Vision in Man and Machine

Part 2
The Human Visual Pathways and Early Feature Processing

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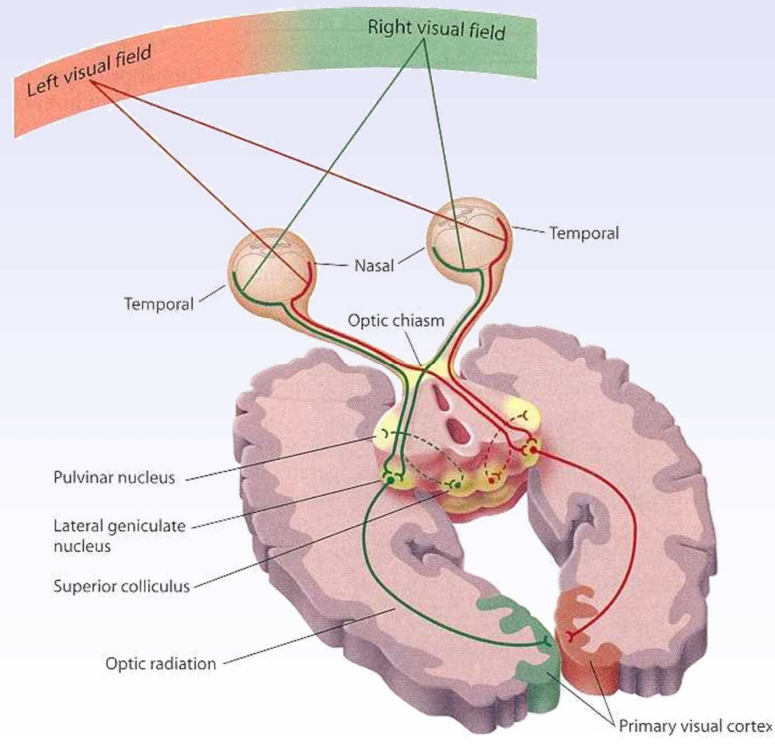
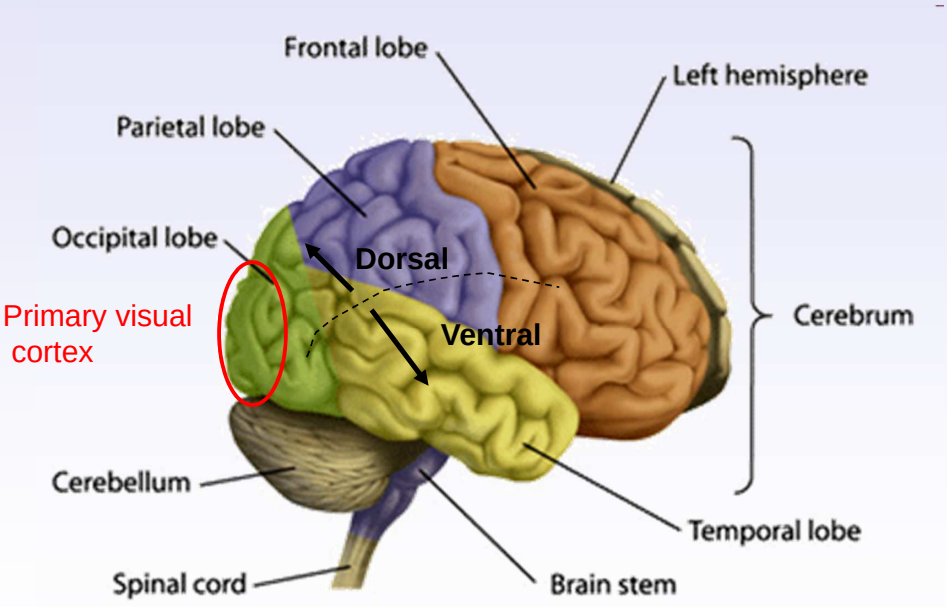
The human visual system

