

Realignment of grid cell activity in continuous attractor models



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Introduction

Nowadays autonomous robotic spatial navigation is a highly active field of research. With the discovery of place cells and grid cells in rats and humans, neuroscientists are starting to disclose the mechanisms underlying spatial representations and navigation in brains. Exploiting grid cell working principles might greatly improve current robotic solutions in terms of robustness (in presence of dynamic environments) and efficiency (to deal with multi-compartment and unstructured environments). However, today's computational models of grid cells are still unable to completely reproduce experimental evidence. As a consequence, their applicability to robotic navigation is still troublesome. In this work we focused on a grid cell model based on continuous attractor networks (CANs) [1] that performs path integration based on velocity information [2]. In absence of an appropriate resetting mechanism, such path integration leads to the accumulation of errors over time due to inevitable noise in the estimation of velocities. In turn, this prevents these models from reproducing stable spatial grid patterns over long periods of time. We are investigating a mechanism based on Hebbian plasticity that applies external sensory signals to stabilize the neural dynamics.

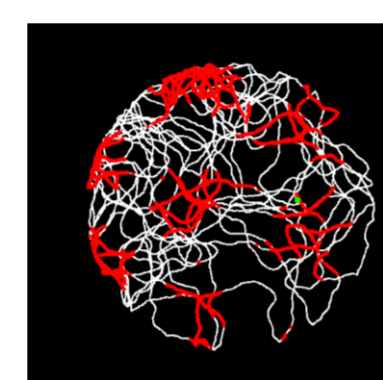
Methods

Continuous attractor models of grid cells

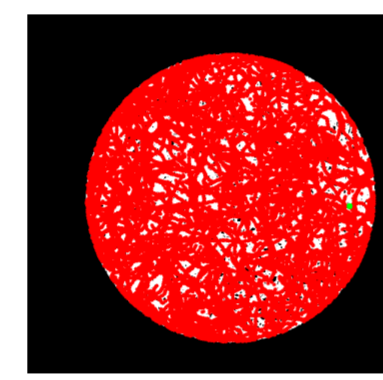
Path integration in CAN models of grid cells depends on the robot velocity estimate $v(t)$ that is in general affected by noise.

$$I_{injected}(t) = I_{baseline} + \alpha v(t) \cos(\vartheta(t) - \vartheta_{preferred})$$

Experiments suggest that grid maps anchor at many locations near salient environmental features. Neuroscientists hypothesize that anchoring based on plasticity may prevent drift due to accumulation of estimate error [3].



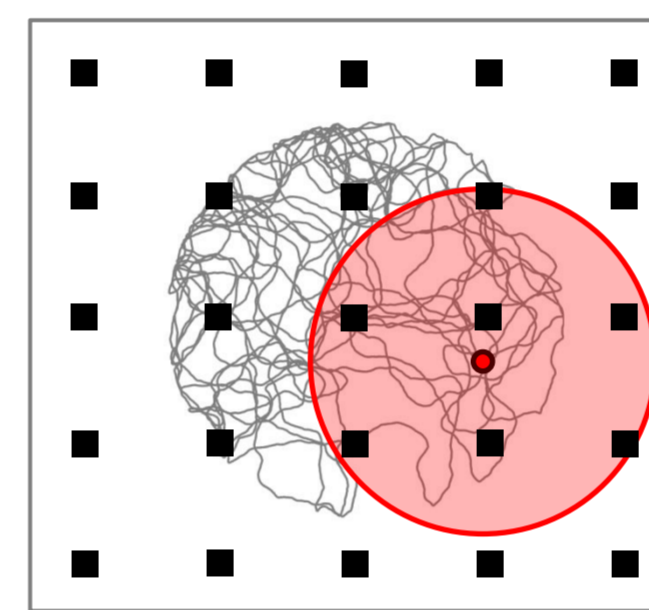
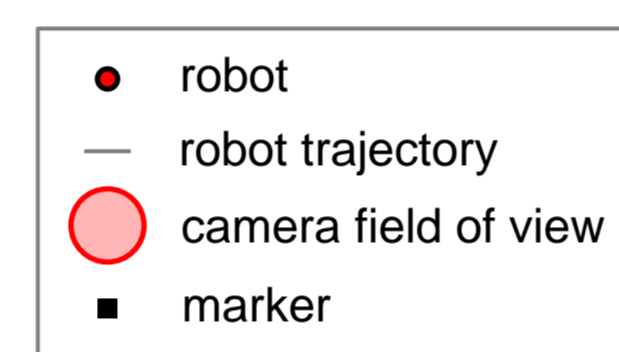
Short trajectory: the grid pattern in space is clearly visible



