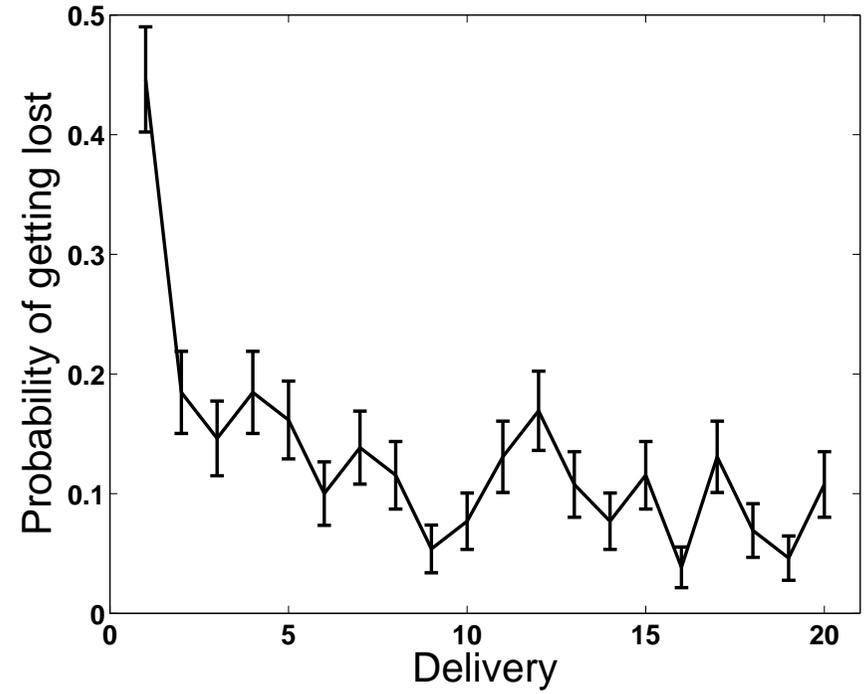


The Neurophysiology of Human Spatial Navigation

Mike Kahana

University of Pennsylvania

Yellow Cab: A virtual Cabbie Game



Jeremy Caplan, Ehren Newman

Psychological Perspectives

- Sensitivity to changes in local views

Psychological Perspectives

- Sensitivity to changes in local views
- Goal, View and Path Dependence

Psychological Perspectives

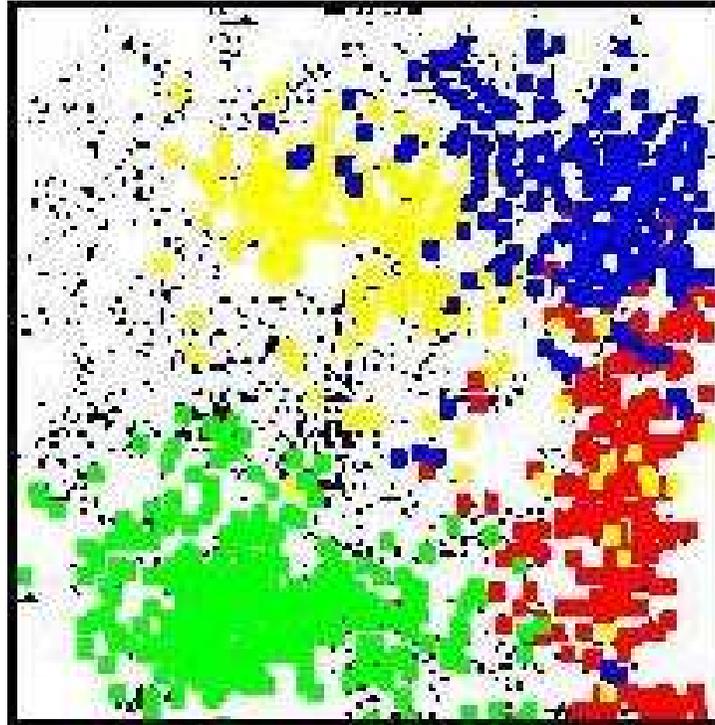
- Sensitivity to changes in local views
- Goal, View and Path Dependence
- Learn associations between views, goals and actions

Psychological Perspectives

- Sensitivity to changes in local views
- Goal, View and Path Dependence
- Learn associations between views, goals and actions
- No direct evidence for pure allocentric (map-like) representations

