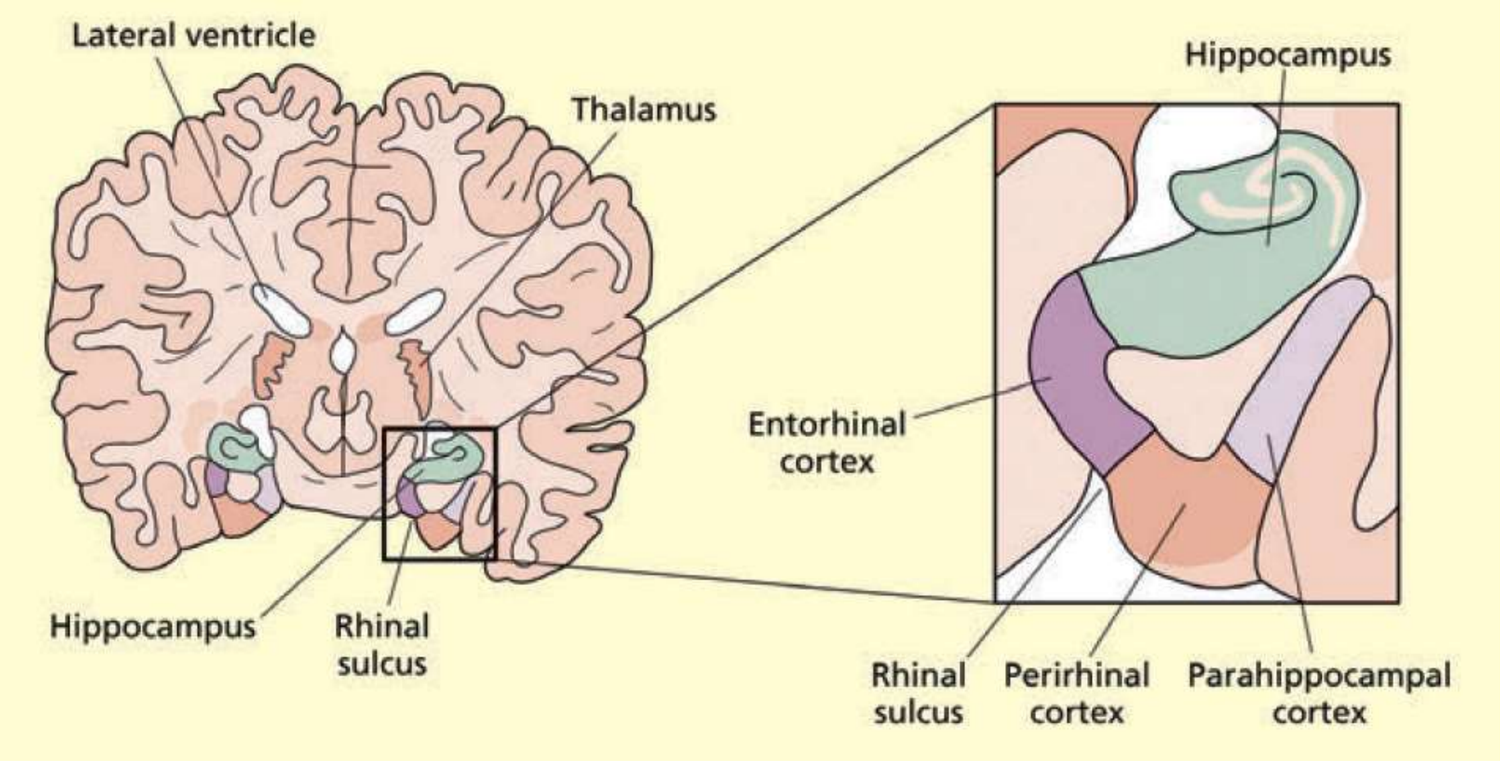
Working memory activates the fronto-parietal brain regions, including the prefrontal, cingulate, and parietal cortices. The prefrontal cortex is responsible for activating, retrieving and maintaining in formation held in the posterior cortex.





Long-term memory in the brain

Episodic and semantic memories are grouped under the umbrella of declarative memory and are assumed to depend (initially) on the medial temporal lobe and (subsequently) on the neocortex.

