From Rats to Robots: Bio-inspired Localization and Navigation

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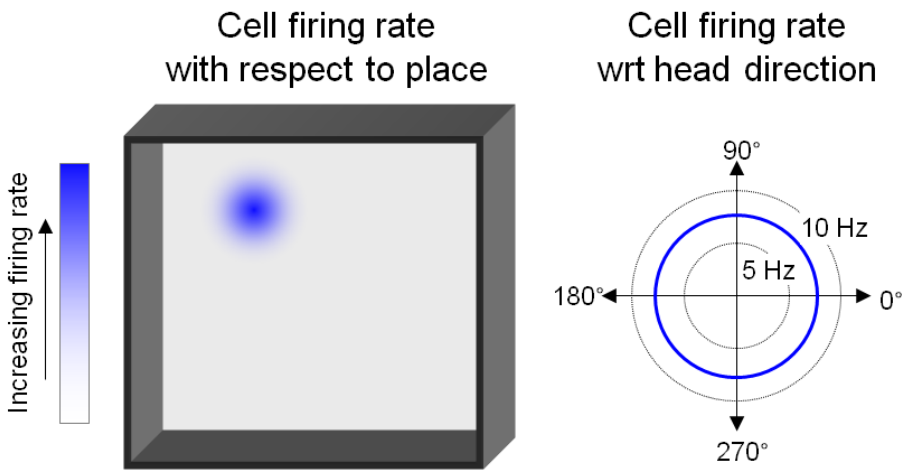
Australian Government
Australian Research Council

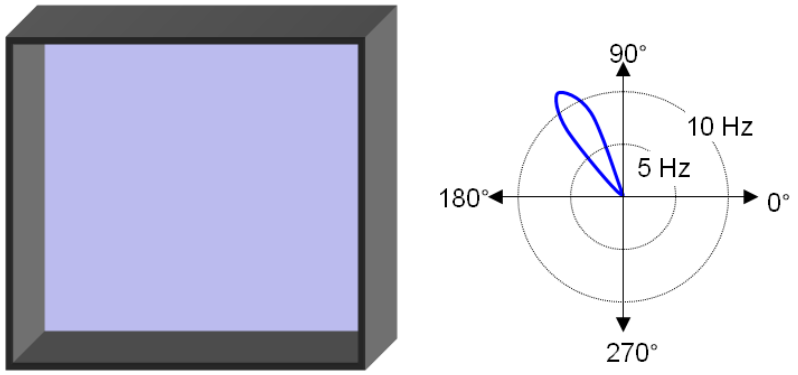
Neural Encoding of Space

Firing rates of neural units are measured with respect to the position in the arena and the absolute bearing of the head.

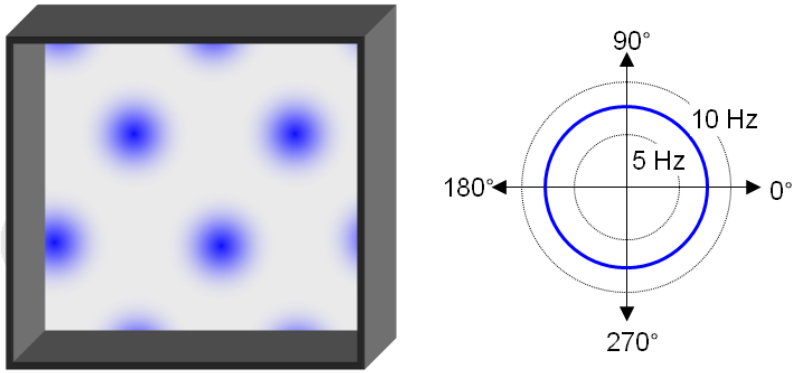
Cells That Encode Space



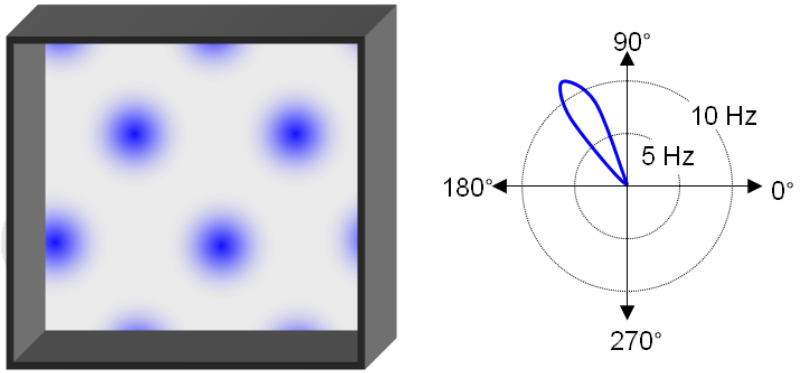
(a) Place cell



(b) Head direction cell



(c) Grid cell

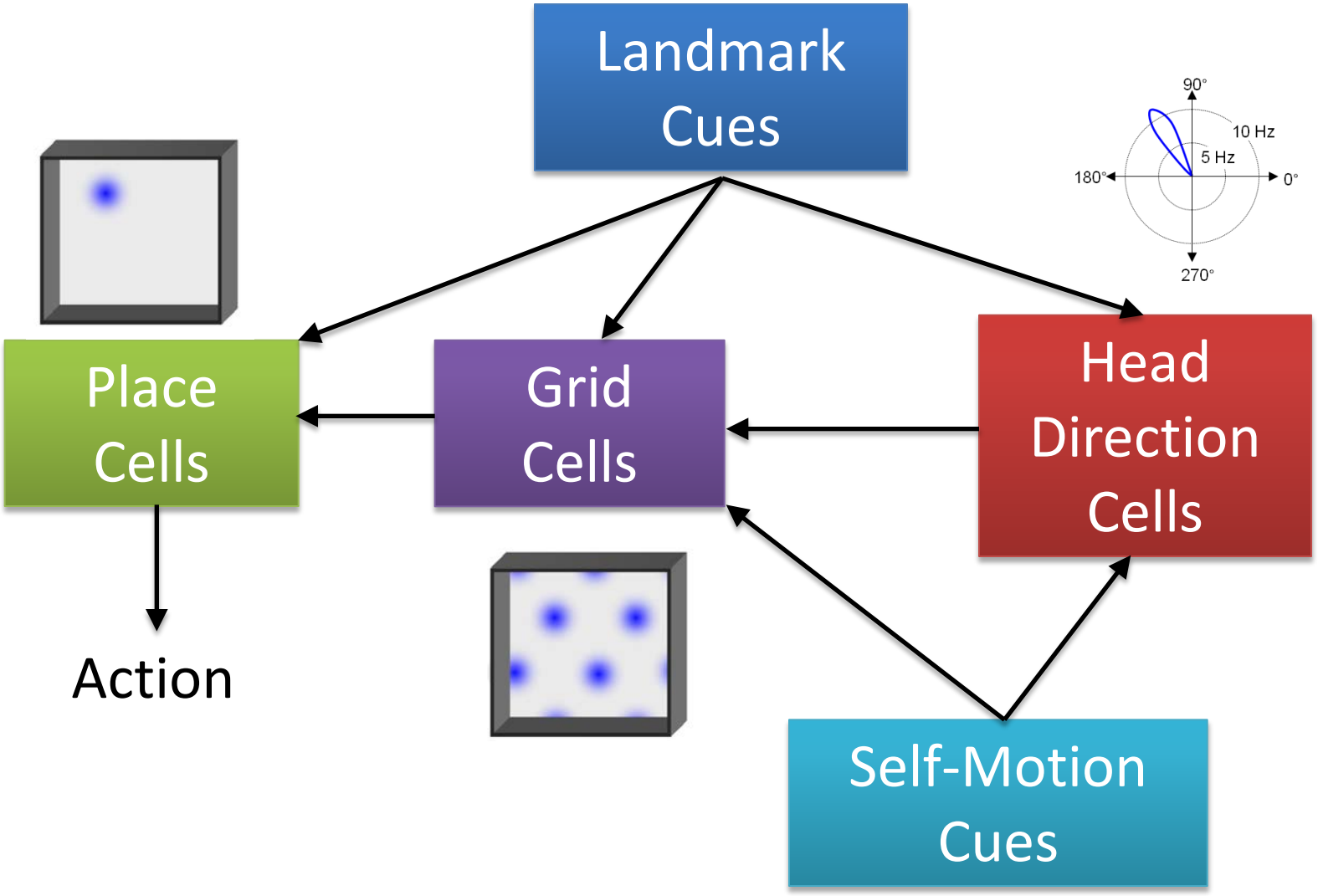


(d) Conjunctive grid cell

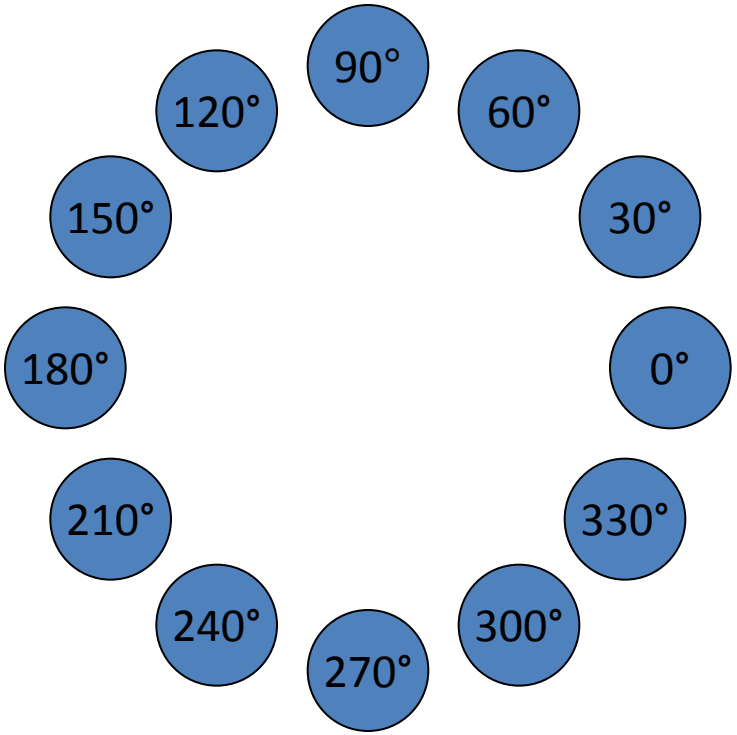
Rat Brains Track Pose

- The rat's brain maintains a *code* that describes rat's global pose in three degrees of freedom (x, y, θ). The code is:
  1. Maintained in absence of sensory input.
  2. Updated from odometric input.
  3. Corrected by distinctive sensory input.

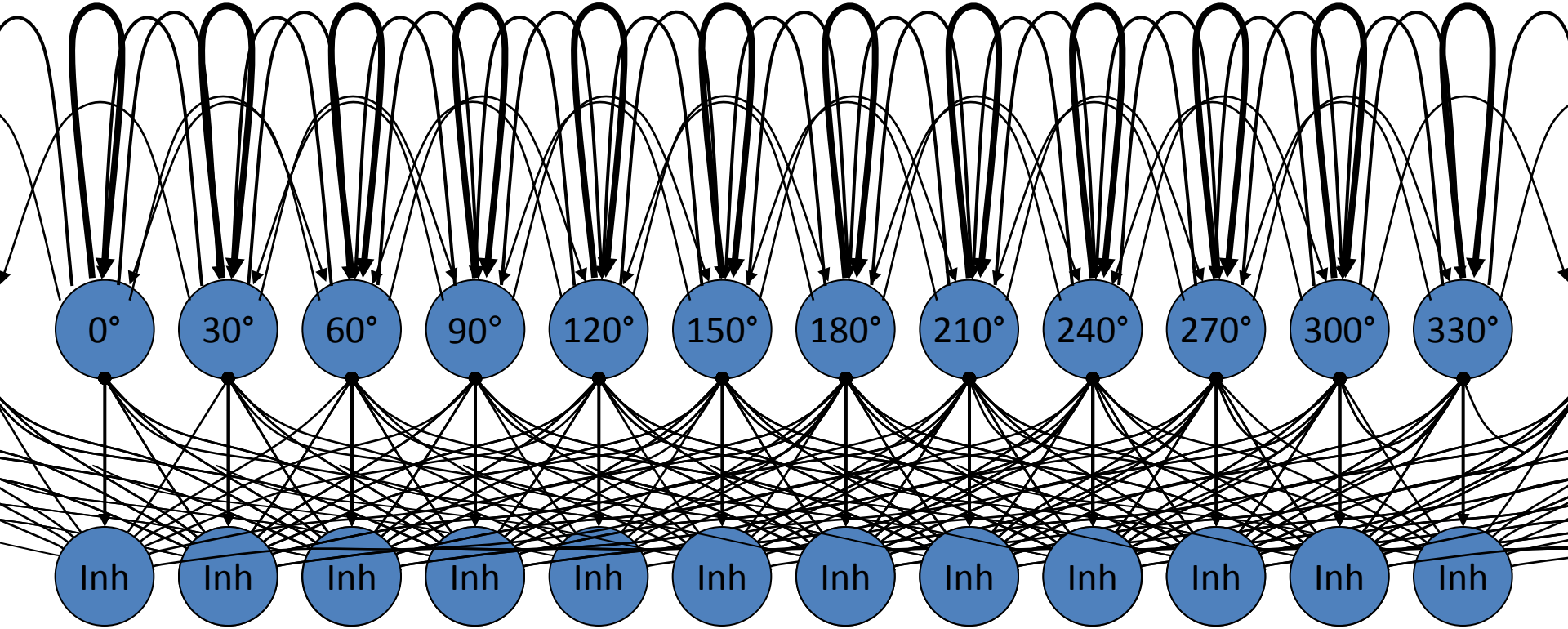
Wiring Diagram of a Rat Brain



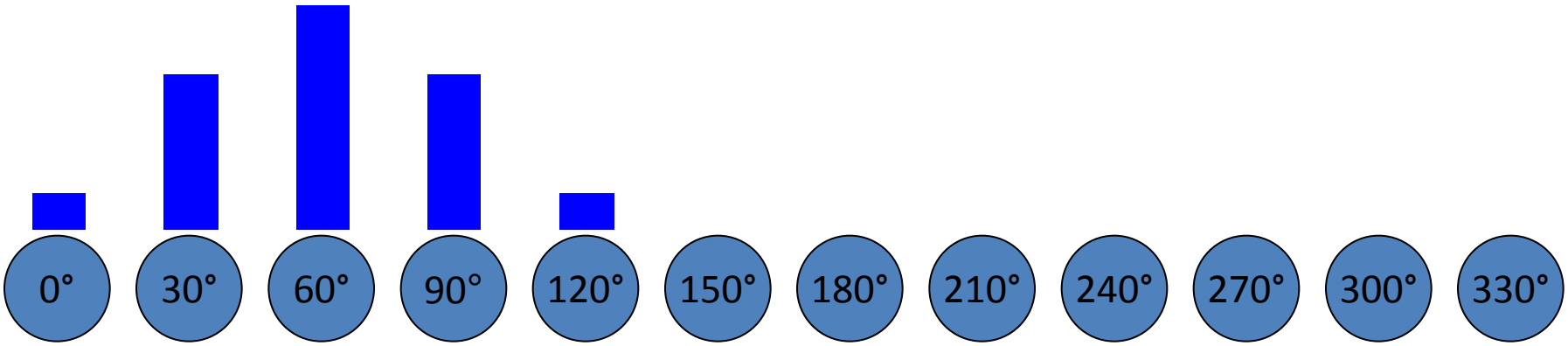
Computational Model of a Head Direction Network