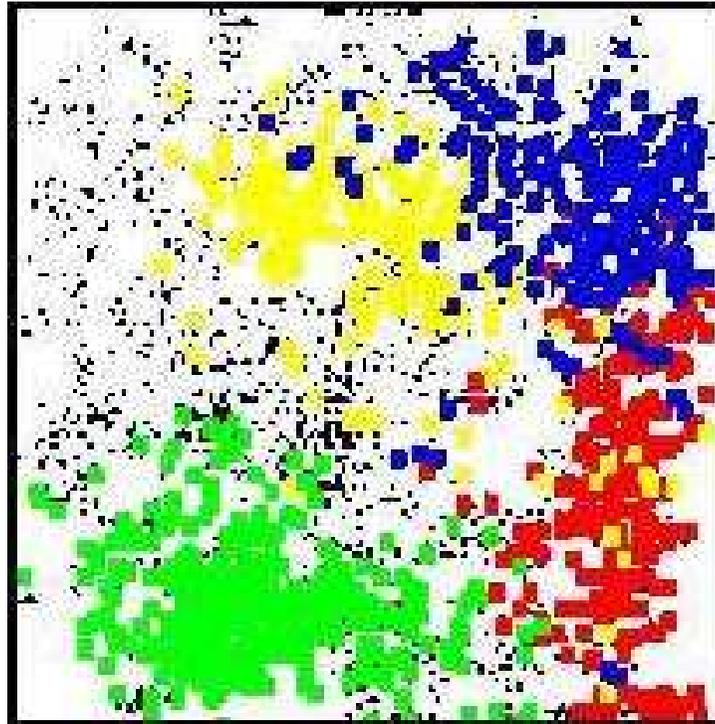
Neurophysiological Perspectives

Hippocampus and Place Cells

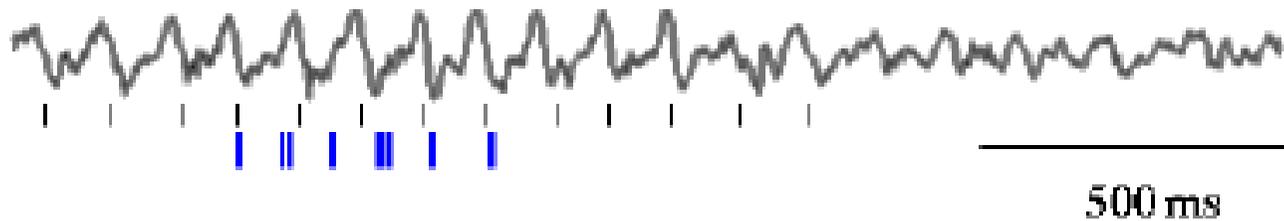


Neurophysiological Perspectives

