# *COMS30127/COMSM2127*
# *Computational Neuroscience*

## Lecture 8: The Hippocampus (e)

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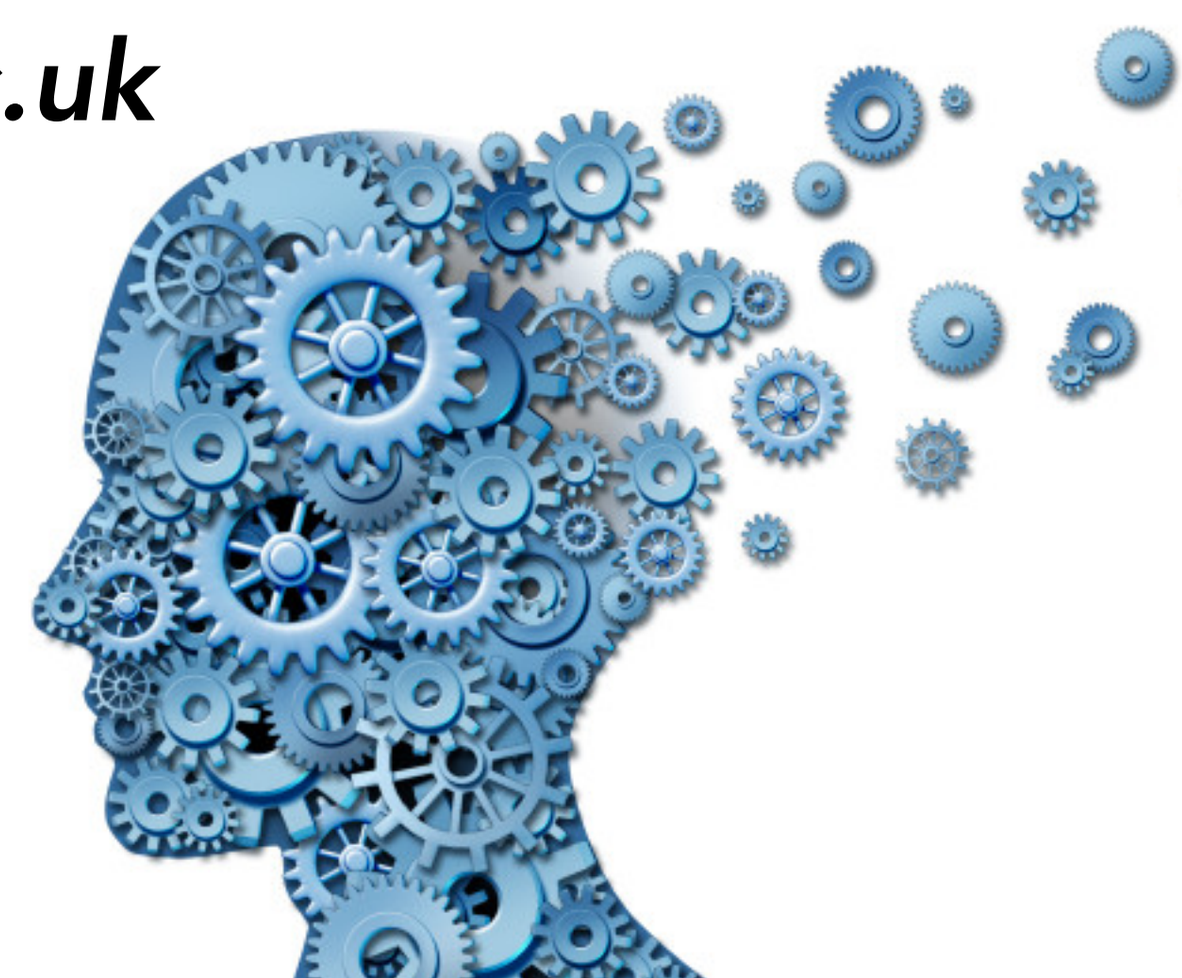
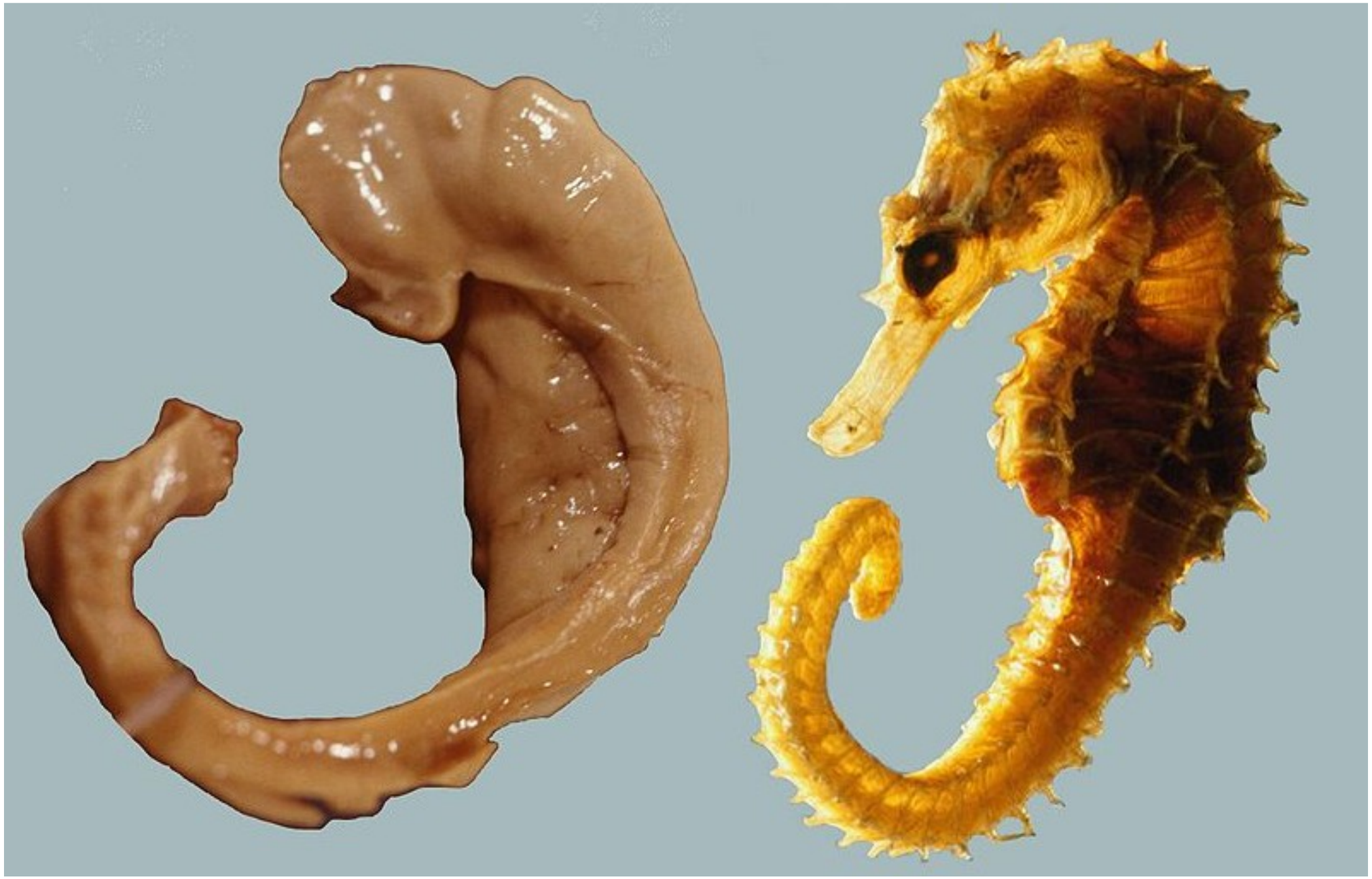