Long trajectory: the grid pattern in space is not clearly distinguishable anymore due to accumulation of errors

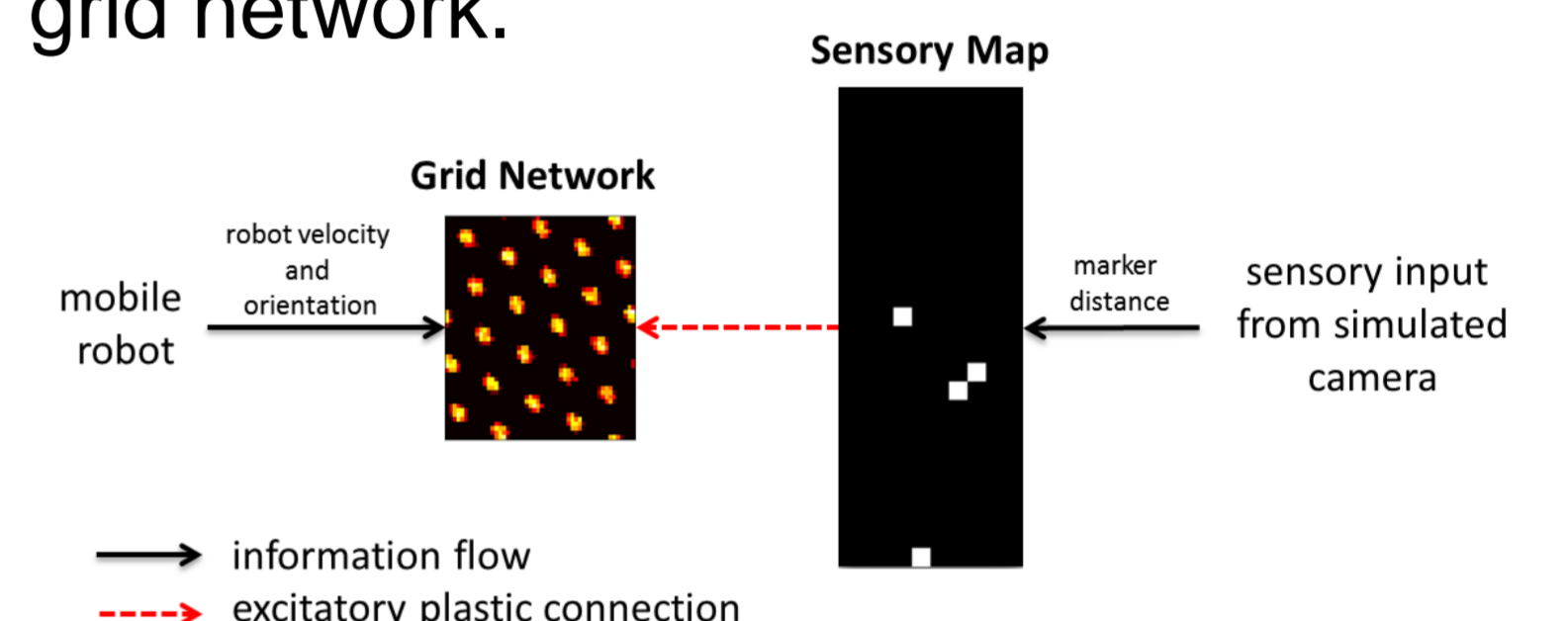
Robotic simulation

We simulated the trajectory of a mobile robot that mimics the random exploration of a rat in a circular arena. A simulated camera on top of the robot records the position of markers on the ceiling.