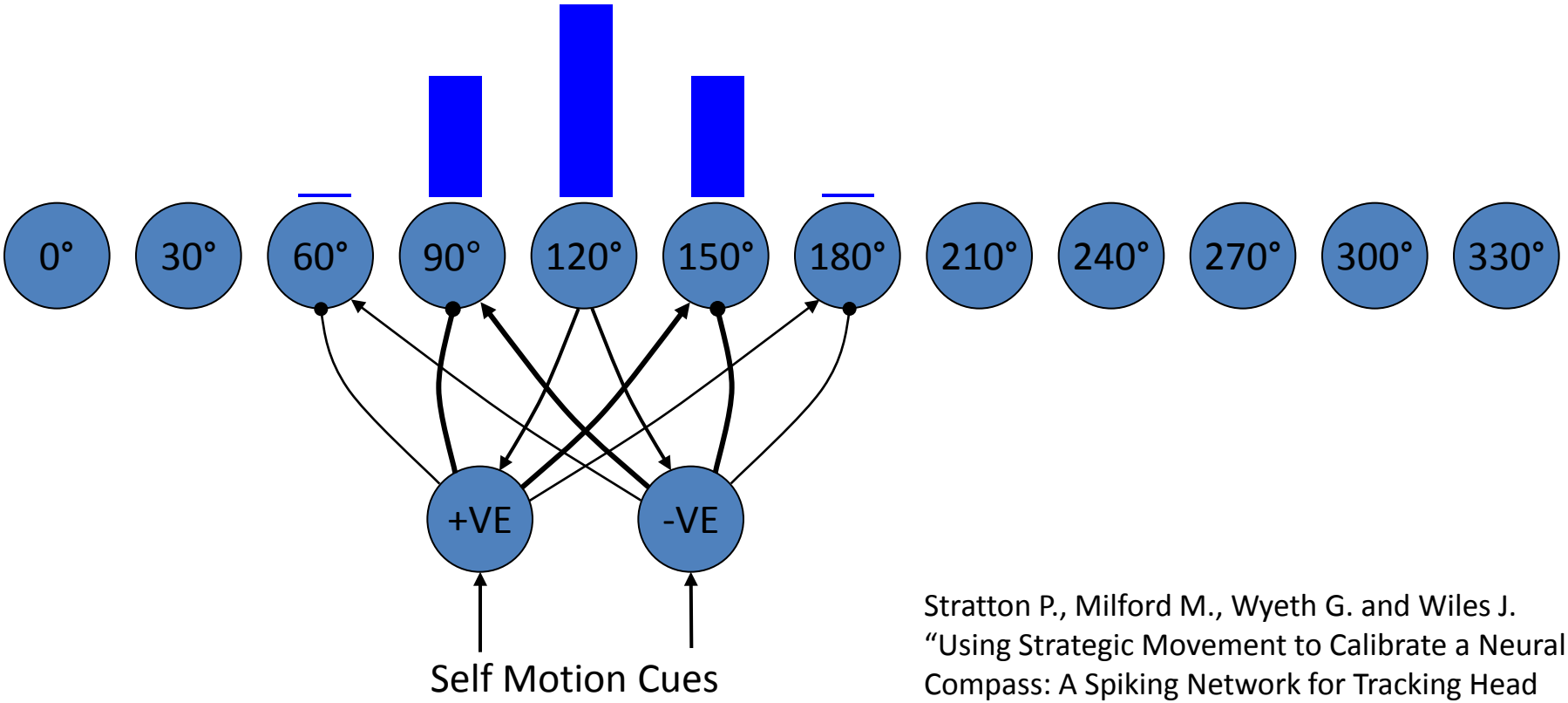
Attractor Connections



Maintaining Head Direction

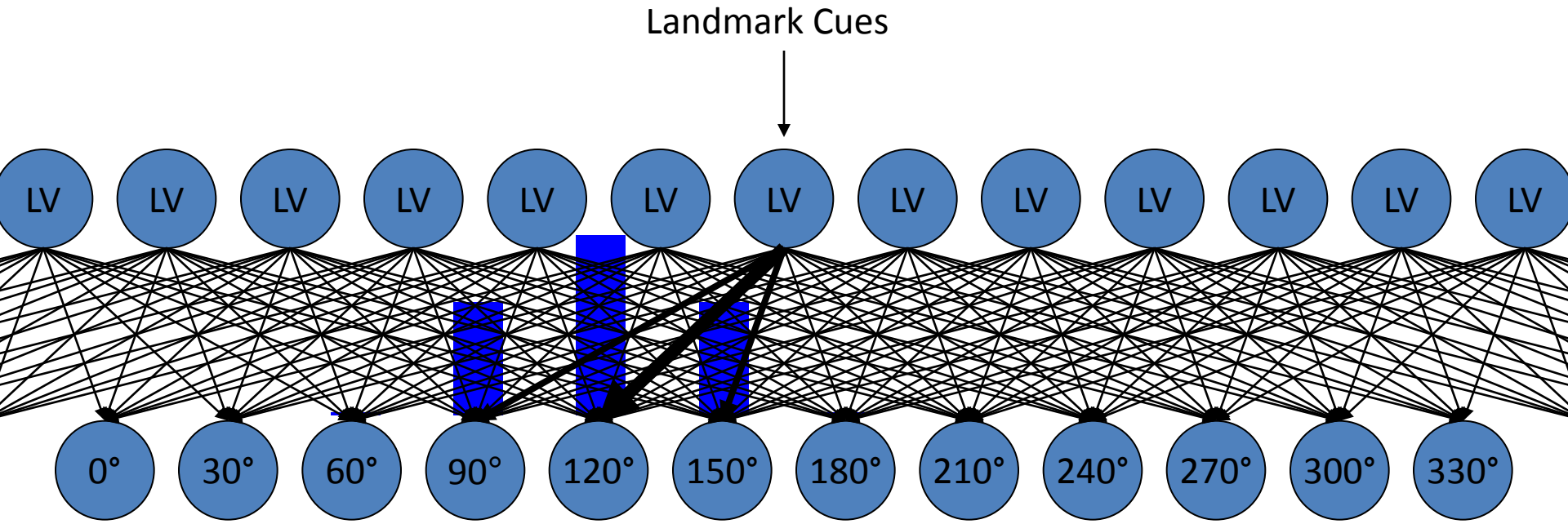


Applying Odometry to Update Head Direction



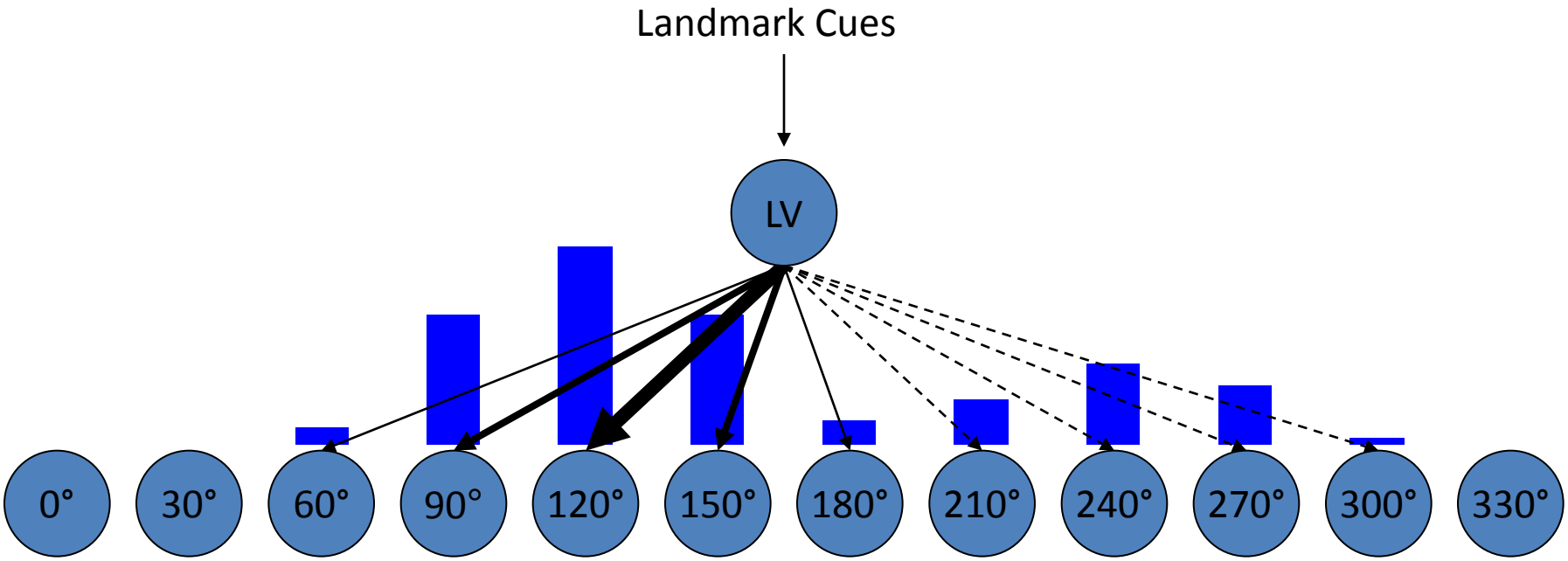
Stratton P., Milford M., Wyeth G. and Wiles J. "Using Strategic Movement to Calibrate a Neural Compass: A Spiking Network for Tracking Head Direction in Rats and Robots", *PLOS One*, Oct 2011

Associating Head Direction with Landmarks



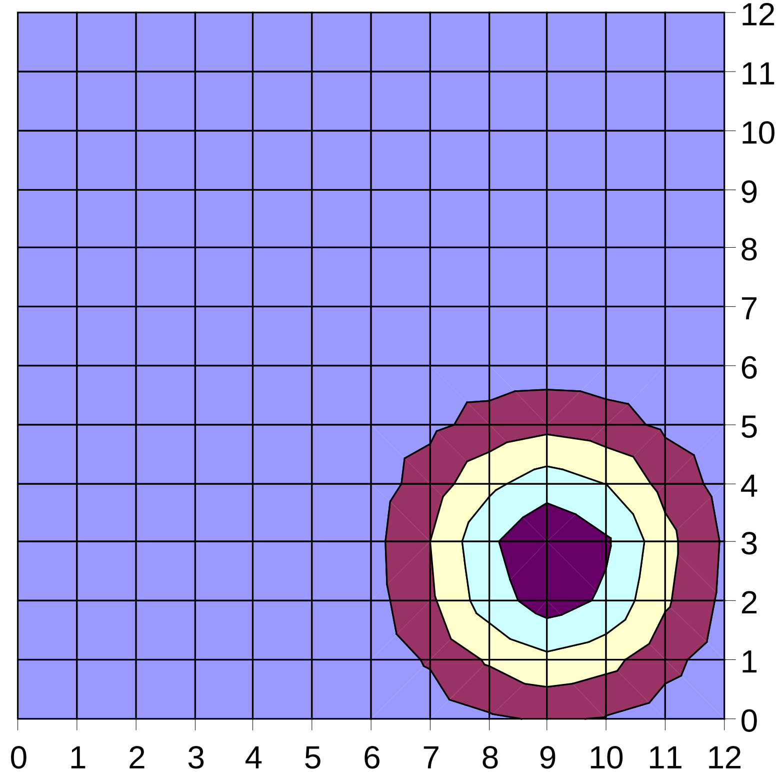
Nolan C., Wyeth G., Milford M. and Wiles J. "The race to learn: spike timing and neuromodulation can coordinate learning and recall in CA3", *Hippocampus*, March 2010

Calibration by Landmarks



Cheung A., Ball D., Milford M., Wyeth G. and Wiles J. "Maintaining a Cognitive Map in Darkness: The Need to Fuse Boundary Knowledge with Path Integration", *PLoS Computational Biology*, August 2012

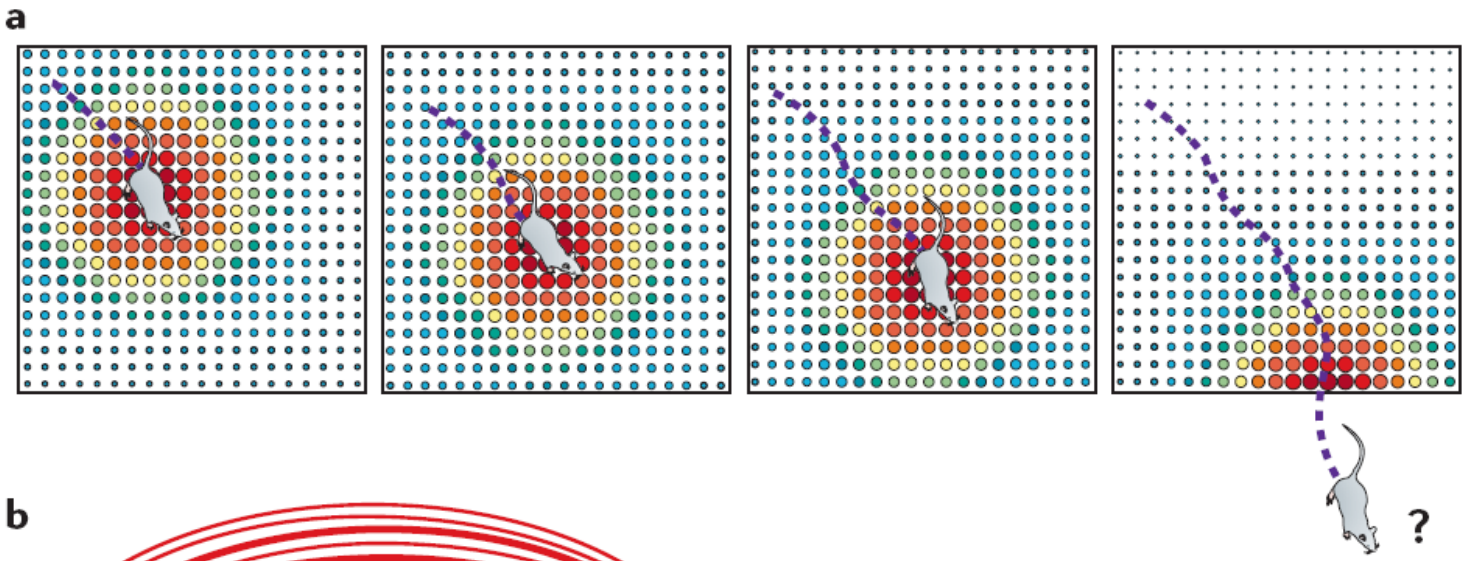
Two Dimensional Attractors

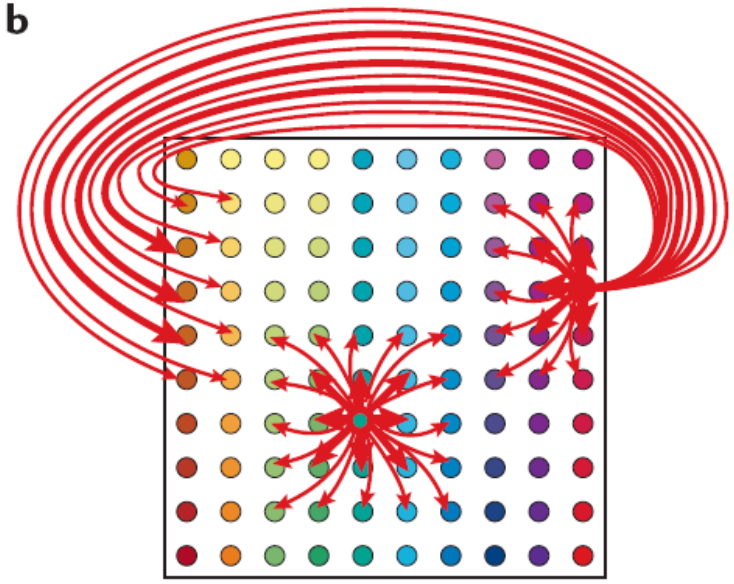


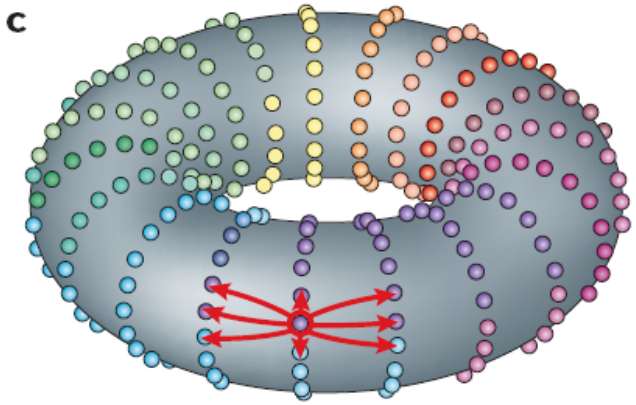
Local View Calibration

Path Integration

Boundary Problem

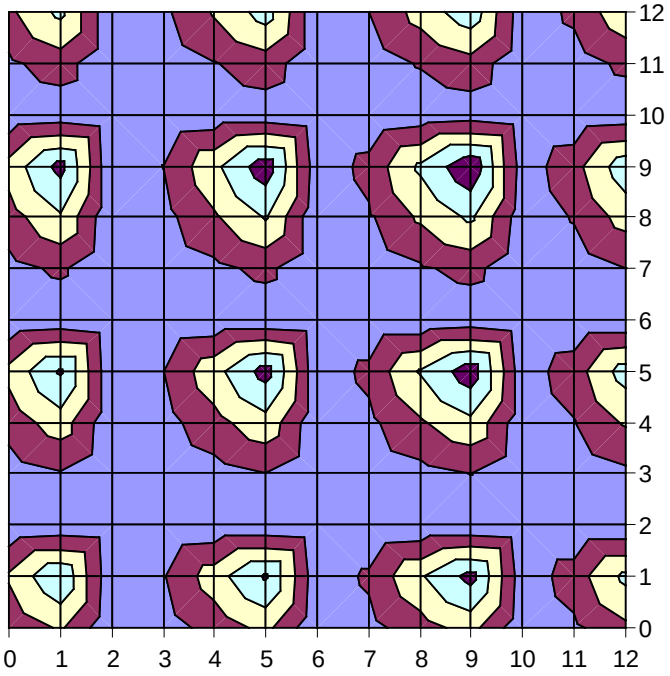






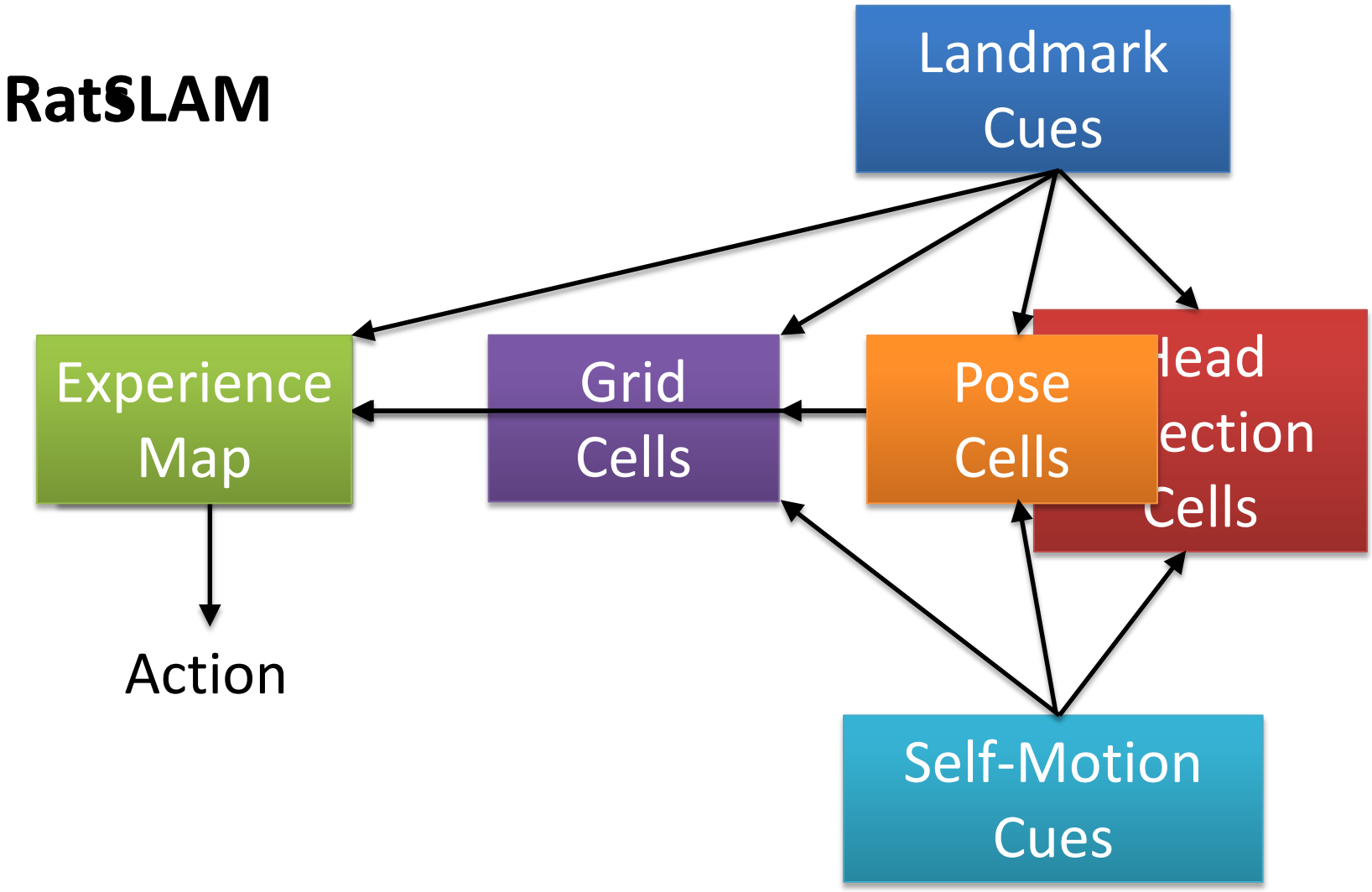
(McNaughton, 2006)

