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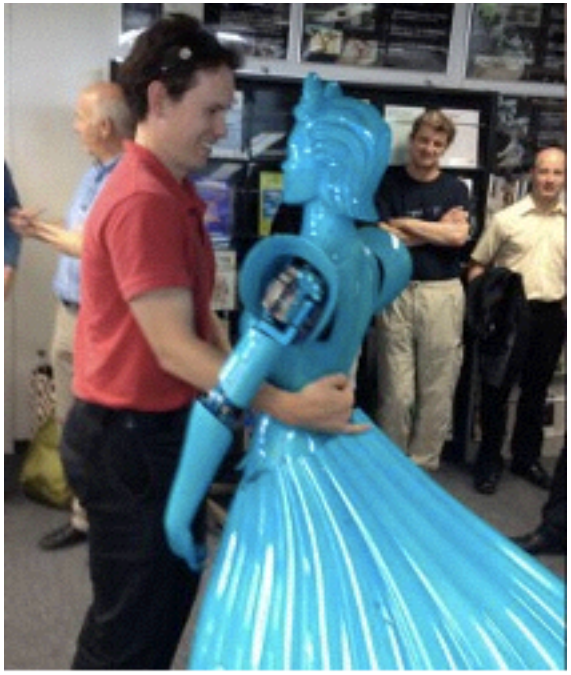
RatSLAM and Grid Cells

An overview of work by Michael Milford and colleagues

People



Michael Milford

Janet Wiles

David Prasser

Gordon Wyeth

Papers

- Milford, Michael J., Gordon F. Wyeth, and David Prasser. "RatSLAM: a hippocampal model for simultaneous localization and mapping." *Robotics and Automation, 2004. Proceedings. ICRA'04. 2004 IEEE International Conference on*. Vol. 1. IEEE, 2004.

- Milford, Michael, and Gordon Wyeth. "Persistent navigation and mapping using a biologically inspired SLAM system." *The International Journal of Robotics Research* 29.9 (2010): 1131-1153.

- Milford, Michael J., Janet Wiles, and Gordon F. Wyeth. "Solving navigational uncertainty using grid cells on robots." *PLoS computational biology* 6.11 (2010): e1000995.

RatSLAM

- Biologically inspired and wired for large-scale, long-term autonomy

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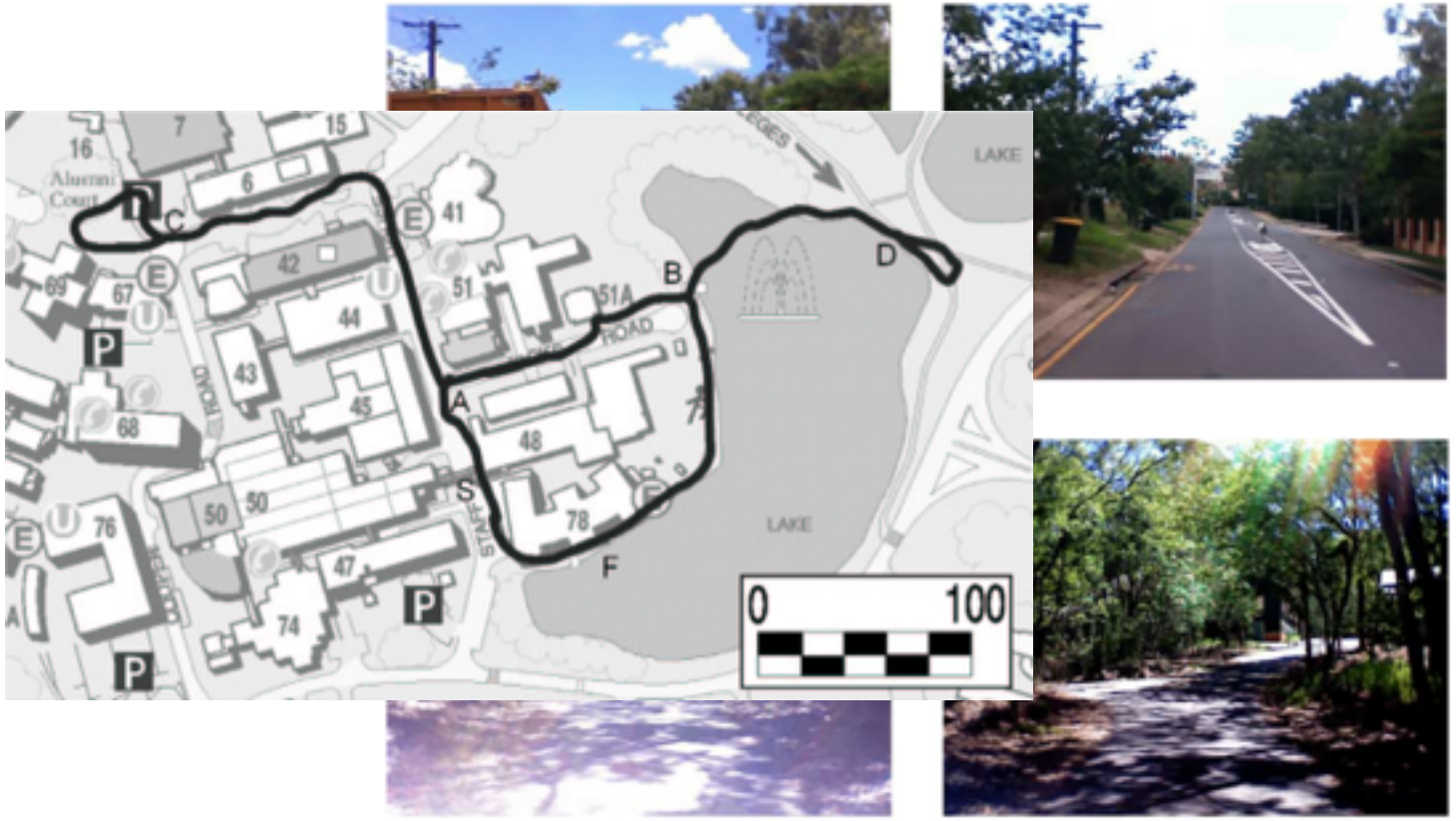

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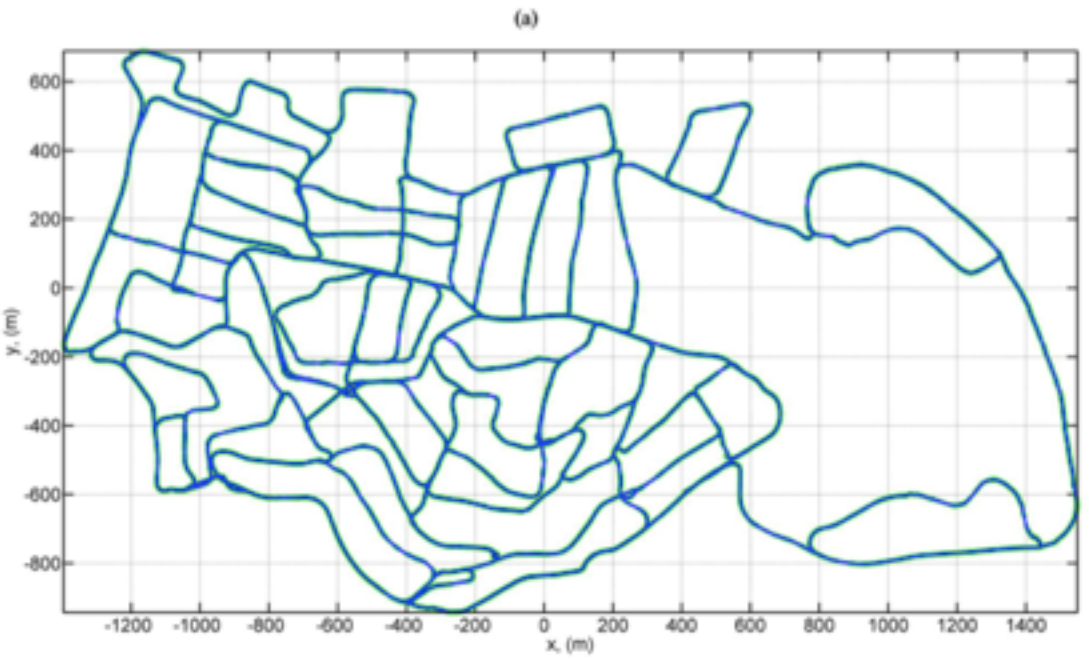
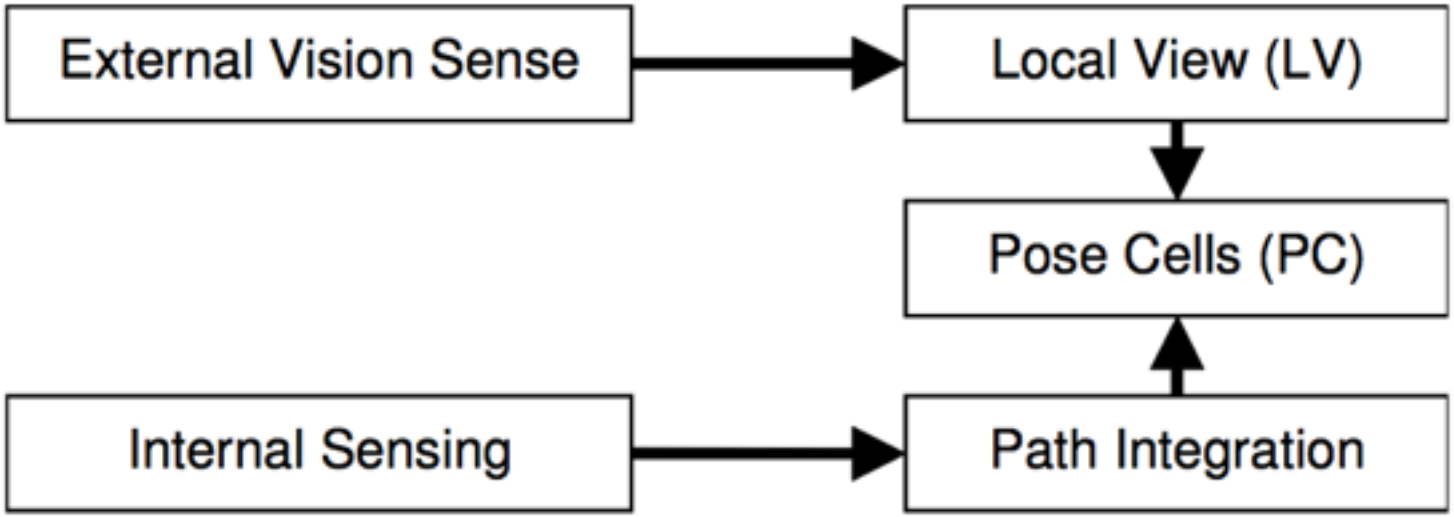
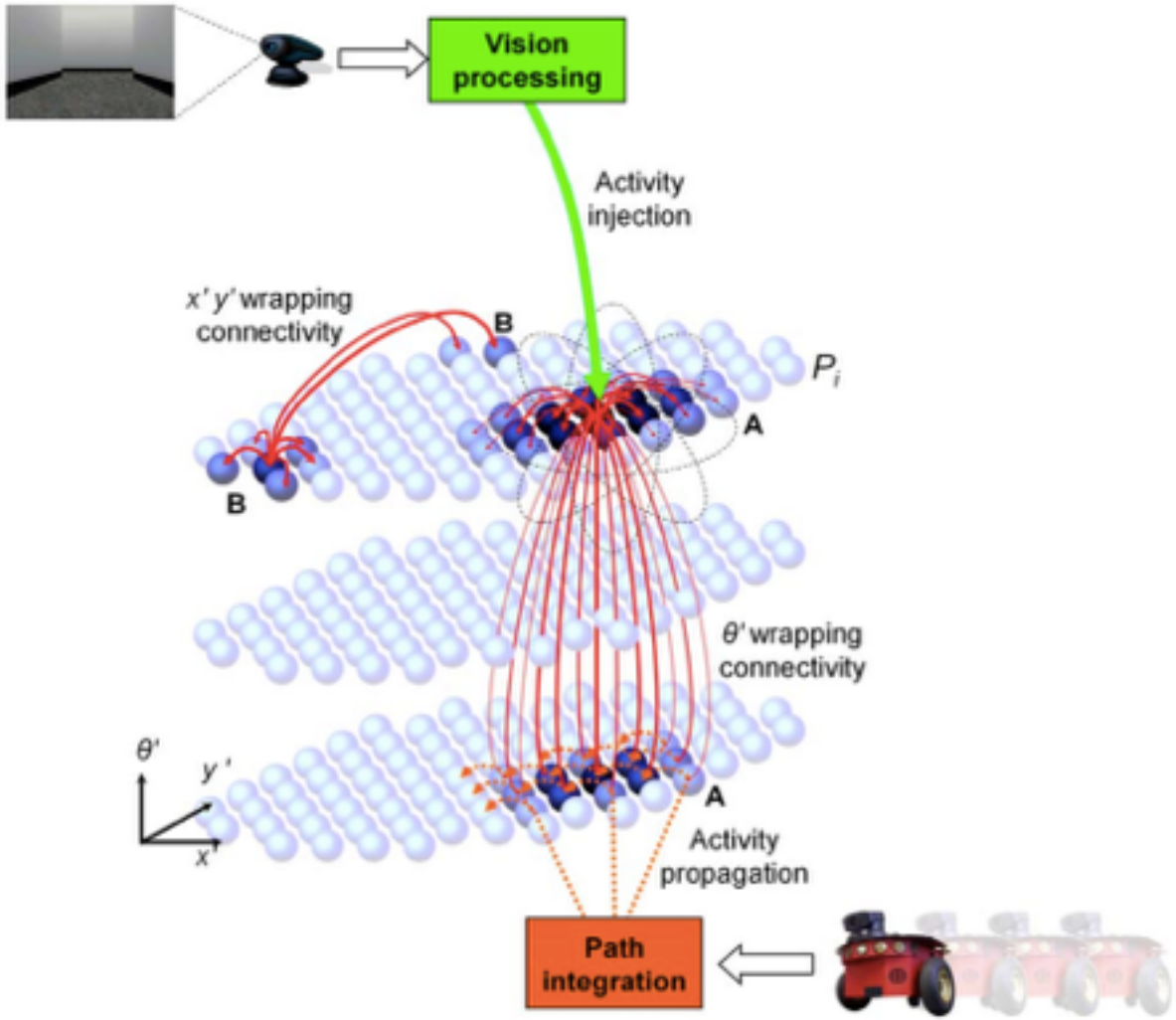
- Biologically i
  scale, long-t



