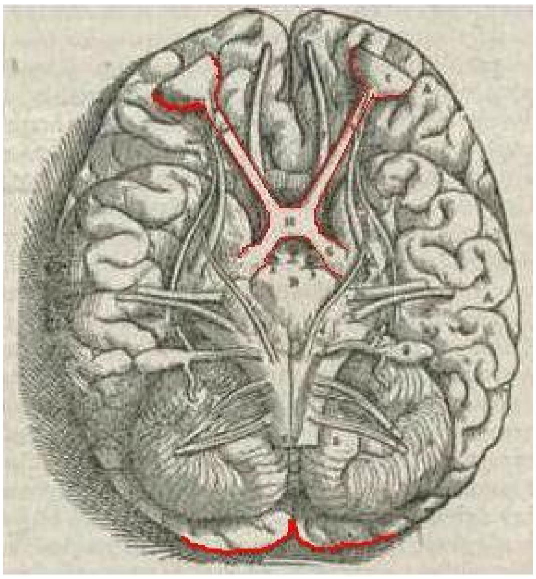


Figure 1: The visual pathway. This is an old drawing due to the C16 Belgian anatomist Andreas Vesalius taken from his influential 1543 textbook *De Humani Corporis Fabrica*. In red are marked the retina, the optic nerves, the thalamus where they cross and the primary visual cortex. [Image from Wikipedia].

Vision

Introduction

This lecture is about vision, when they are complete they will discuss how simple cells in V1 are modelled and how their behavior may be explained by sparseness, at the moment they only contain the introduction.

The visual pathway

The visual system starts at the eye, where photons are detected and some denoising occurs; the optical nerve then carries the information to the thalamus, in the very center of the brain, there it is further processed and denoised before being relayed on to the visual cortex, at the very back of the cortex. As it is processed in stages in the cortex the information is passed forward through the cortex, as objects are recognized the information fans out and is integrated with other signals, from memory, from other sensory modalities and other aspect of our cognition. The basic pathway is shown in an very old drawing in Fig. 1 and is summarized in Fig. 2. One notable aspect is that different sides of the brain deal with different sides of the visual field, so signal from the left sides of the retina of both eyes go to the right side of the brain and signals from the right sides so to the left side.

Light is detected at the retina, the retina is a surprising organ in that it is backwards compared to how you'd expect it to be organized; the layer with light detectors is at the back instead of the front. Leaving that aside though, basically light is detected in specialized cells called *photoreceptors*, these don't spike, but they do convert light into electrical activity; this

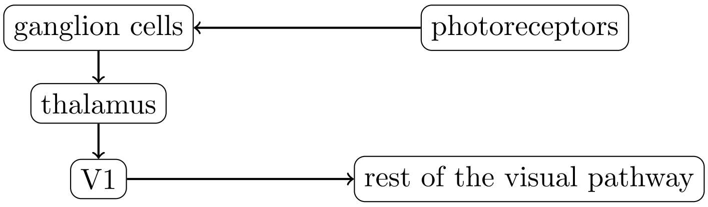


Figure 2: The visual pathway. This is a very rough diagram showing the visual pathway; V1 is the first visual area in the cortex.

is passed forward though *bipolar cells* to *ganglion cells*. Ganglion cells aggregate activity from a number of photoreptors, along with activity from some inhibitory cells in the intermediate layer and their axons form the optic nerve, carrying information to the thalamus. A sketch of the retina is given in Fig. **??**.

Receptive fields

Receptive fields are often described as the stimuli giving the largest response from a neuron. For ganglion and thalamic cells these are contrast patches, see Fig. 4, in *on-cells* small patches of the visual field where an illuminated region surrounded by an unilluminated one causes firing, different cells will respond to different locations. The width of the receptive fields vary from the size of full stop at reading distance in the center, to the size of a page near the periphery. In *off-cells* the contrast is reverse, the cell responds to an unilluminated region surrounded by an illuminated region. In V1 there are cells called *simple cells* and cells called *complex cells*; we will concentrate on the simple cells, these have edge-like receptive fields; different cells respond to particular orientations in particular locations in the visual field.