Torus Attractor “Recording”

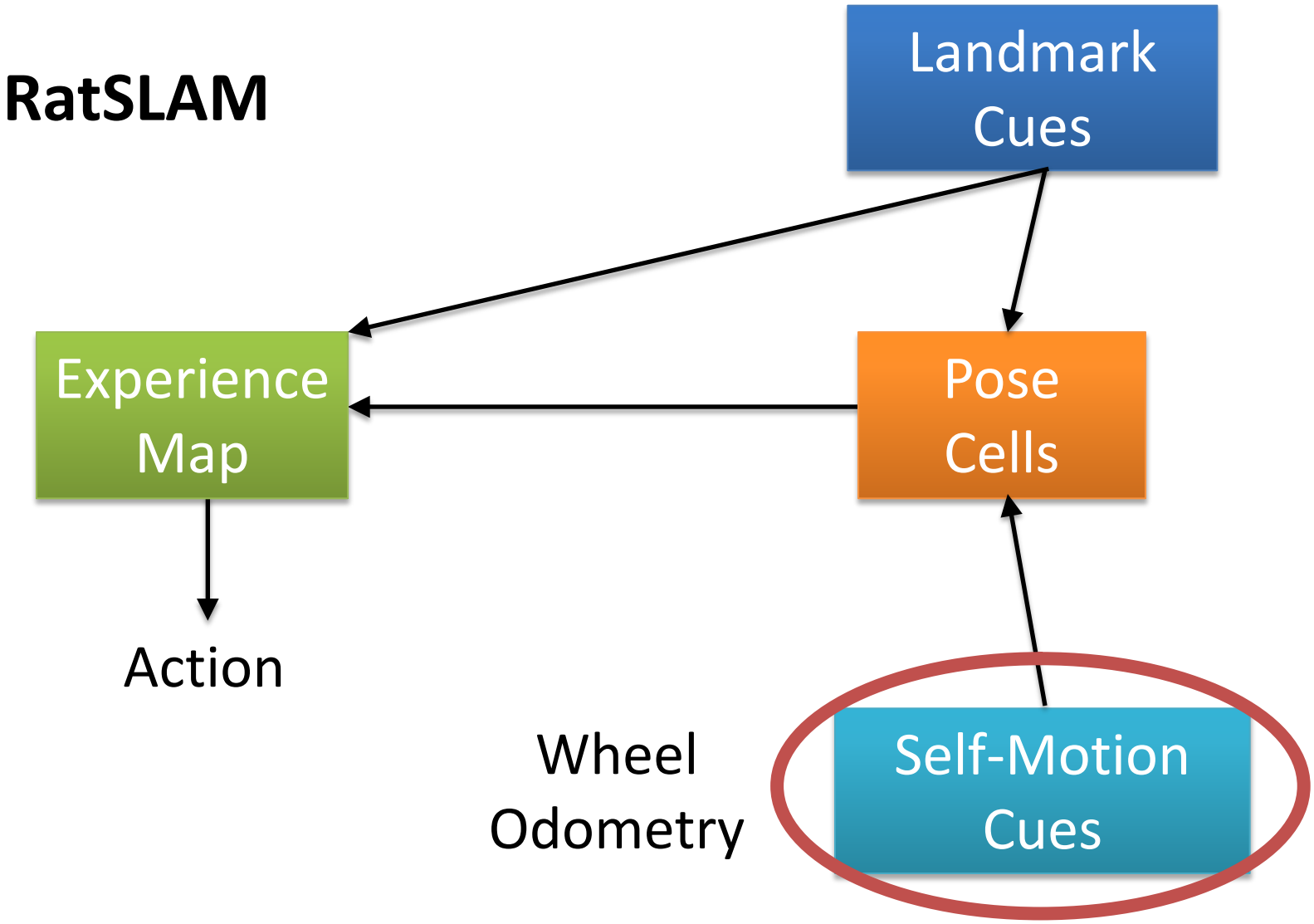


- Similar to tesselations seen in grid cell recordings.

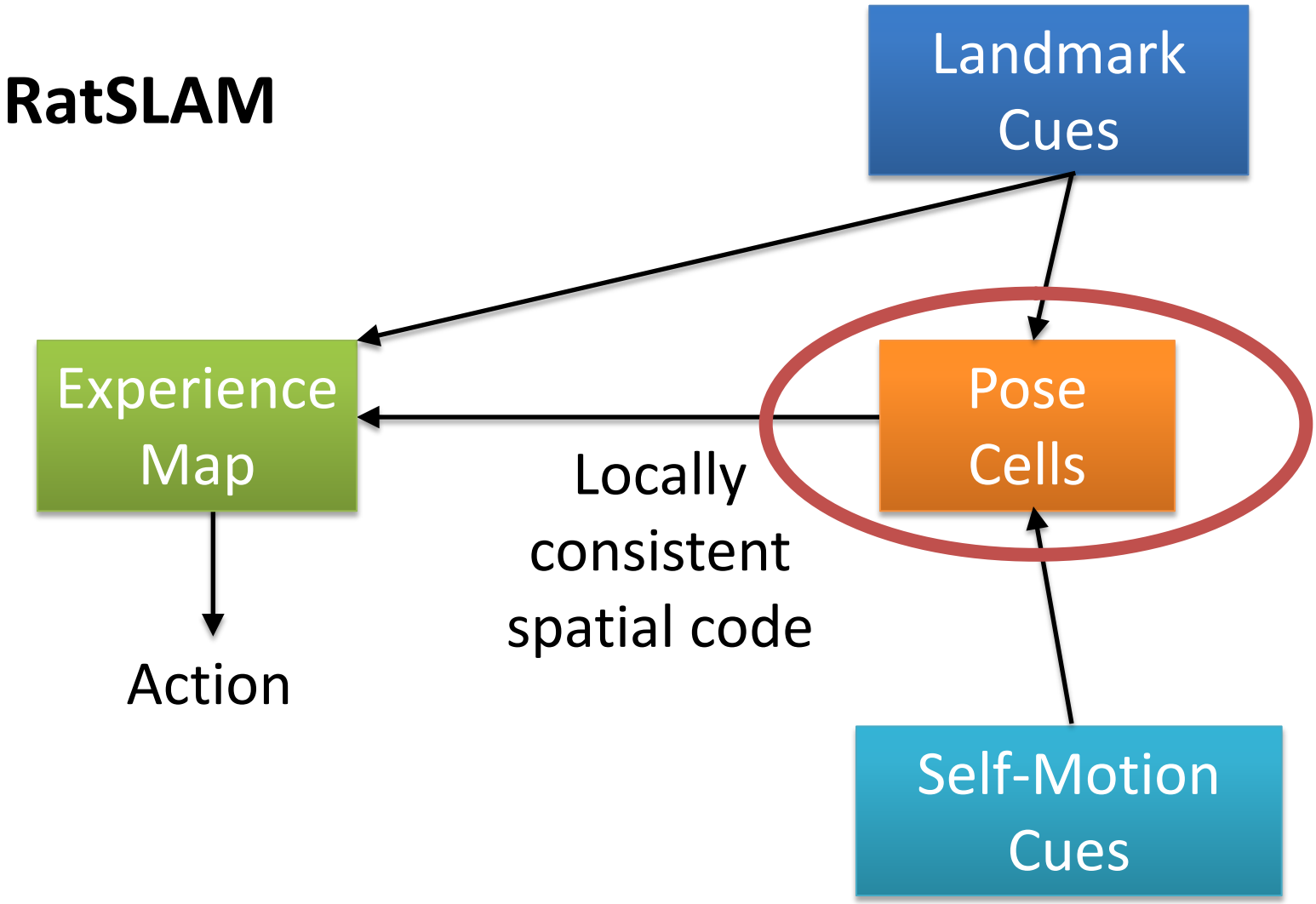
Conventional RatSLAM Model Types



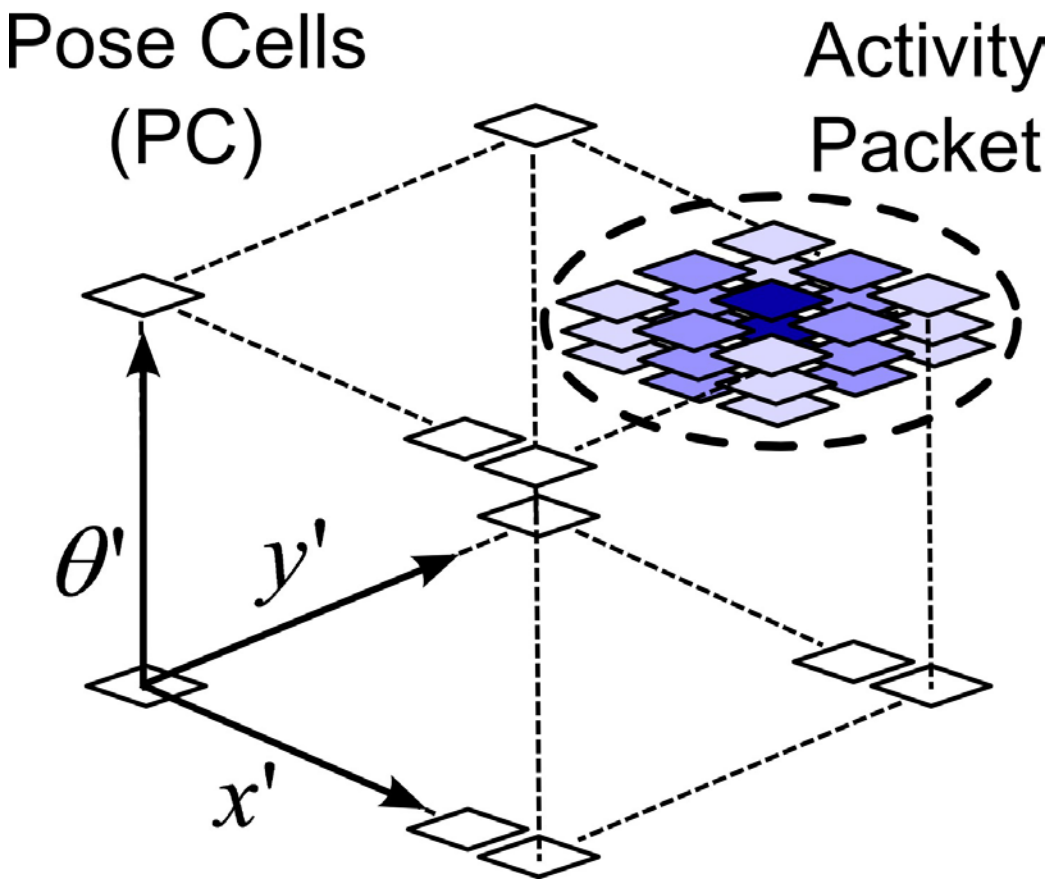
RatSLAM Model



RatSLAM Model



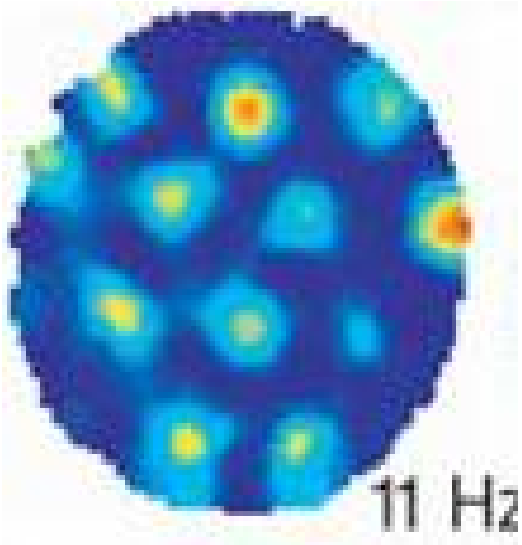
3D Attractor - Pose Cells



Milford M. J., Wyeth G. F., Prasser D. “RatSLAM: A Hippocampal Model for Simultaneous Localization and Mapping,” IEEE International Conference on Robotics and Automation 2004.

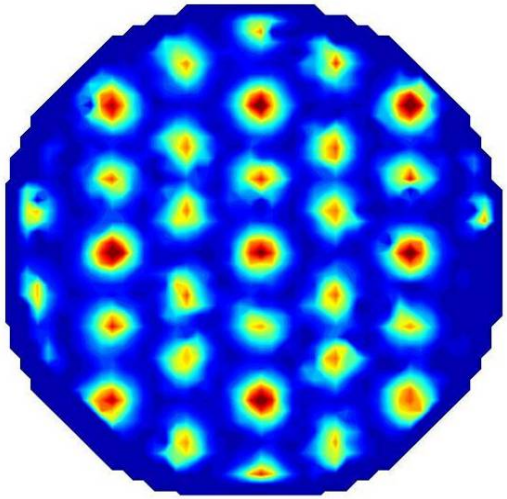
Pose Cells are like Grid Cells

Rats



Hafting, T. *et al*., 2005

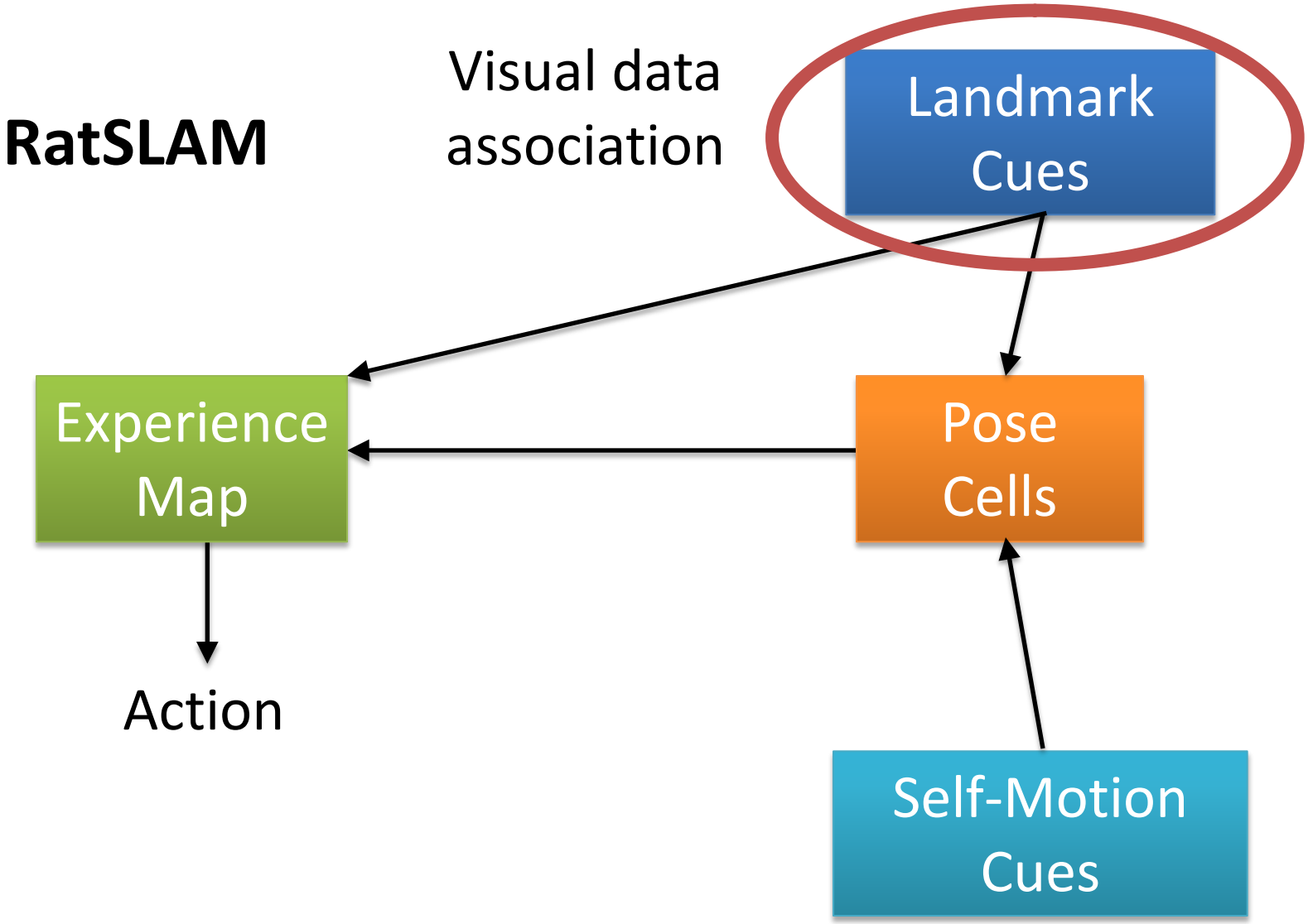
RatSLAM



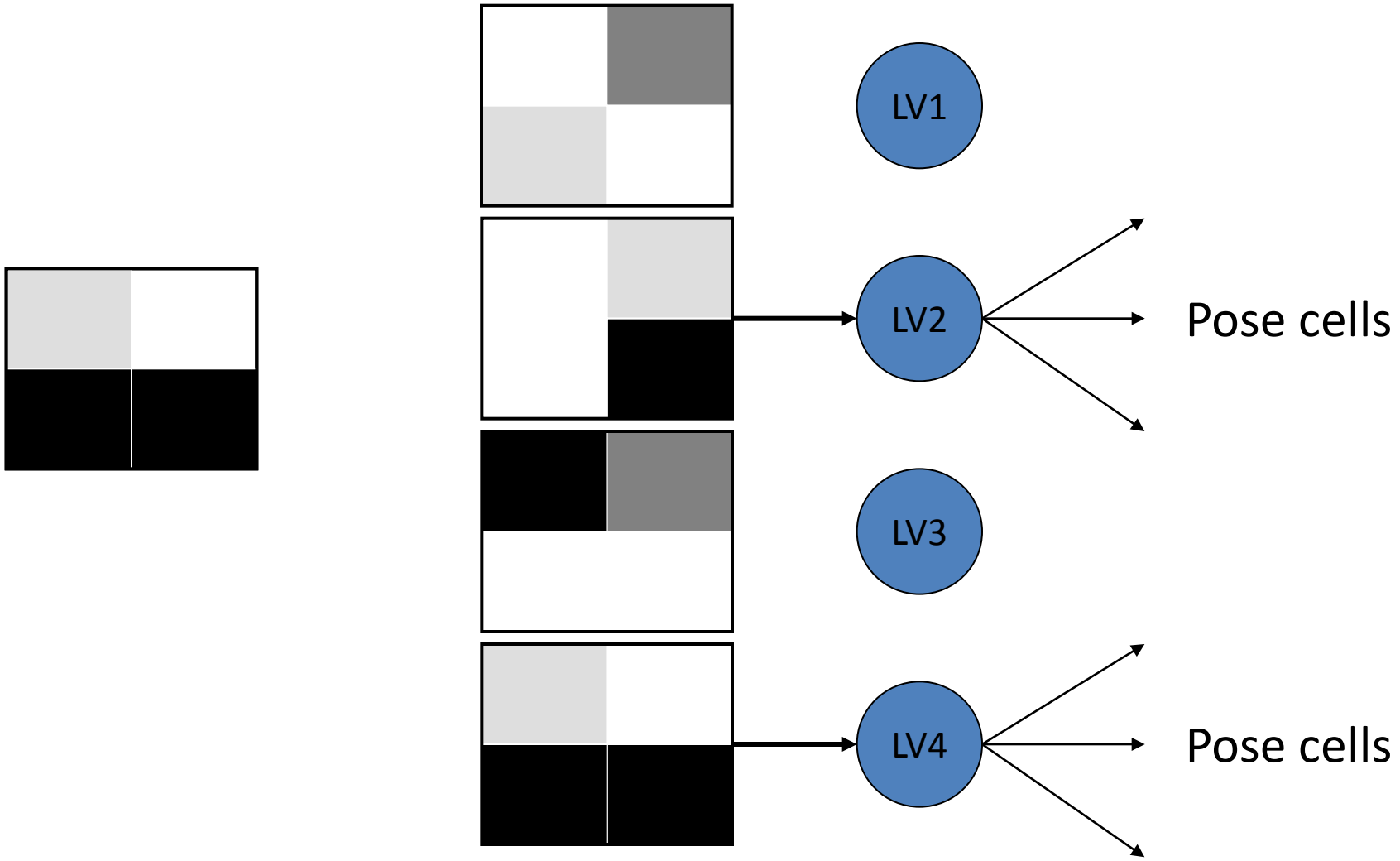
Milford M. J., Wiles J. and Wyeth G. (2010) "Solving Navigational Uncertainty using Grid Cells on Robots", *PLoS Computational Biology*, November 2010

Cells have similar functional characteristics (reset to landmarks, track self motion) and similar connectivity (local excitation, broad inhibition).

