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 am 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) with 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!
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• 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

Place cells in hippocampus

VIDEO
Roddy Grieves: [Place cell (rat hippocampus CA1) activity recorded over 50 minutes of foraging](https://www.youtube.com/watch?v=dQw4w9WgXcQ) (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?

• 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

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Place cells in hippocampus

Do humans have these?
Place Cells in Human Hippocampus

- Recorded from individual neurons human neurosurgery patients while they navigated a virtual space.
Place Cells in Human Hippocampus

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

![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.](https://ocw.mit.edu/fairuse)
Place Cells: YOU ARE HERE

If you want to go here, you also need.

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.
Heading direction cells: you are facing this way.

Place Cells: YOU ARE HERE

But the *coolest* navigation-related cells are.....
Grid cells in entorhinal cortex
Hexagonal “Grid Cells” in Entorhinal Cortex

- 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.

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

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Place, Direction, & Grid cells

- And there is one more kind of cell....
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 \textit{which way is which}!

• The modern human version of a classic problem animals face......
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?
Is it like this? Or like this (U R facing north)

Reorienting
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.

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?

Figures © Julian, Keinath, Muzzio, and Epstein. All rights reserved. This content is excluded from our Creative Commons license, see https://ocw.mit.edu/fairuse. Source: PNAS May 19, 2015 112 (20) 6503 6508; https://doi.org/10.1073/pnas.1424194112
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.

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Recap: Four Kinds of Space/Navigation Cells

Illustration of types of navigation cells © Geetha Yadav/ Bio-Rad Laboratories. All rights reserved. This content is excluded from our Creative Commons license, see https://ocw.mit.edu/fairuse. Source: The Brain’s GPS-Unraveling the Functioning of Our Navigation System. Bioradiations. November 11, 2014.
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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.
Not “just” for Space?
even more radical….

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

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.

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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”!

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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......

Rat animation figure © A. Johnson and A.D. Redish. License: CC BY-NC-SA. Source: JNeurosci 7 November 2007, 27 (45) 12176 12189; DOI: https://doi.org/10.1523/JNEUROSCI.3761-07.2007
• 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 boundary cells
  “navigational affordances” like doors and halls, getting around barriers
- Regaining bearings when lost (“reorientation”).  RSC?/ HD cells