Process


External Vision Sense
Local View (LV)
Pose Cells (PC)
Internal Sensing
Path Integration

Pose Cells and View Cells



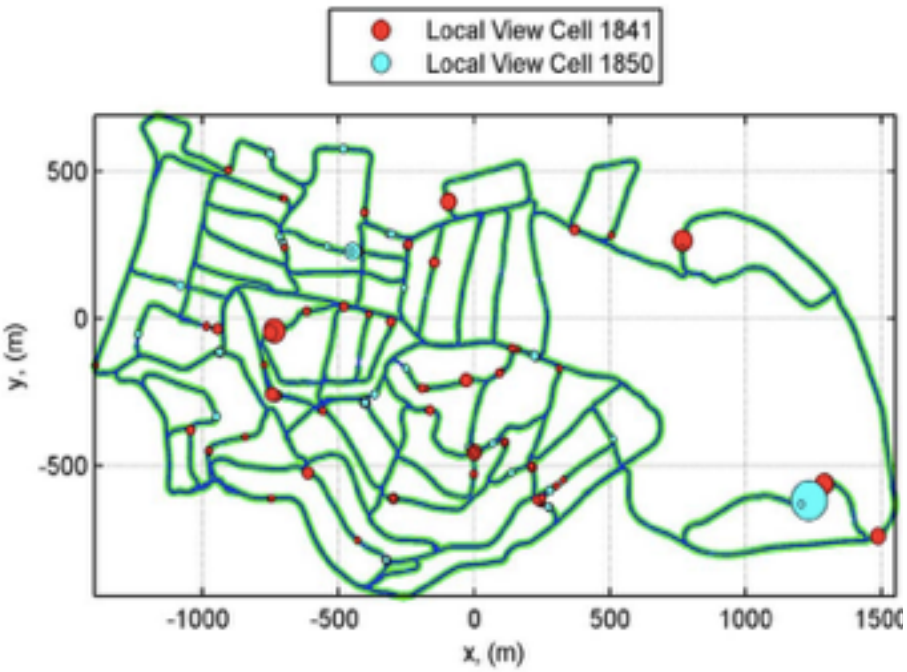
Network Iteration

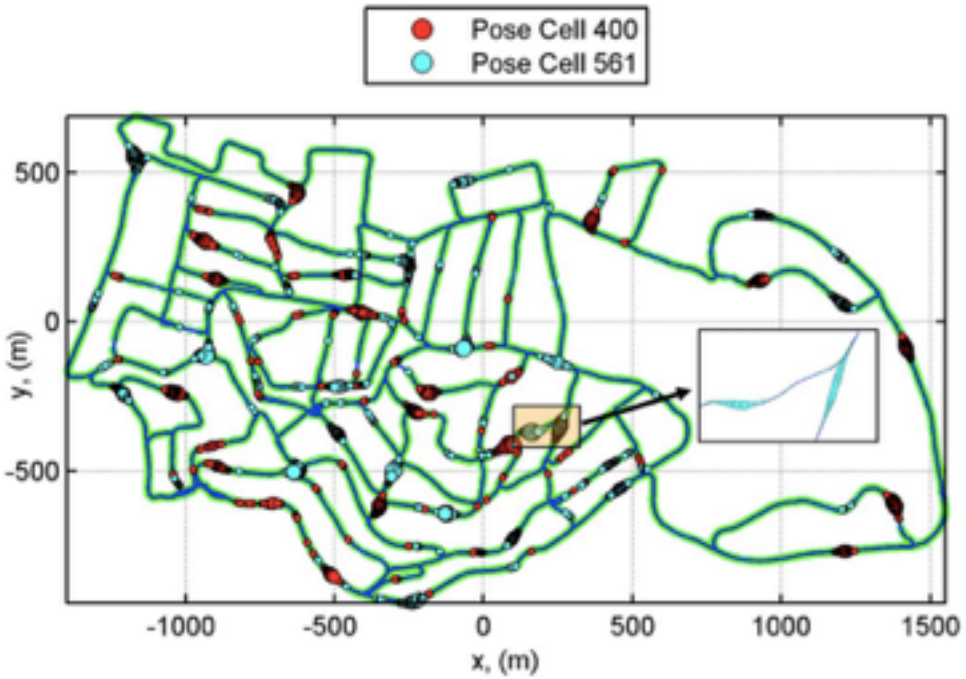
Global pose update: $$\Delta P_{x',y',\theta'} = \sum_{i=0}^{(n_{x'}-1)} \sum_{j=0}^{\left(n_{y'}-1\right)} \sum_{k=0}^{(n_{\theta'}-1)} P_{i,j,k}\varepsilon_{a,b,c} - \varphi$$

Visual weights: $$\beta^{t+1}_{i,x',y',\theta'} = \max\left(\beta^{t}_{i,x',y',\theta'}, \lambda V_i P_{x',y',\theta'}\right)$$

Visual pose update: $$\Delta P_{x',y,'\theta'} = \frac{\delta}{n_l} \sum_i \beta_{i,x',y',\theta'} V_i$$

Re-use of cells





Relationship to Rodent Memory

Place Cells & Head Cells

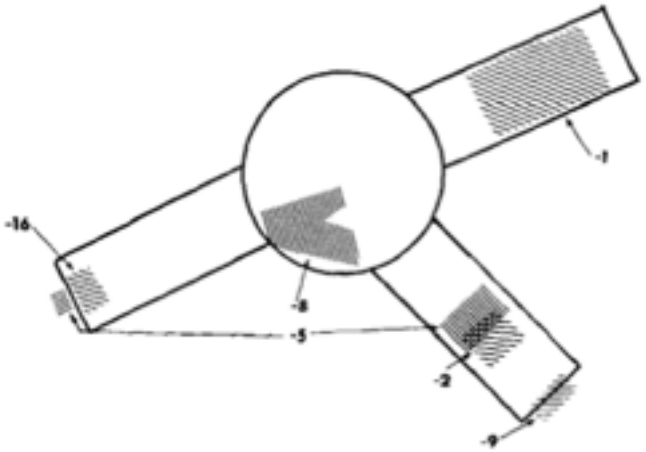
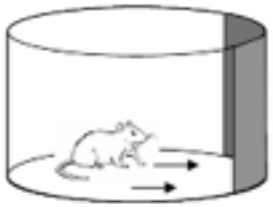
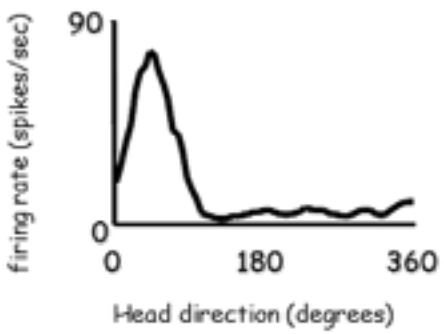
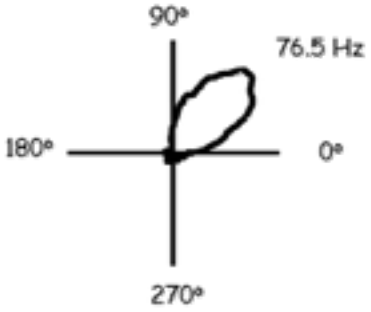


FIG. 3. Place fields for place units from animal 217.

O'Keefe, John. "Place units in the hippocampus of the freely moving rat." *Experimental neurology* 51.1 (1976): 78-109.

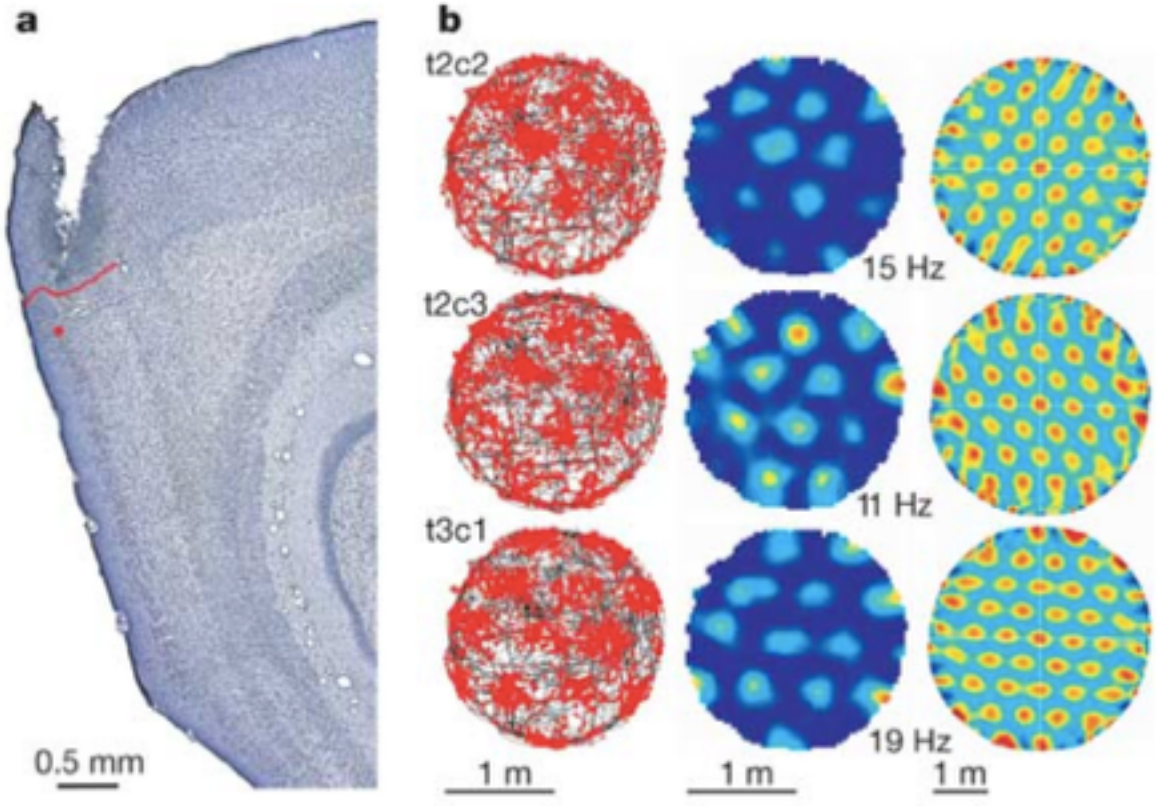






Taube, Jeffrey S., Robert U. Muller, and James B. Ranck. "Head-direction cells recorded from the postsubiculum in freely moving rats. I. Description and quantitative analysis." *The Journal of Neuroscience* 10.2 (1990): 420-435.