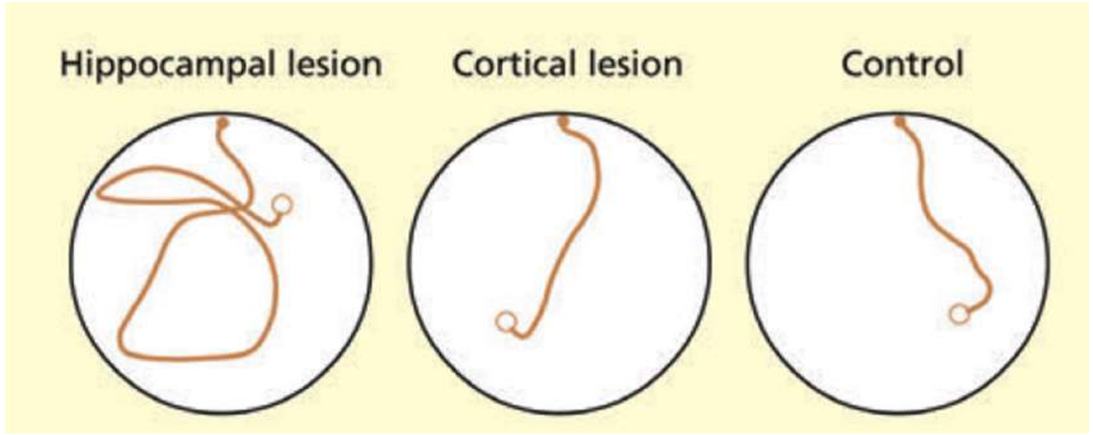


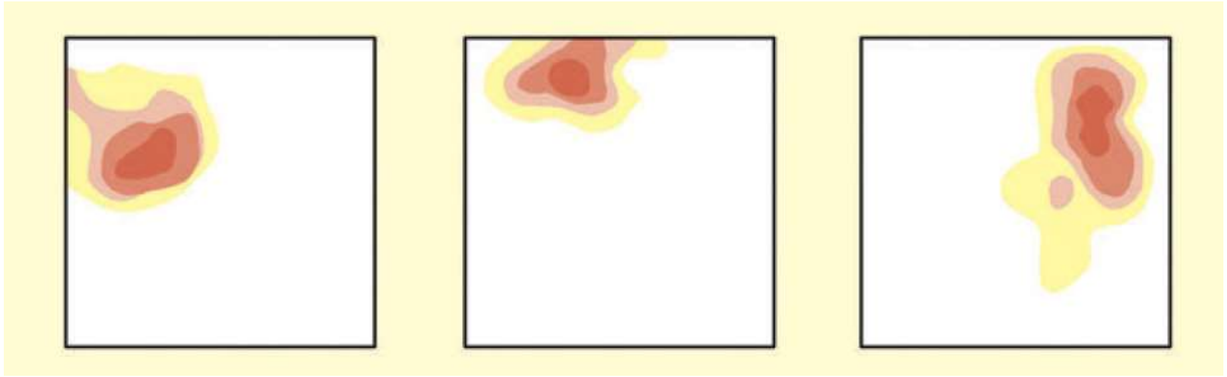
- Grid cells in the entorhinal cortex respond when an animal is in particular locations in an environment such that the responsive locations form a repeating grid-like pattern.
- The parahippocampal complex, by contrast, contains visual representations of scenes and landmarks.
- The perirhinal cortex is linked to memory and perception of complex objects
- The hippocampus is associated with declarative and episodic memory as well as recognition memory
- The temporal cortex appears to be involved in remembering semantic tasks

Cognitive map theory

The hippocampus contains a spatial map of the environment. The hippocampal-lesioned rats find the platform by trial and error.

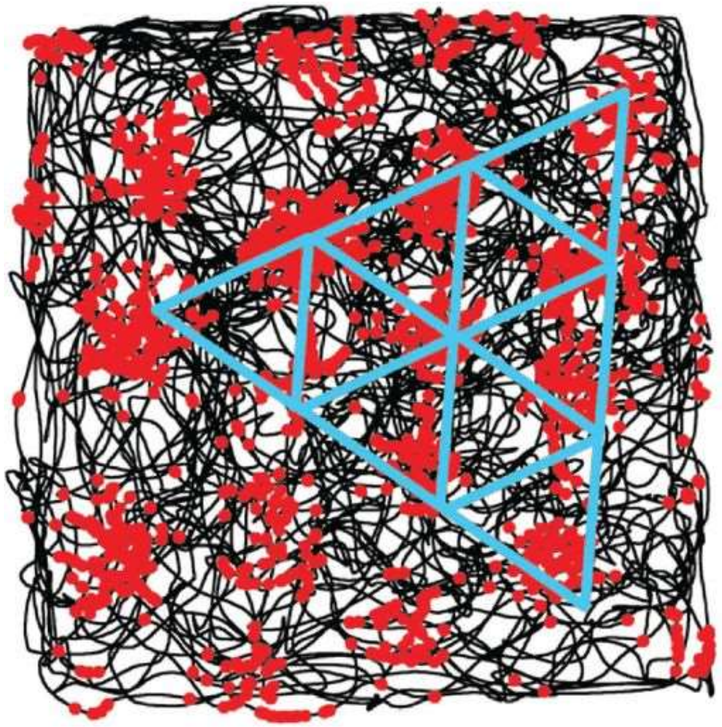
A given neuron(place cell) only responded strongly when the rat was at a particular location.

