

# Vision Part 3

## Informatics 1 Cognitive Science

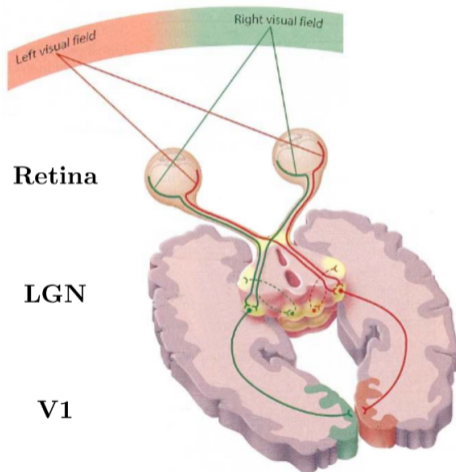
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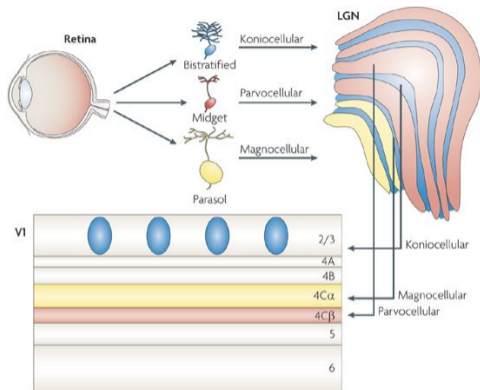
# Topics

- Orientation selective cells in the primary visual cortex
- Receptive field models and convolution
- Simple and complex cells

# Early Visual Pathway



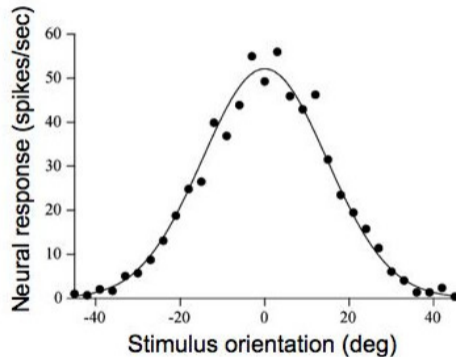
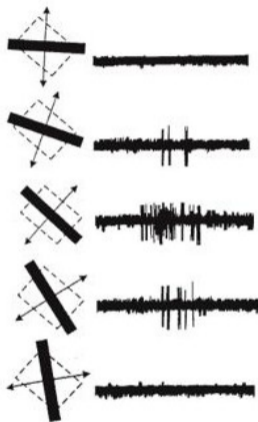
# From the Retina to the Primary Visual Cortex (V1)



Nature Reviews | Neuroscience

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

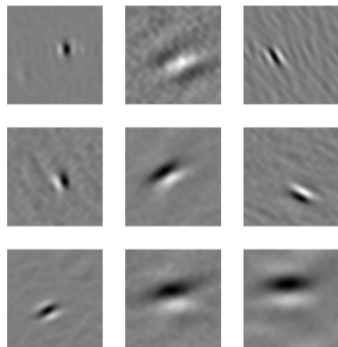


Responses of a neuron to a bar at different orientations (Hubel & Wiesel, 1968). A *tuning curve* can be created by plotting activity as function of angle.

See the original experiments by Hubel and Wiesel

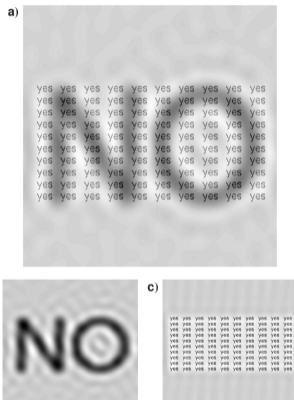
<https://www.youtube.com/watch?v=jw6nBWo21Zk>

# Examples of V1 Simple Cells in a Macaque Monkey



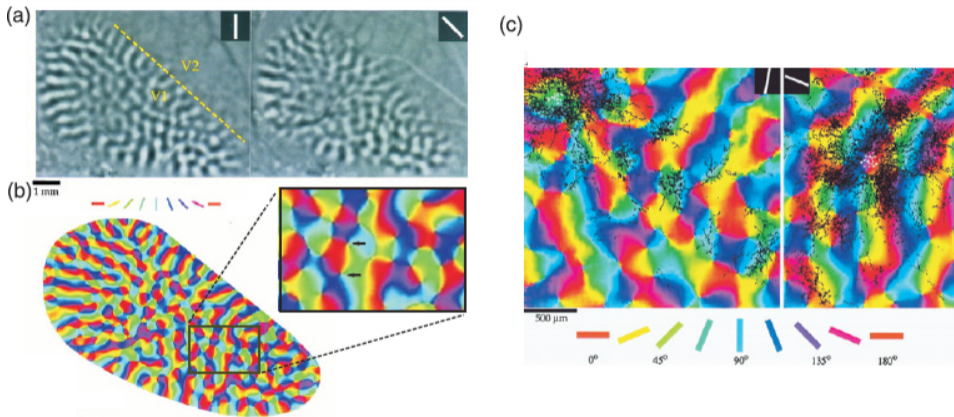
This shows stimuli that cause a strong activation of different simple cells. They cover different orientations, spatial scales and symmetries. (from Dario Ringach, UCLA)

