

Informatics 1 Cognitive Science

Lecture 14: Vision Part 3

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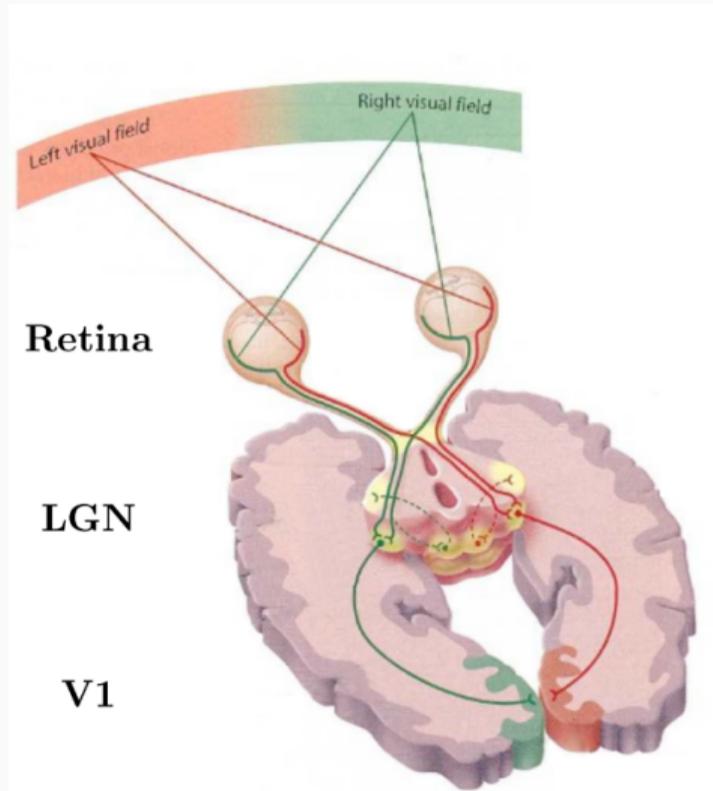
Orientation selective cells in the primary visual cortex