The edge-like receptive fields in V1 were first discovered by Hubel and Wiesel [1]. The used an electrode to record from V1 neurons in anaesthetised cat; the moved an edge-like stimulus around until they found the position that caused the highest firing rate, they observed that the firing rate depended on orientation as well as position, see Fig. 6 and Fig. 7.

Linear models

One way to think about it is to imagine the entries in the receptive field are synapse strengths for inputs from cells responding to illumination at points in the visual field. To formalize this consider linear models of the neuron's activity. Let I_{ij} denote the illumination level at point (i, j) in the visual field, i and j are discrete coordinates, for simplicity we will treat everything discretely. Now, imagine a linear model of the activity of the neuron, with the firing rate depending linearly on the illuminations; leaving out any messing with the firing rate having to be positive, this means

$$\tilde{r} = r_0 + \sum w_{ij} I_{ij} \tag{1}$$

where r_0 is the background firing rate and w_{ij} give the receptive field. Of course the firing rate of a neuron doesn't satisfy a linear model but the idea is to choose the linear model which best approximates the neuron, that is, for example, to choose w_{ij} to minimize the average square error $\langle (r - \tilde{r})^2 \rangle$ between r, the observed firing rate and $\tilde{r}$ is the estimated firing rate from the linear model.

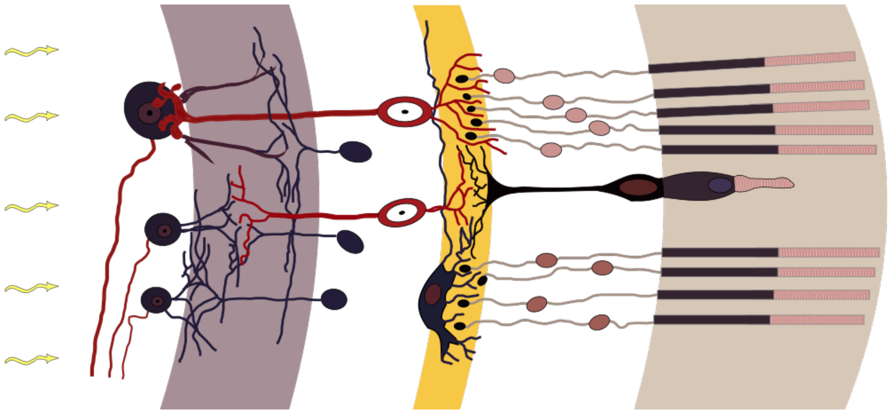


Figure 3: Rods, cones and nerve layers in the retina. The front of the eye is on the left. Light (from the left) passes through several transparent nerve layers to reach the rods and cones (far right). A chemical change in the rods and cones send a signal back to the nerves. The signal goes first to the bipolar and horizontal cells (yellow layer), then to the amacrine cells and ganglion cells (purple layer), then to the optic nerve fibres. The signals are processed in these layers. First, the signals start as raw outputs of points in the rod and cone cells. Then the nerve layers identify simple shapes, such as bright points surrounded by dark points, edges, and movement. (Based on a drawing by Ramón y Cajal, 1911.) [Caption and drawing taken from Wikipedia: Cajal derivative work: Anka Friedrich via Wikimedia Commons]

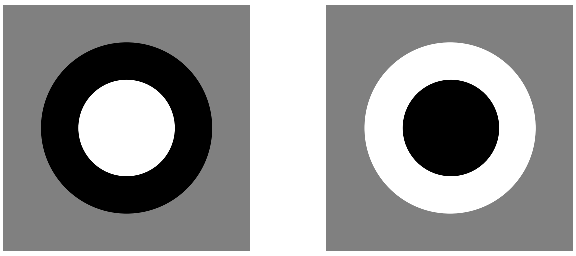


Figure 4: On and off cells respond to small contrast patches.