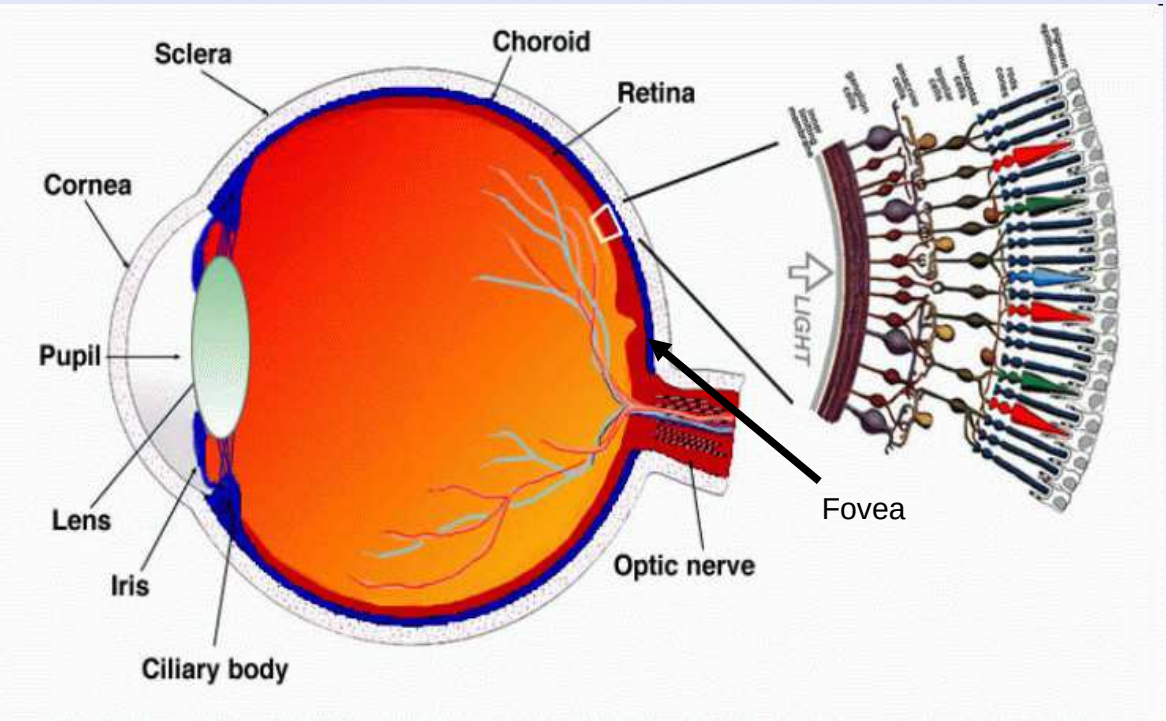
- Eyes → Retina
  - Sensor array
- LGN
  - Thalamic relay station
- Primary visual cortex
  - First visual area: V1
  - Topographical organization
  - Left-right separation
- Secondary and association cortex
  - Intermediate and high-level visual representations