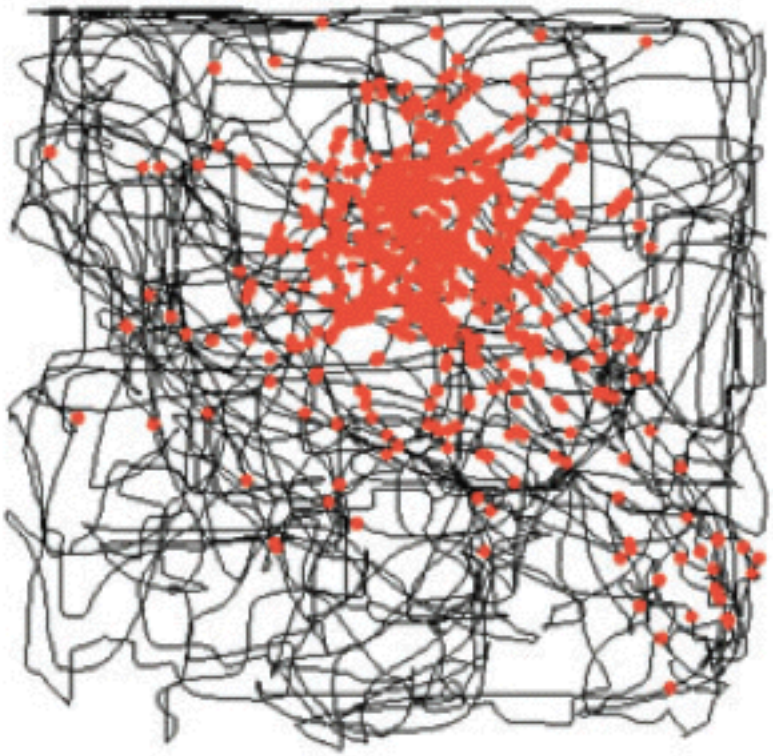
Grid Cells



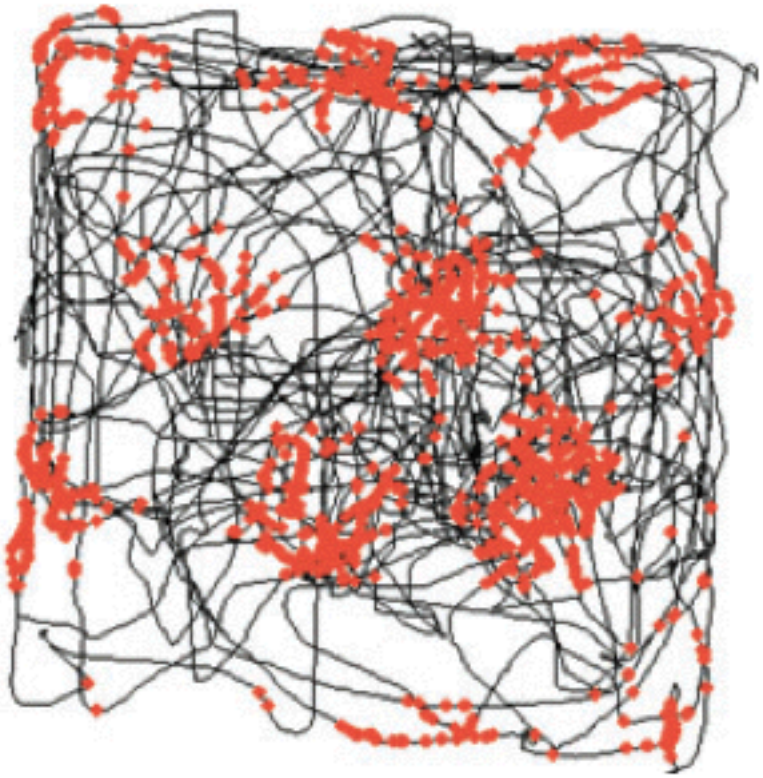
May-Britt & Edvard Moser

Hafting, Torkel, et al. "Microstructure of a spatial map in the entorhinal cortex." Nature 436.7052 (2005): 801-806.