Receptive field models and convolution

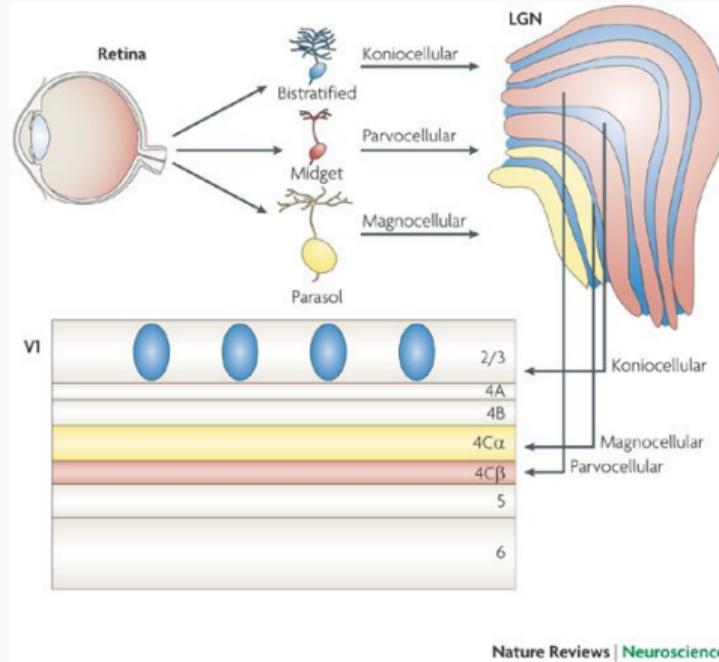
Simple and complex cells

Orientation selective cells in the primary visual cortex

Early Visual Pathway

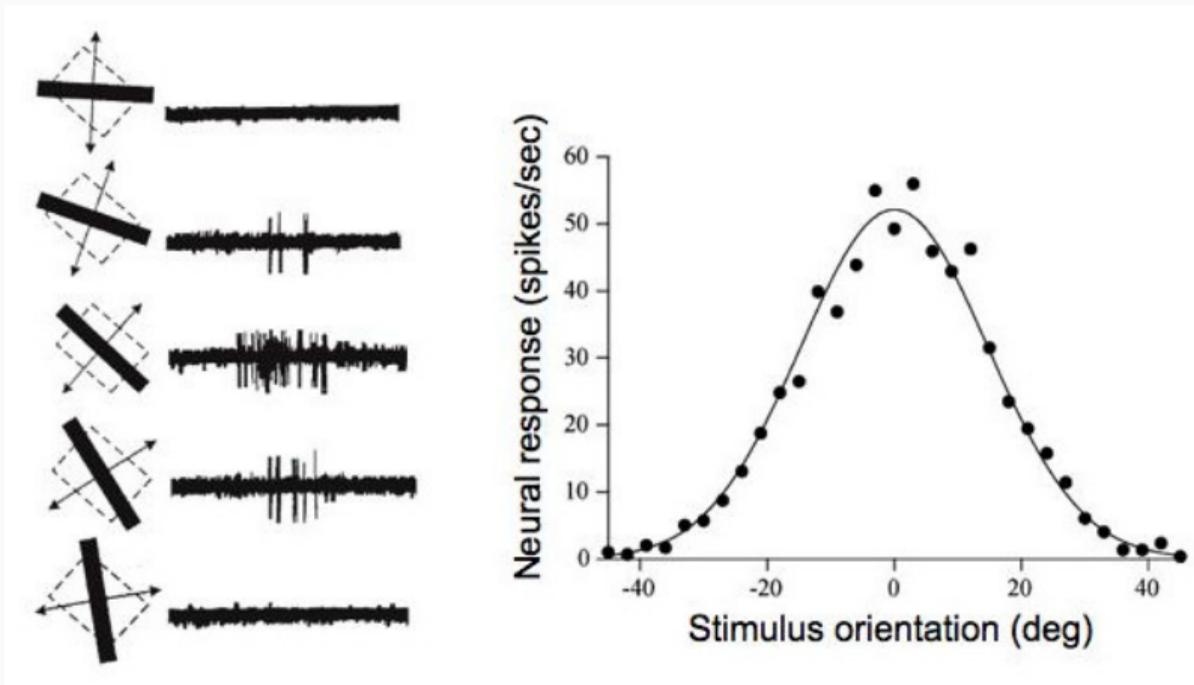


From the Retina to the Primary Visual Cortex (V1)



Output from the retina forms several different anatomical pathways, which continue as the ventral and dorsal cortical pathways (what and where pathways).

V1 Neurons are selective to Stimulus Orientation

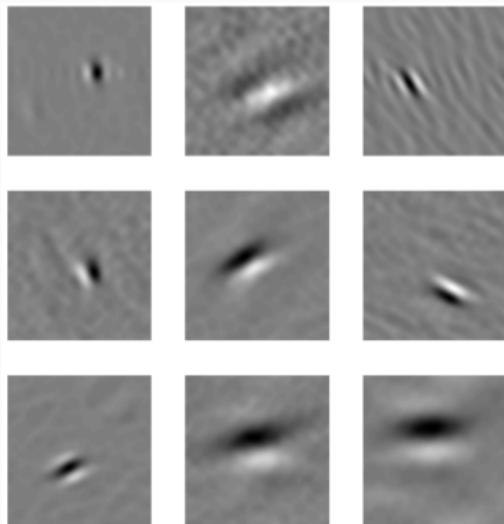


Responses of a neuron to a bar at different orientations (Hubel & Wiesel, 1968). A *tuning curve* can be created by plotting activity as function of angle.

See the original experiments by Hubel and Wiesel

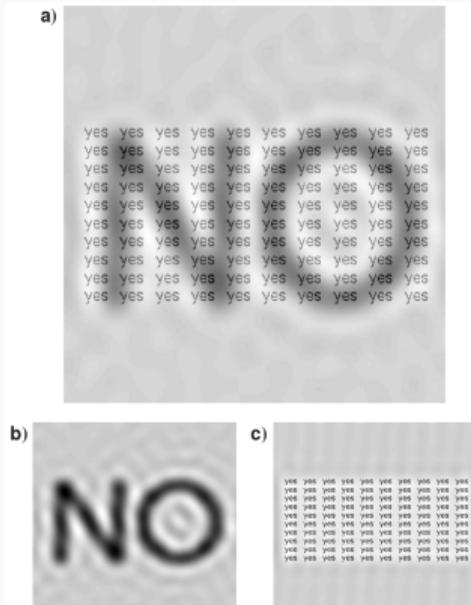
<https://www.youtube.com/watch?v=jw6nBWo21Zk>

