Lecture 9: Navigation II

Monday:

I. What do we need to know and do to get around?

II. The PPA, a region selectively responsive to scenes.

III. The rest of the "scene network": PPA, RSC, & OPA

Today:

I. Neurons that track your location and heading:
place, grid, border, and head direction cells.

II. Reorientation

III. Not "just" for representing space…..

IV. Quiz at 12:17

The Fundamental Problems of Navigation

I. Where am I?

- Recognize a familiar location

  e.g. this is my living room

- Even if unfamiliar: What *kind* of place is this?

  a living room, a city street, a mountain, a desert

- Layout of current location

  e.g. I am next to long wall of rectangular room

II. How do I get from here (A) to there (B)?

- If you can see or hear B, go toward it ("beaconing").

  E.g. head toward lighthouse/foghorn, or landmark.

- Where an I am where is B in the world?

  Need mental map of the world (and your loc and destination in it)

- Also need to know current heading w/ respect to that map

  to determine necessary heading to get to B

- What routes are possible from here?

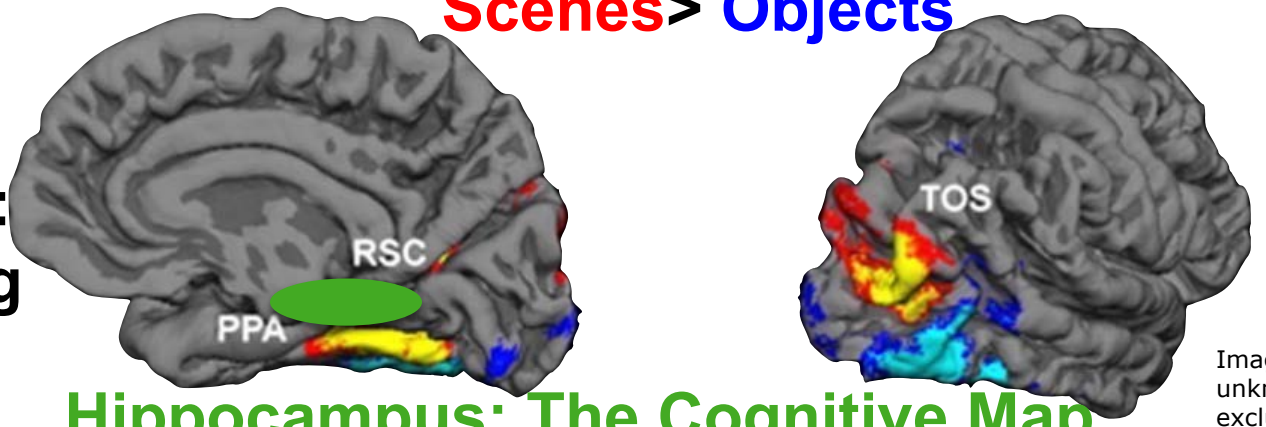
  "navigational affordances" like doors and halls, getting around barriers

- Reset: Regaining bearings when lost ("reorientation").

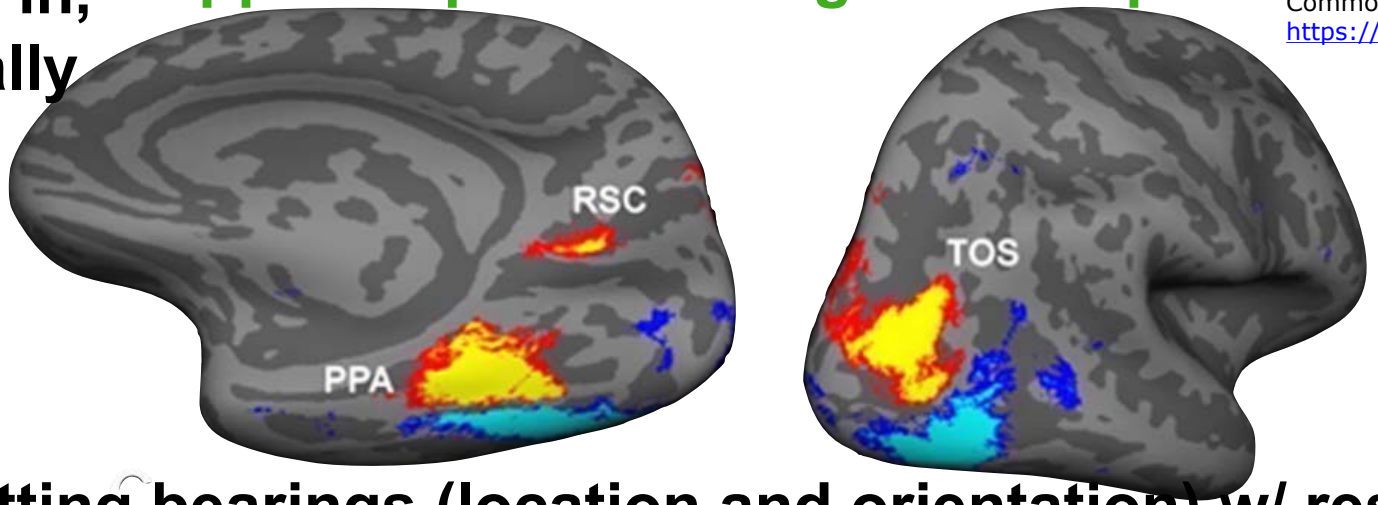
Multiple Brain Regions Engaged in Scene Perception & Navigation

Scenes> Objects

PPA & OPA/TOS: perceiving the scene you are in, especially spatial layout



Hippocampus: The Cognitive Map

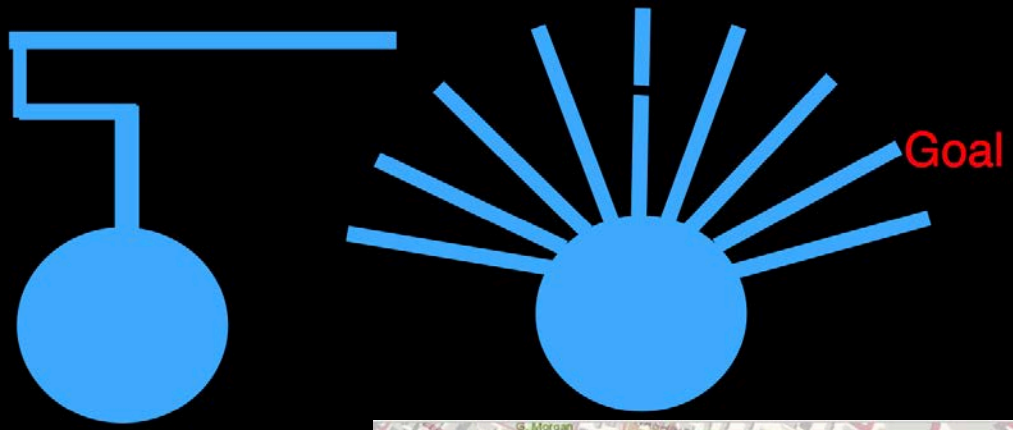


RSC: getting bearings (location and orientation) w/ respect to your cognitive map of your environment.

RSC damage: 'In every case, the patient was able to recognize the landmarks in their neighborhoods and retained a sense of familiarity …'. Despite this, none of the patients were able to find their way in familiar environments, and all but one were unable to learn new routes.

Evidence for “Cognitive Maps”

- Tolman, Ritchie, & Kalish (1946): rat must have cog map:

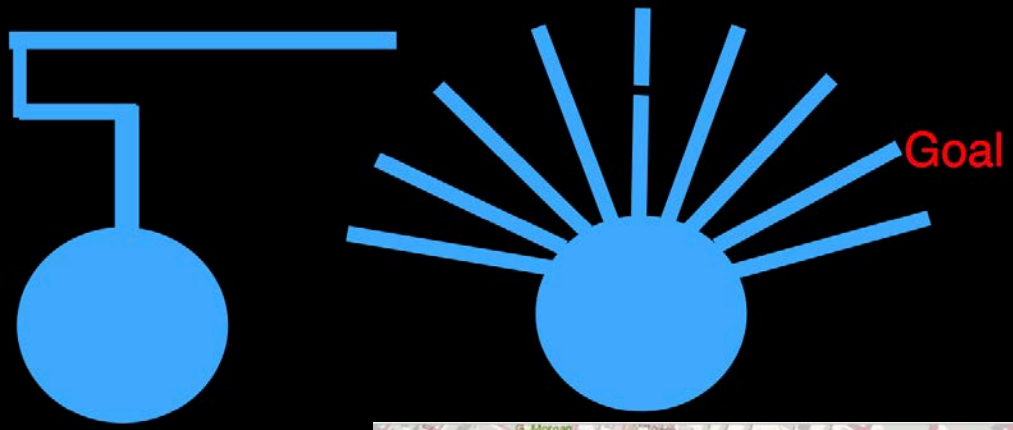


- And so do you:

and further, you know
where you are in this map!

Evidence for “Cognitive Maps”

- Tolman, Ritchie, & Kalish (1946): rat must have cog map:



- And so do you:

and further, you know
where you are in this map!

Specific neurons in your hippocampus are *representing this information right now.*

They are called “place cells”, and this is what they do…..