# What we will cover today and next Tuesday

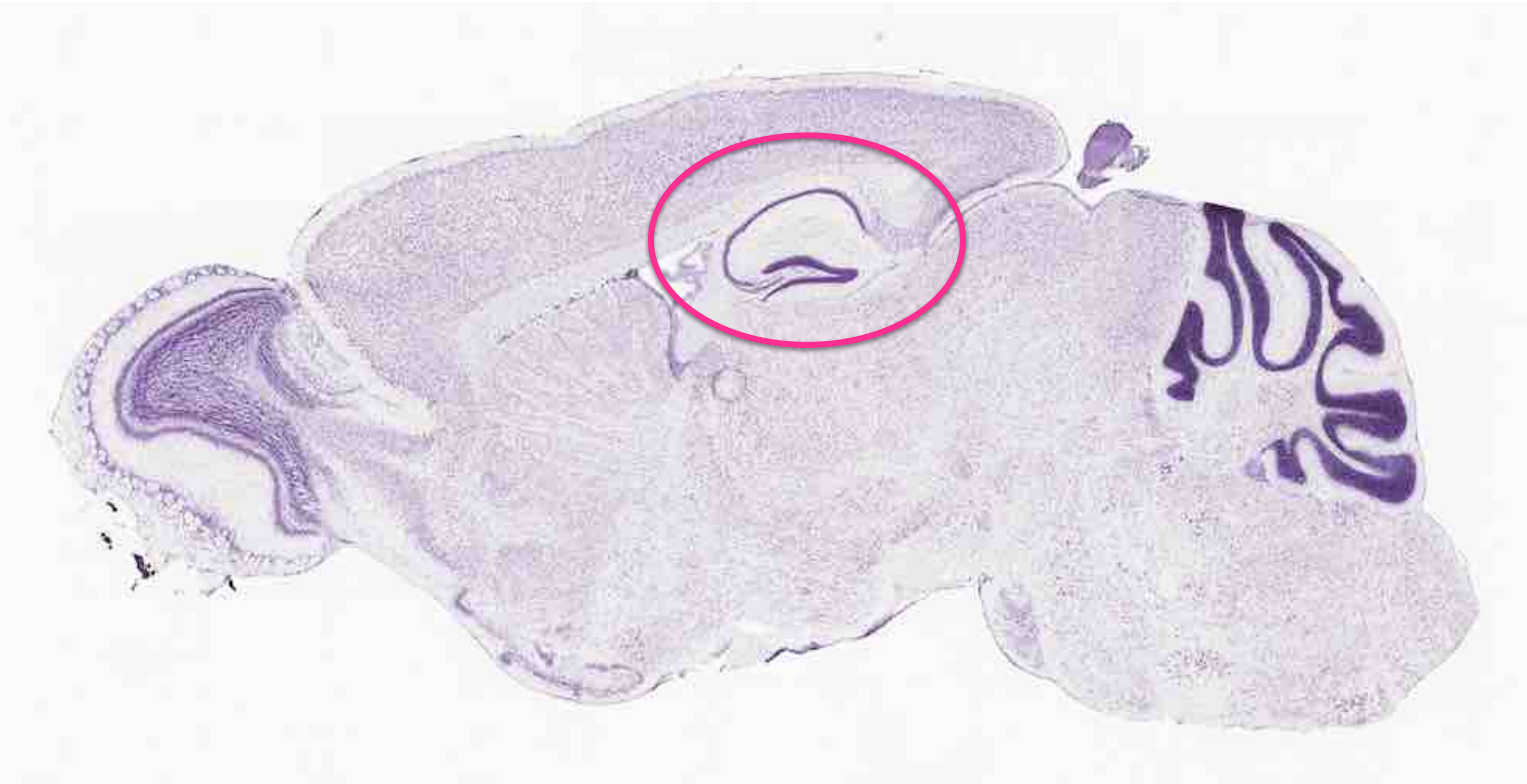
- Anatomy of the hippocampus.
- What does the hippocampus do?
  - Long-term memory
  - Spatial navigation
- What computations does the hippocampus do?
  - Pattern separation vs pattern completion
  - Path integration.
- Computational models of memory encoding and recall in the hippocampal circuit.
- Computational models of spatial navigation in the hippocampal circuit.