Place Cells vs. Grid Cells

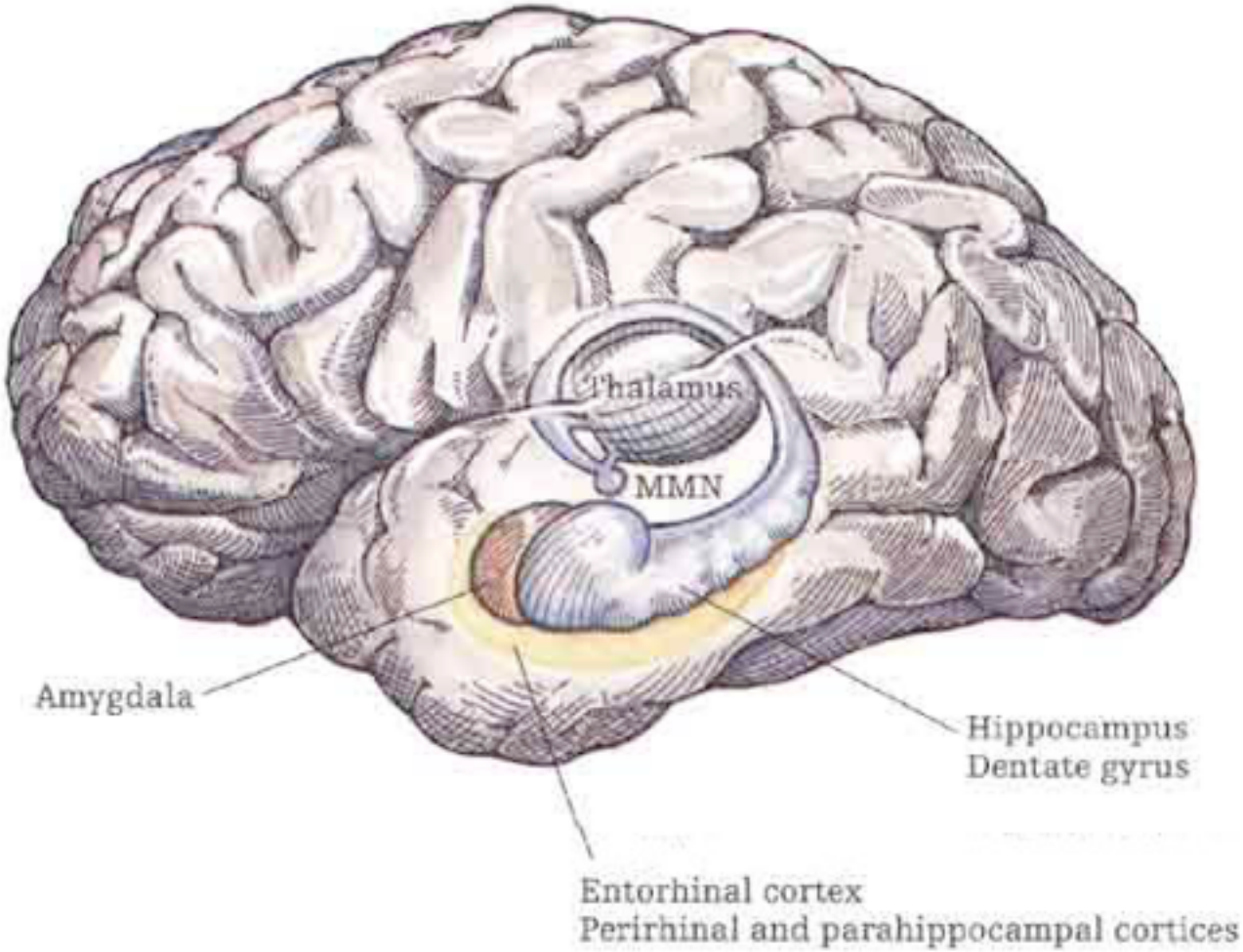


Place Cell

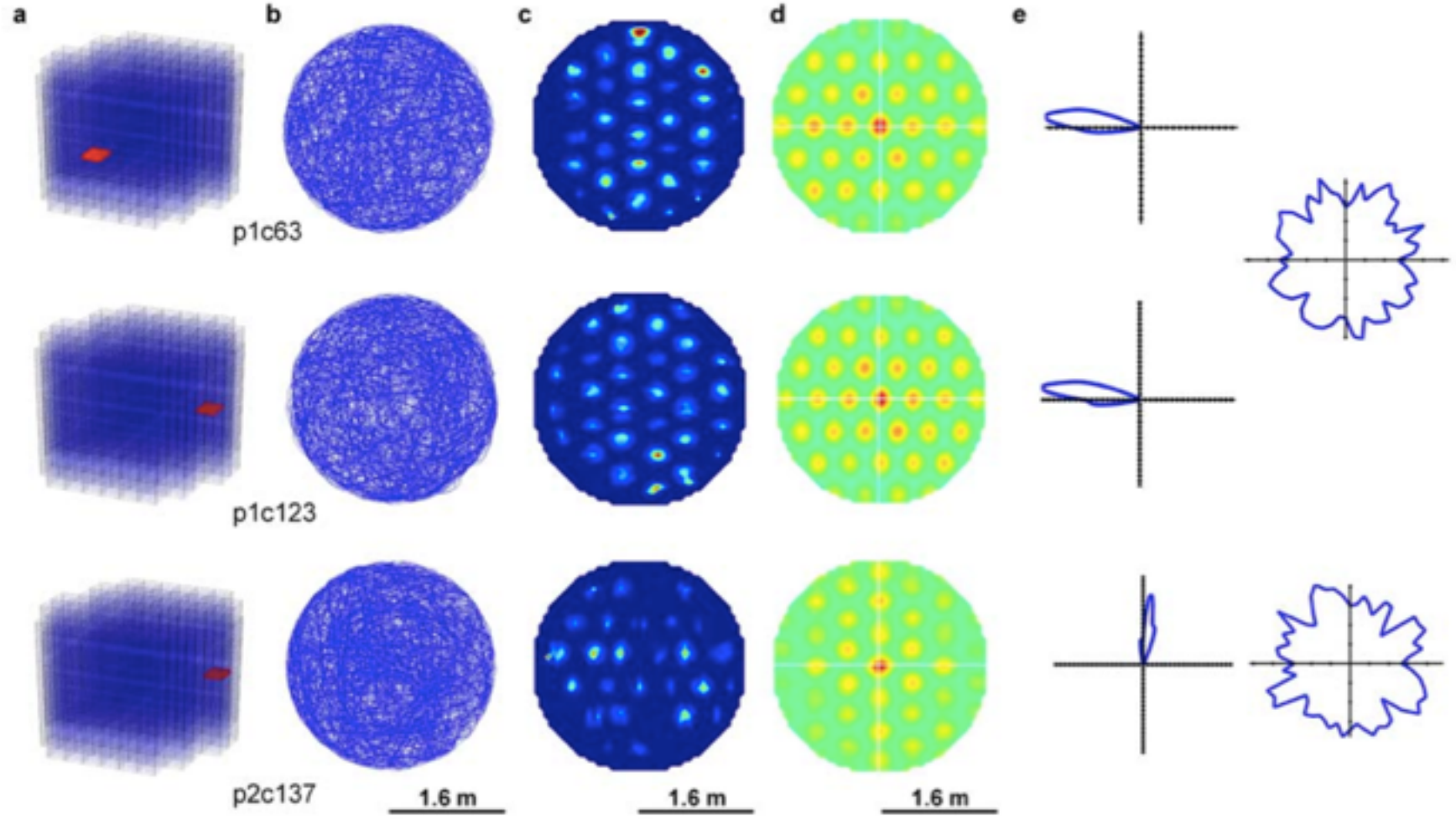


Grid Cell

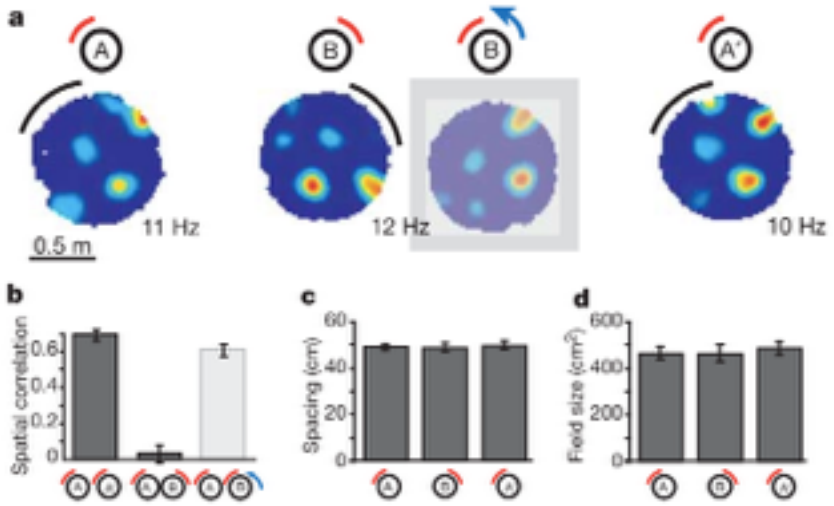
Entorhinal Cortex



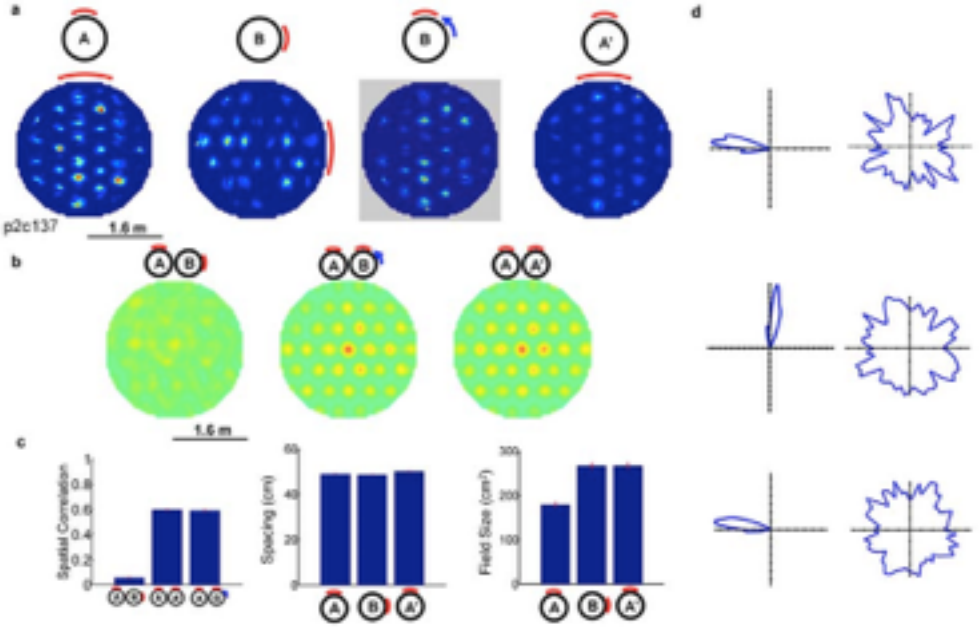
Firing Patterns in RatSLAM cells



“Grids are anchored to external cues”

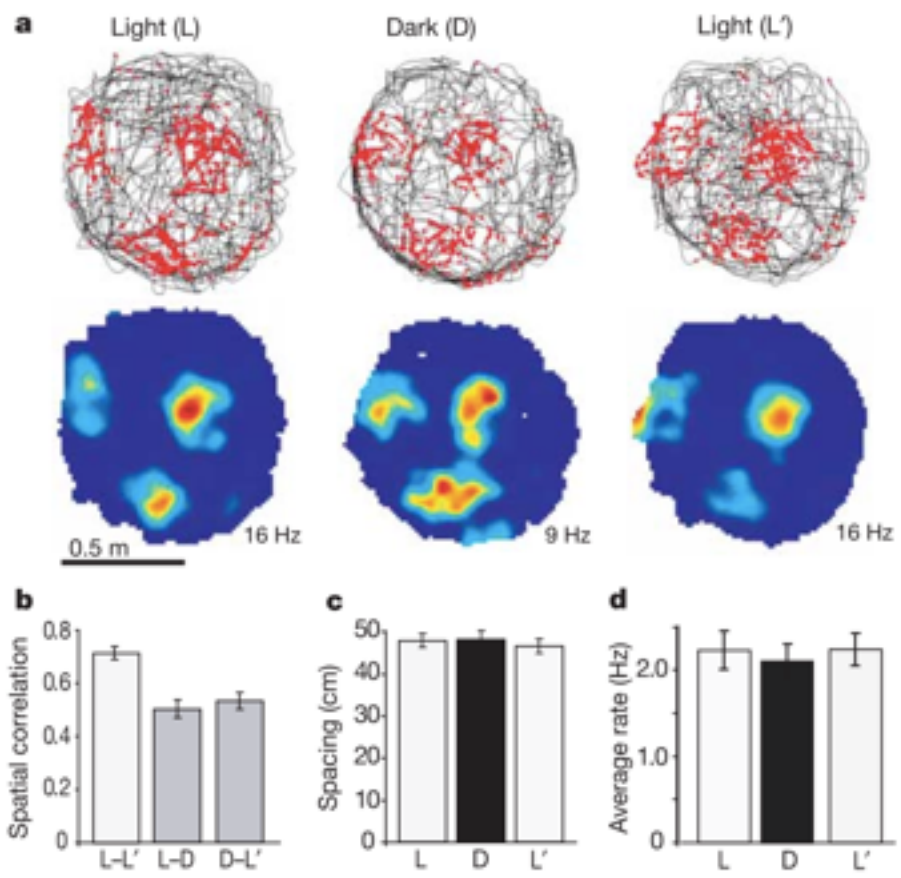


Moser

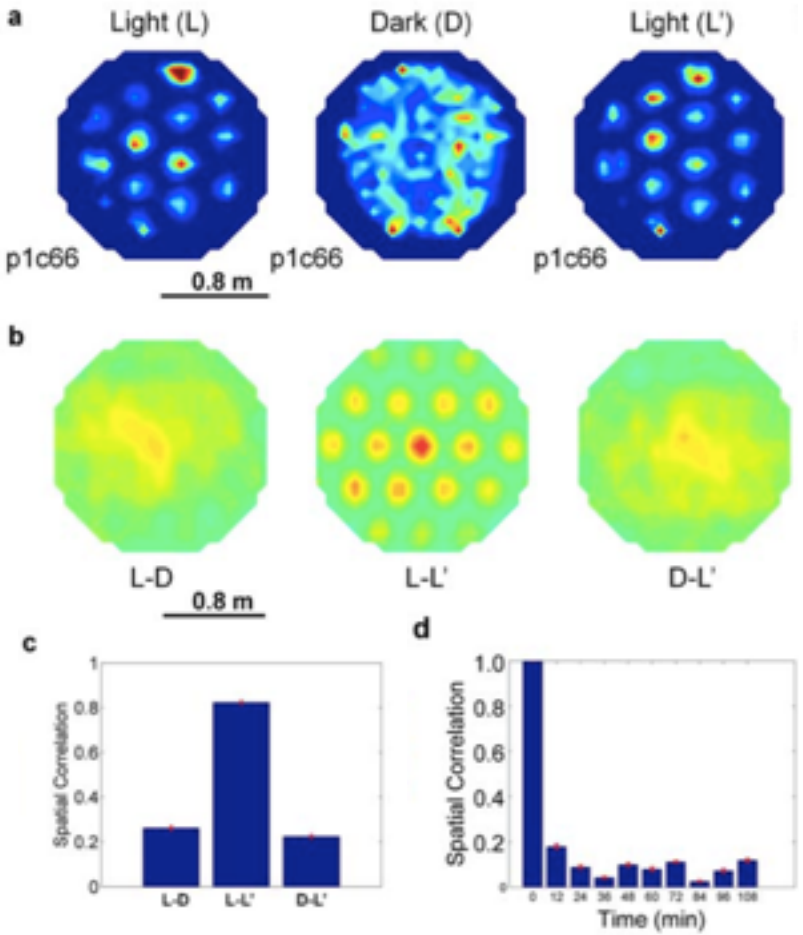


Milford

"Grids persist after cue removal"

