Dynamic Routing Model for Visuospatial Attention

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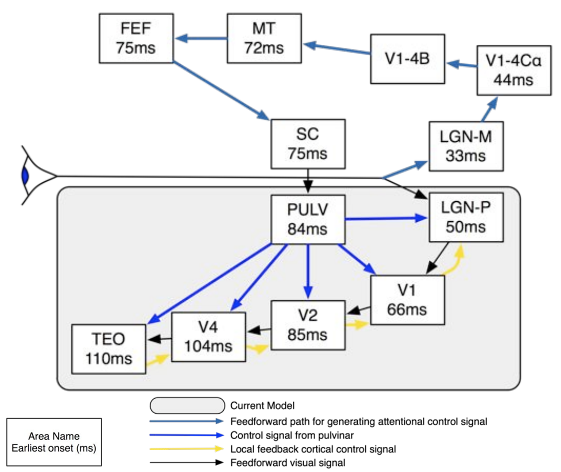
Introduction

- Existing models of visuospatial attention typically deal with determining where to direct attention [1]

  With this location selected, how does attention affect the processing of visual information through cortex?

- Problems with existing models:
  - Lack details of neuronal representations, transformations and dynamics
  - Weight matrices are recomputed for each focus of attention
  - Implausible number of pulvinar neurons (e.g. [2])

Neurobiological Substrate

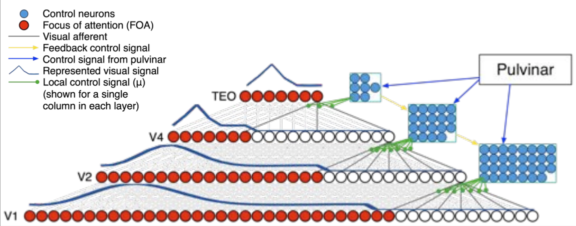


Empirical Observations

- Stronger and earlier attentional modulation in higher cortical areas
- Stimuli surrounding the FOA are suppressed
- A cell's response is primarily driven by the attended stimulus in its RF
- Patients with pulvinar lesions exhibit localization deficits and more often report illusionary conjunctions

Model Architecture

- Layers composed of neuronal columns with similar receptive fields
  - Columns contain control neurons that signal where to sample within the receptive field
- Object-centred reference frame in top most layer
- At each layer, minimize the loss of information from the FOA



Deriving Attentional Control Signals

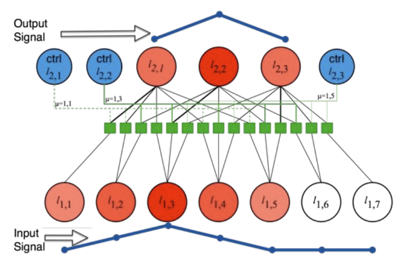
- The pulvinar projects to control neurons in each layer, a signal indicating the FOA's location
- Starting at the top layer (l), control neurons determine the size of the FOA in layer l-1:

$$size_{l-1} = \begin{cases} maxRF_l & if \quad size_1 > maxRF_l \\ size_1 & otherwise \end{cases}$$

- Control neurons determine spatial sampling frequency to resize the FOA for layer l:

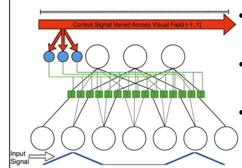
$$sf = \frac{(size_{l-1}) - 1}{(size_l) - 1}$$

- The i^{th} control neuron determines the location ($\mu_{i,l}$) within its RF from which to sample visual information: $\mu_{i,l} = pos_{l-1} + (i - pos_l) \times sf$
- Feedforward signals $x_{j,l-1}$ and control signals $\mu_{i,l}$ project to intermediate neurons which compute the function: $f(\mu_{i,l}, x_{j,l-1}) = \exp^{-(\mu_{i,l} - x_{j,l-1})^2 / 2\sigma^2}$



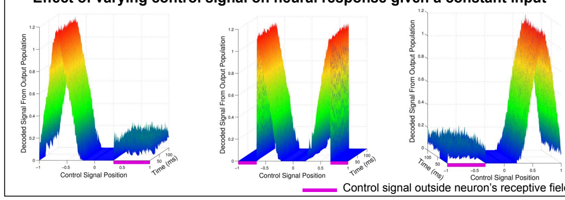
Neural Implementation

- Implemented using the Neural Engineering Framework [3]
- 7 input and 3 output columns – 150 LIF neurons per population
- Intermediate neurons compute a non-linear combination of control and feedforward visual signals



- Input held constant while control signal (μ) is varied across output column's RF
- Control signal indicates where to sample within column's RF
- When control signal is outside of neuron's RF, default routing is used (i.e. entire visual field is resampled at each layer)

Effect of varying control signal on neural response given a constant input



Results

- Detailed spiking LIF implementation of attentional routing
- Requires a plausible number of pulvinar neurons
- Static synaptic weights and low dimensional control signal
- Consistent with timing of attentional modulation of neural activity
- Scales well (tested up to 40,000 neurons)
- Accounts for empirical observations

Predictions

- Case 1 – Linear dendrites
  - Intermediate cortical neurons that are responsive to both cortical afferents and indirect pulvinar signals
  - Non-linear dendrites are not required, however intermediate neurons are required
- Case 2 – Non-linear dendrites
  - Far fewer neurons would be needed
- In either case, cortical neurons in lamina 4 receiving direct pulvinar projections need not be sensitive to visual stimuli

[1] Shipp, S – Trends Cogn Sci, 8(5), 223-230 (2004)
[2] Olshausen et al.– J Comp Neurosci, 2, 45-62 (1995)
[3] Eliasmith and Anderson – Neural Engineering – MIT press (2003)