Examples of V1 Simple Cells in a Macaque Monkey



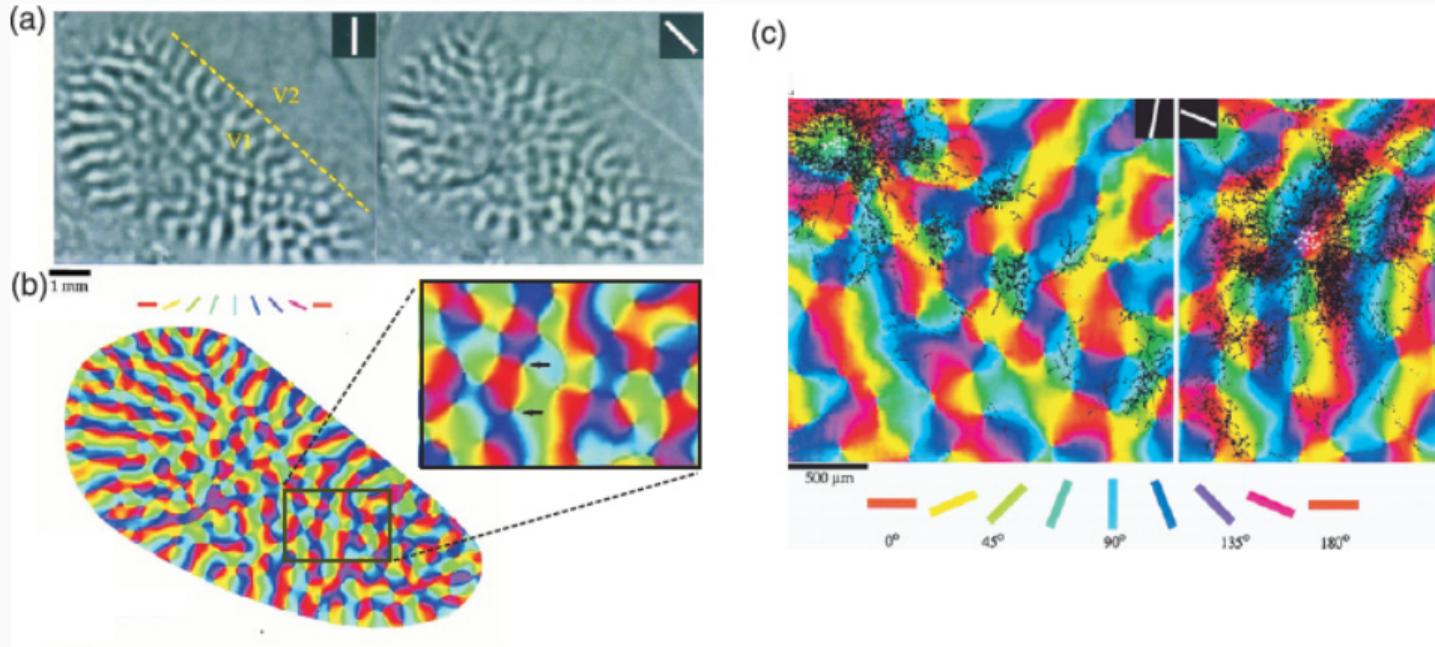
This shows stimuli that cause a strong activation of different simple cells. They cover different orientations, spatial scales and symmetries. (from Dario Ringach, UCLA)

Effect of RFs with different spatial scales



Effect of RF size. **a** original image, **b** image filtered with large receptive fields, **c** image filtered with small receptive fields. The sum of b) and c) equals a).