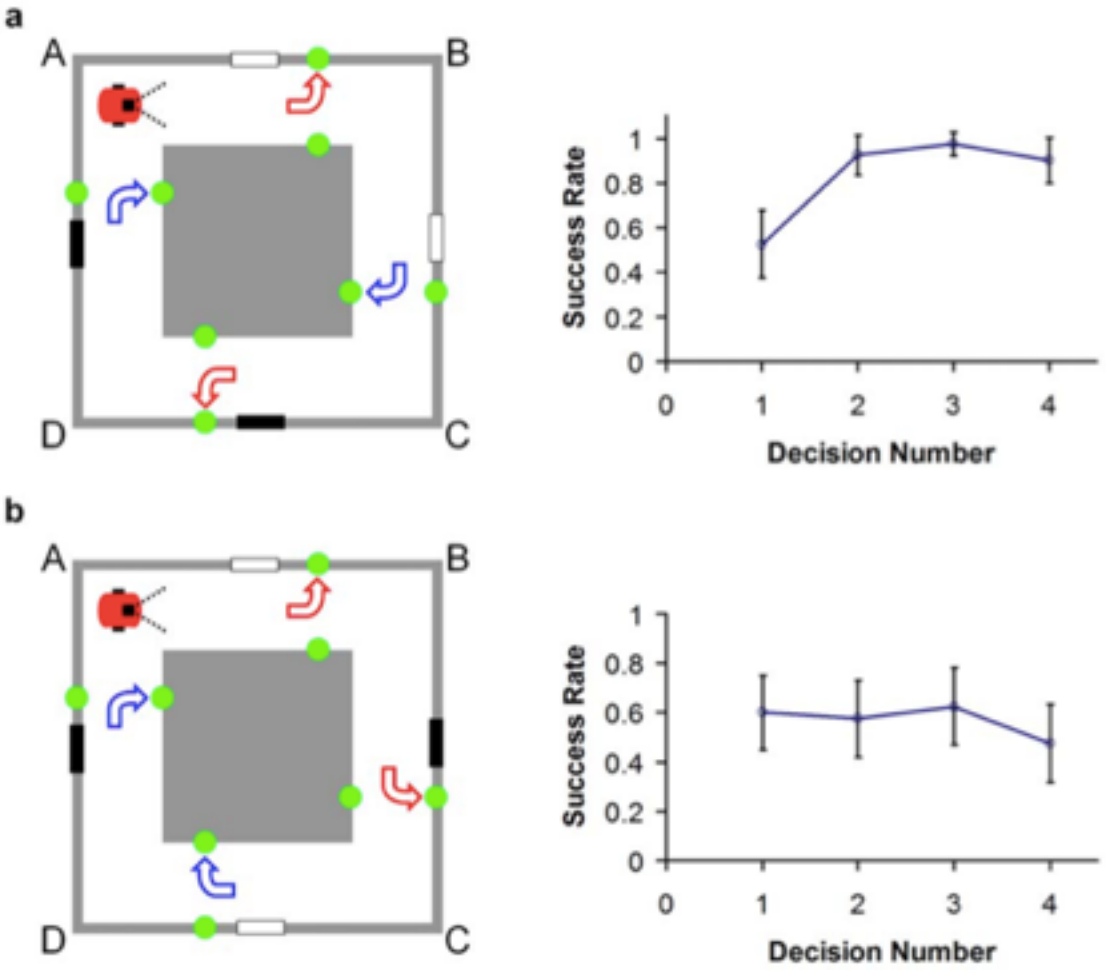


Moser

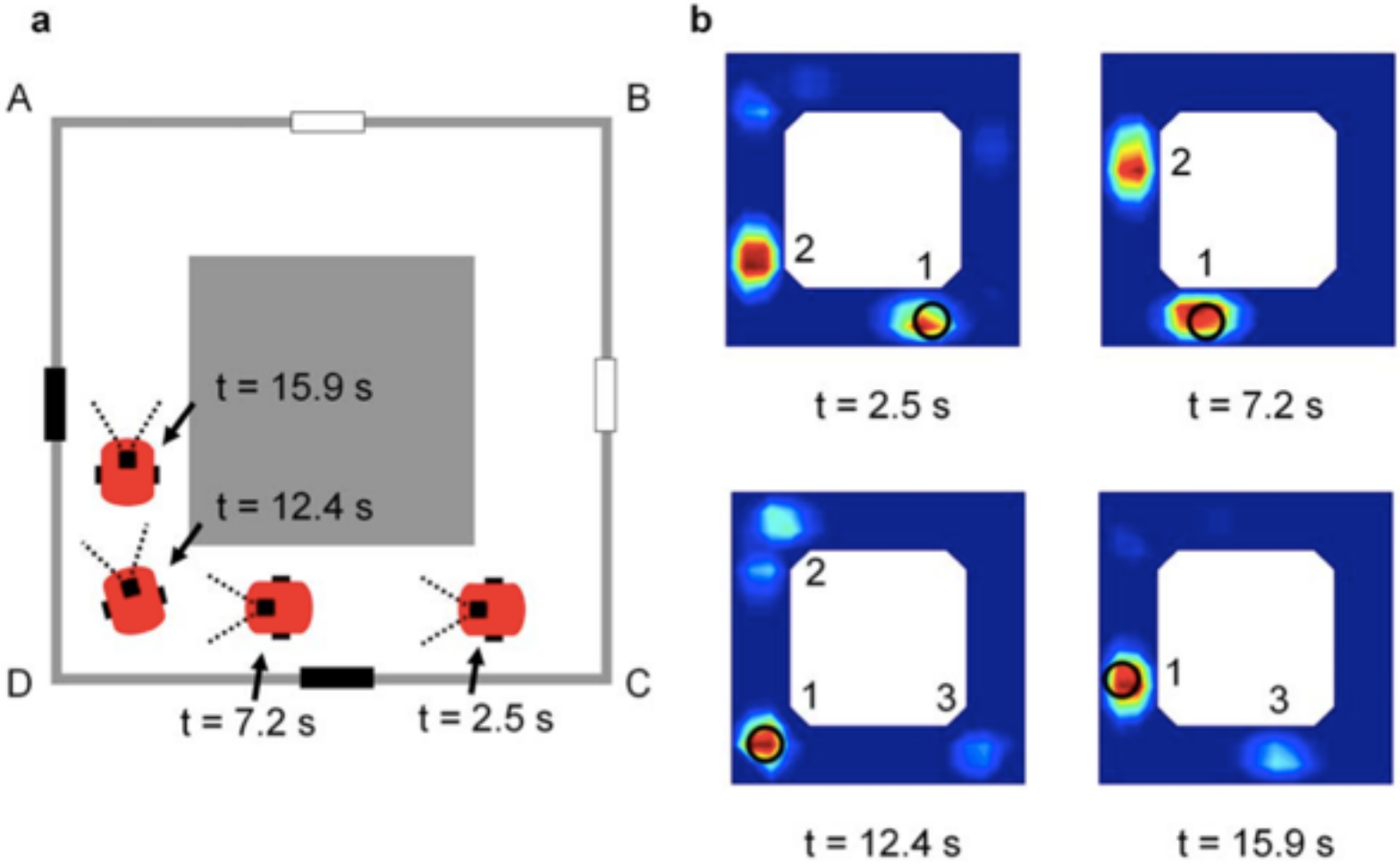


Milford

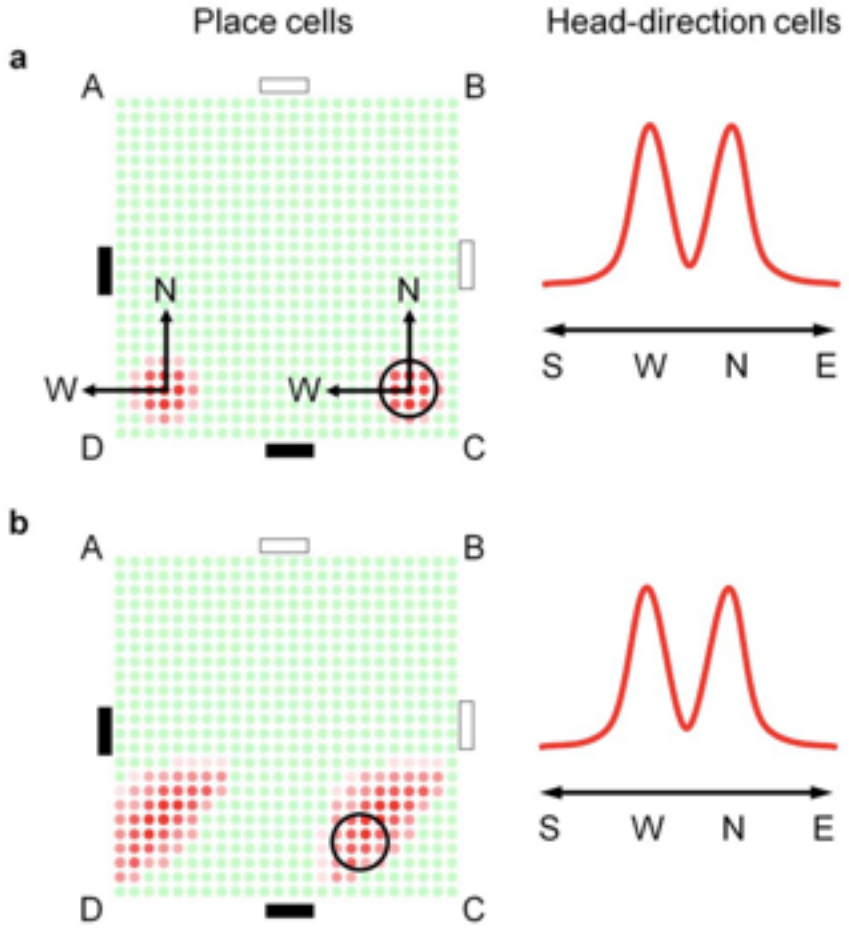
Disambiguation Experiments



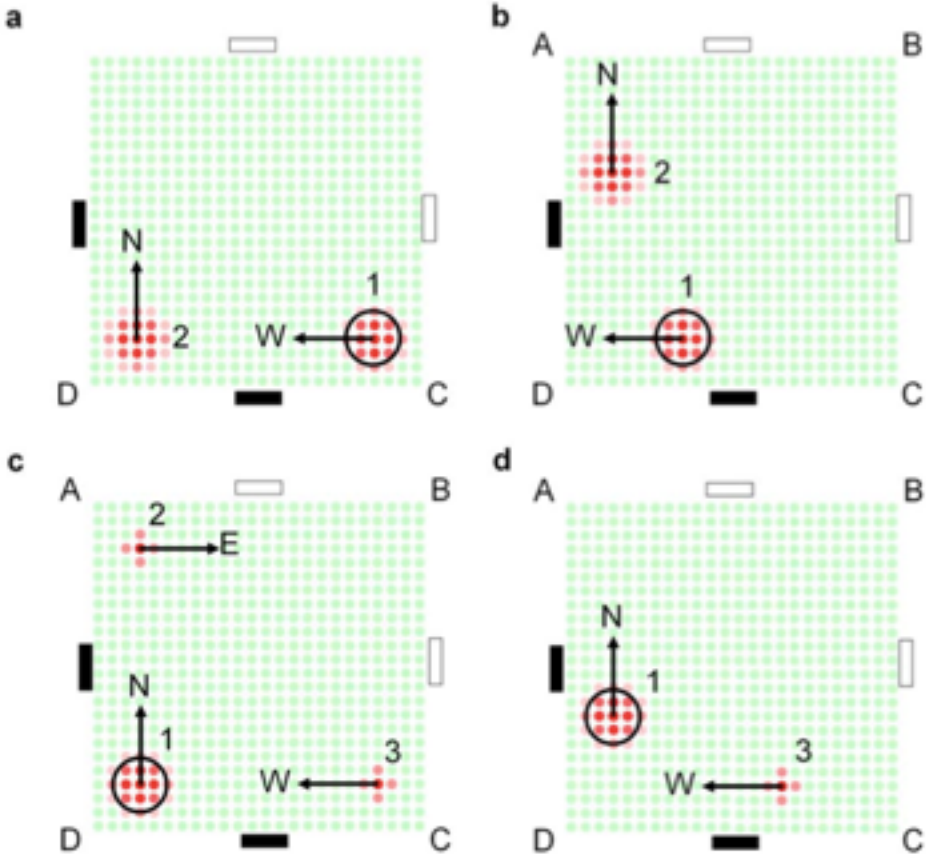
Disambiguation Experiments



The Need for Conjunctive Cells



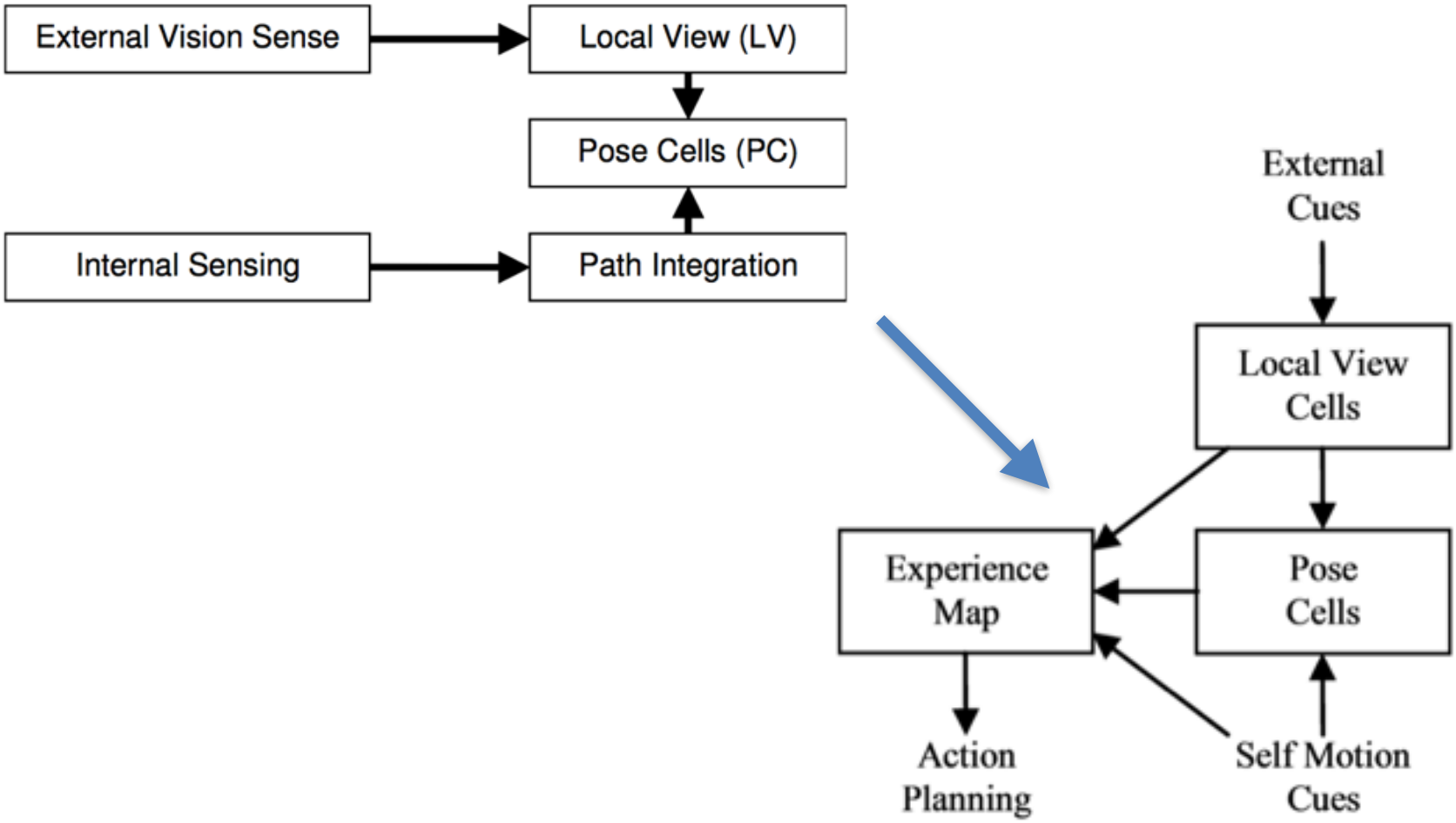
Place/Head Cells



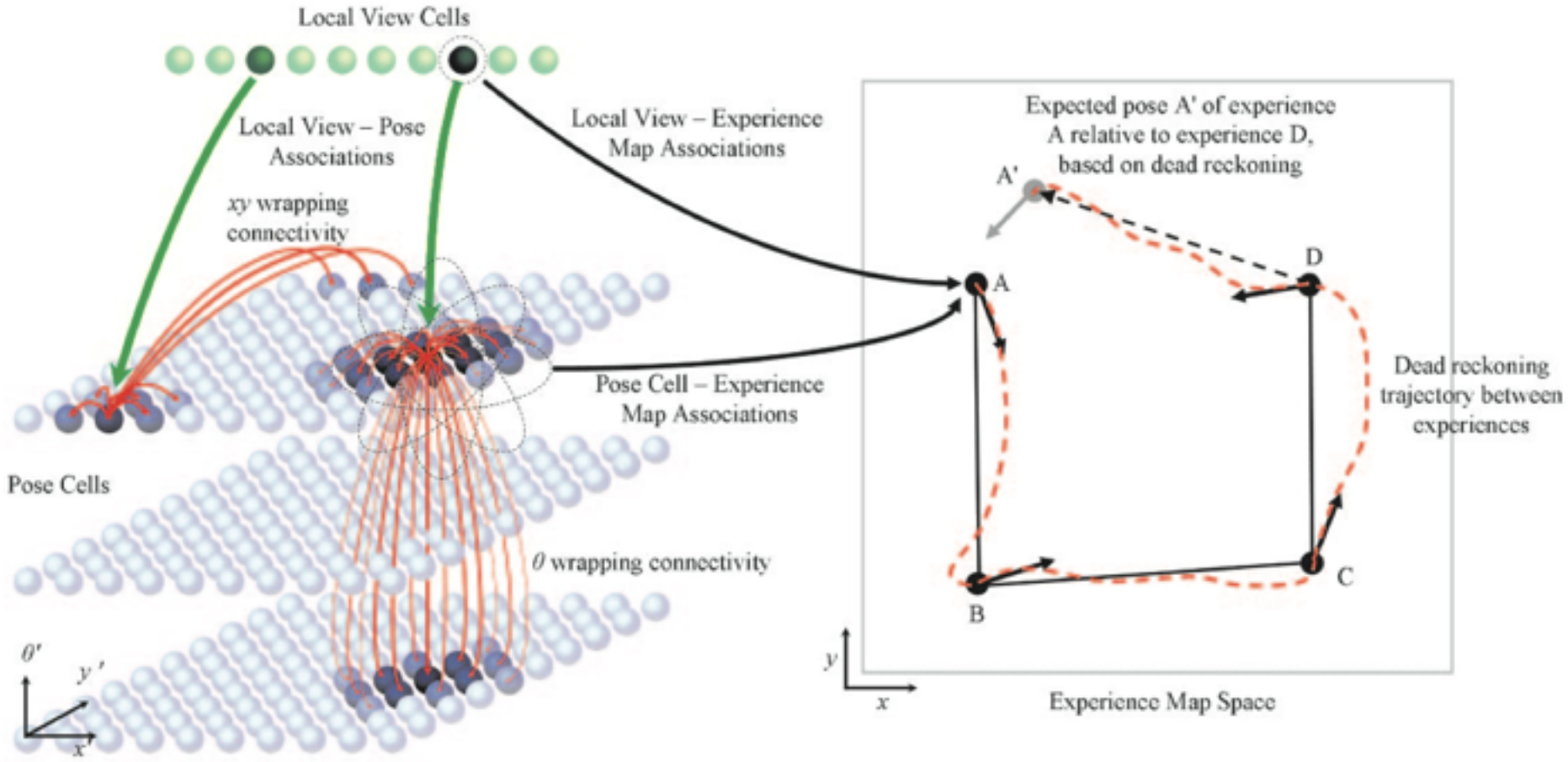
Grid Cells

RatSLAM for Long-Term Autonomy & Goal-Based Navigation

Process


External Vision Sense
Local View (LV)
Pose Cells (PC)
Internal Sensing
Path Integration
External Cues
Local View Cells
Experience Map
Pose Cells
Action Planning
Self Motion Cues

The Experience Map



Building Experiences

