Late breaking news:
Distributed Neural State Machines on Loihi 2

April 24 I Alpha Renner I NICE Conference 2024
New preprint


https://arxiv.org/abs/2405.01305
Motivation for stable attractors in RSNN

- Robust state transitions for decision making
- Context dependent routing and control flow
- Motor planning and execution

→ Training RSNNs to achieve stable dynamics on arbitrary time-scales is non-trivial
Intuition: State machine

Input: “a”
Distributed neural state machines

More **robust**, **flexible** and **scalable**

Store nodes and transitions in an associative memory rather than using distinct populations.

→ Connection terms are programmed in a Hebbian way
→ Nodes are auto-associative, state transitions are hetero-associative
→ Transitions are “protected” and only activated when an inhibitory input acts on the network
Distributed neural state machines inspired by HDC

Encoding and connectivity is inspired by Hyperdimensional Computing (HDC). HDC was proposed as a framework for computation on neuromorphic hardware.

→ Provides an abstraction layer or “instruction set” of a few operations that allows universal computation.

Intuition: State encoding

Nodes/states are encoded as sparse activation patterns in a block-structured vector

\[
\tilde{x}_v = \begin{bmatrix}
0 \\
0 \\
1 \\
0 \\
1 \\
0 \\
0 \\
0 \\
0 \\
\vdots
\end{bmatrix}
\]

Block 1

Block 2
Intuition: State encoding

Nodes/states are encoded as sparse activation patterns in a block-structured vector.
Intuition: Connectivity

Each block only allows one active neuron (WTA)
Intuition: Connectivity

Each state is a stable fixed point attractor.

→ Hopfield-like auto-associative connectivity

Hebbian outer-product weights: “Neurons that fire together wire together”
Asymmetric connections for state transitions are present, but have no effect due to the WTA.
Intuition: Connectivity

Block-wise masking removes the effect of a subset of connections that favor the status quo.
Intuition: Connectivity

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Intuition: Connectivity

Block-wise masking removes the effect of a subset of connections that favor the status quo.

→ Network transitions to transitory “bridge” state

When the input is removed, the network transitions to the stable state.
Results on Loihi 2

State machine with 23 states
Computes “x mod 23”
1024 neurons, 8 neurons per block

Using Loihi2’s custom neuron microcode.

100% reliable if the network is large enough
Arbitrary timing and length of input signals

a) Inputs: 1 0 0 0 0 1 0 0

b) Neuron index

<table>
<thead>
<tr>
<th>Neuron index</th>
<th>63</th>
<th>57</th>
<th>51</th>
<th>45</th>
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c) Neuron index

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d) Spike rate (Hz)

| Spike rate (Hz) | q0 | b1 | q1 | b2 | b4 | q4 | b8 | q8 | b17 | q17 | b11 | b22 | q22 |
|-----------------|----|----|----|----|----|----|----|----|-----|-----|-----|-----|-----|-----|
|                 | 0  | 1000 | 2000 | 3000 | 4000 | 5000 | 6000 | 7000 | 8000 |

Time (ms)
Discussion and future work

- Robust to mismatch, noise and neuron failures
  → suitable for implementation on analog and memristive hardware
    (shown in simulation and on RRAM device in the preprint)
- States and transitions are added in a Hebbian way, no need to add neurons or restructure the network
- Can be used to coordinate information flow in complex neuromorphic algorithms
- Can be generalized to other than fixed point attractors → continuous manifolds
Thank you!

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Neural state machines on hardware

Papers

https://arxiv.org/abs/2405.01305

https://doi.org/10.1162/neco_a_01638