

Building Hippocampal Map(s)

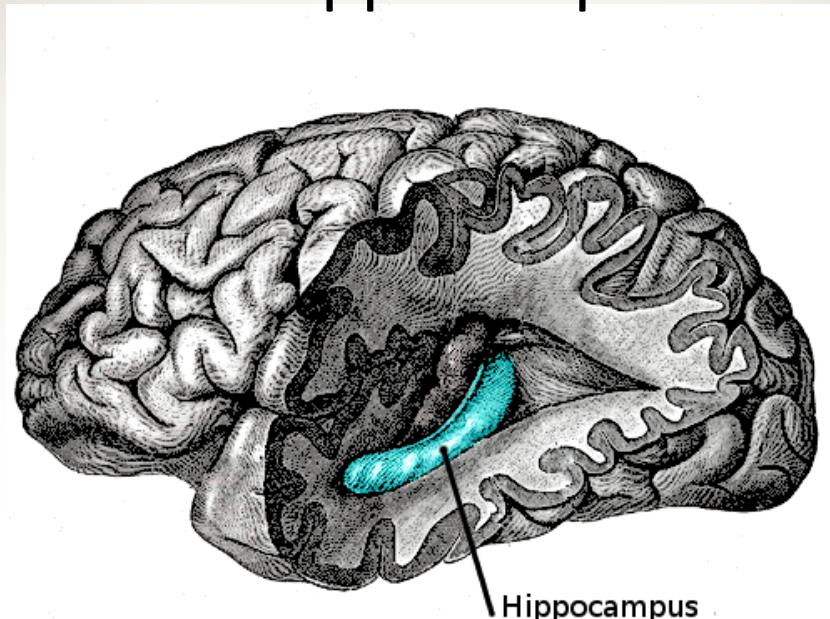
Sachin Deshmukh

Centre for Neuroscience
Indian Institute of Science

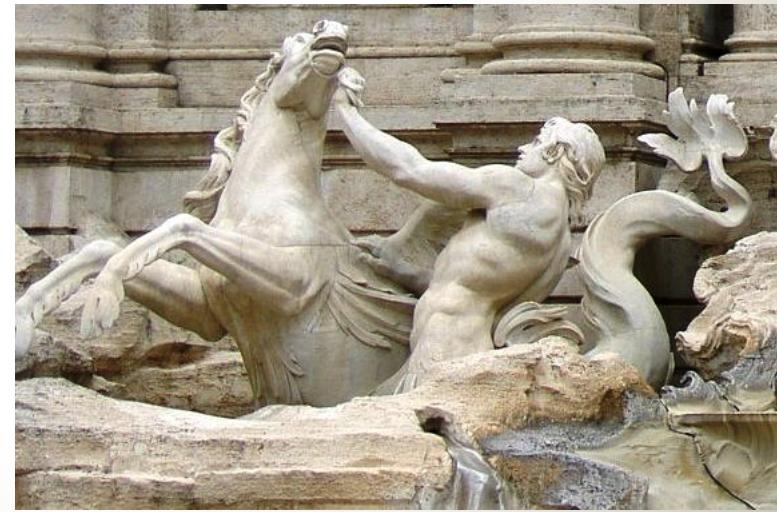
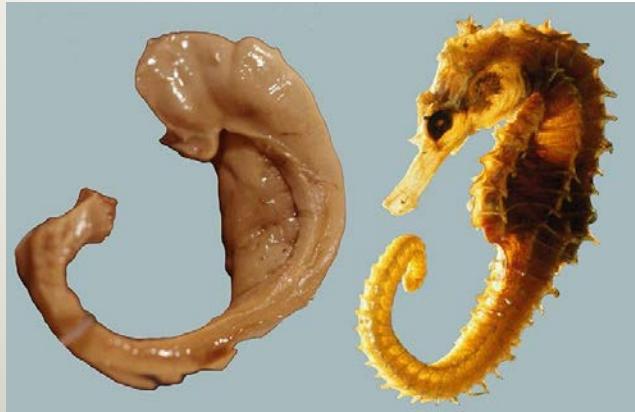
Outline

- Hippocampus and its inputs
- Hippocampal function
 - Space and memory
- How to build a spatial map

Hippocampus



Hippocampus



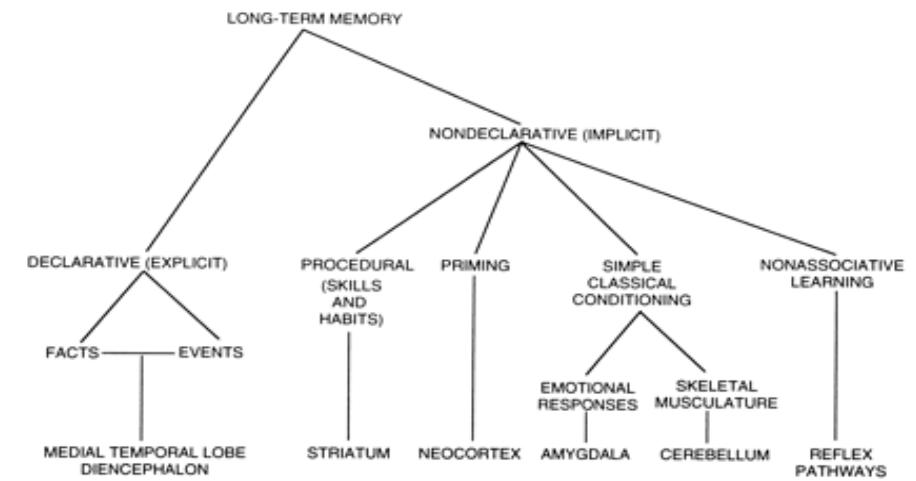
Hippocampus and memory



Henry Molaison

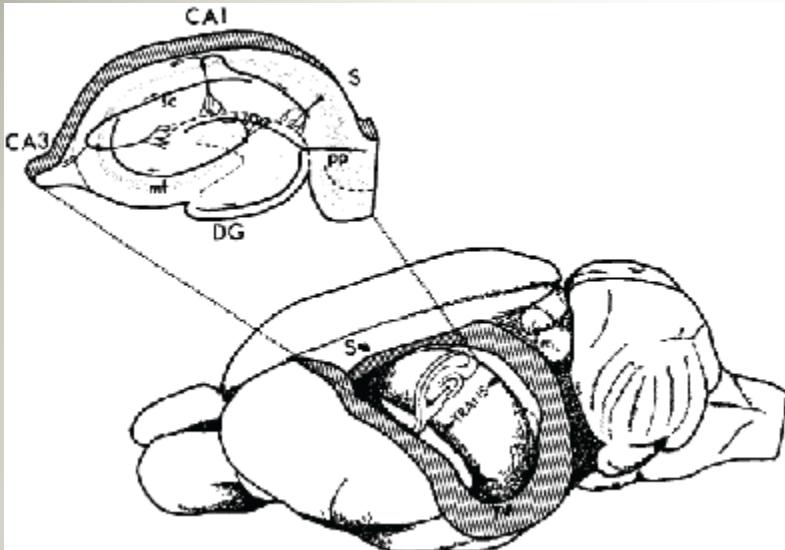
“Patient H.M.”

Scoville and Milner (1957)

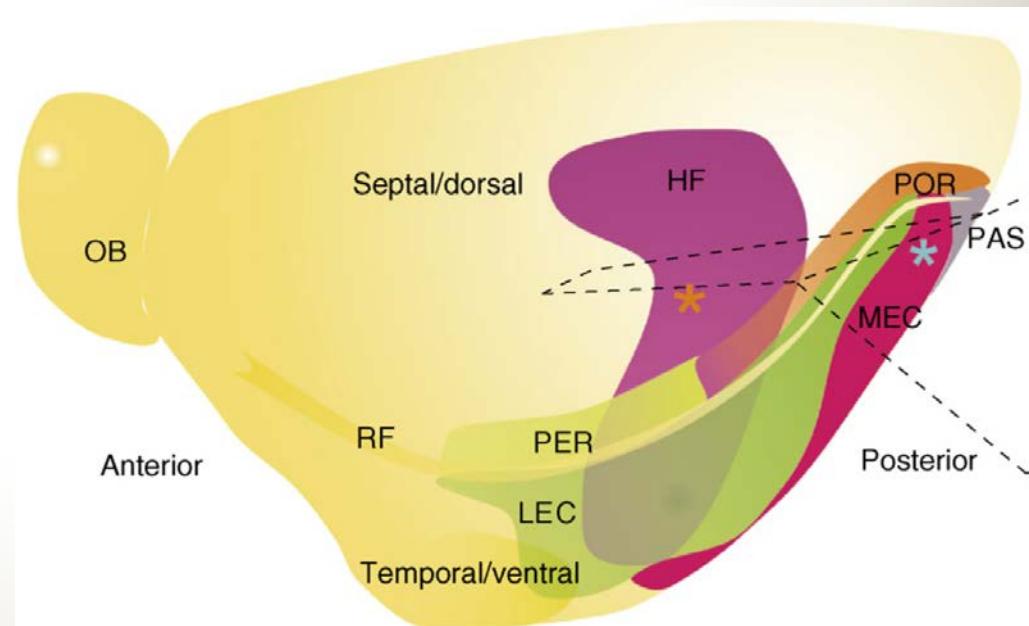
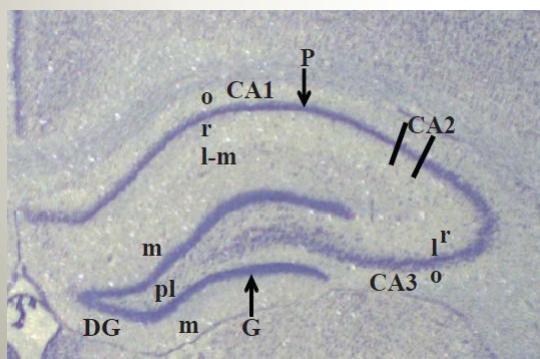
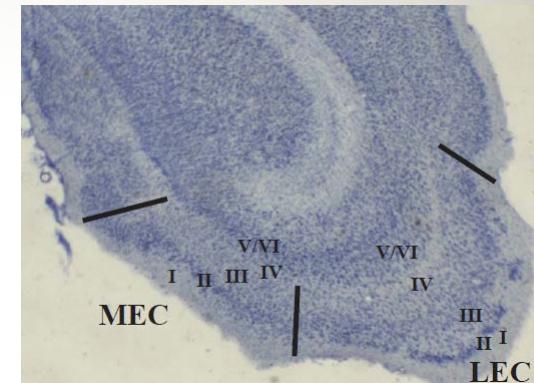


Squire and Zola (1996)

Rat brain: hippocampus and its cortical inputs

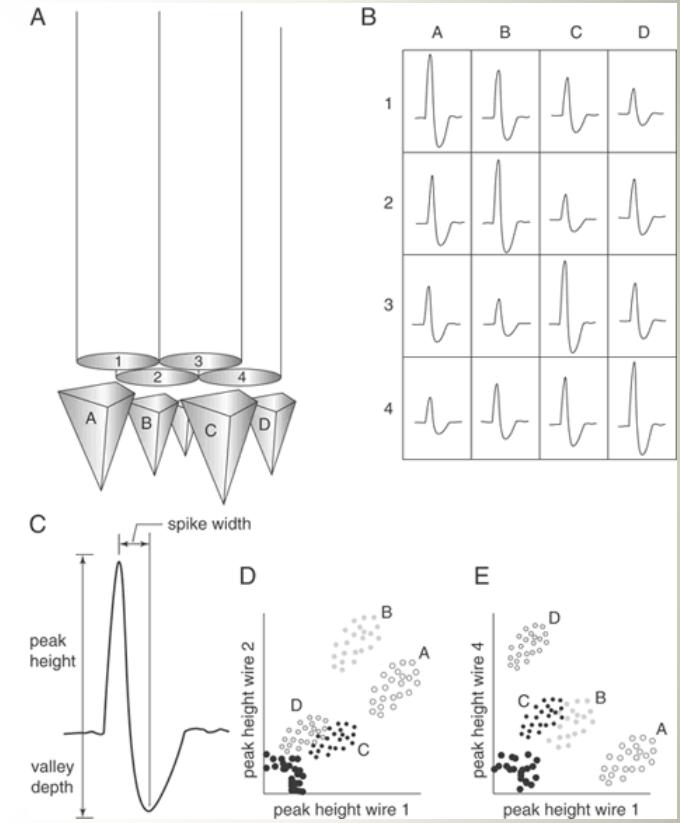
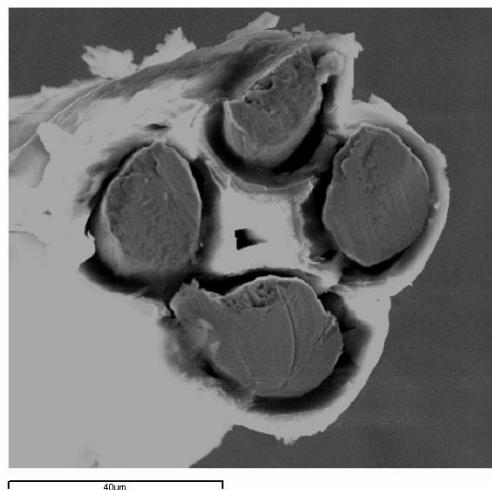
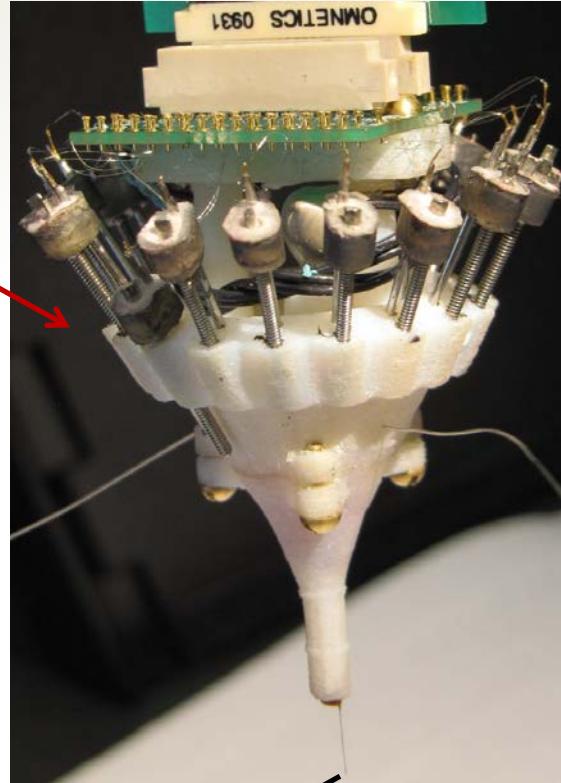


Amaral and Witter, 1989



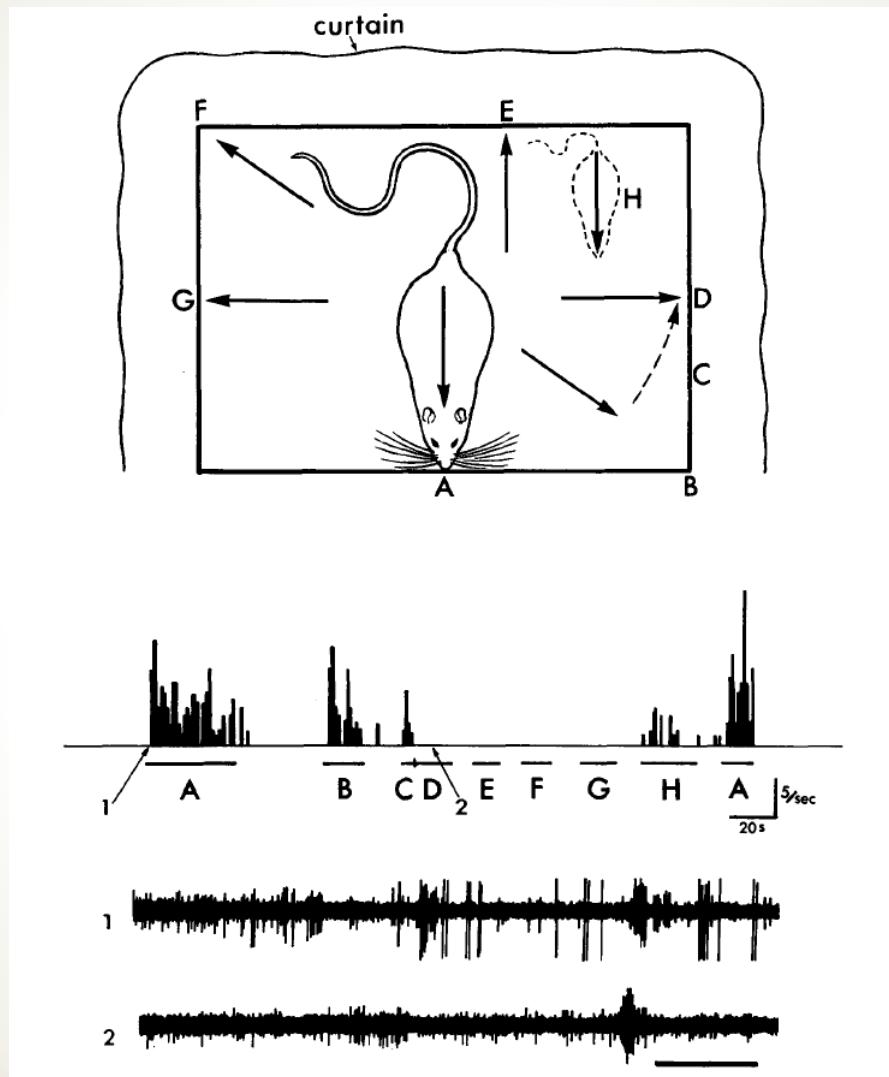
Witter and Moser, 2006

Tetrode recording



Szymusiak and Nitz, 2003

The first demonstration of place cells

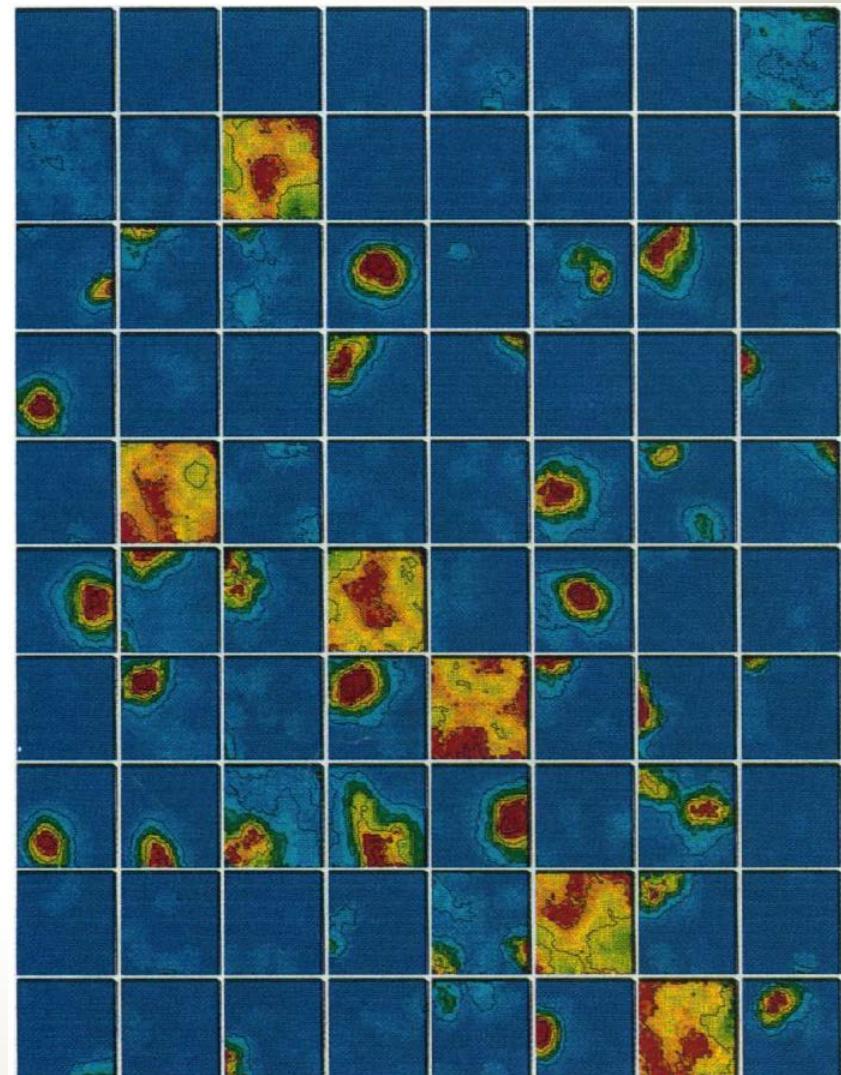
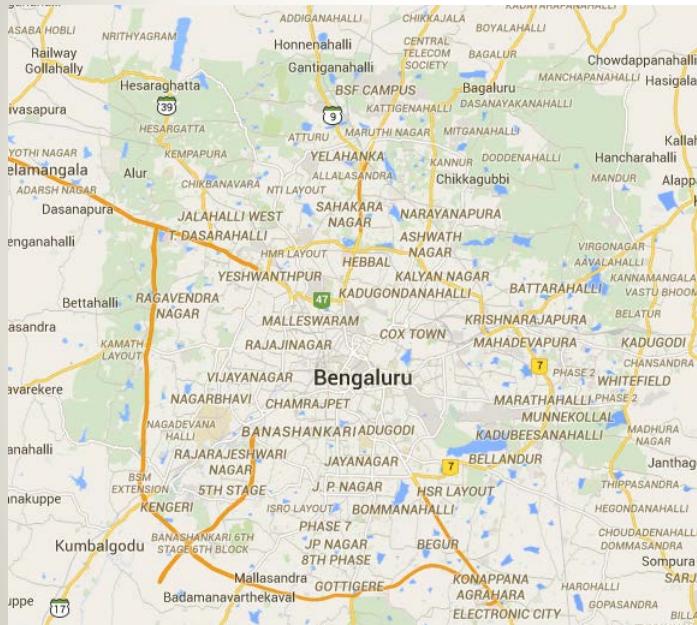


