

Application of multiple generative models for identifying and decoding spatial memory in the hippocampus

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Generative models have been used to explain observed neural activity in terms of neural representations and the neural computations associated with information processing. The application of generative models has typically sought to identify a single information coding scheme and estimate its parameters. While potentially valid within early sensory systems, the assumption of a single information coding scheme or representation type is unlikely to be completely valid within more classical memory systems.

Neural representations within memory systems are derived from two primary sources, incoming sensory-based information that will potentially be encoded *and* retrieval-based memory information that has been encoded. While the represented class of information is the same, regardless of its source, the dynamics of these representation types may be very different. Indeed, hippocampal representations of space display very different dynamics when driven by sensory information during awake behavior and when driven by previously stored, presumably memory, information during rest and sleep.

We investigated spatial information processing within the rodent hippocampus during navigation by comparing the performance of multiple generative models with explicitly defined different dynamical behaviors. We used a predictive filter-based decoding method to transform hippocampal neural activity, s , into a probabilistic representation over space, x . The iterative decoding algorithm employs a prediction step based on the model of representation dynamics $p(x_t|x_{t-1})$

$$p(x_t|s_{t-1}) = \int p(x_t|x_{t-1})p(x_{t-1}|s_{t-1})dx_{t-1} \quad (1)$$

and a correction step based on the observed spiking activity s_t at time t

$$p(x_t|s_t) = \frac{p(s_t|x_t)p(x_t|s_{t-1})}{p(s_t|s_{t-1})} \quad (2)$$

where $p(x_t|s_t)$ is the probabilistic neural representation of space. Multiple dynamical models $p(x_t|x_{t-1})$ based on Brownian motion with different velocities were compared. For time interval, t , the explanatory power of the of each dynamical model was assessed by finding the probability that decoded neural representation [the posterior distribution of model $p(x_t|s_t) \rightarrow p(\hat{x}_t)$] generated the observed neural activity

$$p_{\mathcal{G}}(s_t) = \sum_x p(s_t|x_t)p(\hat{x}_t) \quad (3)$$

This method detected flexible use of multiple well-organized representation dynamics during awake behavior that often deviated from the animal's position to reflect memory-based processing and included route replay and novel spatial decision-making processes. The use of multiple generative models provided a normative approach to identifying the contributions of experimentally observable sensory processes, experimentally covert cognitive (memory) processes, or other (noise) processes within the hippocampus.

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