

A Spiking Neural Network (SNN) Structure for State Machine Execution, Sequential Retrieval, and Online Learning

Xinyun Sheryl Zhang⁽¹⁾, Chiara De Luca⁽²⁾, Giacomo Indiveri⁽²⁾, Leonardo Martinelli⁽²⁾

⁽¹⁾Technical University of Munich, ⁽²⁾Institute of Neuroinformatics, University of Zurich and ETH Zurich

The neural state machine (NSM) implemented with a spiking neural network (SNN) provides a state-dependent, context-driven computational framework suitable for neuromorphic hardware. Prior work has shown that NSMs incorporating a dis-inhibition mechanism operate robustly under hardware and input noise.¹ The architecture consists of multiple recurrently connected neural populations forming a winner-take-all network, along with dedicated transition population responsible for each possible state change. The dis-inhibition mechanism enables selective activation of transition populations, ensuring reliable state transitions despite noise.

Here, we investigate whether this same NSM architecture can also support other brain-like functions that also relies on attractor dynamics, especially sequential memory retrieval and online incorporation of new memory items. We demonstrate that both functions emerge when uniform input is applied non-selectively to all transition populations, rather than selectively driving individual transitions as in conventional state machines.

When suprathreshold noise is delivered uniformly across transition neurons, dis-inhibition enables the network to select the next state conditioned on the currently active state, resulting in automated sequential retrieval of stored states. Within a defined noise range, propagation speed increases monotonically with noise amplitude; dwell time expectation and variation monotonically decrease. More specifically, we observe different regimes for the stochasticity of state propagation. When the unbiased noise stimuli drive target neurons to an activity level near the basin of attraction of its high-activity attractor, a successful transition can be interpreted as a random event; thus the dwell time at each state is largely stochastic. When the unbiased noise stimuli drive target neurons activities consistently within the basin of attraction, each state transition is almost always successful; thus the dwell time at each state is more repeatable, showing an approximately periodic state propagation behavior.

Alternatively, with subthreshold uniform noise input, state propagation does not occur; instead, when seeing external stimuli, the system autonomously detects novel unlearned transitions. This regime potentially supports online learning of new states and transitions through neural plasticity.

Together, these results suggest a generic NSM framework for various brain-like functions. When driven into different regimes, it can carry out state-dependent execution, sequential memory retrieval, and online learning.

1. D. Liang and G. Indiveri, "Robust state-dependent computation in neuromorphic electronic systems," 2017 IEEE Biomedical Circuits and Systems Conference (BioCAS), 2017