O'Keefe and Dostrovsky 1971

Place cells reliably mark the position of the animal in the environment



Place cells form a map of the environment in the hippocampus

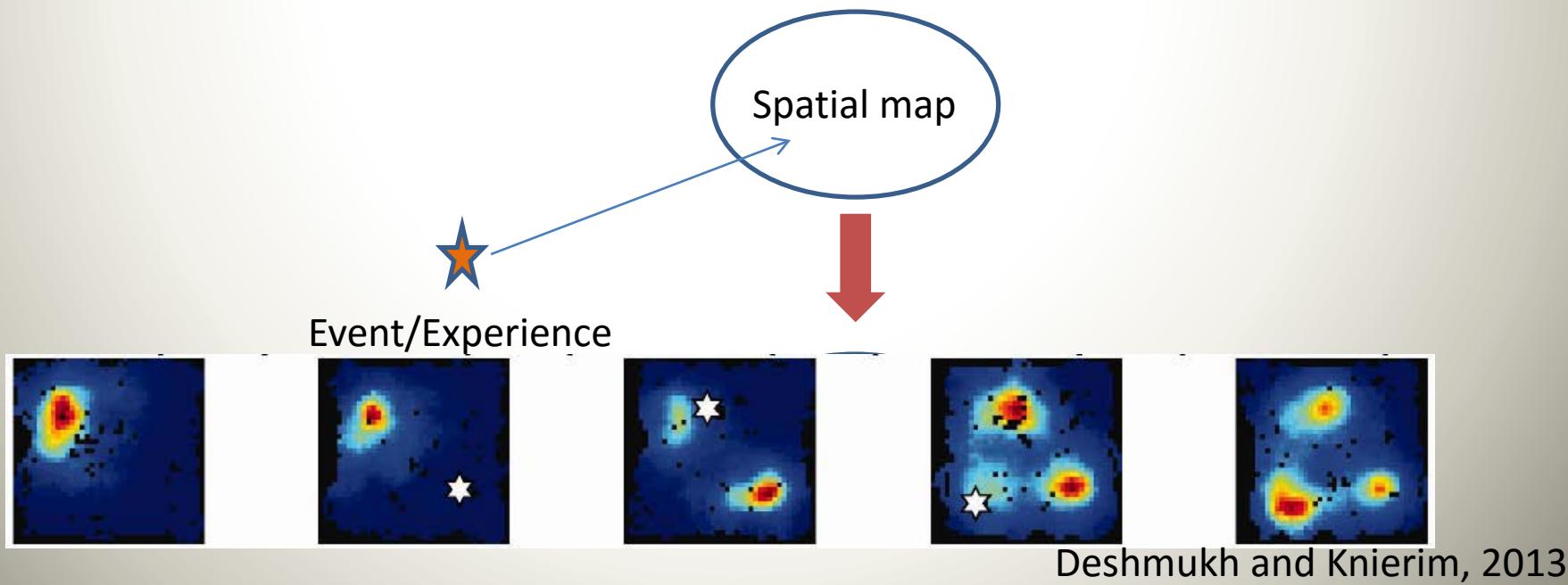


Wilson and McNaughton, 1993

What does a spatial map have to do with memory?

THIS book is concerned with three topics which, at first glance, do not appear to be related: (1) a part of the brain known as the hippocampus; (2) the psychological representation of space; (3) context-dependent memory. We shall argue that the **hippocampus is the core of a neural memory system providing an objective spatial framework within which the items and events of an organism's experience are located and interrelated.**

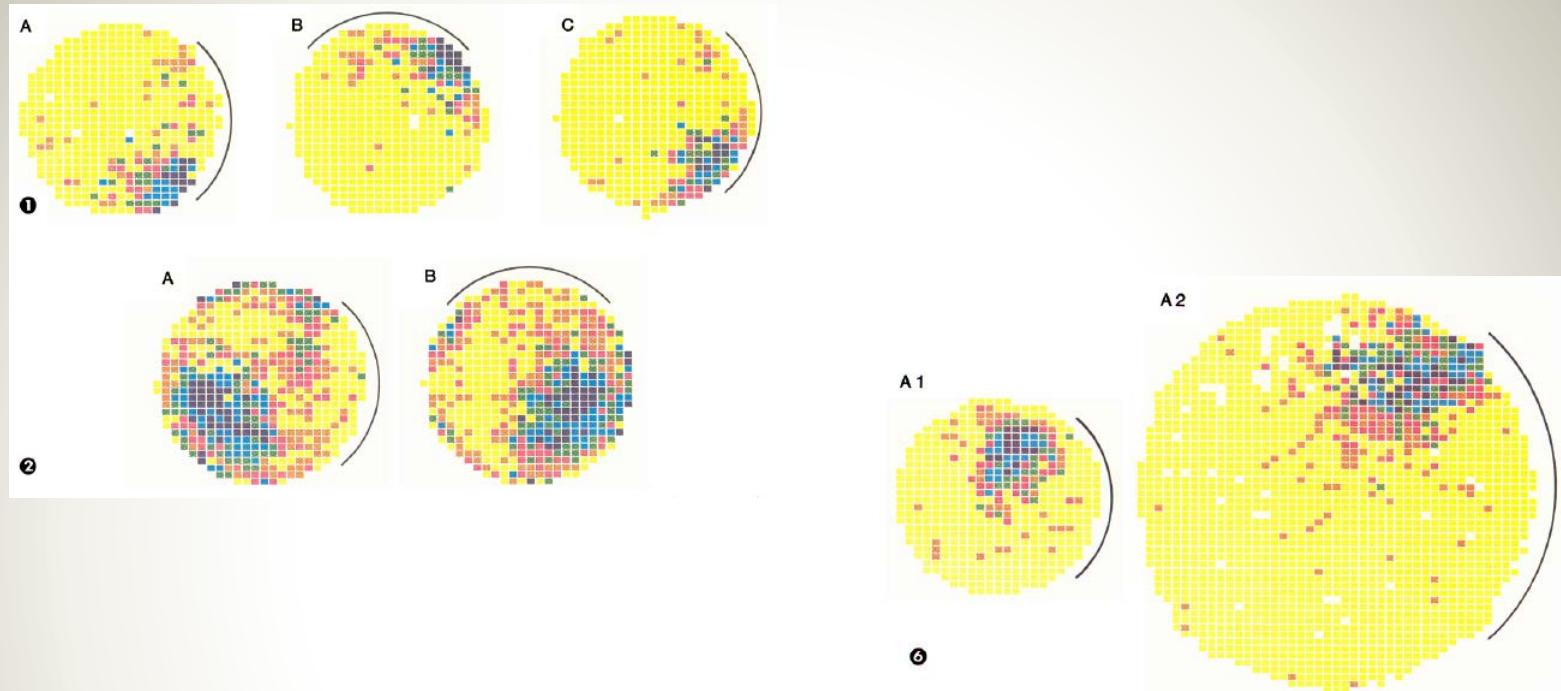
- Hippocampus as a cognitive map, O'Keefe and Nadel, 1978



Space

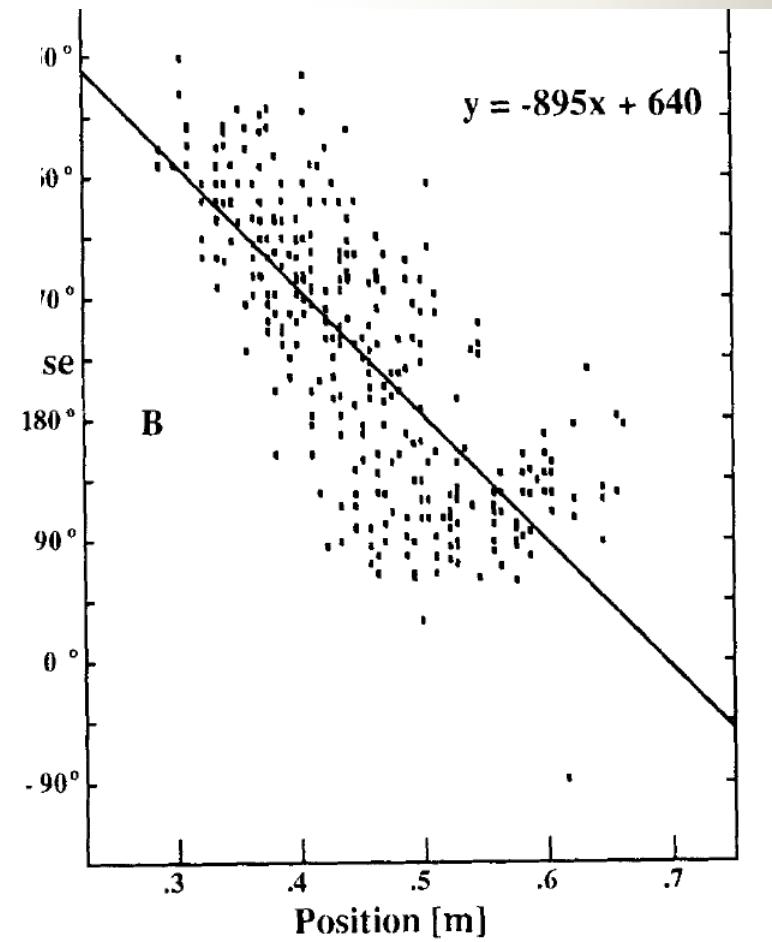
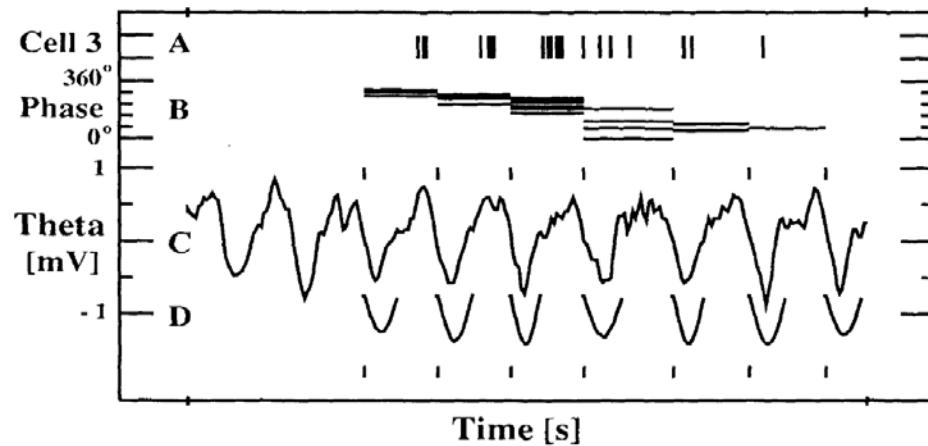
- What makes a map a map?
- Reference frame
- Egocentric vs allocentric space

Do place cells really encode a gestalt spatial map, or is it just sensory representation?

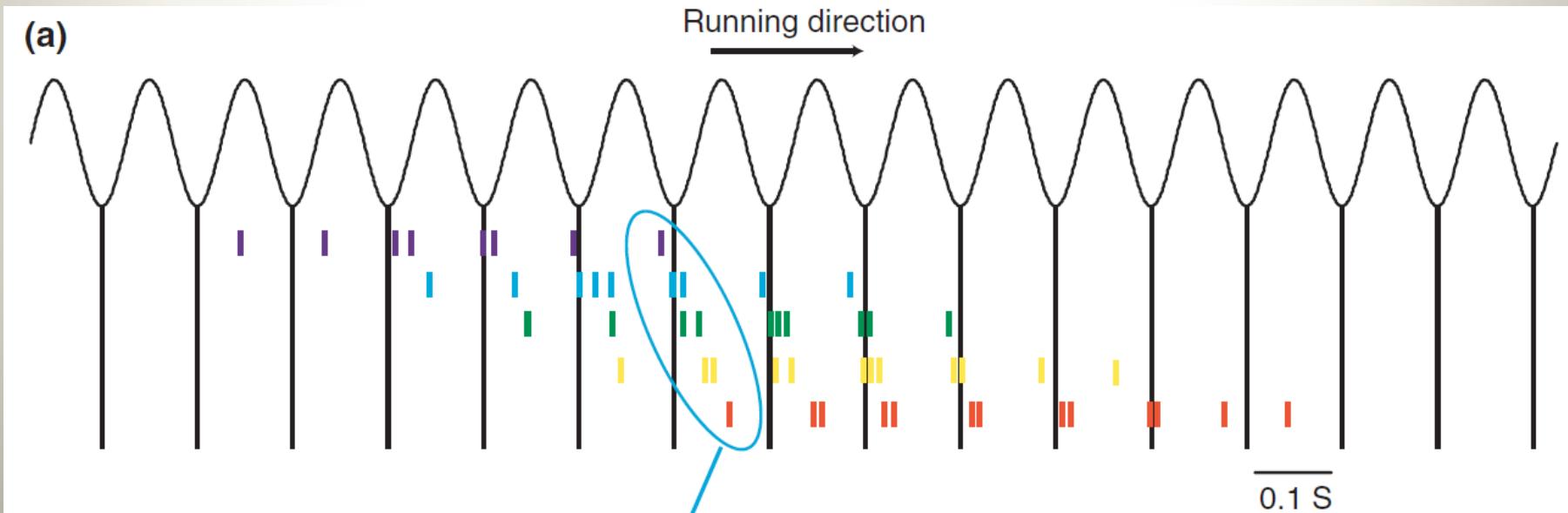
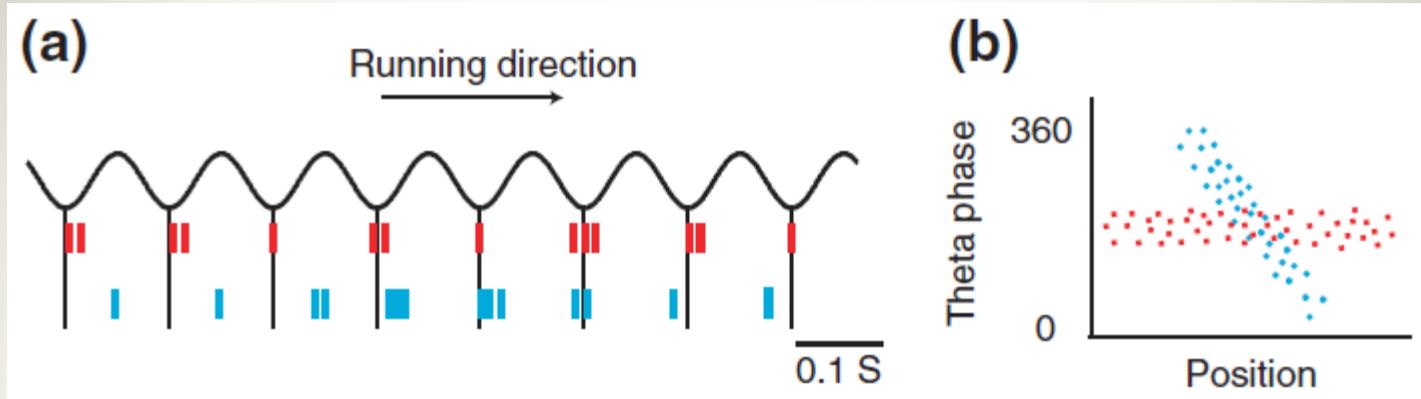


In the Discussion, it is argued that place cells respond to the selected environmental manipulations as if they were processing abstract spatial information rather than raw sensory data. It is concluded that the “cognitive mapping” hypothesis of O’Keefe and Nadel (1978) captures an important aspect of the functioning of the hippocampus.

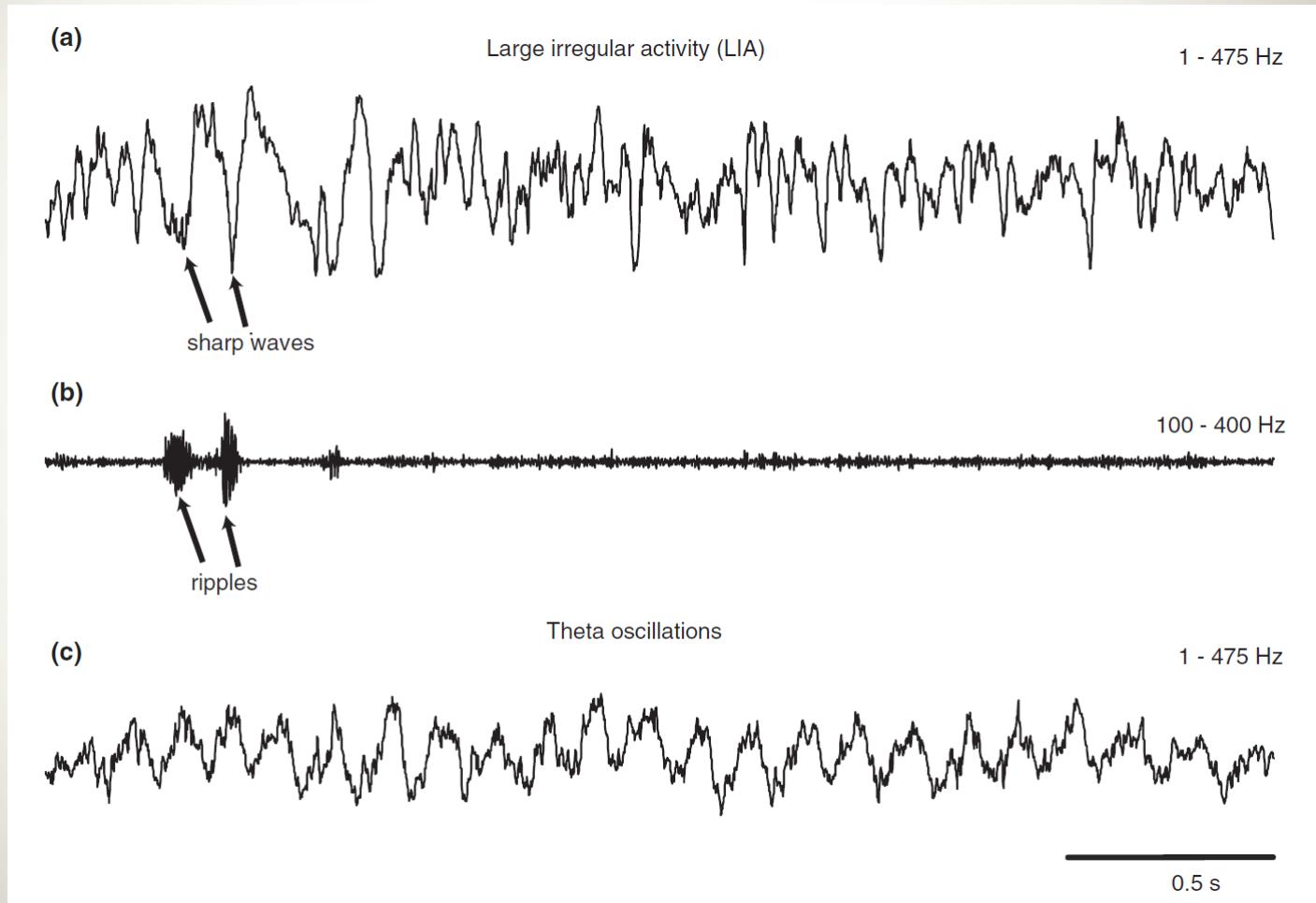
Do place cells use temporal code?