Odometric error correction

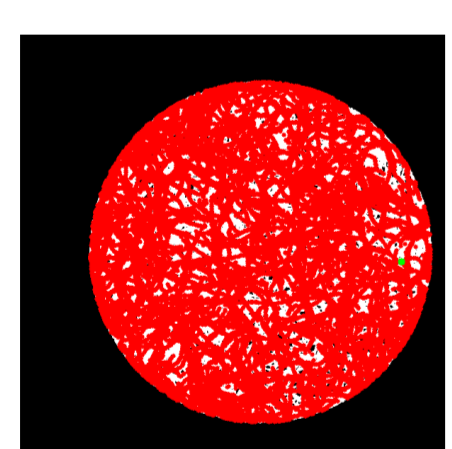
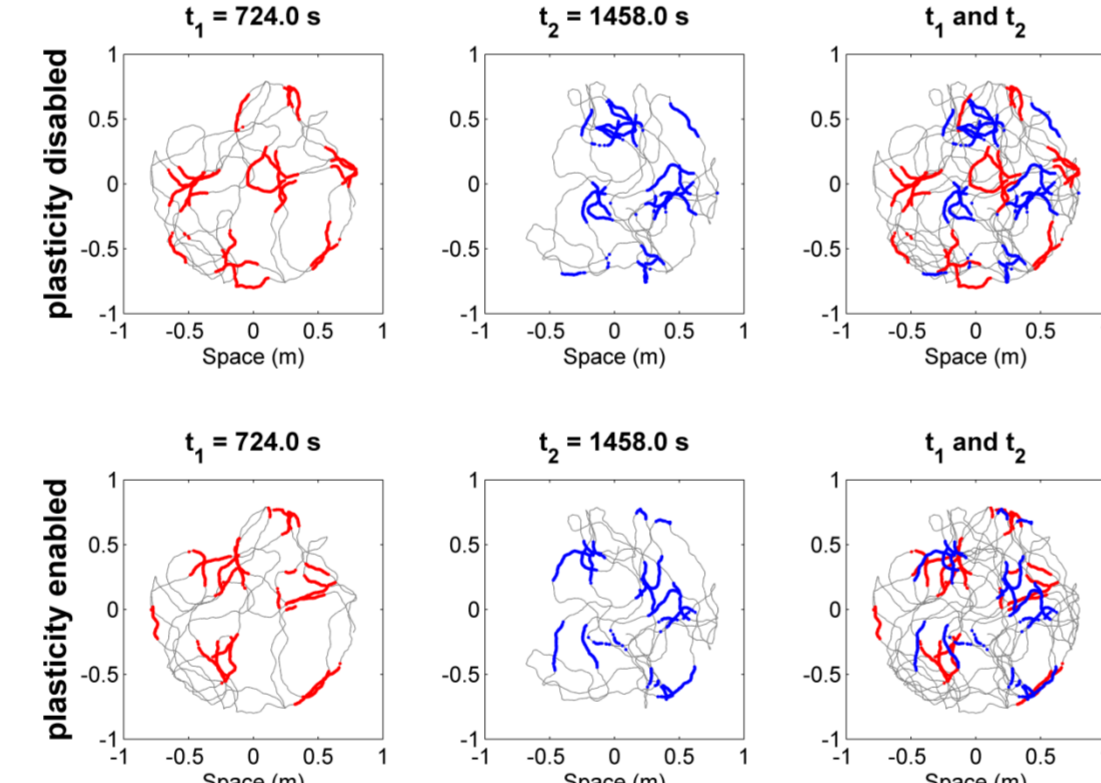
Sensory units encode the relative position of markers with reference to the robot. The stabilization of grid cell activity depends on plastic Hebbian projections from the sensory map to the grid network.