Hippocampus and Place Cells



Theta Rhythm and Phase Coding

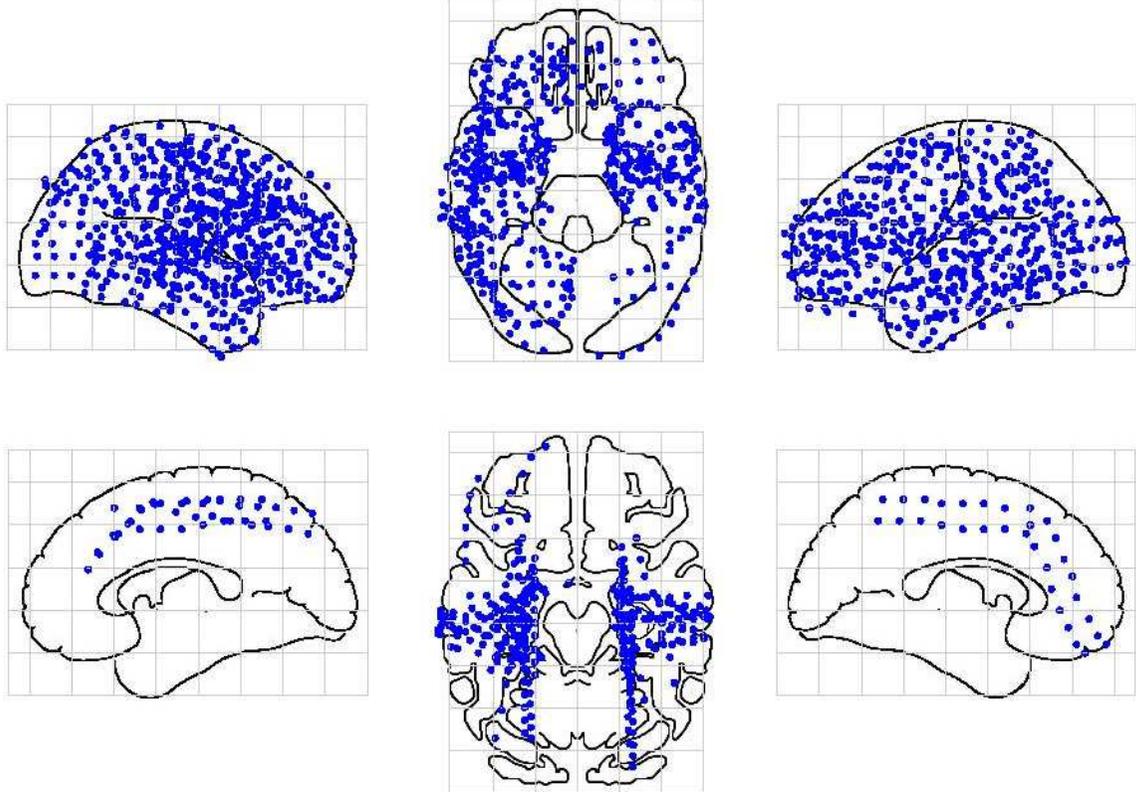
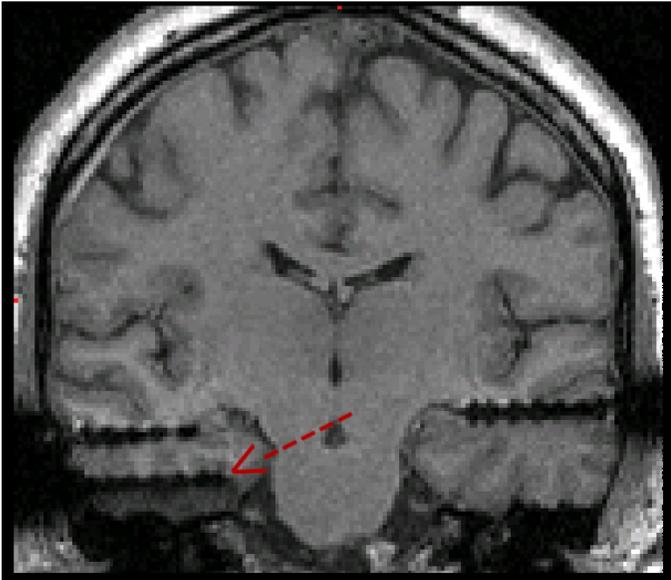
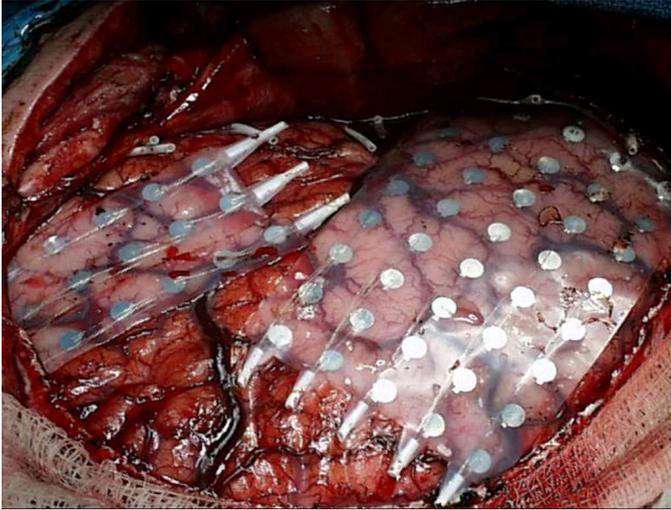


