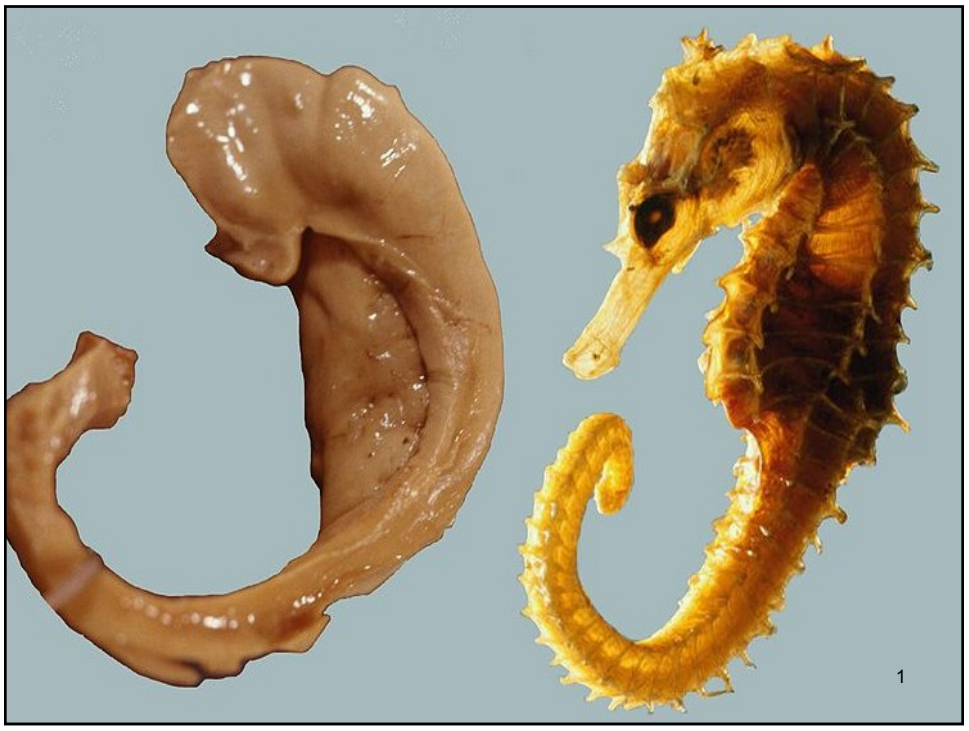

1


“Whoever wants to reach a distant goal
must take small steps”
--Saul Bellow

Neural Navigation I:
constructing a cognitive map of space

1. **Intelligent navigation: getting from here to there**
2. **A place hierarchy in the brain**
3. **Functions of the hippocampus**
   - **A. Representing space and spatial memory**
   - **B. Memory consolidation**

Where things are: coordinate frames

- **Egocentric** frame of reference: represents where things are relative to a specific part of my body (e.g. retina, trunk of body, hand)
- **Allocentric** frame of reference: represents where things are relative to fixed landmarks or boundaries.

Conclusions from Grandmother Cells

- Some medial temporal lobe neurons exhibit responses to individuals, places, or objects that are
  - Sparse: few cells respond to any given image
  - Selective: each cell seems to respond to a specific concept or category
  - Invariant: these cells respond regardless of the current appearance of the individual
- Sparse conceptual (abstract) representations may facilitate encoding specific memories and associations

How to get where you want to be

1. **identify landmarks**: what is this?
2. use landmarks to **determine position and heading**: where am I and which way am I pointing?
3. **access memory of spatial relationships** between landmarks and goal: where are other relevant places?
4. **plan route**…and go!

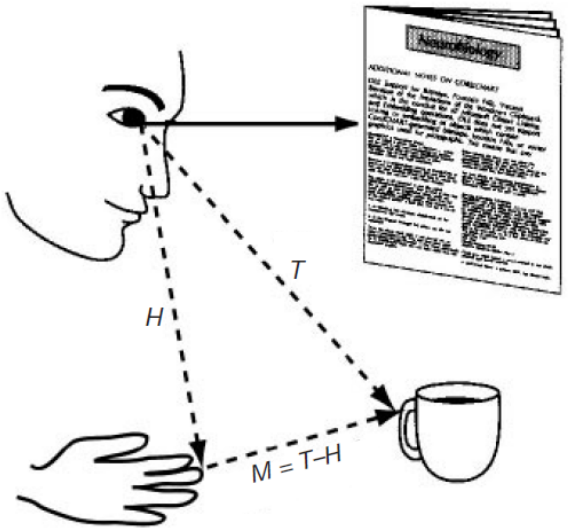
Three strategies to get from here to there

- **Path integration**: count steps in correct direction, e.g. in the dark.
- Perform memorized **series of steps/decisions**: turn left at landmark X then right at Y.
- Represent position on a **cognitive map** of remembered places to guide your movement.

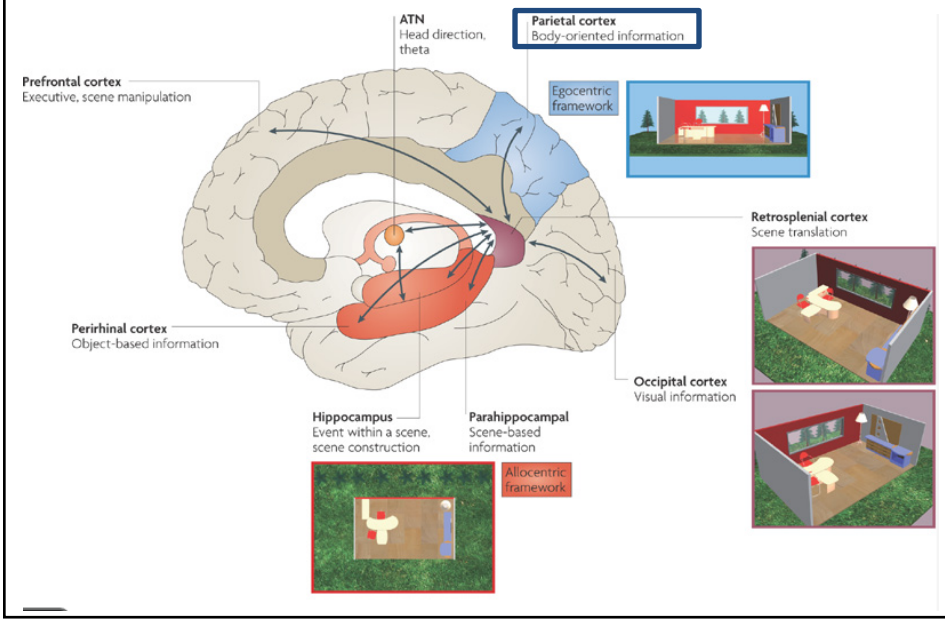
Neural Navigation I: constructing a cognitive map of space

