PSYCHONOMIC SOCIETY
62ND ANNUAL MEETING

A Computational Systems Neuroscience Perspective on Interacting Memory Systems

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Three Major Questions

1. Do hippocampal place fields directly support spatial navigation?
2. Is the hippocampus a predictive learning system?
3. What are sources of forgetting in hippocampus and neocortex?

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Three Major Questions

1. Do hippocampal place fields directly support spatial navigation?
   No – parietal lobe does, hippocampus takes episodic snapshots of locations.
2. Is the hippocampus a predictive learning system?
   No – episodes cannot be predicted – cortex does predictive learning at *semantic* level.
3. What are sources of forgetting in hippocampus and neocortex?
   Initial transient decay of synaptic plasticity – after 1 day, interference.

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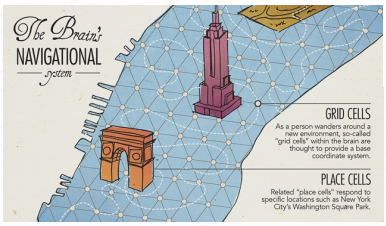
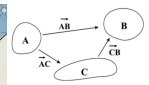
Space -> Navigation in the Brain





EC = entorhinal cortex

HC = hippocampus

The "Standard Model": EC and HC essential for navigation (e.g., Nobel prizes, 2014 for O'Keefe & Mosers)

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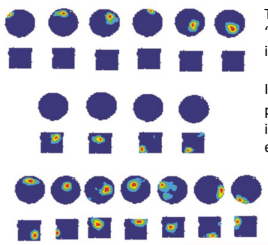
Hippocampal place fields "remap"

Circle only

Square only

Different locations



There is no consistent "language" for space in HC

Imagine if your Nav program talked to you in a different language every time!

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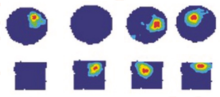
"I want to go up, left"

Sure, let's see.. uhh, are you in a round or square room, with a white or black card, with a window here or there, with this or that goal..... *ad infinitum?*



Place fields are great for remembering *specific details* but *terrible* for a *general-purpose* representation of space!

Space in HC is represented differently in every different place – there is no *consistent* representation of space!

Practically: *you* have to decode place cells separately in each and every different room – how is rest of rat's brain decoding HC output? Same cells fire in every different location..

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Lesion Data?

HC: Little evidence of navigation deficits *independent of memory*
(Eichenbaum & Cohen, 2014; Ekstrom & Ranganath, 2017)

EC: lesions have surprisingly little effect overall (on place cells, on navigation, etc)

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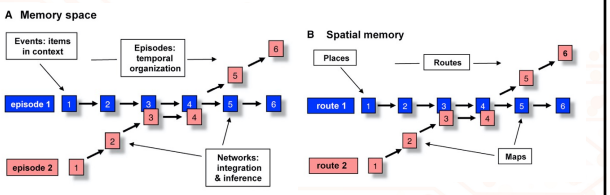
Hippocampus / MTL is for *Memory*
(Eichenbaum & Cohen, 2014; Ekstrom & Rananath, 2017)



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Grid Cells?

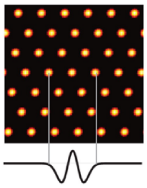
Standard model:
Continuous Attractor (Burak & Fiete, 2009): grid imposed by classic "mexican hat" lateral conns, with *uniform* velocity input.

Essentially a "symmetry breaking" pattern formation w/ all neurons receiving *same* input!

Only works w/ uniform input – not a general-purpose spatial code.

Many sources of error: Rueckemann et al, 2020

In sum: grid cells might help with path integration, but not general-purpose "base coordinate system"!



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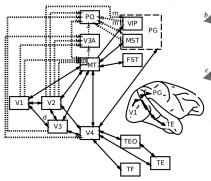
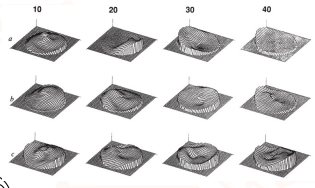
Parietal Lobe is for Space!

Ungerleider & Mishkin, 1982

LIP / IPL: R. Andersen et al

Pouget, Snyder, Zipser: smooth spatial basis





(and action: Goodale & Milner, 1992..)

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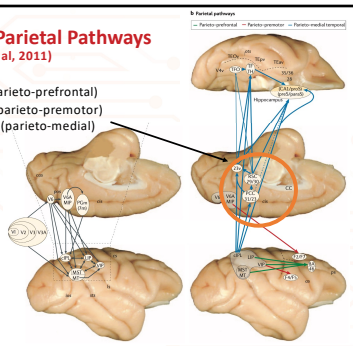
Three Parietal Pathways
(Kravitz et al, 2011)

1. Looking (parieto-prefrontal)
2. Reaching (parieto-premotor)
3. Navigating (parieto-medial)



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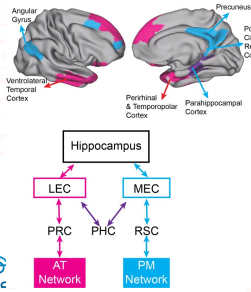
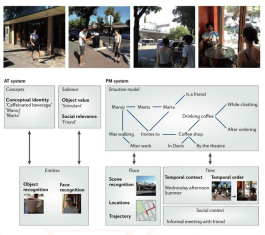
PM / AT Networks (Ranganath)





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Episodic memory and the hippocampus

Dominant theory, extensive data (e.g., HM): Hippocampus binds temporal context and other content to form distinct, *pattern separated* representations of episodes (events)

Each hippocampal representation is unique, distinct from all others (i.e., a "hash code" of the event, like a QR code on your phone)

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Is the Hippocampus a Predictive Learner?