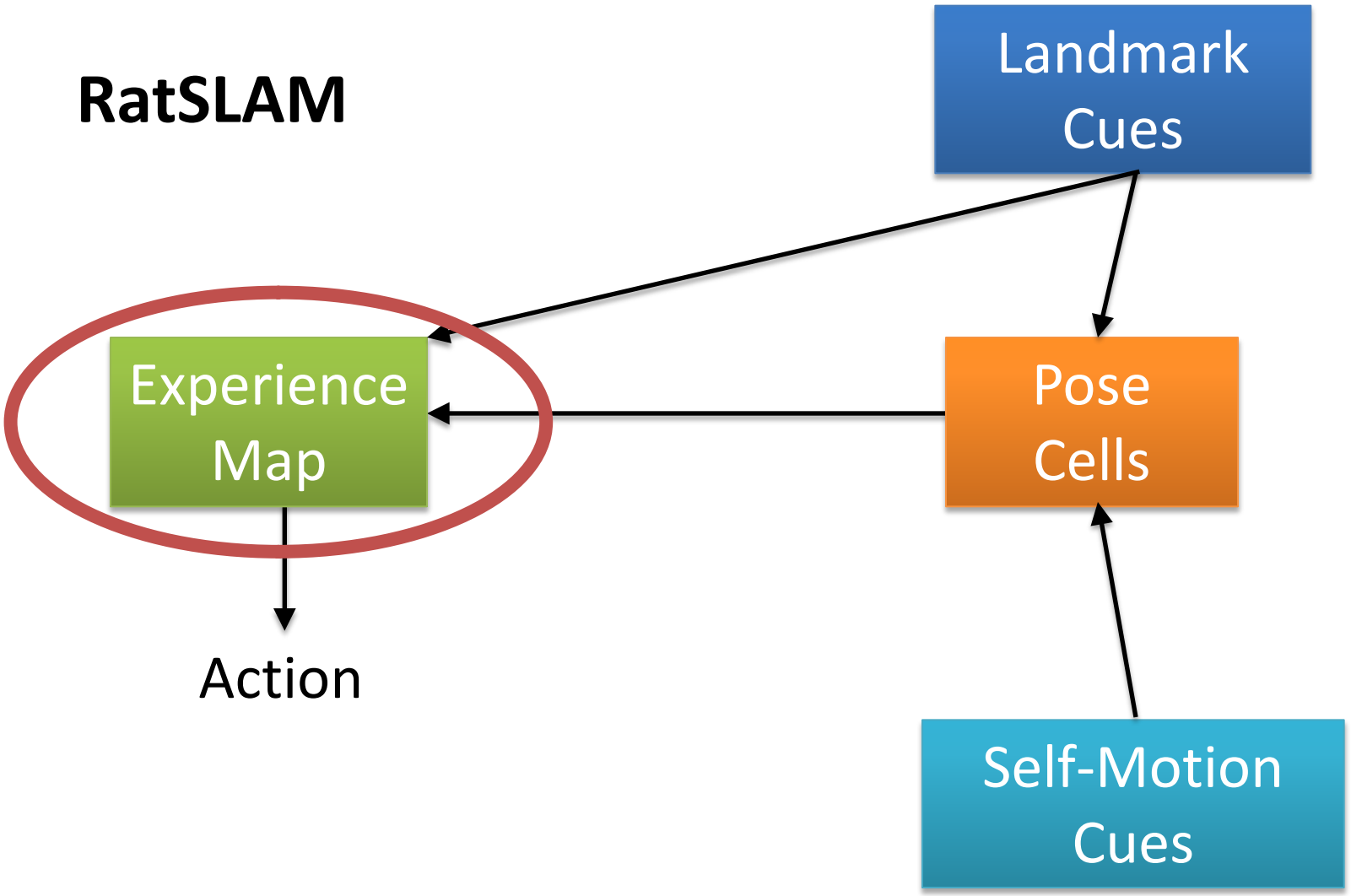
RatSLAM Model



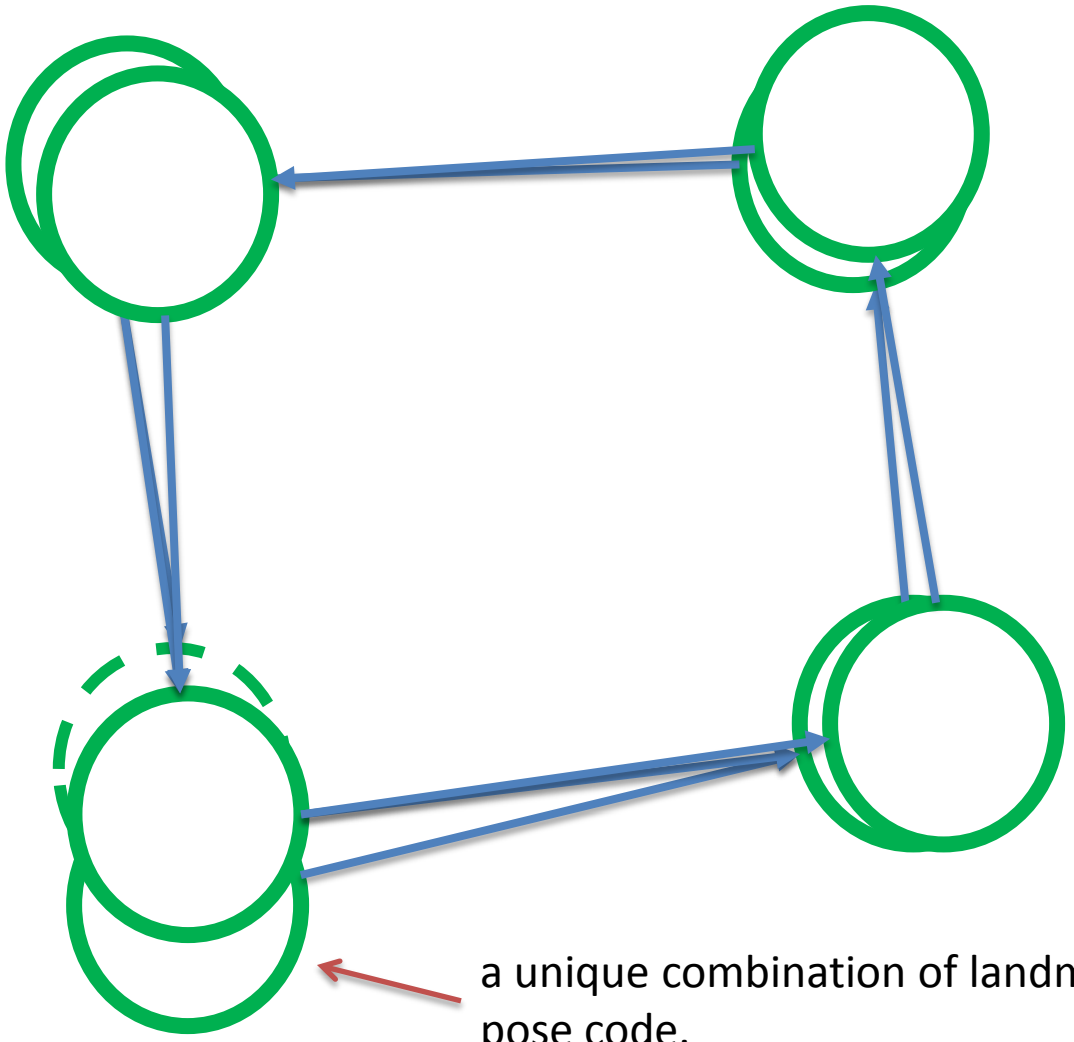
Visual Data Association



RatSLAM Model

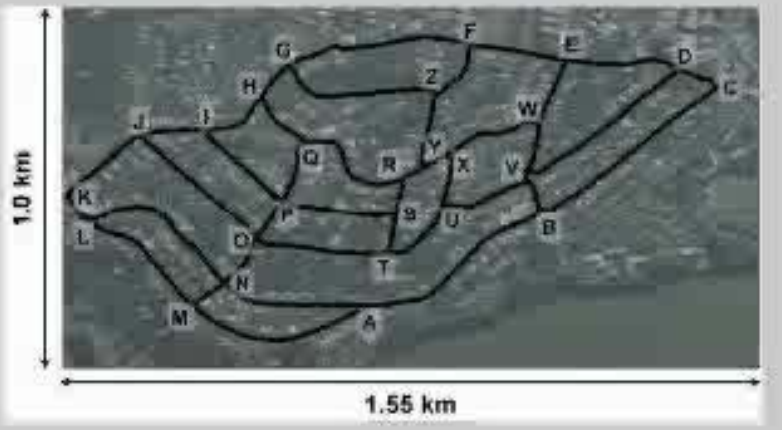


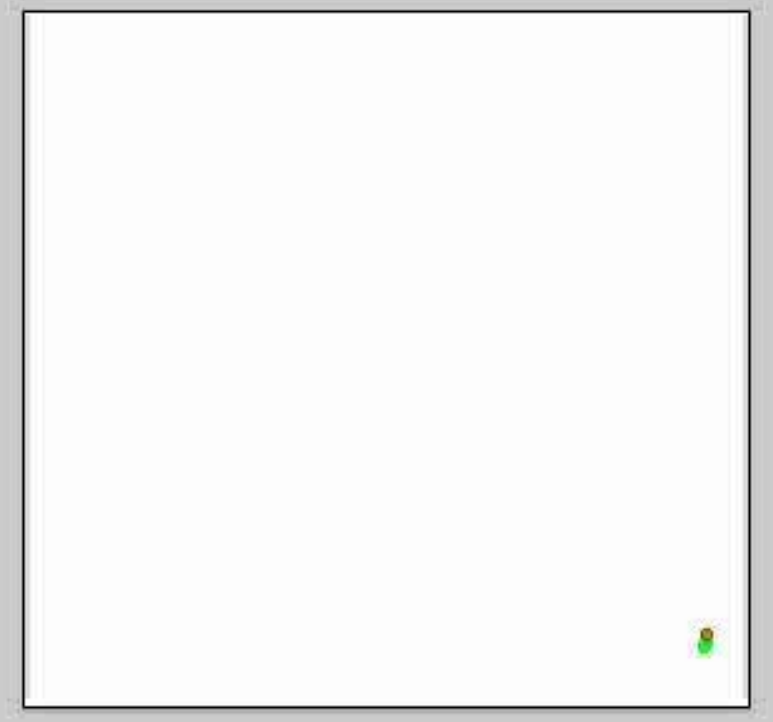
Experience Map Example



a unique combination of landmark cues and pose code.

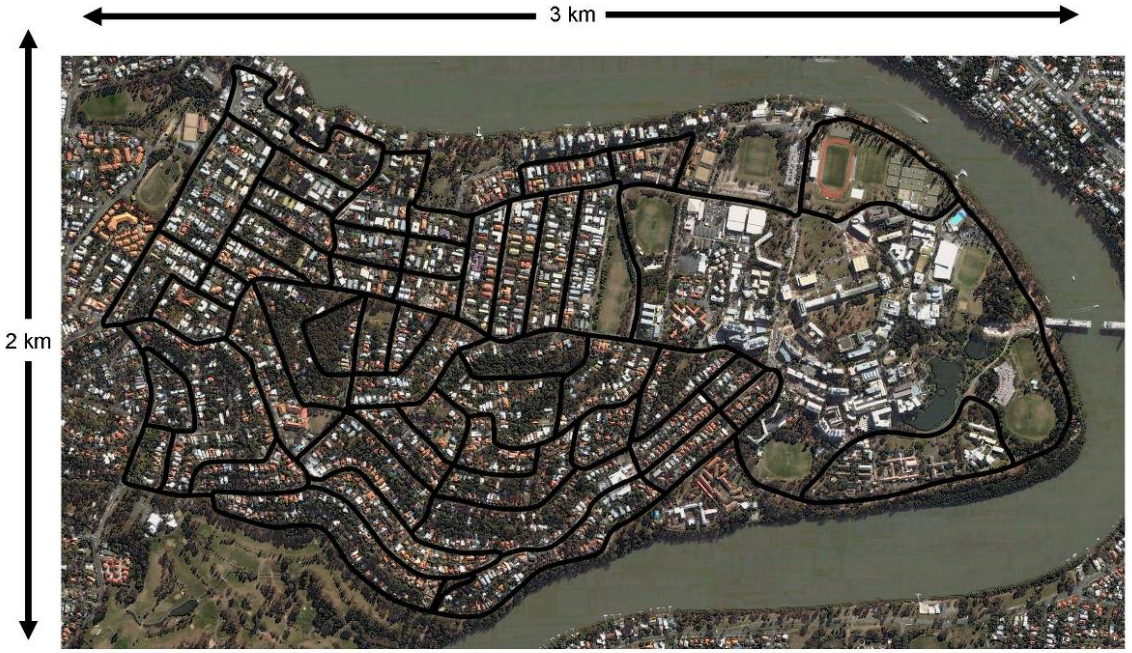
Time: 3.0 s

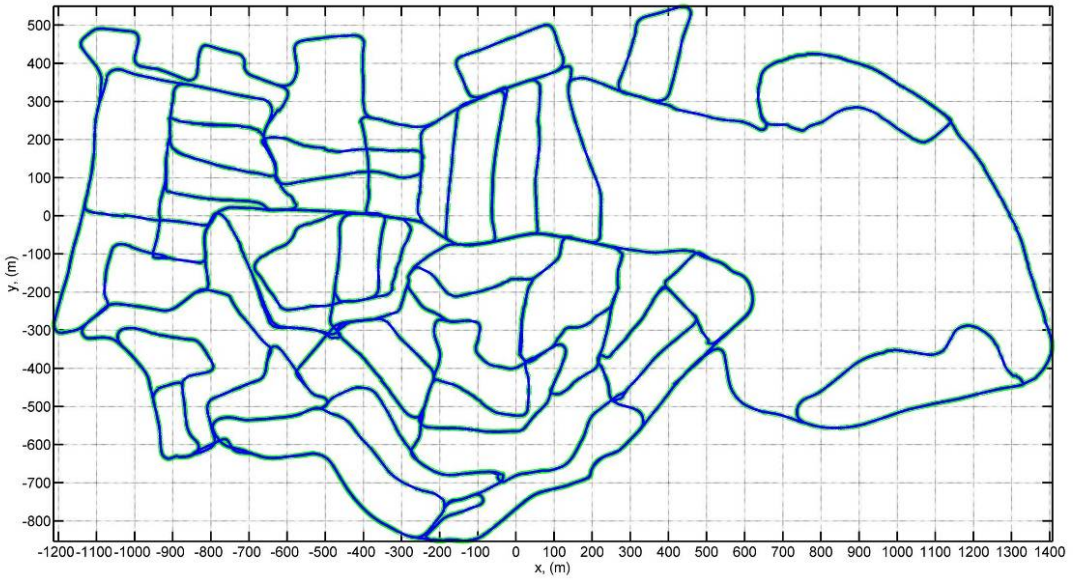




Mapping a Suburb

- Mapped the entire suburb of St Lucia from 100 minutes of webcam video.

