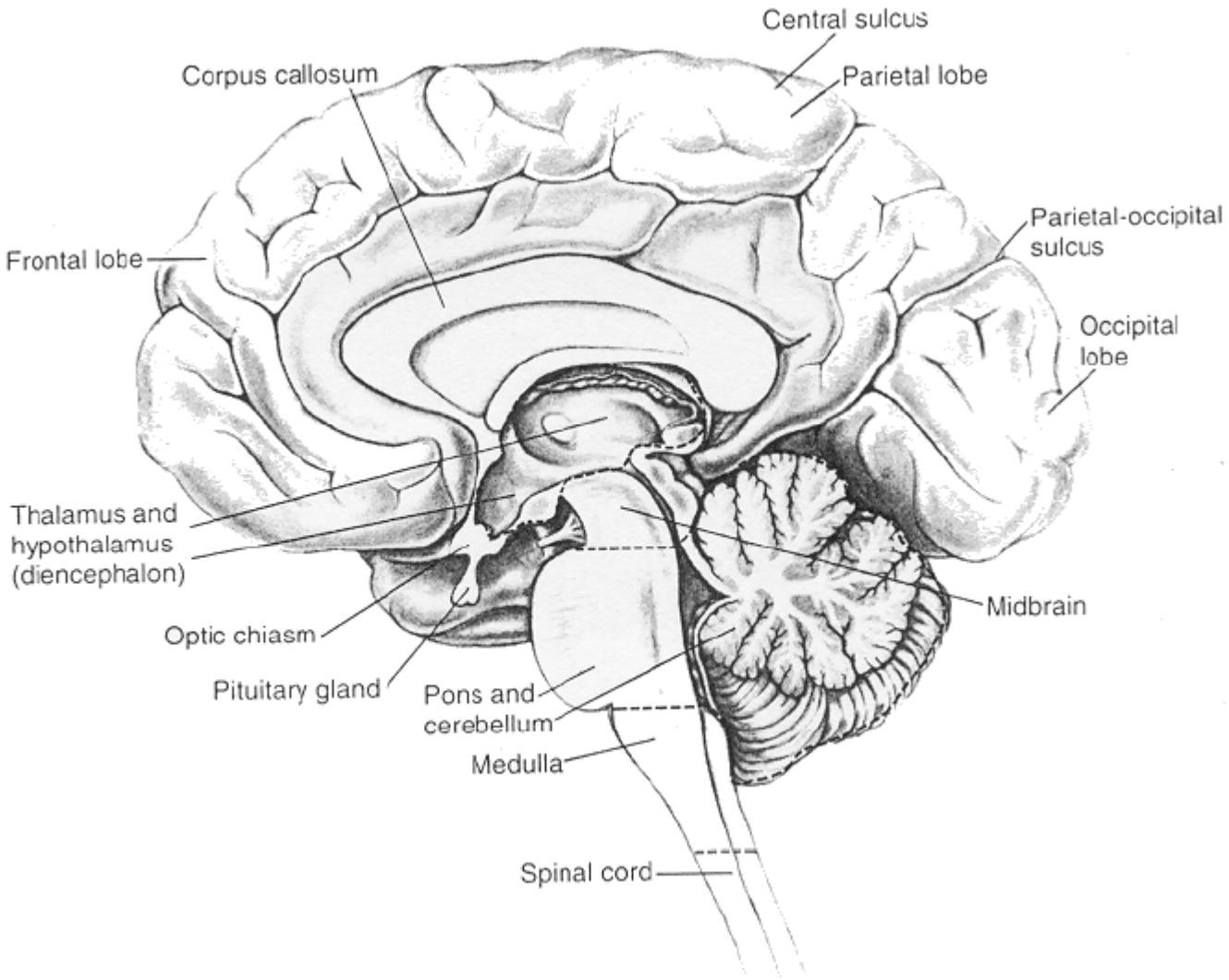
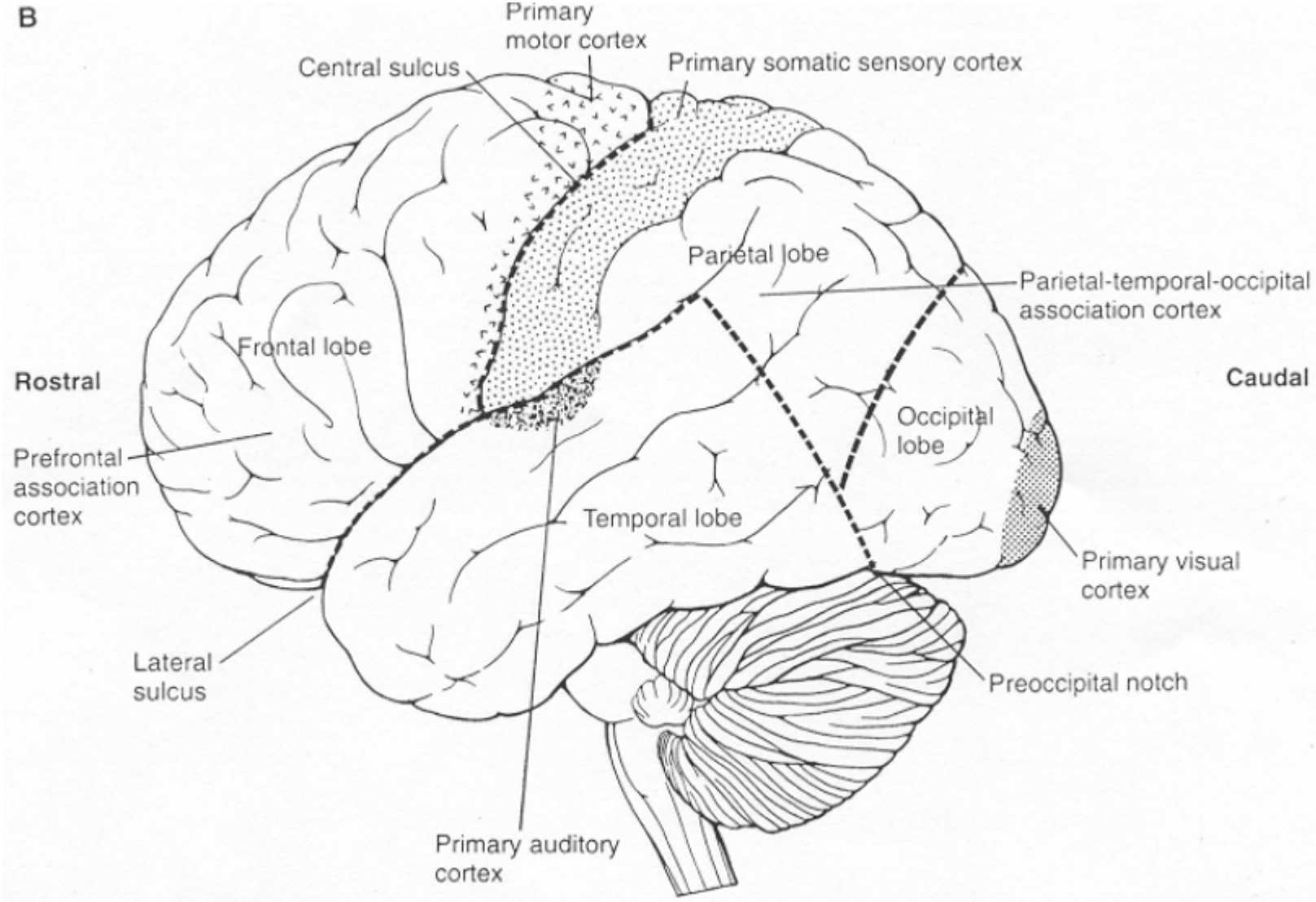
Systems Neuroscience

The CNS


Central sulcus
Corpus callosum
Parietal lobe
Parietal-occipital sulcus
Frontal lobe
Occipital lobe
Thalamus and hypothalamus (diencephalon)
Midbrain
Optic chiasm
Pituitary gland
Pons and cerebellum
Medulla
Spinal cord

Sensory Areas



Senses

- sight (vision)
- hearing (audition)
- touch (somatosensation)
- smell (olfaction)
- taste (gustation)
- pain (nociception)
- body configuration (proprioception)
- acceleration and balance (vestibular sensation)

