Low-Level Vision (Biological)

1. List the range of image properties to which V1 cells show selectivity.

- *colour*
- *orientation*
- *direction of motion*
- *spatial frequency*
- *eye of origin*
- *binocular disparity*
- *position*

2. What is a hyper-column?

A hyper-column is a region of V1 that contains neurons covering the full range of RF types for a single spatial location.

3. Briefly describe the stimulus selectivities of simple and complex cells in V1.

Simple cell: optimum response to an appropriately oriented stimulus, of the right contrast polarity, placed at certain position within the receptive field.

Complex cell: optimum response to an appropriately oriented stimulus, with any contrast polarity, placed anywhere within the receptive field.

4. Describe the receptive field structure of (a) a simple cell, and (b) a complex cell and explain how these inputs give rise to the observed response properties.

Simple cell: input is from a number of centre-surround cells which have RFs on a common line.

Complex cell: input is from a number of simple cells which have RFs that are parallel to each other.

5. Describe how simple cell RFs could be modelled using convolution.

A simple cell RF can be well described by a Gabor function.

Convolving the image with a Gabor mask will simulate the response of all simple cells selective for the same parameters across all hyper-columns.

Repeating the convolution with Gabor masks with different parameters (e.g. orientation, spatial frequency, phase, aspect ratio) will simulate the responses of all different types of V1 simple cell.

6. Describe how complex cell RFs could be modelled using convolution.

A complex cell can be modelled by combining the outputs of two or more simple cells.

For example, the response from a quadrature pair of Gabor functions (two Gabors with a phase difference of $\pi/2$) can be used as input to a model of a complex cell. These inputs need to be combined by taking the square-root of the sum of the squares of the two inputs.

Alternatively, the half-wave rectified response from four Gabor functions differing in phase by $\pi/2$ can be used as input to a model of a complex cell. These inputs are combined by taking the maximum, or by taking the sum.

Hence, complex cell responses can be modelled by performing multiple convolutions with different Gabor masks to simulate simple cell responses (as described in the answer to the previous question), and subsequently combining (as described above) those responses for Gabor masks with identical parameters except with different phases.

7. Gabors functions are the components of natural images under the "sparsity" constraint. What is the sparsity constraint and how is this relevant to efficient coding?

The sparsity constraint requires that the minimum number of components are present in each image.

Hence, by using Gabors as the components by which an image is represented, an image can be coded accurately and efficiently (with a minimum number of active components).

8. Briefly describe what is meant by the classical receptive field and the non-classical receptive field.

Classical Receptive Field (cRF) = the region of visual space / the stimulus properties that can elicit a response from a neuron.

Non-classical Receptive Field (ncRF) = the region of visual space / the stimulus properties that can modulate the response from a neuron, but not generate a response from the neuron in the absence of input to the cRF.

9. What is an "association field". Describe the association field for a V1 cell with an orientation preference.

An association field is the pattern of long-range lateral connections received by a neuron.

A V1 neuron with an cRF selective for a particular orientation will receive lateral excitation from neighbouring V1 cells with similar orientation preferences that are aligned so that they are collinear or co-circular with it. It will receive lateral inhibition from neighbouring V1 cells with similar orientation preferences that are approximately parallel to it.

10. How do lateral connections in V1 give rise to (a) contour integration, (b) pop-out, (c) texture segmentation?

(a) contour integration is generated principally by lateral excitation between cells with nearly co-linear/co-circular orientation preferences. These cells enhance each others response, and hence, make linear or circular contours more visible.

(b) pop-out is generated principally by lateral inhibition between cells with similar preferences. These cells suppress each others response making cells responding to different image features relatively more active, and hence, dissimilar stimuli more visible.

(c) texture segmentation is generated principally by lateral inhibition between cells with similar preferences. Hence, cells responding to features within a uniform region of texture suppress each others response. However, cells on the border between different textures only receive inhibition from one side, giving these cells a relatively higher response, and hence, making the border more visible.