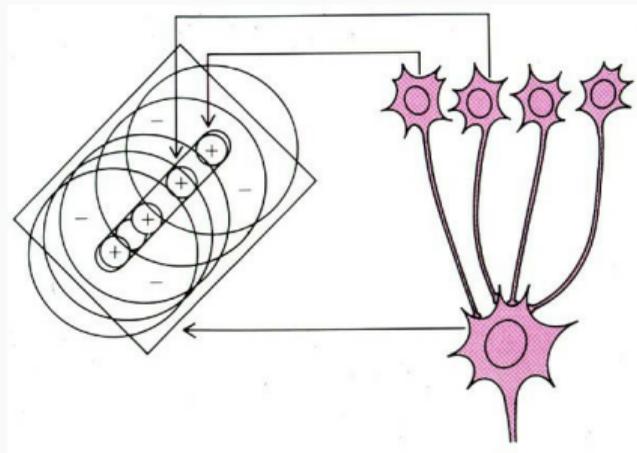
Organisation of Orientation Selectivity in V1



Nearby orientations are represented by neighbouring cells, and superimposed on the retinotopic map. This is called a pinwheel arrangement, and is found in all carnivores, but not in some rodents.

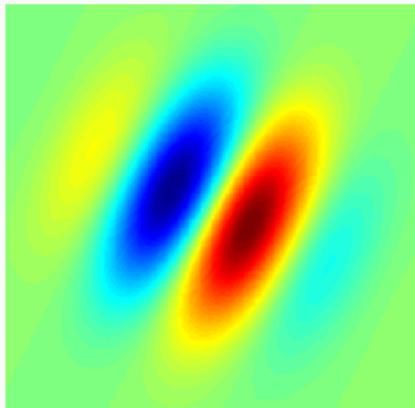
Receptive field models and convolution

A simple Simple Cell Model



Respond to bars/edges at a preferred orientation and preferred location.

A simple Simple Cell Model



Modelled by a Gabor function:

$$g(\mathbf{r}) = Ae^{-\frac{r^2}{2\sigma_c^2}} \cos(\mathbf{r}\omega - \theta)$$

\mathbf{r} is the position, σ_c the width of the Gaussian envelope, ω the frequency of the cosine, θ the orientation, and A the amplitude.

How to predict responses of neurons: Convolution

Definition in 1 dimension:

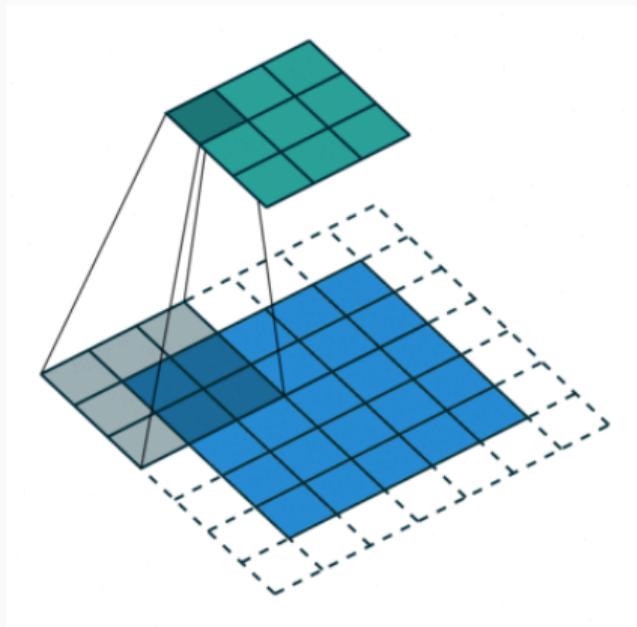
For functions f (image) and g (the receptive field) defined on a set of integers, and g is defined for $-M \dots M$:

$$(f * g)[n] = \sum_{m=-M}^M f[n-m]g[m]$$

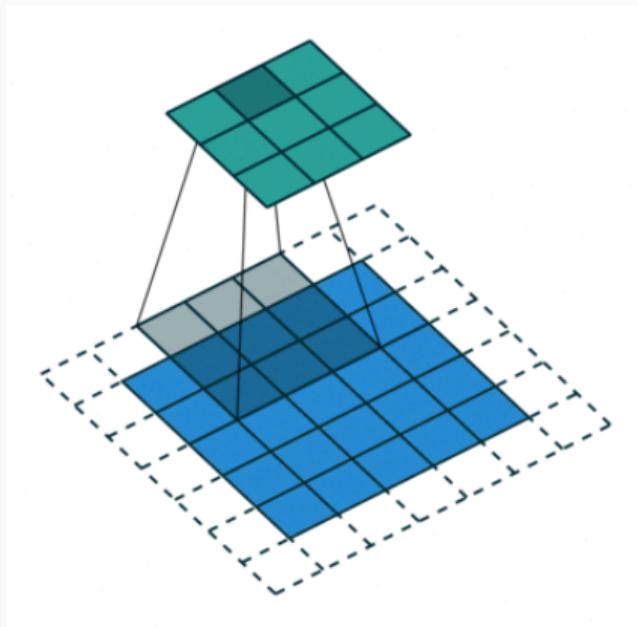
Each point $f[n]$ is re-computed by multiplying f with g , where g is centred in n .