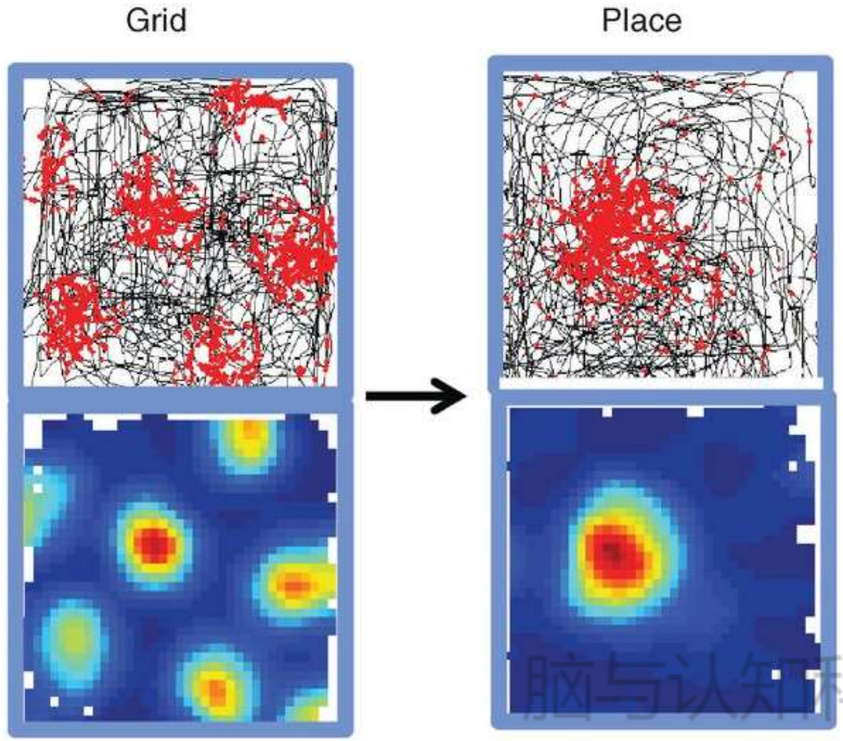




Grid cells

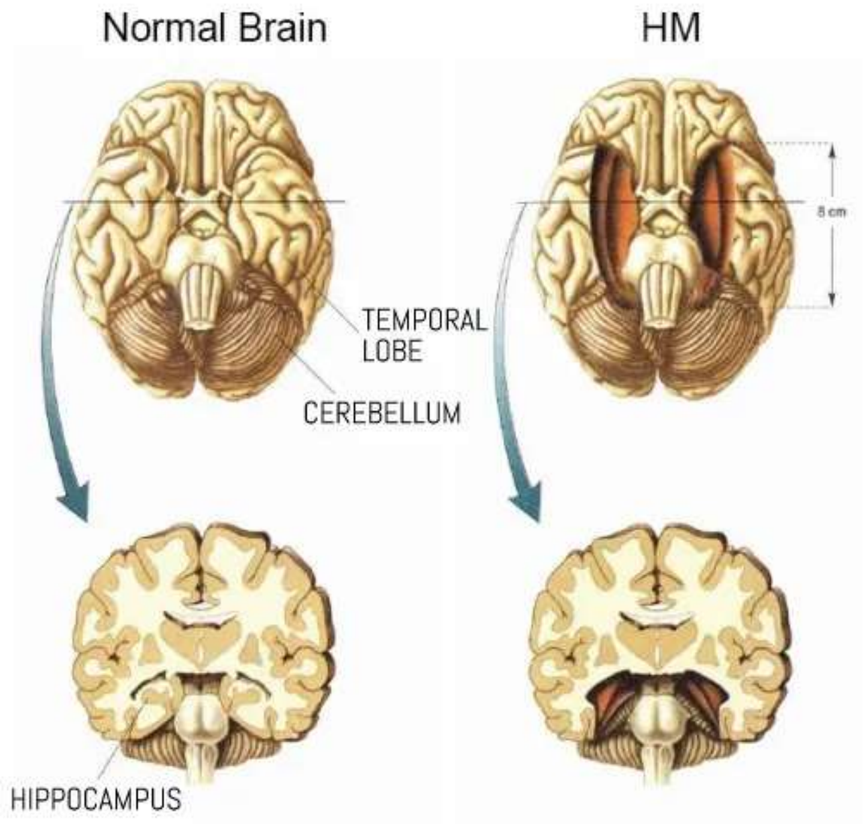
The grid cells in entorhinal cortex fire when the animal is in certain locations within **a particular environment**, but rather than responding to a single location. They respond to multiple locations within a repeating, triangular grid-like structure.



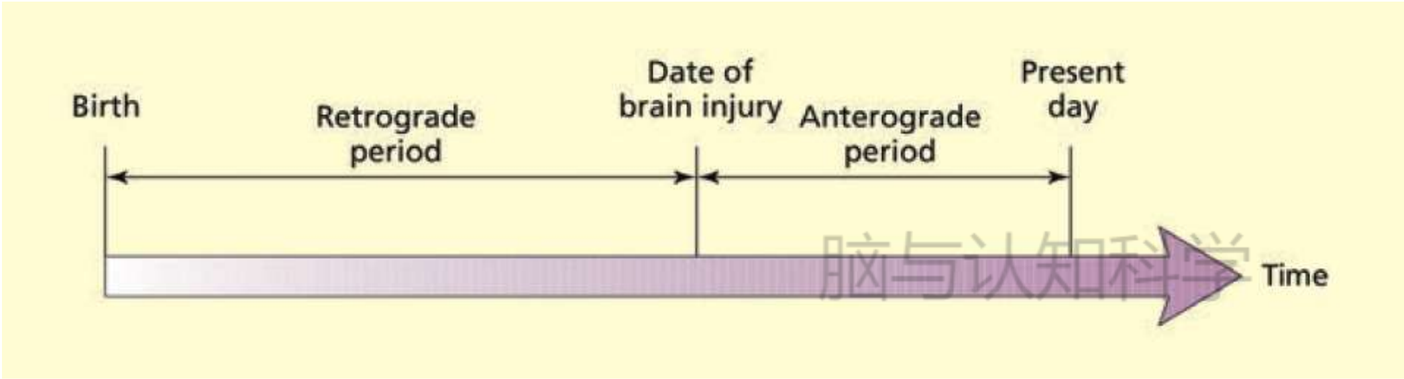


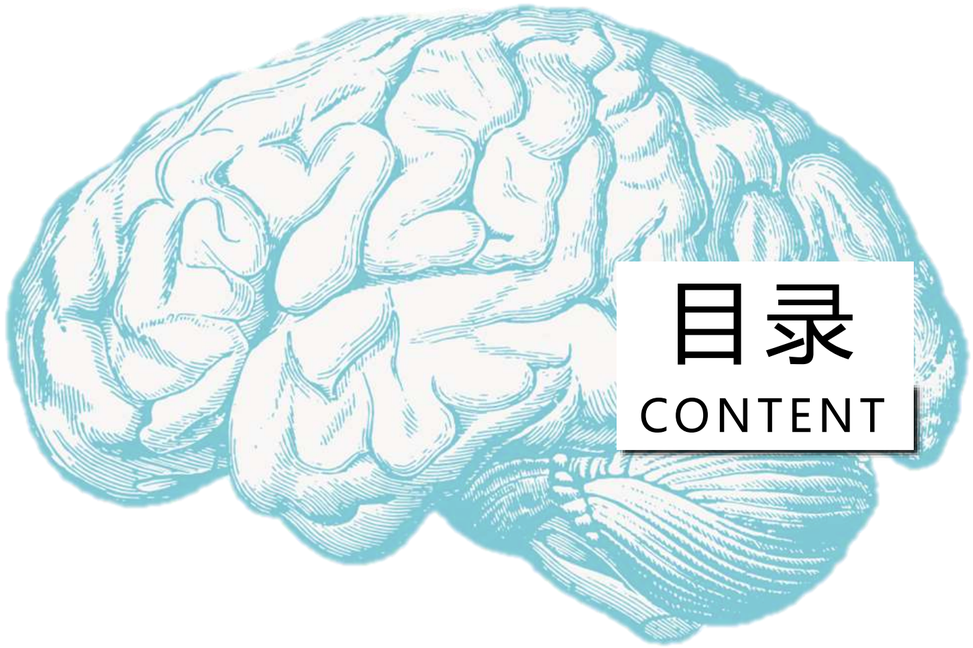
Memory in Amnesia

Henry Molaison (H.M.)



- Amnesic patients are impaired on tests of episodic memory both for events related to their own lives (autobiographical memory) and other types of episode (e.g. learning lists of words).
- Amnesic shows both anterograde and retrograde episodic memory impairment.
- Semantic memory is less vulnerable, because it can be learned through repetition and multiple events.
- STM, procedural and perceptual memory appears to be spared