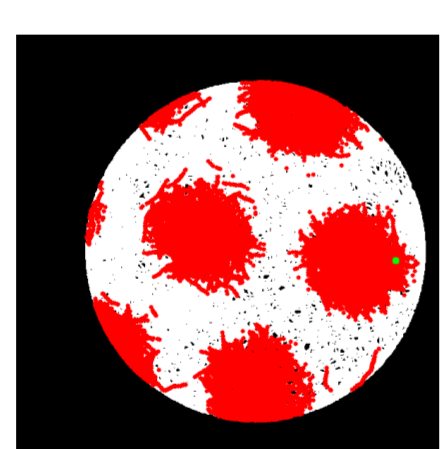
Results

Grid stabilization

In absence of a stabilization mechanism the spatial grid pattern generated by the spiking activity of a grid cell drifts over time. Once the plastic projections are formed, the drift is prevented, resulting in more overlapping spiking activity patterns.



Without Hebbian plasticity

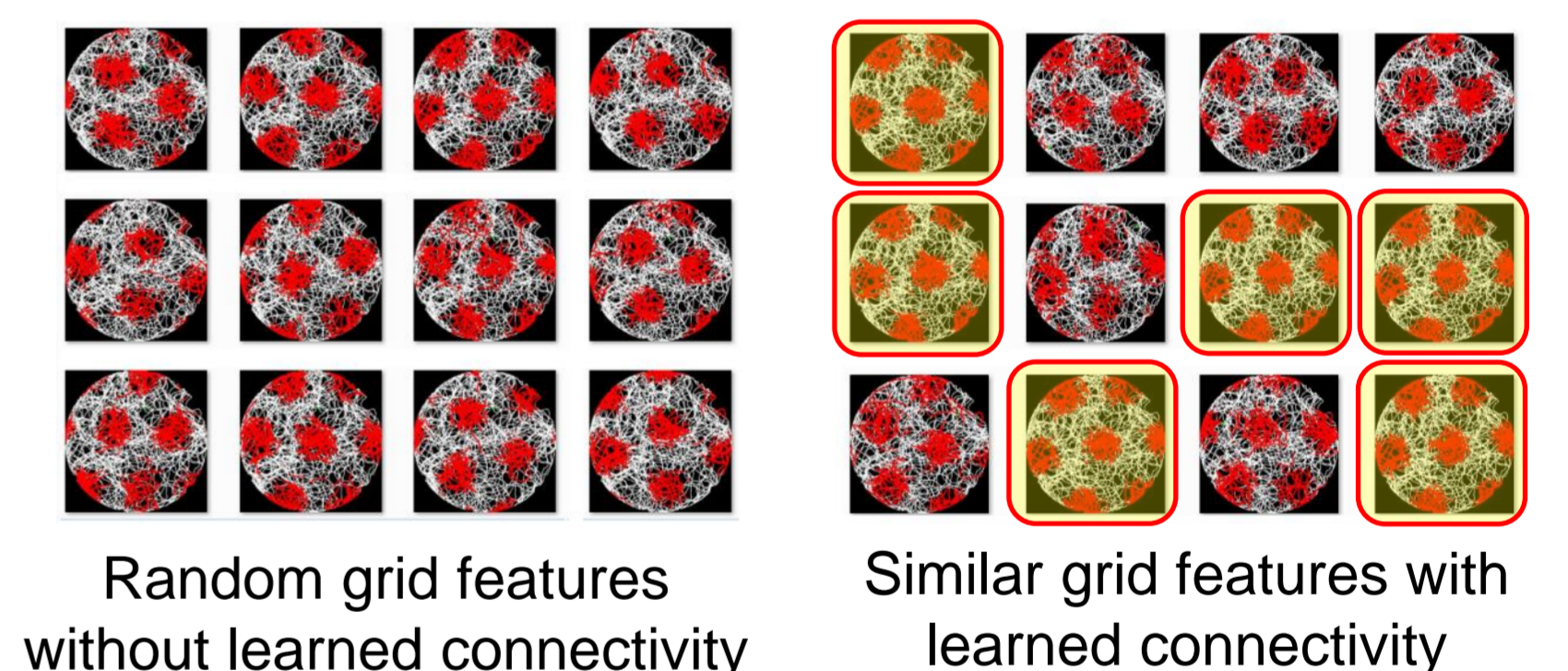


With Hebbian plasticity

The activation of our Hebbian plasticity-based stabilization mechanism successfully anchors the neural activity of grid cells to external sensory cues. This results in a well-defined grid pattern in space over long periods of neural simulation.