Hippocampus, from the greek words for “horse" and “sea-monster”



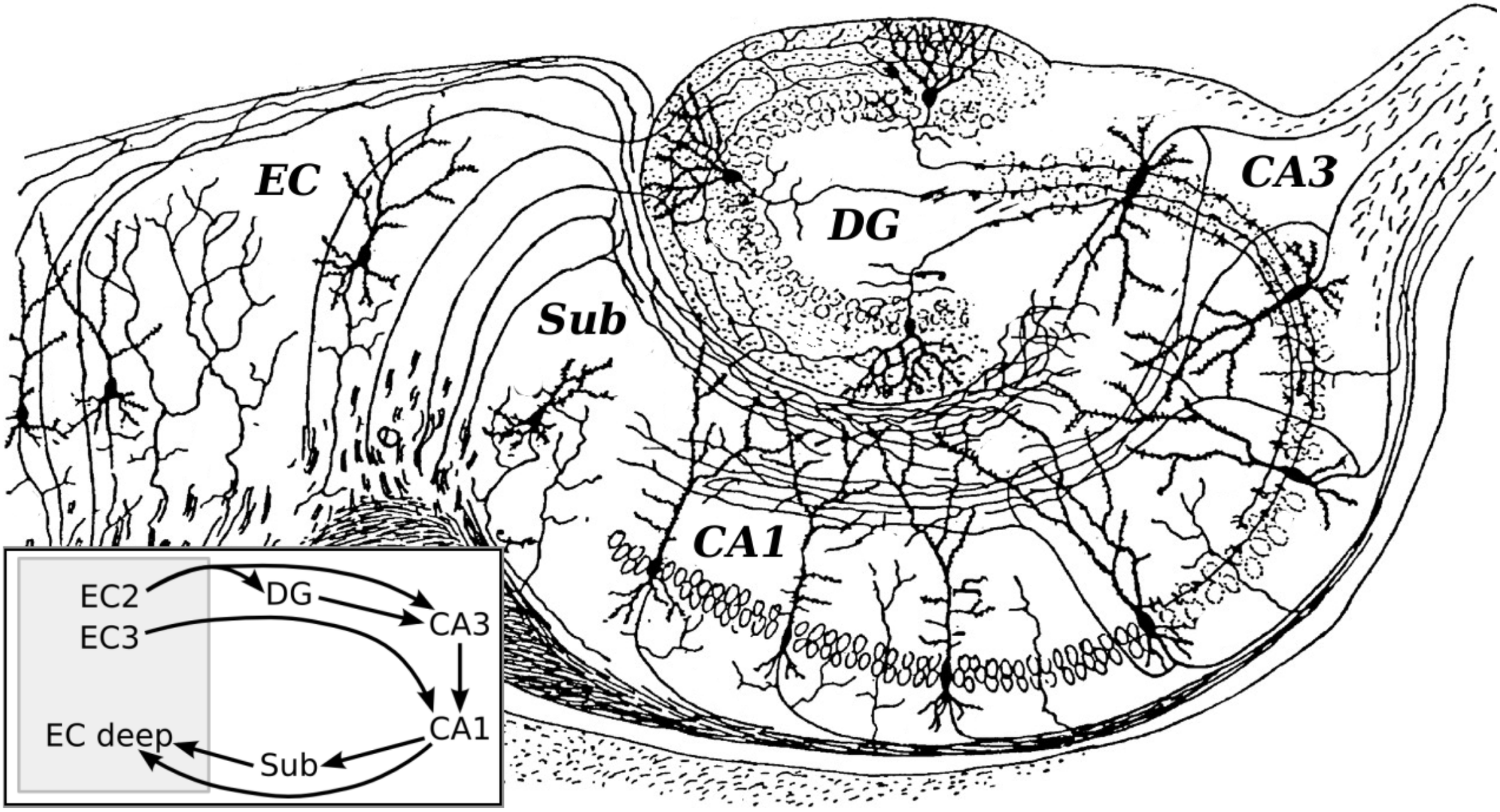
https://en.wikipedia.org/wiki/Hippocampus#/media/File:Hippocampus_and_seahorse_cropped.JPG

# Anatomy of the hippocampus



https://mouse.brain-map.org

# Anatomy of the hippocampus




Original drawing by Ramon y Cajal (circa 1900)

https://en.wikipedia.org/wiki/Hippocampus#/media/File:CajalHippocampus_(modified).png

# The tri-synaptic loop

- Information flows in a mostly feed-forward way through the hippocampus.
- Entorhinal cortex is sometimes described as “the gateway to the hippocampus” (most external singals to the hippocampus are routed via the EC).
- Inside the hippocampus, information propagates along the “trisynaptic loop”:
  - dentate gyrus → CA3
  - CA3 → CA1
  - CA1 → subiculum
- CA3 is the only subregion with substantial recurrent excitatory connectivity (may be mediating attractor networks).

# What does the hippocampus do?

There are two main theories:

1. Long-term memory

2. Spatial navigation

# 1. Hippocampus and memory

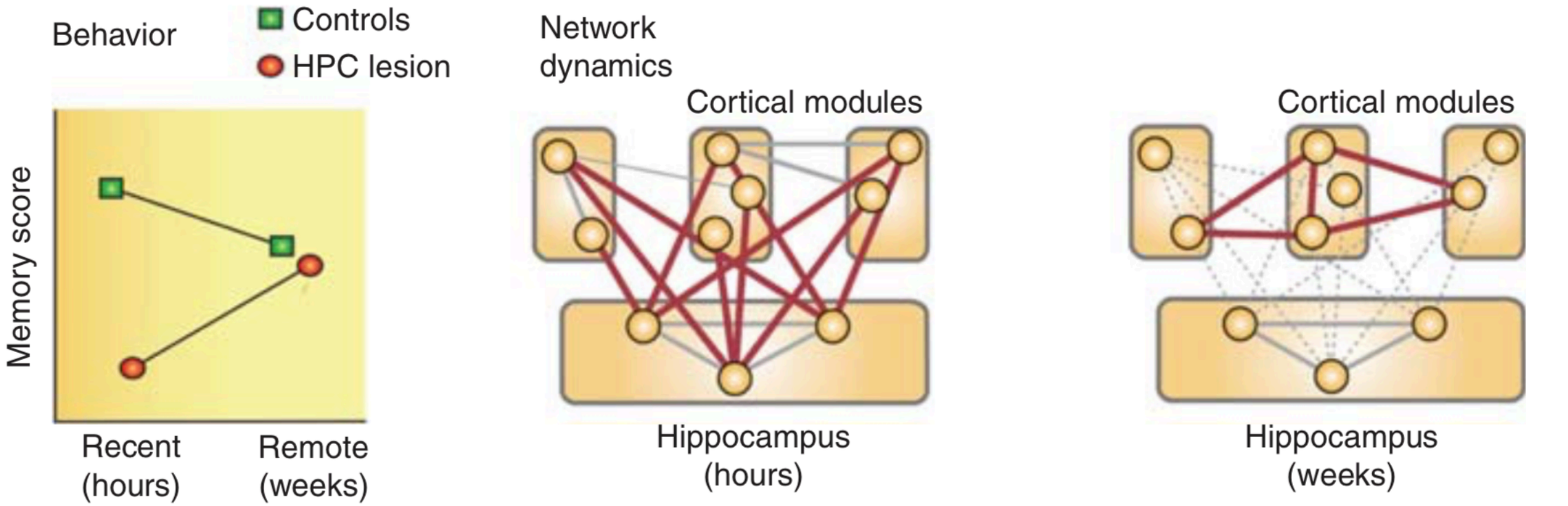
# Hippocampus and memory

- Patient HM (who had his hippocampus surgically removed) could not form new long-term memories, and also had time-limited retrograde amnesia.