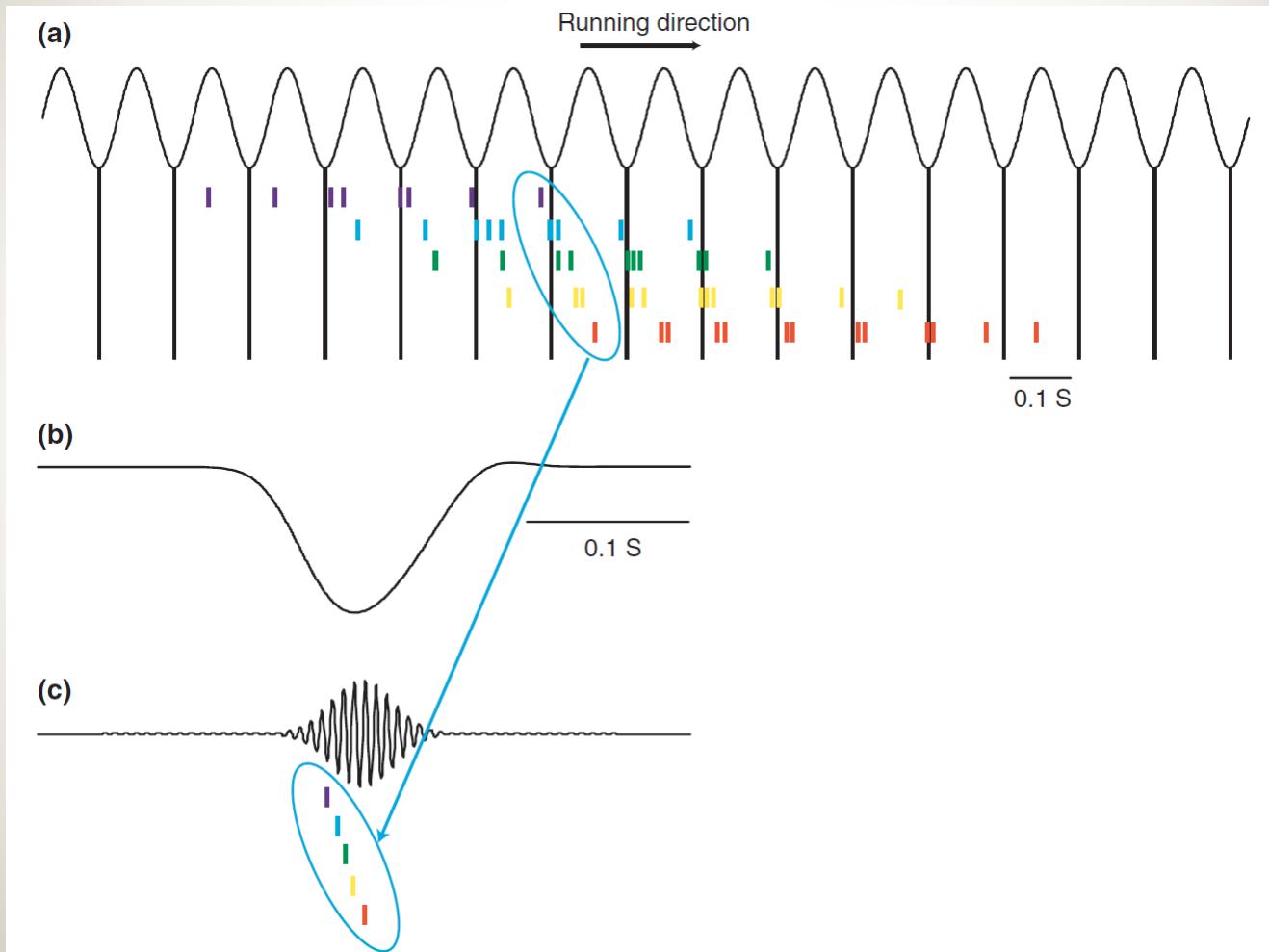
Do place cells use temporal code?



Replay of temporal sequences in the hippocampus



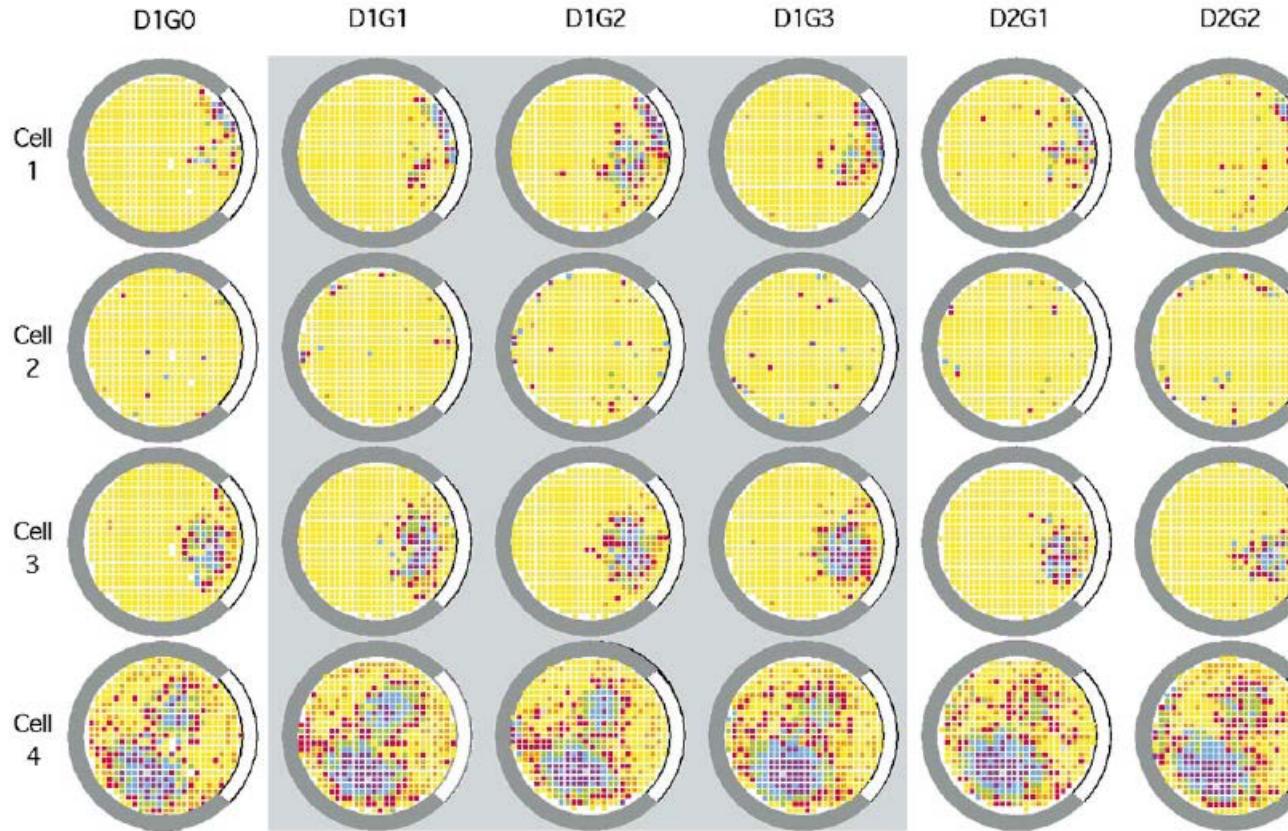
Replay of temporal sequences in the hippocampus



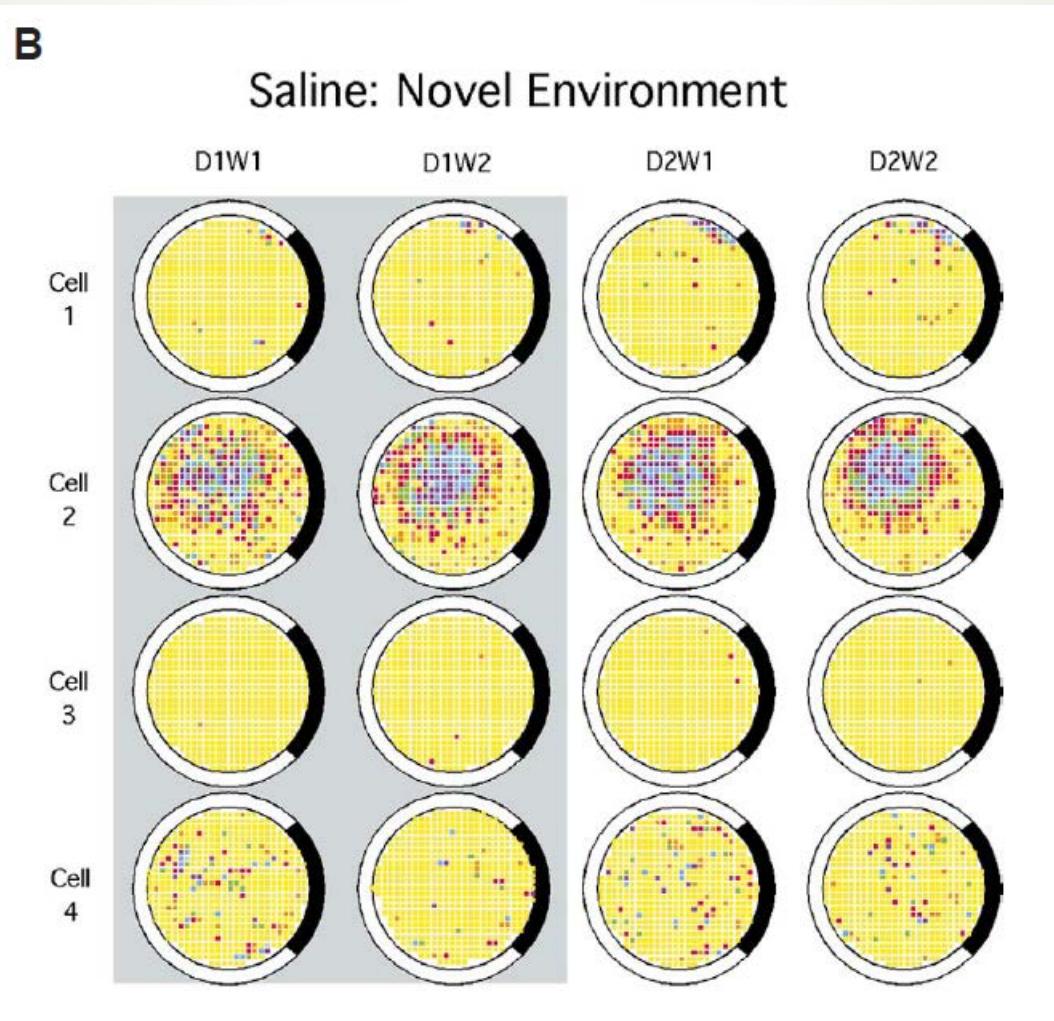
What role does plasticity play in creation of spatial maps?

A

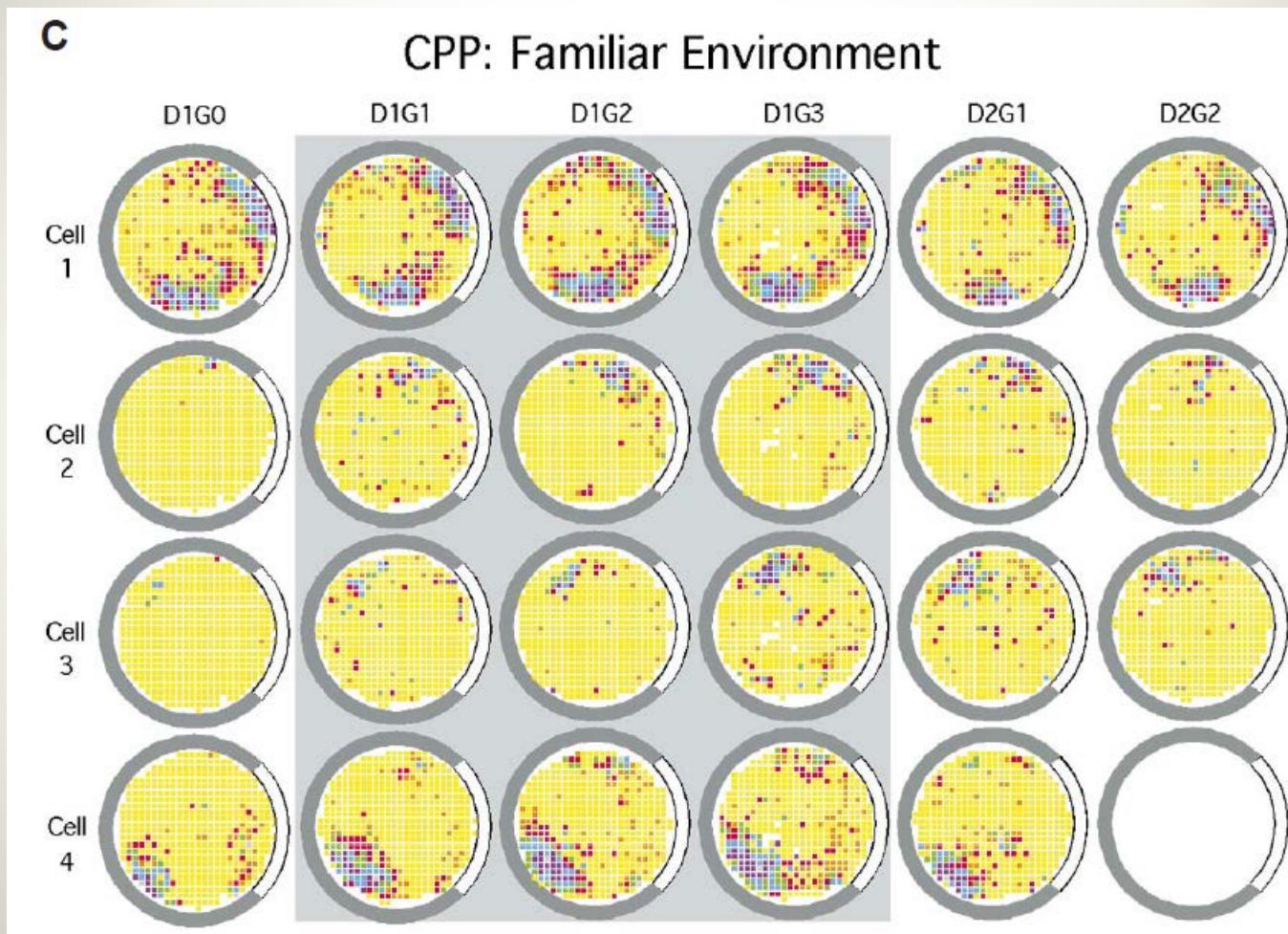
Saline: Familiar Environment



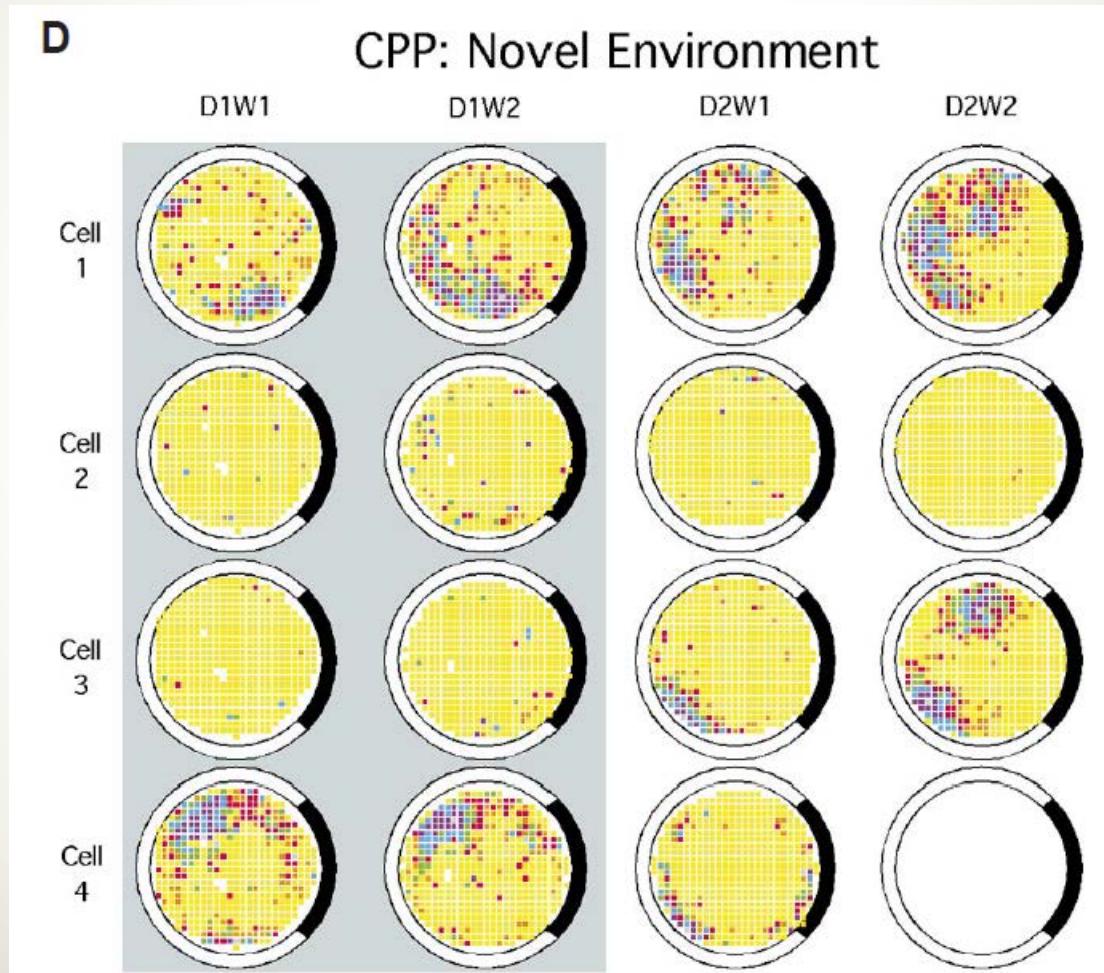
What role does plasticity play in creation of spatial maps?



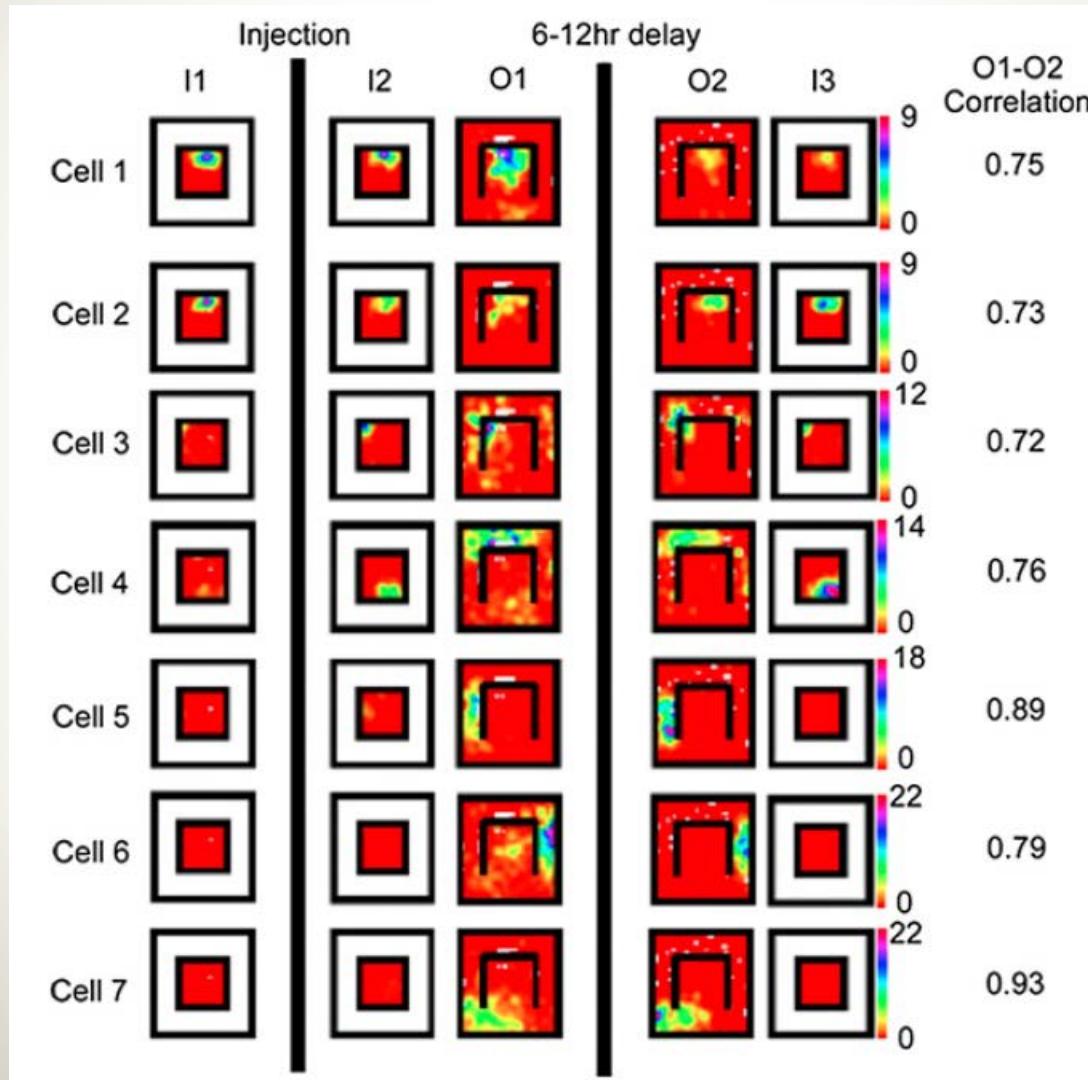
What role does plasticity play in creation of spatial maps?