Examples: https://github.com/vdumoulin/conv_arithmetic

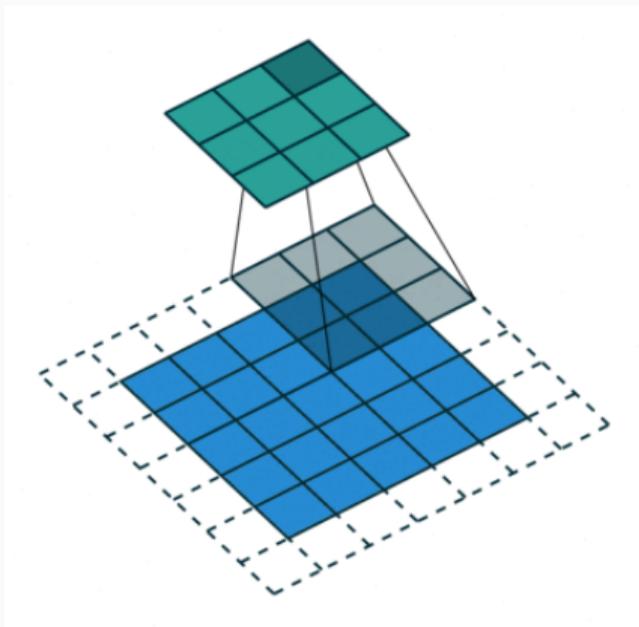
2D Convolution Example



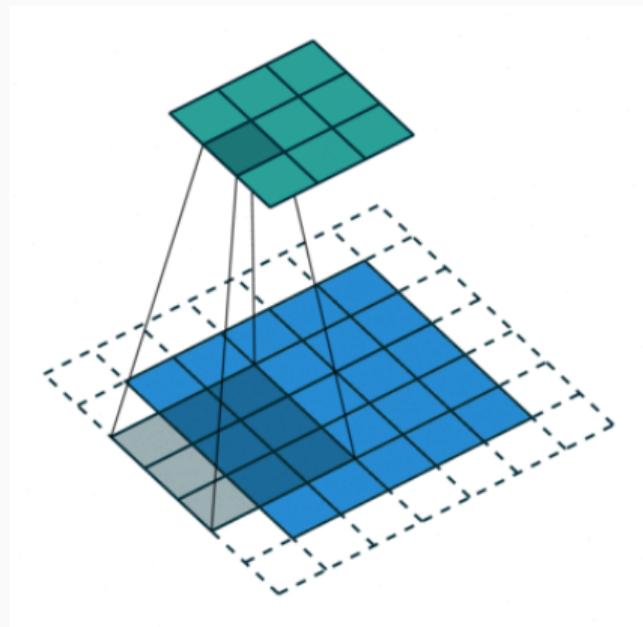
2D Convolution Example



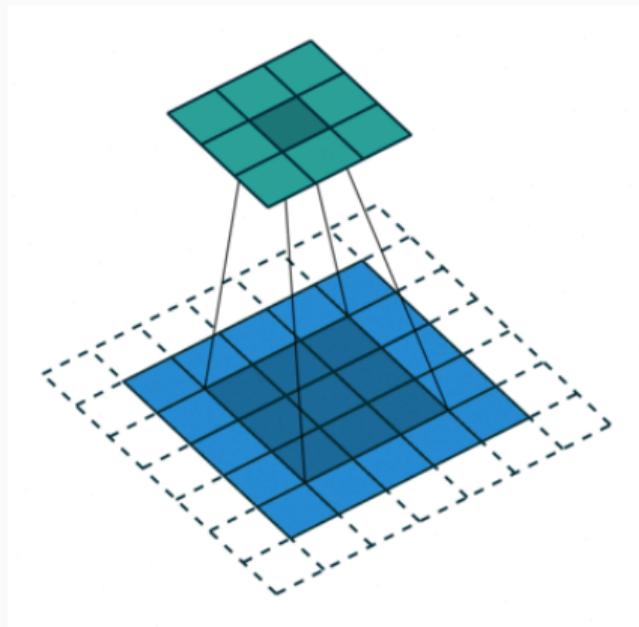
2D Convolution Example



2D Convolution Example