- The hippocampus is specifically needed for encoding new episodic memories, but is not necessary for other memories (e.g. procedural).

- Memory encoding requires synaptic plasticity in the hippocampus.

# Systems consolidation for memory




Squire et al. Cold Spring Harb Perspect Biol 7, a021766.

- New episodic memories are mainly encoded in hippocampus during the day.
- During subsequent sleep, hippocampus replays the neural activity encoding the memory and triggers learning in the cortex.
- Over time, cortex learns the memories, and they become hippocampus-independent.

# Hippocampus is needed for forming episodic memories

## Long-term memory types

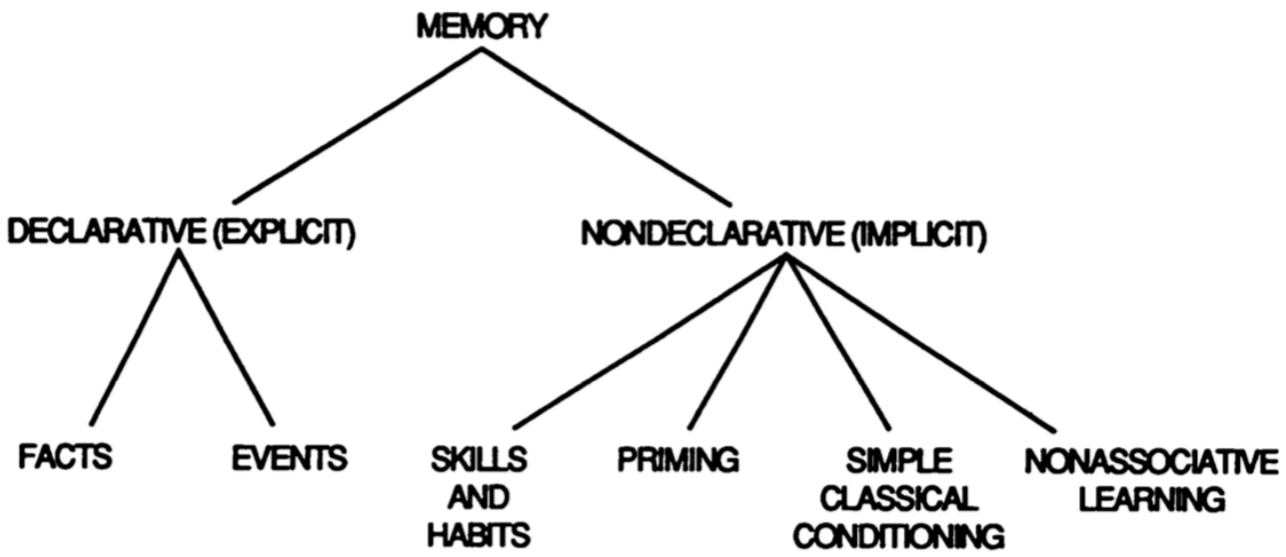
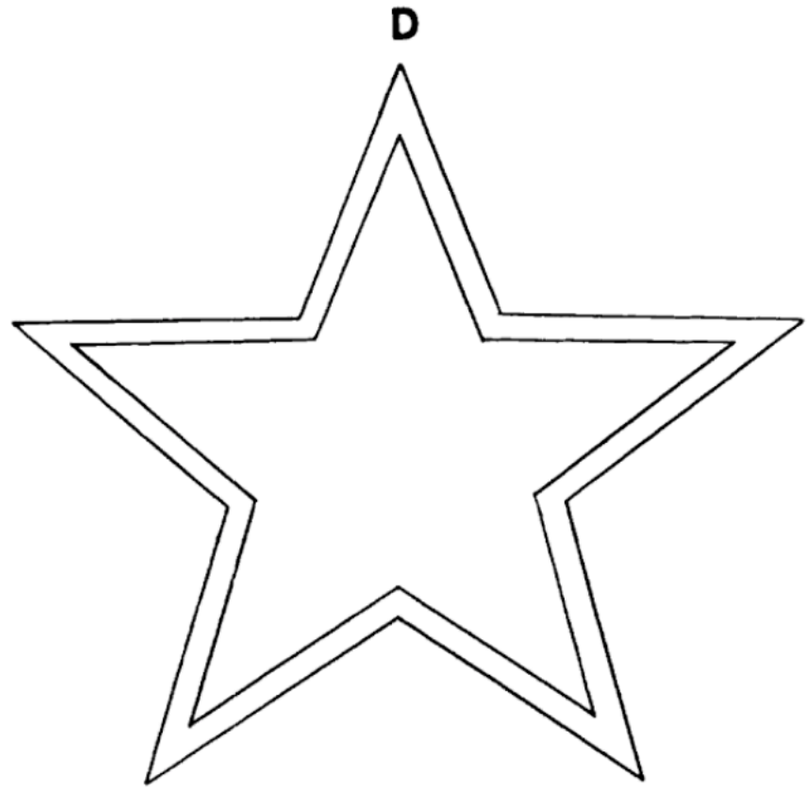



**Fig. 3.** Classification of memory. Declarative (explicit) memory refers to conscious recollections of facts and events and depends on the integrity of the medial temporal lobe (see text). Nondeclarative (implicit) memory refers to a collection of abilities and is independent of the medial temporal lobe (*60*). Nonassociative learning includes habituation and sensitization. In the case of nondeclarative memory, experience alters behavior nonconsciously without providing access to any memory content (*19, 20*).