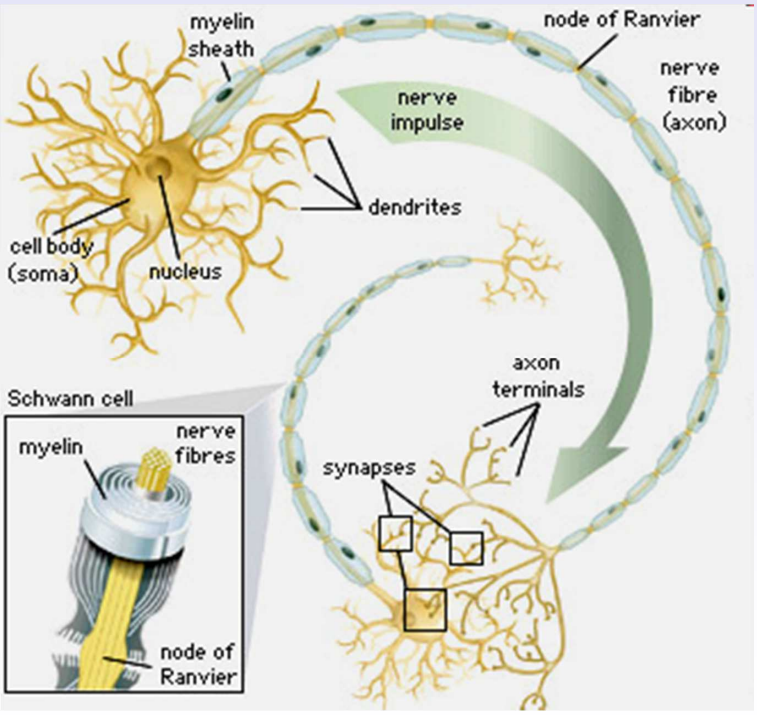
Cortex Areas - Lobes



The eye and retina

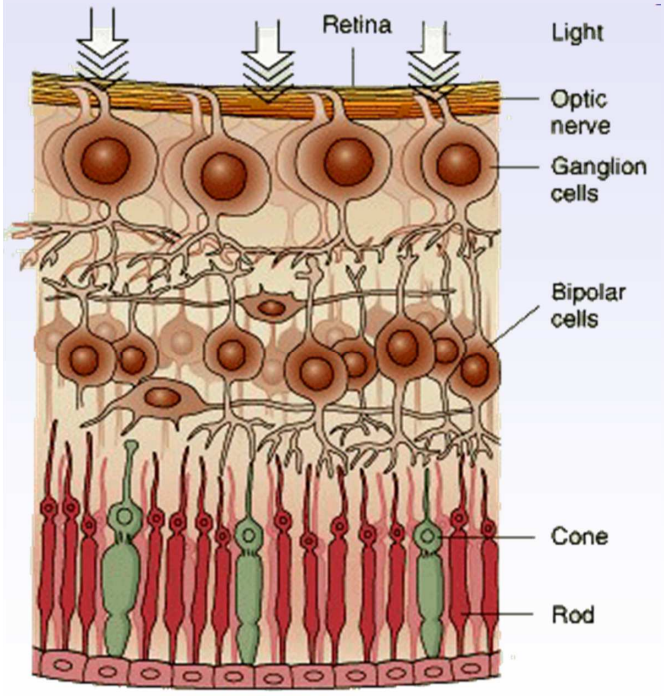


Neurons



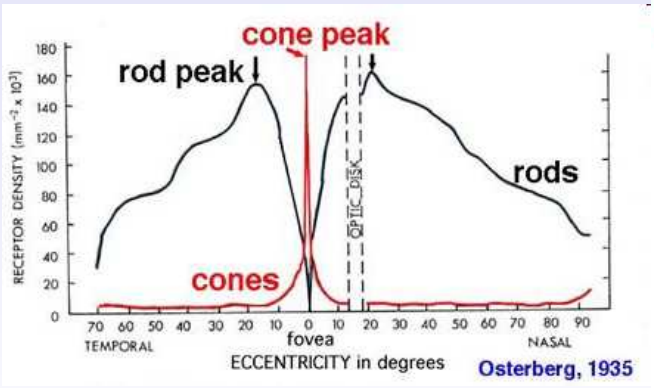
- Cell body integrates electrical signals from dendrites
- Axon projects to other neurons
- Action potentials (spikes) travel along the axons
- Synapses control the signal transmission by chemical signalling

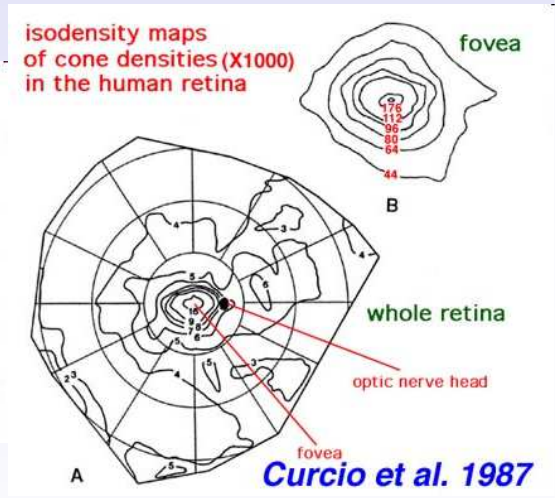
The retinal neural structure



- Powerful computation architecture
- Photoreceptors: Rods and Cones
- Rods: ~120 million
  High sensitivity
- Cones: ~8 million
  Lower sensitivity
  Color vision

Receptor distribution on the retina





- Fovea has highest cone density
- Receptor distribution is not completely regular