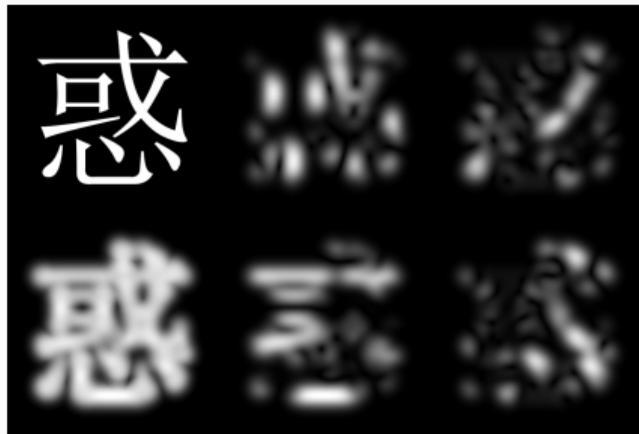
2D Convolution Example



2D Convolution Example

...and so on

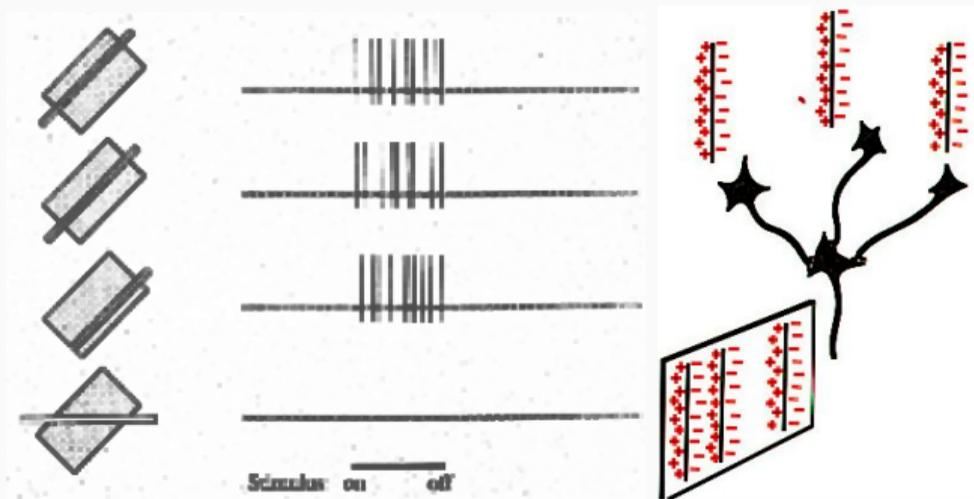
Image convolved with Gabor filters



Output of a Gabor filter for four orientations (source image top left), left bottom is sum of outputs.