Place cells in hippocampus

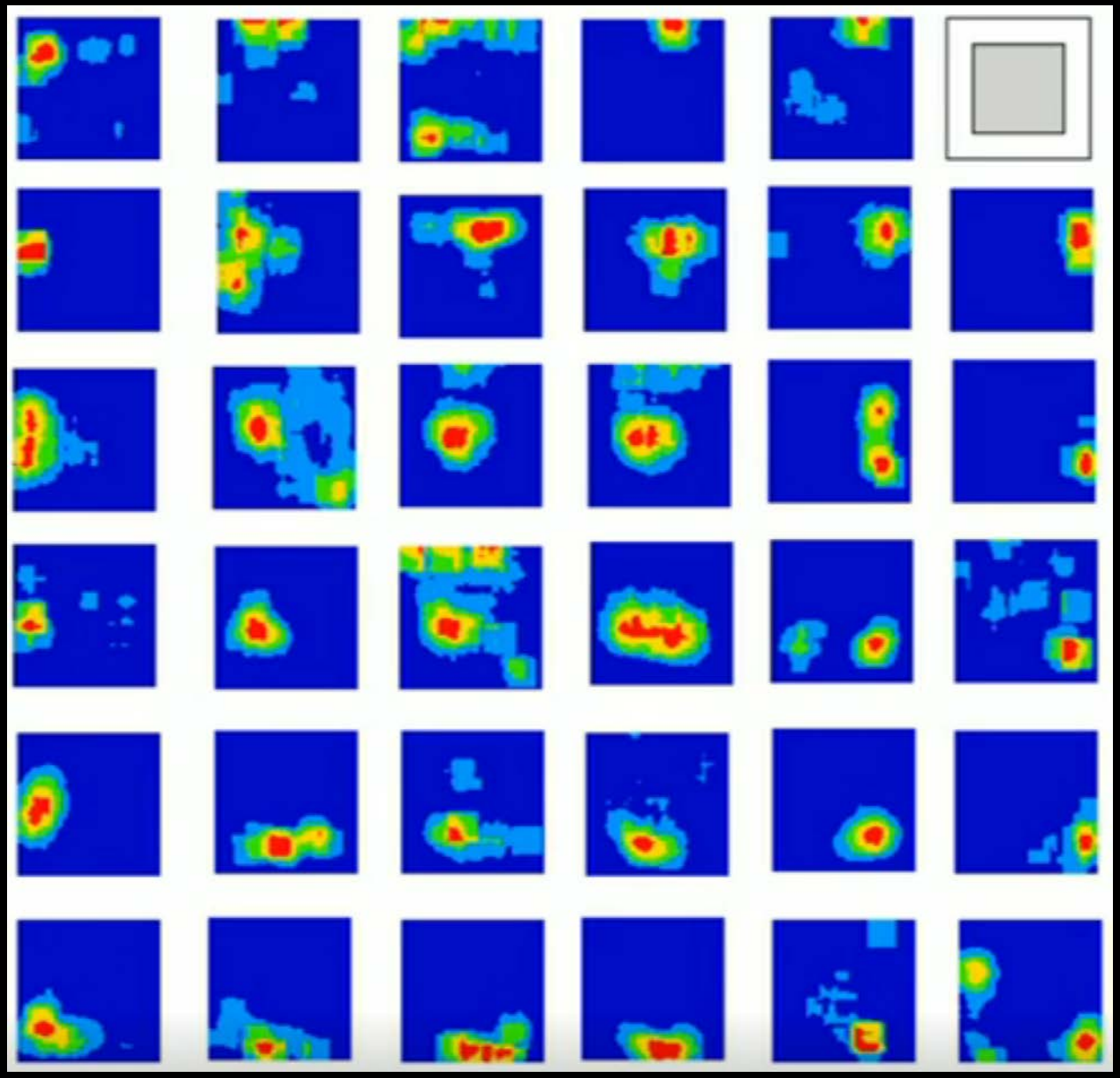
Image from © Grieves, R.M., Jedidi-Ayoub, S., Mishchanchuk, K. et al. Licence: CC BY. Source: The place-cell representation of volumetric space in rats, *Nat Commun* **11**, 789 (2020). https://doi.org/10.1038/s41467-020-14611-7

Place cells in hippocampus

VIDEO

Roddy Grieves: Place cell (rat hippocampus CA1) activity recorded over 50 minutes of foraging.
YouTube (added Apr 27, 2017)

Place cells in hippocampus



Place field: the location in space the animal has to be in to make a hippocampal neuron fire.

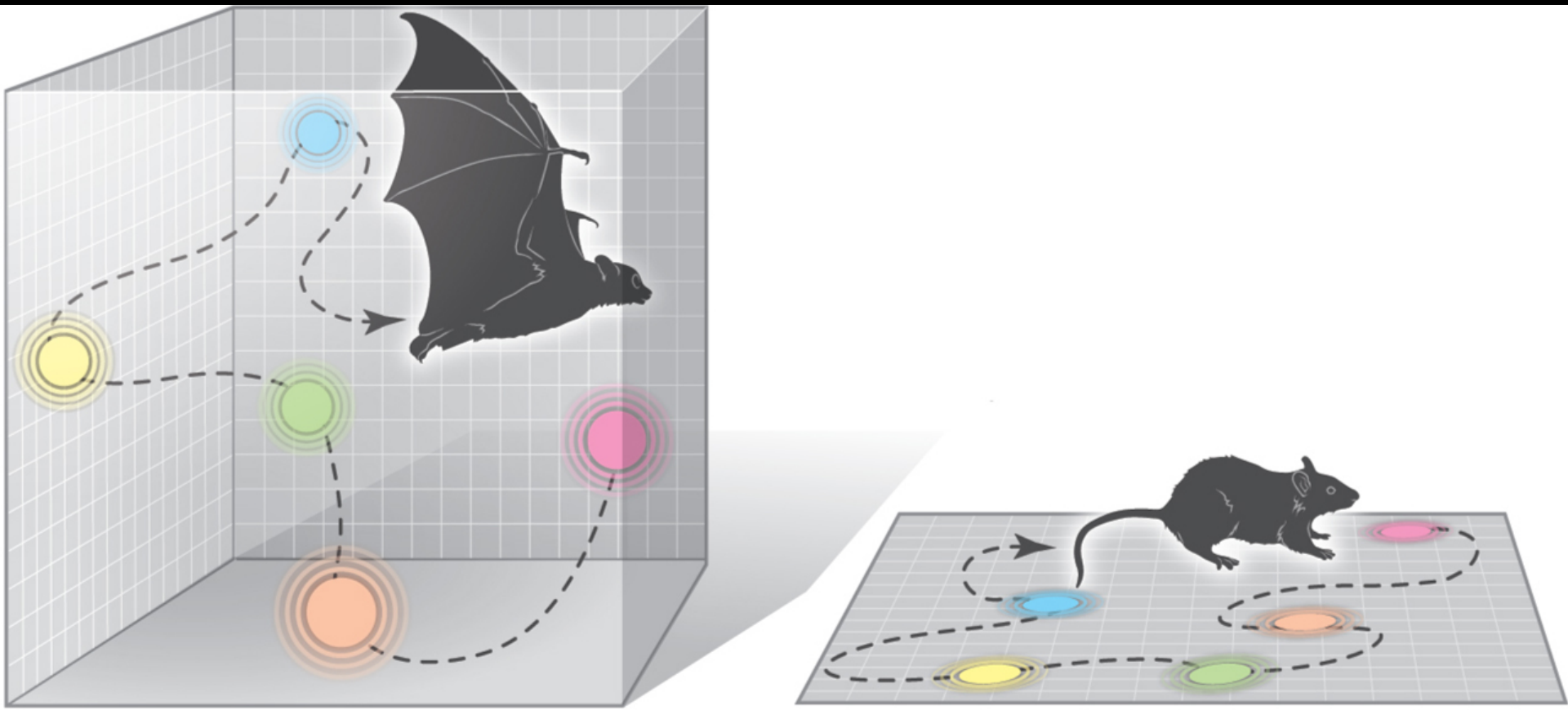
(vs receptive field: the location in visual field where a stimulus must be to make as visual neurons fire)

What about animals that don't operate in 2D?

 Source: The place cell representation of volumetric space in rats, *Nat Commun* **11**, 789 (2020). https://doi.org/10.1038/s41467-020-14611-7

- Bats maintain their sense of direction, even over 30-50 miles of flight each night.
- And even after they do backflips and land upside down on a cave's ceiling.

Place cells in hippocampus



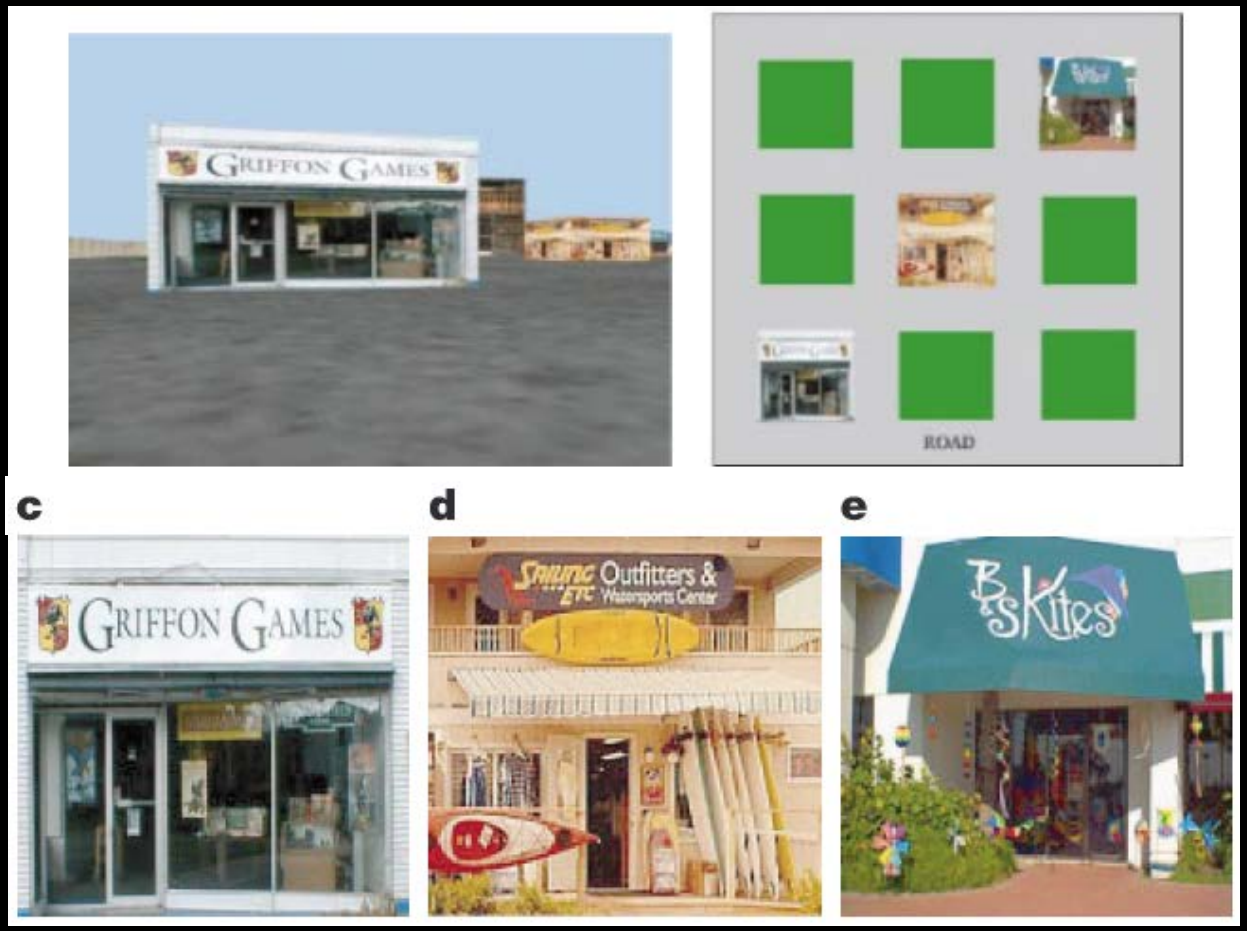
Place cells in hippocampus

Do humans have these?

