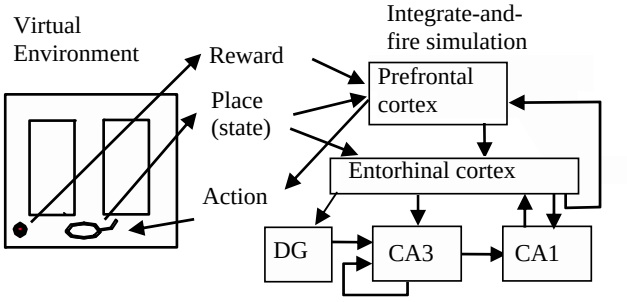
CELEST NUGGET FOR NSF

LEARNING GOAL-DIRECTED NAVIGATION

Humans and animals are very effective at navigating through their environment to find goals such as food or their home, but the neural mechanisms of this navigation are not fully understood. A number of brain regions have been shown to be important in goal-directed navigation, including the prefrontal cortex and hippocampal formation. Research led by Michael Hasselmo and his CELEST colleagues has addressed the circuit level mechanisms which could allow learning of the correct decision for action selection at each state in a behavioral task. This work has focused on simulating performance of spatial memory tasks in rats. The model consists of simulated networks of neurons representing the prefrontal cortex and subregions of the hippocampal formation. These simulations are designed to replicate both behavioral and physiological data. The simulation can guide the movements of a virtual rat in a virtual environment, providing biological mechanisms for techniques used in computer science and robotics research. Initially, the virtual rat explores randomly, but once it finds a food reward this activates a population of neurons in the model's prefrontal cortex which represents the food reward goal, and stays active to guide subsequent behavior. Activity spreads from this reward population through networks of neurons which guide action selection. Different populations of neurons represent distinct sensory input states and distinct motor output actions. Over time, the network has separate phases of encoding and retrieval, which have been shown by several CELEST colleagues to be necessary for effective function in learning tasks. During retrieval, activity spreads from reward states throughout the network. The interaction of this spreading activity with a specific input state directs selection of the next appropriate action. During encoding, strengthening of excitatory connections forms forward and reverse associations between each state, the following action, and a subsequent state, conditional upon the spread of activity from reward during retrieval. Simulations demonstrate how these mechanisms can guide performance in a range of goal-directed tasks, including finding a goal on a linear track, and in an open field, and in a spatial alternation task. In the model, hippocampal circuits encode and retrieve sequences of states as episodic memories. The retrieval of these episodic memories allows performance of tasks such as spatial alternation where the response depends on remembering the response on the previous trial. In addition to simulating behavior, the activity of neurons in the network resembles data obtained by recording with electrodes in these regions while the rat performs these tasks. The network effectively simulates the properties of cells in the hippocampus and prefrontal cortex, including "place cells" which fire only when the rat is in one specific location in the environment, as well as "splitter cells" which fire when the rat is in one place in the environment, but only after it has previously performed specific actions. The network also simulates some of the neuronal responses previously observed in medial prefrontal cortex during performance of spatial memory tasks in rats.



Neural simulation of a virtual rat in a virtual spatial alternation task.
Overview of the neural model that guides actions of a virtual rat in a virtual spatial alternation task.