1. **Intelligent navigation: getting from here to there**
2. **A place hierarchy in the brain**
3. **Functions of the hippocampus**
   - **A. Representing space and spatial memory**
   - **B. Memory consolidation**

Translating between two egocentric coordinate frames



Parietal cortex represents where things in my visual field are, relative to me



How to get where you want to be

1. **identify landmarks**: what is this?
2. use landmarks to **determine position and heading**: where am I and which way am I pointing?
3. **access memory of spatial relationships** between landmarks and goal: where are other relevant places?
4. **plan route**…and go!

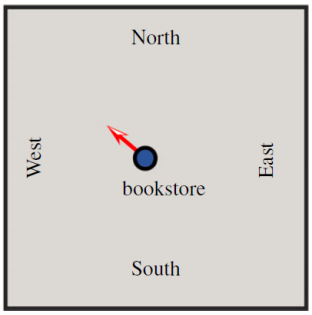
Para-hippocampal place area

PPA

Identifies landmarks

Retrosplenial complex

RSC

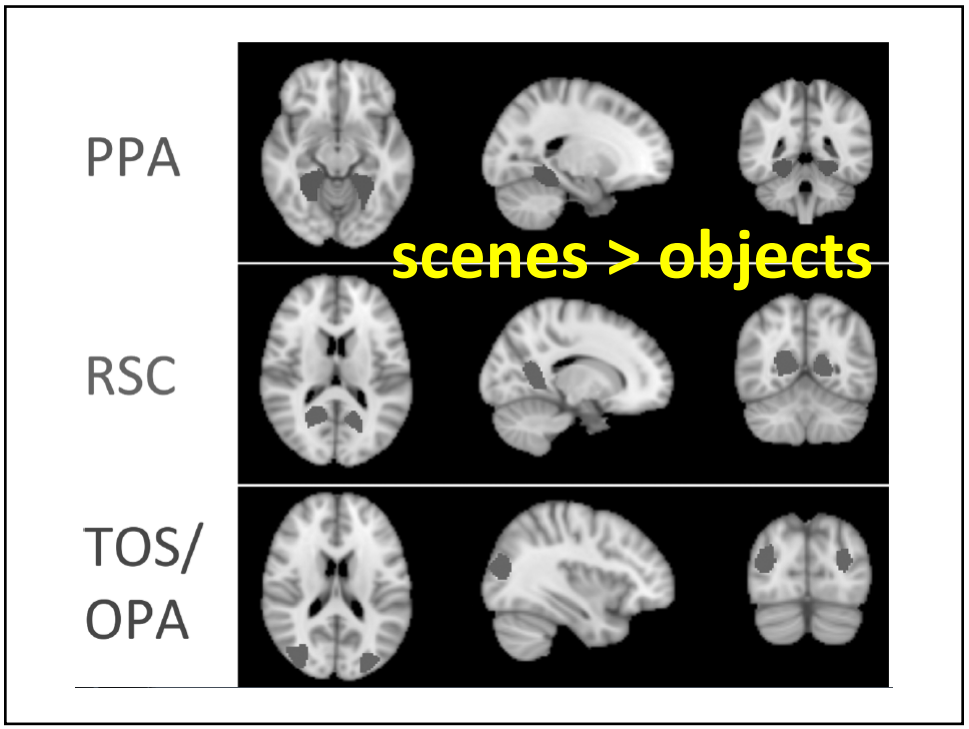


Uses landmarks to determine the current location and direction

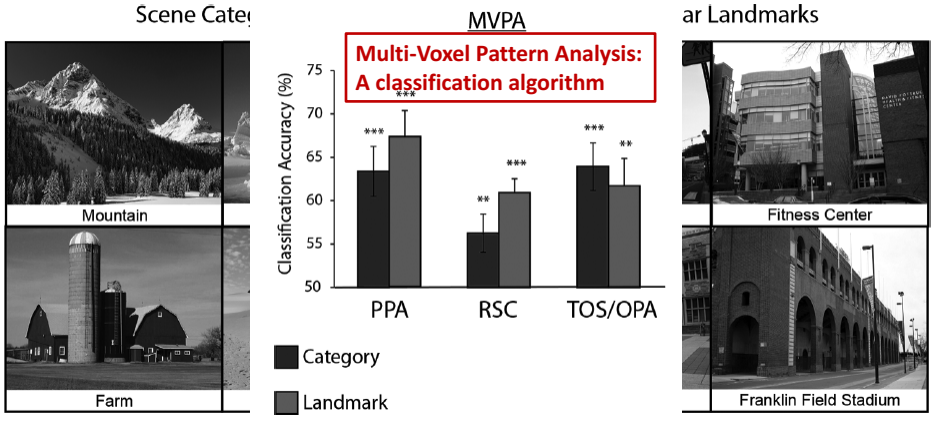
Medial temporal lobe Hippocampus

MTL

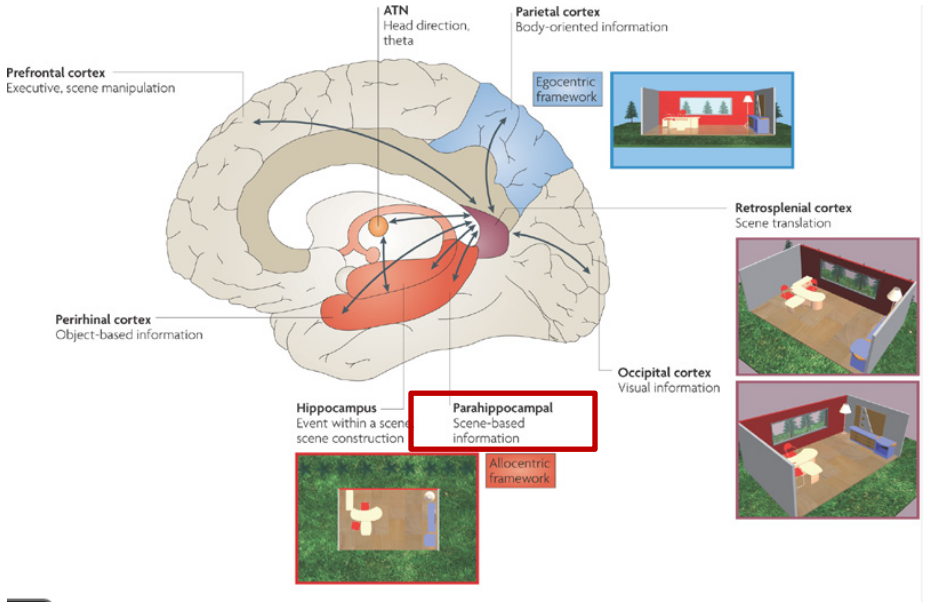
Encodes a cognitive map that represents landmarks and goals in terms of their coordinates in allocentric space