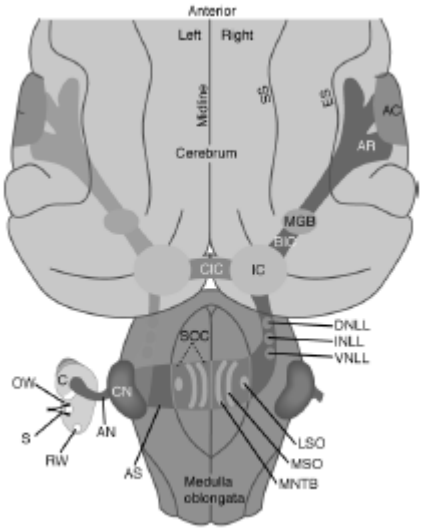
Processing

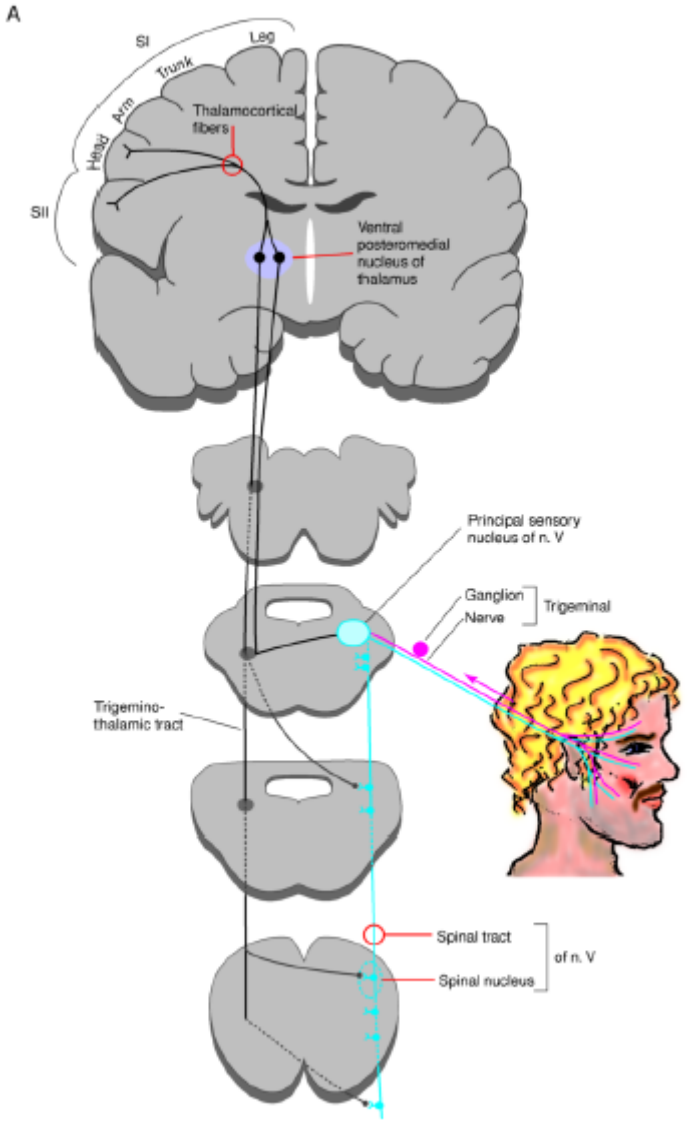
- receptor discretization – sampling
  - frequency-dependent hair cells
  - retinal cone/rod sampling
  - touch receptors
  - olfactory receptors
- combined to make receptive fields
- sensitivity across decades:
  - adaptation and Weber's law
- optimality:
  - matching to natural statistics?
  - matching to behavioural relevance?
  - redundancy reduction

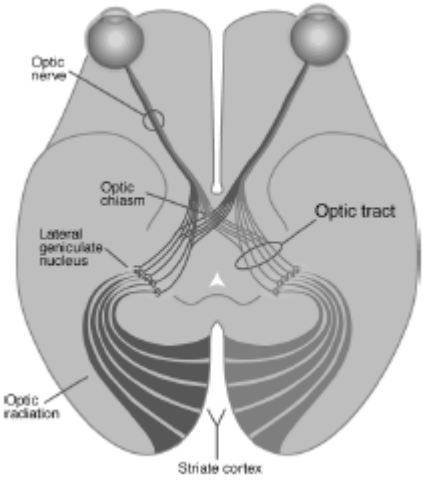
Neocortical Senses

- common pathways:
  - receptors
  - subcortical nuclei
  - thalamus
  - primary cortex
  - secondary + higher cortex

Neocortical Connections

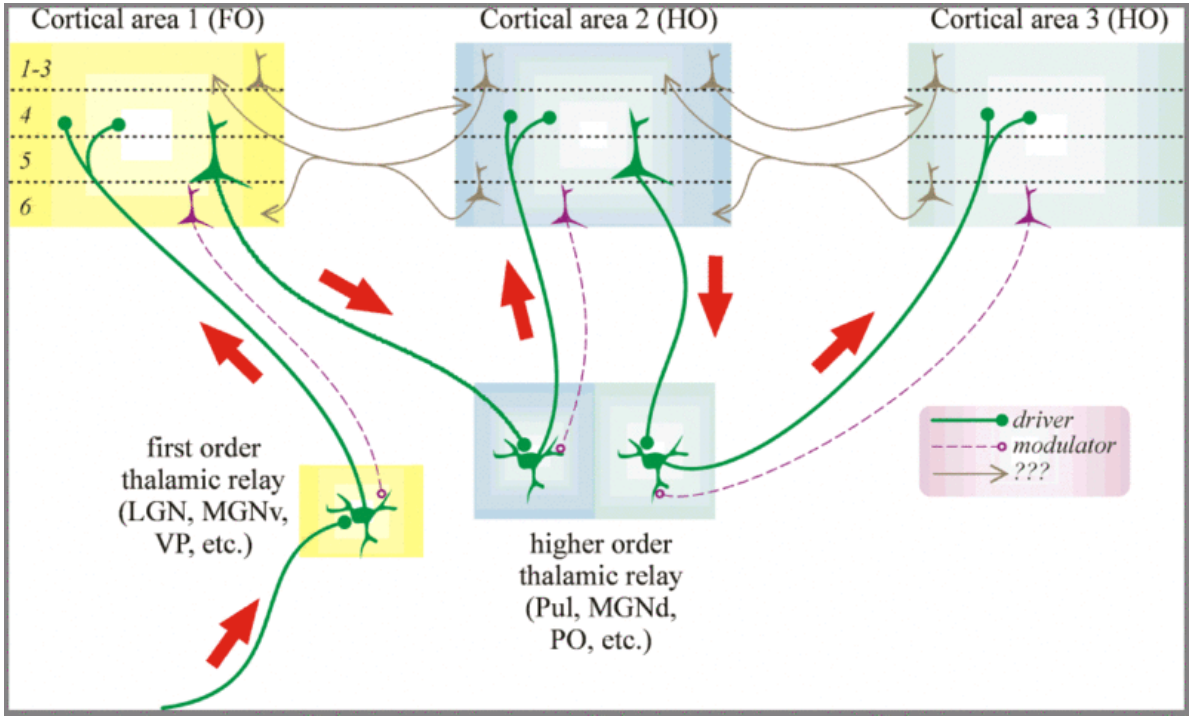




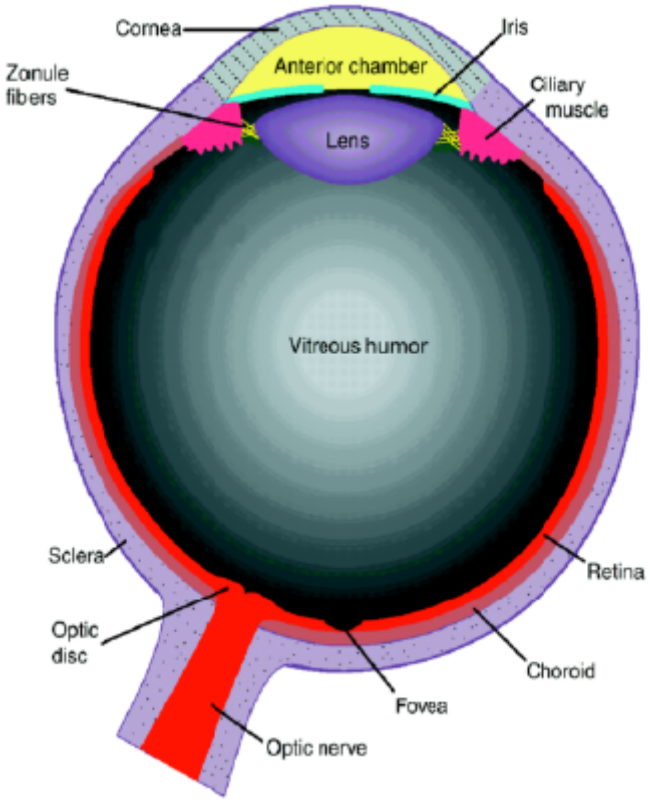


Other Common Properties

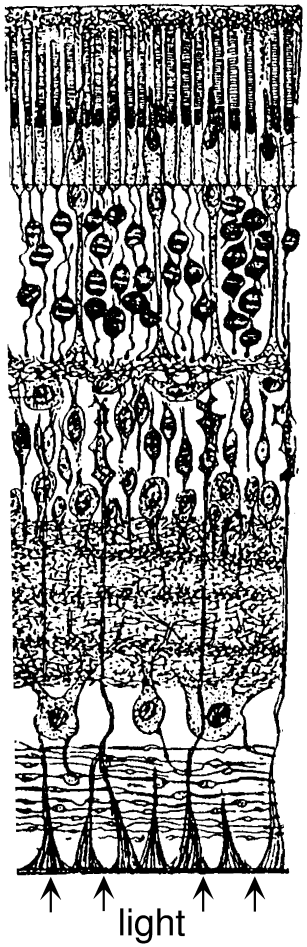
- thalamic loops between cortical areas
- cortical feedback (generative models)
- parallel sub-cortical pathways (tectum)