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Learning

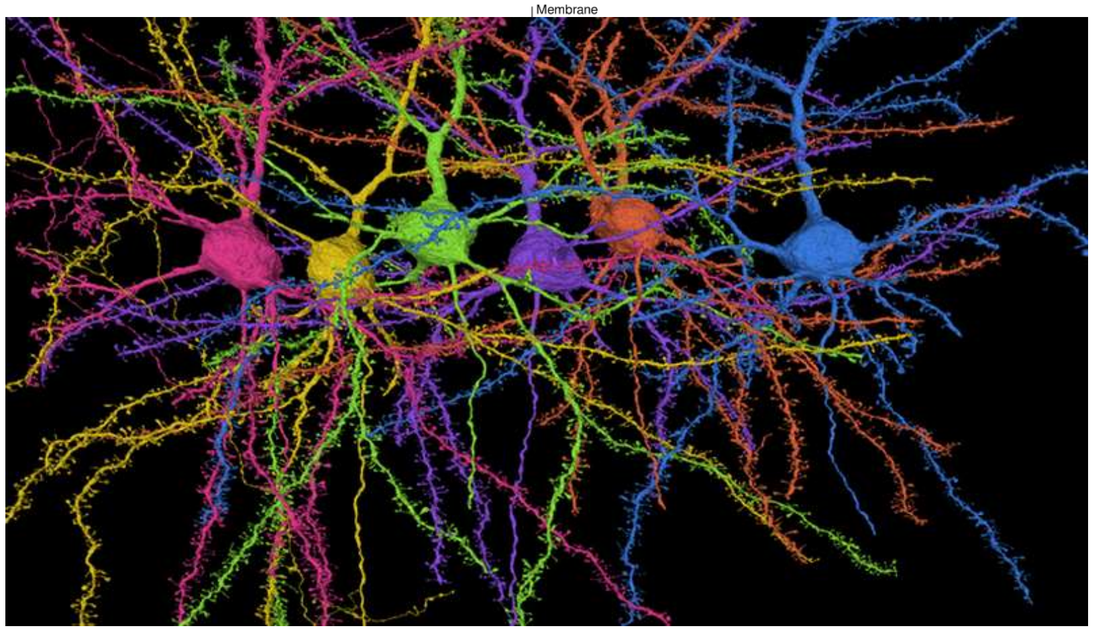
- Learning is the process by which moment-to-moment changes in brain activity are translated into permanent structural changes in the brain (e.g. by forming new neural connections).

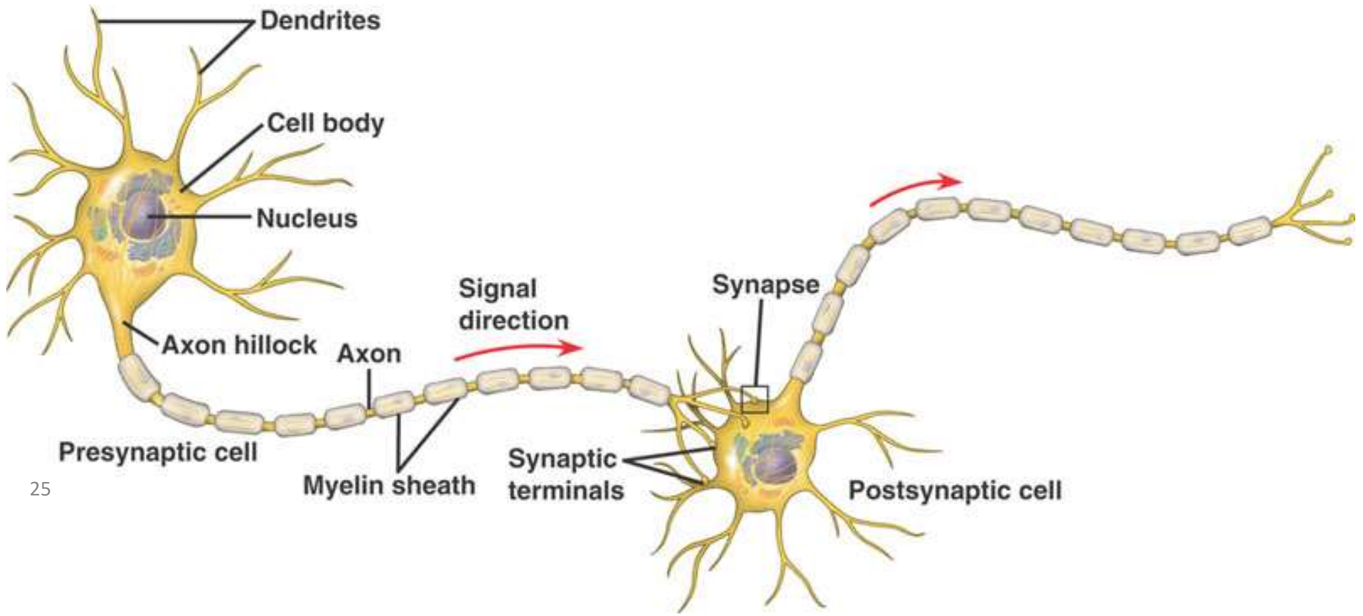
- The initial formation of memories involves an increase in the probability that a postsynaptic neuron will fire in response to neurotransmitters released from presynaptic neurons.

- The synaptic learning turns out to be a universal property of the nervous system.
  - A fast synaptic consolidation that may occur anywhere in the nervous system;
  - A slower system consolidation that may be related particularly to the hippocampus and declarative memory.

Activity-dependent synaptic plasticity

Learning and memory require the formation of new neural networks in the brain. A key mechanism underlying this process is synaptic plasticity at excitatory synapses, which connect neurons into networks.



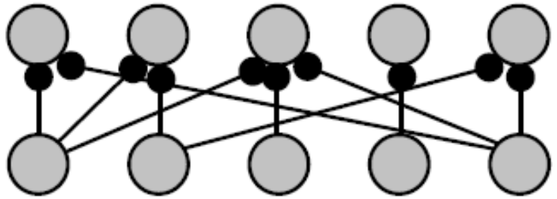


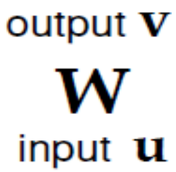
- **Short-term memory** is stored as the neural activity, whereas **long-term memory** is stored in the connection between neurons.
- Activity-dependent synaptic plasticity is believed to be the basic phenomenon underlying learning and memory, and it is also thought to play a crucial role in the development of neural circuits.

Short-term memory is stored as the neural activity

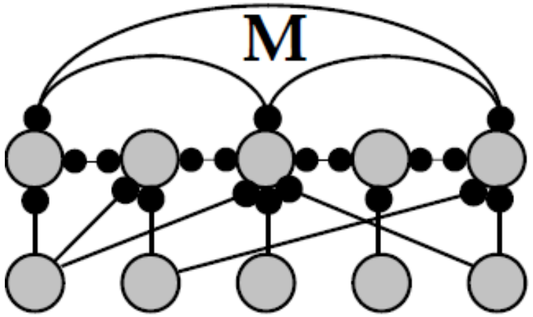
F**eed-forward networks** only feed information forward. **Recurrent networks** maintain a memory of previous inputs by using their internal state (memory) to process sequences of inputs.