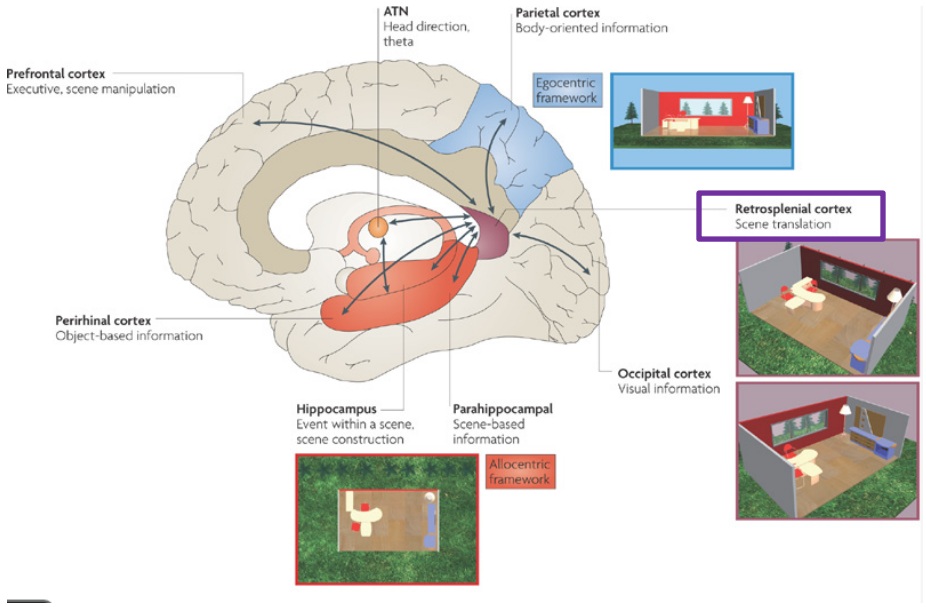
These areas **encode** scene category and landmark identity



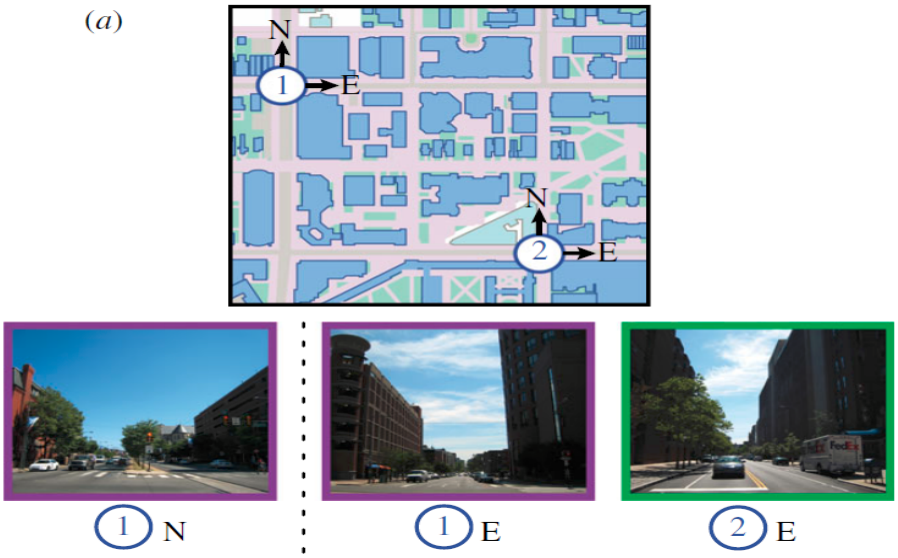
Parahippocampal Place Area identifies the current scene/place



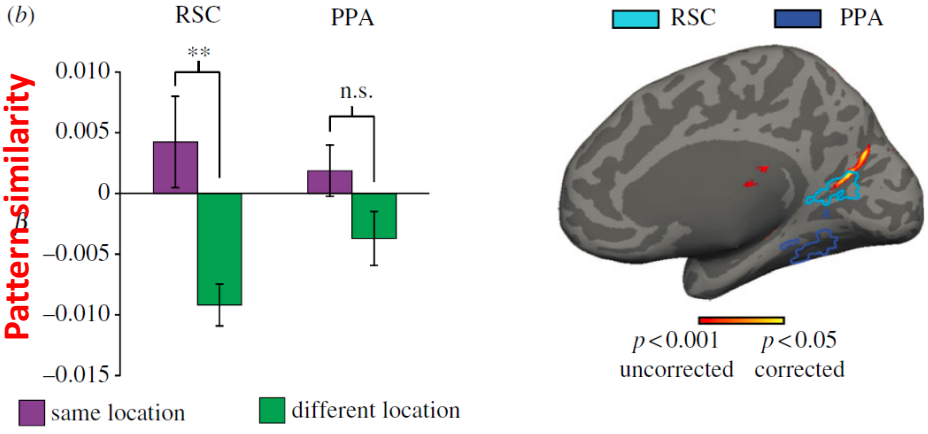
RetroSplenial Complex locates and orients the current scene in the larger space around it