Vision



A



rod and cone receptors (R)

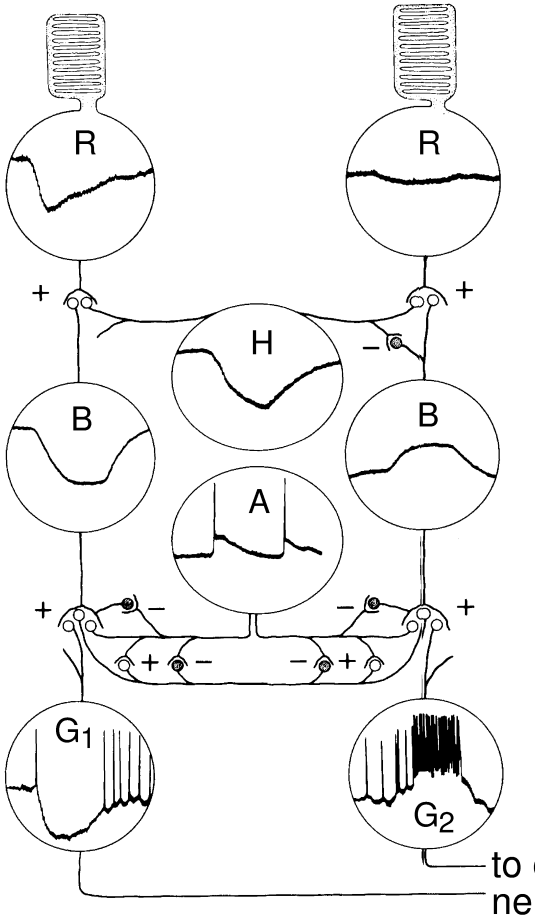
horizontal (H)

bipolar (B)

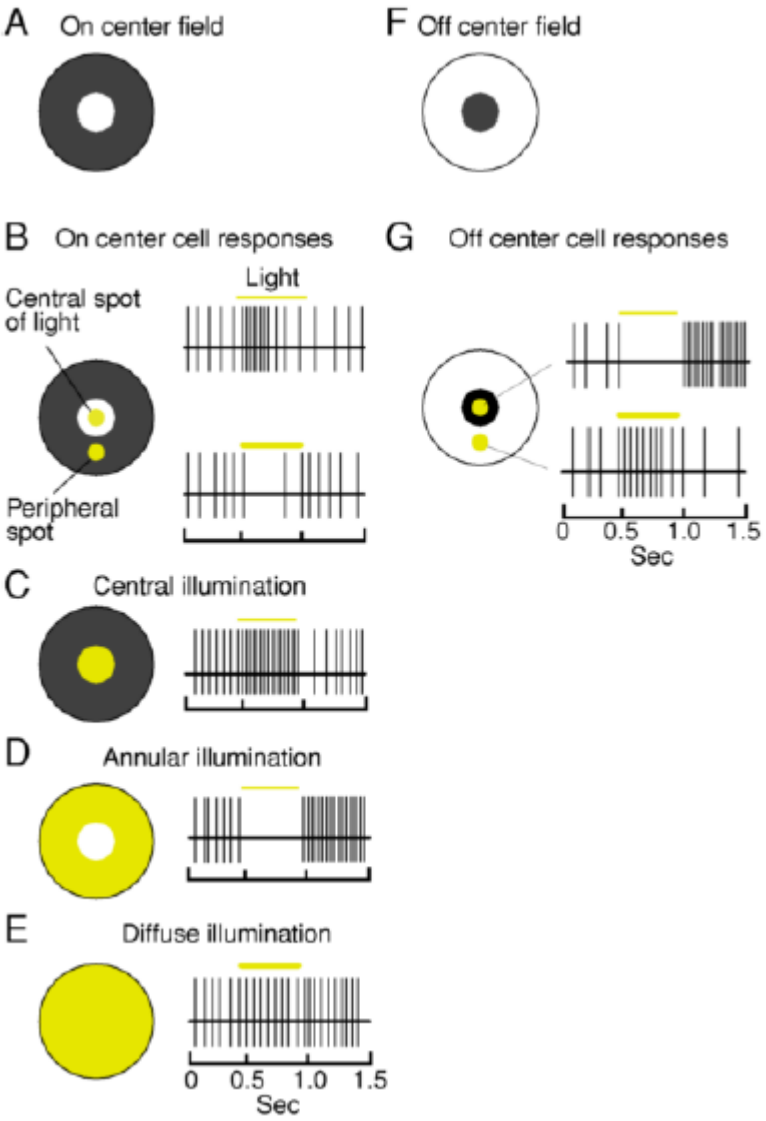
amacrine (A)

retinal ganglion (G)

B



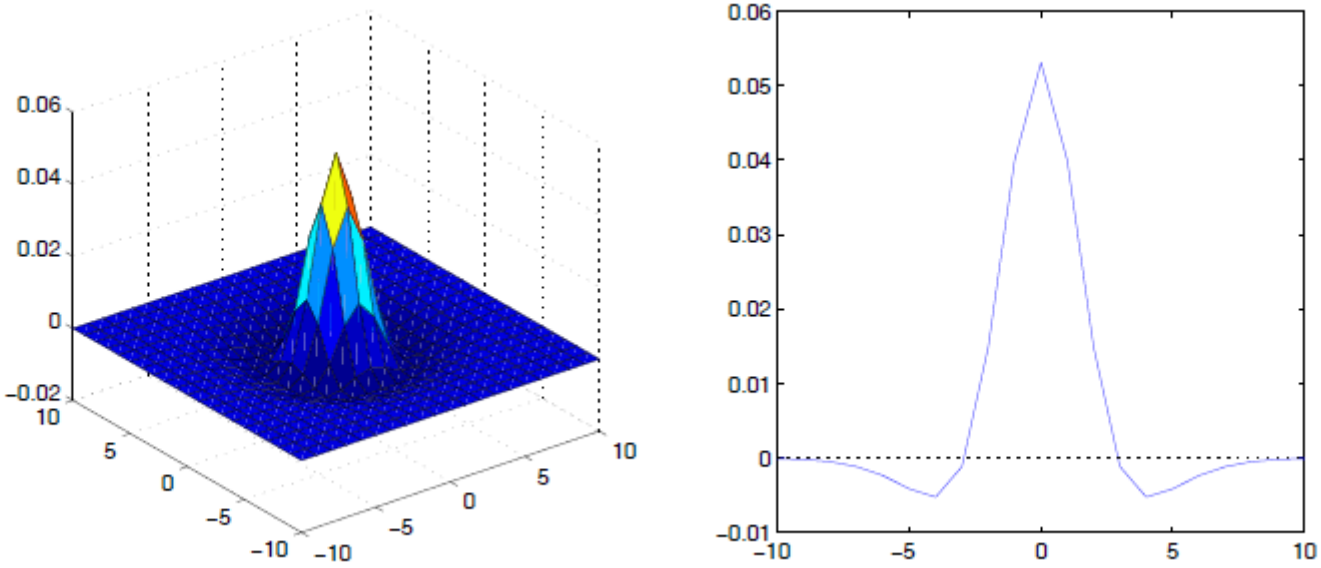
Retinal RFs


A On center field
F Off center field
B On center cell responses
Light
Central spot of light
Peripheral spot
G Off center cell responses
0 0.5 1.0 1.5
Sec
C Central illumination
D Annular illumination
E Diffuse illumination
0 0.5 1.0 1.5
Sec

Centre-Surround Models

- difference of Gaussians model

$$D_{\text{DoG}}(x,y) = \frac{1}{2\pi\sigma_c^2}\exp\left(-\frac{(x-c_x)^2+(y-c_y)^2}{2\sigma_c^2}\right) - \frac{1}{2\pi\sigma_s^2}\exp\left(-\frac{(x-c_x)^2+(y-c_y)^2}{2\sigma_s^2}\right)$$



Leading to a Firing Rate

- firing rate as a dot product for stimulus $s(x,y)$

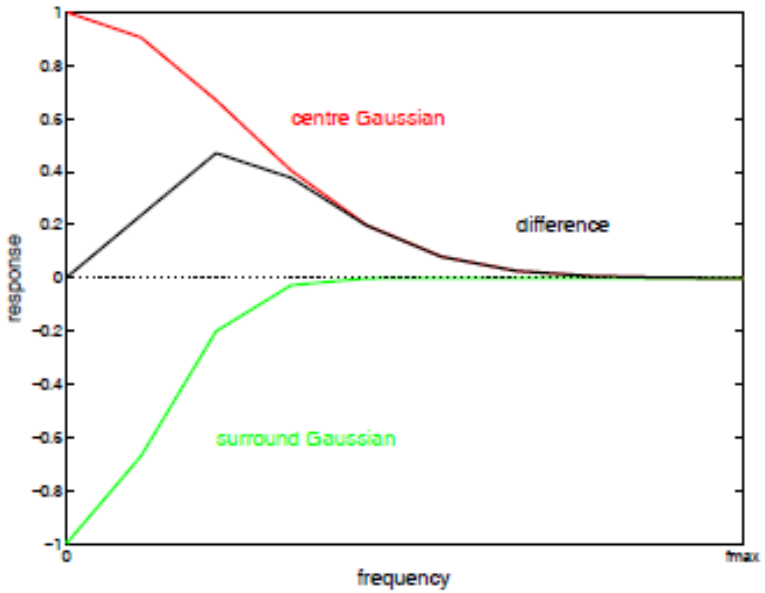
$$r(s(x,y)) = \int dx\, dy\, D(x,y)s(x,y)$$

- if identical RFs are distributed over space with centres (c_x, c_y), we can write the convolution

$$r(c_x, c_y; s(x,y)) = \int dx\, dy\, D(c_x - x, c_y - y)s(x,y)$$

Spatial Frequency

- by the convolution theorem, consider the frequency response of the filter



- formally: bandpass
- but – in low light levels (scotopic vision)...