Experience: $e_i = \{P^i, V^i, \mathbf{p}^i\}$

Similarity score: $S^i = \mu_p \left| P^i - P \right| + \mu_v \left| V^i - V \right|$

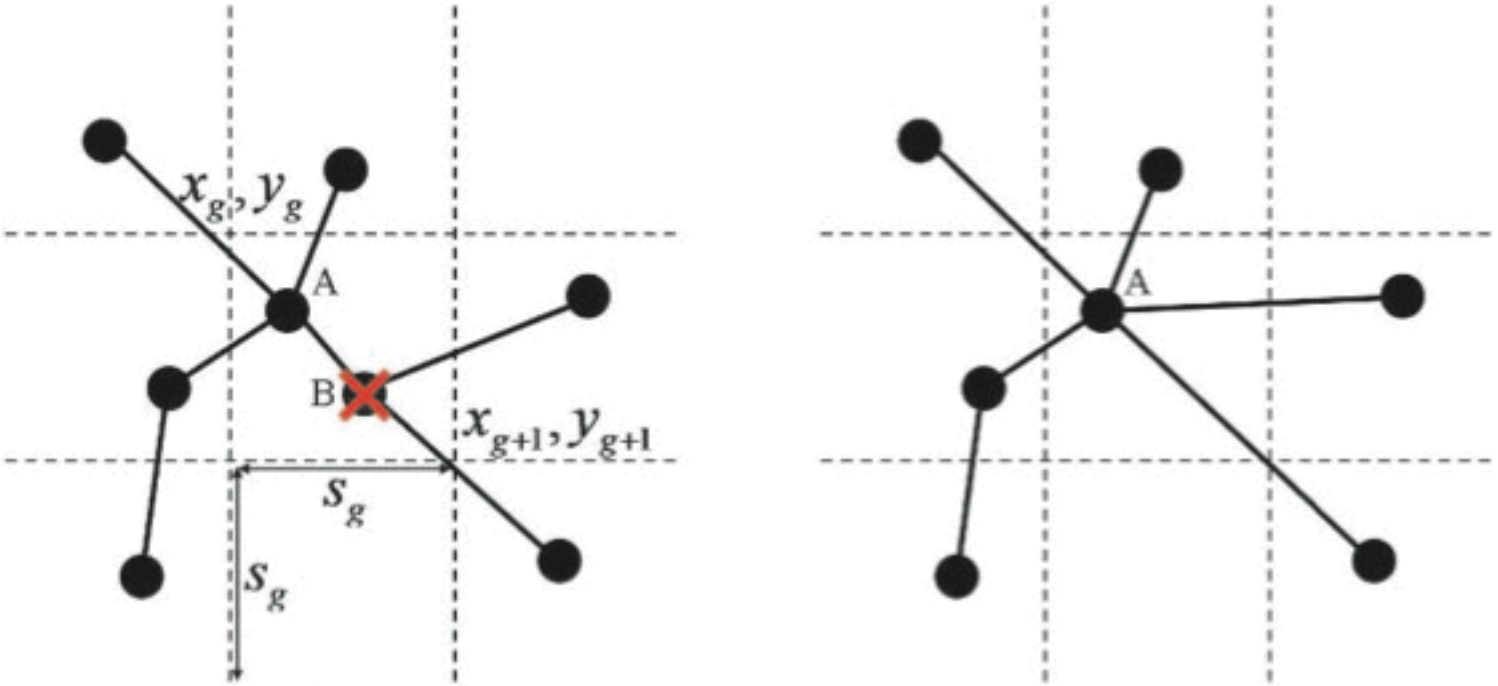
Transition link: $l_{ij} = \{\Delta \mathbf{p}^{ij}, \Delta t^{ij}\}$

New experience: $e_j = \{P^j, V^j, \mathbf{p}^i + \Delta \mathbf{p}^{ij}\}$

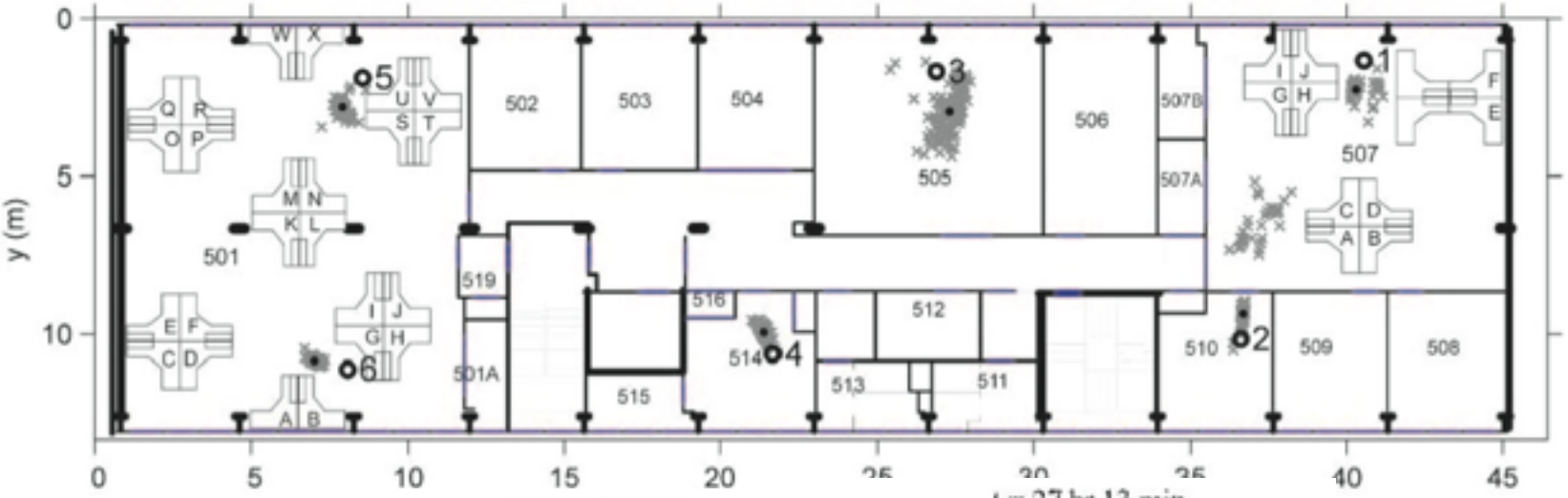
Map relaxation:* $$\Delta \mathbf{p}^i = \alpha \left[\sum_{j=1}^{N_f} (\mathbf{p}^j - \mathbf{p}^i - \Delta \mathbf{p}^{ij}) + \sum_{k=1}^{N_t} (\mathbf{p}^k - \mathbf{p}^i - \Delta \mathbf{p}^{ki}) \right]$$

* Duckett, Tom, Stephen Marsland, and Jonathan Shapiro. "Fast, on-line learning of globally consistent maps." Autonomous Robots 12.3 (2002): 287-300.