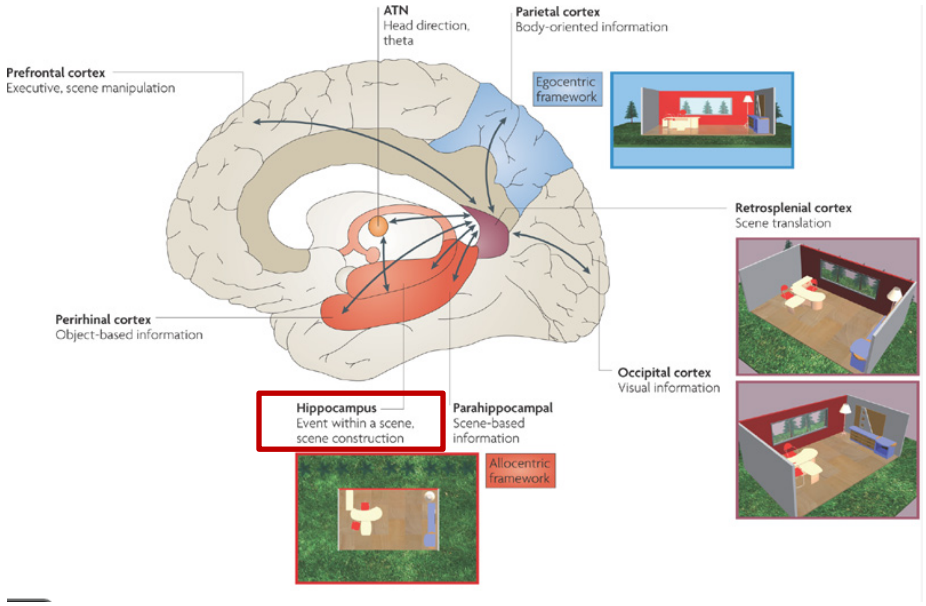
Scanned while viewing images taken at different locations on a **familiar** college campus

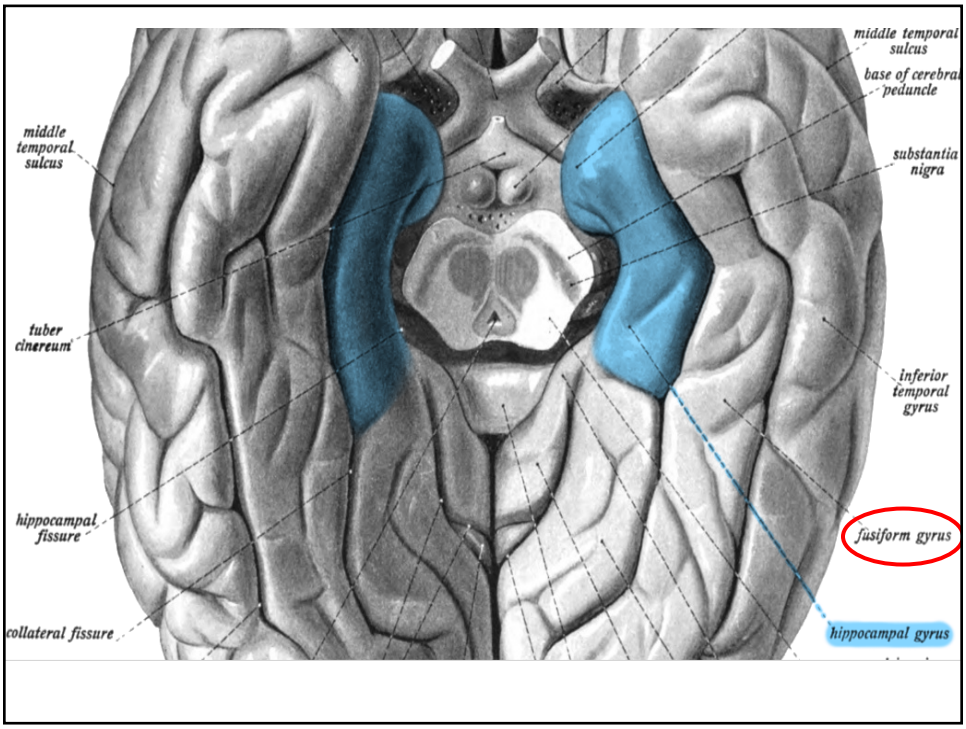


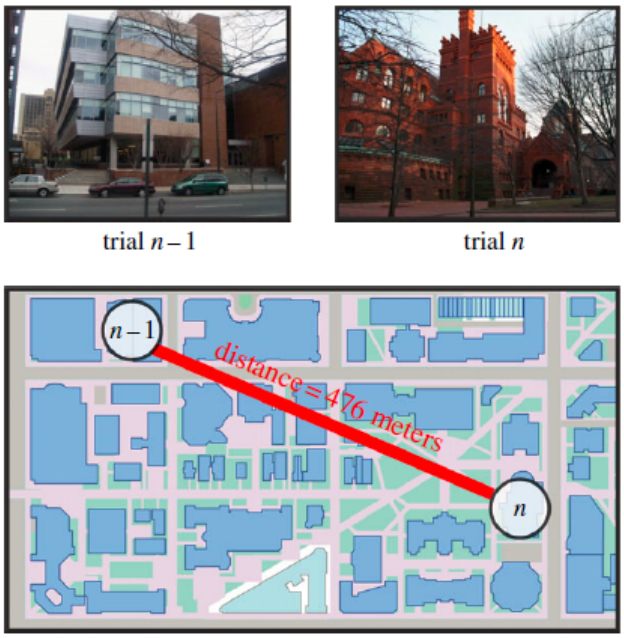
fMRI evidence that RSC codes location in a manner that abstracts away from perceptual features



Hippocampus (MTL) represents locations on an allocentric cognitive map







fMRI evidence that the human hippocampus encodes distances: a key feature of a cognitive map