# Effect of RFs with different spatial scales



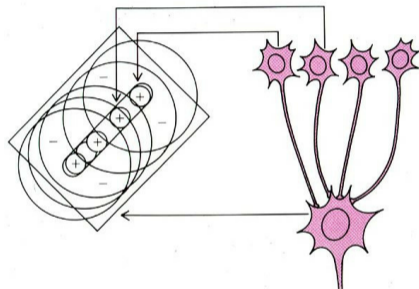
Effect of RF size. **a** original image, **b** image filtered with large receptive fields, **c** image filtered with small receptive fields. The sum of b) and c) equals a).

# Organisation of Orientation Selectivity in V1



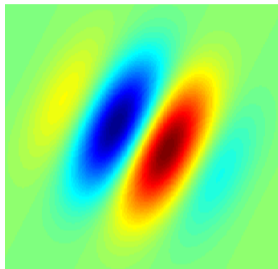
Nearby orientations are represented by neighbouring cells, and superimposed on the retinotopic map. This is called a pinwheel arrangement, and is found in all carnivores, but not in some rodents.

# 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:

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

$\mathbf{r}$  is the position,  $\sigma_c$  the width of the Gaussian envelope,  $\omega$  the frequency of the cosine,  $\theta$  the orientation, and  $A$  the amplitude.

# How to predict responses of neurons: Convolution

Definition in 1 dimension:

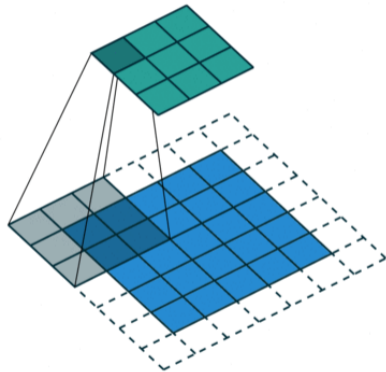
For functions  $f$  (image) and  $g$  (the receptive field) defined on a set of integers, and  $g$  is defined for  $-M \dots M$ :

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

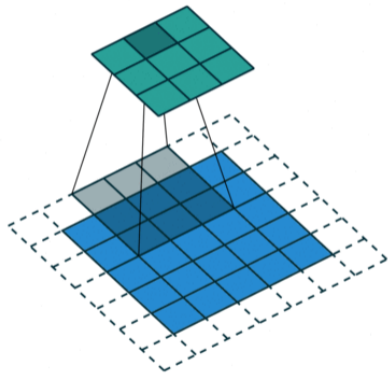
Each point  $f[n]$  is re-computed by multiplying  $f$  with  $g$ , where  $g$  is centred in  $n$ .

Examples: [https://github.com/vdumoulin/conv\\_arithmetic](https://github.com/vdumoulin/conv_arithmetic)