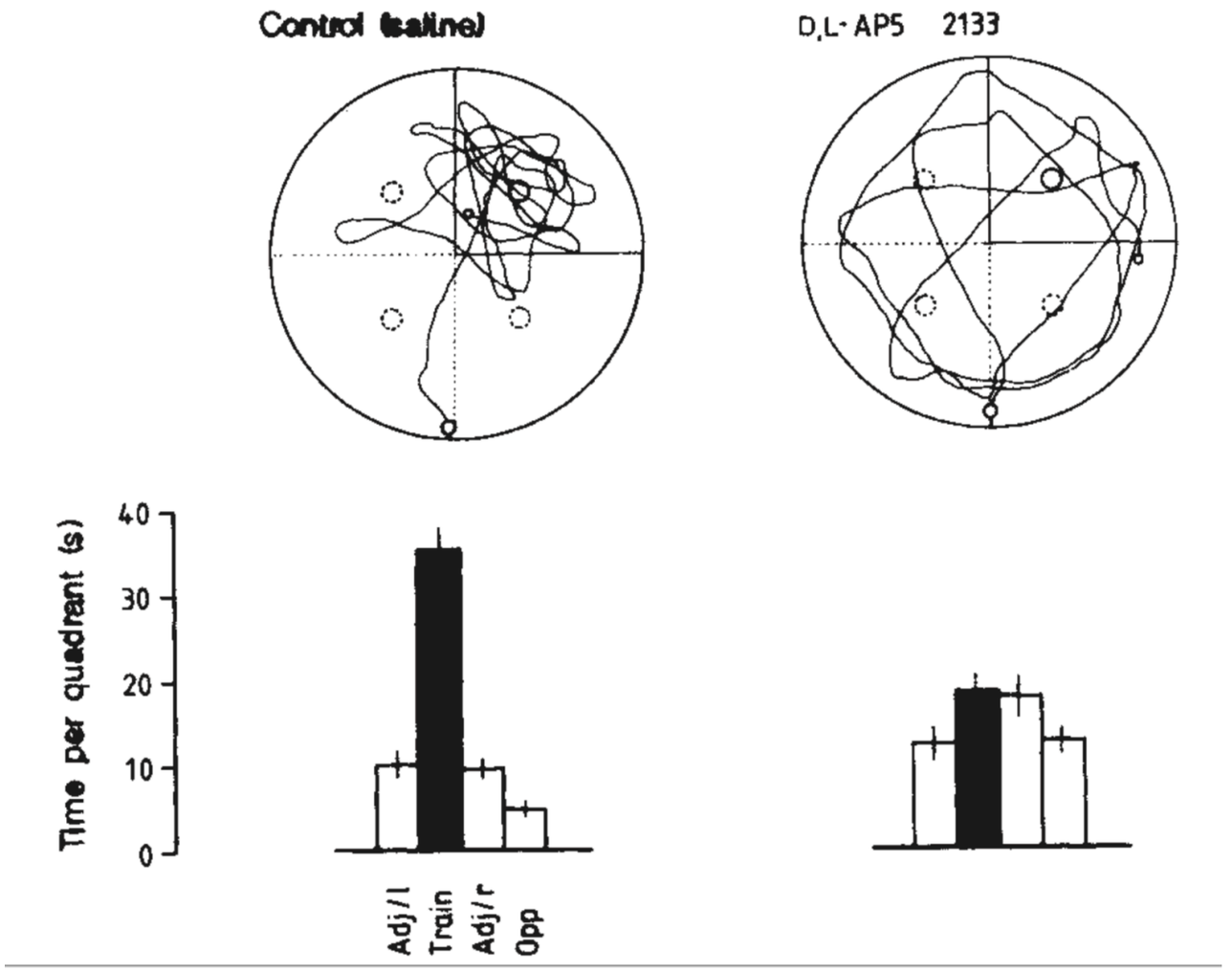
Squire & Zola-Morgan, *Science* 1991

## H.M. could form new motor memories




Milner (1962)

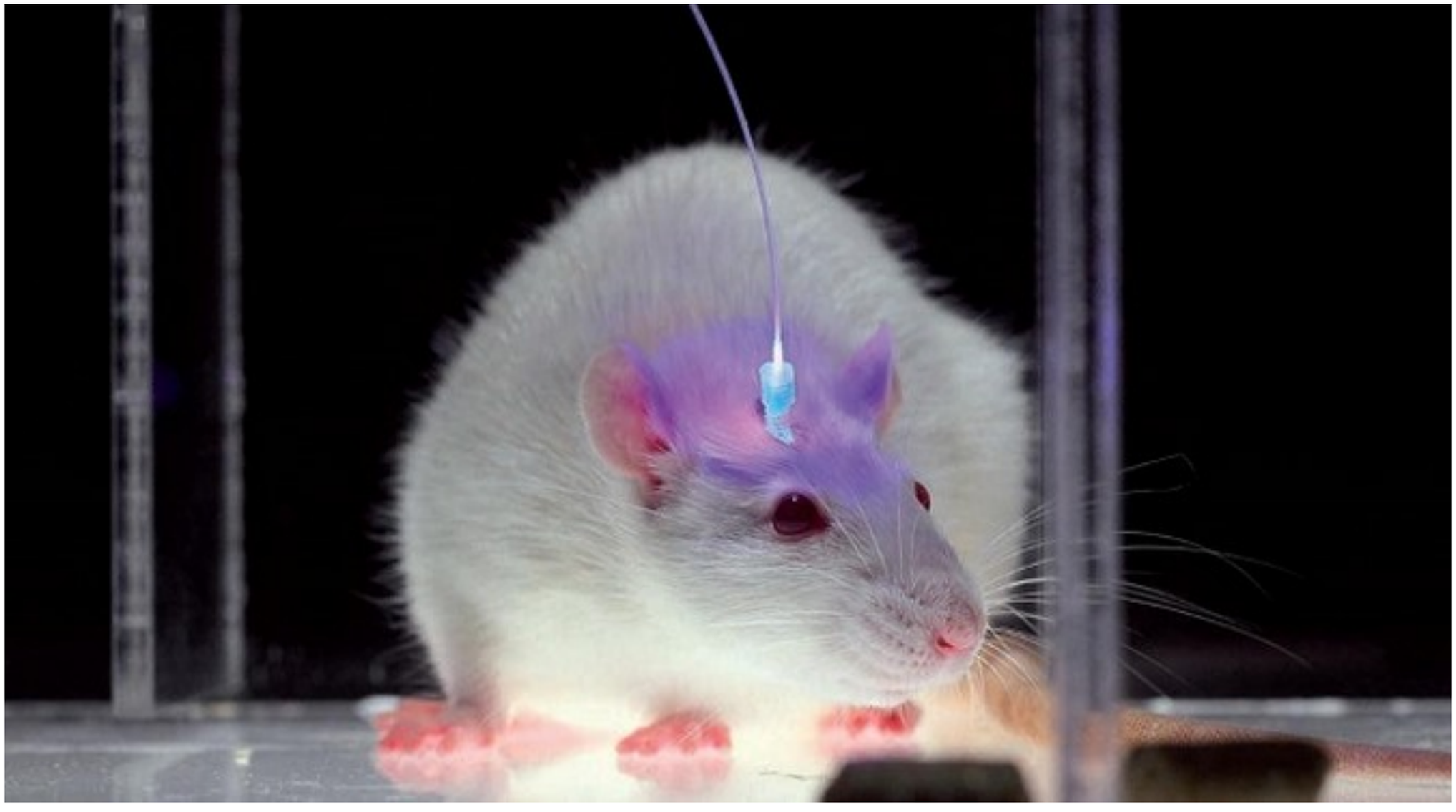
# Synaptic plasticity in the hippocampus is needed for learning