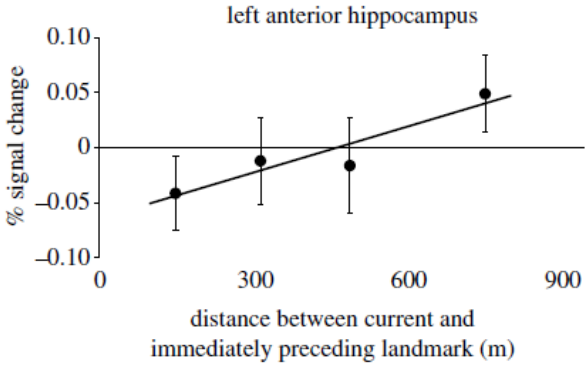
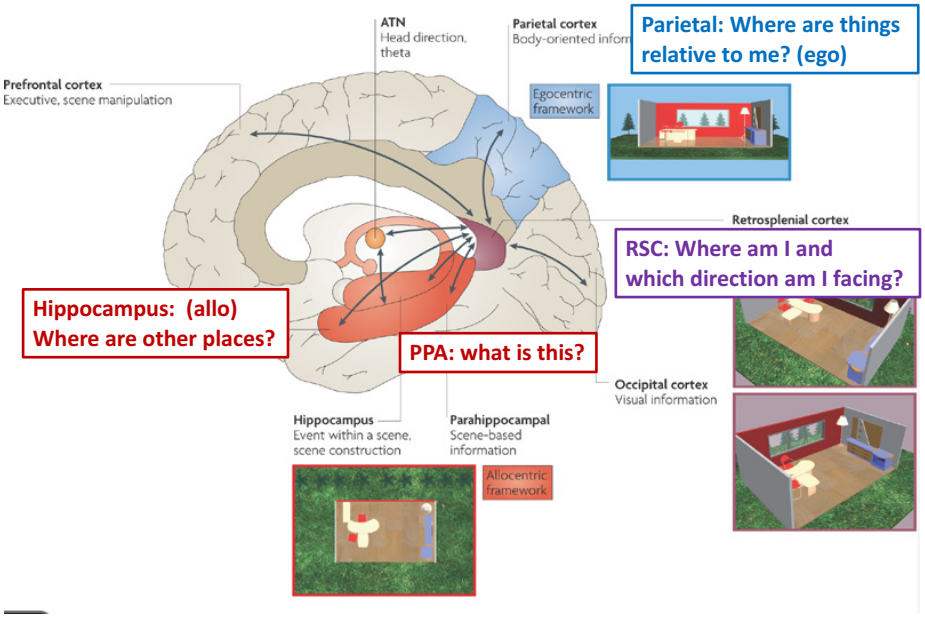


Figure 3. fMRI evidence that the human hippocampus encodes distances between real-world locations, thus exhibiting a key feature of a cognitive map. Subjects were scanned while viewing landmarks from a familiar college campus. Activity in the left anterior hippocampus scaled with the real-world distance between the landmark shown on each trial and the landmark shown on the immediately preceding trial. Adapted from [49]. (Online version in colour.)

Division of labor



Three strategies to get from here to there

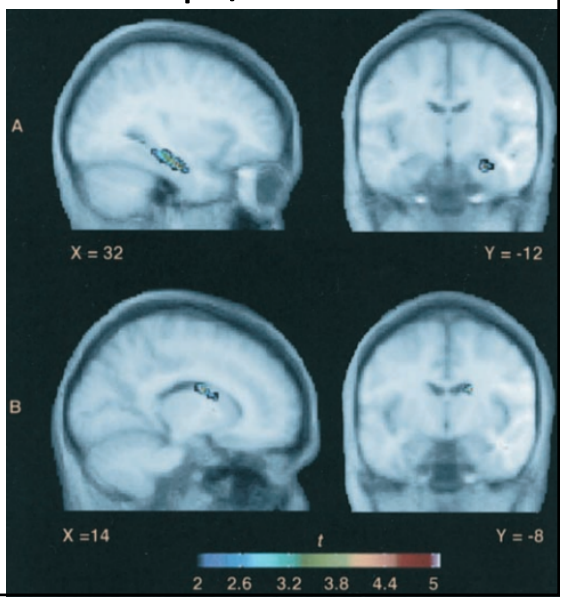
- **Path integration**: count steps in correct direction, e.g. in the dark.
- Perform memorized **series of steps/decisions**: turn left at landmark X then right at Y.
- Represent position on a **cognitive map** of remembered places to guide your movement.

Spatial navigation vs. sequence of stimulus-response steps/decisions

Spatial strategy: hippocampus

Non-spatial strategy: striatum

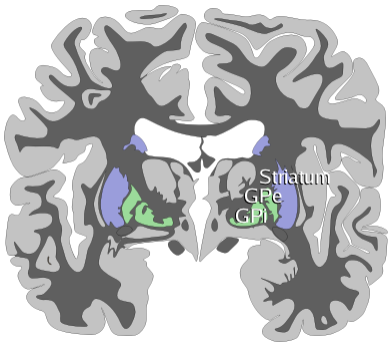
Iaria et al 2003



Striatum: Motor skills and habits, Procedural Memory

Striatum = two elements of basal ganglia:

- Caudate nucleus
- Putamen



26

Neural Navigation I:
constructing a cognitive map of space

1. Intelligent navigation: getting from here to there
2. A place hierarchy in the brain
3. Functions of the hippocampus
   - A. Representing space and spatial memory
   - B. Memory consolidation

► The Three Major Structures of the Medial Temporal Lobe

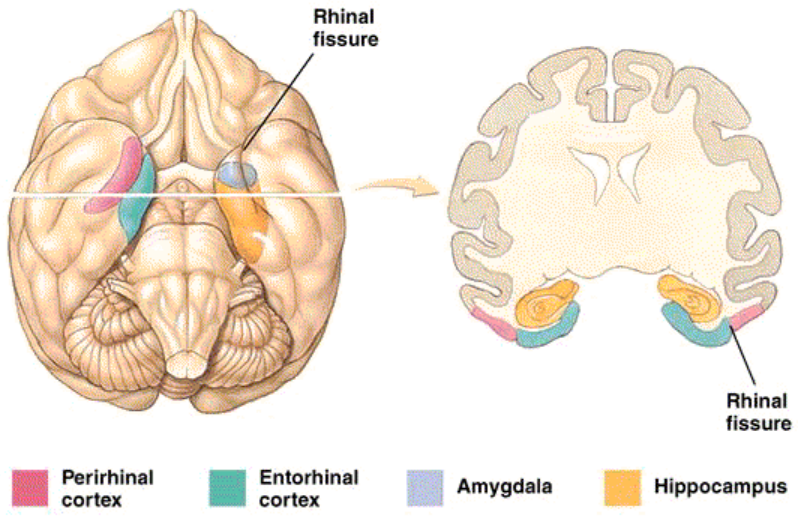
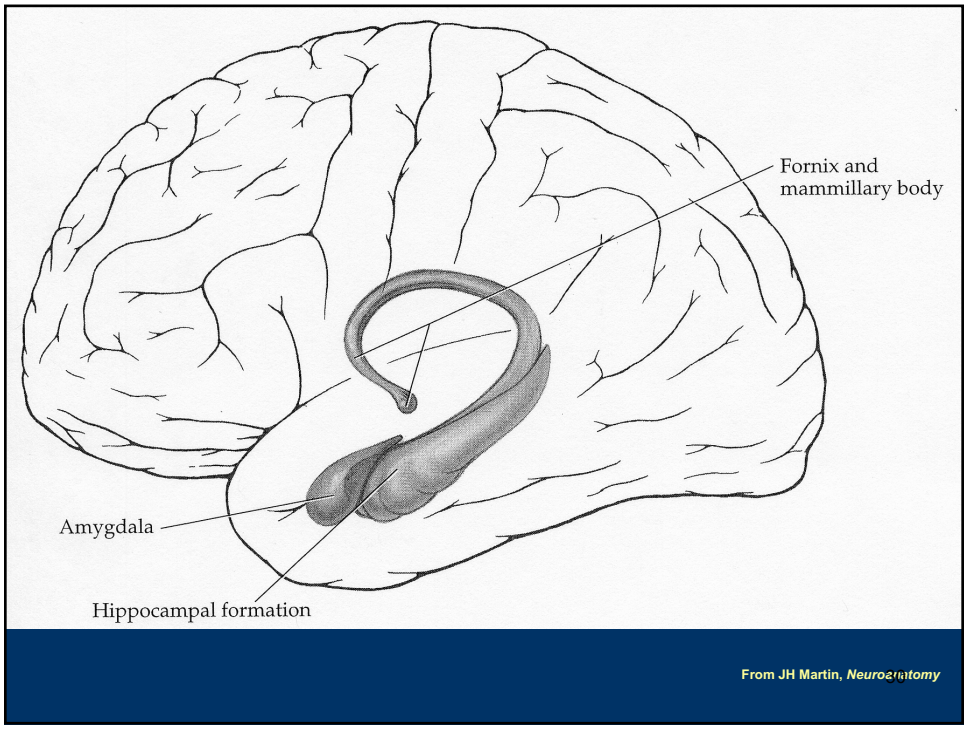