Human neuroimaging and lesion studies:

1. Hippocampal damage impairs spatial memory (Vargha-Khadem et al., 1997)
2. Increased hippocampal activity correlates with performance in spatial navigation tasks (Maguire et al, 1998; Burgess et al, 2002)
3. Viewing spatial scenes activates the parahippocampal region (Epstein, 2003)

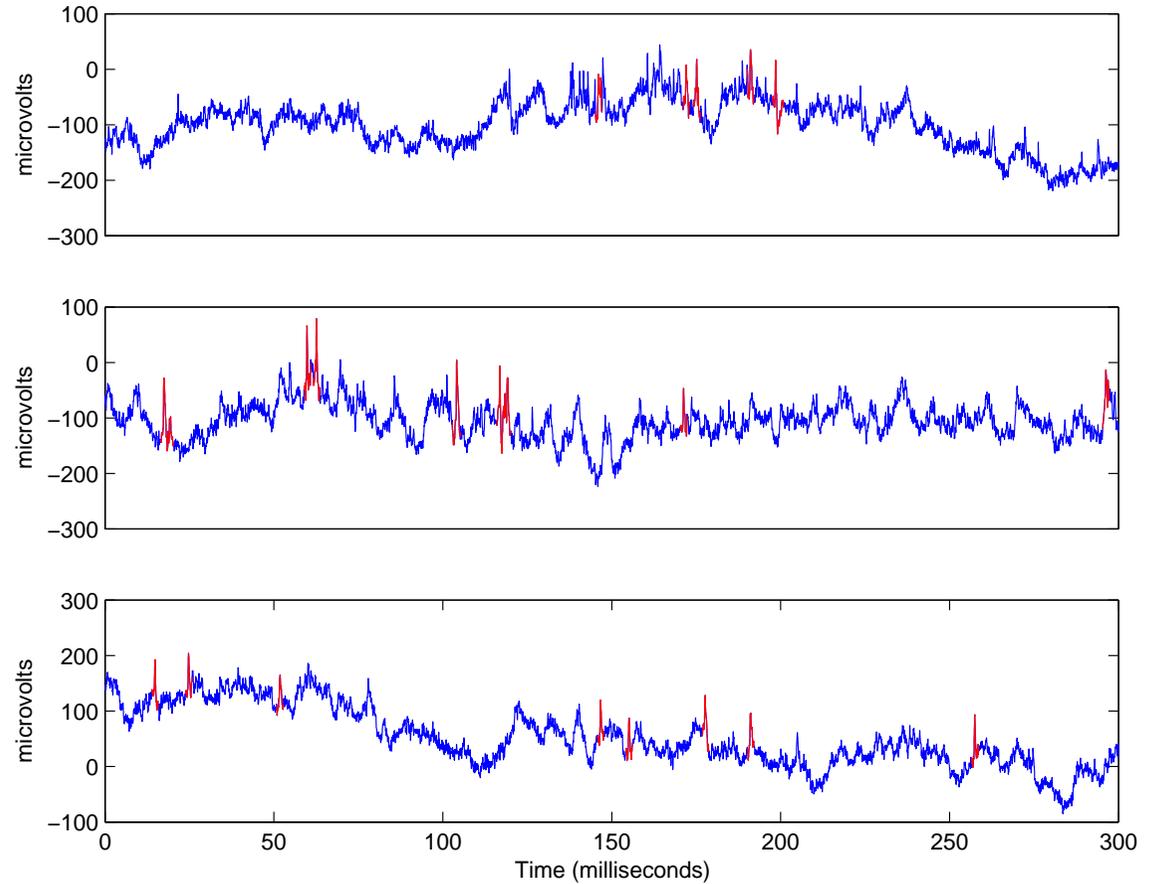
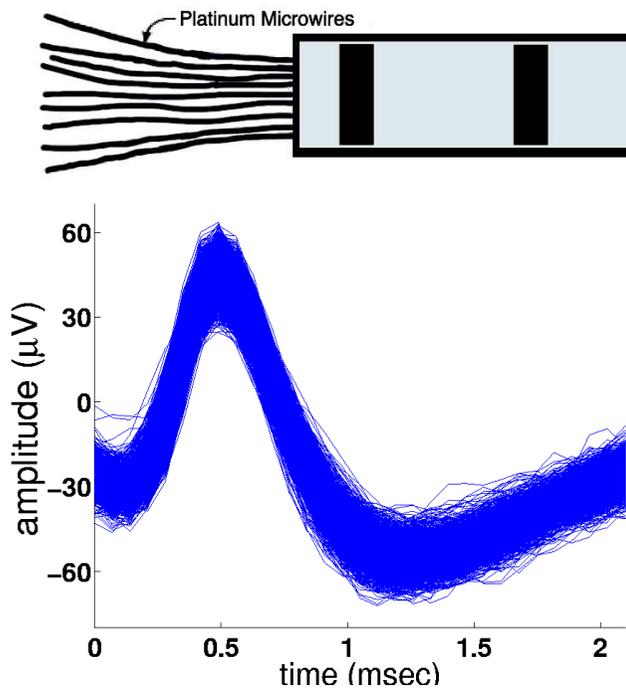
Measuring local brain oscillations and neuronal responses in humans

Intracranial EEG



Joseph Madsen (Childrens Hospital/BWH Boston)

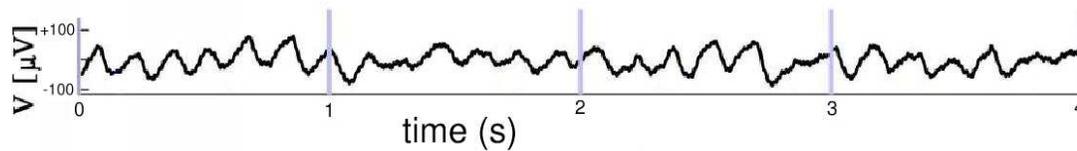
Recording field and action potentials



Itzhak Fried (UCLA/Tel Aviv)

Human Brain Oscillations

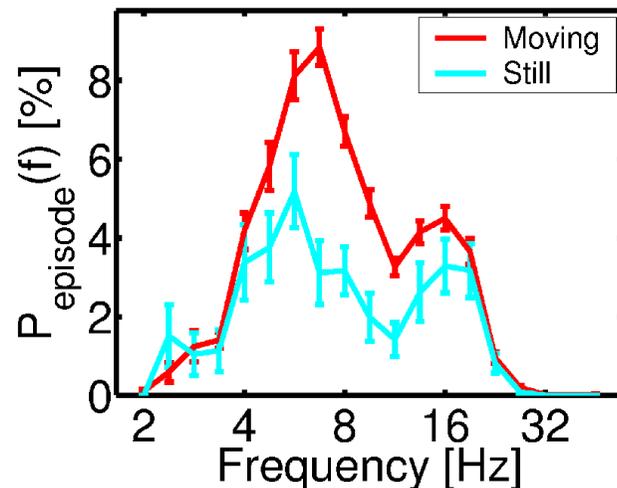
1. **Seen as peaks in the power spectra in EEG, MEG and intracranial EEG (iEEG) recordings**



Kahana, Caplan et al. (1999, *Nature*)

Human Brain Oscillations

1. Seen as peaks in the power spectra in EEG, MEG and intracranial EEG (iEEG) recordings
2. **Covary during cognitive activity/demands (generally increasing during):**
 - maze navigation and virtual movement (Caplan, de Aroujo)
 - verbal and non-verbal working memory (Tallon-Baudry, Bertrand, Raghavachari, Klimesch, Jensen,...)
 - episodic encoding and retrieval (Sederberg, Klimesch, Bastiensen, ...)



