The Role of Hippocampal Replay in a Computational Model of Path Learning

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1. Introduction

1.1 Previous research has shown that the hippocampus contains cells that code for the spatial position of an animal.
1.2 Hippocampal place cells reactivate during sleep. This reactivation occurs during Sharp Wave Ripple complexes (SPWs). The post-learning pattern of pairwise correlations is similar to what is observed during the task.
1.3 Spike Timing Dependent Plasticity (STDP) is a mechanism of activity-mediated weight change in the hippocampus.
1.4 During a spatial navigation task, place cell population activity can be used to estimate the position of the rat in the environment.
1.5 Few studies have used mobile robots to mimic the behavior of rats or to interact with rats in real-time.
1.6 We build a computational model of place cells in the hippocampus, investigate the nature of cells that replay, and quantify the information content of replayed and non-replayed cells’ activities.

2. Methods

2.1 Sphero
2.1.1 Wireless connection (100 m radius).
2.1.2 Joystick control or autonomous navigation using predefined targets and speeds.
2.1.3 Capable of interacting with rats and replicating their trajectories from a recorded track file.

2.2 Model

2.2.1 Built in NEURON.
2.2.2 Single-compartment cells.
2.2.3 100 place cells, 20 interneurons.
2.2.4 All-to-all connectivity.
2.2.5 Synaptic currents: AMPA and GABA.
2.2.6 Membrane currents: Na+, K+, Ca2+, IK(Ca2+), and calcium dynamics.
2.2.7 Ornstein-Uhlenbeck stochastic process mimicking in vivo-like membrane noise.

2.3 Decoder

2.3.1 Algorithm: Linear Decoder
2.3.2 Requirements:
   - Matrix of firing rates of ensemble of place cells (PFs).
2.3.3 Example:
   - Place cells whose fields overlap with the track and each other are frequently co-active.
   - Correlated activity results in synaptic changes due to STDP.
   - The synaptic matrix becomes sparser with the number of trials.

3. Results

3.1 Sphero and rat movement

3.2 Basic model

3.3 Synaptic modification - single synapse

3.4 Synaptic modification - full network

3.5 Decoder

3.6 Replay

3.7 Decoding from different populations

3.8 Replay depends on path-place field overlap

4. Conclusions

4.1 Sphero can approximate rat spatial trajectories.
4.2 We build a realistic biophysical model of a hippocampal CA1 neural network.
4.3 We implement STDP and show that the connectivity matrix becomes sparser with the number of trials.
4.4 The highest synaptic weights belong to cell pairs whose fields overlap and intersect the learned path.
4.5 We use a linear decoder to reconstruct the path from spike trains.
4.6 After learning, SPWs activate path-relevant place cells.
4.7 Replayed cells produce a better reconstruction of the path than random, non-replayed cells.
4.8 Cells with place fields that highly overlap the path are the most likely to replay.

5. References

6. Acknowledgements