Morris et al, *Nature* 1986

- A drug that blocks NMDA receptors blocks both synaptic plasticity and performance on a spatial learning task (left side is data from control animals, right side data from animals with drug).

# False memories (the Inception experiment)



Tonegawa group (MIT) and Mayford group (UC San Diego)

# 2. Hippocampus and spatial navigation

# Hippocampus and spatial navigation

- Neurons in the hippocampus and surrounding regions respond to aspects of the spatial environment:

- *Place* cells in CA3 and CA1 are active only when an animal is one particular location.

- *Grid* cells in entorhinal cortex are active when the animal is in any of a set of locations, arranged in a hexagonal grid.

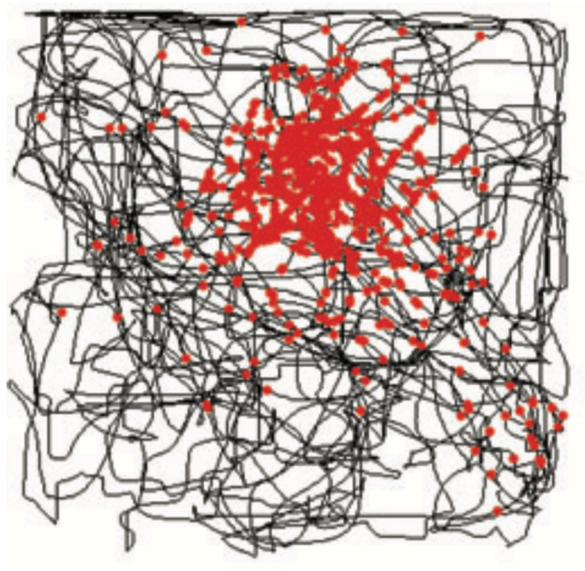
- *Head direction* cells in subiculum (and also hippocampus, entorhinal cortex, and other neighbouring structures) don't care where the animal is located, but are active only when the animal is facing a certain direction.

# Place cell example video

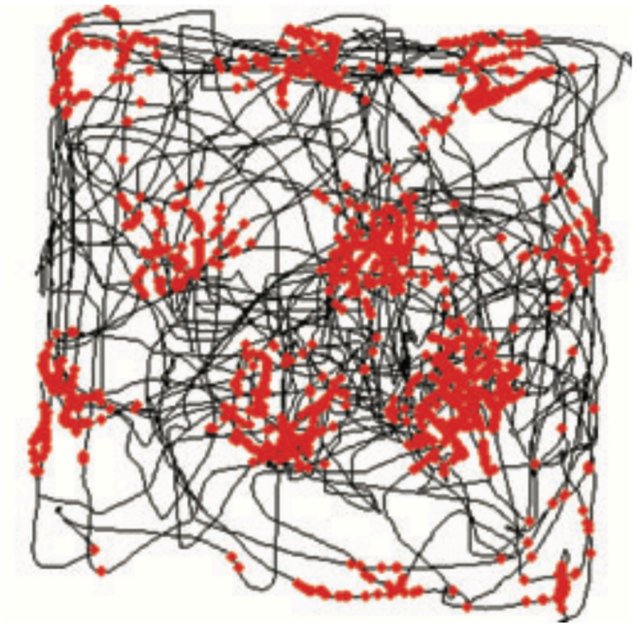

https://www.youtube.com/watch?v=lfNVv0A8QvI

# Place cells, grid cells, head direction cells

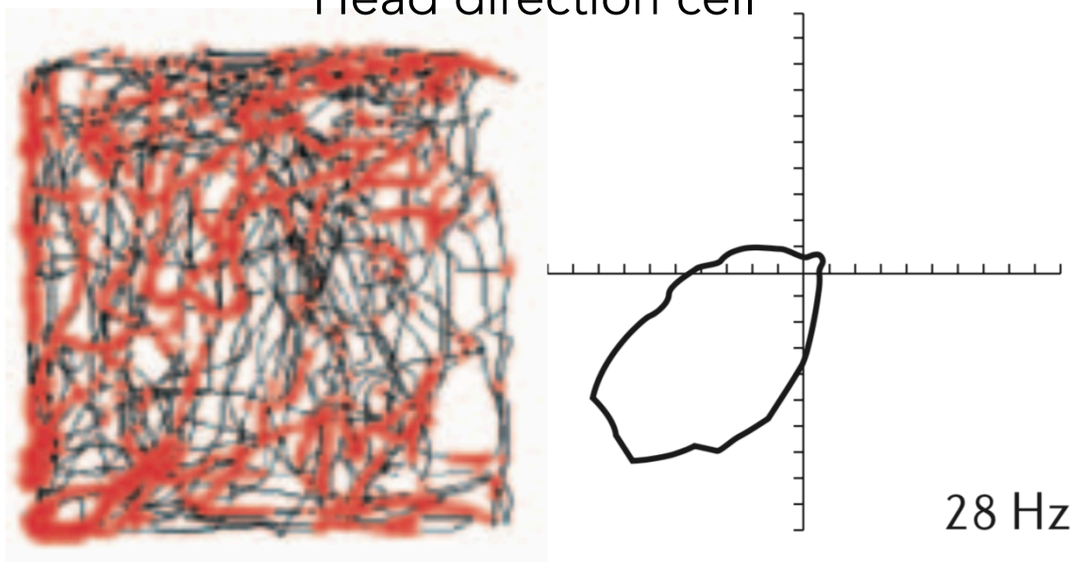
Place cell



Grid cell



Head direction cell



# Hippocampal computations

For both memory and spatial navigation, the hippocampus is thought to perform two key classes of computation:

- Pattern separation vs pattern completion.
- Path integration.