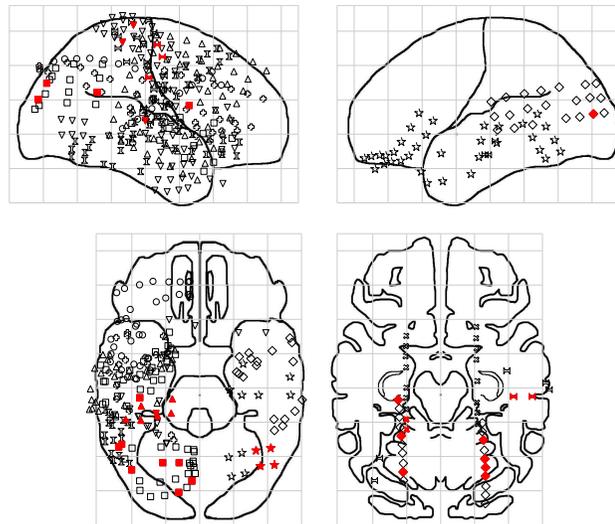
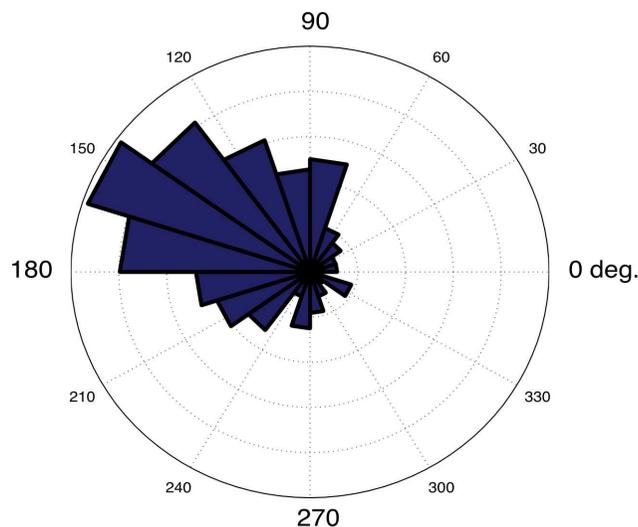
Caplan, Kahana et al. (2003, *J. Neurosci.*)

Human Brain Oscillations

1. Seen as peaks in the power spectra in EEG, MEG and intracranial EEG (iEEG) recordings
2. Covary during cognitive activity/demands
3. **Can be coherent across very long distances and independent across short distances (Raghavachari)**

Human Brain Oscillations

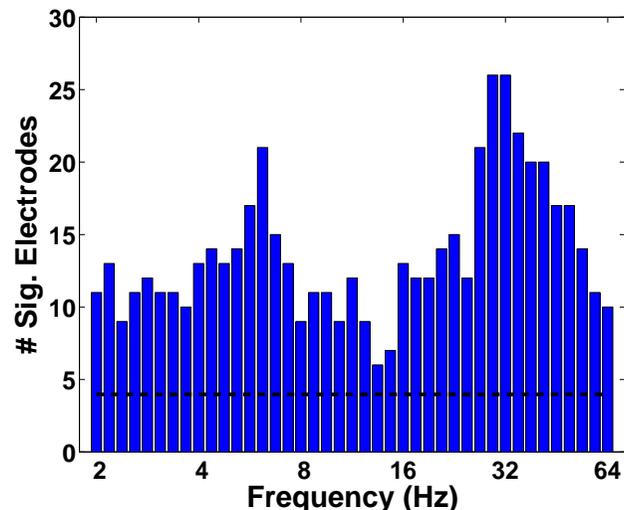
1. Seen as peaks in the power spectra in EEG, MEG and intracranial EEG (iEEG) recordings
2. Covary during cognitive activity/demands
3. Can be coherent across very long distances and independent across short distances
4. **Resets following salient stimuli (Makeig, Rizzuto, Bertrand, ..)**



Rizzuto, Kahana et al. (2002, *PNAS*)

Human Brain Oscillations

1. Seen as peaks in the power spectra in EEG, MEG and intracranial EEG (iEEG) recordings
2. Covary during cognitive activity/demands
3. Can be coherent across very long distances and independent across short distances
4. Resets following salient stimuli
5. **Predicts behavior, e.g., successful memory encoding memory**



Sederberg, Kahana et al. (2003, *J. Neurosci.*)

Oscillations and Communication

- Synchronization of different brain regions
- Timing of neural processes within a given region (e.g., encoding/retrieval)

Analyzing Neuronal Activity During YellowCab

Arne Ekstrom's Dissertation



Ekstrom, Kahana, Fried et al., Sept. 2003, *Nature*

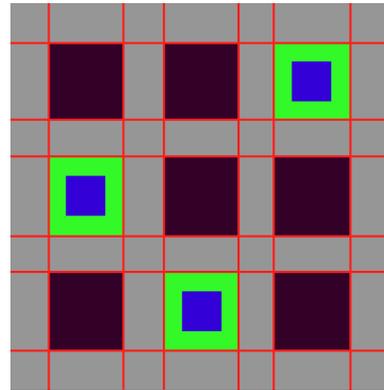
334 cells recorded across 8 patients.