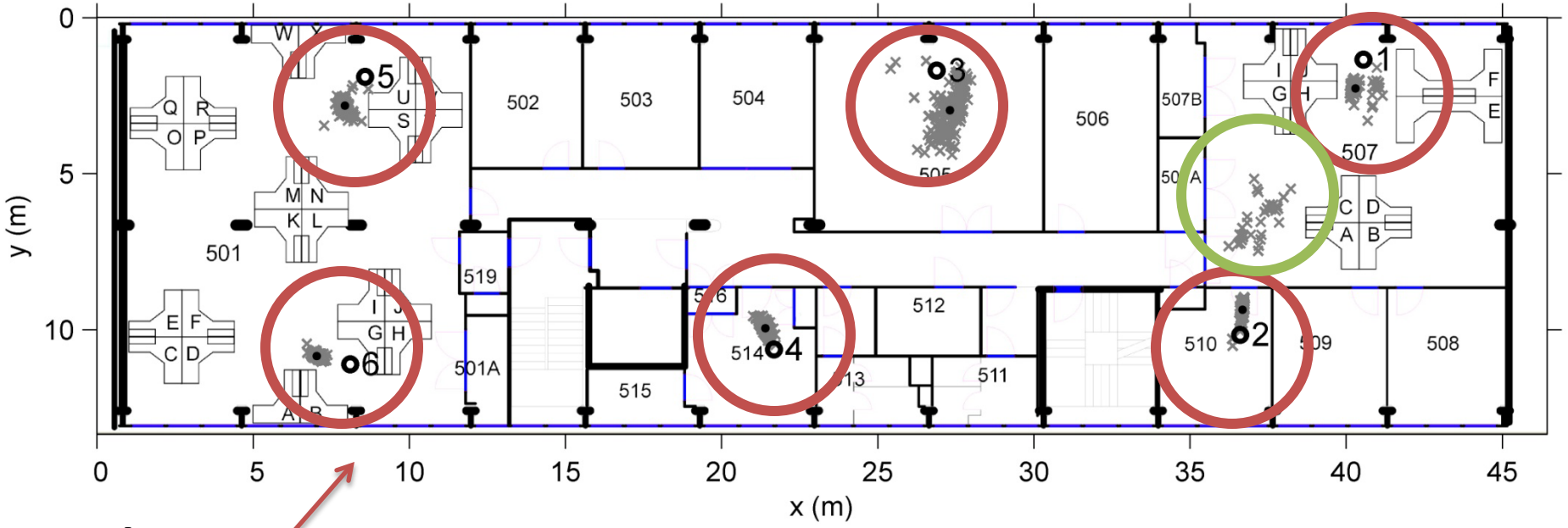




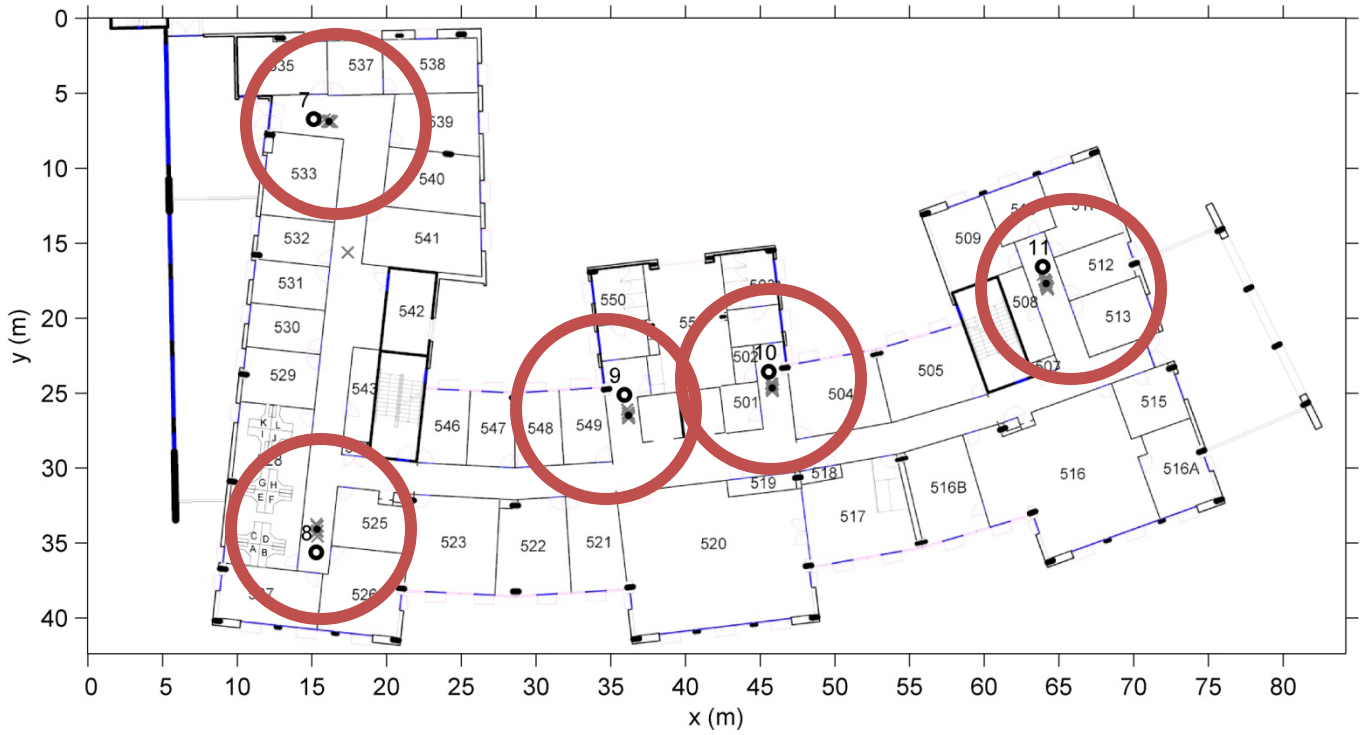
Milford M. J., and Wyeth G. (2008) "Mapping a Suburb with a Single Camera using a Biologically Inspired SLAM System," *IEEE Transactions on Robotics*, vol.24, no.5, Oct. 2008, pp.1038-1053.

Office Delivery Challenge

- The robot started “out of the box” in an unknown office and laboratory complex.
- 1000 “deliveries” made over a two week period at all times of night and day.
- The robot maintained it batteries by locating and docking with its charger.
- Kidnapped the robot to another unknown office and laboratory complex.



Axon Building



GP-South Building

Office Delivery Key Results

- 1177/1178 successful deliveries / recharges.
- Maintained minimum delivery times over the two week period.
- Negligible growth in space and computation requirements after initial exploration.
- Robot recovered robustly from kidnapping.

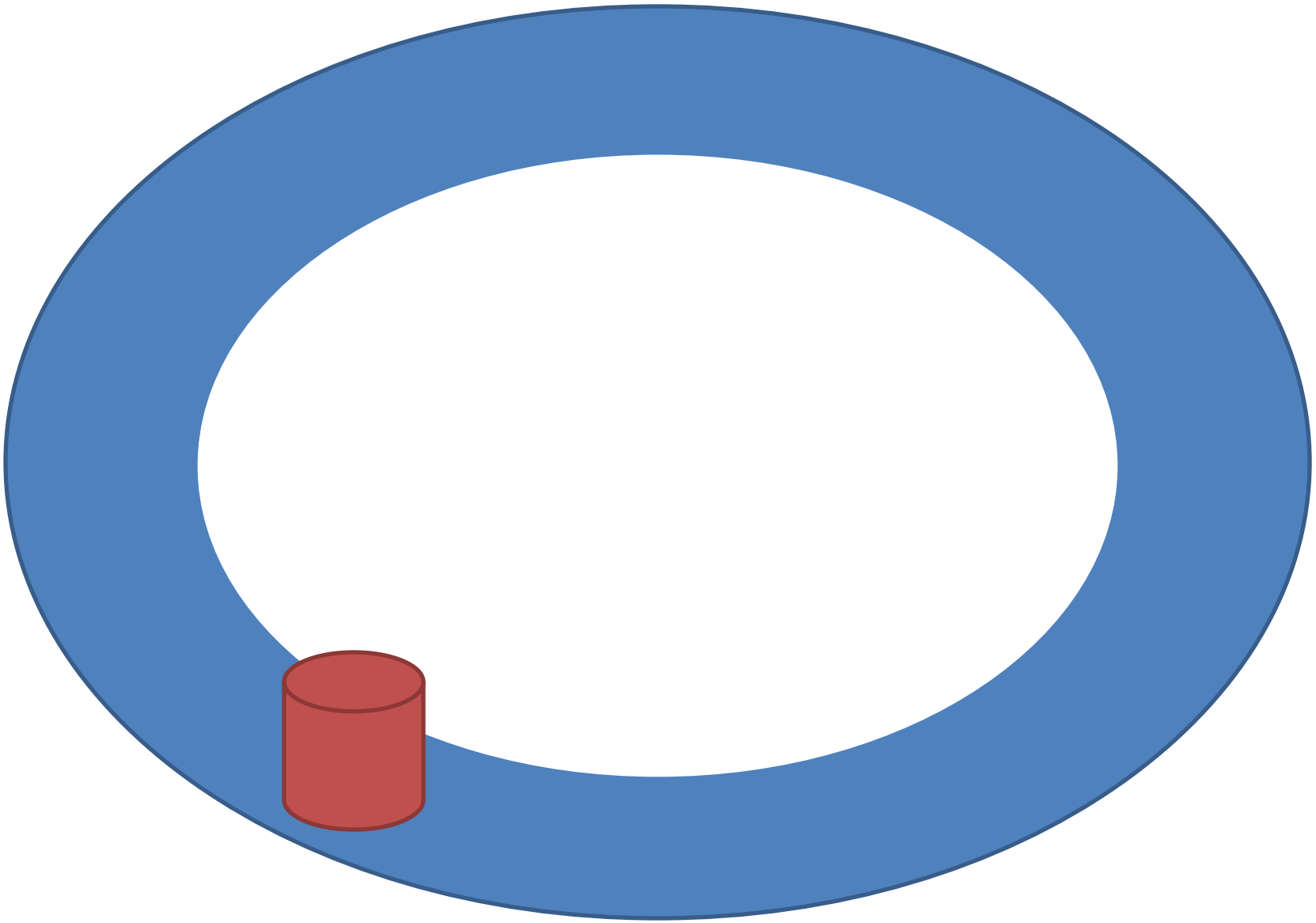
Milford M. J., and Wyeth G. (2010) “Persistent Navigation and Mapping using a Biologically Inspired SLAM System,” *International Journal of Robotics Research*, vol 29, no. 9, August 2010, pp. 1131 – 1153.

The Down Side ...

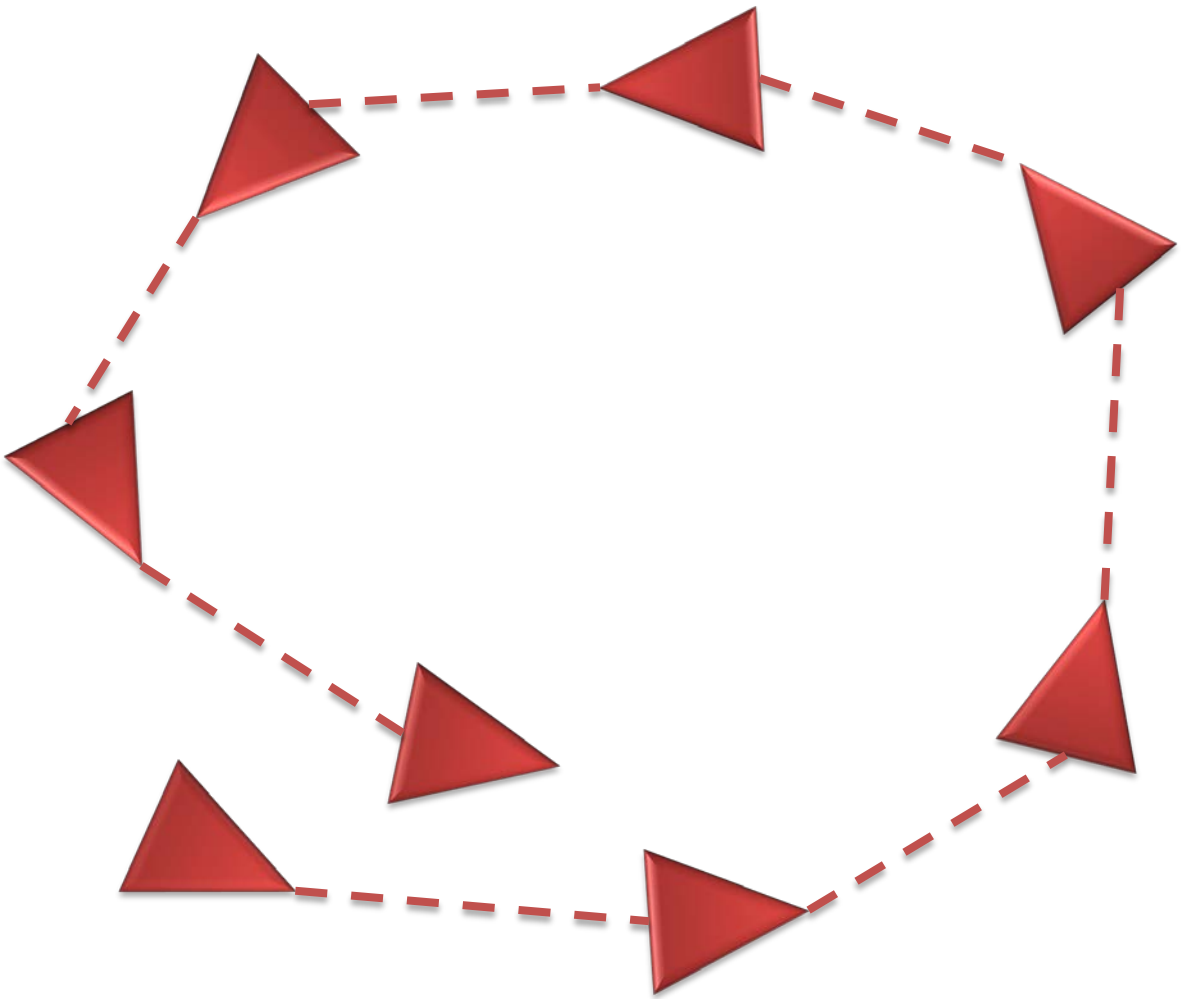
- Rat-SLAM relies on 20+ parameters (magic numbers) to work effectively
- Many parameters are unit-less and empirically chosen
- No engineering basis for setting parameters

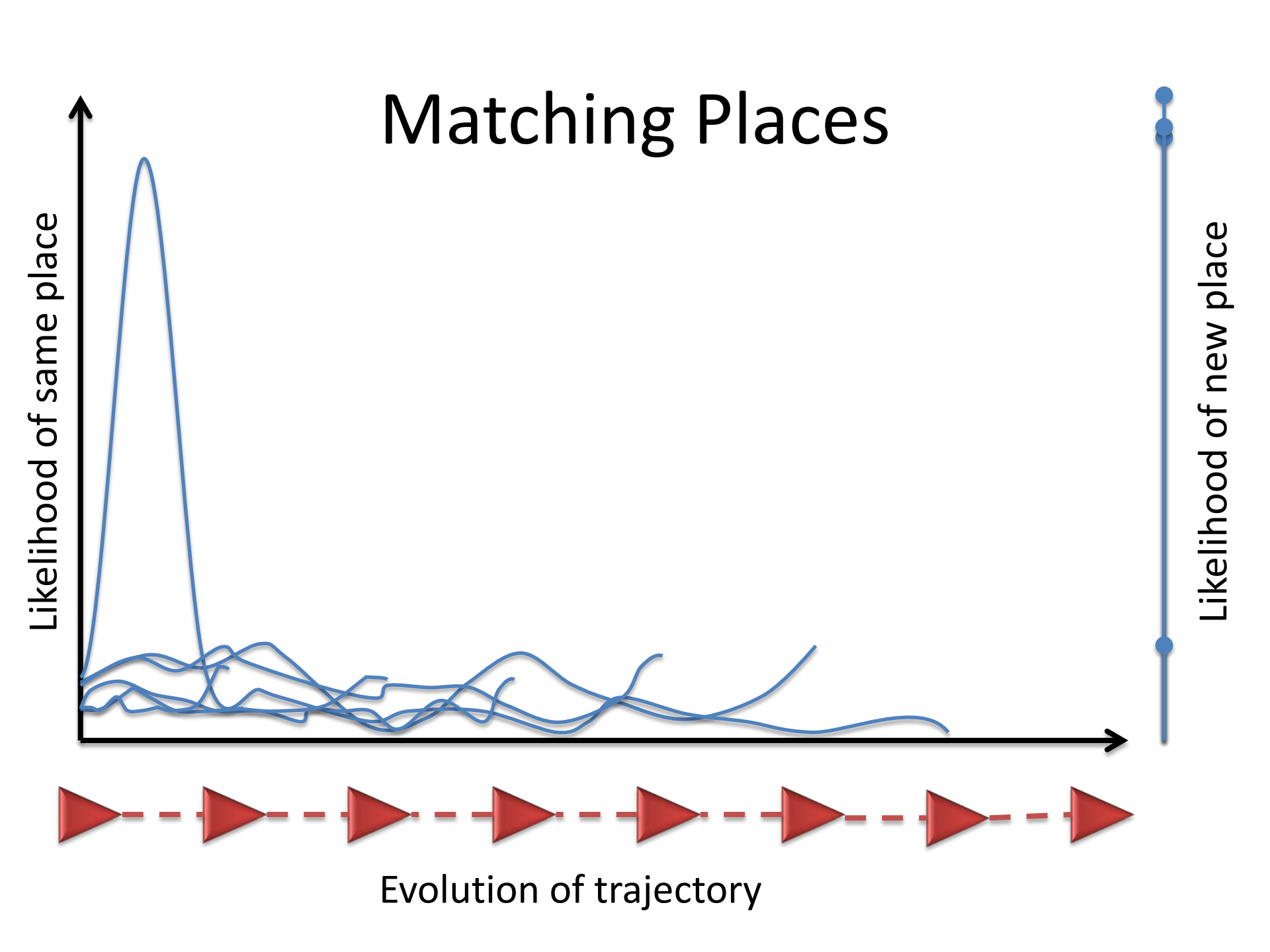
CAT-SLAM

- Continuous Appearance-based Trajectory SLAM
- Replaces the neural mechanisms for pose filtering and pose-view association with probabilistic mechanisms.
- No magic numbers!