Fig. 24.9

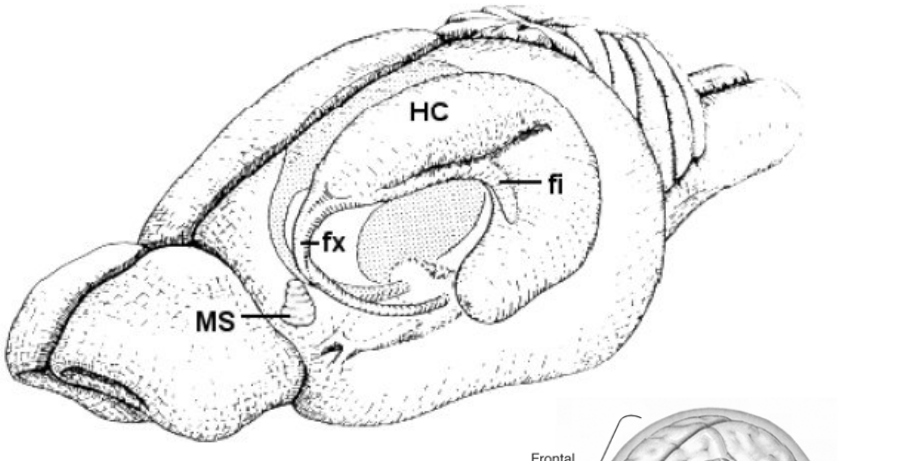
28

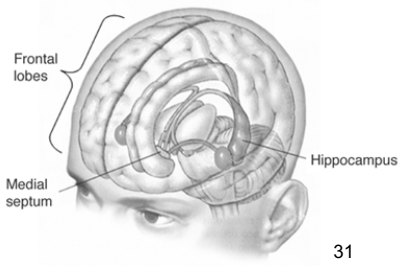
Hippocampus!