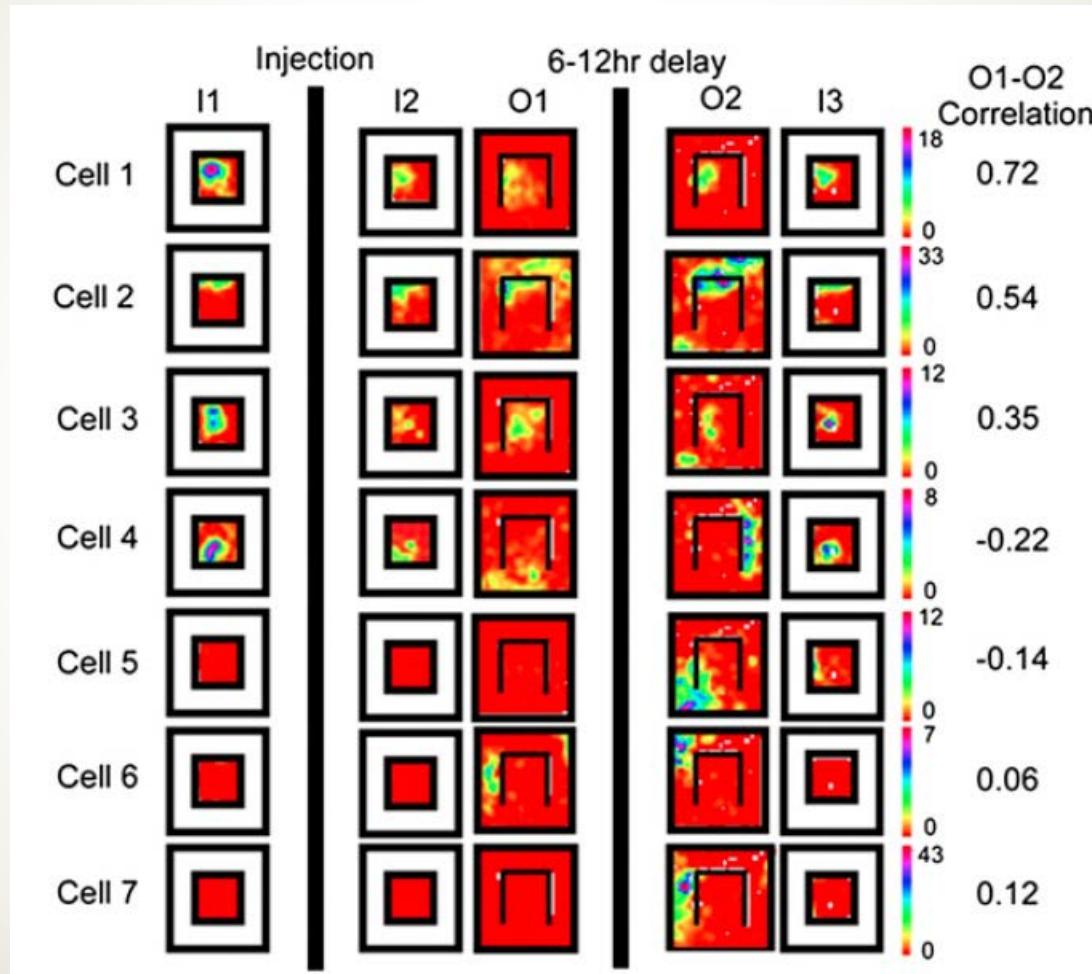
What role does plasticity play in creation of spatial maps?



What role does plasticity play in creation of spatial maps?



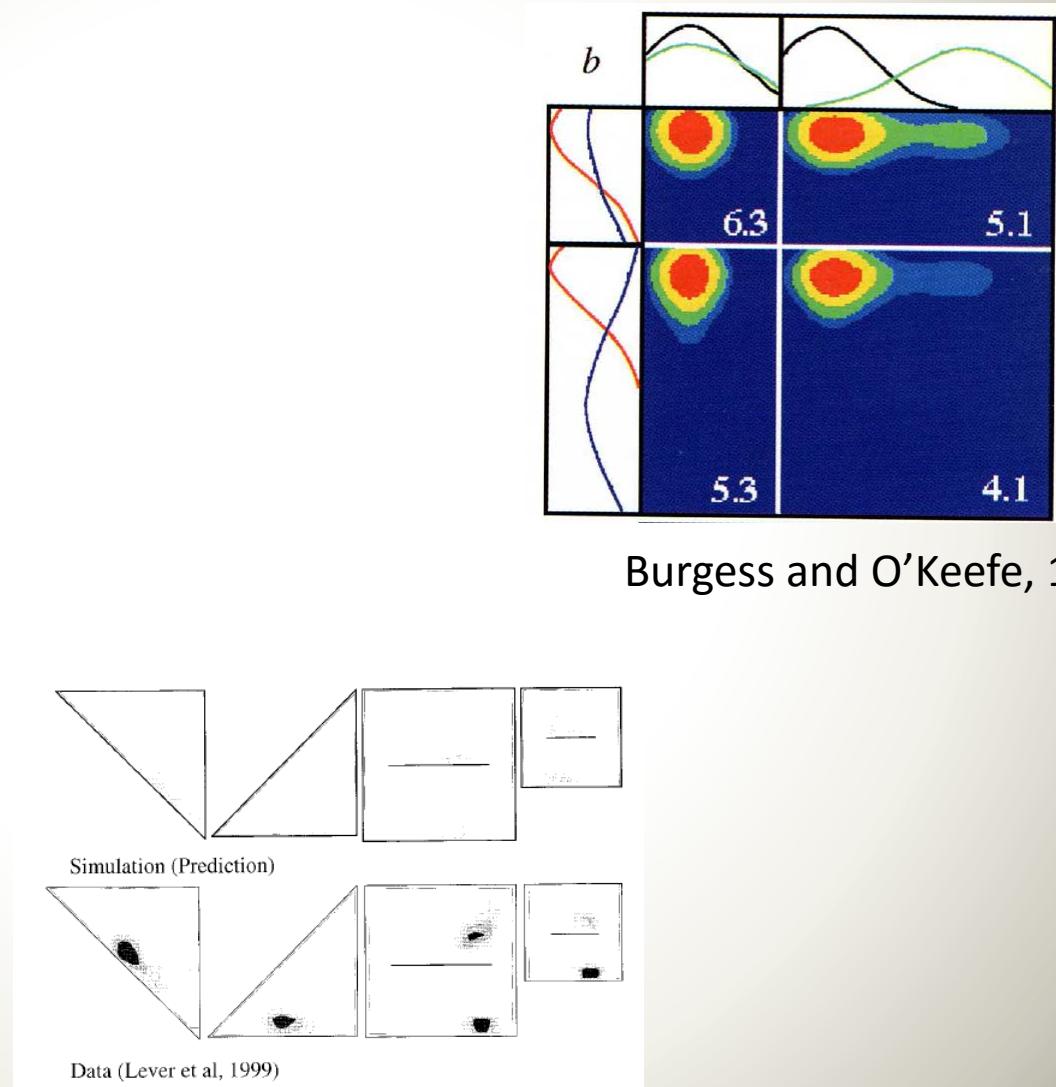
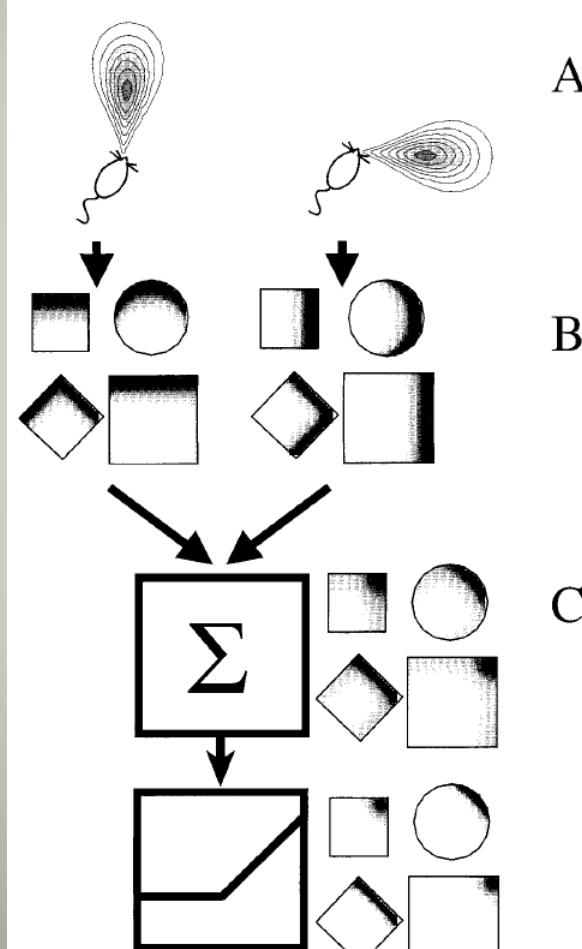
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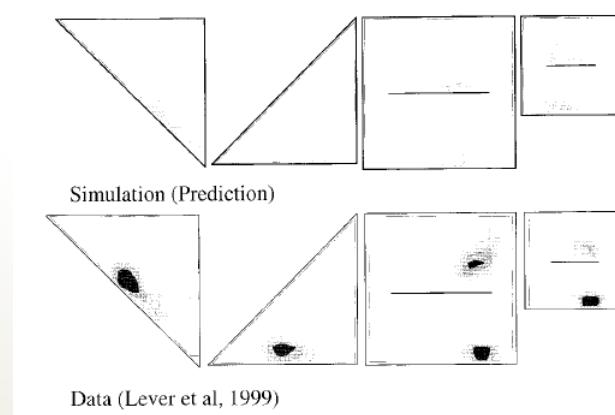
Building blocks of spatial information

Building blocks for spatial representation

Boundary vector cells

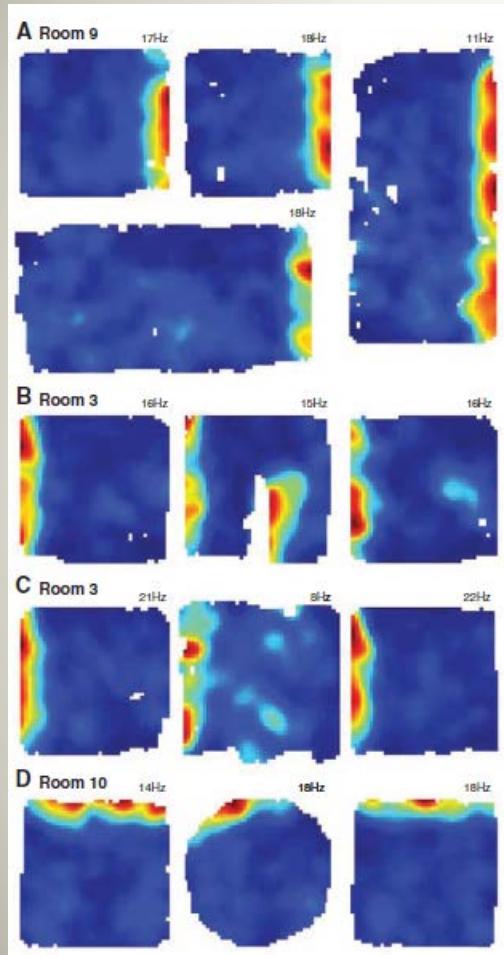


Burgess and O'Keefe, 1996

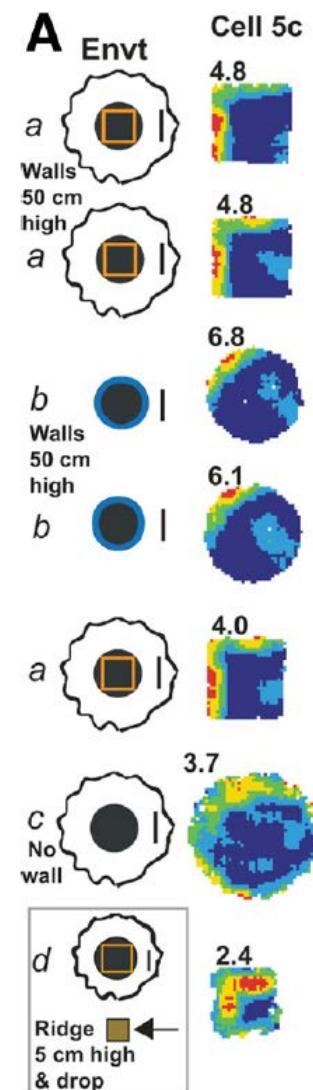


Hartley, Burgess,..., O'Keefe, 2000

Building blocks for spatial representation Boundary vector cells

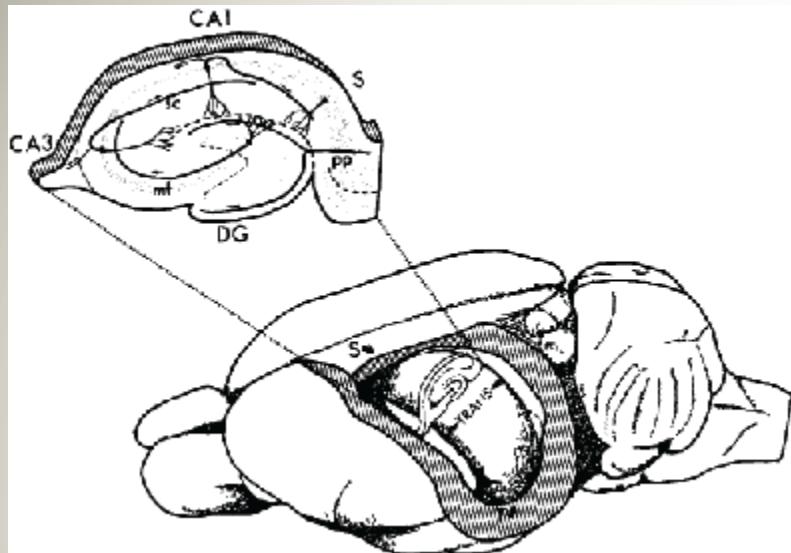


Solstad,...,Moser,Moser, 2008

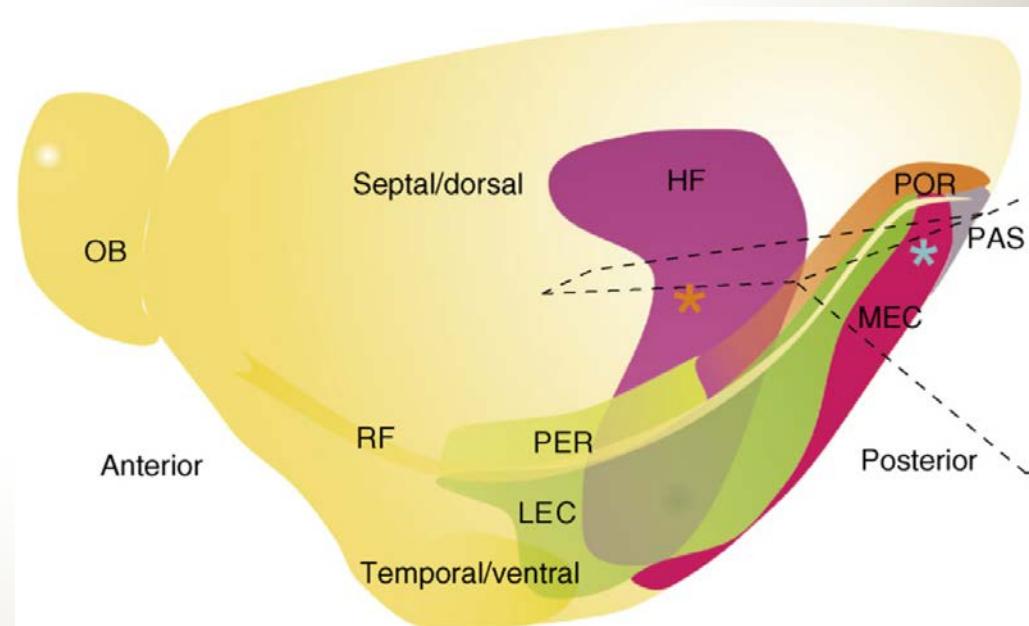
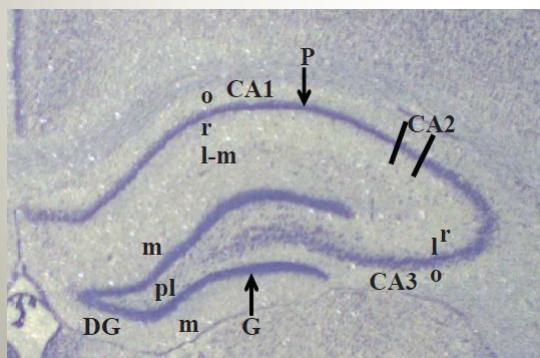
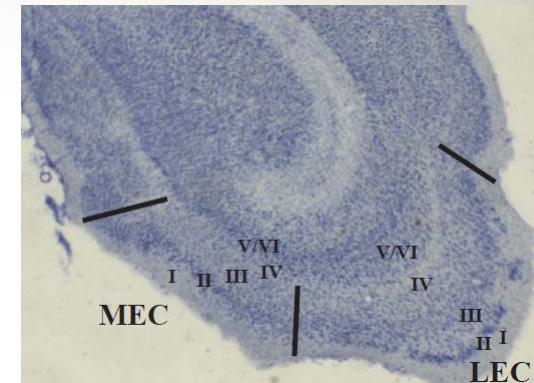