- Hippocampus (H) = 78
- Parahippocampal Region (PR) = 68
- Amygdala (A) = 112
- Frontal Region (FR) = 76

Place, Goal and View

Compare firing rates as a function of three underlying factors (using ANOVA). Only periods of movement were considered.

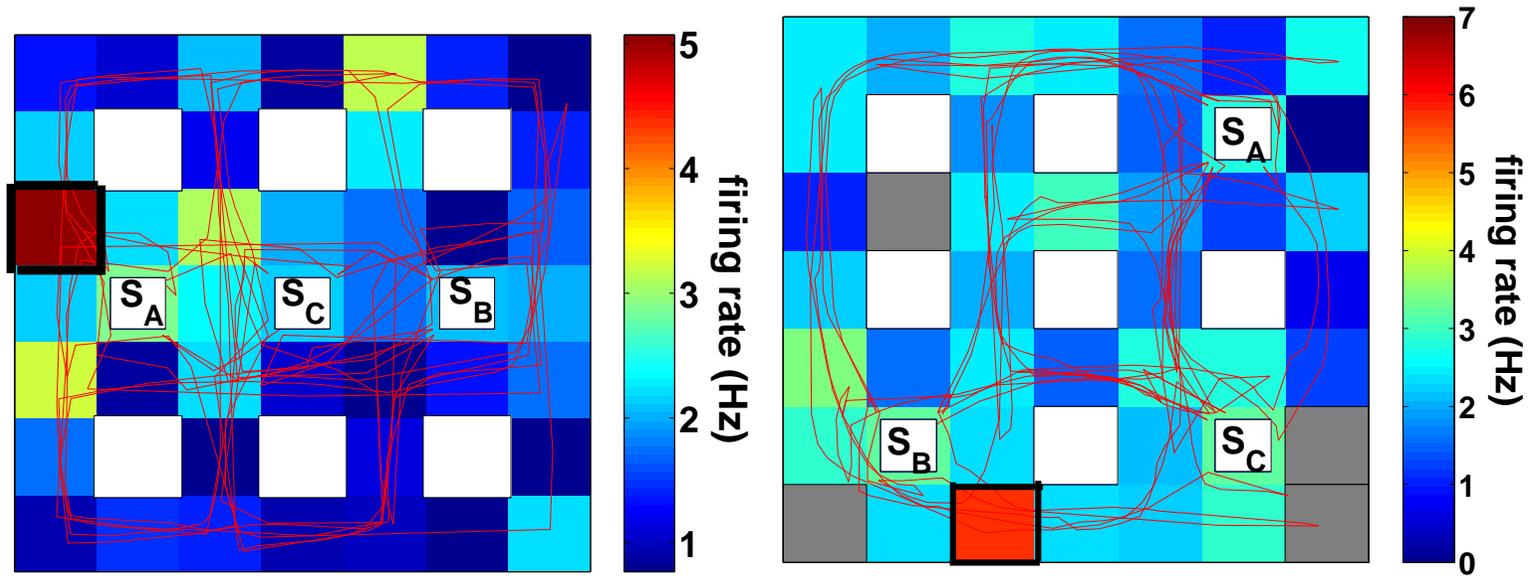
- *Place*: Where you are in the town. We divided each town into 43 regions.



- *Goal*: Searching for Store A, B or C; Searching for Passenger.
- *View*: Looking at Store A, B, C, Passenger, or control view.

Place-responsive cells

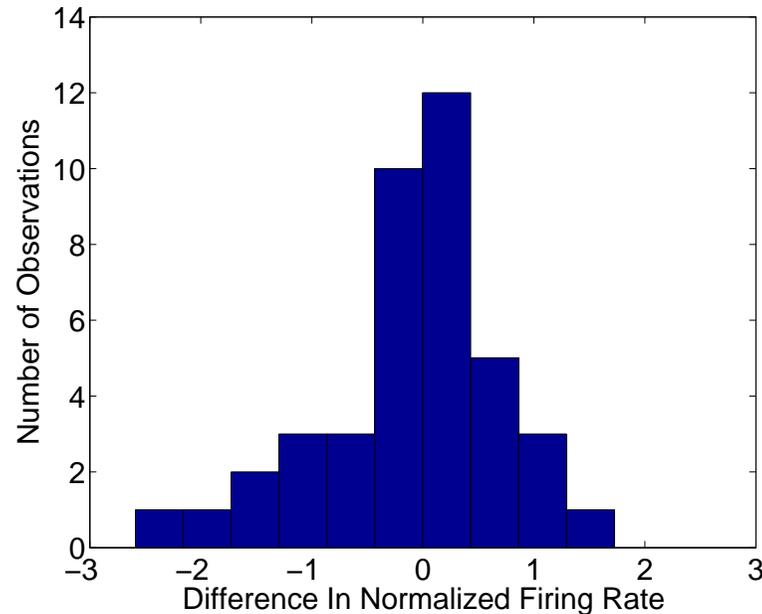
Both in right hippocampus.