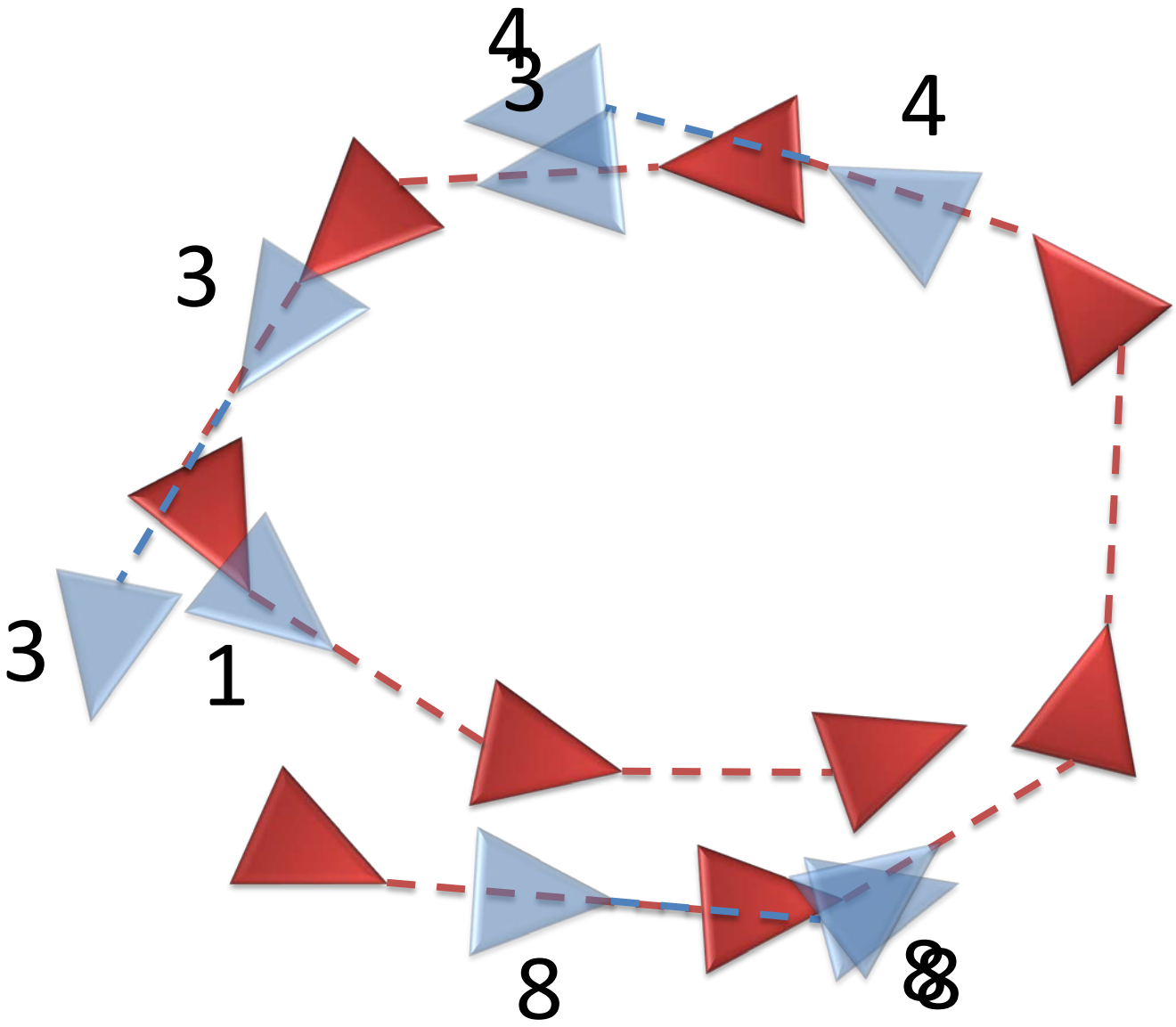


Creating a Trajectory

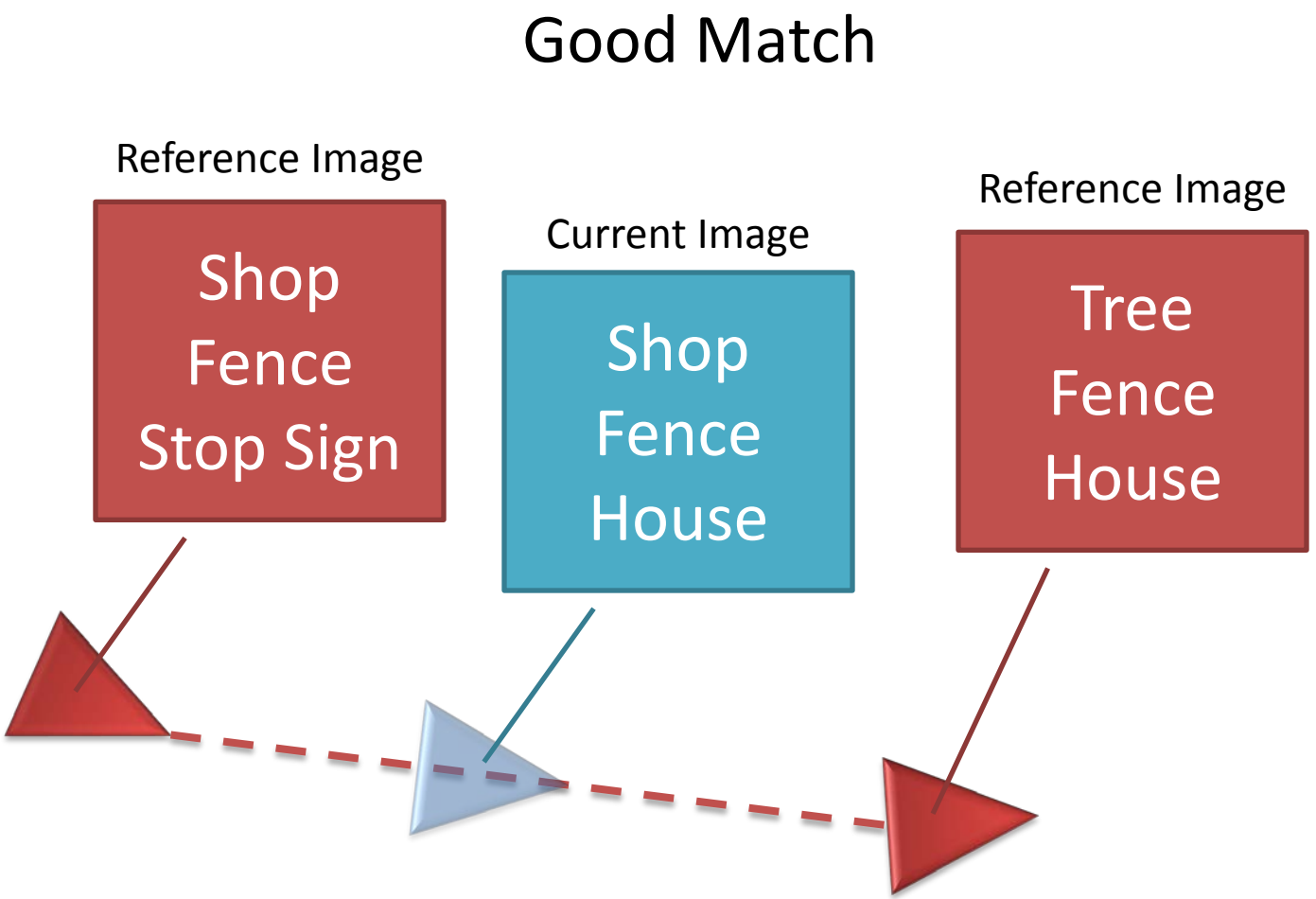



Matching Places
Likelihood of same place
Likelihood of new place
Evolution of trajectory

Updating the Place Hypothesis



Incorporating Visual Information



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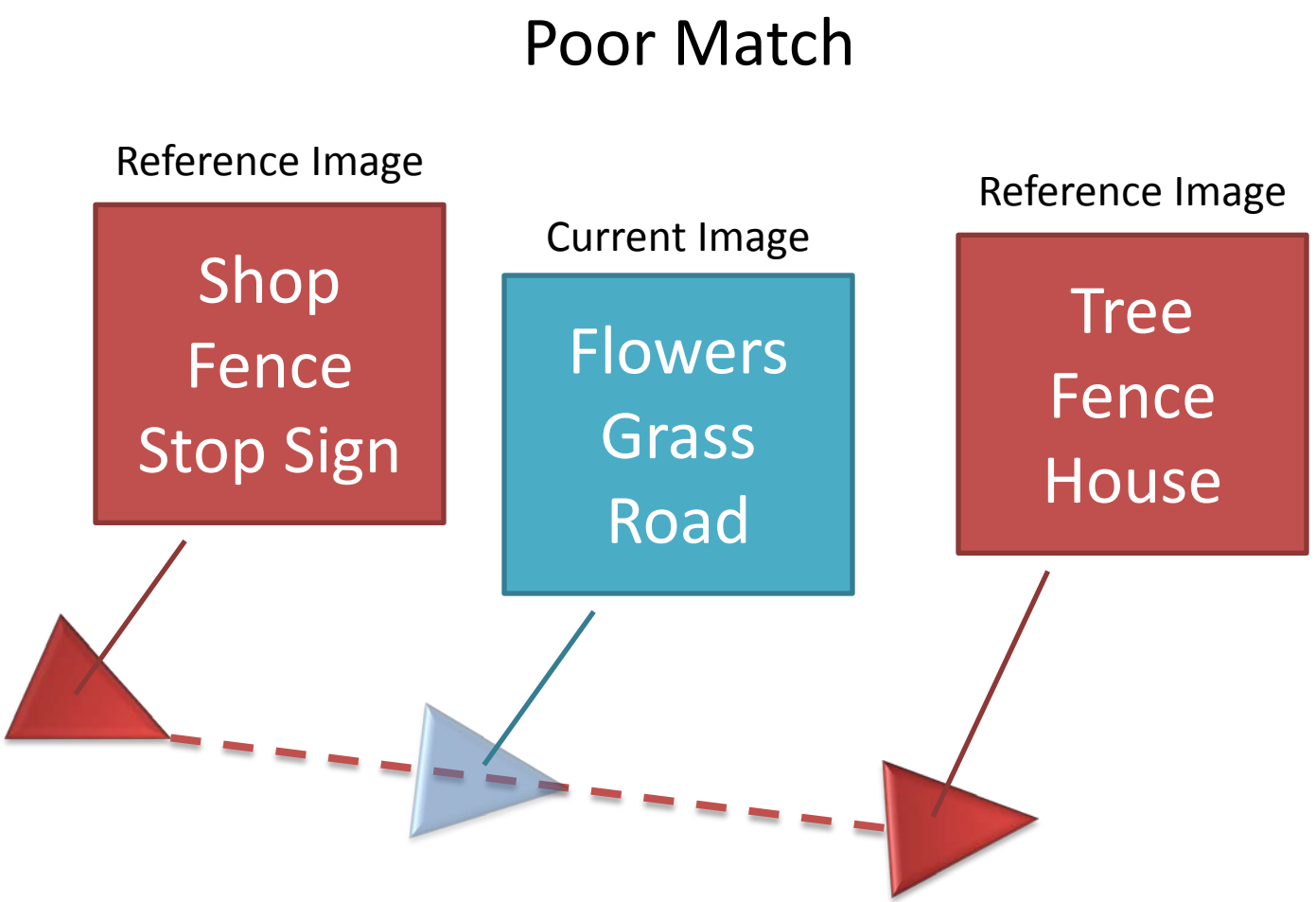
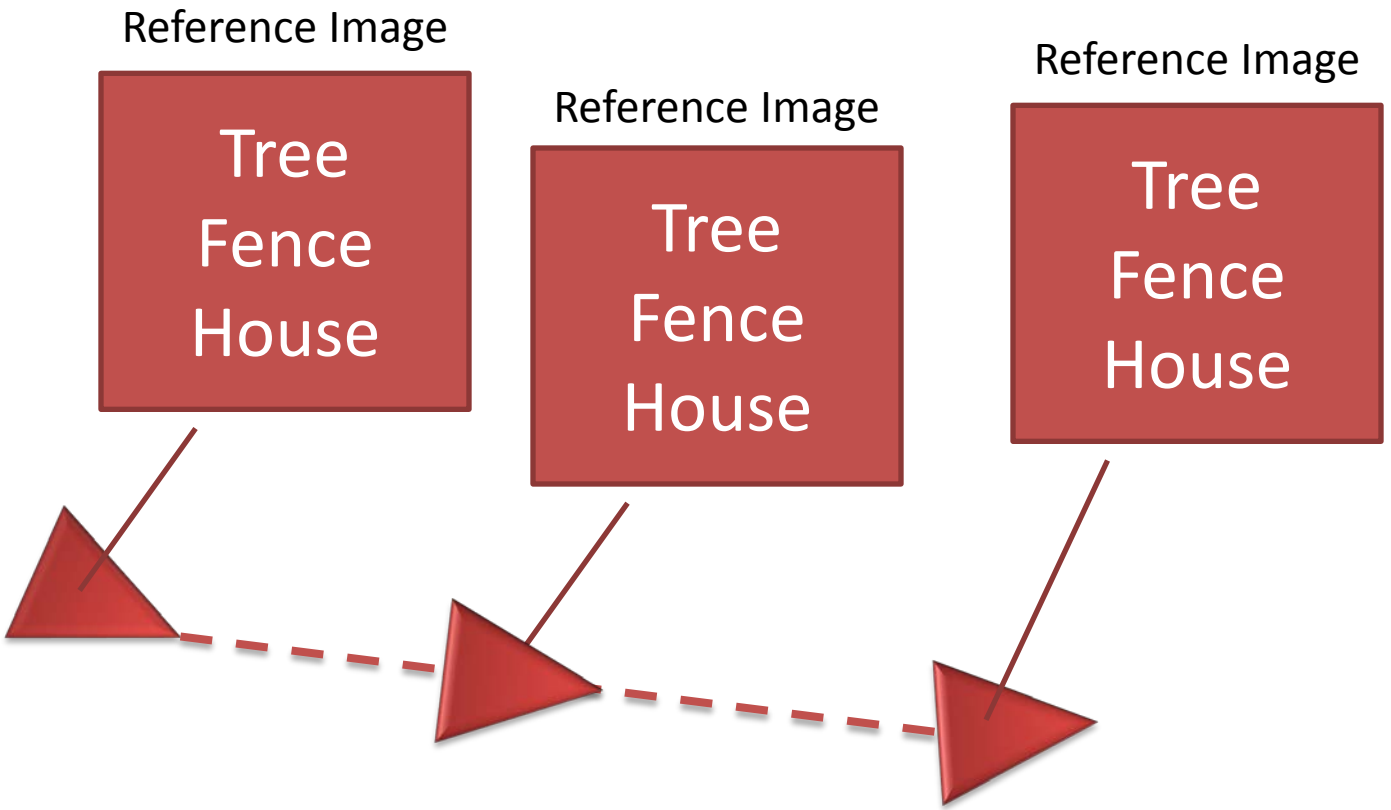
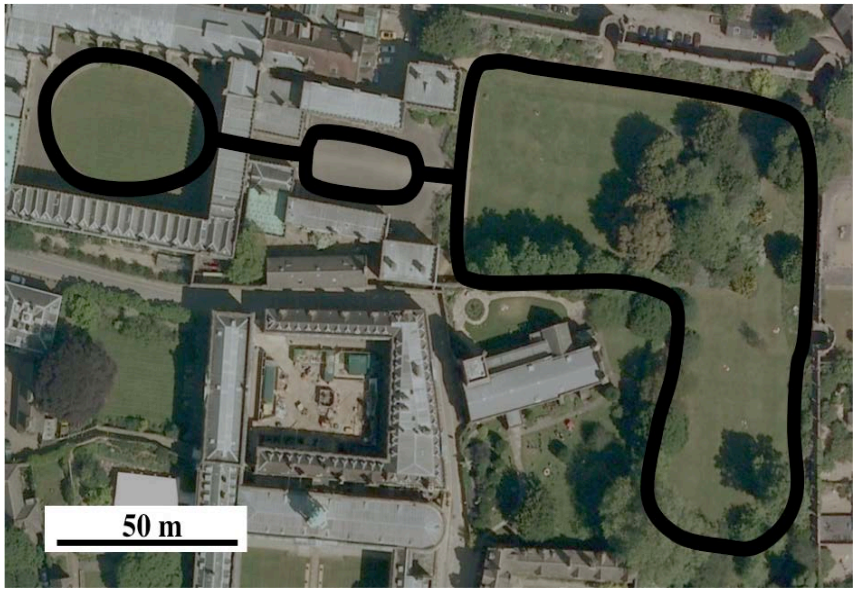


Removing Redundant Information



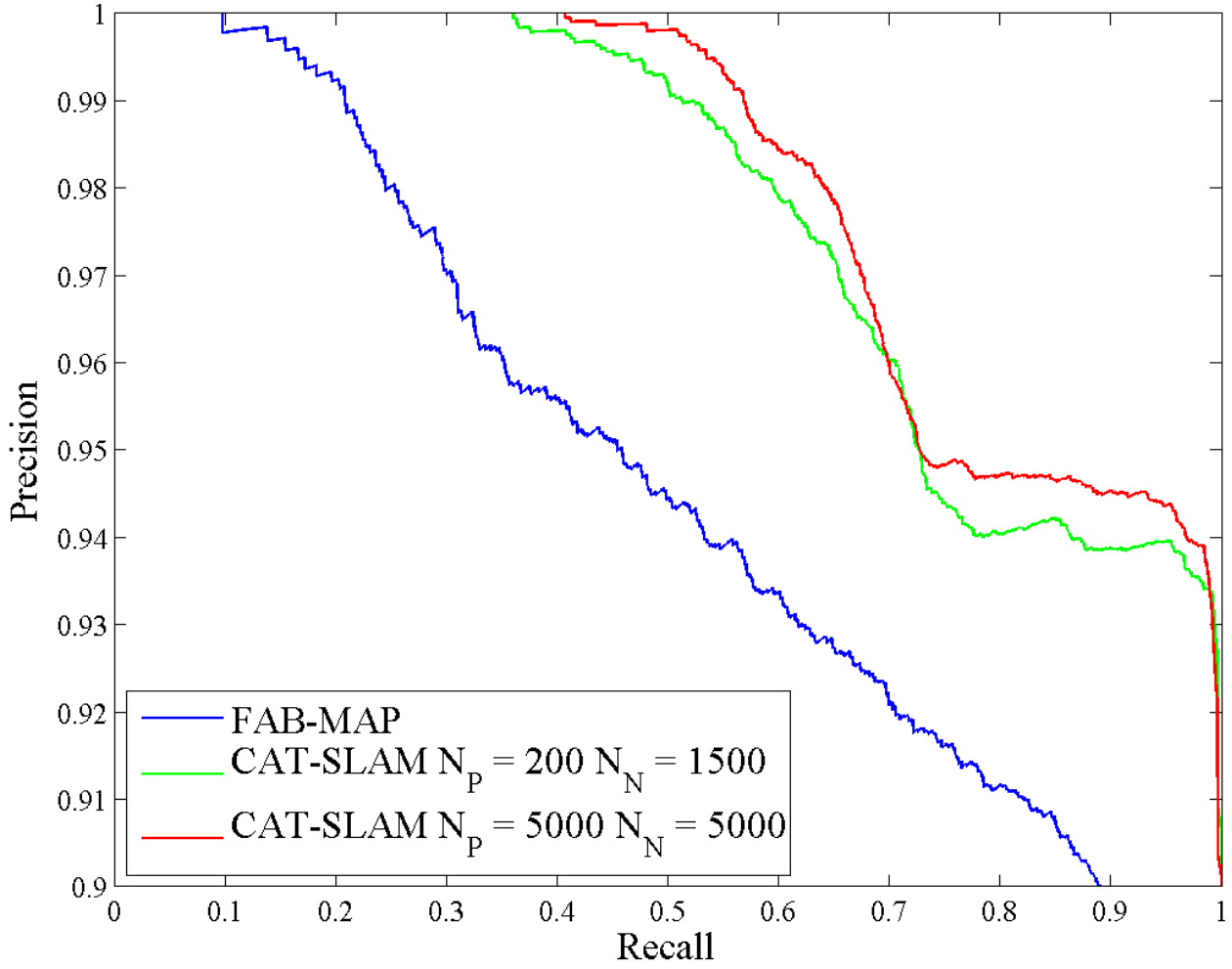
Experimental Setup – New College

- 2.25km tour of Oxford New College
- Ladybug2 panoramic camera
- Odometry from shaft encoders on Segway platform
- GPS ground truth
- Results compared to FAB-MAP



