Control of Attention

We saw that responses of visual neurons are controlled by selective attention. This leads to two questions:

- How is this control accomplished?
- Where do the control signals come from?

Two types of models:

- Input Gating: the inputs to a cell are modulated by attention control signals.
- Cell Gating: the output of a cell, or the overall operation of the cell, is modulated by attention control signals.

Input Gating

Attentional signals inhibit inputs to a cell coming from cells having receptive fields in the non-attended area.

For example, suppose a neuron in V4 receives input from neurons in V2. The receptive field of the V4 neuron is the union of the receptive field of these V2 neurons.

Input gating operates by inhibiting the inputs to the V4 neuron except for a small number of neurons whose receptive fields are in the attentional "spotlight".

Desimone's model of input gating proposes that attentional control signals excite an intermediary neuron which has a small receptive field. The output of this neuron inhibits or blocks (perhaps by "shunting" inhibition) just those inputs from V2 neurons whose receptive fields lie outside that of the intermediary neuron.

Attentional control of this kind appears to shrink a cell's receptive field to that of the intermediary cell.

The Desimone input gating model does not specify the location of the intermediary cells, nor that it be an individual neuron as opposed to an assembly of neurons that collectively accomplish the same function.

The small receptive field of the intermediary cell could arise from the intersection of an ensemble of neurons with larger receptive fields.

Cell Gating

Attentional signals modulate the output of a neuron.

The Desimone cell gating model assumes that neighboring cells laterally inhibit each other. This leads to a competitive interaction between cells with both contrasting stimulus sennsitivities and overlapping receptive fields in V4.

For example, consider red and green stimuli presented close together. The red stimulus will activate red-sensitive cells in V4 and the green stimulus will excite green-sensitive cells. These cells' activity will try to inhibit each other.

In the absence of attention, neither type of cell has an advantage over the other. The role of attention, in the cell-gating model, is to $bias$, this competition so that one type of cell wins.

The "spotlight" of attention enhances the responsiveness of all V4 neurons whose receptive fields include the attended location.

Another possibility is that the attentional signal increases the strength of the inhibitory acitivity of cells whose receptive field includes the attended location.

If a red stimulus happens to fall within the attended location, then red-sensitive neurons whose receptive fields include the attended location will be potentiated, and other types of feature-sensitive neurons will be suppressed.

V4 Receptive fields do not shrink in this model

Anatomically, cell-gating is simpler than input-gating, as extra neurons are not required (such as the intermediary neurons in the input-gating model).

Attentional Control via Correlation

(Niebur, E. and Koch, C., 1994, "A model for the neuronal implementation of selective visual attention based on temporal correlation among neurons", *Journal of Computational Neuroscience*, Vol. 1, pp 141-158)

Crick and Koch proposed a theory of perception that is based on the idea that it is the temporal correlation of activity within an ensemble of neurons, across different cortical and sub-cortical areas, that produces a unitary percept.

There is some evidence, albeit controversial, for this theory. For example, 40 Hz oscillations detected in various brain structures have been hypothesized as arising from synchronized or correlated firing of groups of neurons.

Crick and Koch hypothesize that selective visual attention manifests at the single cell level by *temporal tagging*. This means that attention modulates the neuron's firing pattern so as to be correlated with the activity of a number of other neurons.

Neurons that are not attended to have firing patterns that are de-correlated with the patterns produced by other neurons.

Niebur and Koch describe a cell-gating type of attentional model which is based on the Crick-Koch idea.

As in the Desimone cell-gating model, competition between cells in V4 is biased in favor of cells representing attended stimuli. in the Neibur-Koch model this is done by using modifying the neuron firing patterns of the neurons that feed into the V4 neuron (i.e. V2 neurons).

The attentional modulation (from a saliency map) influences the timing of neural spikes so that V2 neurons within the attentional spotlight tend to fire together (within a few milliseconds) than do neurons outside the attentional focus.

This influence is such that the average firing rate is not changed, just the firing pattern.

At the level of V4 this correlation improves the efficiency of the correlated neurons in inhibiting the uncorrelated ones.

In the Neibur-Koch model, the influence over the firing pattern is implemented by transiently increasing the probability that a neuron will fire (for example, by releasing a spurt of some neuromodulatory substance at random times).