Feedforward network





Recurrent network



$\boldsymbol{\mu}$ and $\boldsymbol{v}$ are presynaptic and postsynaptic firing rate. W is synaptic weights.

The output layer are only driven by input layers with synaptic weights **W**

$$\tau_r \frac{d\mathbf{v}}{dt} = -\mathbf{v} + \mathrm{F}(\mathbf{W} \cdot \mathbf{u})$$

$$\tau_r \frac{dv_a}{dt} = -\mathbf{v} + F\left(\sum_{b=1}^{N_u} W_{ab} u_b\right).$$

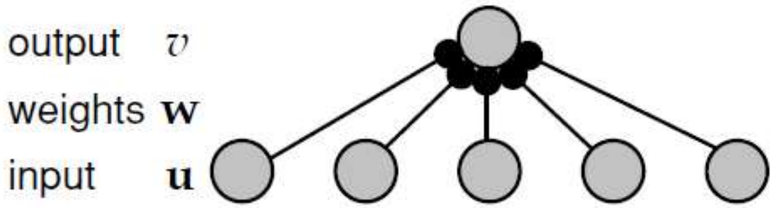
The output layer are **additional** driven by itself with synaptic weights **M**

$$\tau_r \frac{d\mathbf{v}}{dt} = -\mathbf{v} + \mathrm{F}(\mathbf{W} \cdot \mathbf{u} + \mathbf{M} \cdot \mathbf{v}).$$

$$\tau_r \frac{d\mathbf{v}}{dt} = -\mathbf{v} + \mathrm{F}(\mathbf{h} + \mathbf{M} \cdot \mathbf{v}).$$

Synaptic plasticity rules for long-term memory

Activity-dependent synaptic plasticity is widely believed to be the basic phenomenon underlying learning and memory, and it is also thought to play a crucial role in the development of neural circuits.



$$\tau_r \frac{dv}{dt} = -v + \mathbf{w} \cdot \mathbf{u} = -v + \sum_{b=1}^{N_u} w_b u_b \,,$$

$$v = \mathbf{w} \cdot \mathbf{u} \,,$$

$\boldsymbol{u}$ and v represent the firing rates of the pre- and postsynaptic neurons

- In firing-rate neural networks, synaptic strengths are characterized by synaptic weights.
- w_b is the synaptic weight that describes the **strength of the synapse** from presynaptic neuron b to the postsynaptic neuron, and **w** is the vector formed by all N_u synaptic weights.
- Activity-dependent synaptic plasticity rules describe the rate of change of synaptic weights **W** as a **function of the pre- and postsynaptic activity**.

The Hebb rule

If input from neuron A often contributes to the firing of neuron B, then the synapse from A to B should be strengthened. That is, neurons that **fire together, wire together**.

Basic Hebb rule $\tau_w \frac{d\mathbf{w}}{dt} = v\mathbf{u}$,

τ_w is a time constant that controls the rate at which the weights change.

As long as the synaptic weights change slowly enough, the **averaging** method provides a good approximation of the weight changes produced by **the set of input patterns**.

Averaged Hebb rule $\tau_w \frac{d\mathbf{w}}{dt} = \langle v\mathbf{u} \rangle$. $v = \mathbf{w} \cdot \mathbf{u}$,

Correlation-based rule $\tau_w \frac{d\mathbf{w}}{dt} = \mathbf{Q} \cdot \mathbf{w}$ $\mathbf{Q} = \langle \mathbf{uu} \rangle$ or $Q_{bb'} = \langle u_b u_{b'} \rangle$.

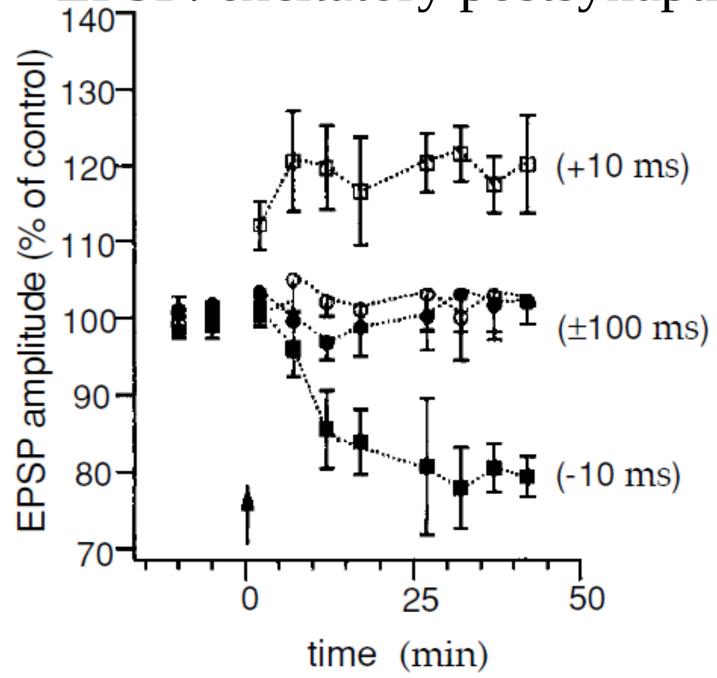
Discrete updating rule $\mathbf{w} \rightarrow \mathbf{w} + \epsilon \mathbf{Q} \cdot \mathbf{w}$

As $\tau_w d|\mathbf{w}|^2/dt = 2v^2$, Hebb rules are unstable and non-competitive.

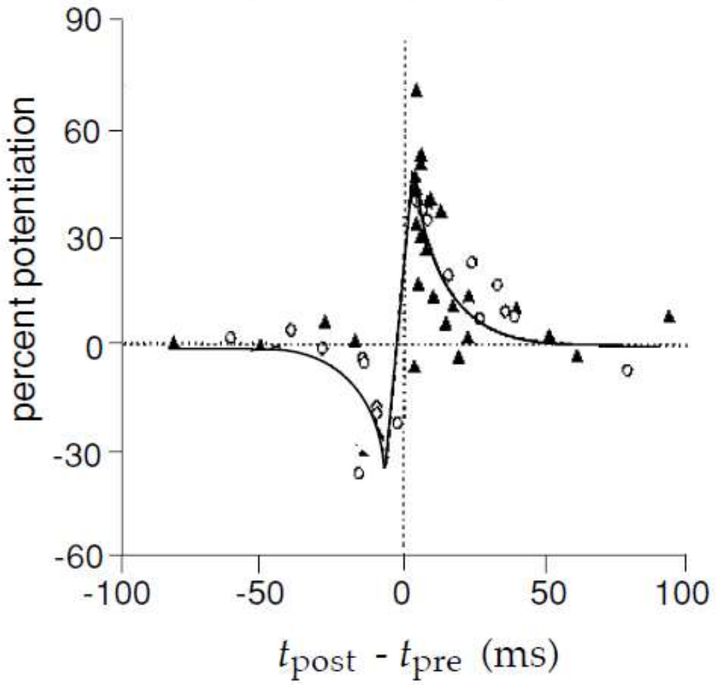
Timing-based rules

The **relative timing** of pre- and postsynaptic action potentials plays a critical role in determining the sign and amplitude of the changes in synaptic efficacy.