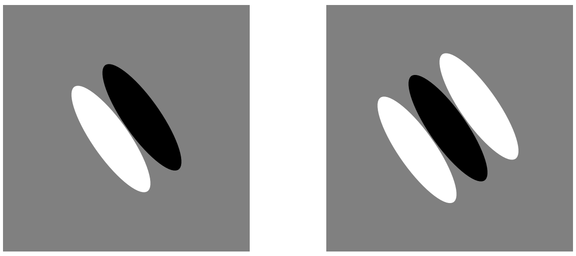


Figure 5: Simple cells in V1 respond to edges.

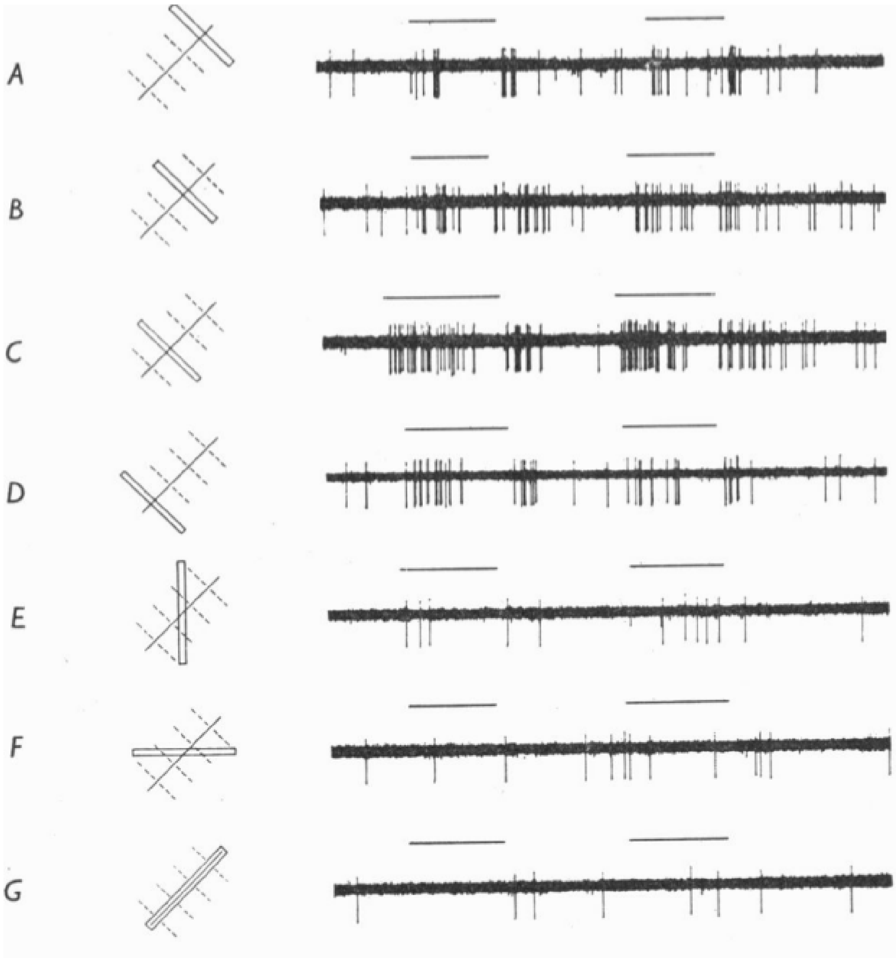
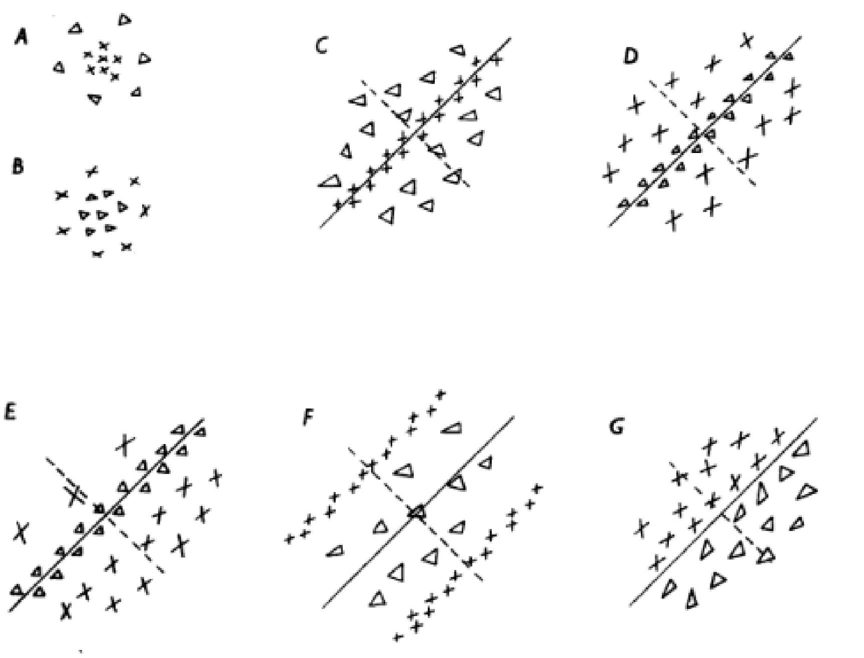