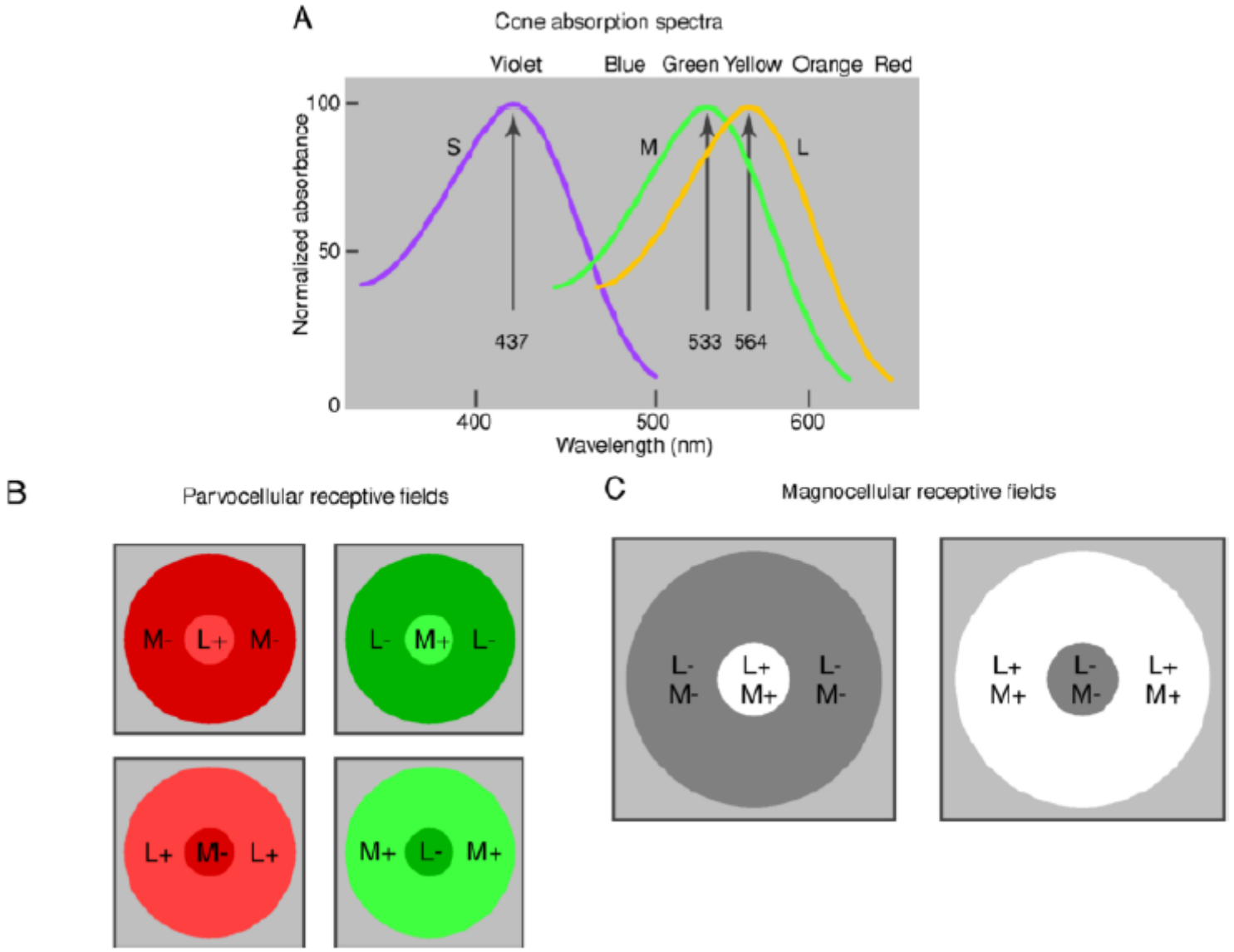
Edge Detection

orginal image

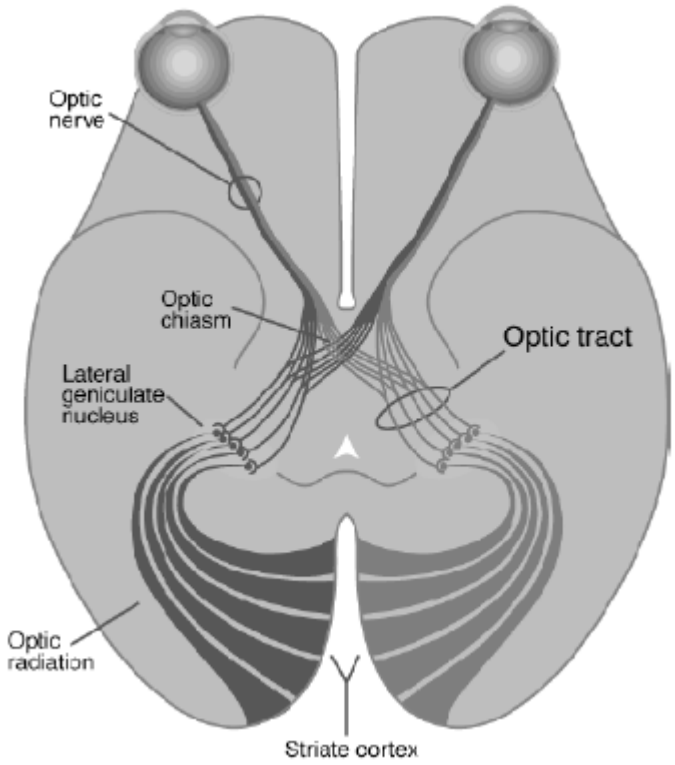
DoG responses

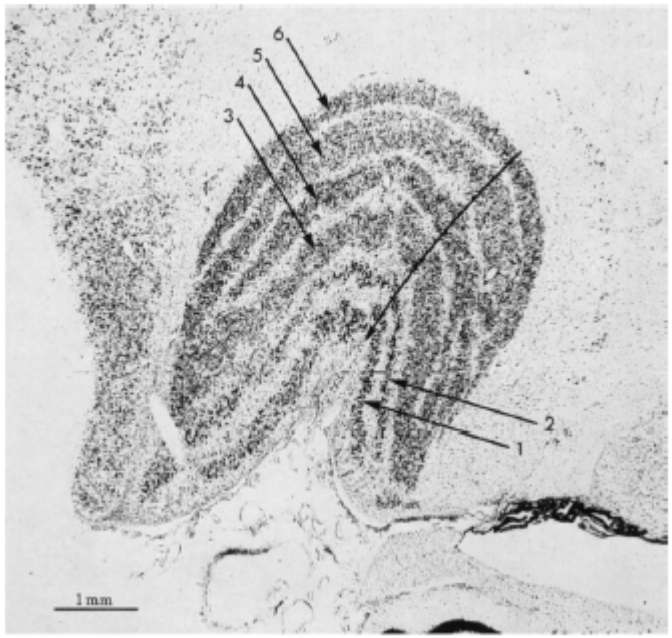
thresholded

Colour Coding



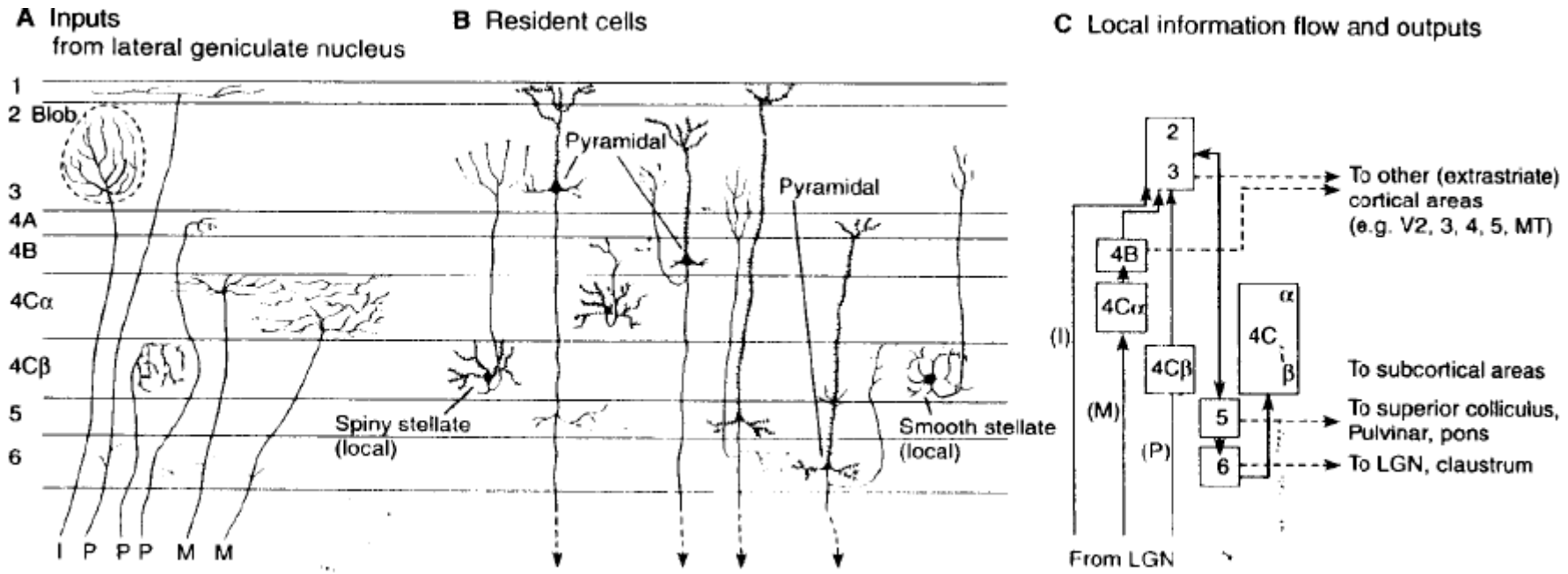
Thalamus



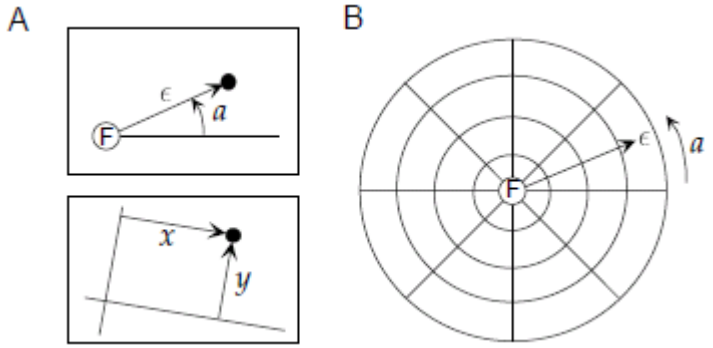