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Long history of predictive theories

Gray, 1982; Vinogradova, 2001; Lisman & Grace, 2005: *scalar mismatch between prediction and actual*:

- "it is proposed that … the septo-hippocampal system (SHS) acts as a comparator: it compares predicted to actual sensory events and activates the outputs of the BIS when there is a mismatch or when the predicted event is aversive"

Levy, 1996; Wallenstein & Hasselmo, 1997; Jensen & Lisman, 1996; Tsodyks et al, 1996; Rolls, 2013; Schapiro et al, 2017; **Stachenfeld et al, 2017**: *predict next step(s) in sequence:*

- "We argue instead that the [hippocampal] map is essentially predictive, encoding expectations about an animal's future state. This view resonates with earlier ideas about the predictive function of the hippocampus [lots of *additional* cites]

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Can you predict unique events?

Hippocampus cannot generate predictions because it has a highly reduced representation of *lots of randomly related info* and its job is to *pattern separate* to encode *unique* memories of even similar events.

By definition, unique events are not predictable!

Instead, sensory cortex can predict what happens next because: a) physics, b) it has extensive, systematic encoding of current and recent prior state at multiple levels of abstraction.

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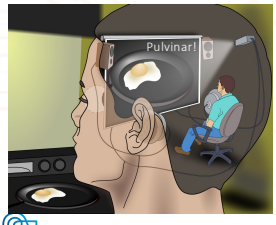
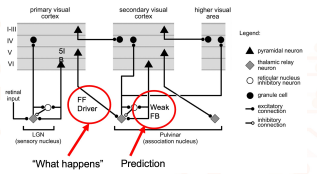
Predictive learning in Neocortex & Pulvinar

(O'Reilly et al, 2021; JOCN)





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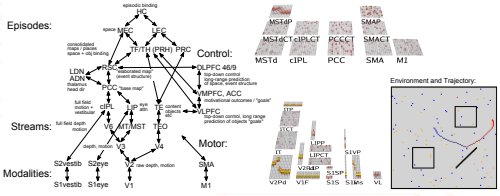
Multimodal Action-Cued Predictive Learning in Parietal Pathways



- Multimodal sensory prediction: full field depth, foveal vision, somatosensory (whiskers, vestibular), body state (thirst, hunger)
- Error-driven predictive learning based on action: predict next state
- New fully spiking error-driven learning (bio backprop) model!

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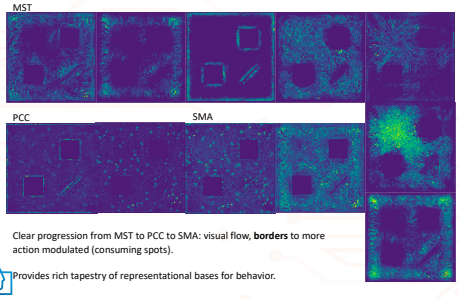
Computational Model Results



Clear progression from MST to PCC to SMA: visual flow, **borders** to more action modulated (consuming spots).

Provides rich tapestry of representational bases for behavior.

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But what about *preplay* in rodents?

Turns out it is mostly retrospective, not prospective..

Gillespie et al & Loren Frank (2021): *Hippocampal replay reflects specific past experiences rather than a plan for subsequent choice:*

- "hippocampal replay does not reliably relate to immediately subsequent choice in a spatial memory task. Instead, replay preferentially represents previous goals and places that have not been visited recently, suggesting a role in storing and updating memories rather than in directly guiding upcoming behavior."

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Reward Prediction Error (RPE; DA) -> Hip

Even if Hippocampus does not *generate* prediction error, can be sensitive to it!

Sinclair et al & Barense (2019, 2021): Prediction errors disrupt hippocampal reps and update episodic memories.

Review: Ergo, De Loof & Verguts (2020): extensive evidence for RPE effects on "declarative memory"

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Prediction error signals event boundaries?

Zacks et al (2007):

- "Perceptual systems continuously make predictions about what will happen next. When transient errors in predictions arise, an event boundary is perceived"

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Novelty, Recall, Event Segmentation, etc

Hippocampus can easily signal familiar (recalled) vs. not: novelty OK. (it just has no idea what will happen *next*..)

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Interim Summary

- Hippocampus is an episodic memory system, *binding* spatial, event, and content information into unique "hash coded" *pattern separated* representation.
- Unique representations do not support prediction (unique = unpredictable!)
- Each environment has unique spatial "map" – i.e., no map of any use at all! A map with unique topology essentially has no topology until decoded.
- Predictive learning in the parietal lobe can develop systematic, low-dimensional, graded representations supporting spatial navigation.
  - Based on thalamocortical loops?

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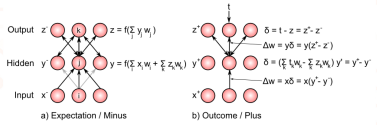
Two Sources of Forgetting

1. Synaptic weights are *constantly* changing whenever neurons are active across the synapse! This results in constant ongoing **interference.**



2. Transient changes prior to more permanent protein-synthesis dependent aspects of synaptic plasticity (stable after 24hr or so)

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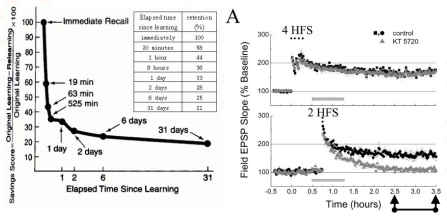
Memory Retention: Decay / Interference



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Dynamics of Synaptic Forgetting

Across learning, shared synapses are strengthened, distinct are weakened, resulting in "semanticization" of traces.

Happens in neocortex *and* hippocampus

Learning old pattern with new "goal / plan" component can produce more interference vs. previous goal / plan: potential "no think" effect?

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