Lever,...,O'Keefe,..., 2009

Rat brain: hippocampus and its cortical inputs

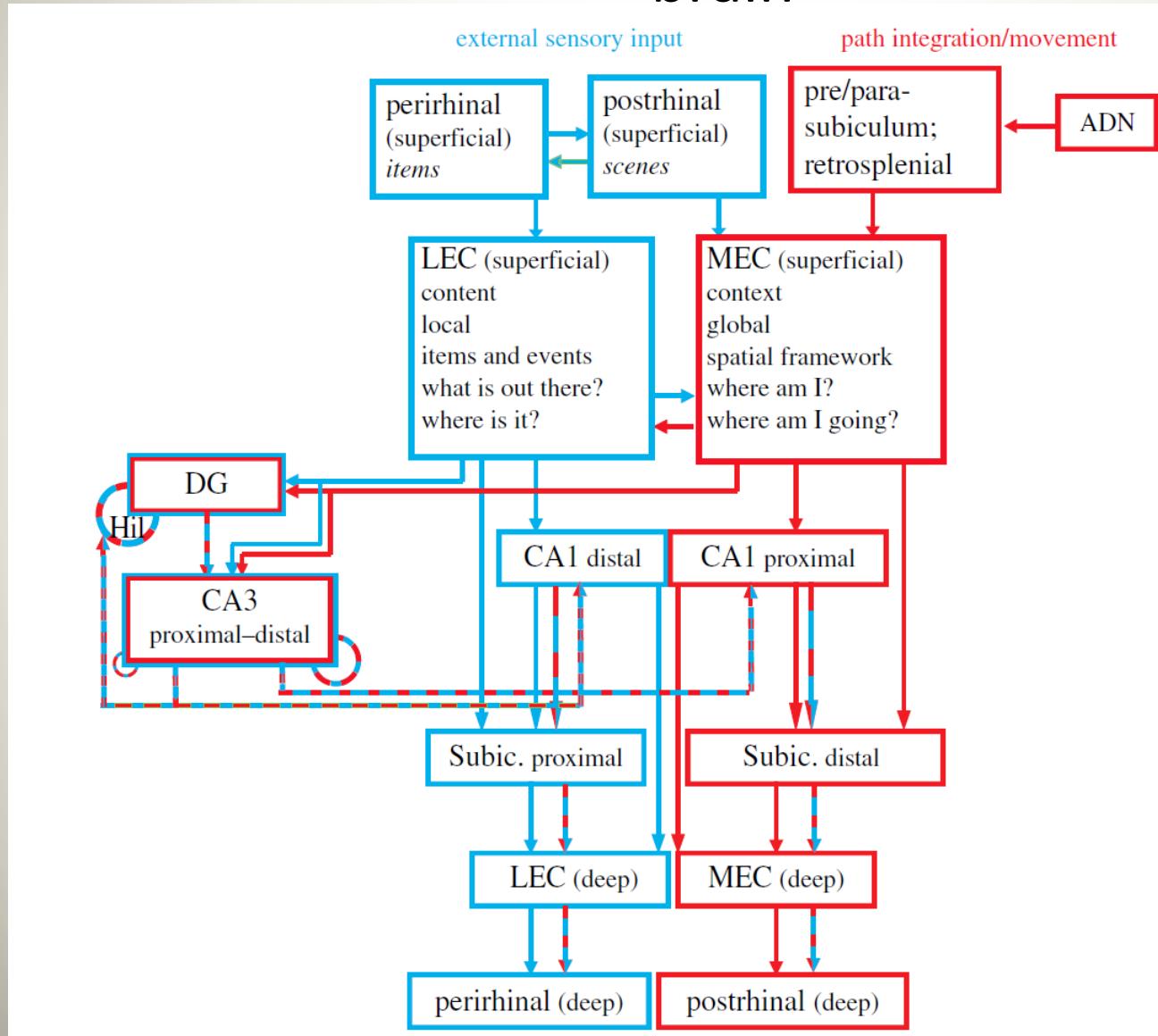


Amaral and Witter, 1989



Witter and Moser, 2006

Hippocampal spatial representation is a consequence of complex computation involving multiple regions of the brain



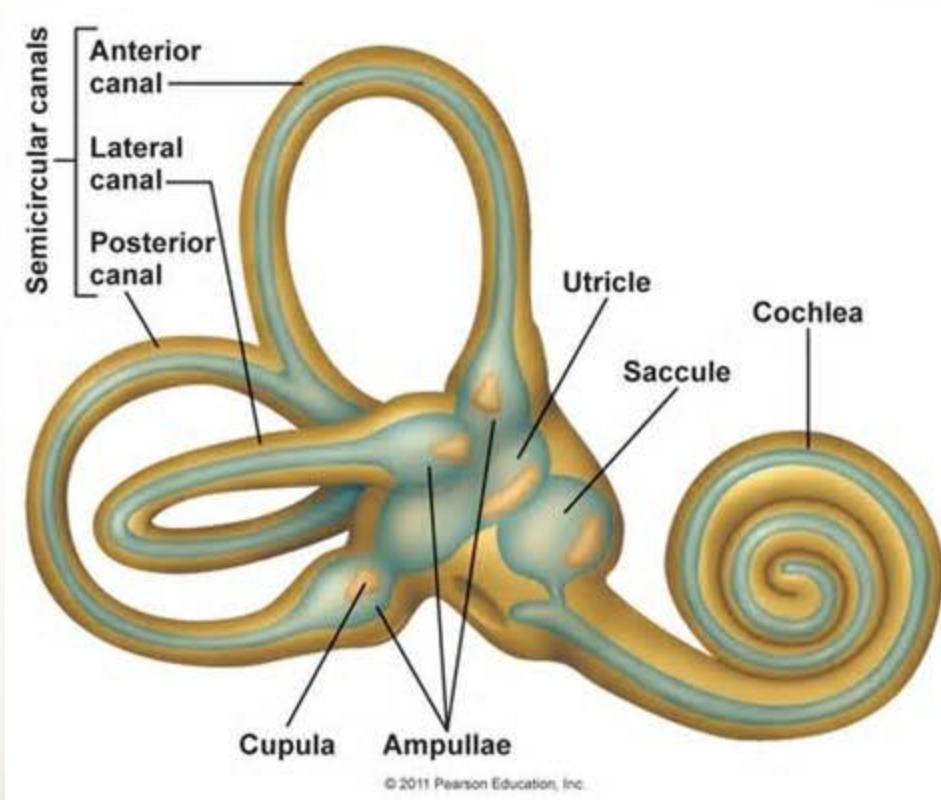
Navigation

On the featureless Tunisian desert, a long-legged, fast-moving ant leaves the protection of the humid nest on a foraging expedition. It moves across the desert in tortuous loops, running first this way, then that, but gradually progressing ever farther away from the life-sustaining humidity of the nest. Finally it finds the carcass of a scorpion, uses its strong pincers to gouge out a chunk nearly its own size, then turns to orient to within one or two degrees of the straight line between itself and the nest entrance, a 1-millimeter-wide hole, 40 meters distant. It runs a straight line for 43 meters, holding its course by maintaining its angle to the sun. Three meters past the point at which it should have encountered the entrance, the ant abruptly breaks into the search pattern by which it eventually locates it. A witness to this homeward journey finds it hard to resist the inference that the ant on its search for food possessed at every moment a representation of its position relative to the entrance to the nest, a spatial representation that enabled it to compute the solar angle and the distance of the homeward journey from wherever it happened to encounter food.

Building blocks for spatial representation

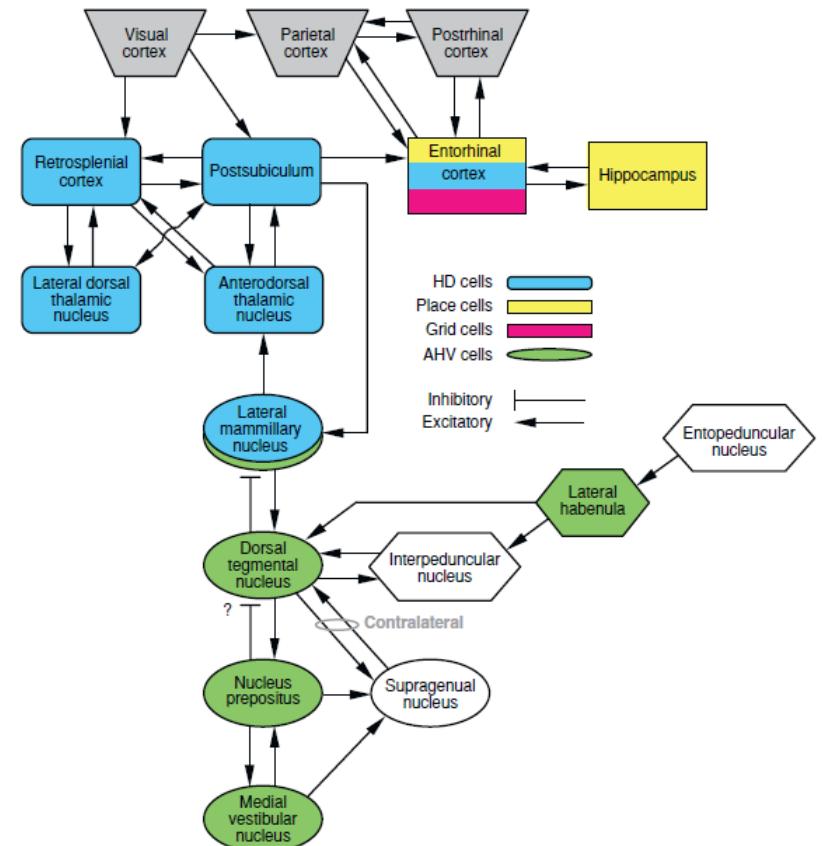
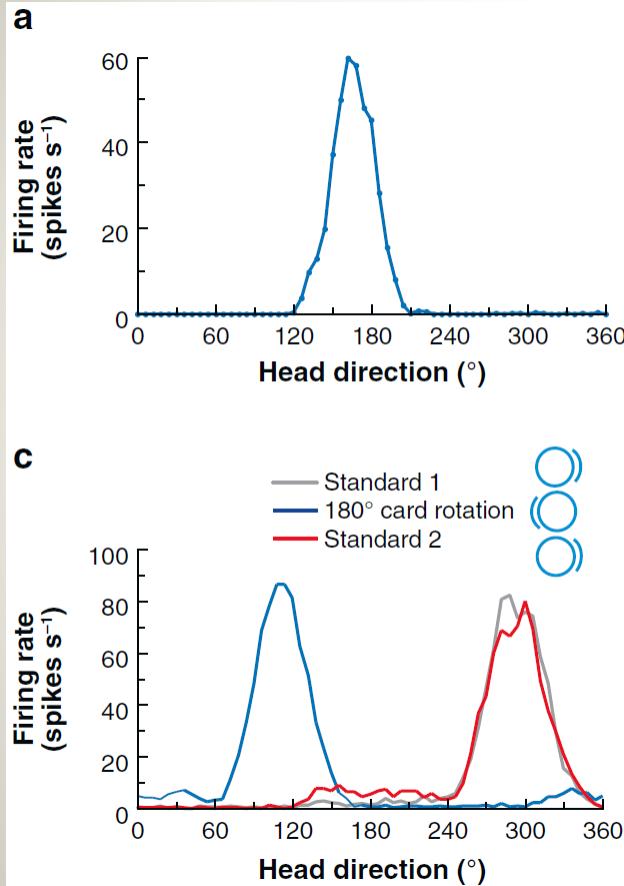
Path integration

- Direction
- Speed



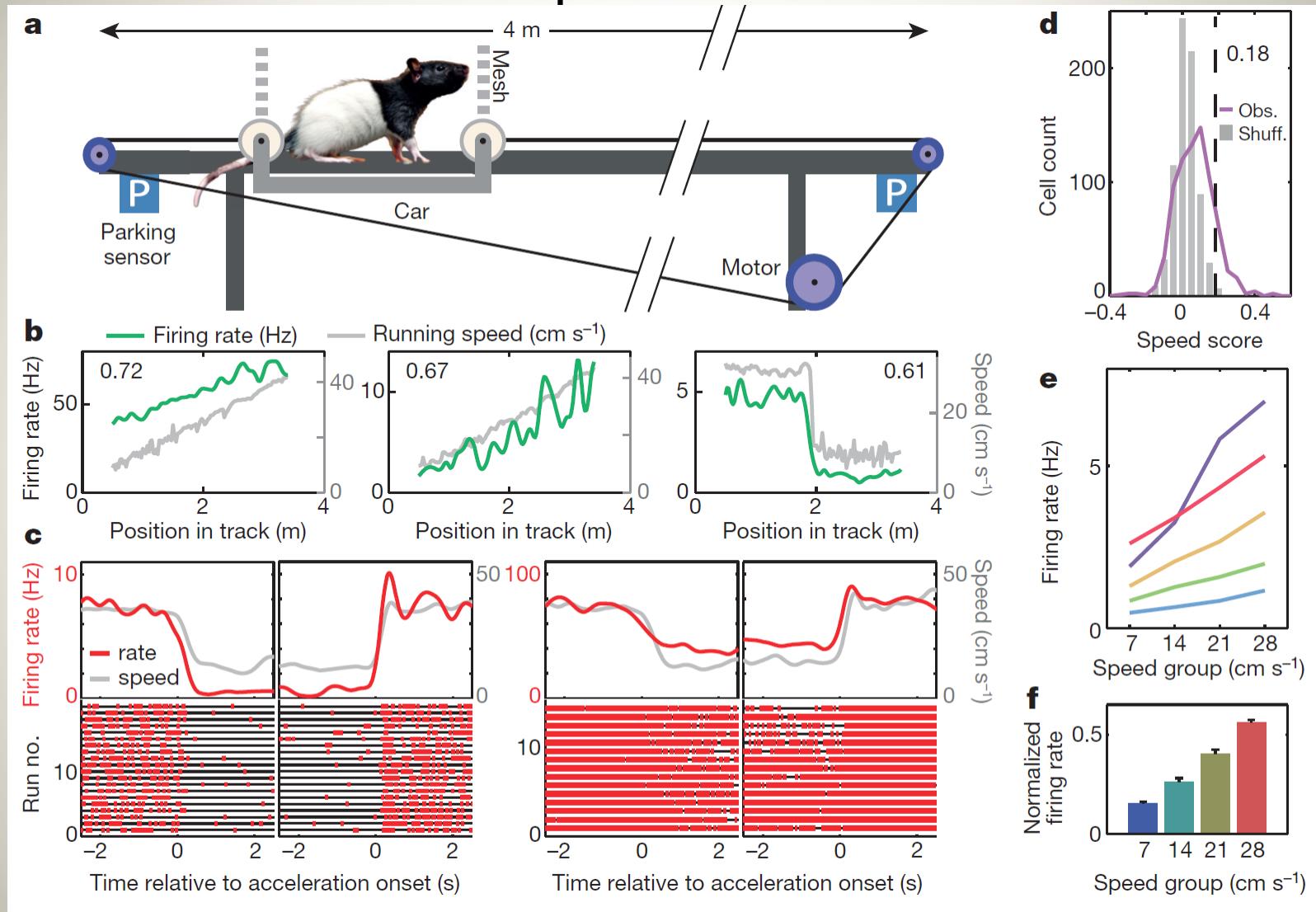
Building blocks for spatial representation

Head direction cells

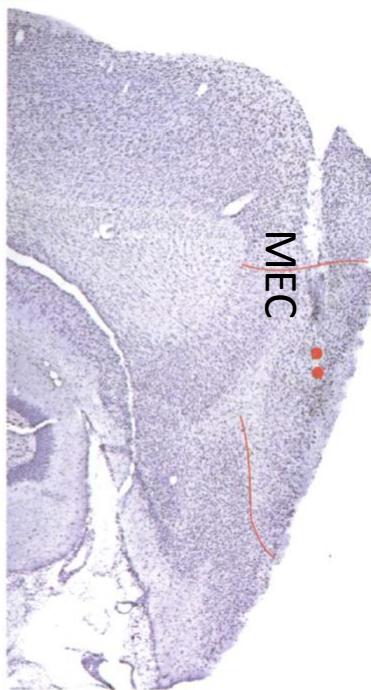
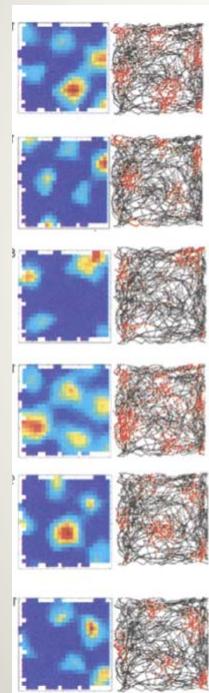


Building blocks for spatial representation

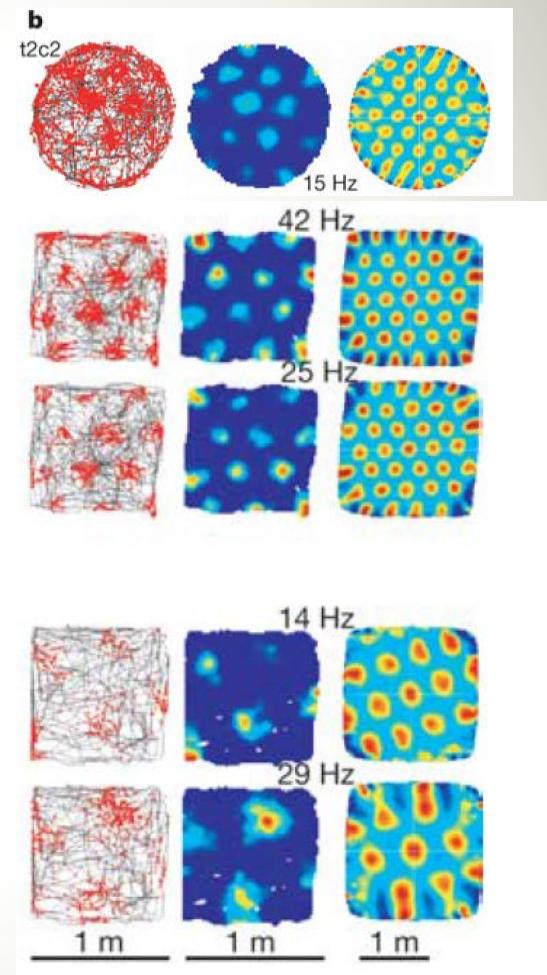
Speed cells



Building blocks for spatial representation Grid Cells



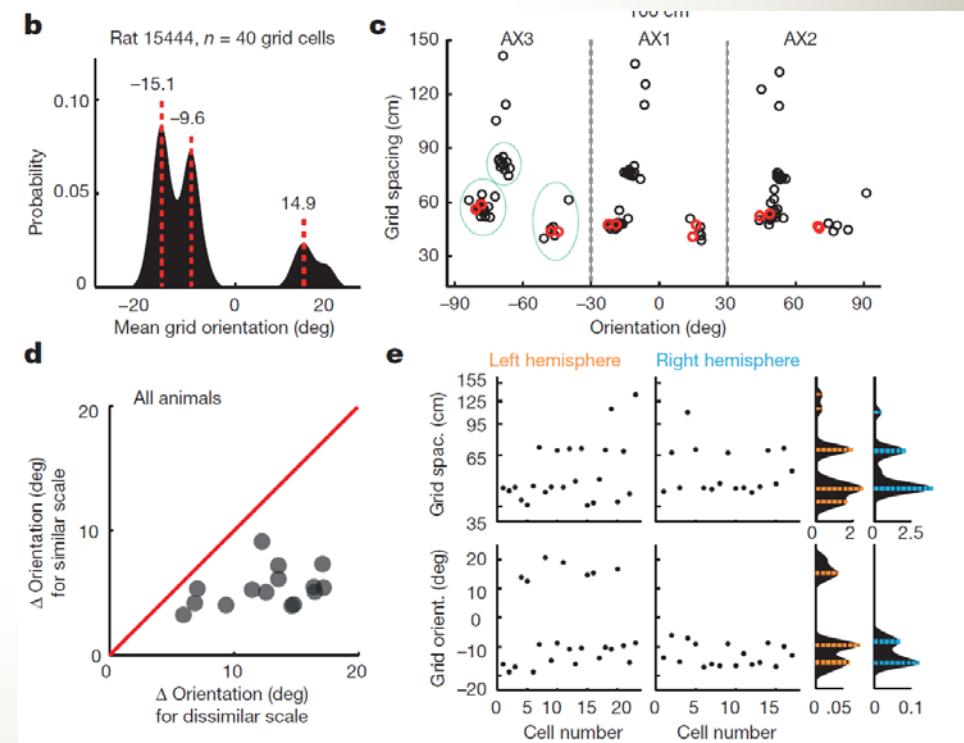
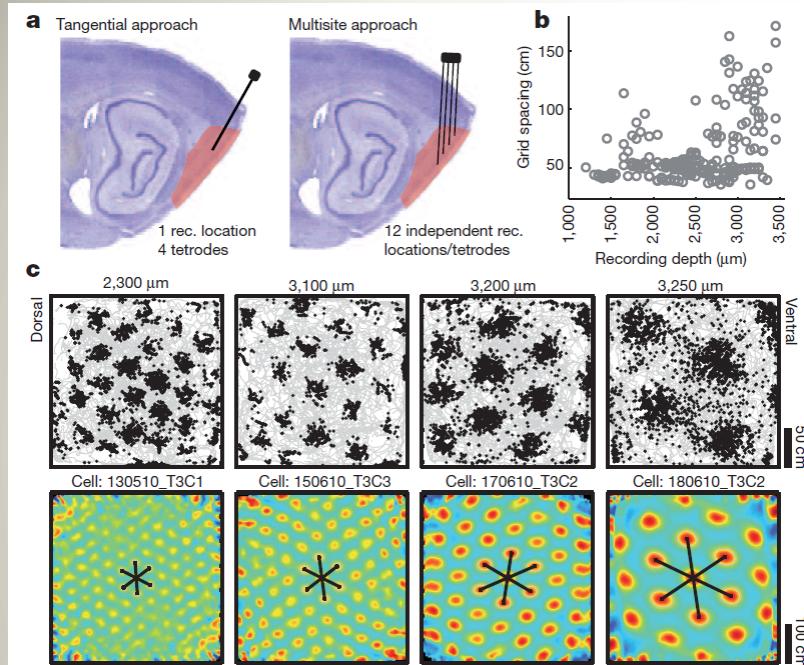
Fyhn, Molden, Witter, Moser, Moser, 2004



