Spiking neural network model of simultaneous localization and mapping with Spatial Semantic Pointers

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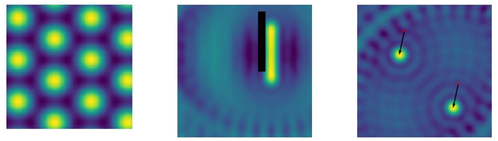
Summary

- Simultaneous localization and mapping (SLAM) is the problem of keeping track of your location while simultaneously creating and updating an internal map of features in the environment.
- Spatial Semantic Pointers (SSPs) are a vector representation of continuous space that can be encoded via neural activity. These spatial representations can be bound with other features, both continuous and discrete, to create compressed structures containing information from multiple domains (e.g. spatial, temporal, visual, conceptual).
- In this work, SSPs are used as the basis for a biological-plausible SLAM model called SSP-SLAM.
- Self-motion driven dynamics of SSPs can be implemented with a hybrid oscillatory interference/ continuous attractor network of grid cells.
- An environment map is learned in the form of an associative memory between landmarks and their positions This map in turn is used to provide corrections to the path integrator.



- Grid cells, boundary cells, and object vector cells are included in this model. Examples of firing rate maps of different neurons in SSP-SLAM are shown above.

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Spatial Semantic Pointers

A Spatial Semantic Pointer (SSP) representing coordinates (x, y) in two dimensional space is given by

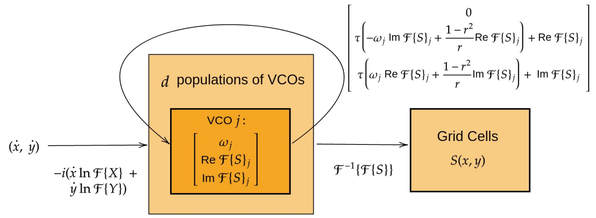
$$S(x, y) = X^x \circledast Y^y$$

$$X^x = \mathcal{F}^{-1}\{\mathcal{F}\{X\}^x\},\ Y^y = \mathcal{F}^{-1}\{\mathcal{F}\{Y\}^y\}$$

In SSP-SLAM, SSPs are used to encode an animal's estimation of its own location. The derivative of an SSP is itself bound with vectors weighted by the animal's velocity,

$$\dot{S}(x(t), y(t)) = S(x(t), y(t)) \circledast \left(\dot{x}(t)\mathcal{F}^{-1}\{\ln \mathcal{F}\{X\}\} + \dot{y}(t)\mathcal{F}^{-1}\{\ln \mathcal{F}\{Y\}\}\right)$$

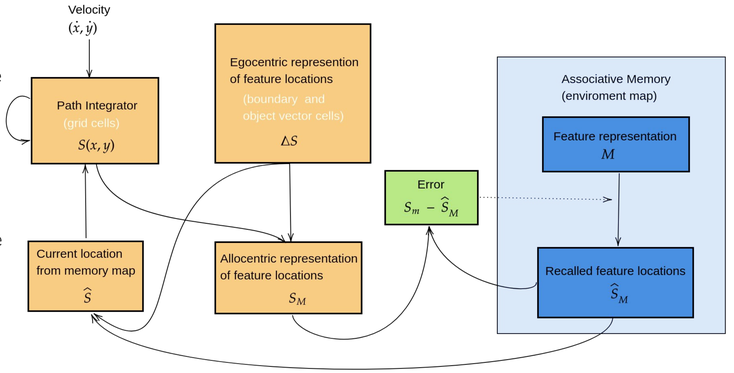
Path Integrator



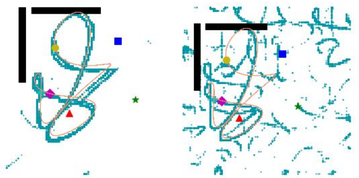
- A set of recurrently connected neural populations are used to represent the components of the self-position SSP in the Fourier domain.
- Each population is an oscillator whose frequency is modulated by the animal's velocity -- e.g. a velocity controlled oscillator (VCO)
- We substitute the dynamics of a nonlinear oscillator with a stable limit cycle.
- Considering the set of VCOs as a whole, the system has a toroidal attractor, making this a hybrid of oscillator-inference and continuous attractor models of path integration.
- The neural population of oscillators is connected to a population of grid cells to recover the SSP in the time domain.

SSP-SLAM

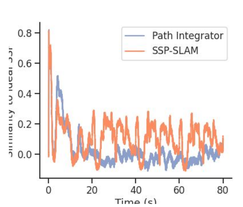
- Sensory systems provide input in the form of an SSP representation of the vector between features in view and the agent
- The neurons in the population representing this SSP will have activity patterns like those of boundary and object vector cells.
- The output of the path integrator and that population are used to compute the features' locations in space.
- That estimate to used to train an associative memory network. It represents an environment map.
- The map is used to compute an estimate the agent's current position. This provides error correction to the path integrator.

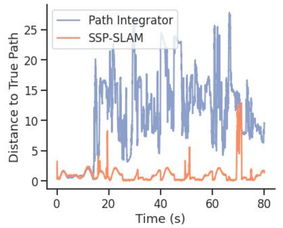


Results



An example path and environment consisting of walls and landmarks (the symbols in the plots). The position of the SSP most similar to the vector represented by the grid cell population at every timestep is plotted in blue.
(Right) Results using just the path integrator
(Left) Results using the full SSP-SLAM model.





(Right) The similarity (dot product) of the vector represented by the grid cell population to the SSP representing the true position at every time-step
(Left) The distance between the true path and the location the network is closest to representing