Spatio-Temporal Signals Processing in Polychronizing Spiking Neural Networks

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The Importance of Spike Timing

Structure in network connectivity drives spike-timing patterns

Simple network with timing-dependent connectivity

Suboptimal activation of neurons x, y

Optimal activation of neuron x

Optimal activation of neuron y
Spatio-Temporal Encoding in Spiking Neural Networks

Spatio-temporal characterization:
- Spatial component (which neuron spiked)
- Temporal component (when that neuron spiked)
- Common of real-world signals (e.g. speech, video, etc.)

In a spiking neural network:
- Self-organization driven by spiking activity, network structure, synaptic plasticity
- Associative processing of signals onto a (reproducible) spatio-temporal encoding
- Inherently distributed representation (scalable w.r.t. neuromorphic hardware)
Polychronous Neural Groups (PNGs)

Some definitions and terminology:
- **Polychronous** means many times, and is characterized by time-locked spiking activity
- **Polychronization** is the self-organization of a spiking neural network that yields PNGs
- **Polychronizing** describes networks that exhibit polychronization

Acquiring PNGs:
- From *Primary Repertoire*
  - Potential groups that are structurally supported
- To *Secondary Repertoire*
  - Activity dependent
  - Forward assembly + Backward selection

Graphical representation of PNG
Learning Experiments

Demonstrating a spatio-temporal encoding via polychronization in a toy network

- **Step 1:** Transform signals to spatio-temporal (spiking) domain (e.g. TIMIT speech)
- **Step 2:** Feed spikes into network model with plasticity (e.g. STDP)
- **Step 3:** Correlate PNG activations to classes during training
- **Step 4:** Use PNG activations to estimate classes during testing

<table>
<thead>
<tr>
<th>Signal/Class</th>
<th>Accuracy</th>
</tr>
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<tbody>
<tr>
<td>Phonemes</td>
<td>26.4%</td>
</tr>
<tr>
<td>Phonetic Categories</td>
<td>47.1%</td>
</tr>
<tr>
<td>Handwritten Digits</td>
<td>41.9%</td>
</tr>
</tbody>
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Conclusions and Future Work

Demonstration of learning as result of polychronization
- Spatio-temporal signals encoded as time-locked patterns of spiking activity
- Flexible with respect to multiple modalities (as long as in spatio-temporal domain)
- Nowhere near state-of-the-art classification accuracy (but toy network with no tuning)

Paths to improvement
- Better spiking neural network models (possibly structural plasticity)
- Processing hierarchy (abstraction, lateral and feedback connections)
- Tooling/support for more collective operations on spiking activity