A EPSP: excitatory postsynaptic potential



B The changes in synaptic efficacy



Synaptic plasticity **occurs only if** the difference in the pre- and postsynaptic spike times falls within a window of roughly ±50 ms. Presynaptic spikes that precede postsynaptic action potentials produce LTP. Otherwise, LTD.

Timing-based rules

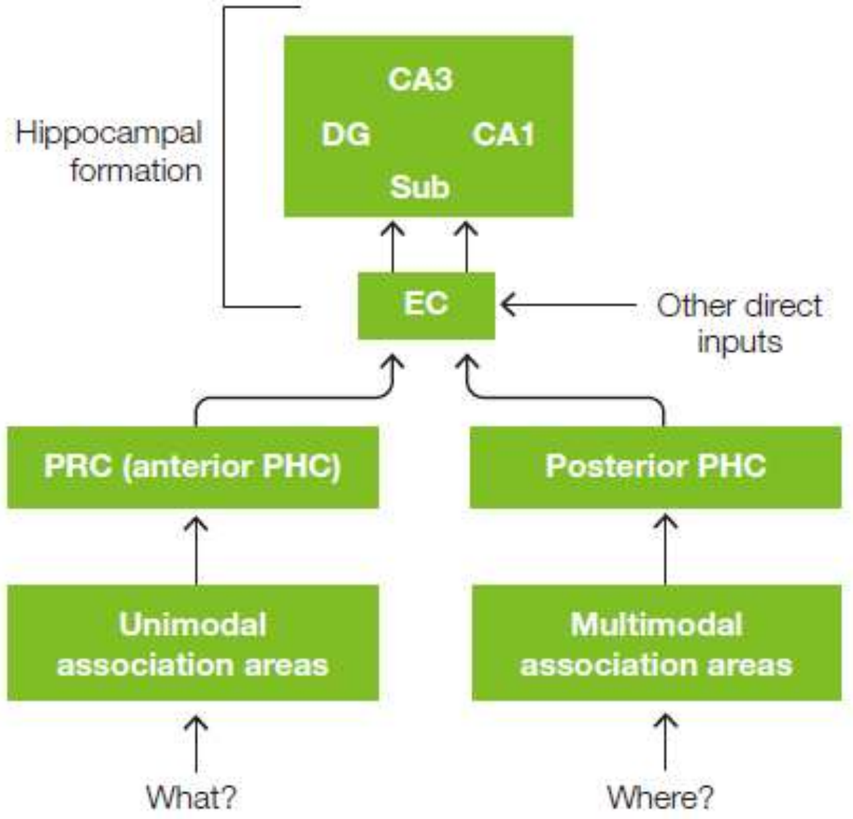
Simulating the spike-timing dependence of synaptic plasticity requires a spiking model. However, an approximate model can be constructed on the basis of firing rates.

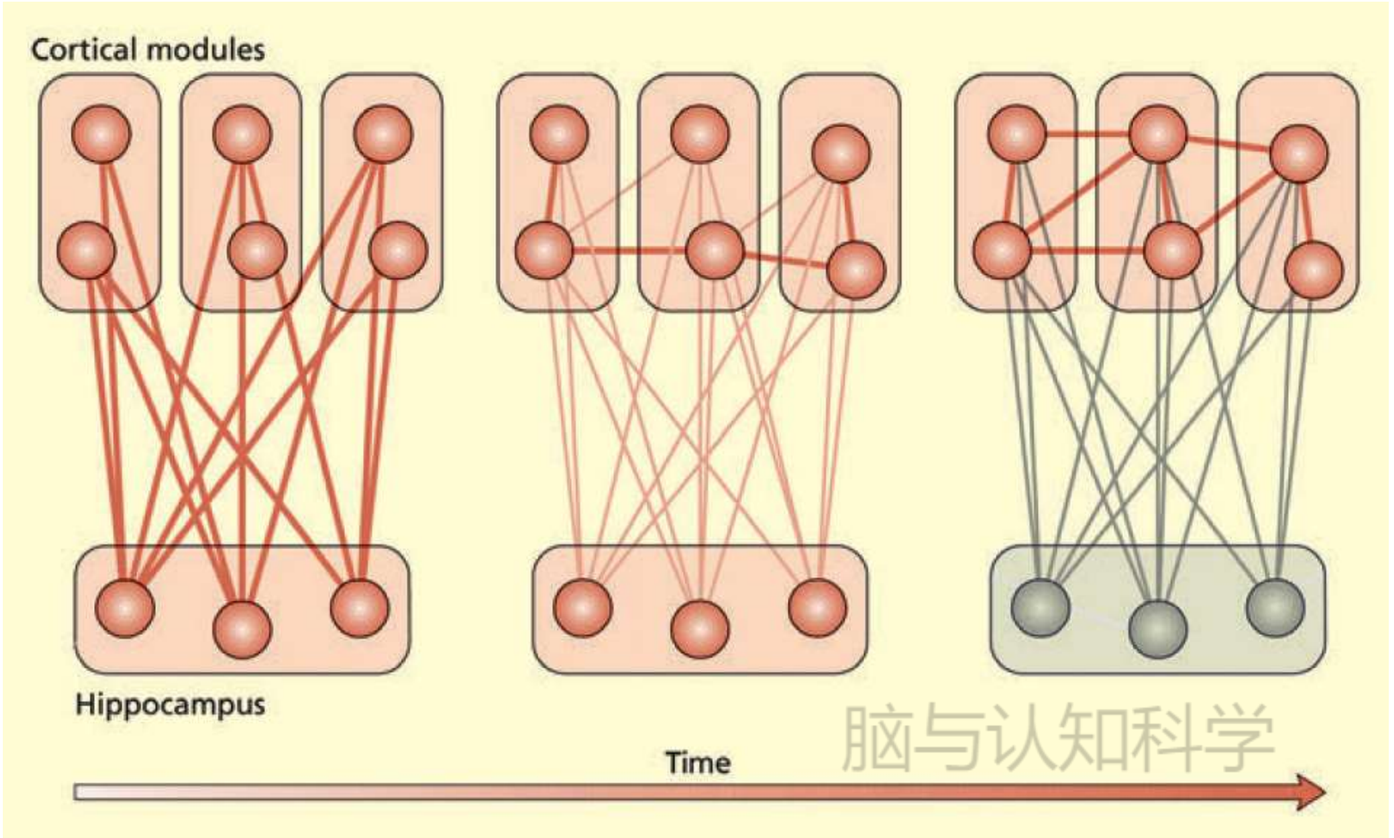
$$\tau_w \frac{d\mathbf{w}}{dt} = \int_0^\infty d\tau \; (H(\tau)v(t)\mathbf{u}(t-\tau) + H(-\tau)v(t-\tau)\mathbf{u}(t)) \; .$$