W. Maddern, M. Milford and G. Wyeth, “Continuous Appearance-based Trajectory SLAM,” IEEE International Conference on Robotics and Automation 2011

Results: Precision-Recall

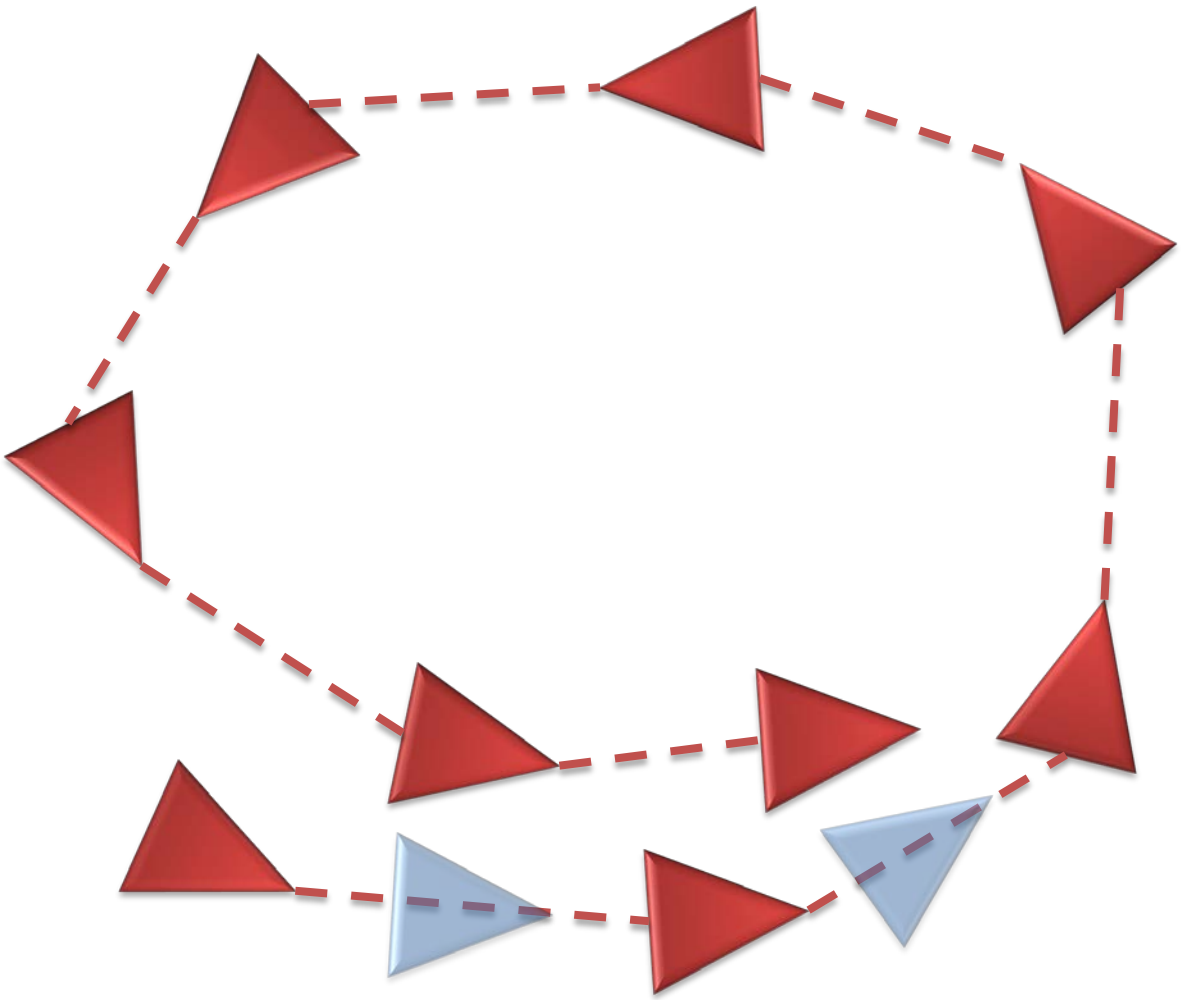


W. Maddern, M. Milford and G. Wyeth, “Continuous Appearance-based Trajectory SLAM,” IEEE International Conference on Robotics and Automation 2011

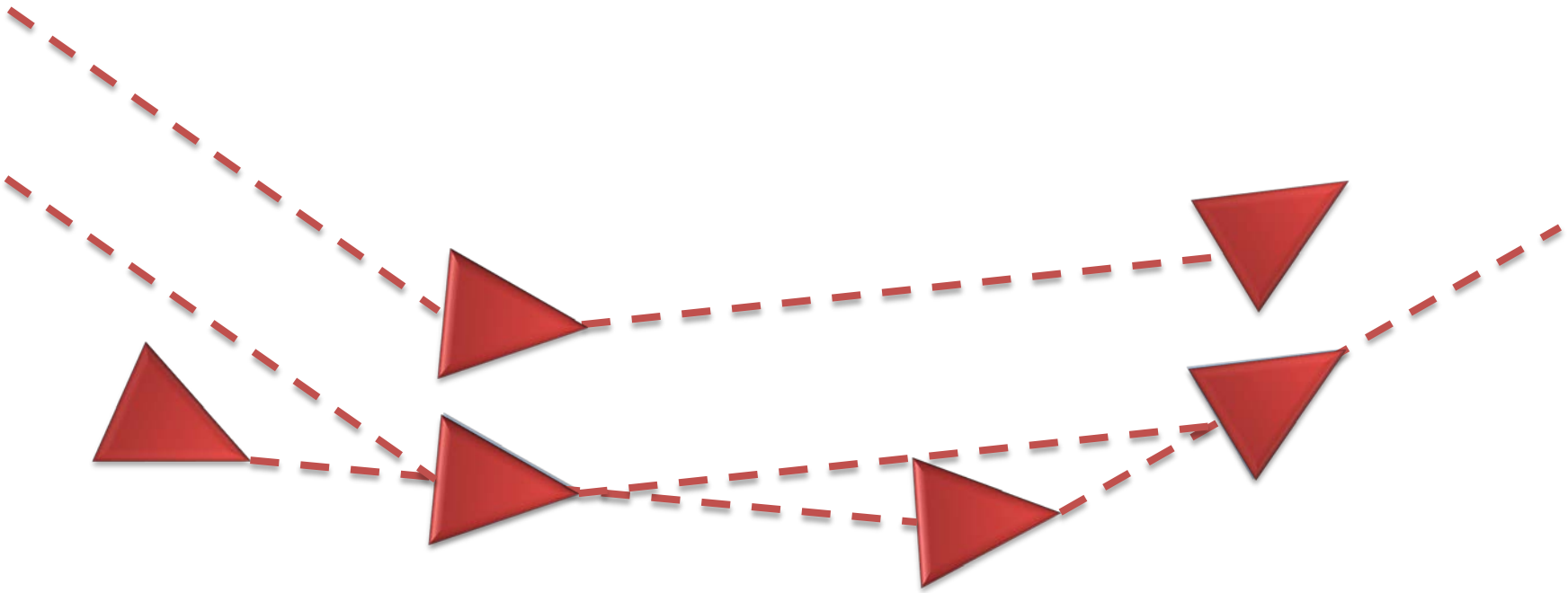
CAT-Graph

- CAT-SLAM develops a trajectory - a set of points over time.
  - Not suitable for many revisits to the same location
  - Not suitable for path planning.
- By introducing one parameter for certainty required for loop closure, we can form a graph rather than a trajectory.

Creating a Graph



Creating a Graph



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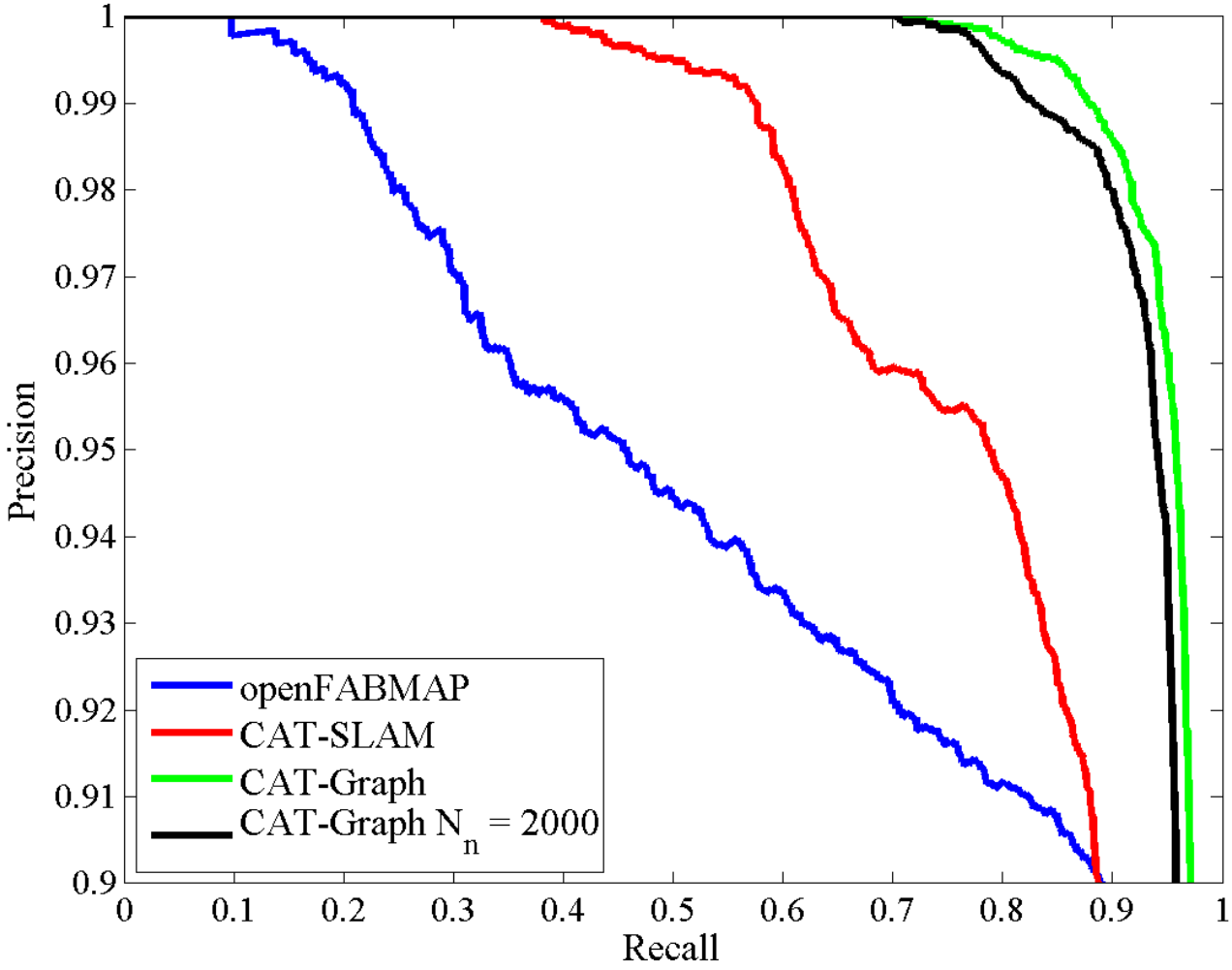


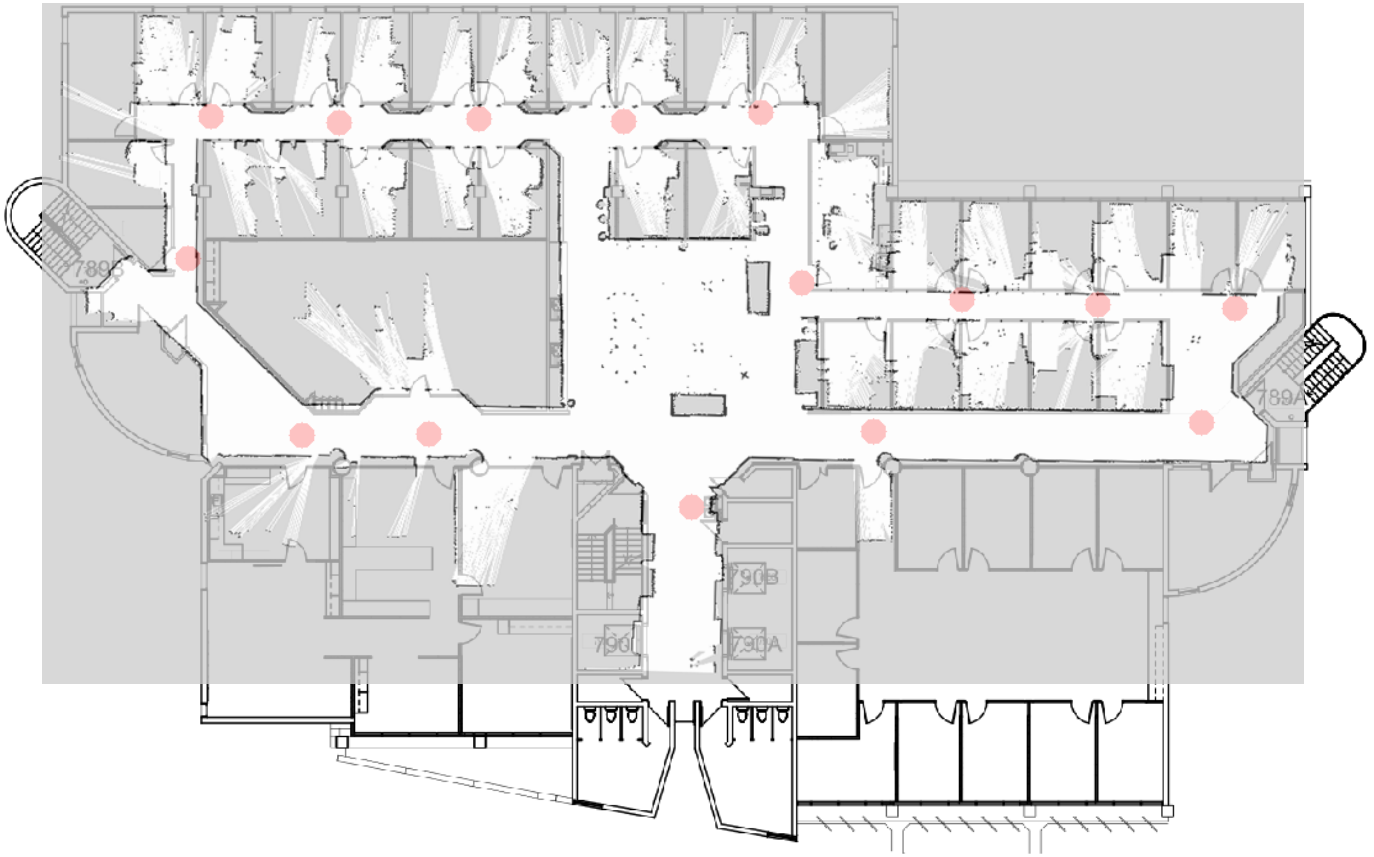
W. Maddern, M. Milford and G. Wyeth, "Towards Persistent Localisation and Mapping with a Continuous Appearance-based Topology " in 2012 Robotics: Science and Systems Conference

Experimental Setup: S Block QUT

- 7 routes through S Block Level 7 over a week
- CAT-Graph with 2000 particles, 5000 nodes
- openFABMAP
- Metric ground truth from laser scanner

