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Dual coding in an auto-associative network model of the hippocampus

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Introduction

The activity of pyramidal cells in the hippocampus has been empirically demonstrated to encode both spatial and non-spatial cues by means of a dual code [1]. The phase of place cell firing with respect to the theta oscillation encodes spatial information: primarily the position of an animal and its current heading [2]. Conversely, firing rate has been demonstrated to encode a variety of non-spatial cues, including running speed, complex visual stimuli and concepts [3-5]. Here we present a novel spiking neural network model which is, to our knowledge, the first to use a dual coding system in order to learn and recall associations between both temporally coded (spatial) and rate-coded (non-spatial) activity patterns.

Methods

The postulated function of the hippocampus in spatial and episodic memory has been widely and successfully modelled using auto-associative networks [6]. Here we use a spiking auto-associative network with a novel STDP rule that replicates a BCM-type dependence of synaptic weight upon mean firing rate. An abstract acetylcholine signal tied to the theta oscillation modulates external input, synaptic currents and synaptic plasticity [7]. Place cell activity consists of a compressed temporal sequence of neural firing within each theta phase. Non-spatial cues, which are present at a subset of the locations traversed, are represented by neural bursting at the peak of the theta phase.

Results

We simulate the network moving along a circular track of 50 place fields with objects present at five equidistant locations. Following learning, we demonstrate that:

1. The external stimulation of any place cell generates the sequential recall of upcoming place fields on the learned route;

2. The external stimulation of any place cell generates the recall of any object that was previously encountered at that place;

3. The external stimulation of cells which encode an object generates recall of both the place at which that object was observed, and the upcoming place fields on the learned route; and

4. The network performs pattern completion, meaning that only a subset of cues is required for this recall activity to be generated.

This model is the first known network instantiation of an asymmetric STDP rule which can mediate both rate and temporal coding. Furthermore, it provides the first demonstration of an auto-associative network that can use this dual code to integrate dynamic and static activity patterns and thus model the disparate mnemonic functions ascribed to the hippocampus.

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