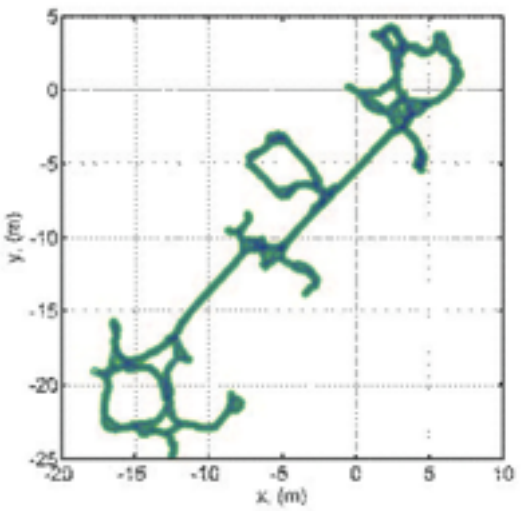
Pruning the Experience Map



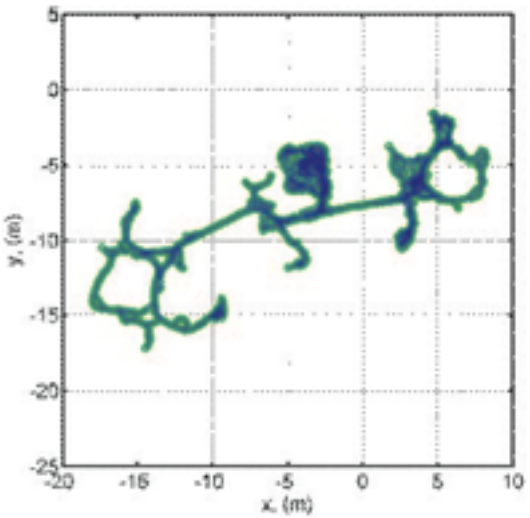
Experience Map Results



t = 2 hr 52 min



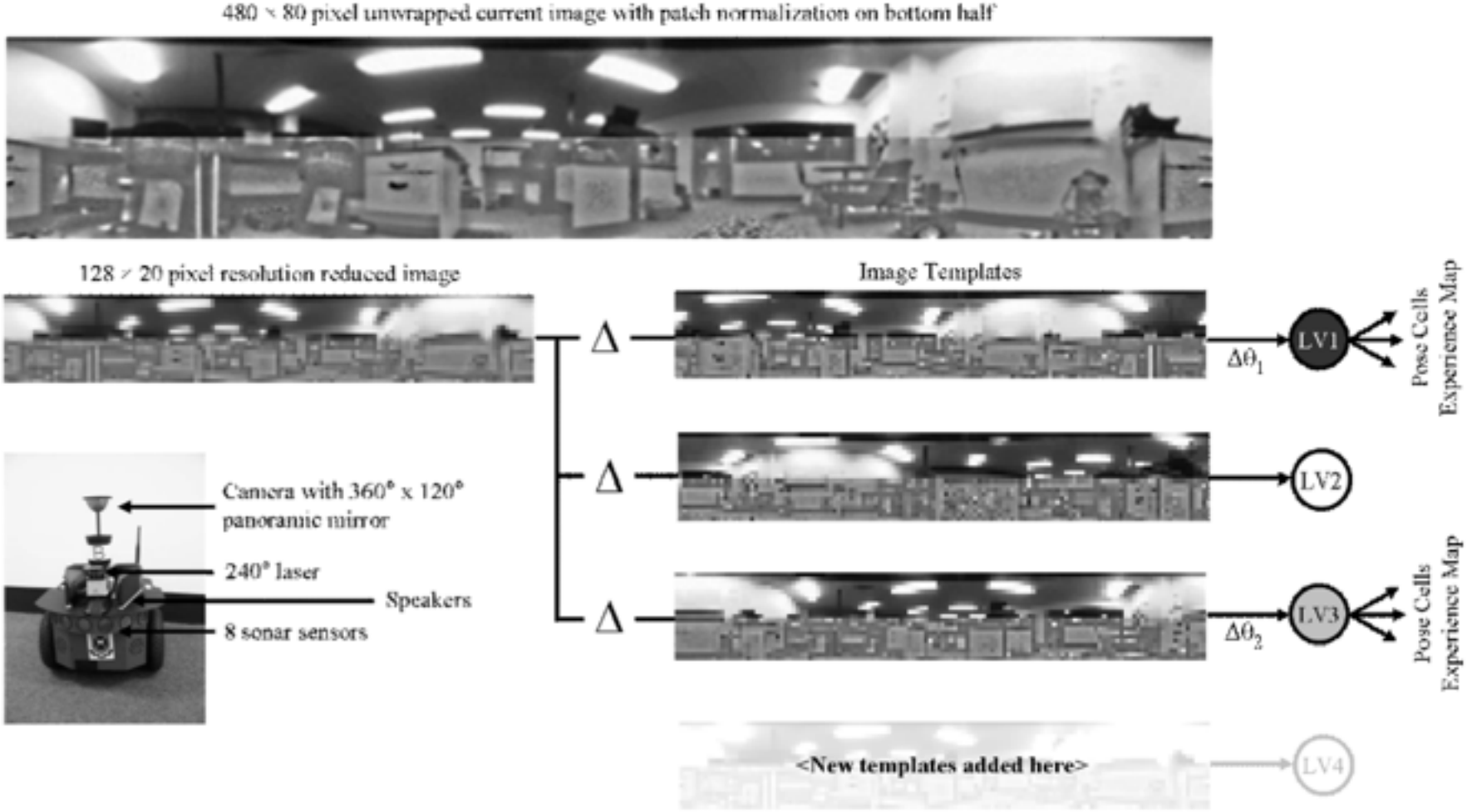
t = 27 hr 13 min



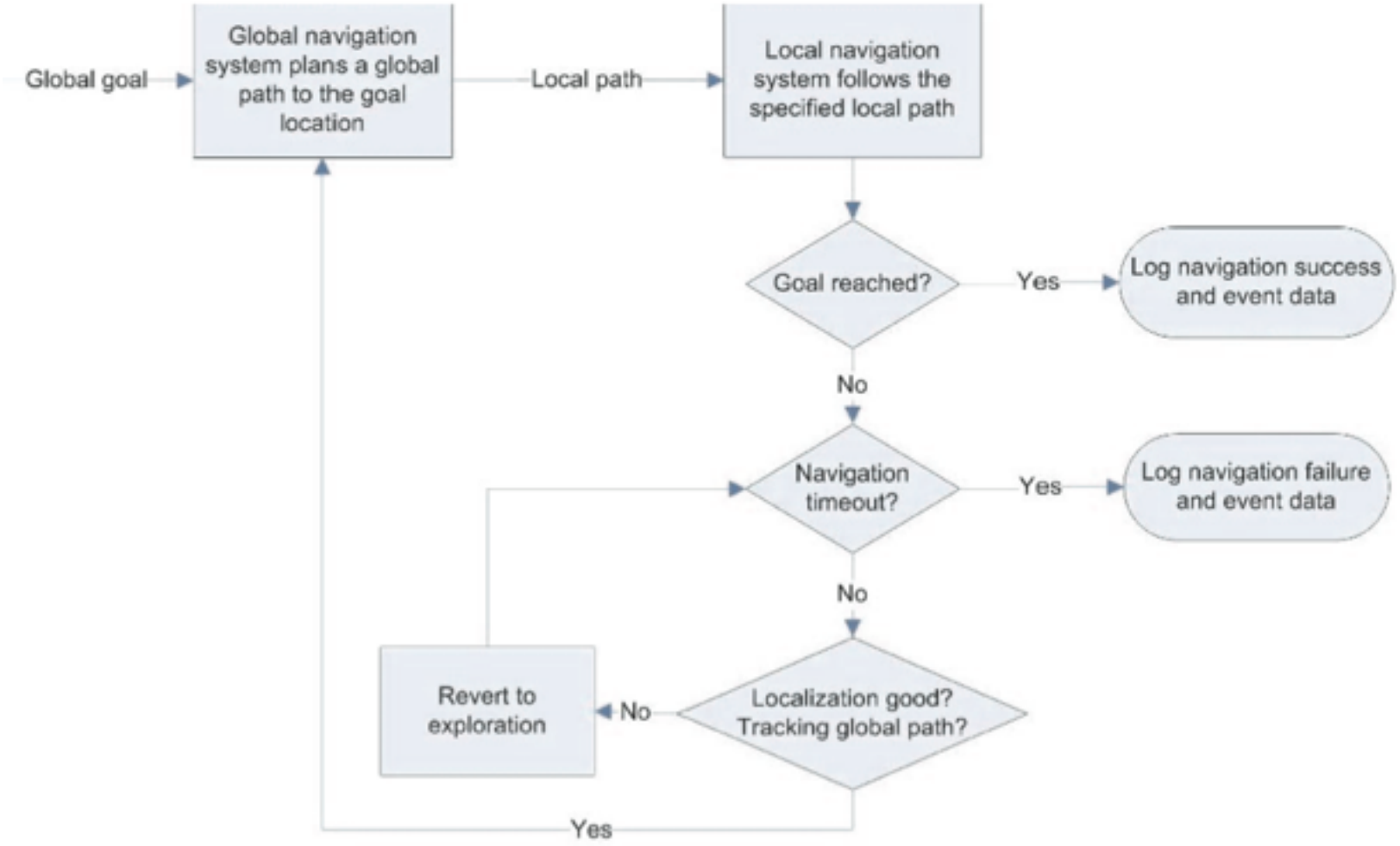
Experience Map Results

Architecture

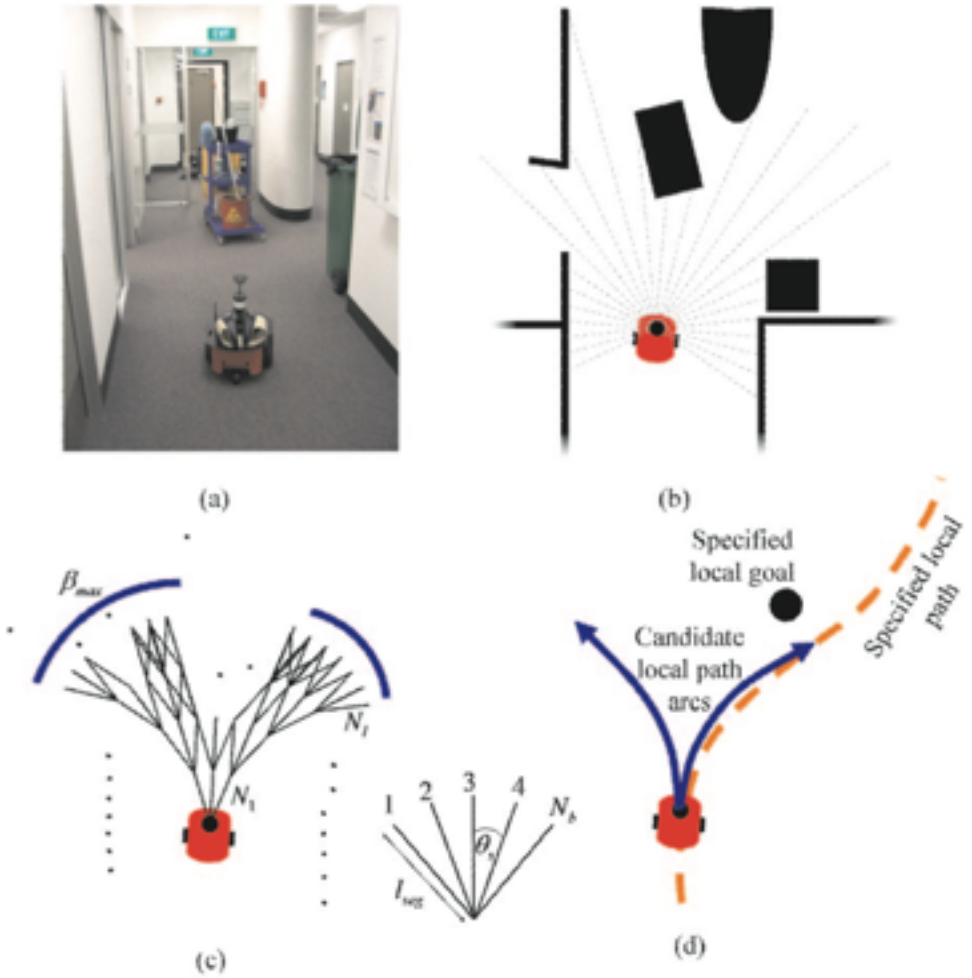
Place Recognition



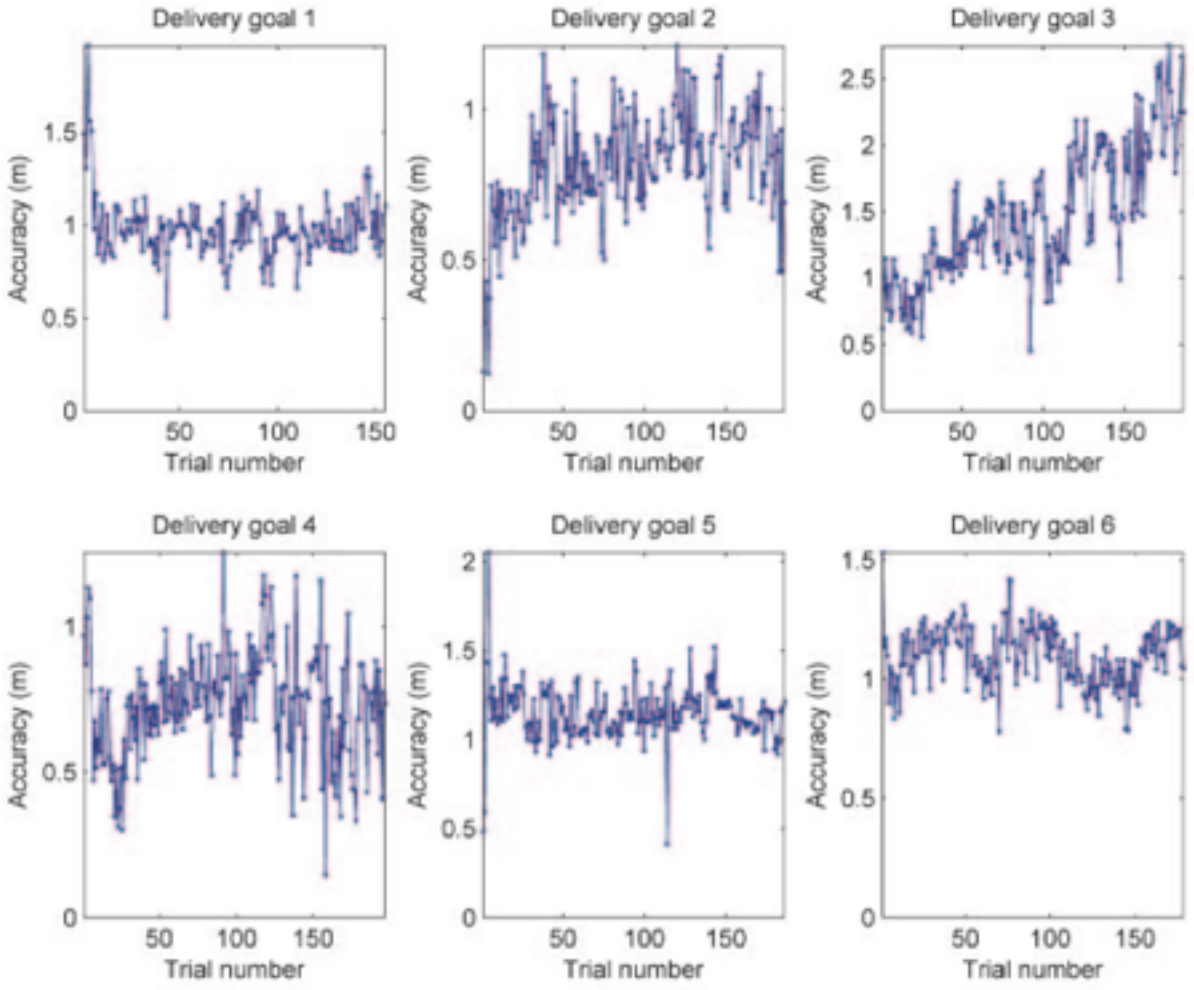
Global Navigation



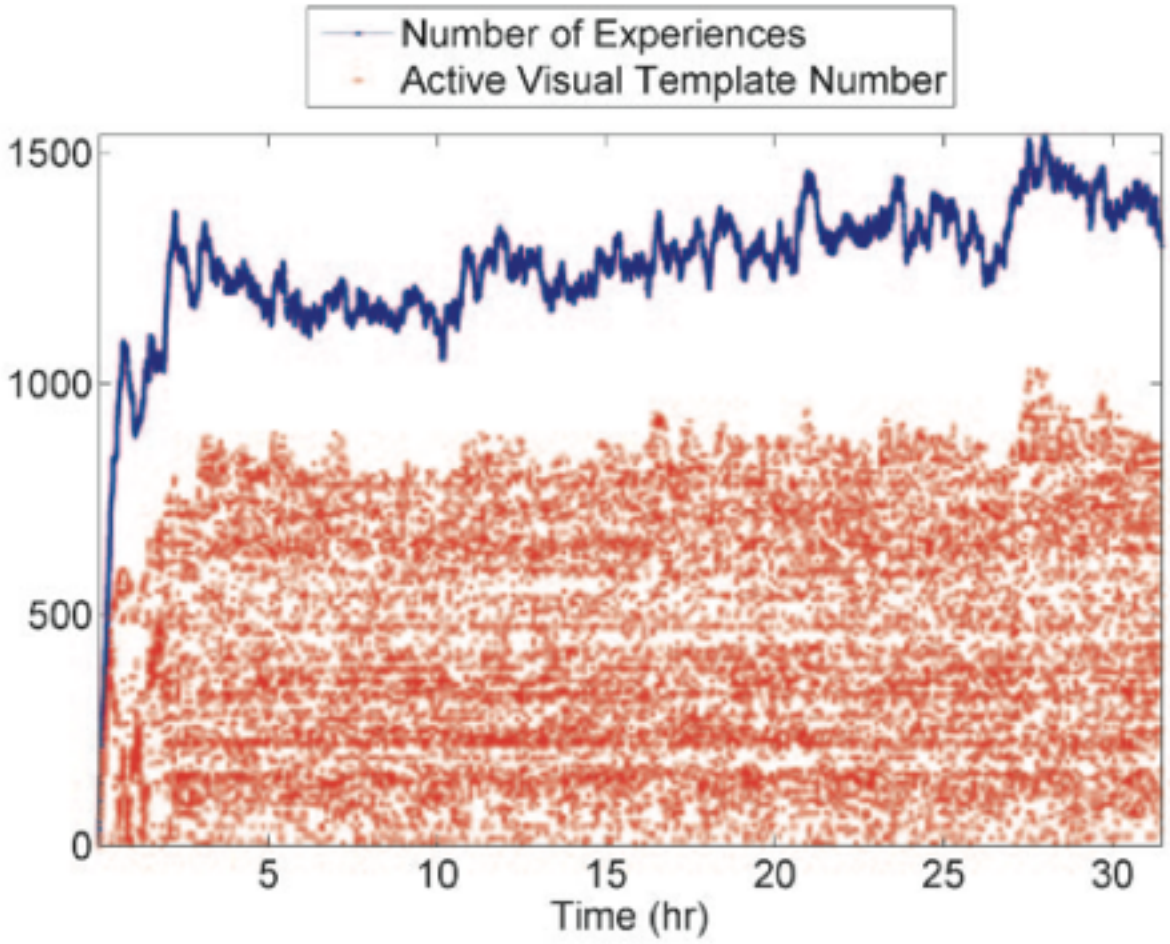
Local Navigation