Place Cells in Human Hippocampus

Ekstrom et al (2003)

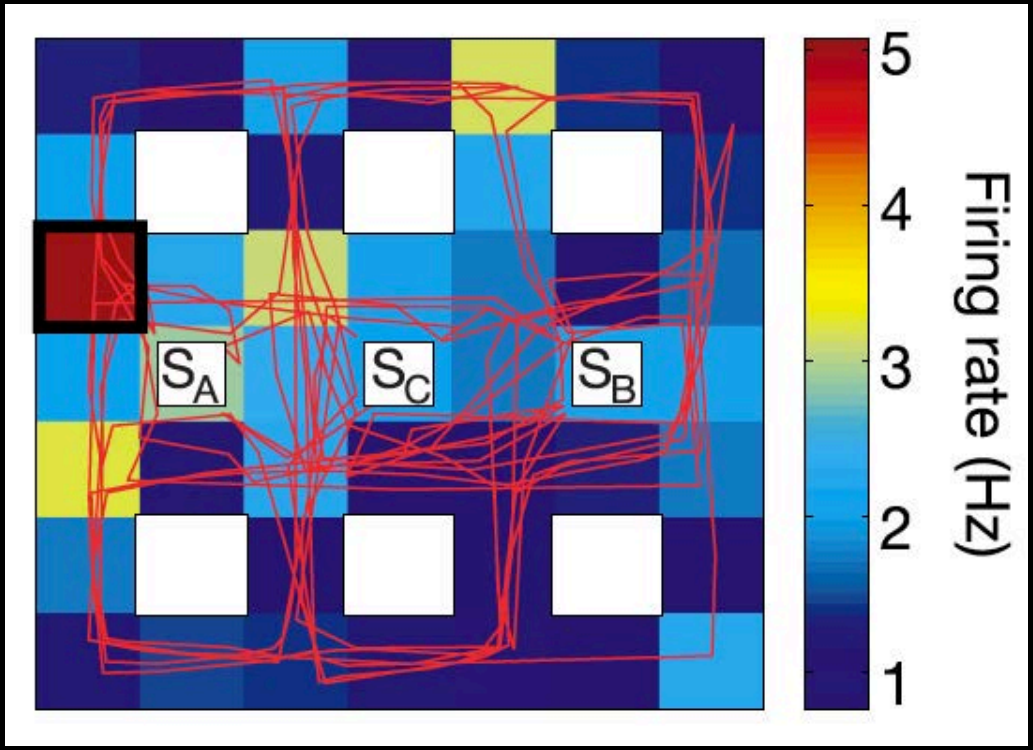
- Recorded from individual neurons human neurosurgery patients while they navigated a virtual space.



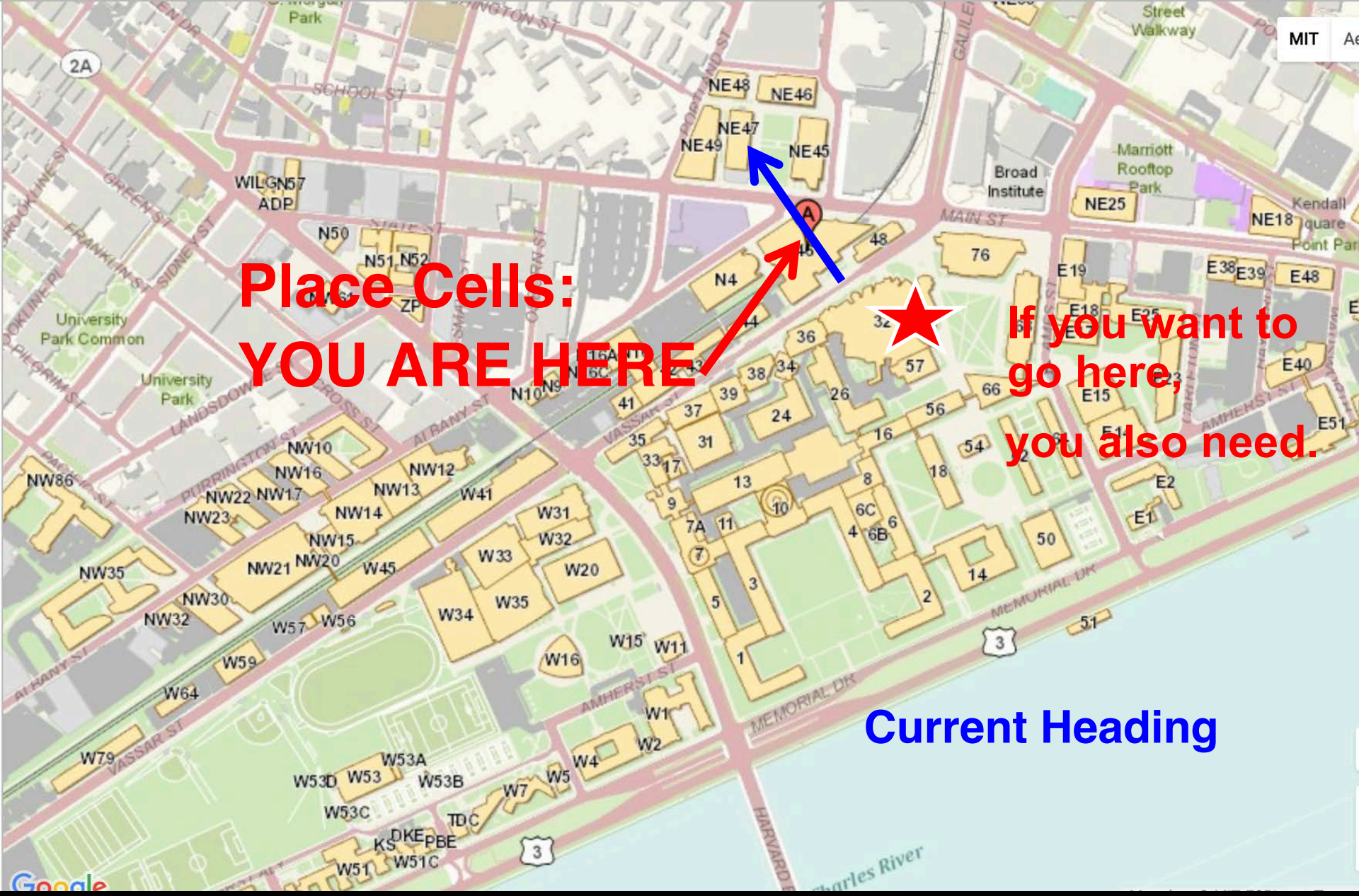
Place Cells in Human Hippocampus

Ekstrom et al (2003)

- Recorded from individual neurons human neurosurgery patients while they navigated a virtual space.
- Here is an example place cell in human hippocampus:



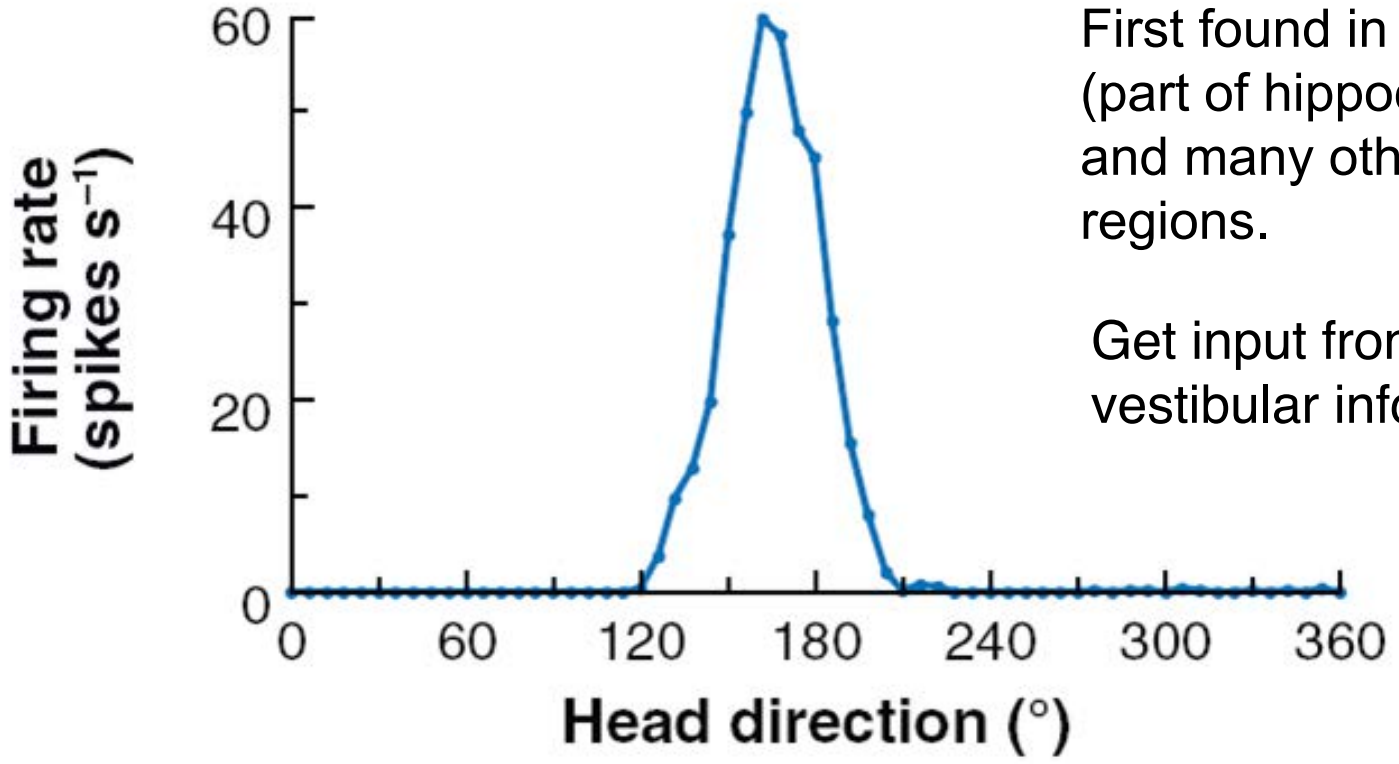
a, Firing-rate map of a right hippocampal cell showing significant place selectivity. Letters (SA,SB,SC) indicate shop locations, white boxes indicate non-target buildings, grey boxes indicate unoccupied areas, red lines indicate the subject's trajectory, and black squares indicate regions of significantly high firing rate.



