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Network dynamics of encoding and retrieval of behavioural spike sequences during theta and ripples in a CA1 model of the hippocampus

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Spatial memory in the hippocampus is encoded and retrieved by the firing frequency and spike timing of pyramidal cells and inhibitory interneurons during network oscillations. Theta oscillations (4-10 Hz) are observed in rats during exploration and rapid eye movement (REM) sleep, whereas sharp wave-associated ripples (100-200 Hz) are observed during slow-wave sleep (SWS) and consummatory behaviours. Hippocampal theta rhythm has been suggested to contribute to memory formation by separating encoding and retrieval into functional sub-cycles [1]. On the other hand, ripple activity has been demonstrated to structure temporally compressed forward and reverse replay of waking neuronal activity [2-4]. Recent experimental studies have shown that different CA1 excitatory and inhibitory neurons fire at different phases of the theta and ripple rhythms [5-7]. Similarly, medial septal GABAergic neurons differentially phase their activities with respect to theta and ripple [8,9].

We investigate, via computer simulations, the biophysical mechanisms by which storage and recall of behavioural spike sequences are achieved by the CA1 microcircuitry. A model of the CA1 microcircuit [10-12] is extended that uses biophysical representations of the major cell types, including pyramidal (P) cells and five types of inhibitory interneurons: basket (B) cells, axo-axonic (AA) cells, bistratified (BS) cells, IVY cells and oriens lacunosum-moleculare (OLM) cells. Inputs to the network come from the entorhinal cortex (EC), the CA3 Schaffer collaterals and medial septum.

Our model addresses two important issues: (1) How are encoding and replay (forward and reverse) of behavioural place sequences controlled in the CA1 microcircuit during theta and ripples? (2) What roles do the various types of inhibitory interneurons play in these encoding and retrieval processes?

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