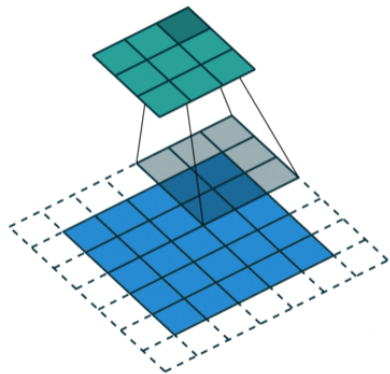
# 2D Convolution Example



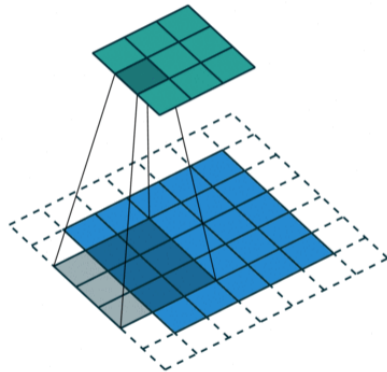
# 2D Convolution Example



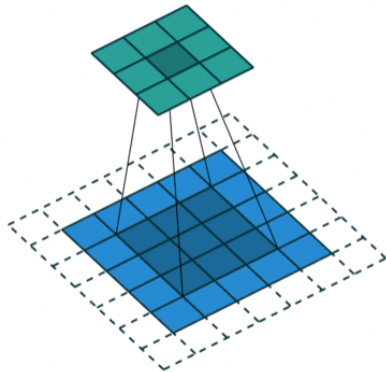
# 2D Convolution Example



# 2D Convolution Example



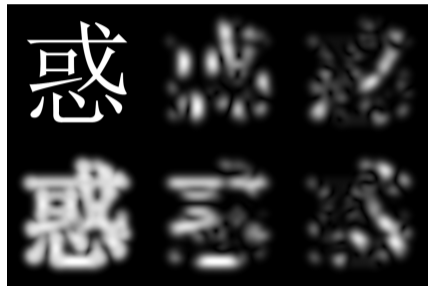
# 2D Convolution Example



## 2D Convolution Example

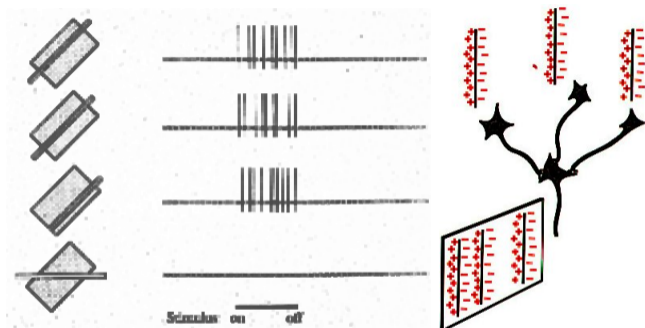
...and so on

# Image convolved with Gabor filters



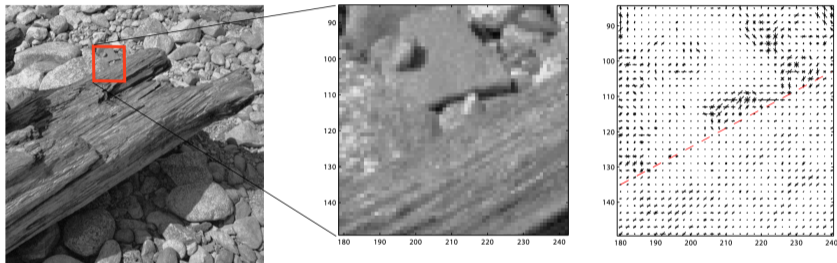
Output of a Gabor filter for four orientations (source image top left), left bottom is sum of outputs.

## The next step: V1 Complex cells



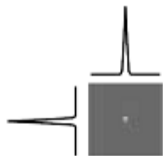
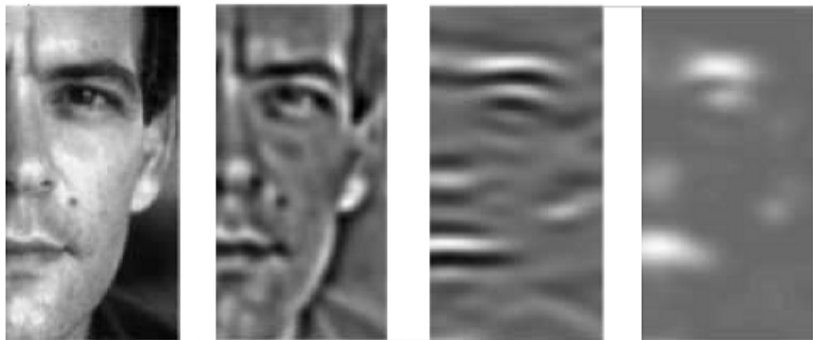
Like simple cells, but here the response is *position-invariant*. This involves a non-linear computation (pooling of thresholded inputs). Finding invariances is essential to describe objects in images.

# V1 Complex cells

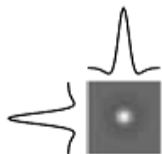


Responses of complex cells at different locations. Each bar shows the orientation with the strongest response, bar length is response magnitude.

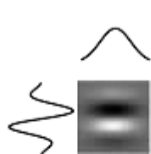
## An image along the early visual pathway



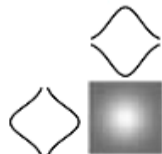
photoreceptor



LGN cell



V1 simple cell



V1 complex cell

# Summary

- V1 neurons are selective to stimulus orientation
- Simple cells respond at a preferred orientation and location
- Complex cells respond at a preferred orientation, but are position-invariant
- Responses of neurons can be predicted by convolution
- Gabor filters are a good model for simple cells
- Complex cells are created by pooling of simple cell responses