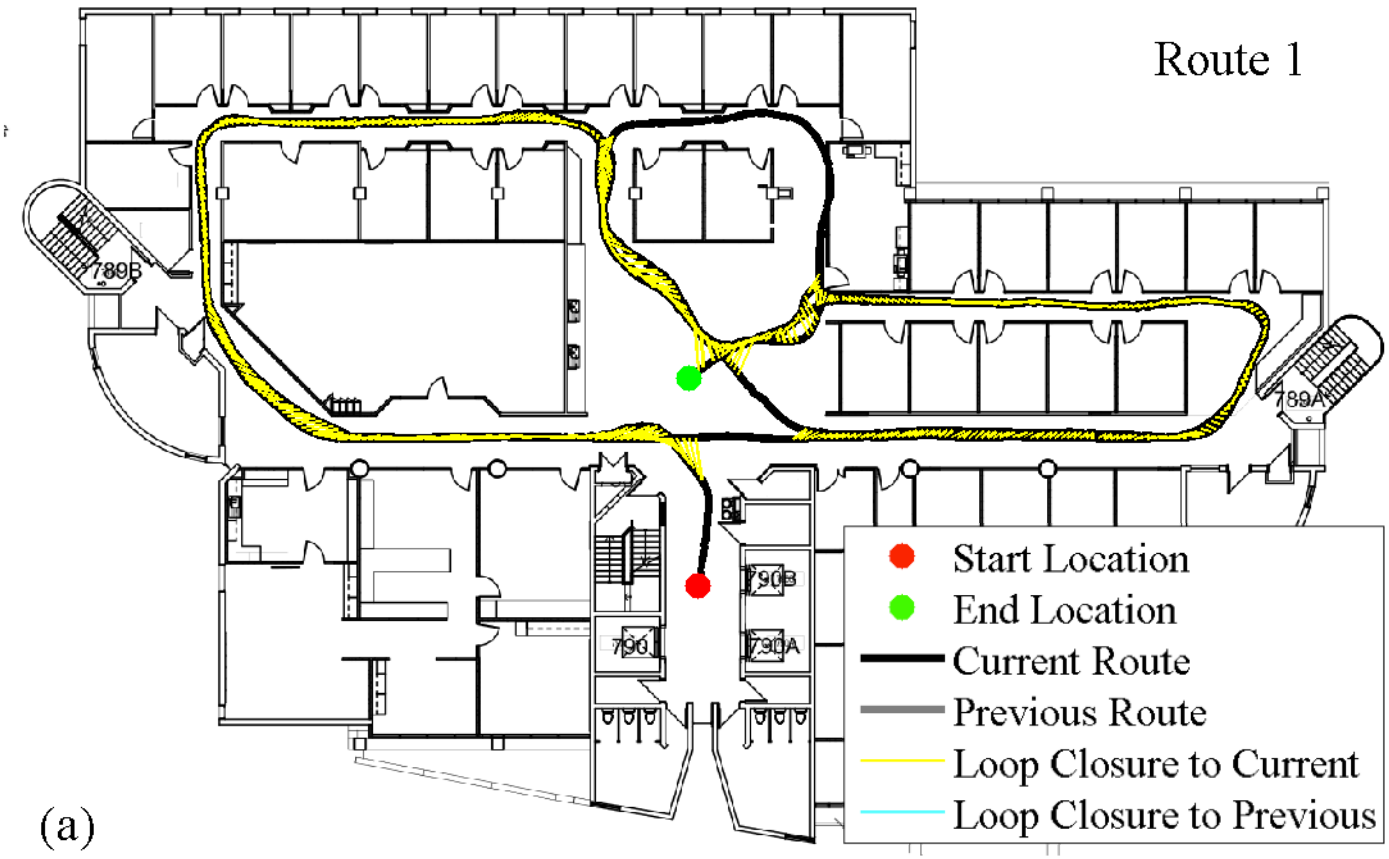
W. Maddern, M. Milford and G. Wyeth, “Towards Persistent Indoor Localisation, Mapping and Navigation with CAT-Graph ” IEEE International Conference on Intelligent Robots and Systems 2012

Experimental Setup: S Block QUT



W. Maddern, M. Milford and G. Wyeth, “Towards Persistent Indoor Localisation, Mapping and Navigation with CAT-Graph ” IEEE International Conference on Intelligent Robots and Systems 2012

Results: Loop Closure Distribution



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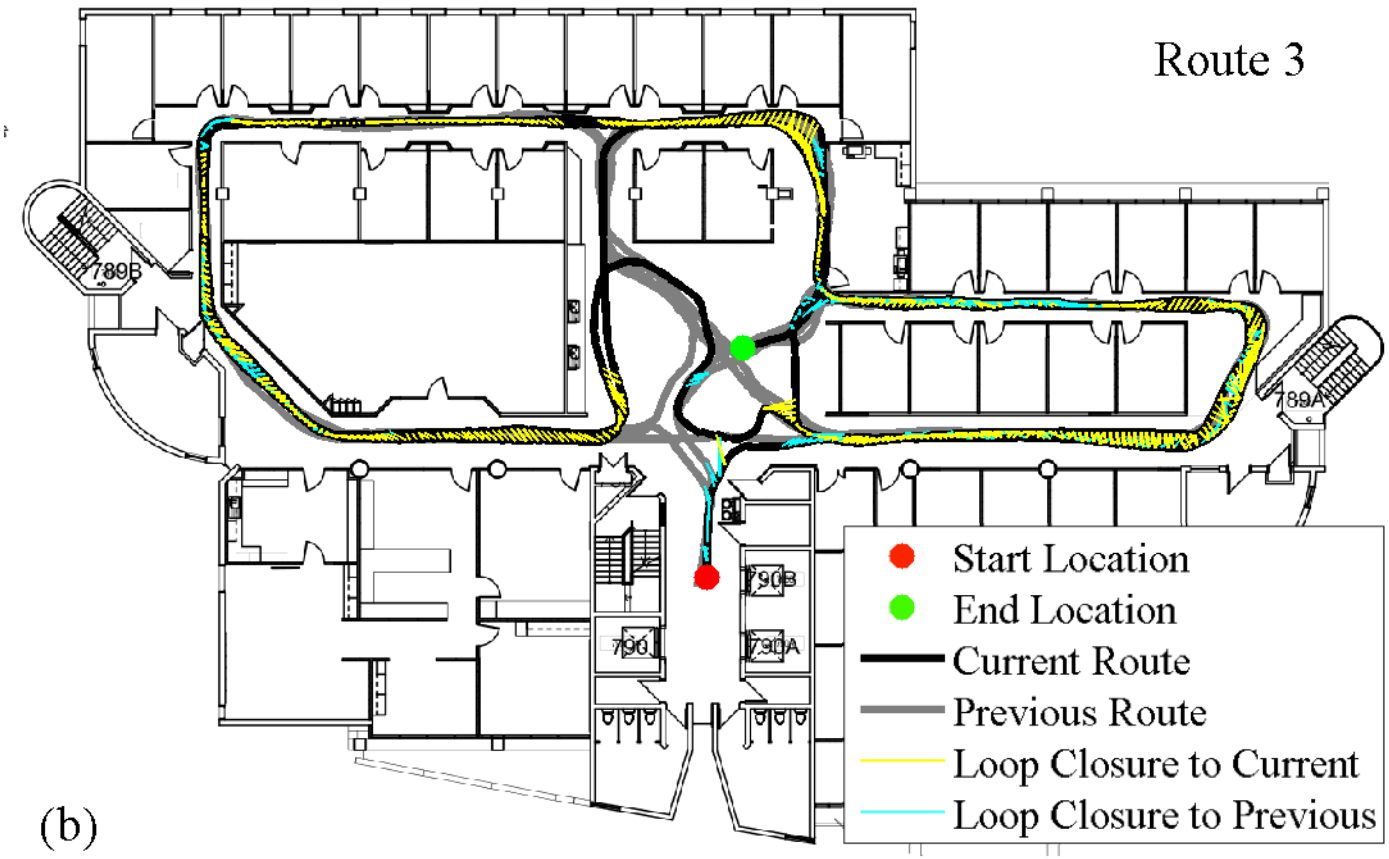

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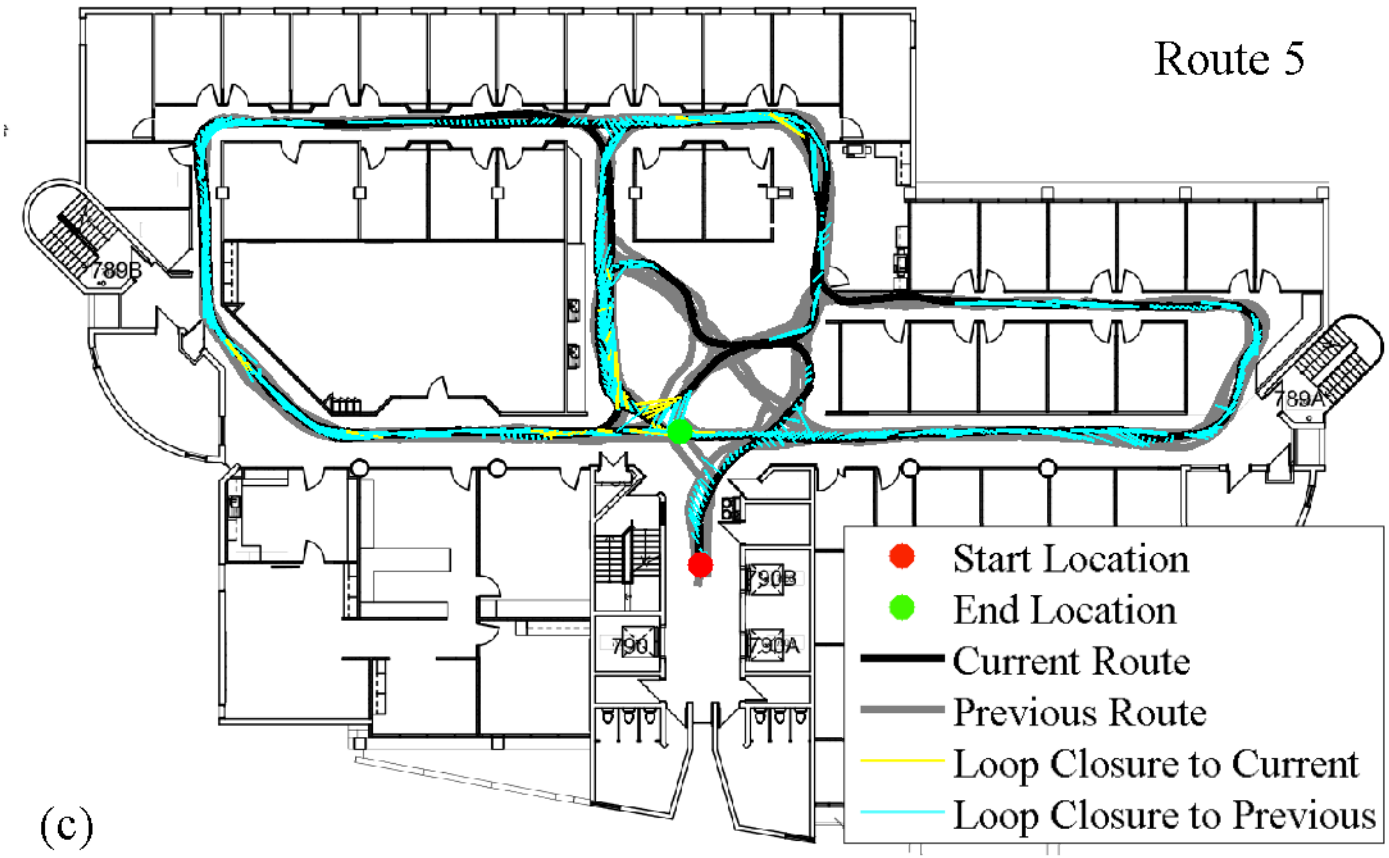

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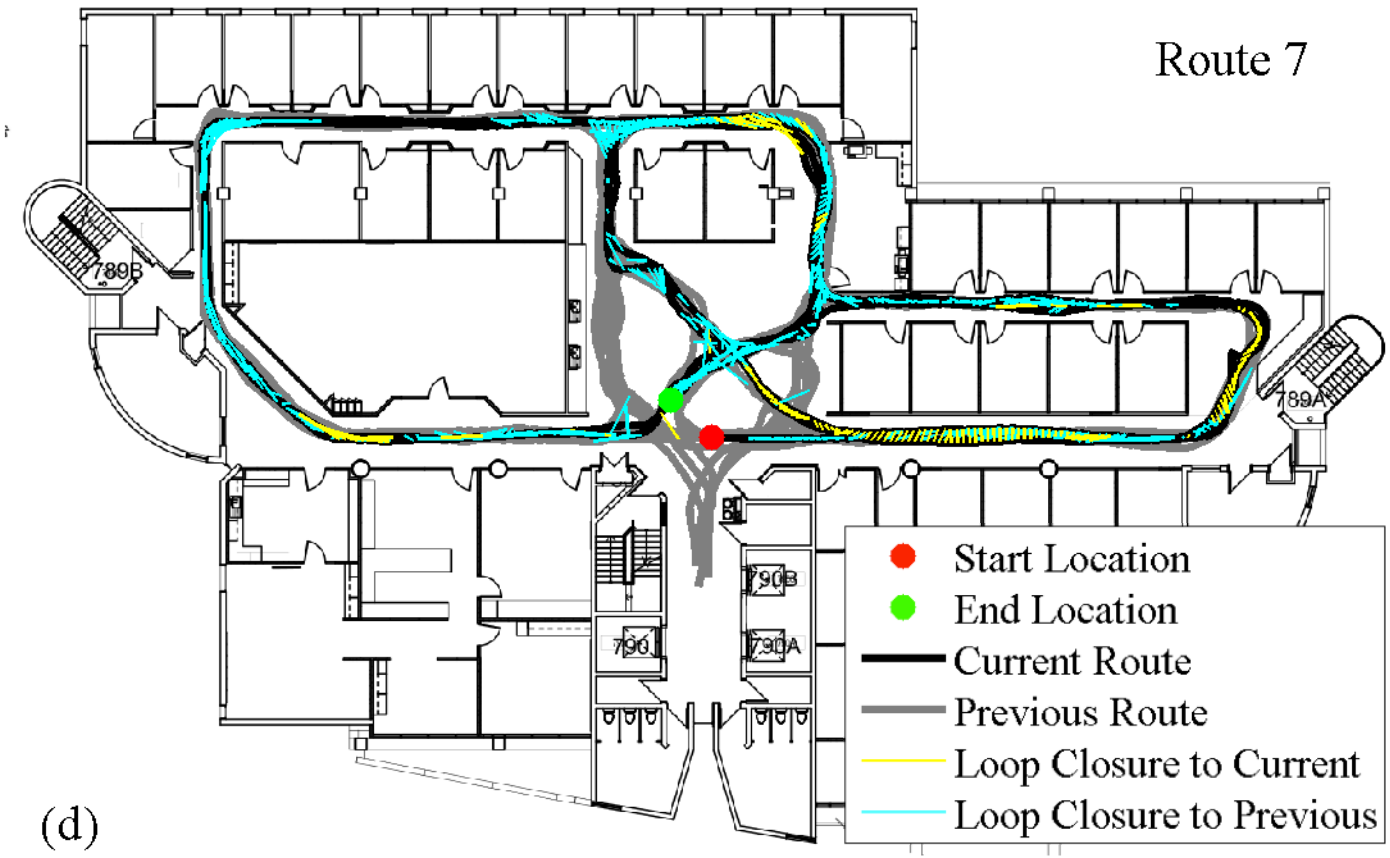
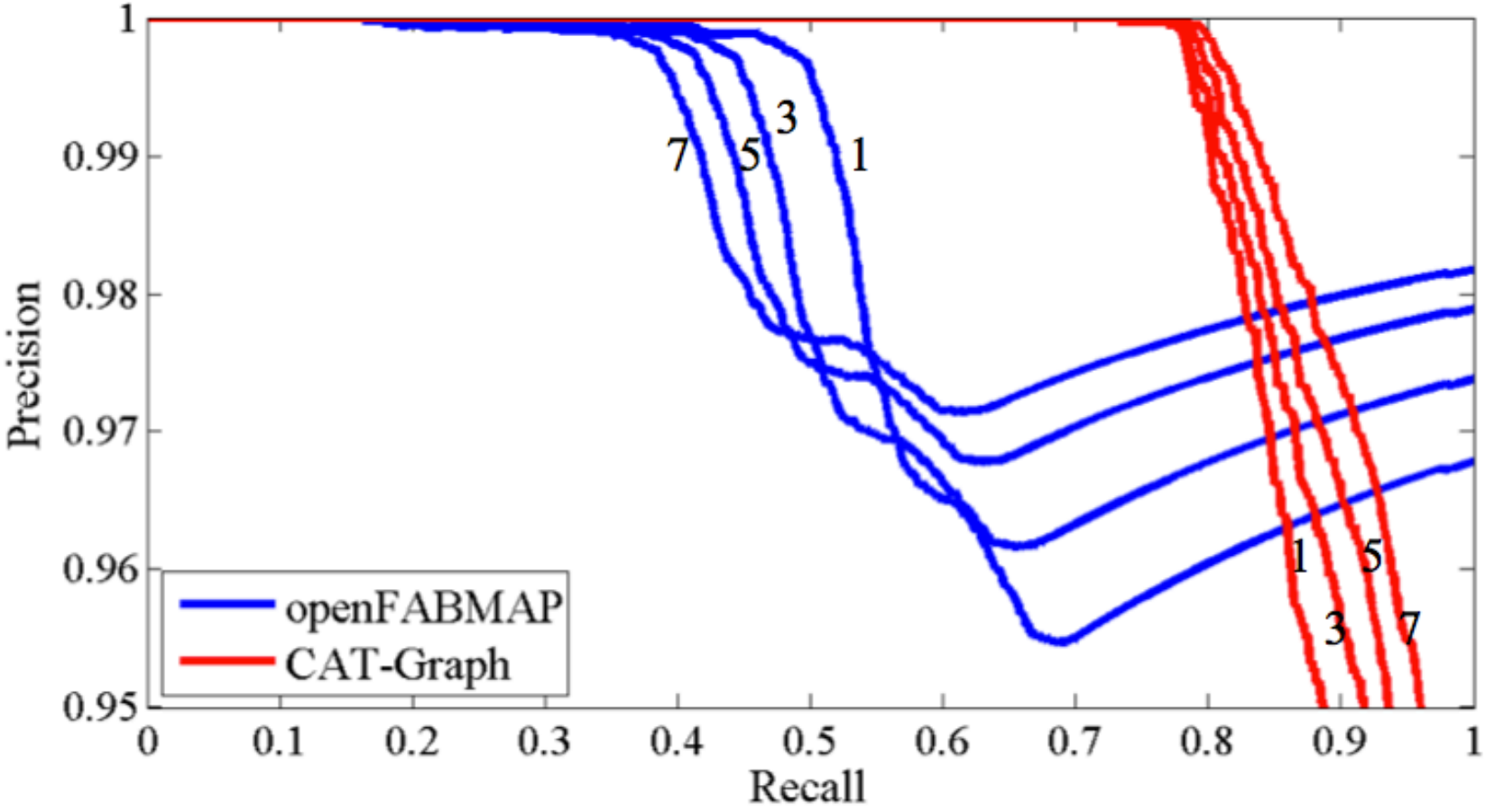


W. Maddern, M. Milford and G. Wyeth, “Towards Persistent Indoor Localisation, Mapping and Navigation with CAT-Graph ” IEEE International Conference on Intelligent Robots and Systems 2012

Results: Precision-Recall



W. Maddern, M. Milford and G. Wyeth, “Towards Persistent Indoor Localisation, Mapping and Navigation with CAT-Graph ” IEEE International Conference on Intelligent Robots and Systems 2012

Conclusions

- Understanding the biological basis of rodent navigation created a highly competent robot navigation system – RatSLAM.
- CAT-SLAM and CAT-Graph are a further evolution of RatSLAM that are more applicable to engineering applications.

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