- A function H(τ) determines the rate of synaptic modification that occurs due to postsynaptic activity separated in time from presynaptic activity by an interval.
- If H(τ) is positive for positive τ and negative for negative τ, the first term on the right side of this equation represents LTP, and the second, LTD.
- The total rate of synaptic modification is determined by **integrating** over all time differences τ.
- The rule still require **saturation constraints** for stability. But, in spiking models, they can generate competition between synapses without further constraints or modifications.

Transformation between distinct type of memory

The hippocampus initially acts to bind together different aspects of memory represented in disparate regions of the brain. Over time, these different aspects of the memory trace may be linked as part of a cortico-cortical network that is largely independent of the hippocampus.





本章关键知识点

1. Memories can be short-term or long-term. Long-term memories may be declarative, consisting of either the conscious memory for facts (semantic memory) or the conscious memory of past experiences (episodic memory). Long-term memories may also be nondeclarative memories for how to do things, such as brushing your teeth or skating on ice.
2. Different types of information may be retained in partially or wholly distinct memory systems.
3. The medial temporal lobe memory system is made up of the hippocampus and the surrounding entorhinal cortex, perirhinal cortex, and parahippocampal cortex within the temporal lobes.
4. Learning and memory have three major stages: encoding (acquisition and consolidation), storage, and retrieval.
5. Learning is the process of acquiring new information, the outcome of which is memory.