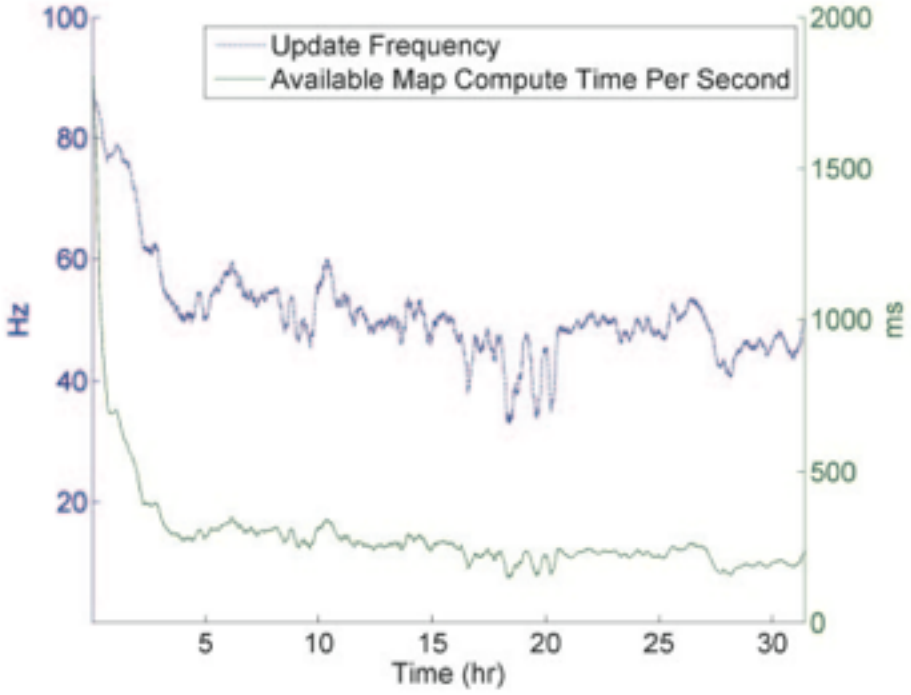
Long-Term Stability

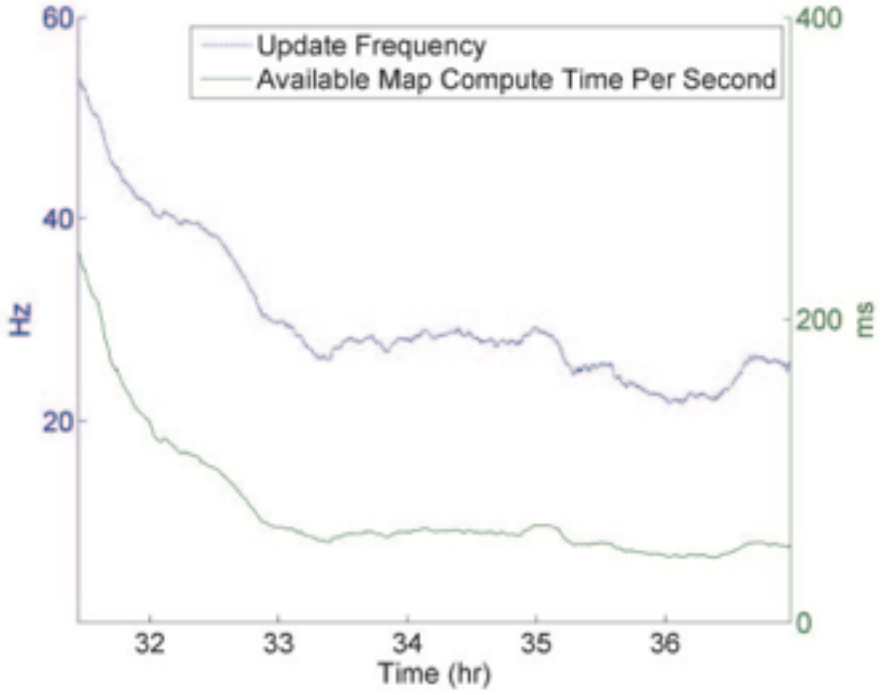


Long-Term Stability



Long-Term Stability





Weaknesses

- "The weakness is that the system deals rather inefficiently with cyclic changes such as day–night time cycles."
- "We would not expect the experience map maintenance and navigation procedures to handle major changes to the topology or geometry of the environment; this capability would require additional maintenance methods"