Mean firing rate as a function of spatial region.

39 place cells.

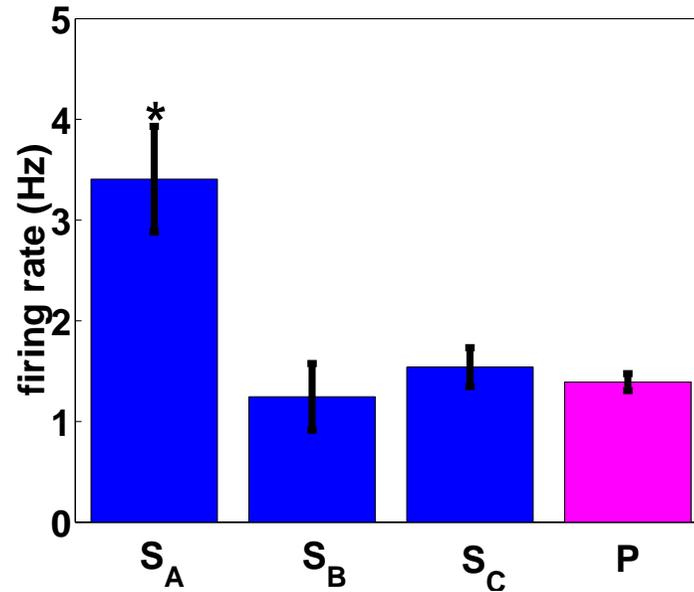
Most hippocampal place cells are omnidirectional



Firing rate for north minus south, east minus west.

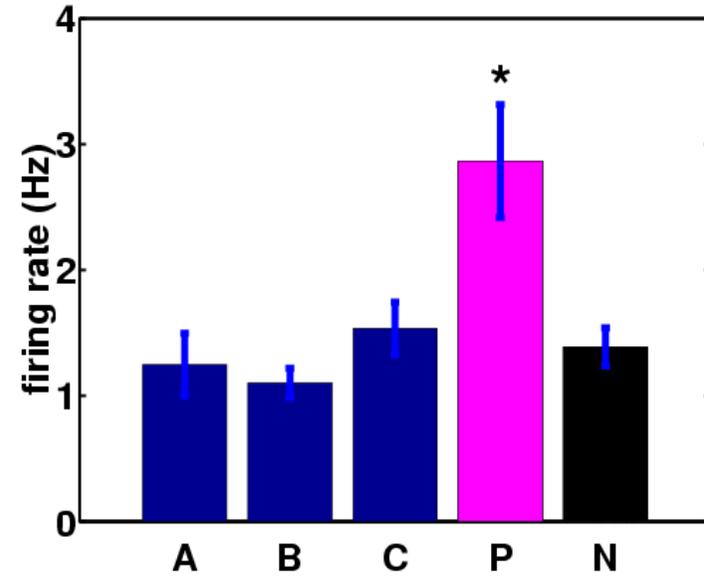
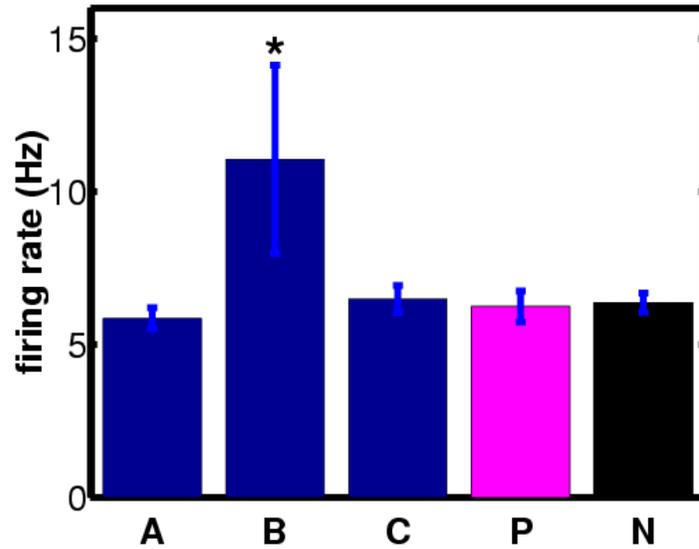
- Unidirectional cells should appear as peaks away from zero.
- Omni directional cells are centered around zero.