How is that coded?

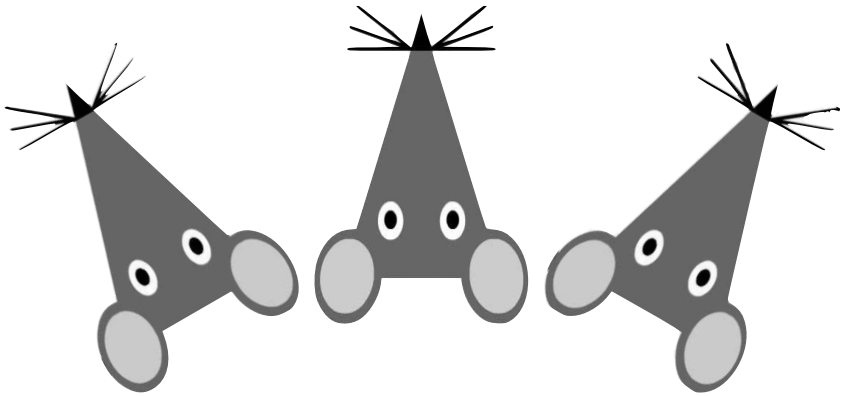
Head direction cells

~the brain's compass.



First found in subiculum (part of hippocampus), and many other brain regions.

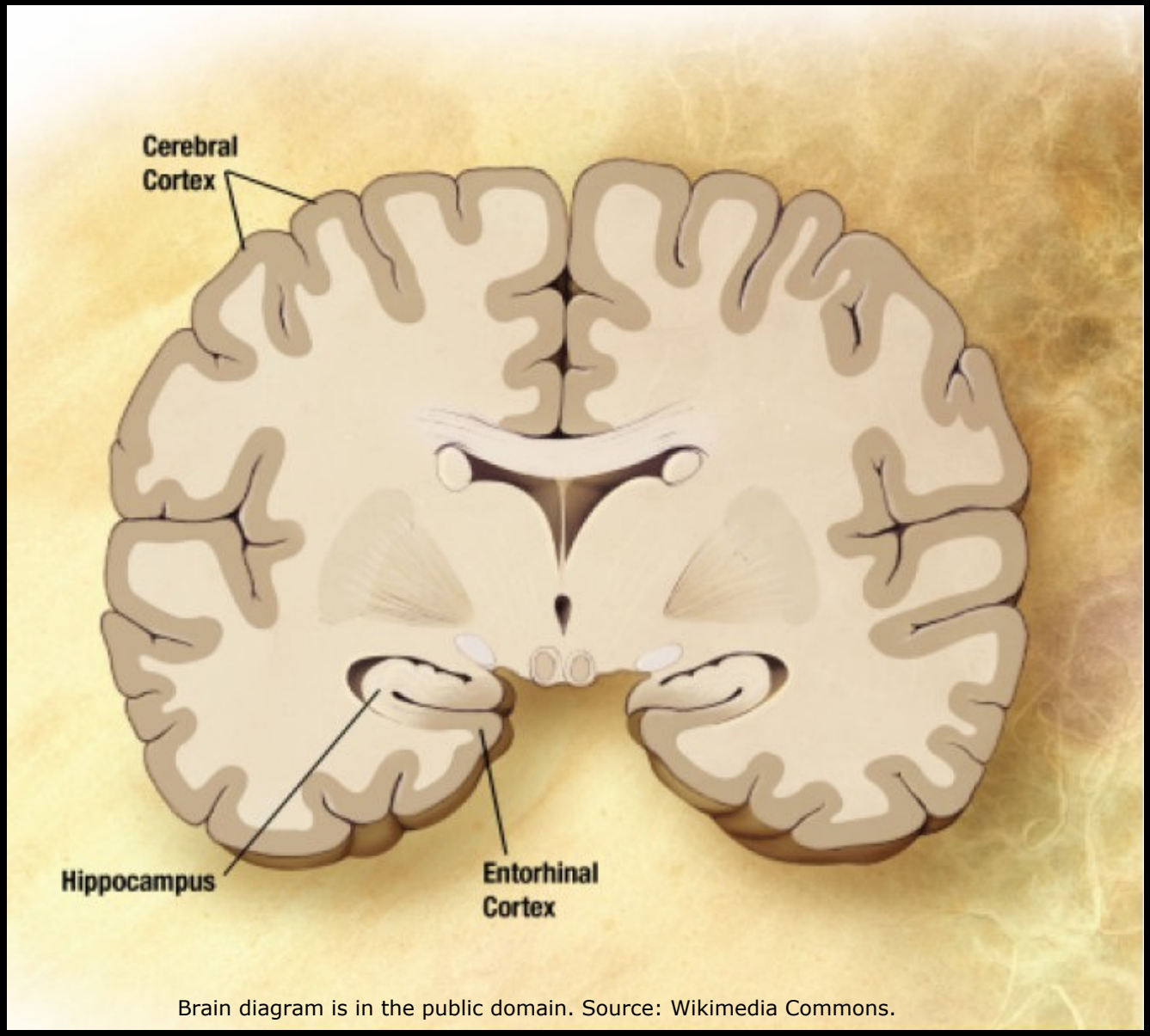
Get input from vision, vestibular info, etc.



Each cell tuned to a diff direction; A population of these cells can represent any direction of the 360° range.

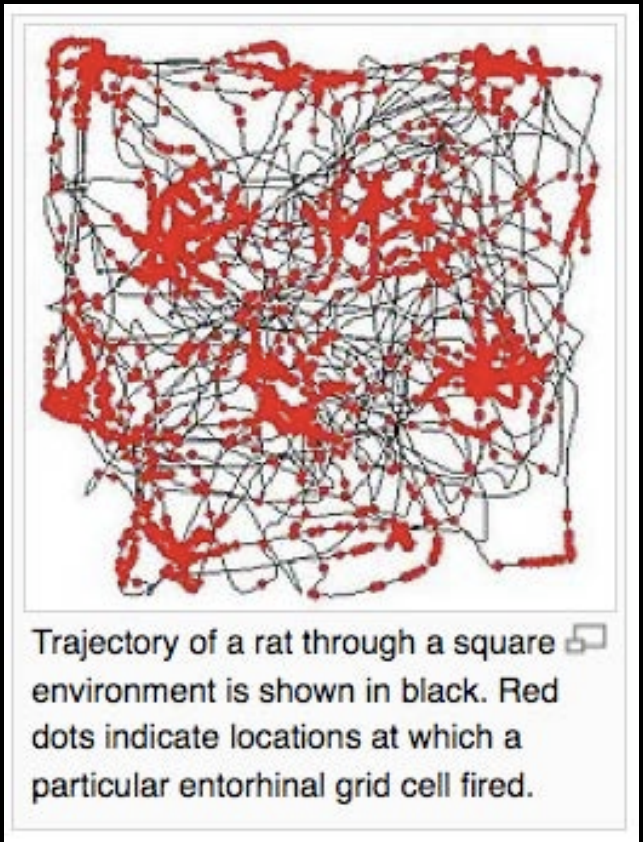
But the *coolest* navigation-related cells are…..

Grid cells in entorhinal cortex

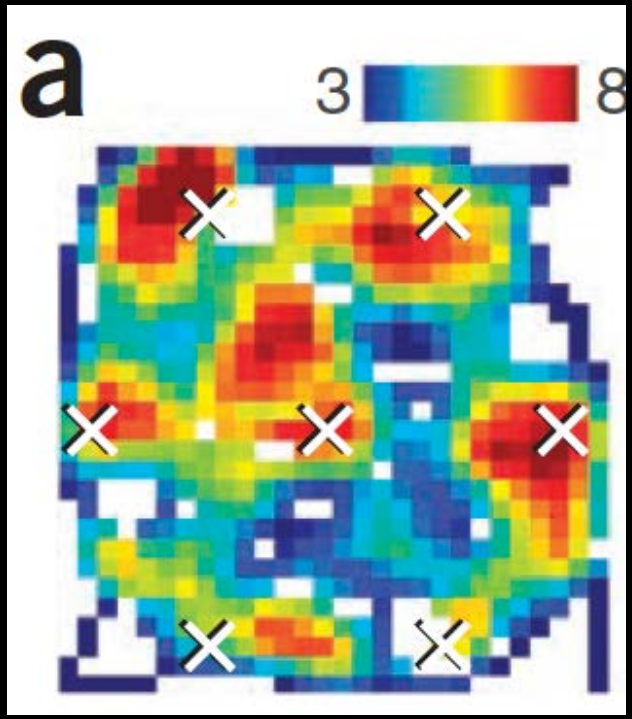


Brain diagram is in the public domain. Source: Wikimedia Commons.

