

Hippocampal coding of point-free topology

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Rodent hippocampal neurons are generally referred to as “place cells,” a name derived from the fact that each active neuron tends to fire in a restricted region of the animal’s environment. This property has led to the general statement that the rodent hippocampus codes for “space” but it is not clear exactly what is meant by this claim. In particular, space can be thought of in terms of two types of representations: topological (e.g. connectivity of locations) and geometric (e.g. distances and angles). Current theories suggest that the hippocampus explicitly represents geometric elements of space derived from a path integration process that takes into account distances and angles of self motion [1].

We hypothesize that this idea is not correct, and that hippocampus preferentially represents topological as opposed to geometrical information, allowing the animal to understand the connectivity of its environment even if the geometry changes. To test that hypothesis we carried out multielectrode electrophysiological recordings of the cell populations in CA1 hippocampal region in a dynamic environment. The environment consisted of a multi-component U-shaped linear track where each arm of the U could change its geometric shape from a linear to a zig-zag configuration. The shape of each arm was controlled through a stepper motor system, making it possible to sample the neural responses associated with numerous different geometric configurations that shared the same internal topology.

Our preliminary analysis of the resulting patterns of the PF behavior on the dynamic U-track indicate that single neurons tend to be active on the same section of the track despite the displacement of that section from its initial location. In addition, the sequential order of multiple simultaneously recorded place fields is preserved as the track expands and contracts. These initial findings are not compatible with the idea that the hippocampus preferentially represents geometry and thus absolute spatial locations. Instead, they suggest that the hippocampal map emphasizes topological rather than geometric information.

The apparent topological nature of spatial coding in hippocampus suggests a theoretical approach to understanding hippocampal spatial computations. In particular, the paradigm and technical approaches associated with point-free topology and specifically of the Region Connection Calculus [2] and Formal Topology [3] may be adequate for describing the biological principles of space and memory coding in the hippocampal network. Conceptually, these mathematical formalisms allow us to understand how topological spatial maps, as mathematical objects, can arise from the discrete patterns of neuronal activity.

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References

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