- 1;4;6 contra; 2;3;5 ipsi

Cortical Layers



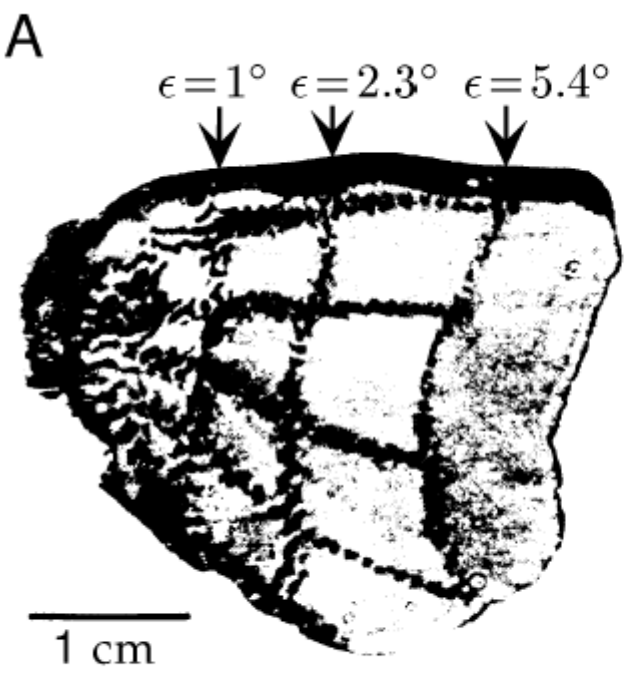
Cortical Topography

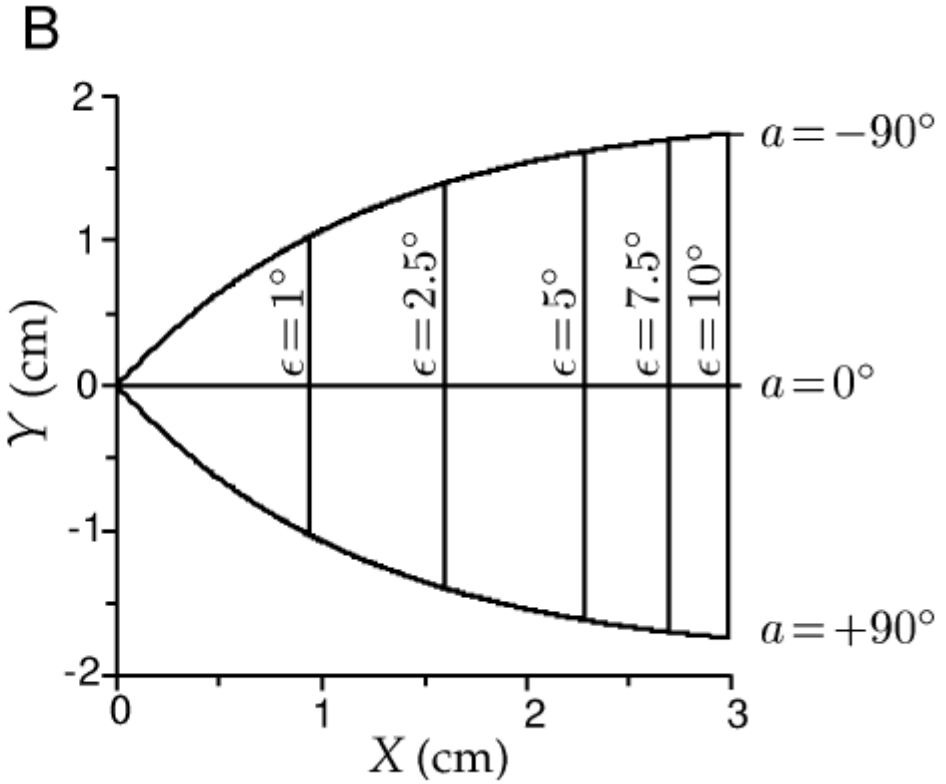


$$Z = X + iY$$

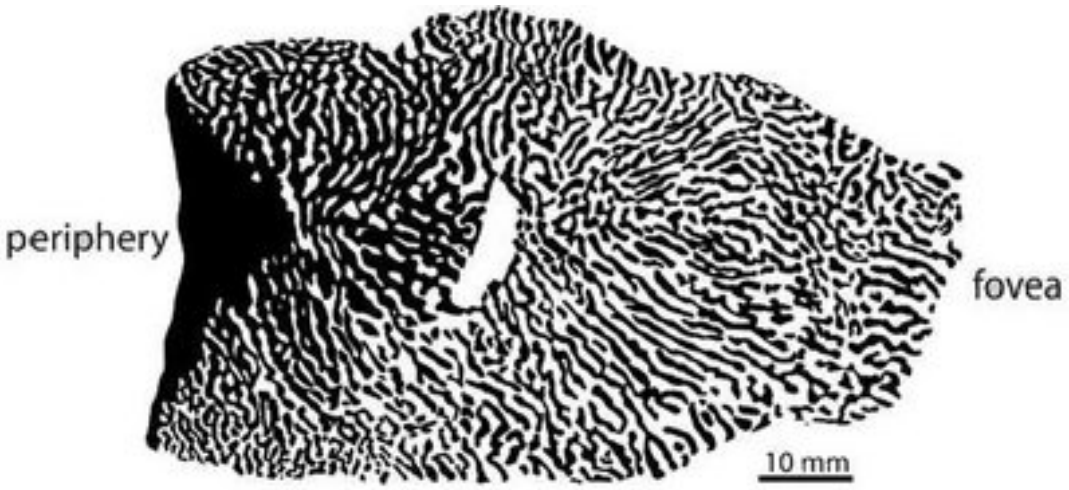
$$z = \left(\varepsilon / \varepsilon_0 \right) e^{-i\pi a / 180^\circ}$$