思考题

1. Is STM needed for long-term learning?

2. What types of memory are typically impaired in amnesia?

3. Are semantic and episodic memory separate memory systems?

4. Contrast the role of the hippocampus in memory with that of other structures in the medial temporal lobes.

5. Does the hippocampus have a time-limited role in memory consolidation?

6. What is the role of the frontal lobes in memory?

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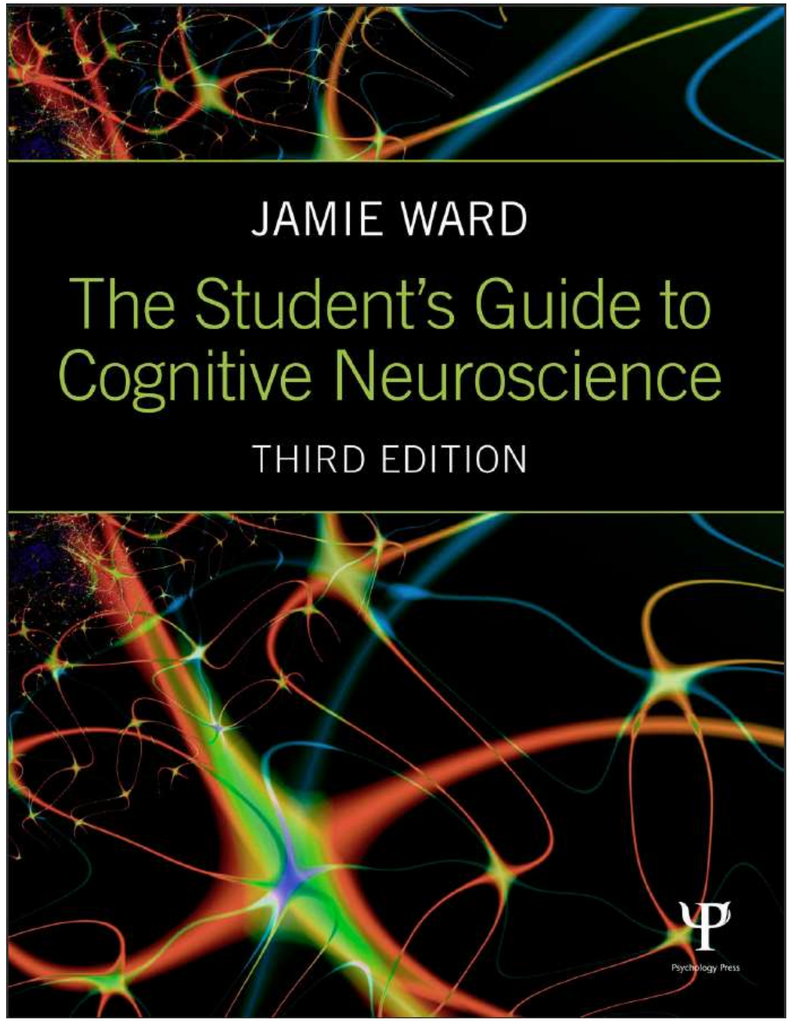
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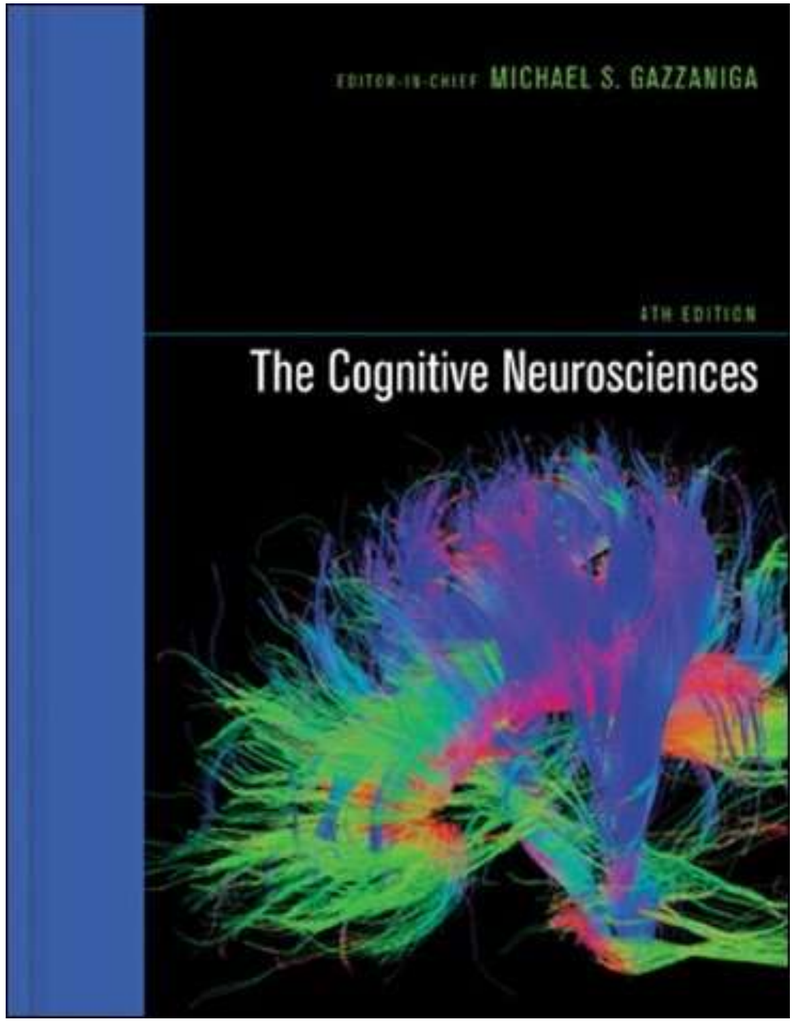
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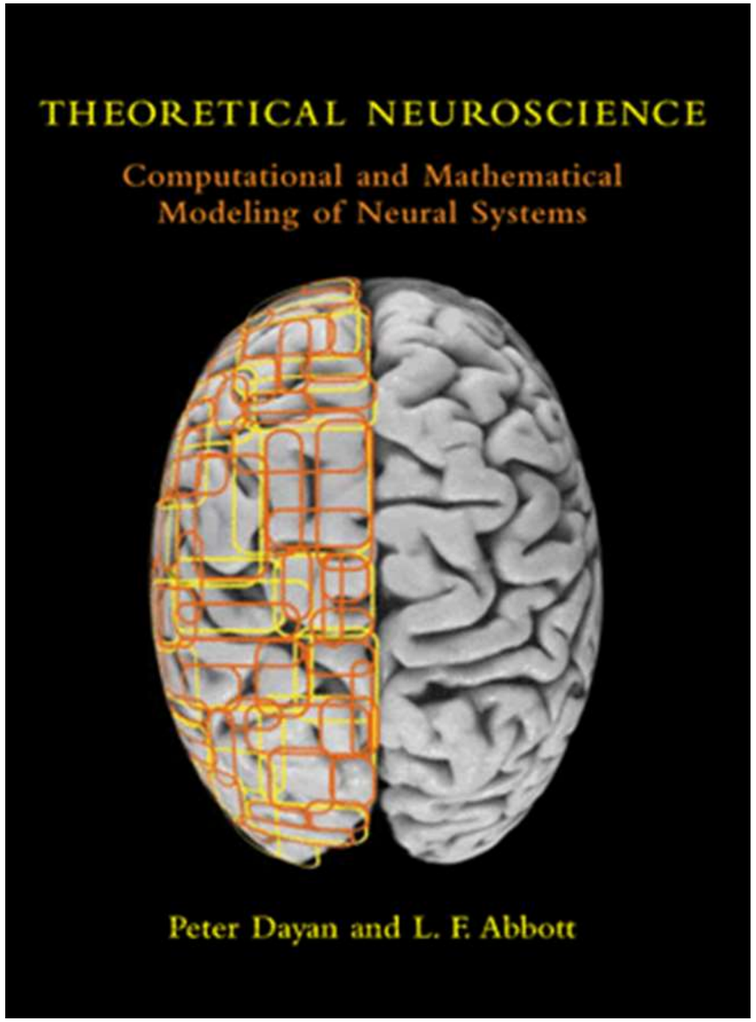
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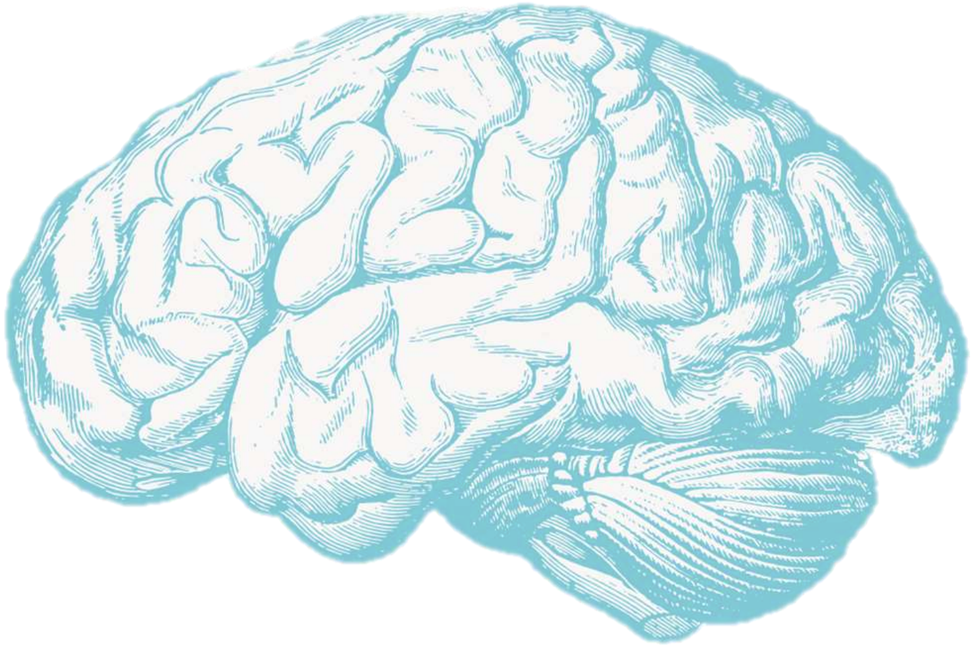

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