Spatial Maps and Spatial Navigation

Albert LEE

HHMI Janelia Campus

How do animals know how to get from place A to place B? This problem of spatial navigation requires the following neural representations and computations: (1) A map of the spatial layout of the environment, which is stored in long-term memory. (2) The desired goal location, which is maintained in short-term memory. (3) The animal's current location and (4) the action (e.g. heading) needed to go from the current location to the desired location, both of which must be continuously updated. Furthermore, a new map must be learned for each environment encountered.

The hippocampus has been shown to rapidly learn spatial maps of novel environments (1), and signal the animal's current location (3) via the activity of place cells. We have previously investigated the mechanisms underlying place cell activity and the formation of place cell maps using intracellular recordings in behaving animals. These experiments revealed mechanisms that contrasted with standard views of neuronal integration and the role of plasticity, respectively. We have also studied the structure of place cell maps using extracellular recording and imaging of large populations of hippocampal neurons. Unexpectedly, we found that there is a very large difference among cells in the probability that they display place cell activity, and that cells with very high and low activity probabilities are anatomically distributed in a salt-and-pepper manner. This difference strongly shapes the structure of hippocampal maps and has implications for the encoding, recall, and capacity of hippocampal memory representations in general.

While much is known about place cell maps and the encoding of the animal's current location, little is known about other key aspects of spatial navigation. Namely, it is not known how the desired goal location is specified (2), or how the brain computes the appropriate action to take to reach that goal (4). Because we do not know where in the brain such representations and processes are located, we sought to develop methods to greatly increase the number of neurons whose activity could be monitored during behavior. The result was Neuropixels, a very high-channel-count extracellular recording probe developed and produced by a multi-institute consortium, and now commercially available to the community. We have developed a novel spatial navigation task and have been using Neuropixels to search across multiple brain regions for the representation of spatial goals. We have also been using a range of analysis methods to analyze the resulting population activity for goal and other task-relevant signals.

The combination of task design, large-scale recording, and large-scale data analysis methods should allow for the discovery of these key missing aspects of spatial navigation. It should also allow our group and others to discover the brain-wide interactions underlying an animal’s ability to perform a wide range of tasks and natural behaviors.