$$Z = \lambda \log(z)$$





Ocularity



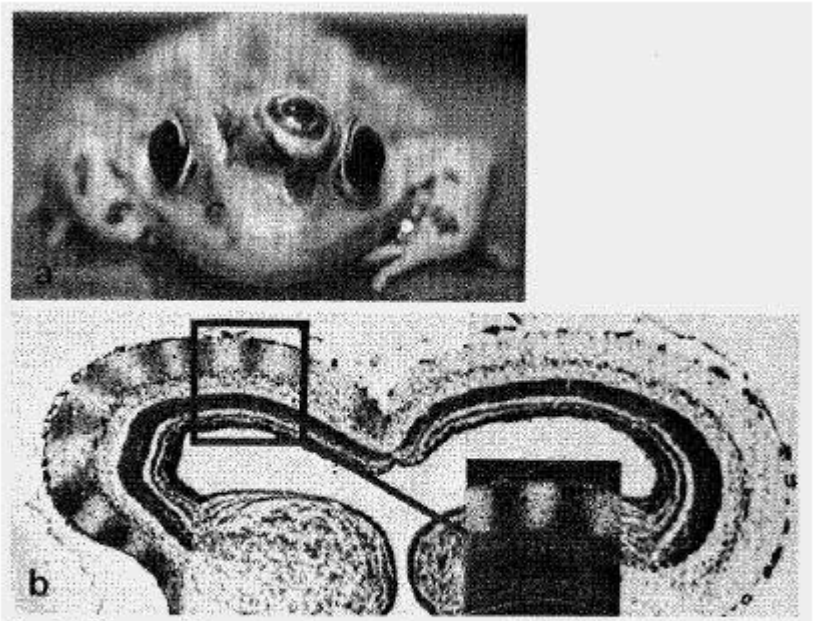
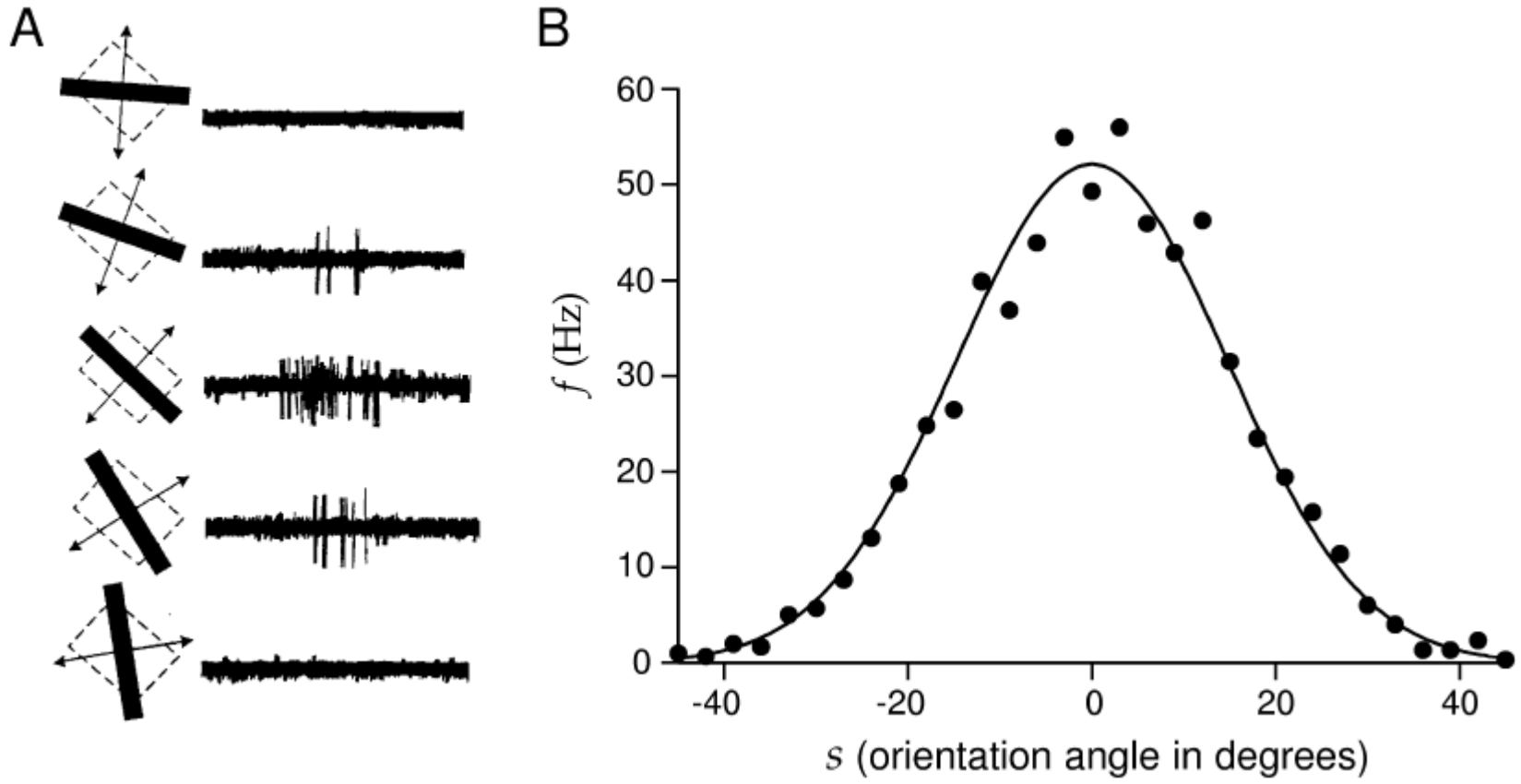
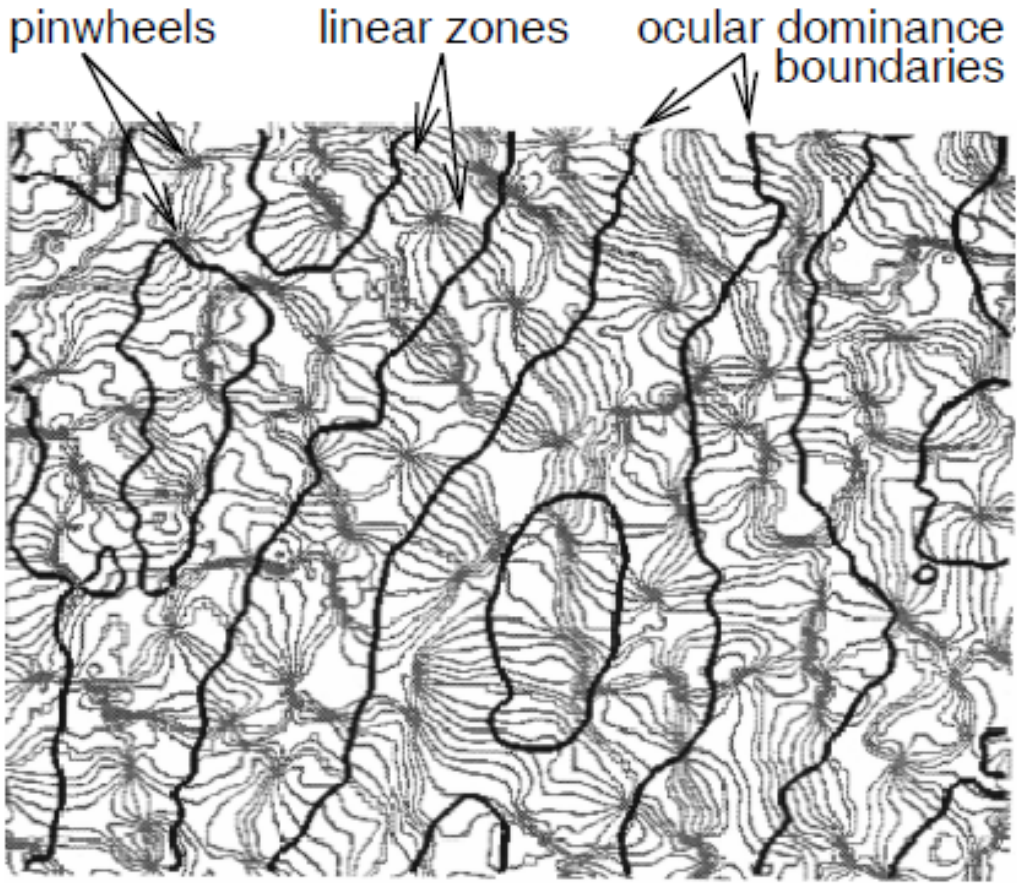


Fig. 1. (a) Three-eyed *Rana pipiens* 8 months after metamorphosis. The central eye primordium was implanted at Shumway stage 17 from a similarly staged donor. The supernumerary eye has externally normal dimensions, but lacks a pupillary response. (b) Autoradiographic distributions of grain densities in the optic tectum of a 3-month postmetamorphic three-eyed frog after injection of 10 μCi of [^{3}H]proline into the vitreous body of the normal eye. (Inset) Dark-field enlargment showing the pronounced segregation of labeled and unlabeled regions of the tectal neuropil.