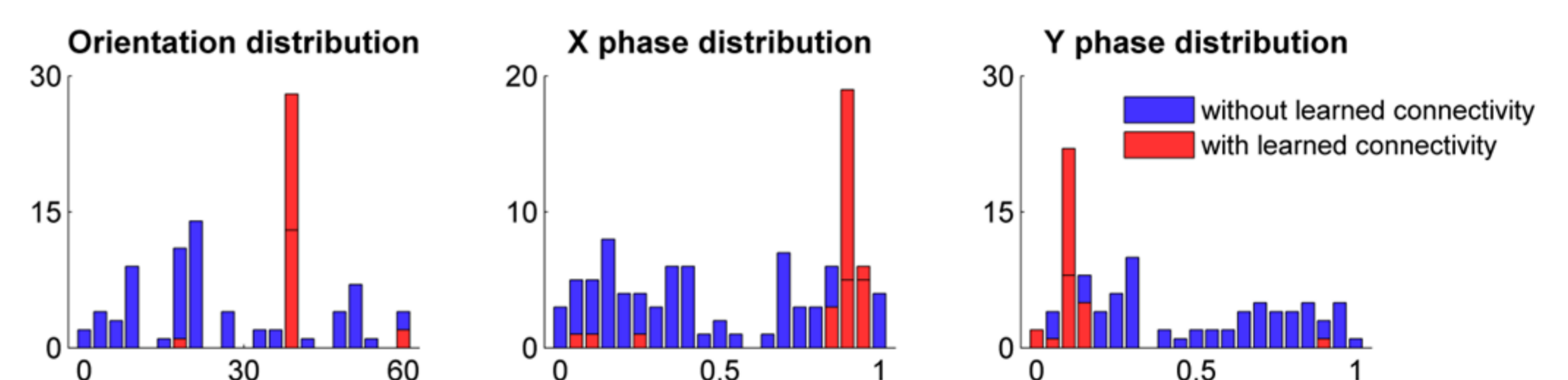
Grid realignment

In good agreement with experimental evidence, simulations that use the same previously learned connectivity show the repetition of grid pattern features such as orientations and phases.



Random grid features without learned connectivity

Similar grid features with learned connectivity



Conclusions and Future Works

In line with neuroscientists' hypothesis [3], our simulation results show that Hebbian plasticity can be used to anchor the spatial pattern generated by grid cells to surrounding landmarks by exploiting the dynamic properties of continuous attractor networks. In the future we will validate our stabilization mechanism on data recorded from a mobile robotic platform. We will test its robustness and reliability when velocity and sensory information are corrupted by real sources of noise.

References

- [1] Couey JJ, Witoelar A, Zhang SJ, Zheng K, Ye J, Dunn B, Czajkowski R, Moser MB, Moser EI, Roudi Y, Witter MP. Recurrent inhibitory circuitry as a mechanism for grid formation. In: Nat Neurosci. 2013 Mar;16(3):318-24.
- [2] Burak, Y. & Fiete, I.R., 2009. Accurate Path Integration in Continuous Attractor Network Models of Grid Cells. *PLoS Computational Biology*, 5(2), p.e1000291
- [3] Moser EI, Roudi Y, Witter MP, Kentros C, Bonhoeffer T, Moser MB., 2014. Grid cells and cortical representation. *Nature Review Neuroscience* 2014 Jul;15(7):466-81.

This work is supported by the EU FET FP7 GRIDMAP project.

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