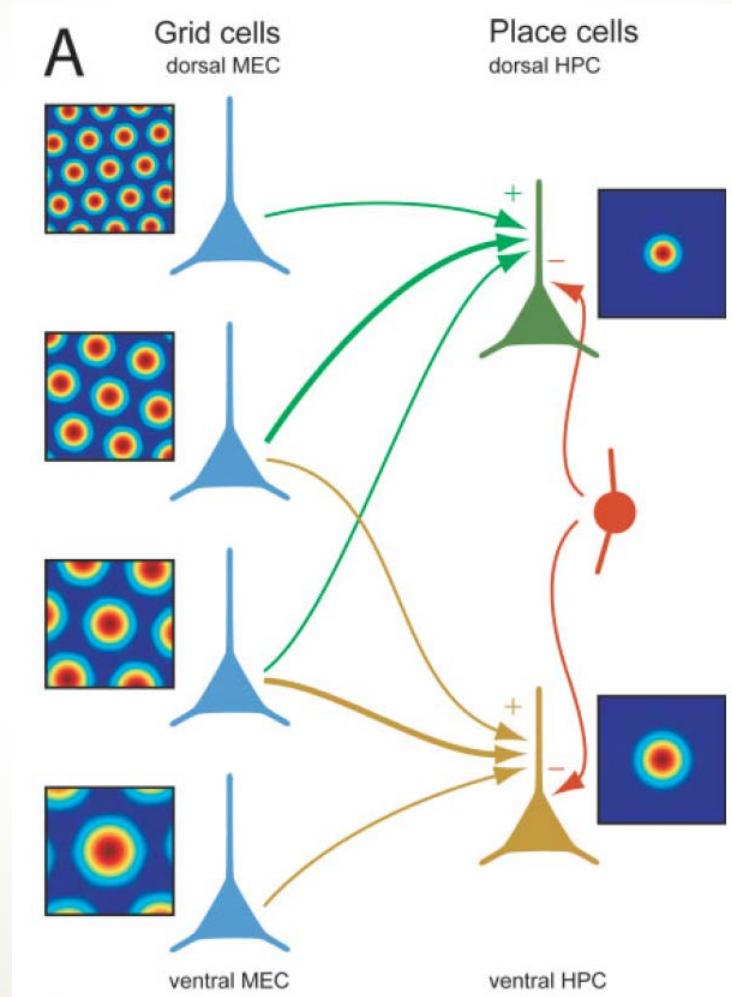
Hafting et al, 2005

Building blocks for spatial representation

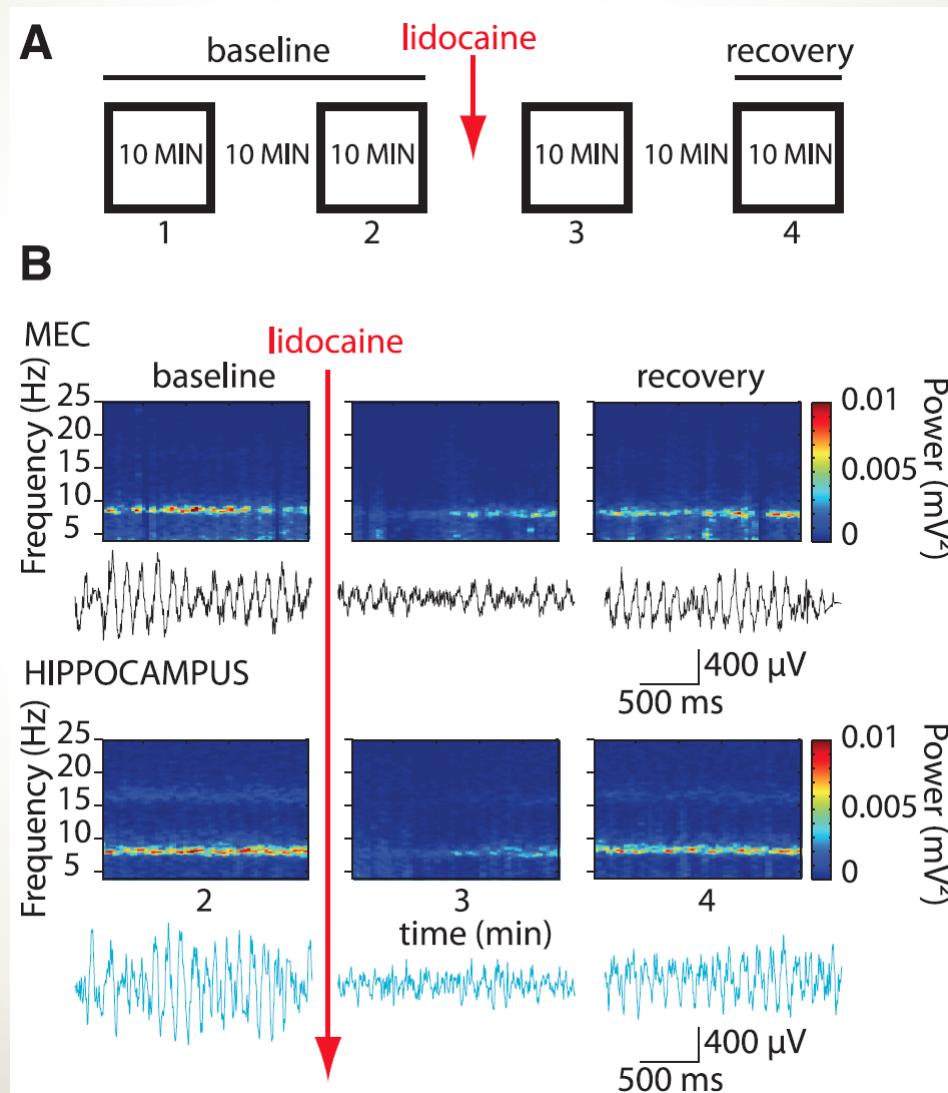
Grid cells



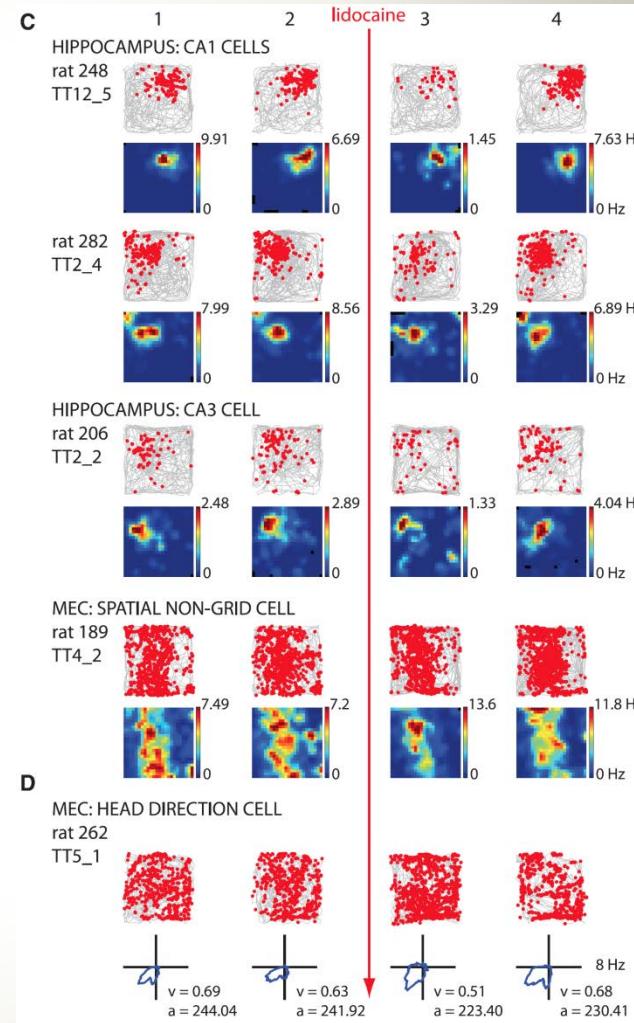
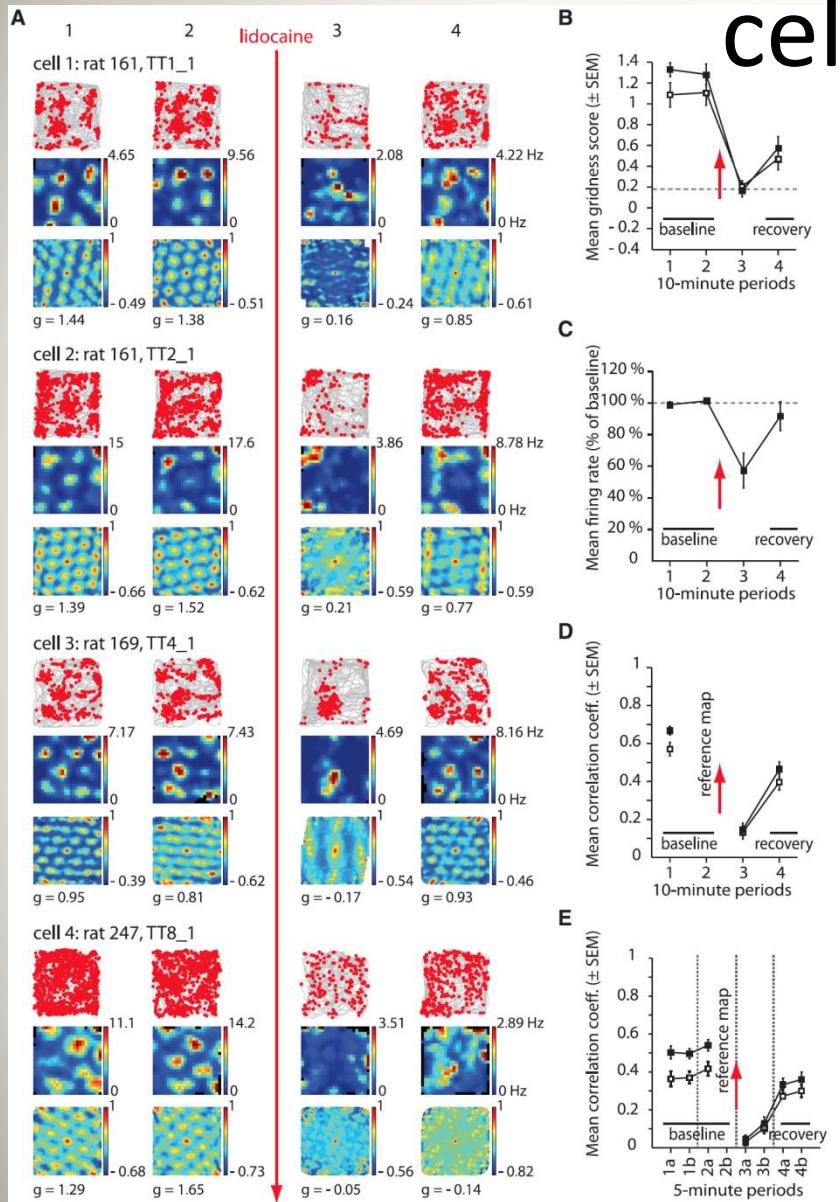
How does one make place cells from grid cells?



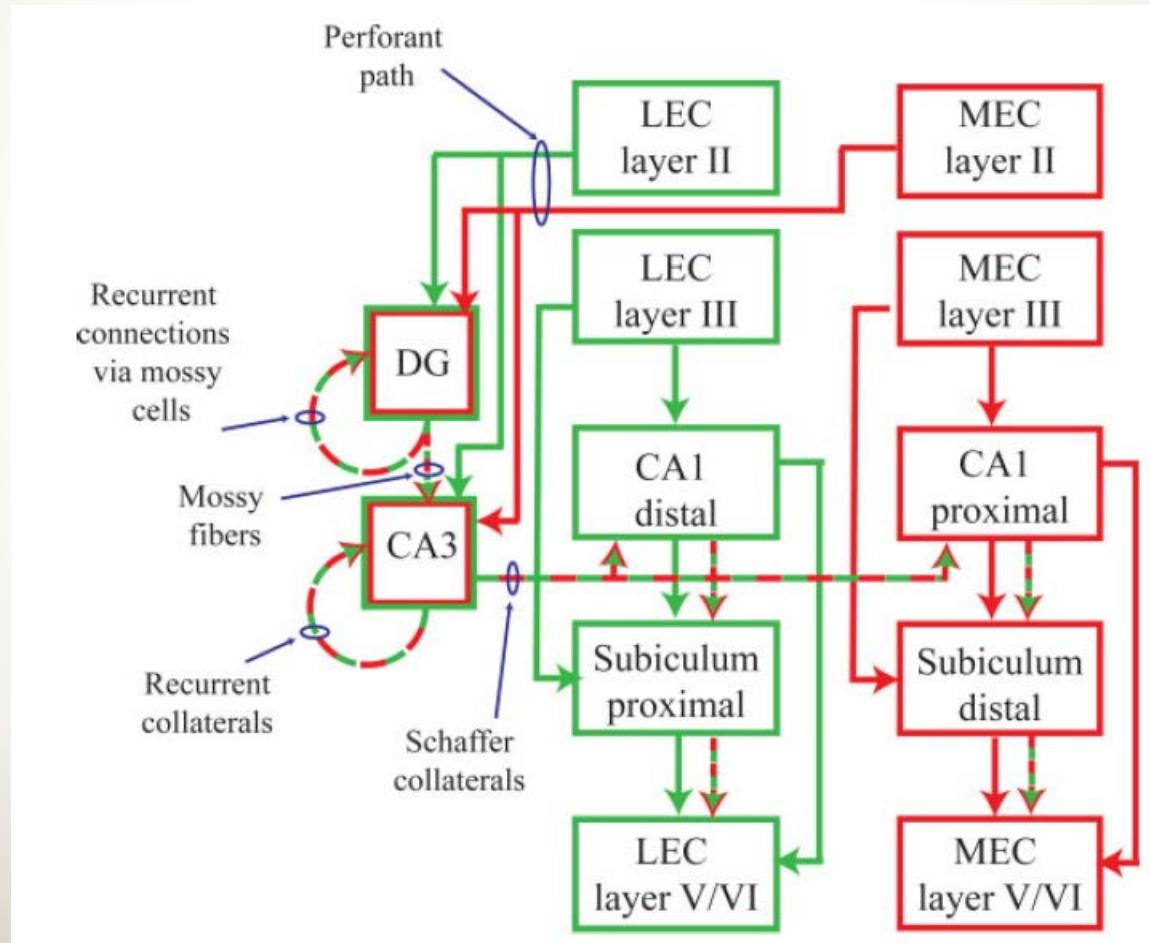
Are place cells really made from grid cells?



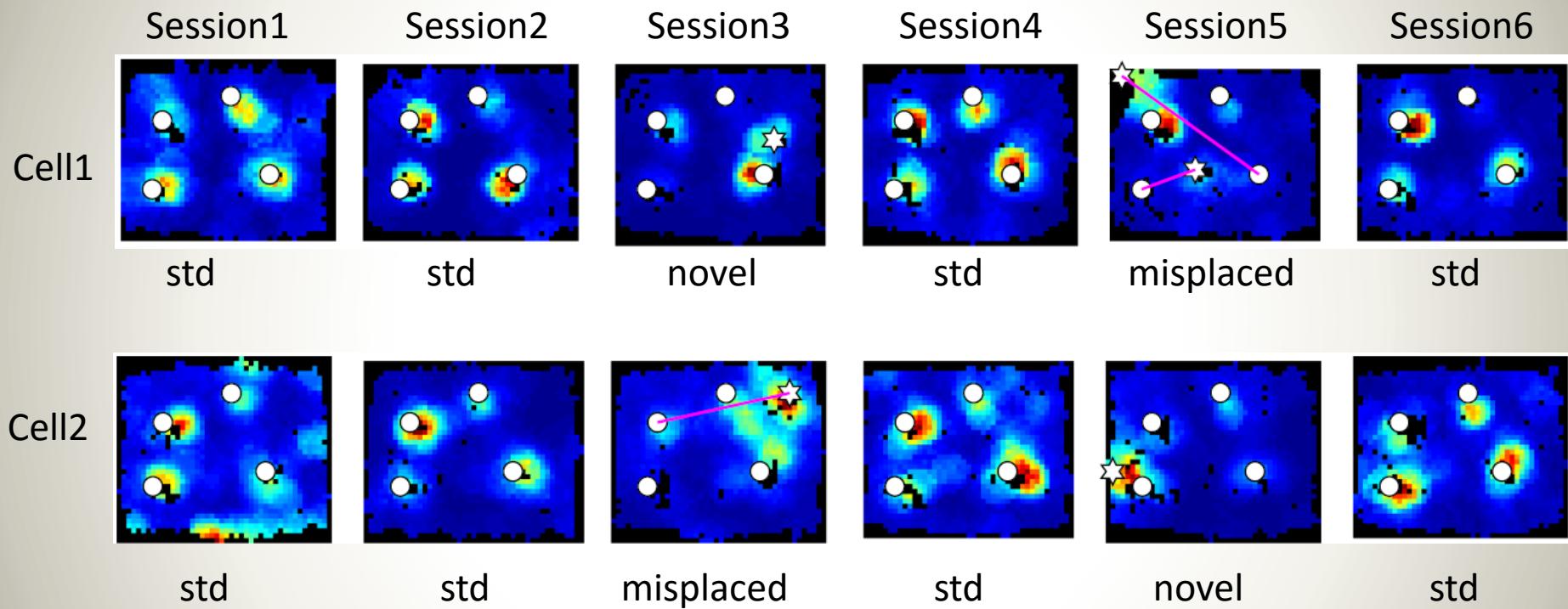
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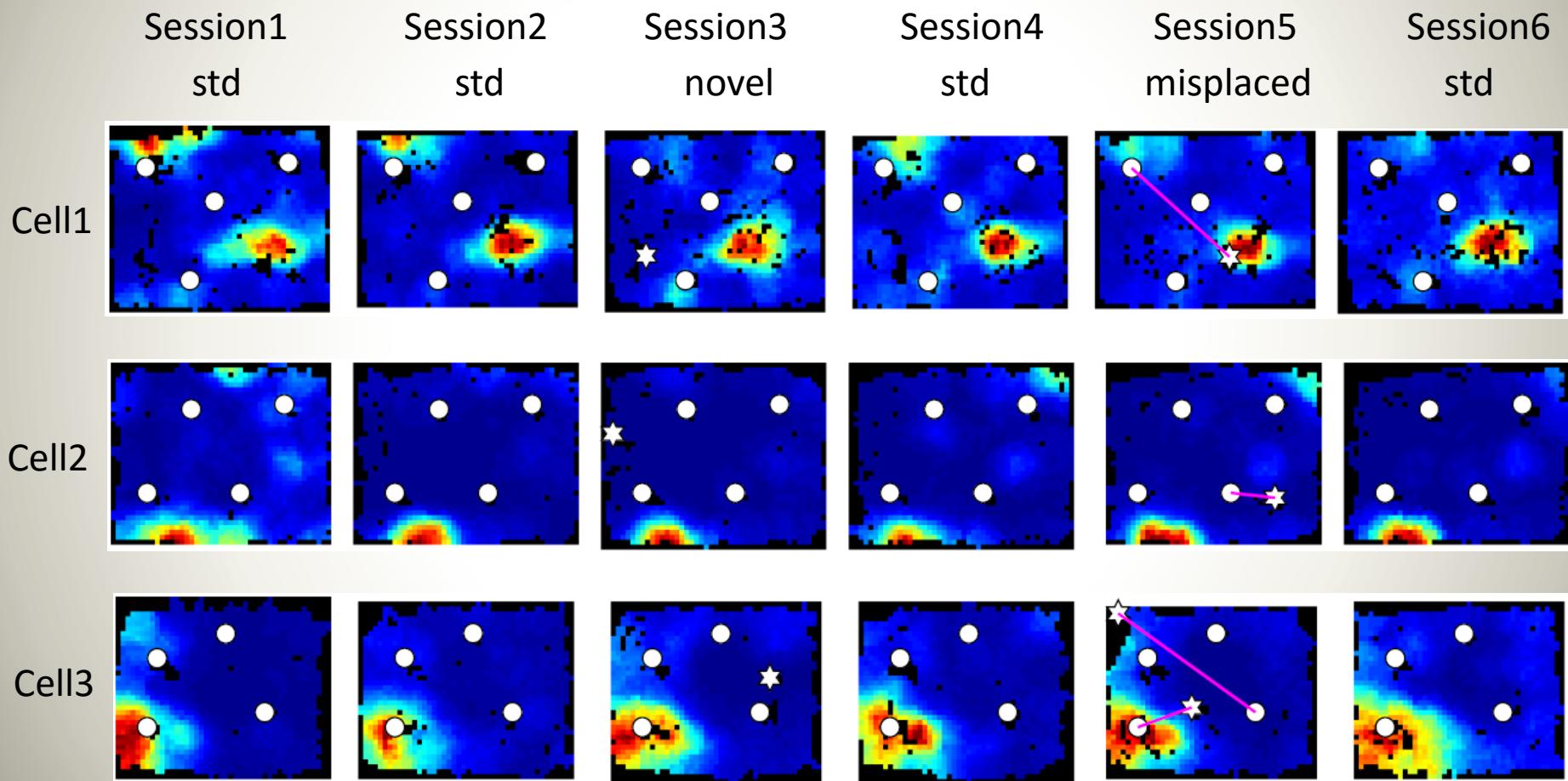
Hippocampal spatial representation is a consequence of complex computation involving multiple regions of the brain