# Pattern separation vs pattern completion

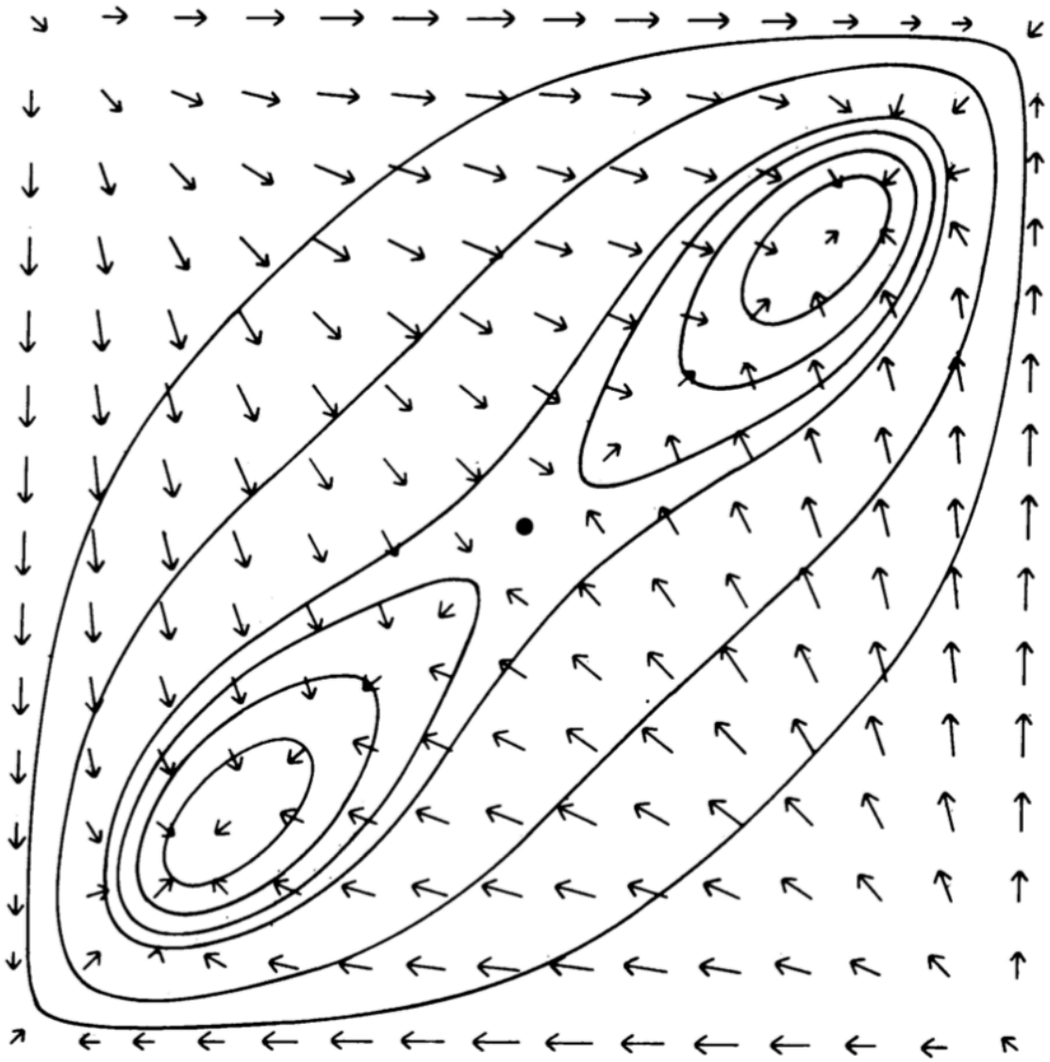
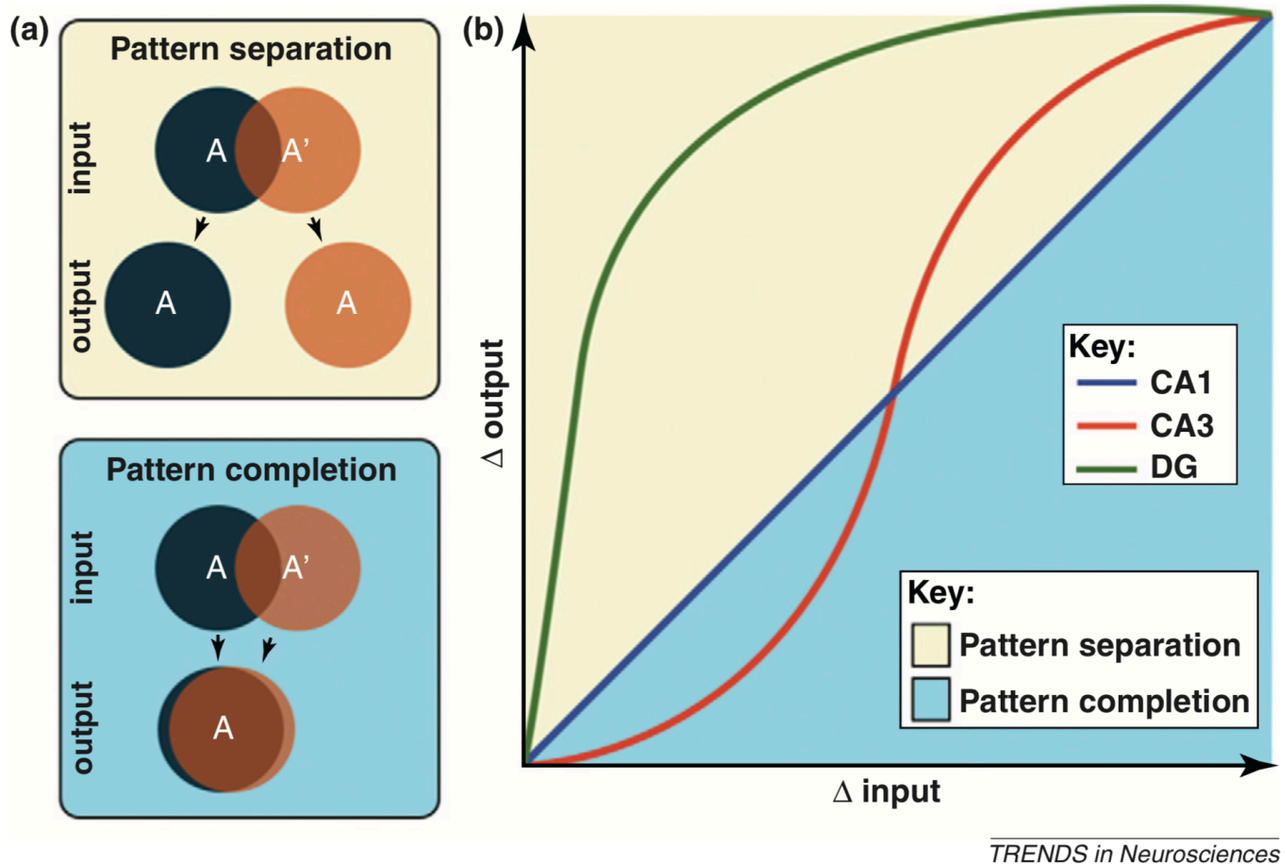


