Quantifying Changes in Relationships Between V4 Neurons During Perceptual Learning

Joseph Young1, Valentin Dragoi2, Behnam Aazhang1
1 Department of Electrical and Computer Engineering, Rice University, Houston, USA
2 Department of Neurobiology and Anatomy, The University of Texas Medical School at Houston, Houston, USA

Research Objective
Quantify changes in neuronal relationships by use of information theory to understand physiology of visual task learning in V4. Specific tools interested in using:
- Directed Information
- Mutual Information as a function of frequency

Background on Perceptual Learning
Practice-based improvement at a task involving senses
- Occurs with repeated trials of task
- Task used in this project:
  - Identify if image rotated
  - Visual cortical area V4 sensitive to such rotation

Background on Visual Cortical Area V4
V4: Mid-layer region in visual cortex
- Object recognition
- Neuronal sensitivity to orientation

Perceptual Learning in Primates
1990s Focus on Single Neurons
- Learning thought to involve modifications in the brain on the order of single cells and single synapses
- No support - network more promising

New Tech Allows Ensemble Recording - Network Analysis
- UTHSC found local neuronal synchronization in Rhesus monkey V4 during task learning
- We further analyze this same data set by estimating directed information (DI) between neurons to quantify relational changes between neurons

Experimental Setup - Visual Task Learned
Rhesus Monkeys Performed Numerous Trials of Rotation Recognition Task:

<table>
<thead>
<tr>
<th>Time</th>
<th>Fixation</th>
<th>Target</th>
<th>…</th>
<th>Test</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>500 ms</td>
<td>300 ms</td>
<td>1000 ms</td>
<td>300 ms</td>
<td>1500 ms</td>
</tr>
</tbody>
</table>

Rotated or not?

Decision: monkey must release a bar by the end of the period if the test image is a rotated version of the target image. Correct decision results in juice for the monkey.

Preliminary Results Show Changes in Information Flow During Learning

<table>
<thead>
<tr>
<th>Trial</th>
<th>DI Rate Between Neurons Over Trials</th>
<th>DI Rate Between Neurons Over Trials After Break</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Algorithm: Context-Tree Weighting (CTW)
Universal Estimation of Directed Information
- Feed sequences of neuronal spikes into the context-tree weighting (CTW) algorithm

CTW
- M-ary tree of depth D with weights
- Provides probability estimates to plug into directed information equations (quantifying causal relations)

Procedure:
- Slide D-length window across an input sequence of finite-alphabet size M
- Match window with context of a bottom level node (e.g. “01”) then update parameters based on the next symbol after the window

Example context-tree for D=2

References
2. Watanabe, S., Hasegawa, T., Sato, T., & Takeda, H. Rates of directed information in visual cortices during learning. 2015.

Future Work:
- Previous work found local neuronal synchronization in theta band using spike-field coherence (SFC)
- Mutual information as a function of frequency could reveal higher order relations / nonlinearities
- Develop temporal network model that describes the time course of learning in the visual cortex
- Stimulate population areas to improve learning