Hexagonal “Grid Cells” in Entorhinal Cortex



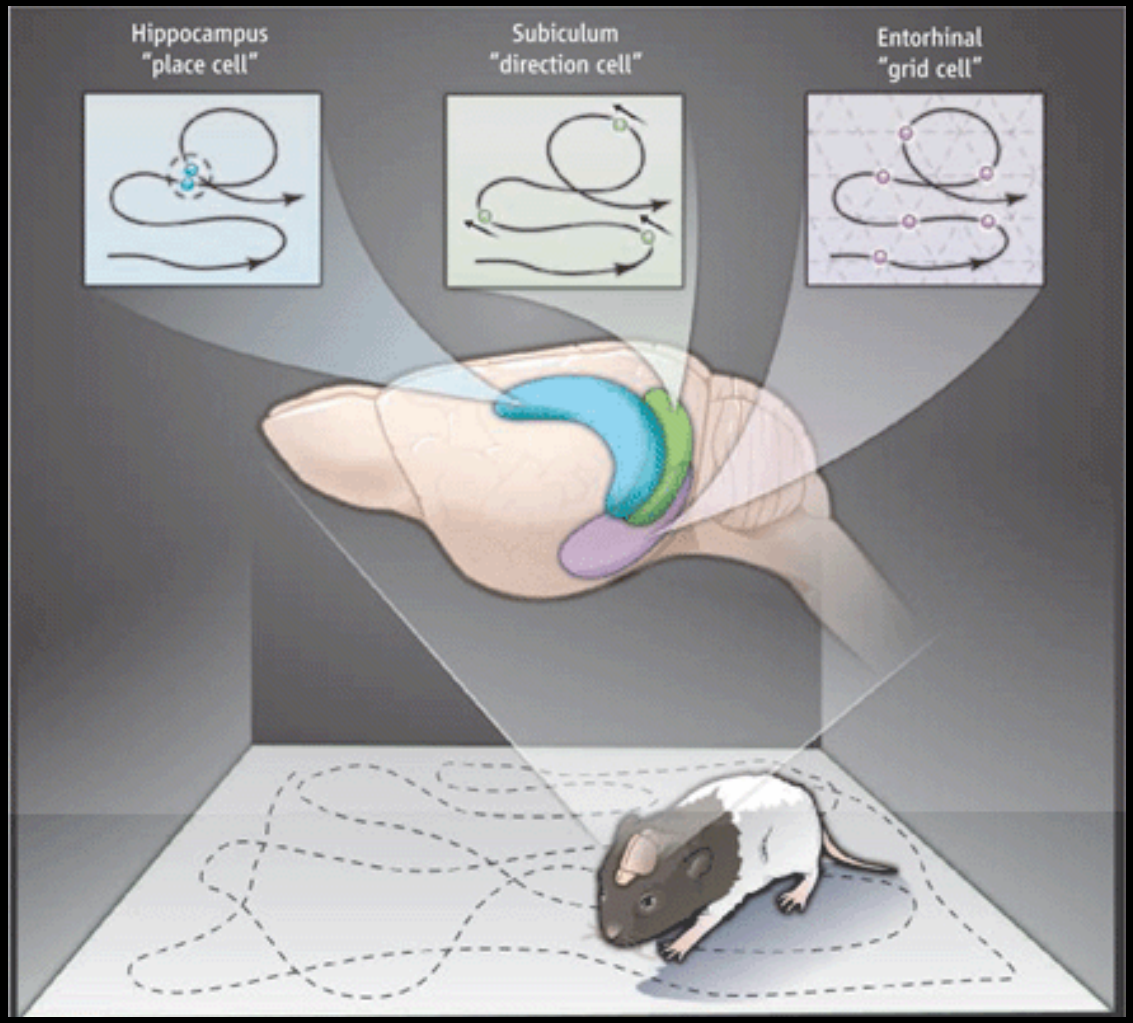
Trajectory of a rat through a square environment is shown in black. Red dots indicate locations at which a particular entorhinal grid cell fired.



The 2014 Nobel prize for the work on place cells and grid cells: O’Keefe and the Mosers

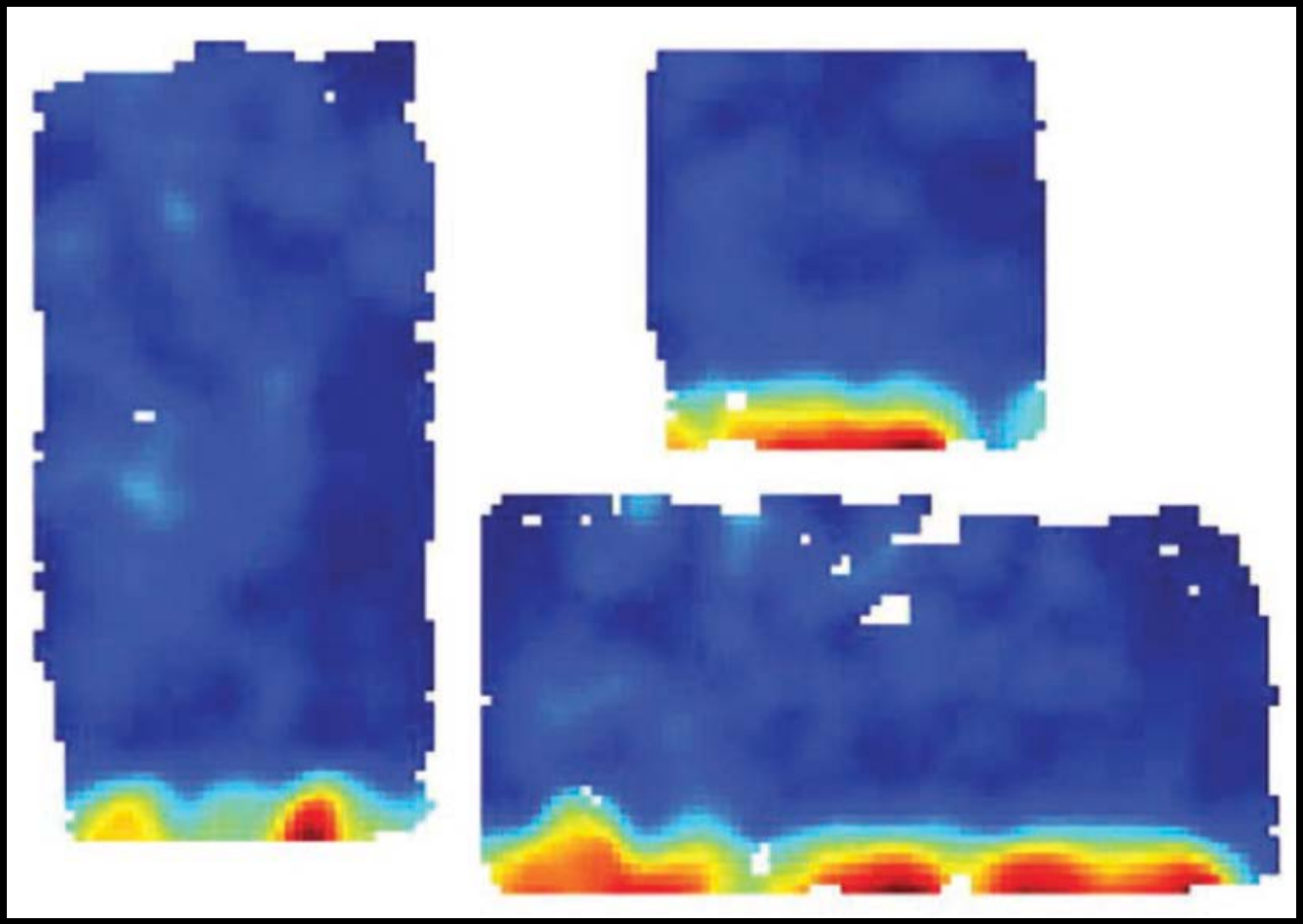
- Thought to support the coding of metric distance as an animal moves around in its environment.
- Especially important for path integration” or “dead reckoning”: use HD cells and grid cells to calculate a displacement vector.

Place, Direction, & Grid cells



- And there is one more kind of cell….

Border cells



What are these cells doing?

- They are coding your position relative to navigational obstacles.
- They care about the shape of surrounding space

sound familiar?

it turns out the shape of space plays a special role in navigation……

Reorienting
(after becoming disoriented in a known environment)

- You come up from the subway in Manhattan, and you know what stop you are at, but you don't know *which way is which!*

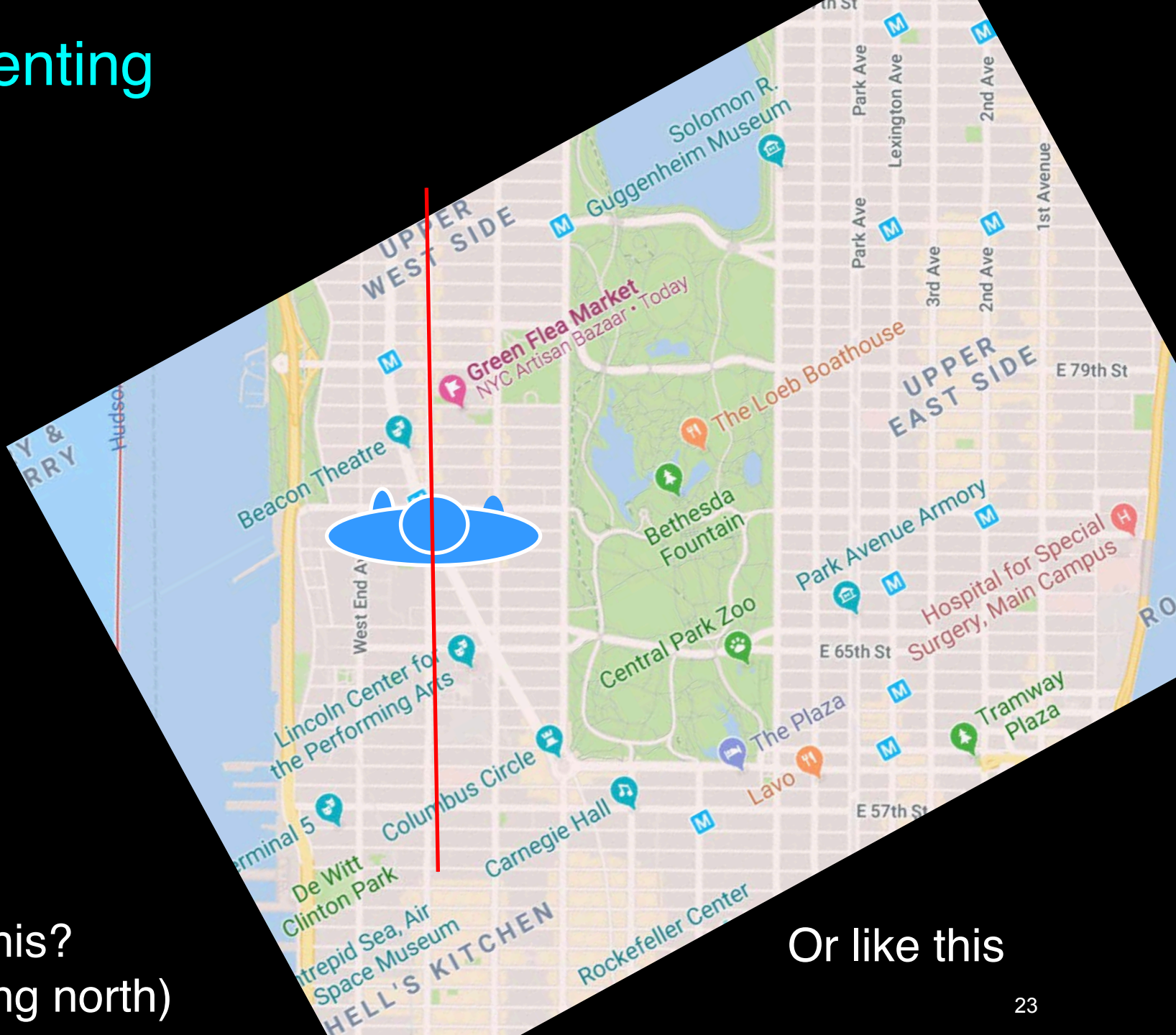
- The modern human version of a classic problem animals face……

Reorienting

You are standing there.
You have a cognitive map

And you know your location in it .
And you are looking down a street.
But how should your mental map be aligned with the street?
Is it like this?