29



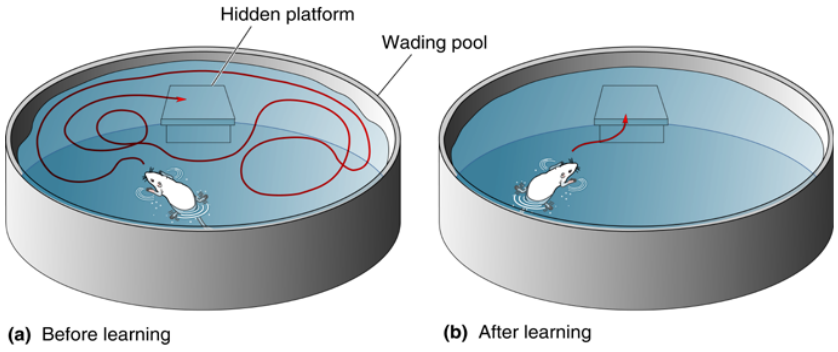
From JH Martin, *Neuroanatomy*





31

Morris Water Maze



HP lesion → can't remember where the platform is
→ spatial memory

32

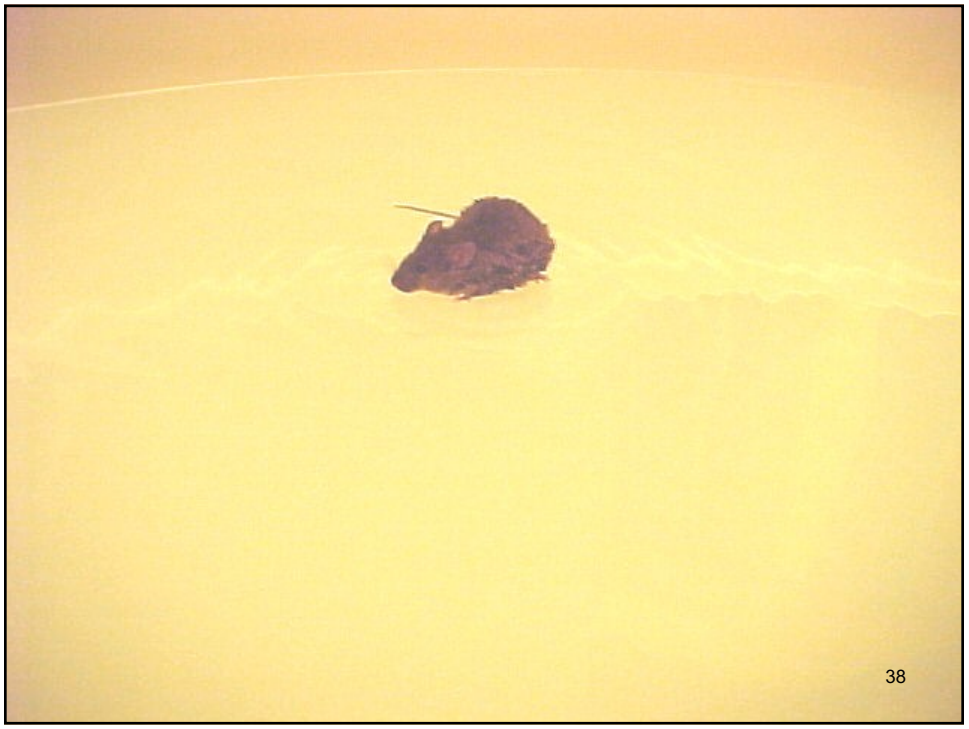

33


34

35

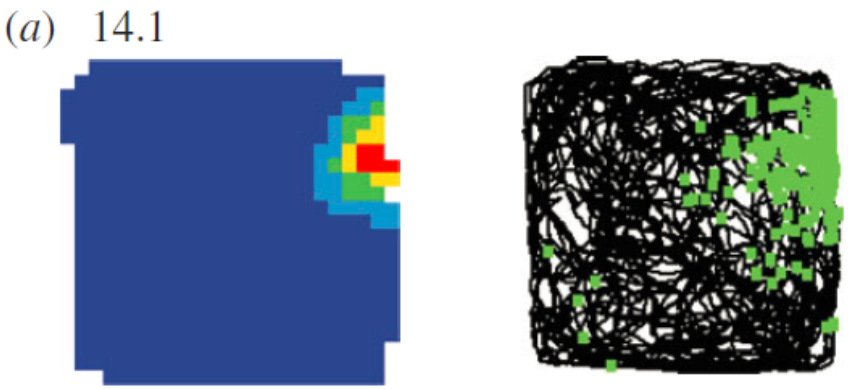
36

37



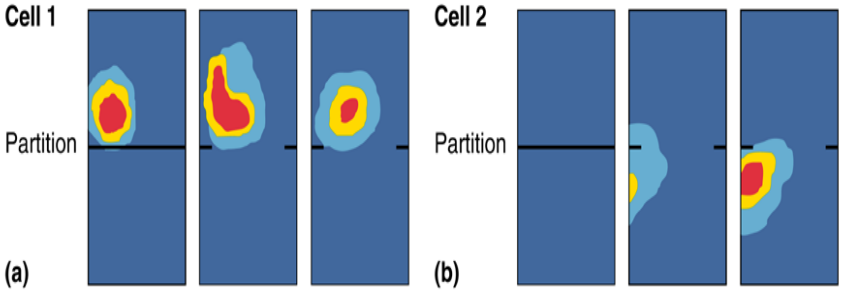
38

Hippocampal place cell



40

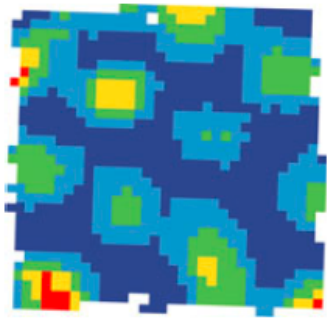
Hippocampal place cells

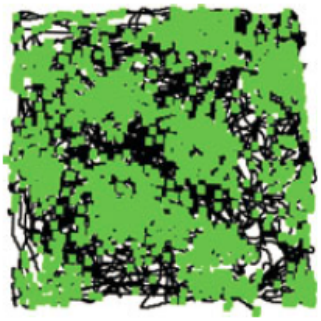


41

Grid cell

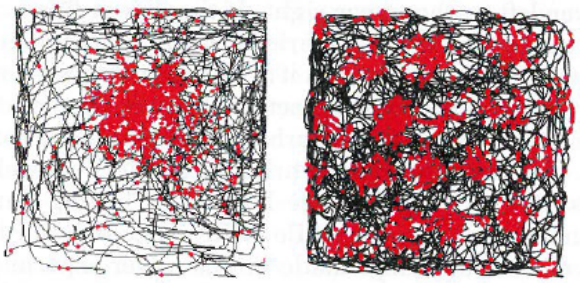
(c) 8.1





42

Grid cell in entorhinal cortex

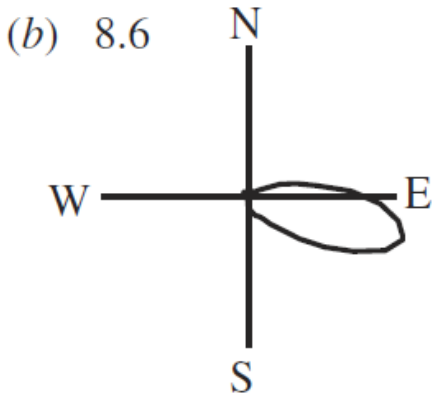


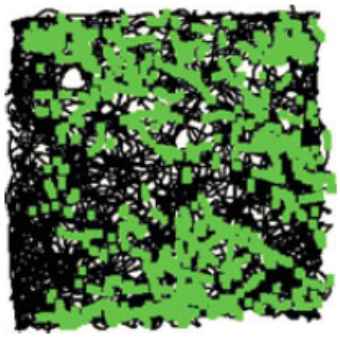
(a) (b)

▲ FIGURE 24.23
A rat place cell and a grid cell. The black lines show the path a rat took through a square enclosure. Red spots indicate locations of the rat associated with neural activity. (a) A place cell in the hippocampus responds when the rat is in one region of the enclosure. This is the cell's place field. (b) A grid cell in entorhinal cortex is active when the rat is at multiple locations that form a grid pattern. (Source: Moser et al., 2008, Fig. 1.)