Orientation Selectivity



Cortical Arrangment



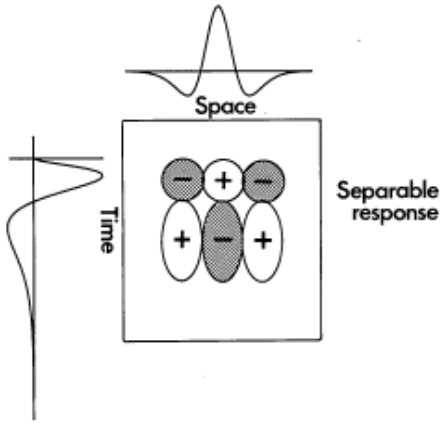
Linear RFs

- extend retinal model to time

$$r(t_0, s(x, y, t)) = \int_0^\infty d\tau \int dx\, dy\, s(x, y, t_0 - \tau) D(x, y, \tau)$$

- separability:

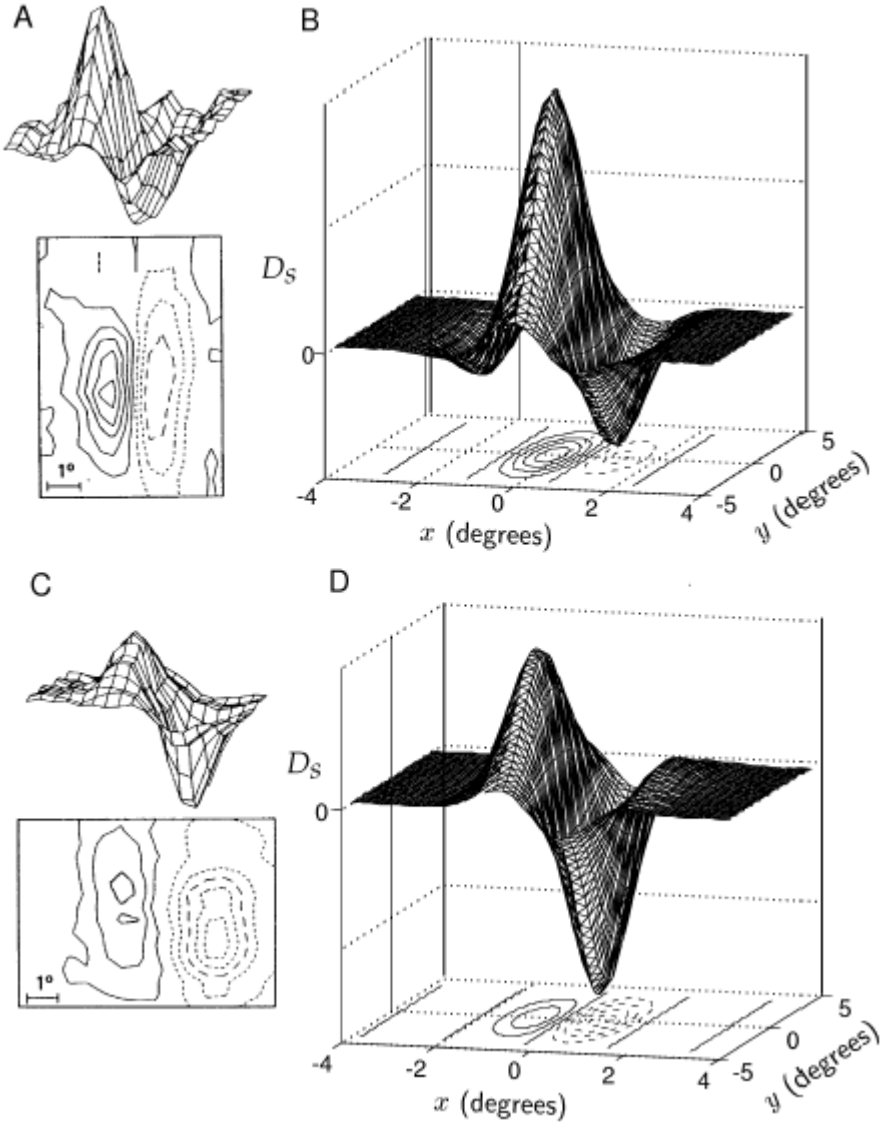
$$D(x, y, \tau) = D_s(x, y) D_t(\tau)$$



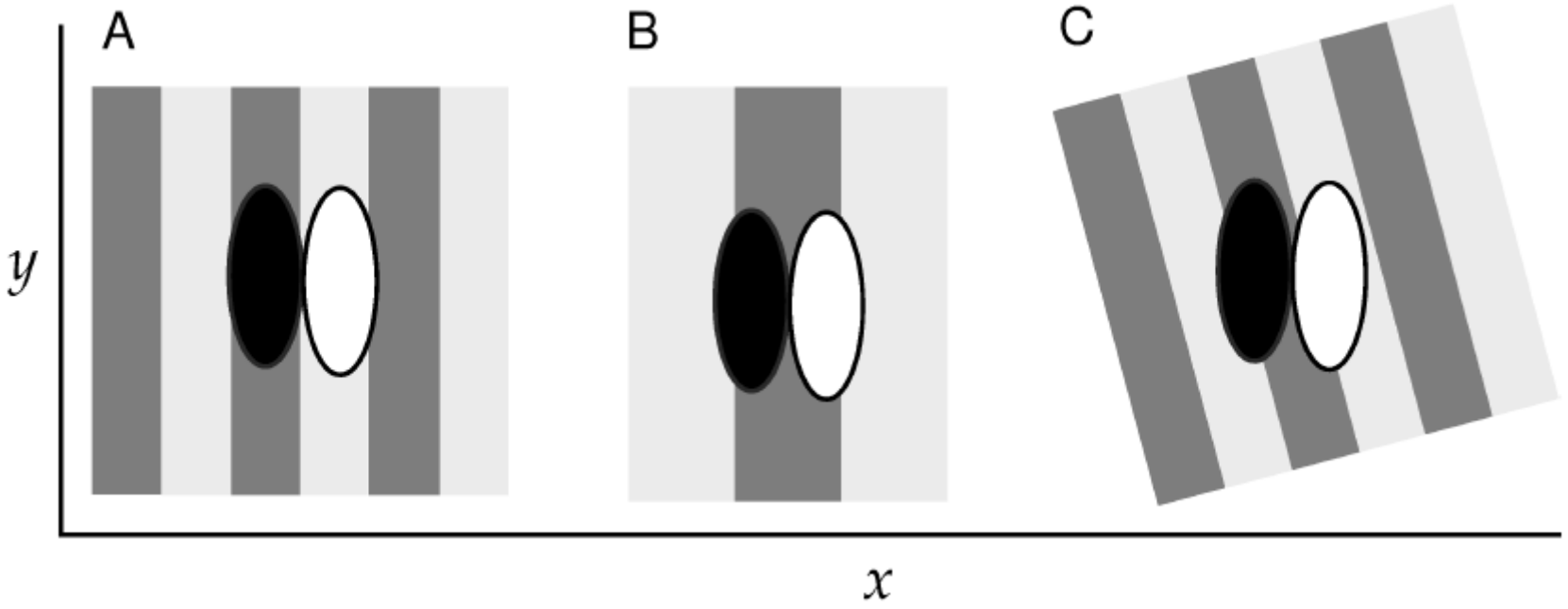
- Gabor-like spatial tuning for simple cells:

$$D_s = \exp\left(-\frac{(x - c_x)^2}{2\sigma_x^2} - \frac{(y - c_y)^2}{2\sigma_y^2}\right) cos(kx - \phi)$$

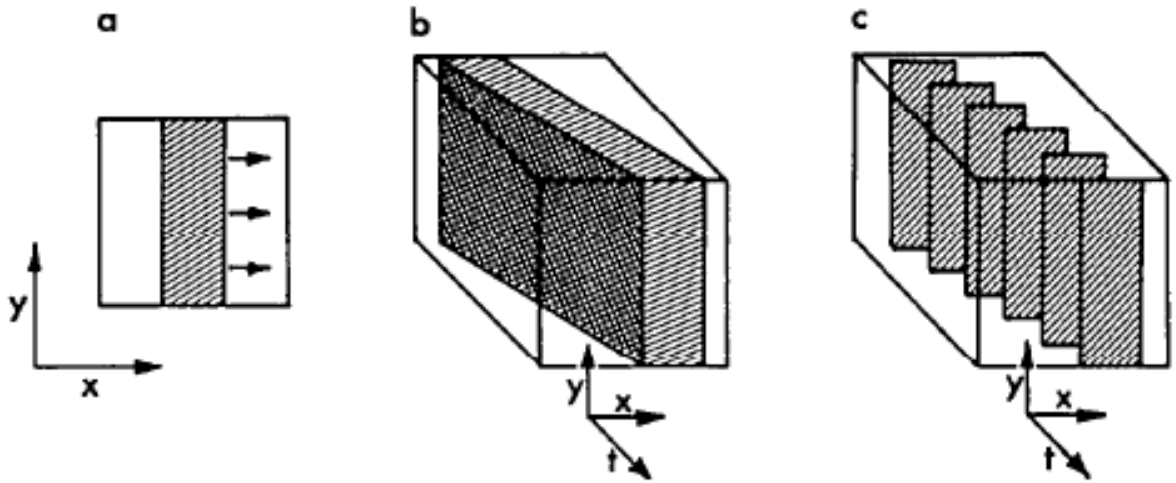
Linear RFs


A
B
C
D
1°
1°
D_S
0
D_S
0
-4
-2
0
2
4
x (degrees)
-5
0
5
y (degrees)
-4
-2
0
2
4
x (degrees)
-5
0
5
y (degrees)