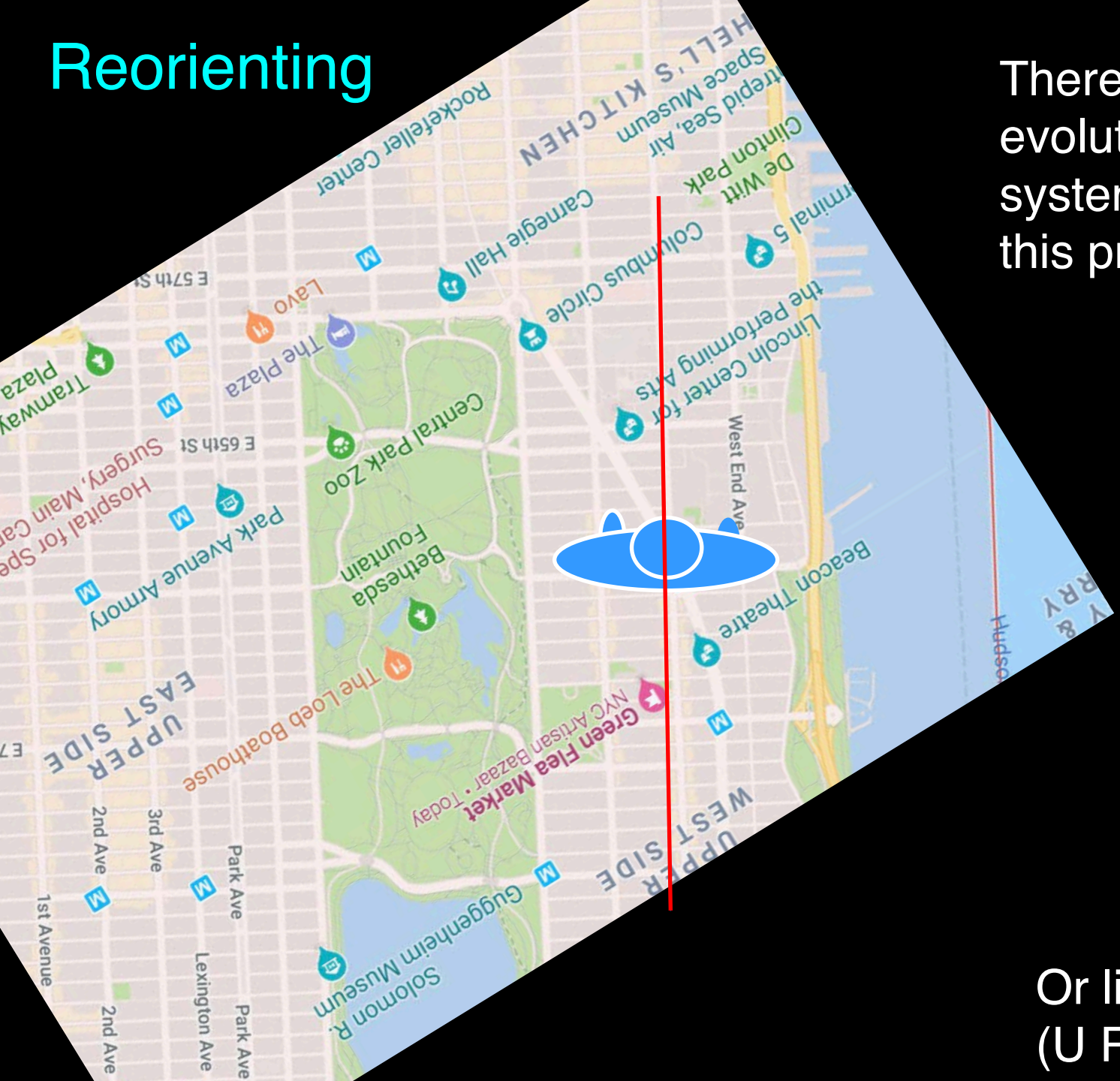
Reorienting



Is it like this?
(U R facing north)

Or like this

Reorienting

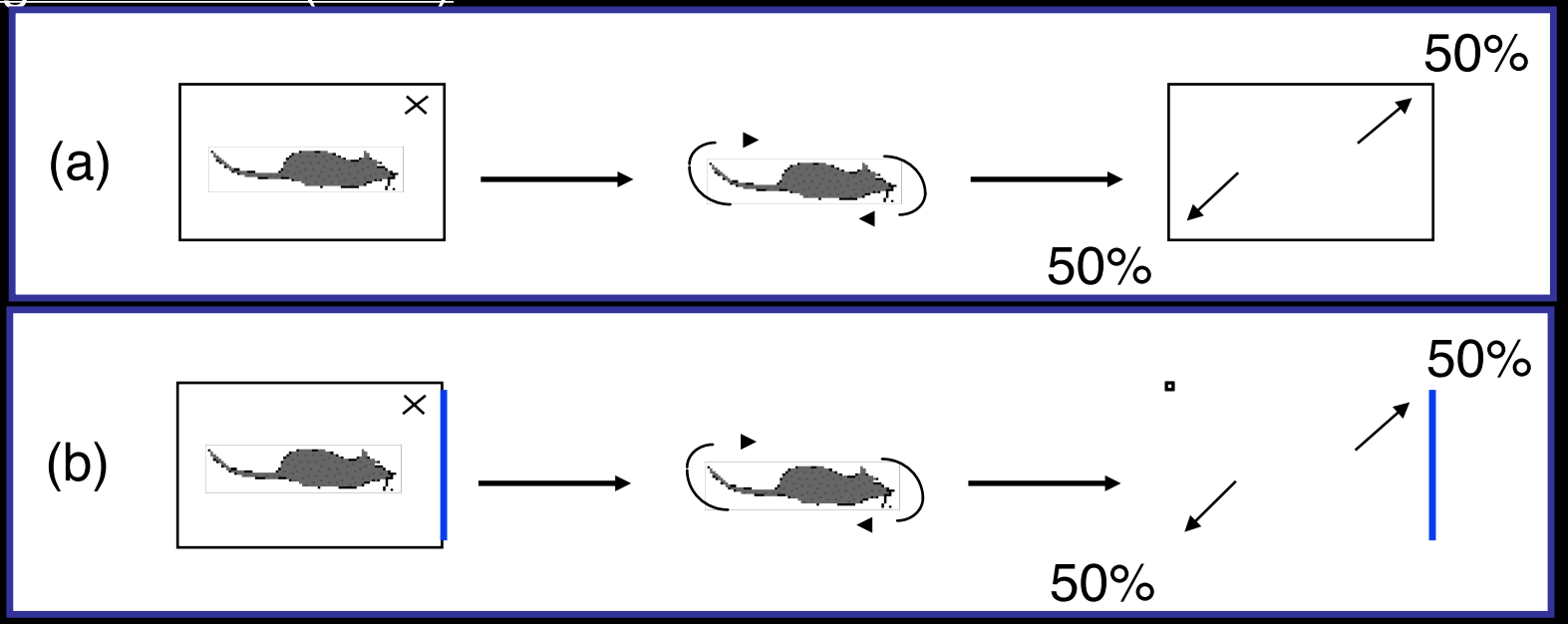


There is an evolutionarily old system for solving this problem…..

Or like this
(U R facing south)

Reorientation and The "Geometric Module"

Cheng & Gallistel (1986)



Hermer & Spelke (94)

- Same result for 18 - 24 month old infants.
- Same result for adults when performing a verbal shadowing task.

Some pushback on this claim, but it is partly true, and the idea of info. encapsulation is influential.

Idea

- "Geometric Module" uses ONLY spatial layout to orient animal/baby in environment
- Evolutionary rationale: Layout of environment is unchanging, colors, odors, etc. are not
- Example of "informational encapsulation" in cognitive modularity:

  Even though the information is available, this system does not have access to it

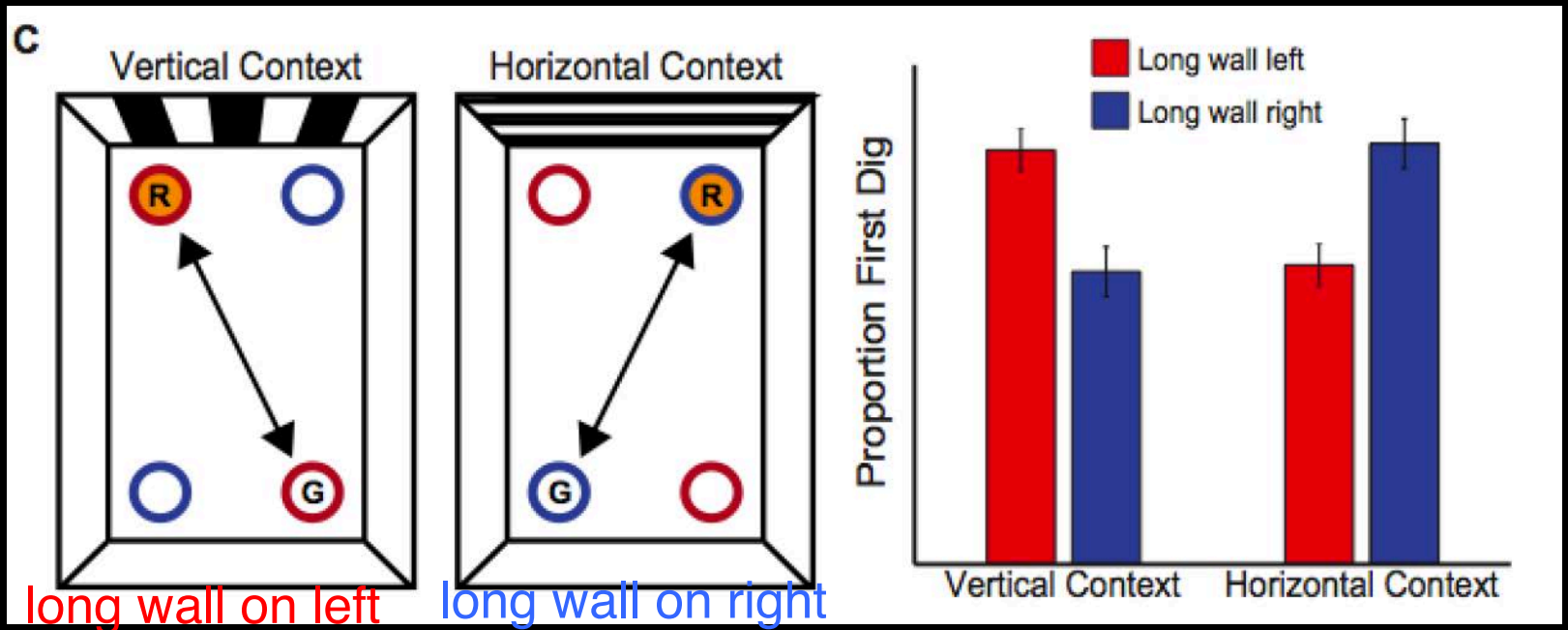
When Lost, Need to Answer Two Questions

1. Where am I? (Place recognition)
2. Which way am I facing in that place? (Heading Direction)

General finding: "Geometric" cues dominate for heading (2).