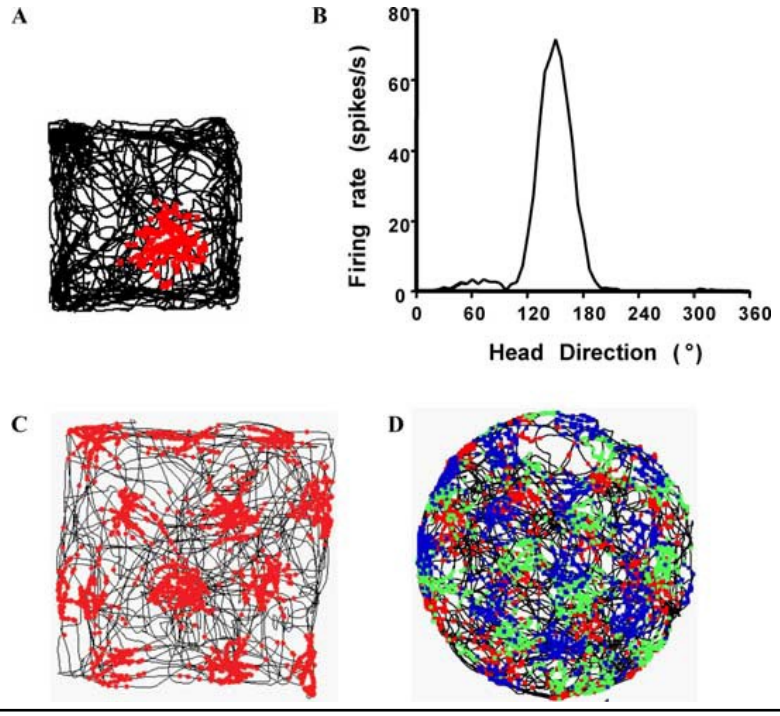
43

Head Direction (HD) cell





44



45

Nobelförsamlingen
The Nobel Assembly at Karolinska Institutet

Press Release

2014-10-06

to award

for their discoveries of cells that constitute a positioning system in the brain

46

47

Cellular networks underlying human spatial navigation

Arne D. Ekstrom[1], Michael J. Kahana[1], Jeremy B. Caplan[1], Tony A. Fields[2], Eve A. Isham[2], Ehren L. Newman[1] & Itzhak Fried[2,3]

Place cells of the rodent hippocampus constitute one of the most striking examples of a correlation between neuronal activity and complex behaviour in mammals[1,2]. These cells increase their firing rates when the animal traverses specific regions of its surroundings, providing a context-dependent map of the environment[3–5]. Neuroimaging studies implicate the hippocampus and the parahippocampal region in human navigation[6–8]. However, these regions also respond selectively to visual stimuli[9–13]. It thus remains unclear whether rodent place coding has a homologue in humans or whether human navigation is driven by a different, visually based neural mechanism. We directly recorded from 317 neurons in the human medial temporal and frontal lobes while subjects explored and navigated a virtual town. Here we present evidence for a neural code of human spatial navigation based on cells that respond at specific spatial locations and cells that respond to views of landmarks. The former are present primarily in the hippocampus, and the latter in the parahippocampal region. Cells throughout the frontal and temporal lobes responded to the subjects' navigational goals and to conjunctions of place, goal and view.

48

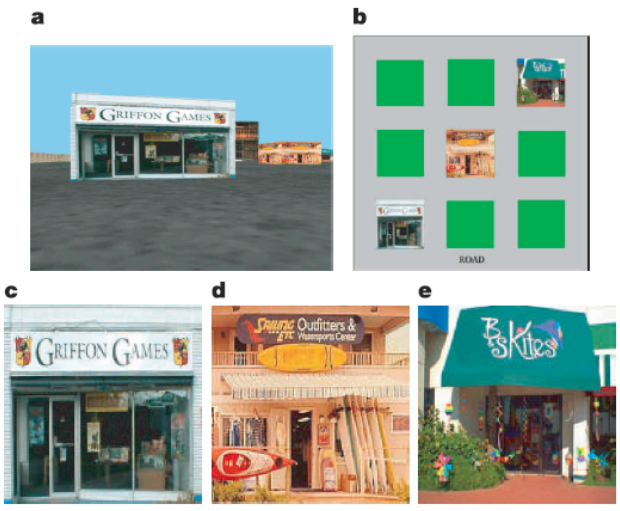
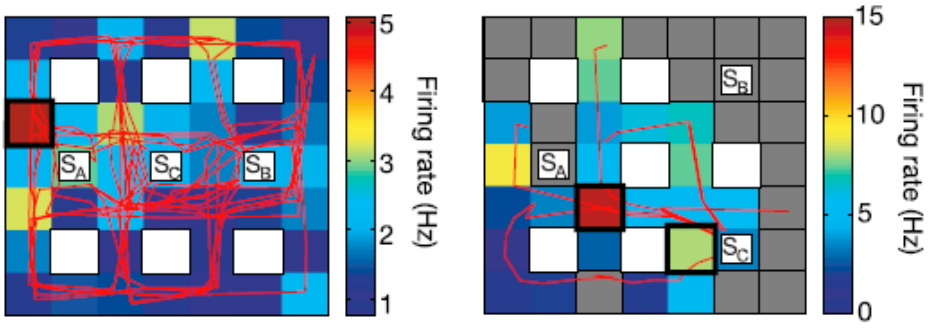


Figure 1 Taxi driver game. **a**, An example of a view seen as a subject navigated through a randomly generated town. Each town contained three labelled, target shops chosen randomly from a pool of 20 possibilities, and 6 unlabelled, non-target buildings chosen from a pool of 48 possibilities. **b**, An example of one particular spatial layout is shown with the corresponding shops (**c**–**e**) searched for during navigation.

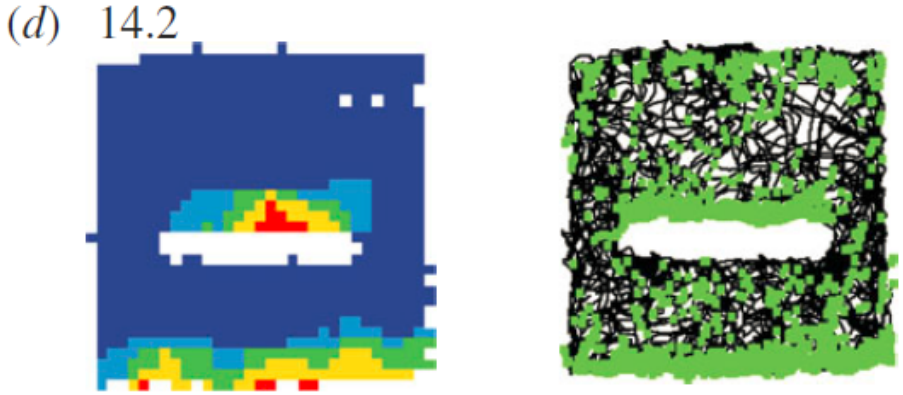
49

Place cells recorded in human hippocampus!



50

Boundary cell



51