Figure 6: Experimental results from Hubel and Wiesel; the stimulus is a slit that allows light through from a souce, it is $0.125° \times 2.5°$ and is presented during the one-second period marked by the two bars over the plots. In the plots the vertical lines correspond to spikes. [Image from [1]].



Text-fig. 2. Common arrangements of lateral geniculate and cortical receptive fields. *A*. 'On'-centre geniculate receptive field. *B*. 'Off'-centre geniculate receptive field. *C–G*. Various arrangements of simple cortical receptive fields. ×, areas giving excitatory responses ('on' responses); △, areas giving inhibitory responses ('off' responses). Receptive-field axes are shown by continuous lines through field centres; in the figure these are all oblique, but each arrangement occurs in all orientations.

Figure 7: More experimental results from Hubel and Wiesel; here they have mapped out the excitatory (crosses) and inhibitory (triangles) areas for a number of neurons. [Image from [1]].

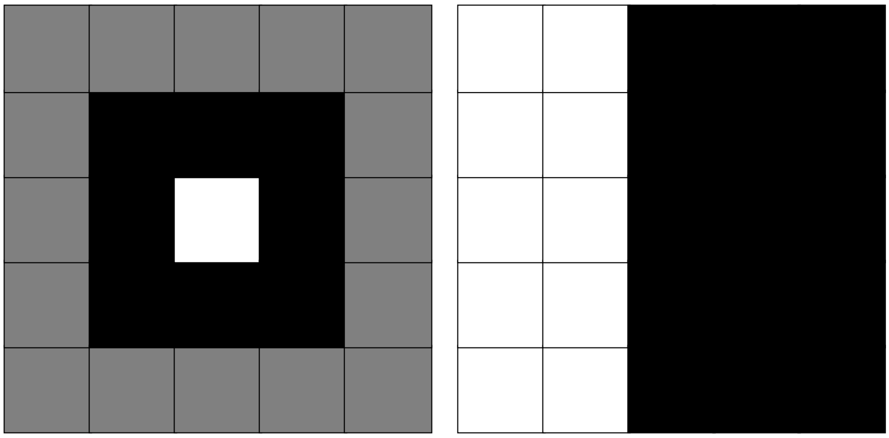


Figure 8: Receptive field and visual stimulus.

As an example consider

$$[w_{ij}] = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & -1/8 & -1/8 & -1/8 & 0 \\ 0 & -1/8 & 1 & -1/8 & 0 \\ 0 & -1/8 & -1/8 & -1/8 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix} \tag{2}$$

and

$$[I_{ij}] = \begin{pmatrix} 1 & 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 \end{pmatrix} \tag{3}$$

which is like a ganglion cell responding to an edge and is illustated in Fig. 8. If $r_0 = 2$ say then $\tilde{r} = 13/8$.

References

[1] Hubel DH, Wiesel TN. (1962) Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. The Journal of Physiology 160: 106.