Question: Diff cues used for place rec'n (1) and heading (2)?

Julian et al. (2015): Train mice to do both tasks, two places.



Result: Mice use features (vert vs horiz) to identify the place.

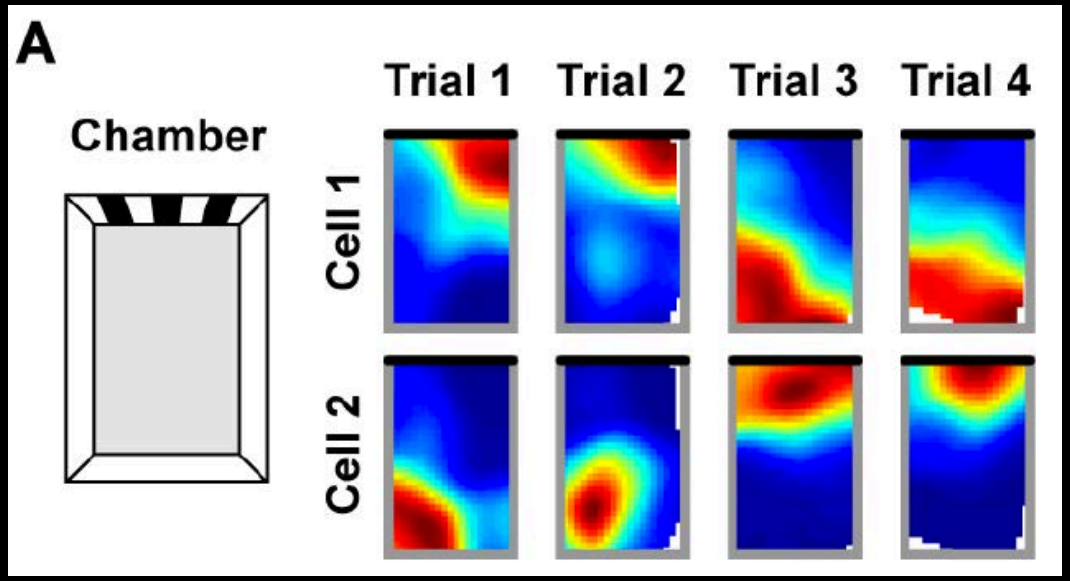
But they still search 50/50 in the opposite corners! (data not shown here)

So: Mice use features for place recognition, but only geometry (not features) to determine orientation in that same known place!

What do Place Cells do during Reorientation?

Keinath et al (2017)

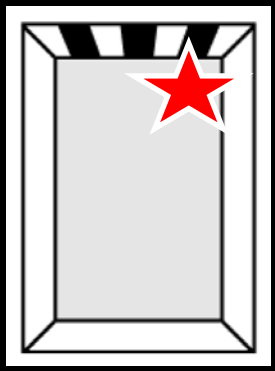
- Mice forage for crumbs in a rectangular box.
- Disorient mouse before each trial.
- Place cells have fields in particular locations in box



- But sometimes they are off by 180 degrees, even though stripes should could resolve ambiguity.
- When one cell is rotated 180 degrees, so are others.
- How does this relate to behavior?

What do Place Cells do during Reorientation?

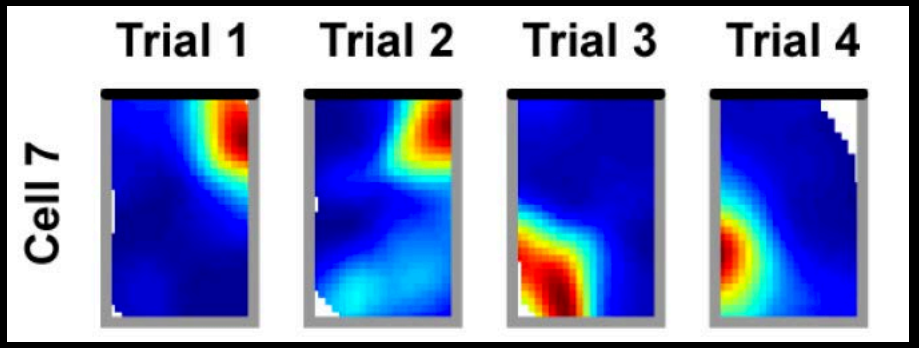
Keinath et al (2017)



- Train mouse on classic reorientation task, disorienting the mouse before each trial, while recording from hippoc. place cells.

- As before, a given cell flips 180 degrees from trial to trial, despite disambiguating stripes.

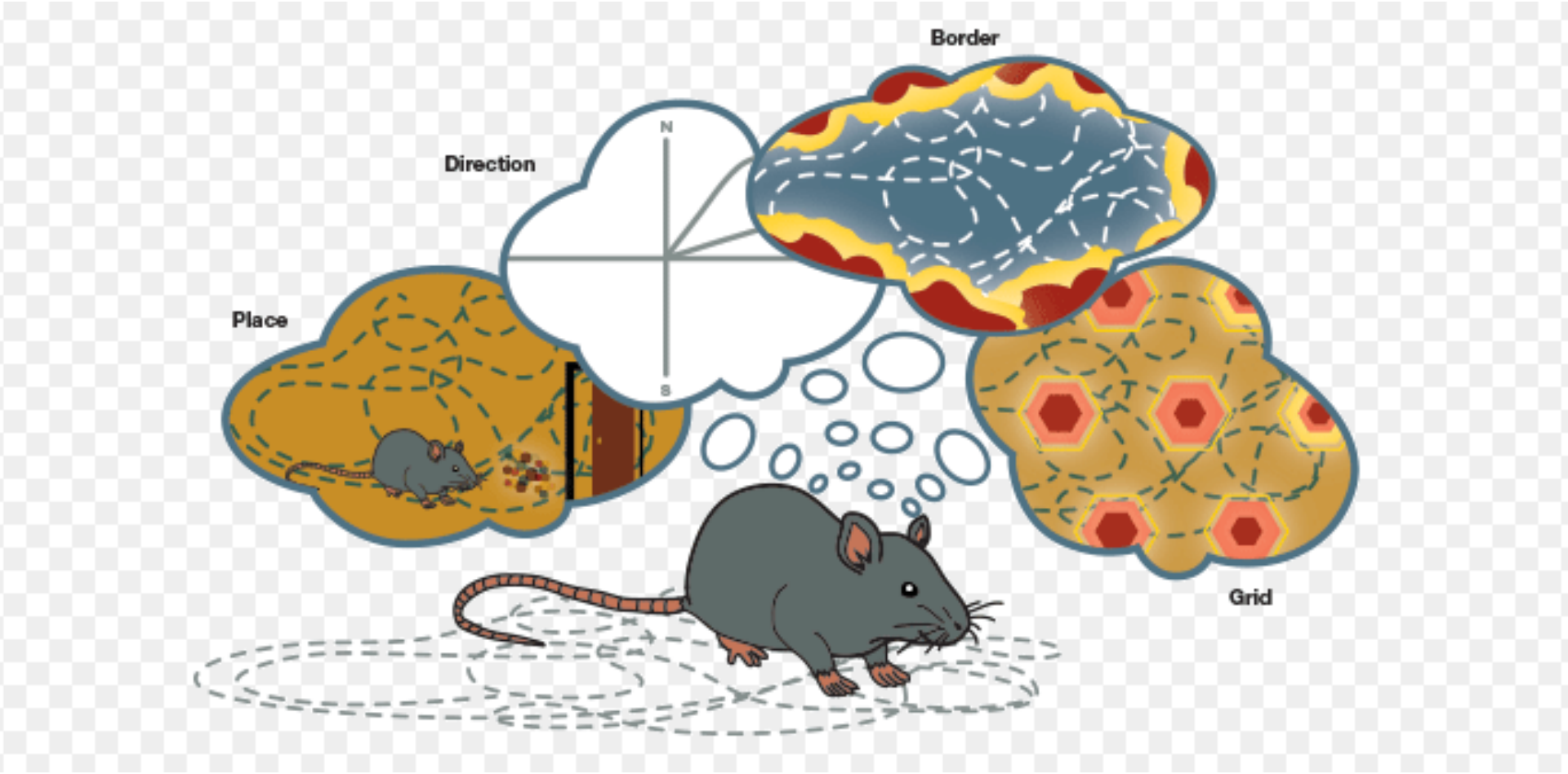
(HD & Grid cells do same)



- Orientation of place fields predicts where mouse looks for the food!

- Shows a strong link between place cells and behavior.

Recap: Four Kinds of Space/Navigation Cells



Lecture 9: Navigation II

Monday:

I. What do we need to know and do to get around?

II. The PPA, a region selectively responsive to scenes.

III. The rest of the "scene network": PPA, RSC, & OPA

Today:

I. Neurons that track your location and heading:
place, grid, border, and head direction cells.

II. Reorientation

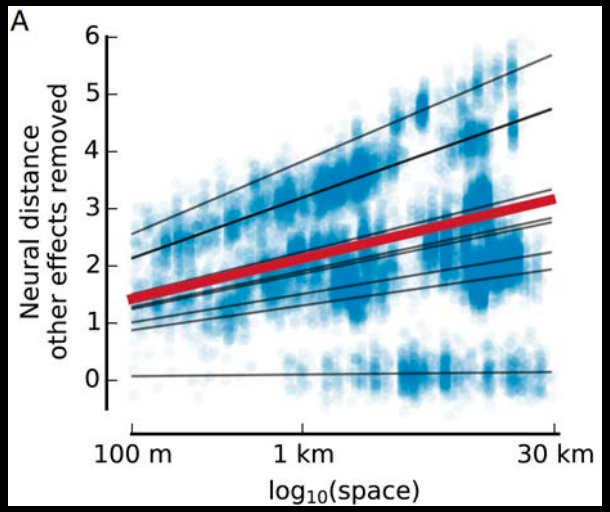
III. Not "just" for representing space…..