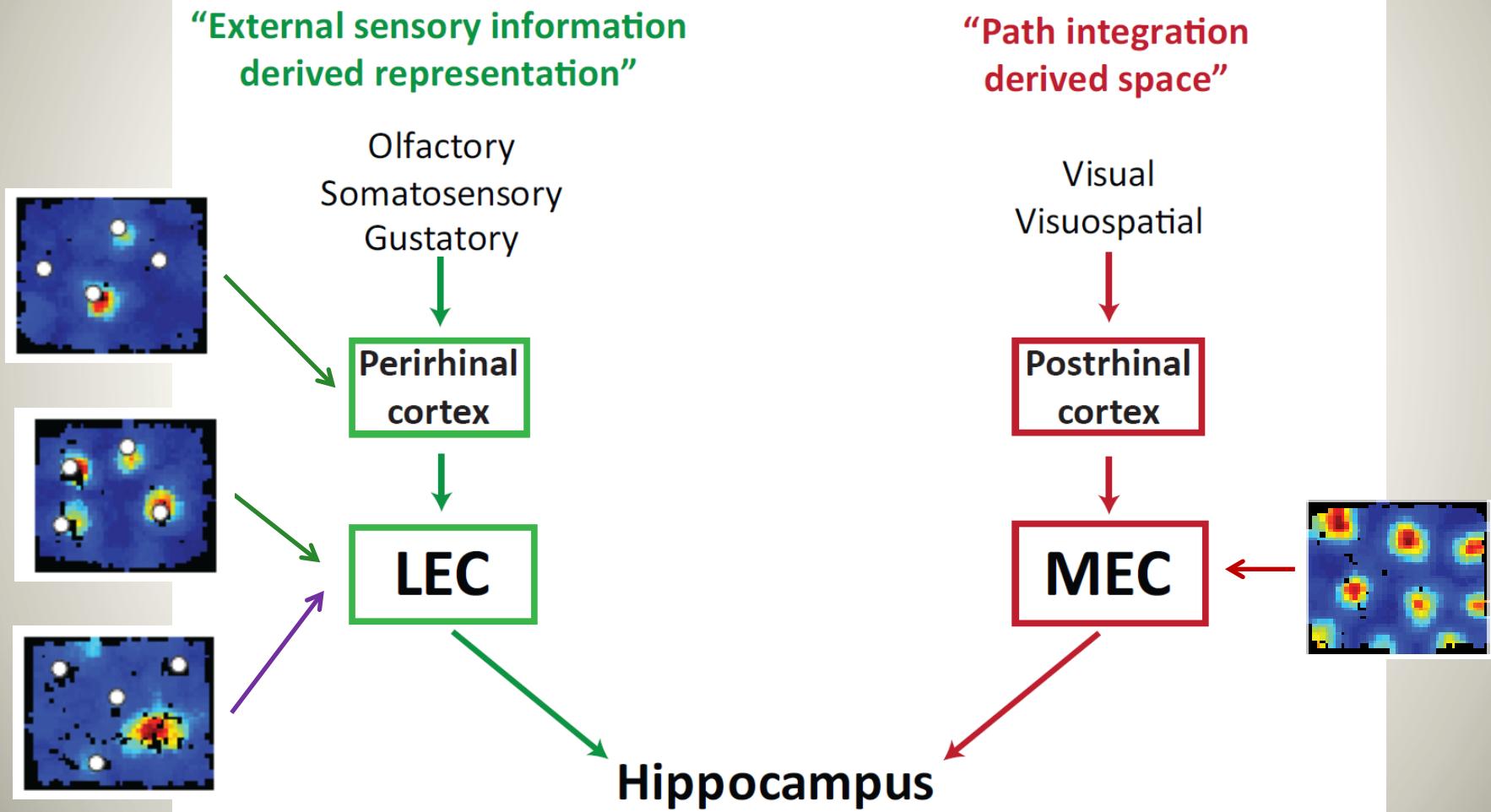
Rate maps of object-responsive LEC neurons



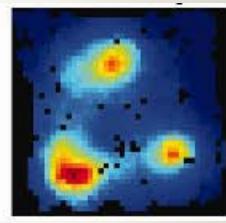
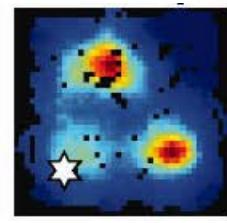
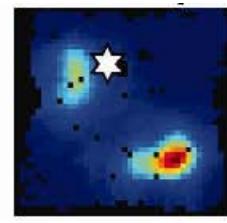
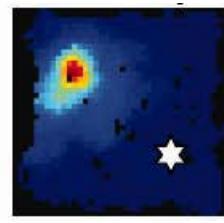
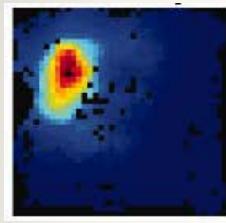
Rate maps of spatially selective LEC neurons



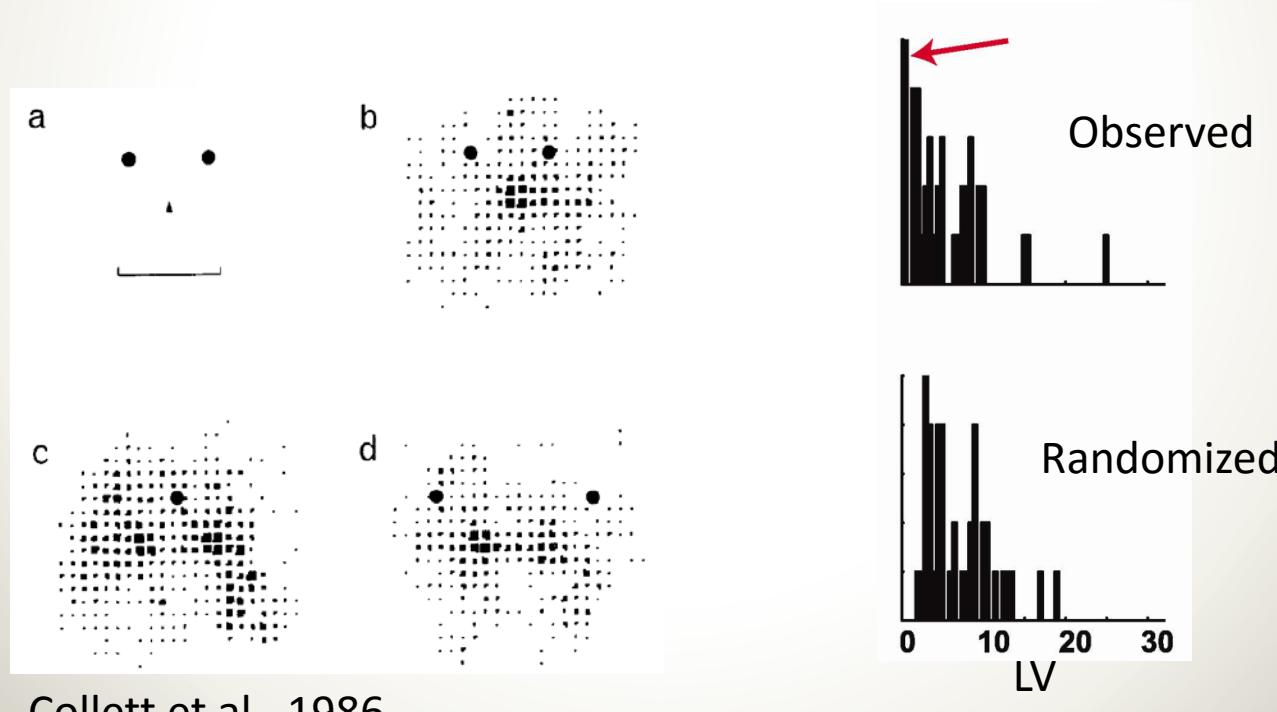
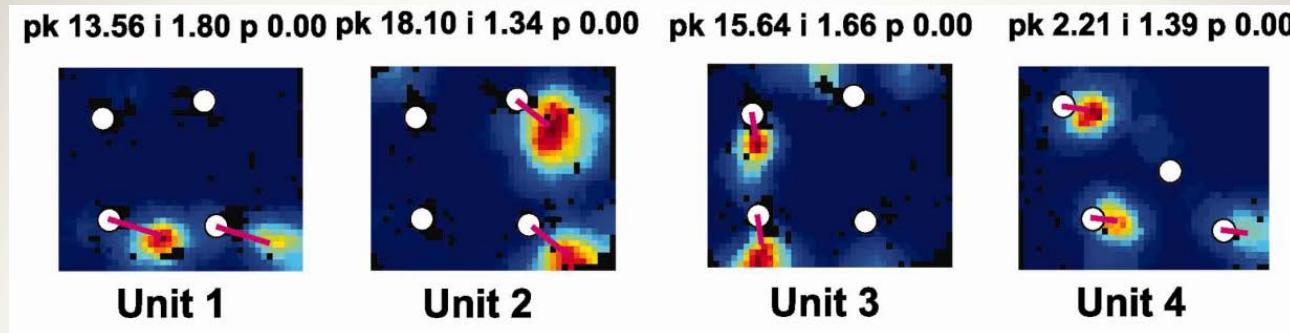
Complementary sources of spatial information to the hippocampus



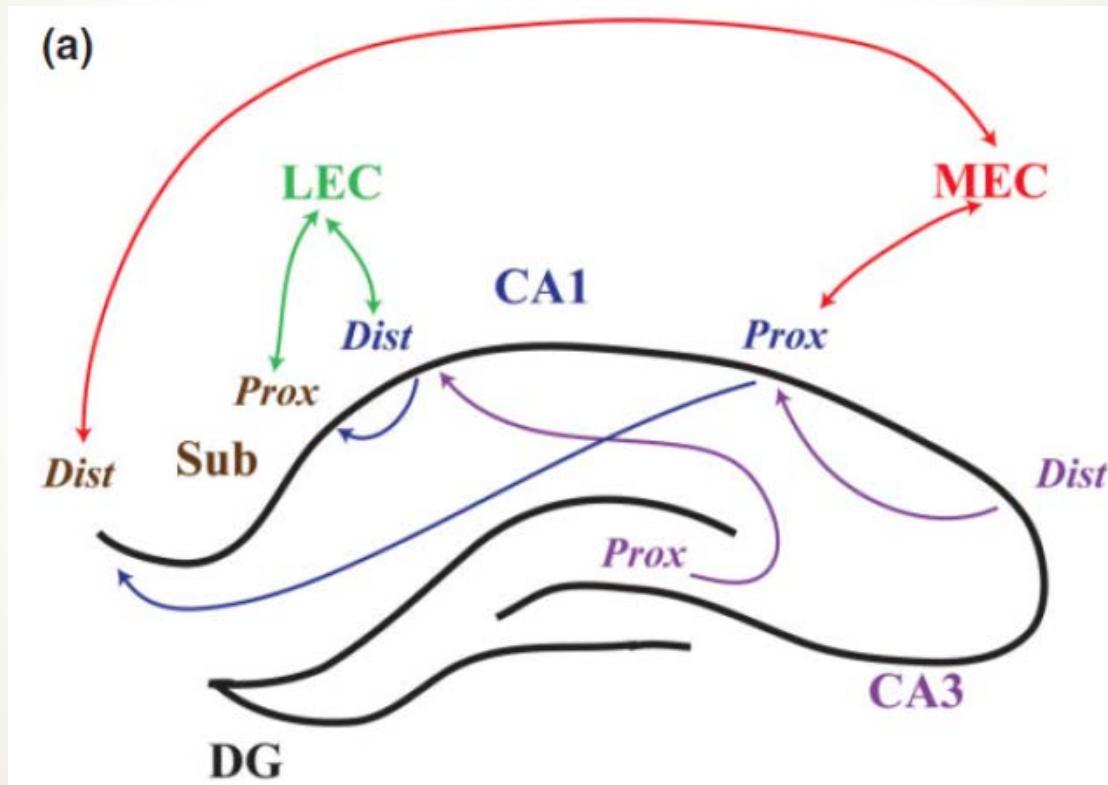
Misplace cells in the hippocampus



Landmark vectors in the hippocampus



Functional dissociation along the transverse axis of CA1



Functional dissociation along the transverse axis of CA1

session 1
(STD)



session 2
(MIS)



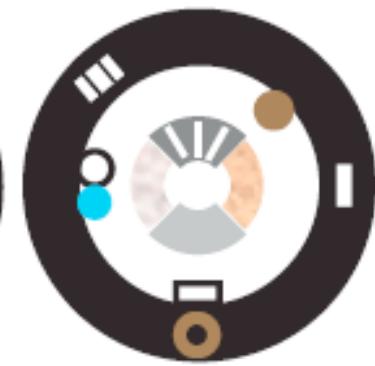
session 3
(STD)



session 4
(MIS)



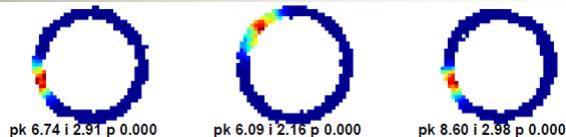
session 5
(STD)



Single unit responses to cue rotation along Proximo-distal axis of CA1

Response classification

Global (CW) rotation



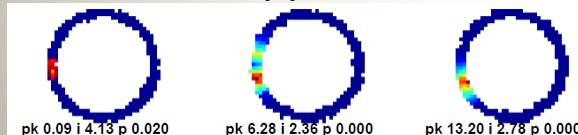
Local (CCW) rotation



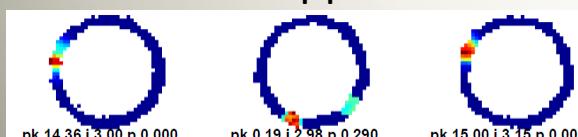
Ambiguous



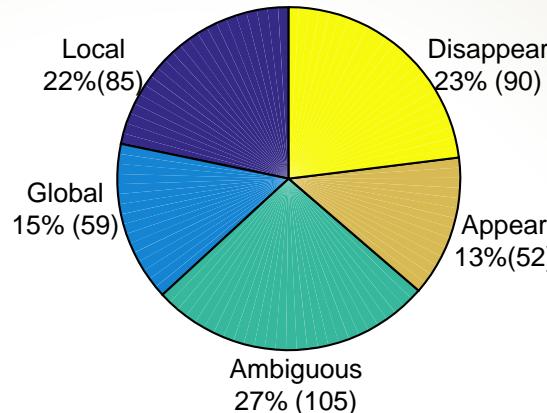
Appears



Disappears

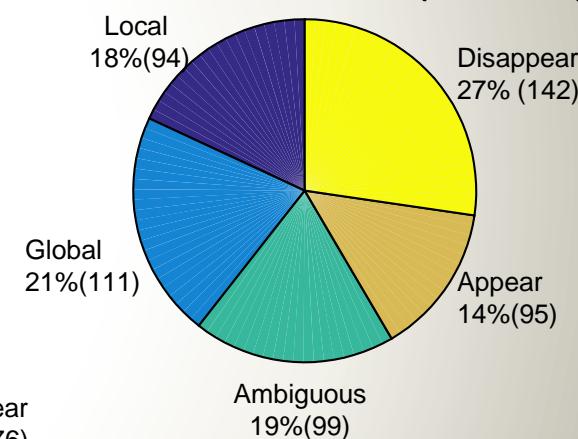


Proximal CA1 (n = 391)

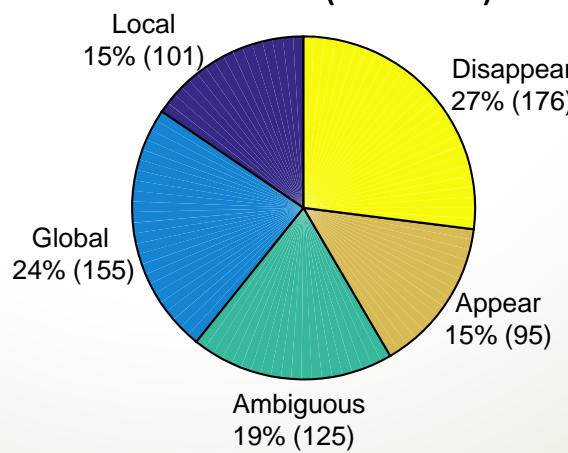


Proportion of units

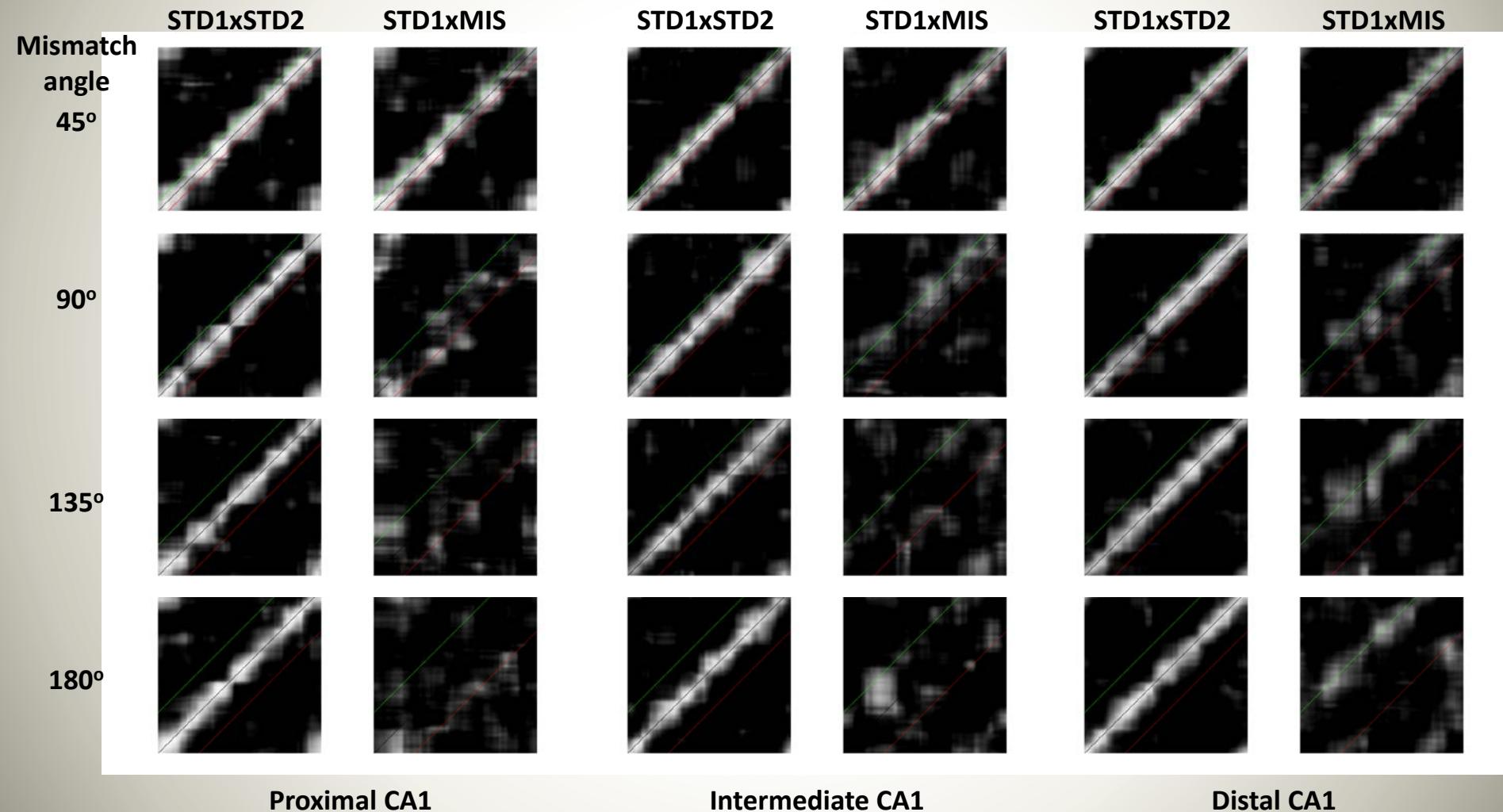
Intermediate CA1 (n = 520)