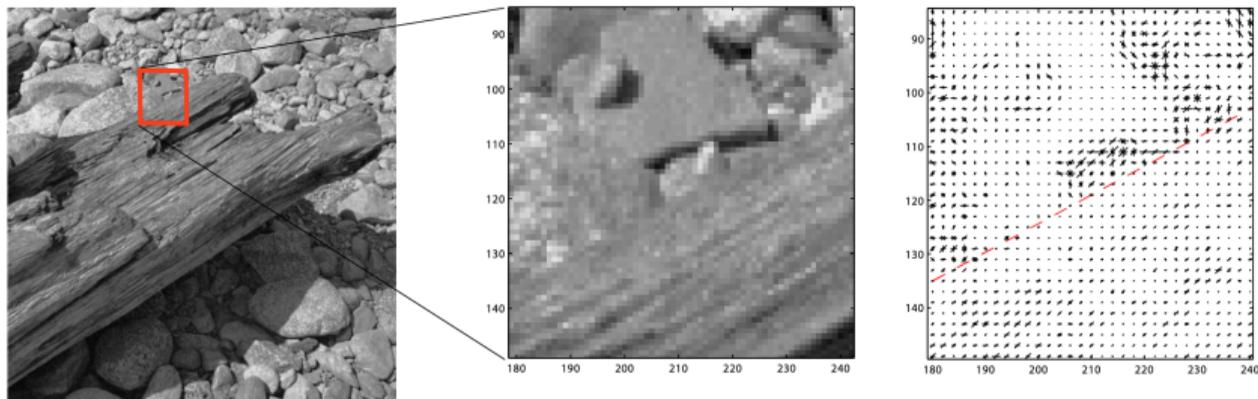
Simple and complex cells

The next step: V1 Complex cells



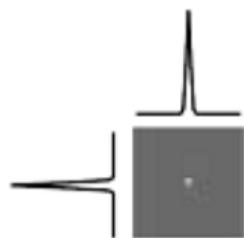
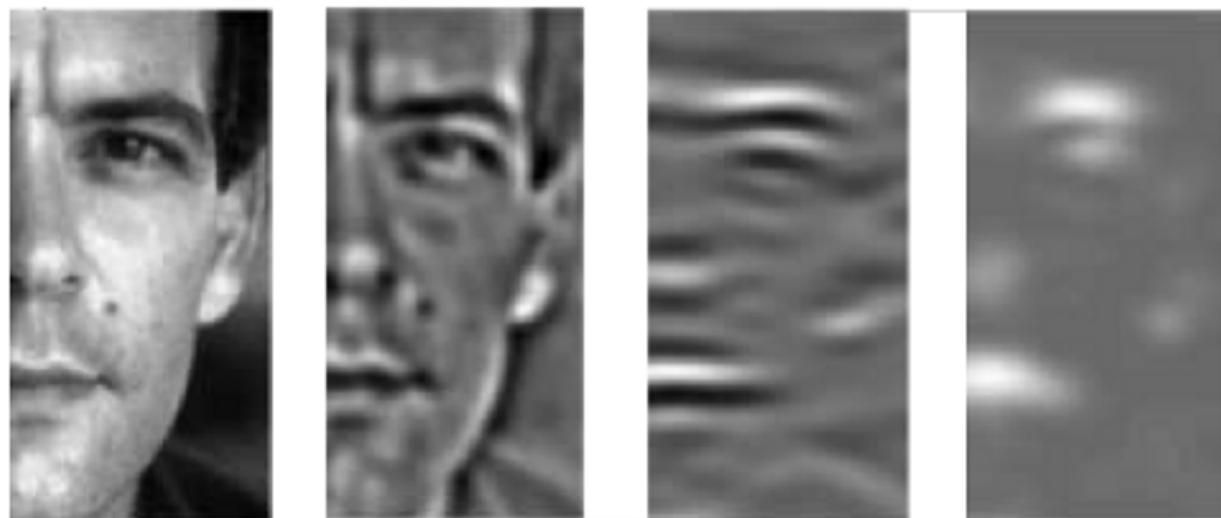
Like simple cells, but here the response is *position-invariant*. This involves a non-linear computation (pooling of thresholded inputs). Finding invariances is essential to describe objects in images.

V1 Complex cells

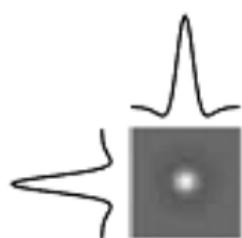


Responses of complex cells at different locations. Each bar shows the orientation with the strongest response, bar length is response magnitude.

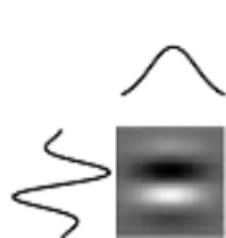
An image along the early visual pathway



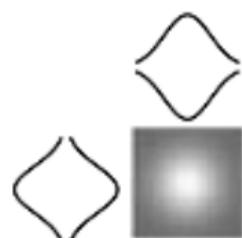
photoreceptor



LGN cell



V1 simple cell



V1 complex cell

Summary

- V1 neurons are tuned to stimulus orientation (tuning curves)
- Orientation preferences are organised across cortex (retinotopy + pinwheels)
- Simple cells respond to oriented edges at a preferred *position* and scale
- Gabor functions provide a good receptive-field model for simple cells
- Responses can be predicted by (2D) convolution of image and receptive field
- Complex cells pool (nonlinearly) over simple cells to gain *position invariance*