Not "just" for Space?
Nielsen et al. 2015

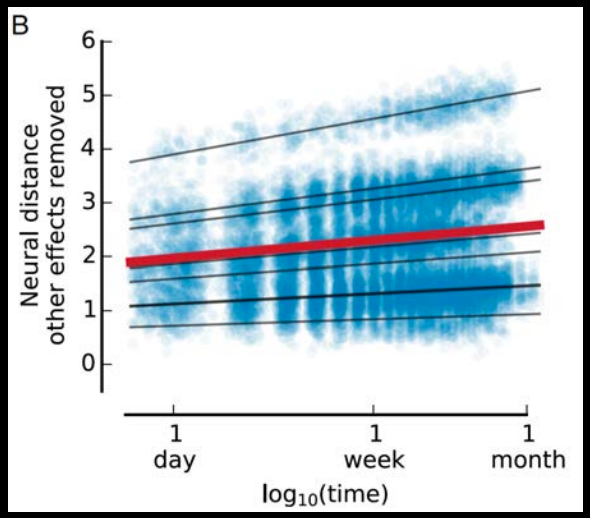
- Participants wore a "lifelogging" device for a month, recording GPS location and pictures.

- Then scan w/ fMRI while looking at their pix, "reliving" the experience.
- Extract pattern of response across voxels in hippocampus for each relieved experience.
- Is the pattern more similar for remembered events nearby in…..

Space?



Time?

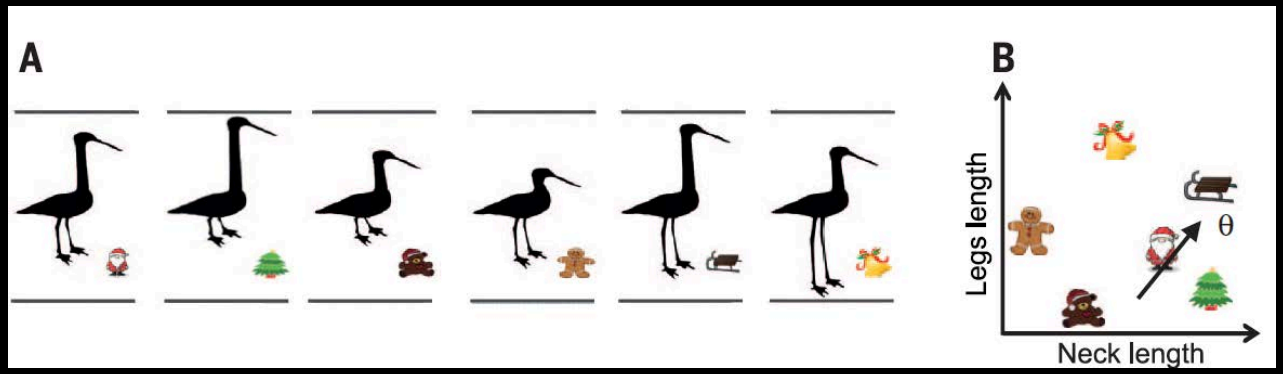


So: hippocampus holds large spatial scale reprs of space and time, giving structure to our memories, for distances betwn 100 m and 30 km and for times between 15 h and 1 mo.

 Source: PNAS September 1, 2015 112 (35) 11078 11083; https://doi.org/10.1073/pnas.1507104112.

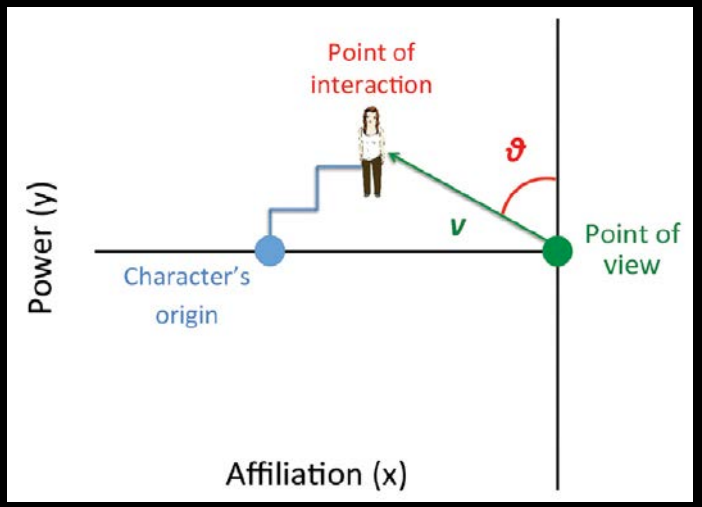
Not "just" for Space?
even more radical….

- Grid-like representation of 2D *conceptual* spaces in many brain regions (navigational and other)



Constantinescu et al 2016

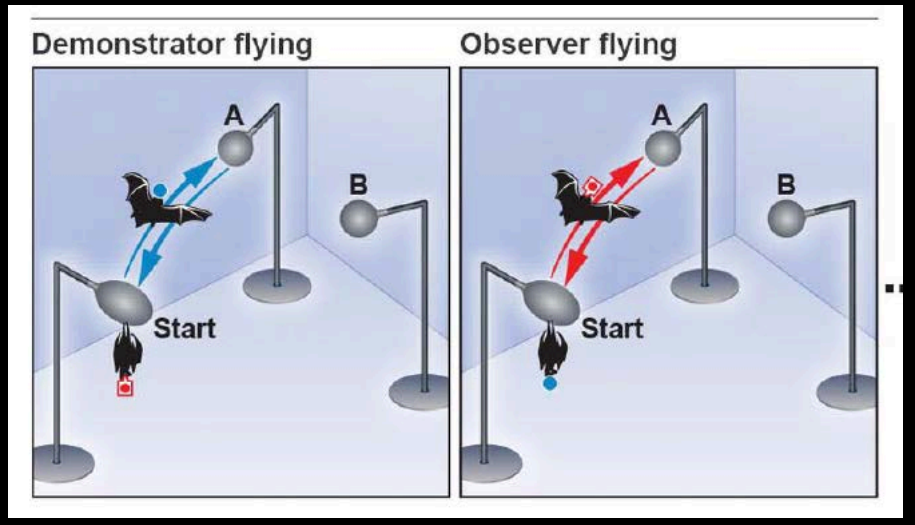
- Participants were lead characters in a role-playing game entailing interactions with virtual characters.
fMRI Hippocampal activity fit a 2D model of "social space" framed by power and affiliation.



Tavares et al 2015

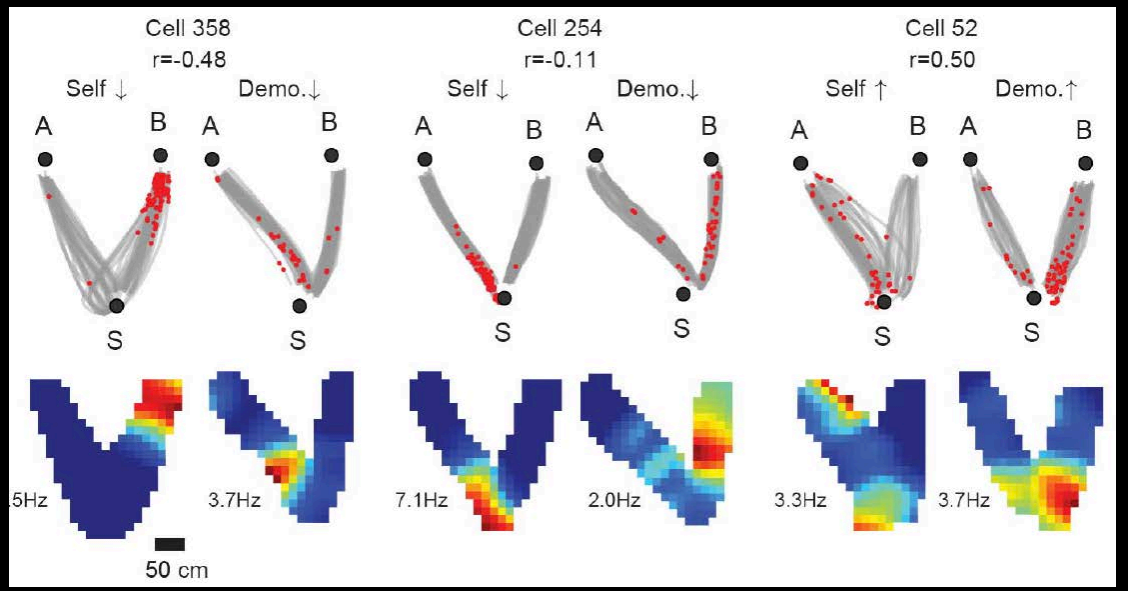
Not "just" for Space?
Omer et al, 2018

- Place cells in hippocampus of bat represent not just own location, but…..



The location of another bat!

"Social place cells"!



Omer et al 2018

Not just for Representing, but for Thinking!

Johnson & Redish 2007

- As rats run in maze, record from multiple hippocampal place cells, and estimate from their response the position being represented.

- When a rat reaches an intersection in a maze, it pauses as if considering which path to take.

Watch what happens in his hippocampus as he decides……

Not just for Representing, but for Thinking!

Johnson & Redish 007

- As the rat decides, place cells fire corresponding to positions along *possible future paths*, the apparent neural correlate of the rat's *thinking about locations that would be encountered if it traveled down each route*…..

The Fundamental Problems of Navigation

Best Current Guesses of brain regions involved

I. Where am I?

- Recognize a familiar location — RSC

  e.g. this is my living room

- Even if unfamiliar: What *kind* of place is this? — PPA & OPA

  a living room, a city street, a mountain, a desert

- Layout of current location — PPA & OPA

  e.g. I am next to long wall of rectangular room

II. How do I get from here (A) to there (B)?

- If you can see or hear B, go toward it ("beaconing").

  E.g. head toward lighthouse/foghorn, or landmark.

  Where am I in that map, and where is B

- Need a mental map of your world….. — Hippocampus, place cells
- Also need to know current heading w/ respect to that map

  to determine necessary heading to get to B — RSC, HD cells

- What routes are possible from here? — OPA, PPA, etc

  "navigational affordances" like doors and halls, getting around barriers — boundary cells

- Regaining bearings when lost ("reorientation"). — RSC?/ HD cells

9.13 The Human Brain
Spring 2019