Orientation Selectivity

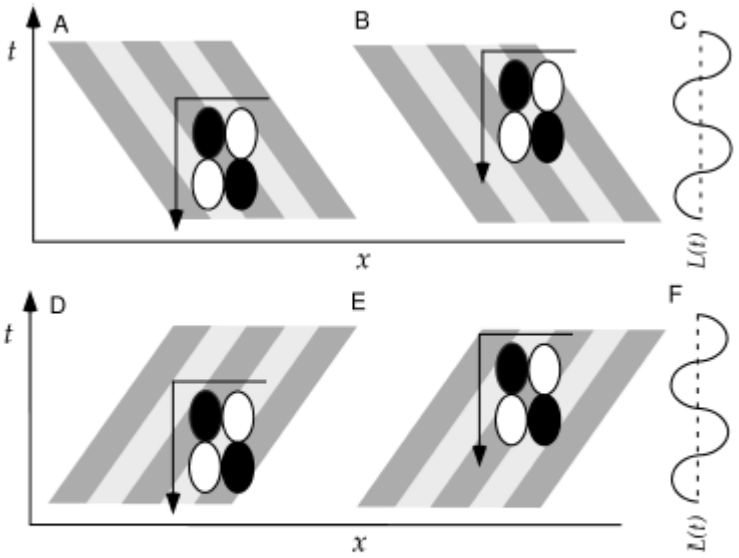


Drifting Gratings

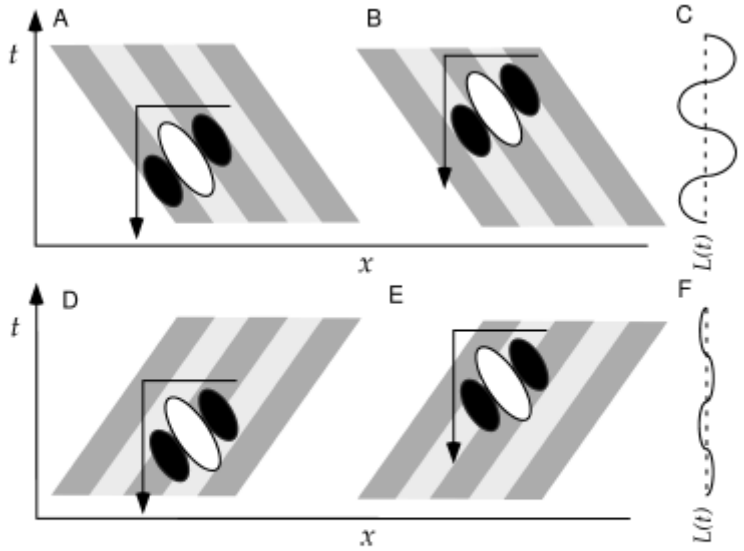


$$s(x, y, t) = G + Acos(kx - \phi)cos(\omega t)$$

Space-Time (In)Separability



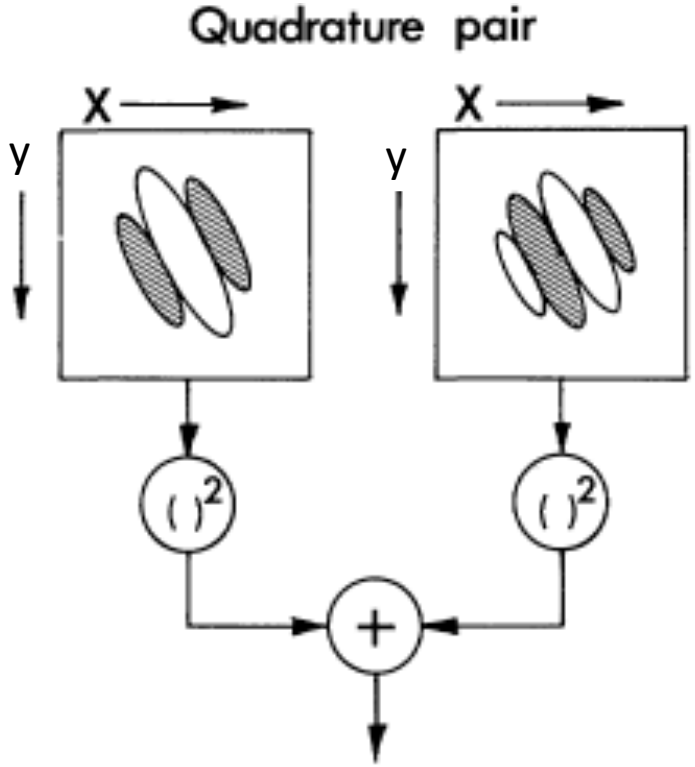
Separable: motion sensitive;
not direction sensitive



Inseparable: motion sensitive;
and direction sensitive

Complex Cells

- sensitive to orientation, but not spatial phase



Visual Hierarchy

hierarchical processing:

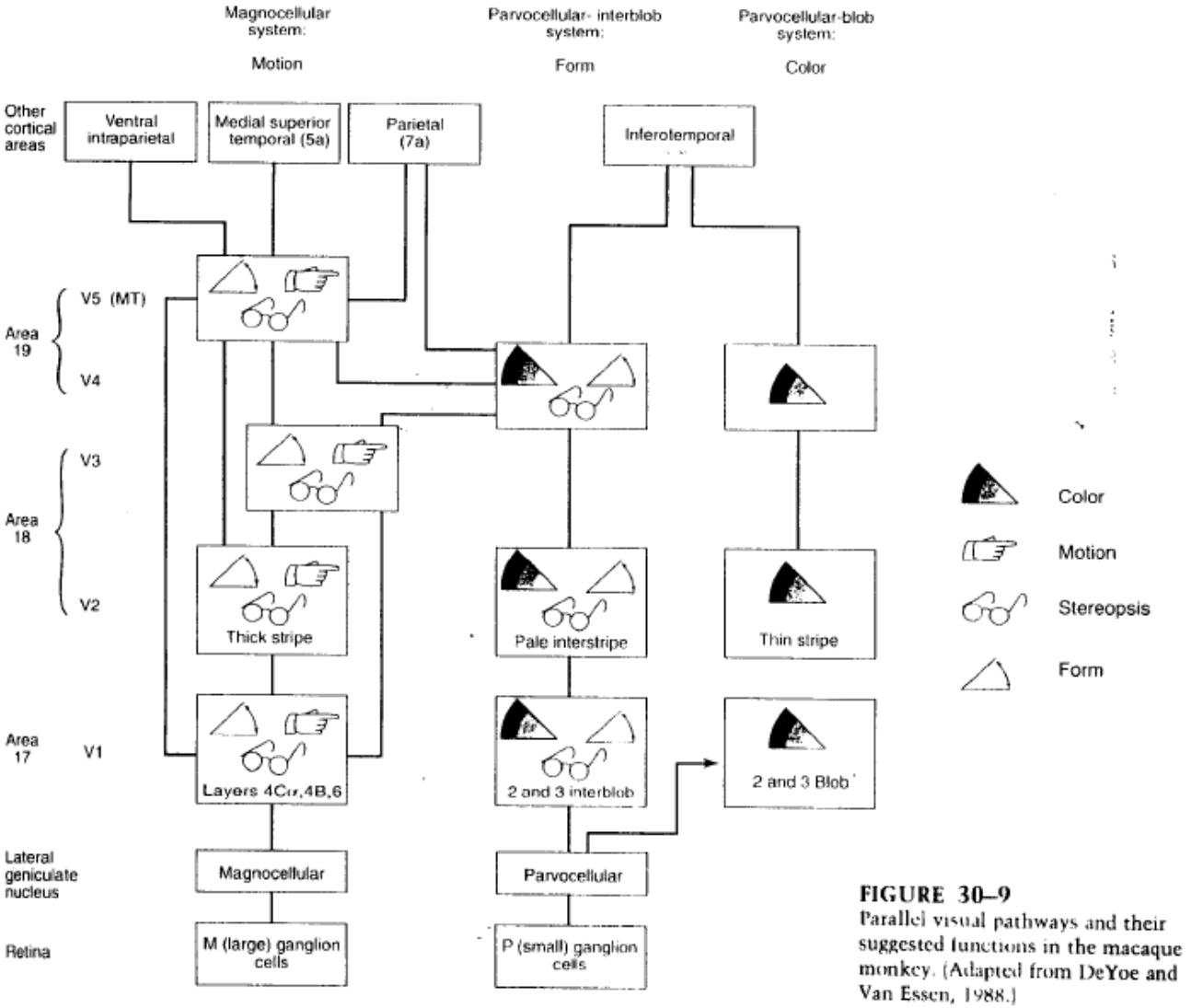


FIGURE 30–9
Parallel visual pathways and their suggested functions in the macaque monkey. (Adapted from DeYoe and Van Essen, 1988.)