FIG. 3. An energy contour map for a two-neuron, two-stable-state system. The ordinate and abscissa are the outputs of the two neurons. Stable states are located near the lower left and upper right corners, and unstable extrema at the other two corners. The arrows show the motion of the state from Eq. **5**. This motion is not in general perpendicular to the energy contours. The system parameters are $T_{12} = T_{21} = 1$, $\lambda = 1.4$, and $g(u) = (2/\pi)\tan^{-1}(\pi\lambda u/2)$. Energy contours are 0.449, 0.156, 0.017, −0.003, −0.023, and −0.041.

Hopfield, *PNAS* 1984

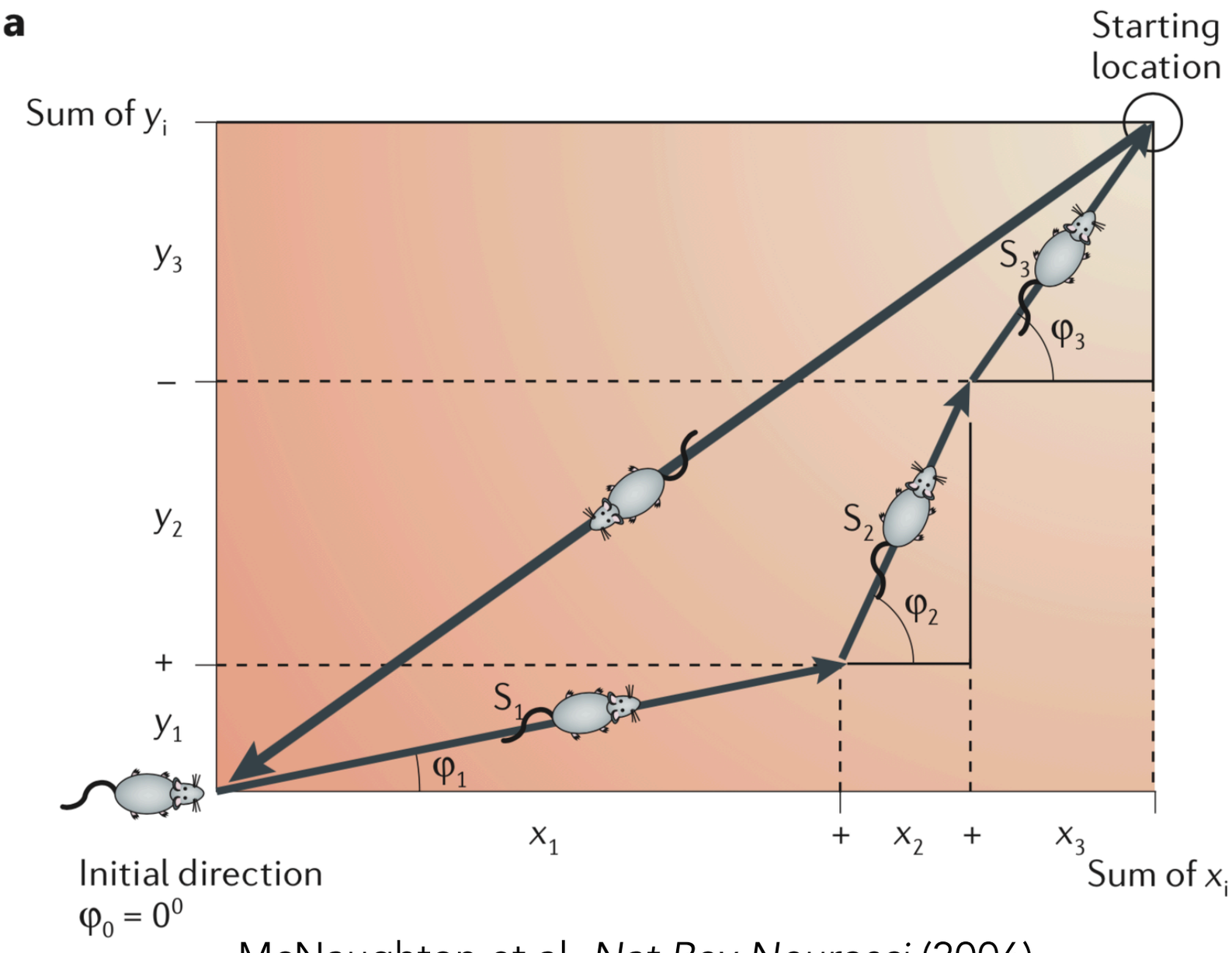



Yassa & Stark, *Trends Neurosci* (2011)

- Dentate gyrus is thought to do pattern separation.
- CA3 is thought to do pattern completion.

# Path integration

Path integration is the idea that an animal can keep a running internal estimate of its spatial location by integrating its direction and velocity signals.




McNaughton et al, *Nat Rev Neurosci* (2006)

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