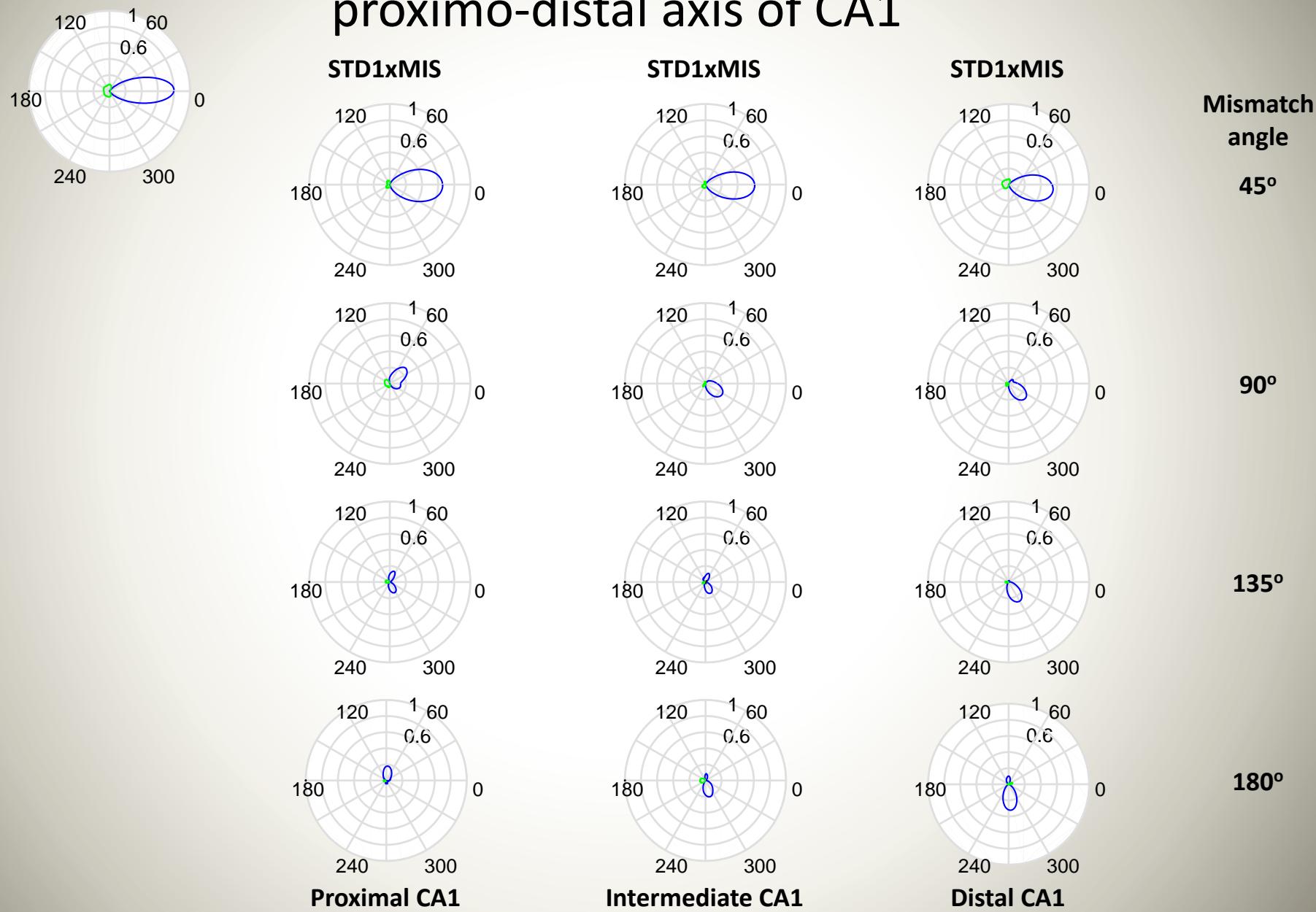
Distal CA1 (n = 652)



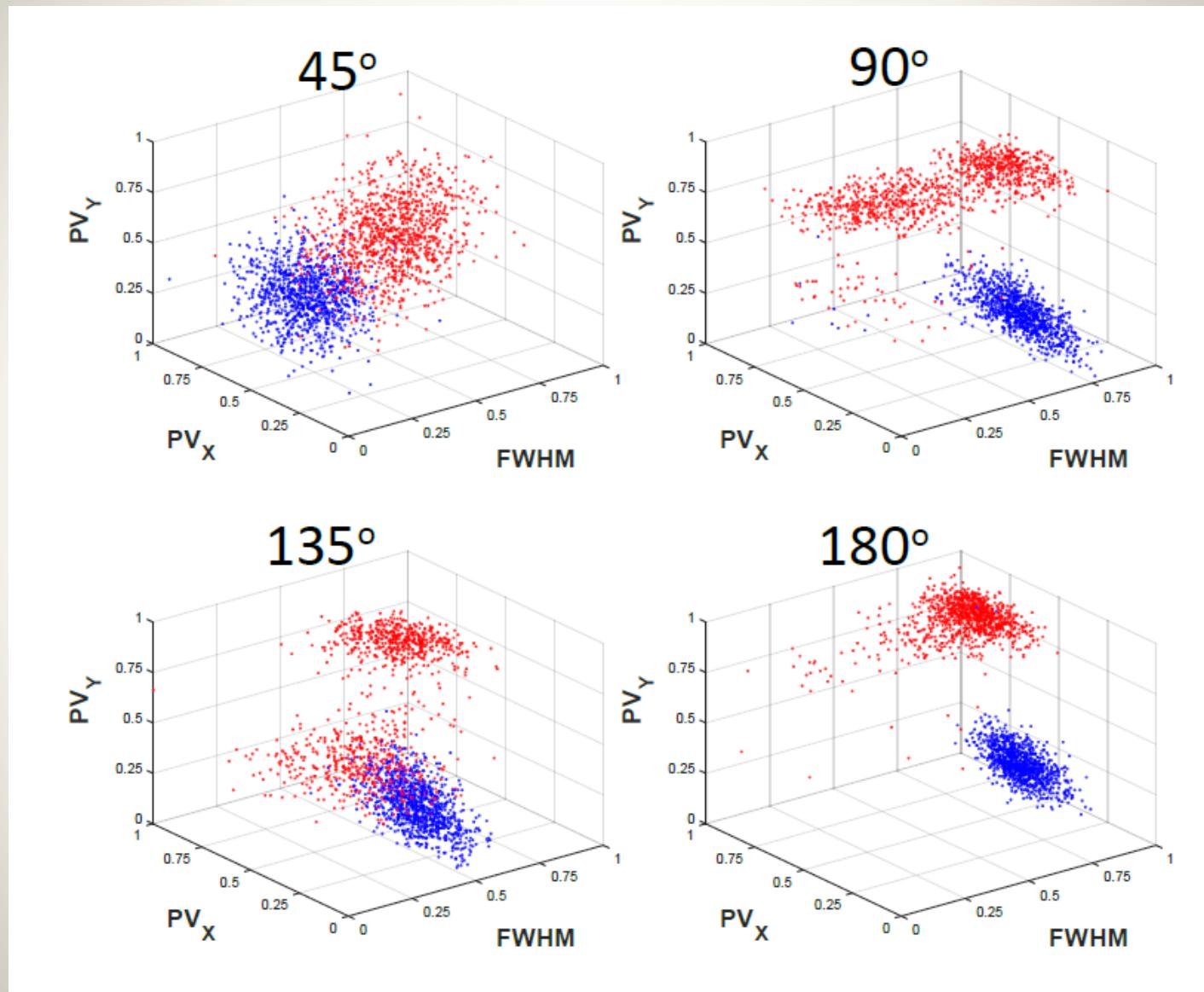
Cue conflict reveals functional dissociation along the proximo-distal axis of CA1



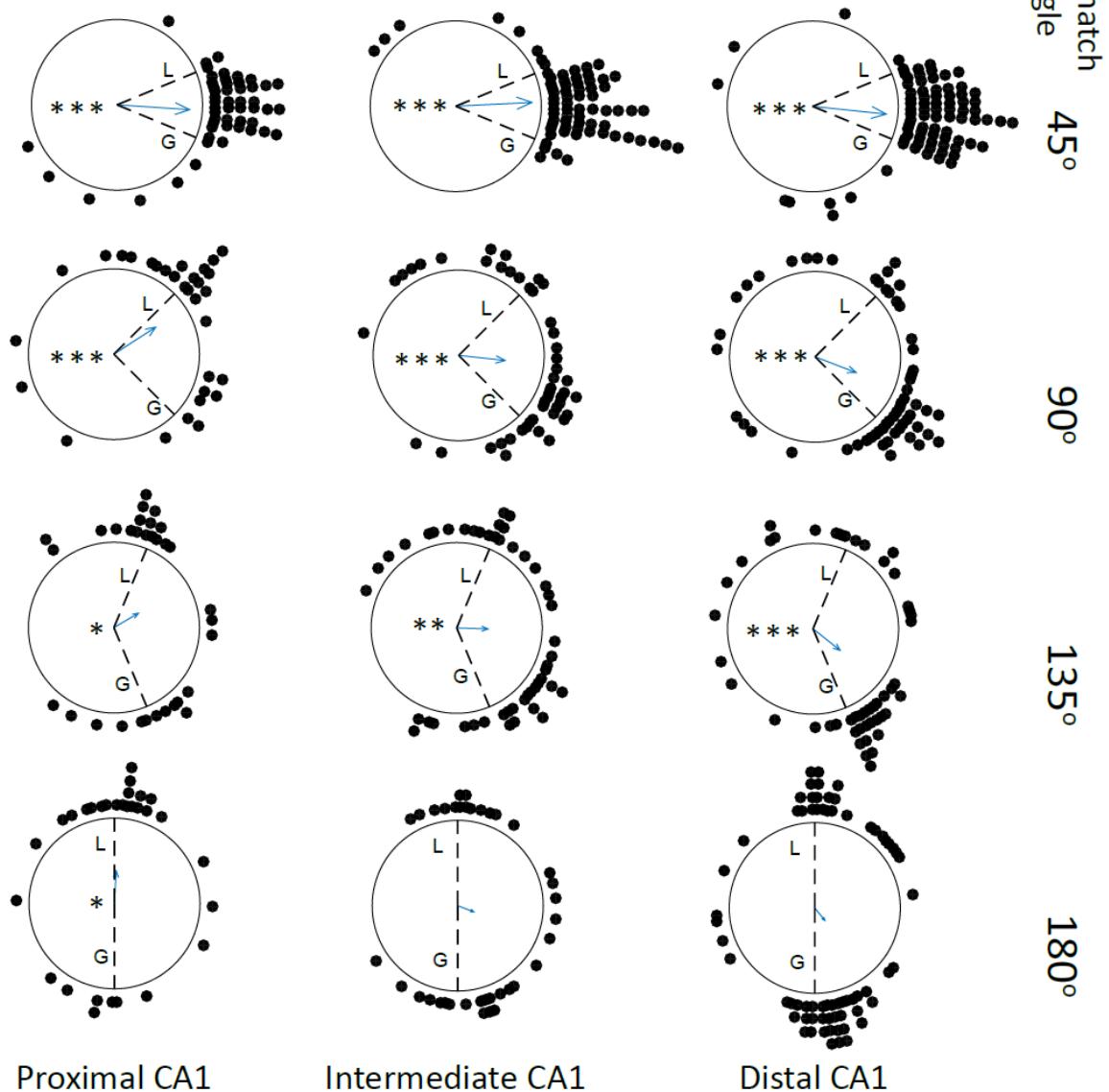
Cue conflict reveals functional dissociation along the proximo-distal axis of CA1



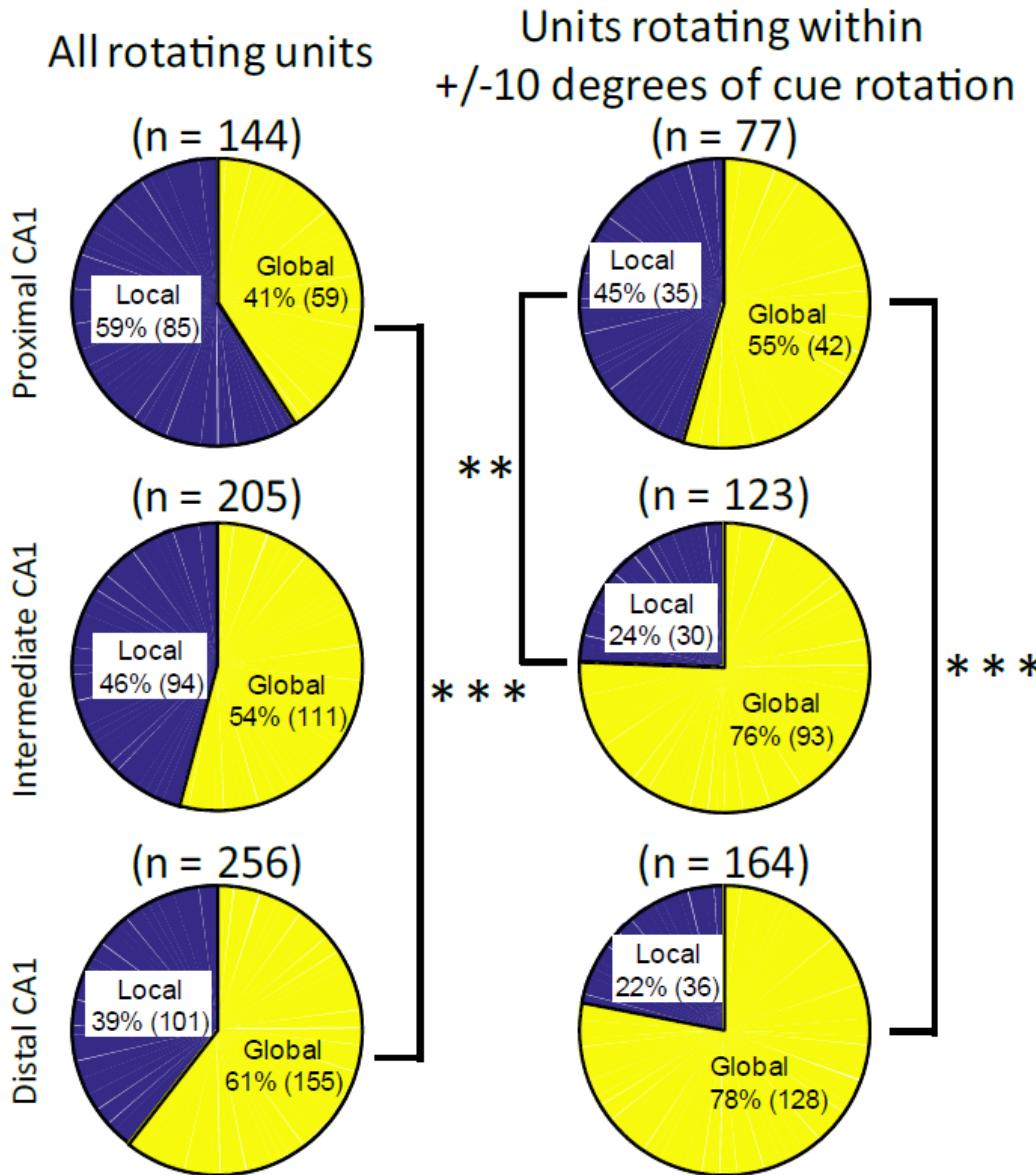
Proximal vs. Distal CA1 bootstrap comparisons



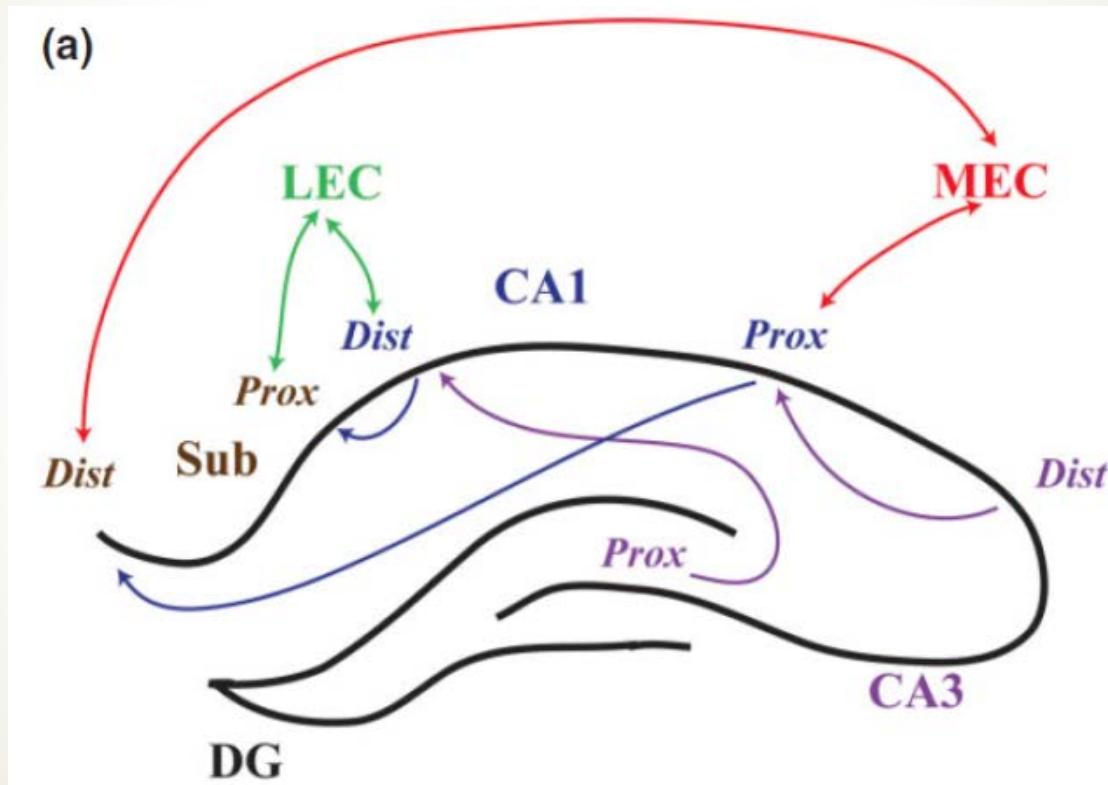
Single unit rotation distribution



Tighter control of place field locations by global cues than local cues



Functional dissociation along the transverse axis of CA1



Summary

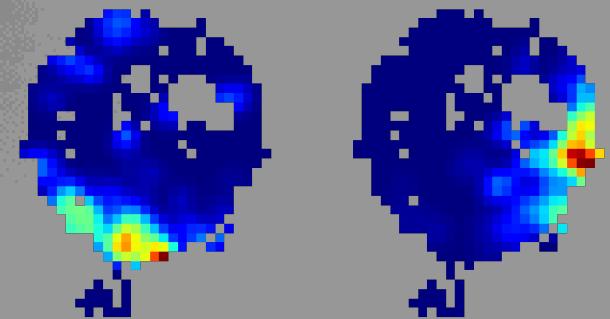
- Hippocampal spatial map is an abstract representation of space, and may provide a framework for organizing items and events of experience into a cognitive map.
- Plasticity plays an important role in stabilization of spatial representation.
- Path integration and landmark derived information provide complementary sources of information about space to the hippocampus.

Acknowledgement

James J Kneirm
Geeta Rao
Jeremy Johnson
Vyash Puliyadi
Amanda Smolinski
Francesco Savelli
Lou Blanpain
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Warsha Barde
Benny Jacob
Shrabasti Jana

Niikhil Deep Singh
Akshay Simha



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Tata Trusts