Goal-responsive cells



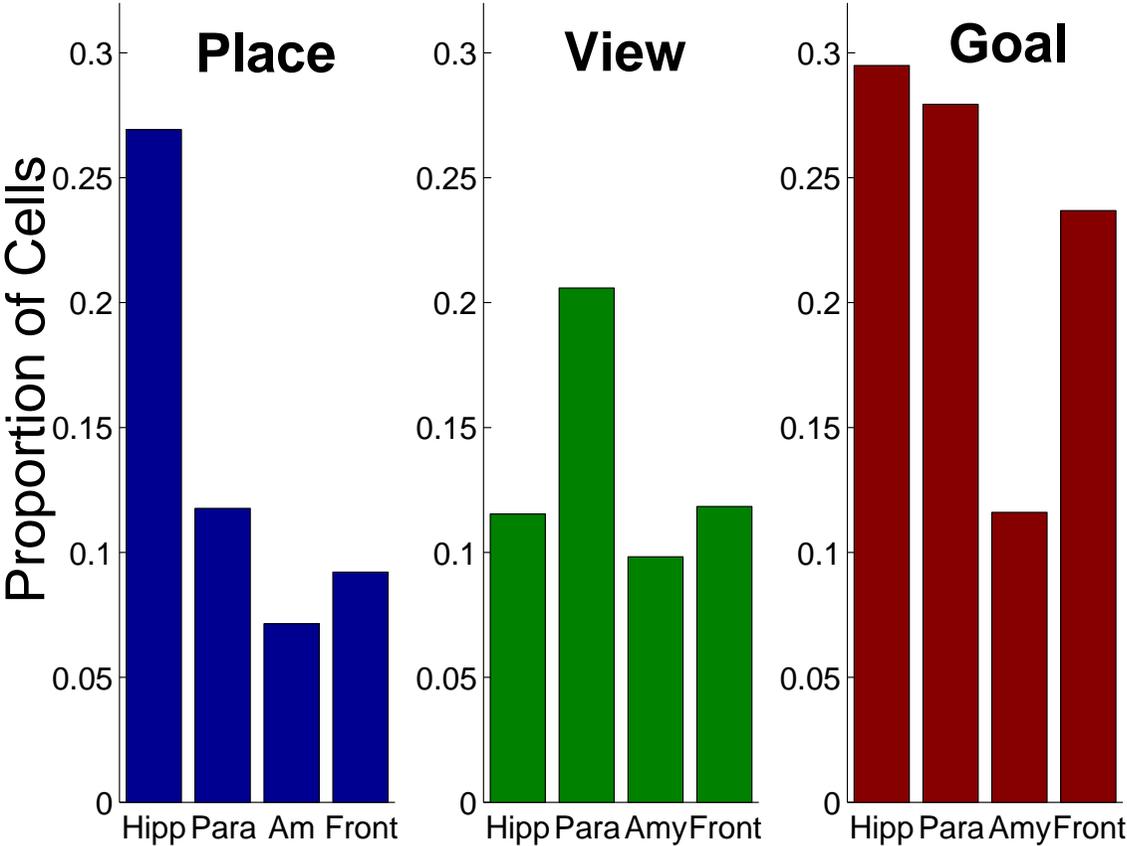
- Goals: Store A; Store B; Store C; P = Passenger
- **69 goal cells.**

View-responsive cells



- View of Store A; Store B; Store C; P = Passenger; N = Background/Control
- 41 view cells.

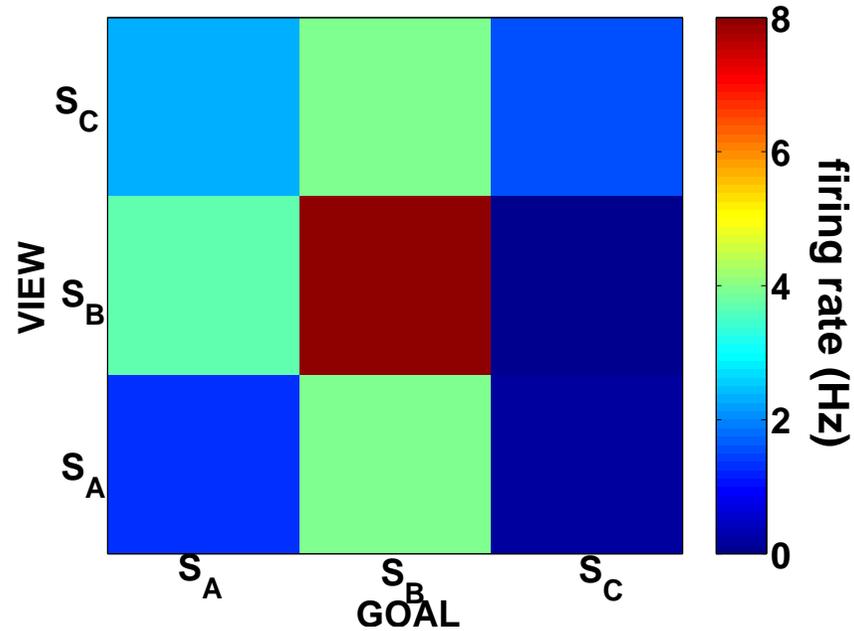
Anatomical distribution of place, view and goal cells



Interaction Cells

View-modulated goal responses

Cell in right amygdala...



fires most strongly when goal (Store B) is in view.

Current Projects

- Remapping (A,B,A)
- Relation between oscillations and spikes (precession?)
- Learning of place, goal and view representations