Spotting the blind spot

Localizing functions - Phrenology

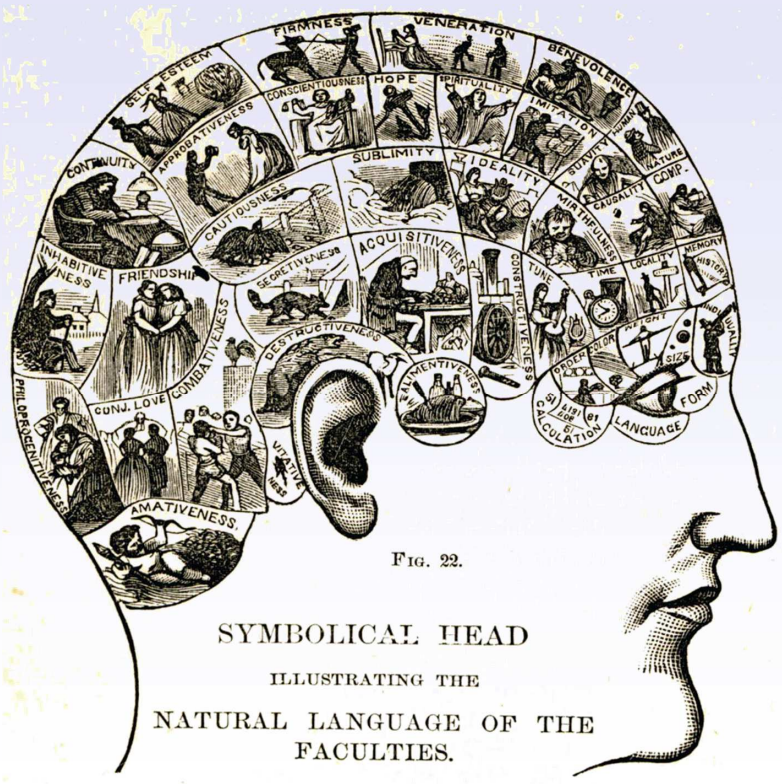


FIG. 22.

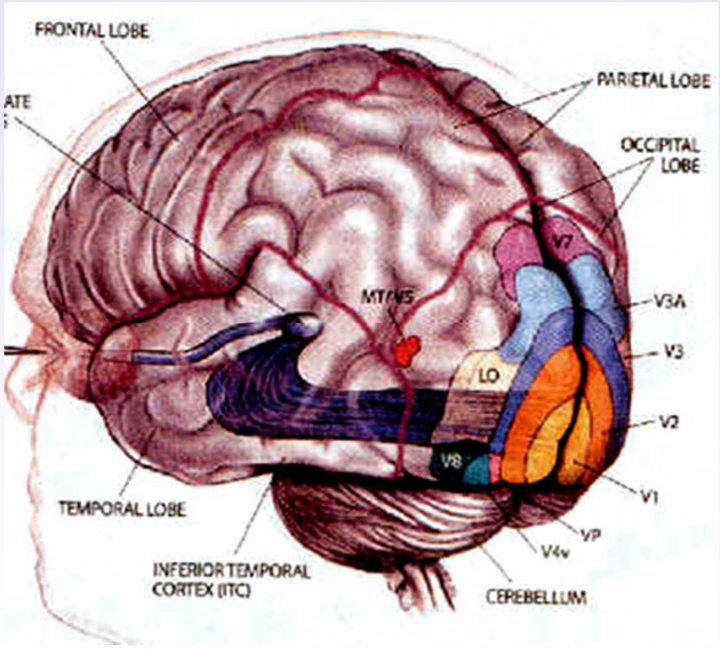
SYMBOLICAL HEAD

ILLUSTRATING THE

NATURAL LANGUAGE OF THE FACULTIES.

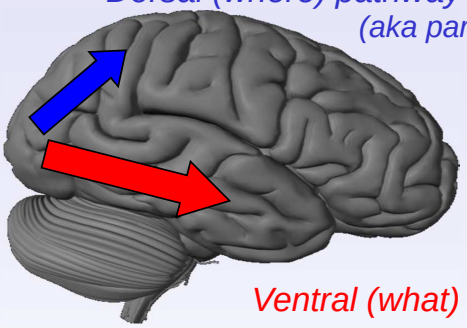
Localizing functions – Visual cortex areas

- A large part of the brain deals with visual information (macaque monkey >50% van Essen 1990)

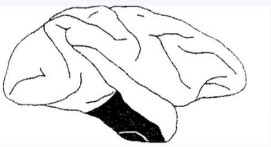


Localizing functions – Ventral and dorsal pathways

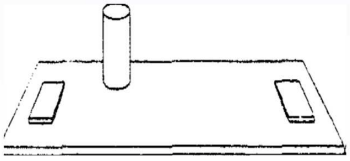
- What and where separation in visual processing (Ungerleider & Mishkin 1982)



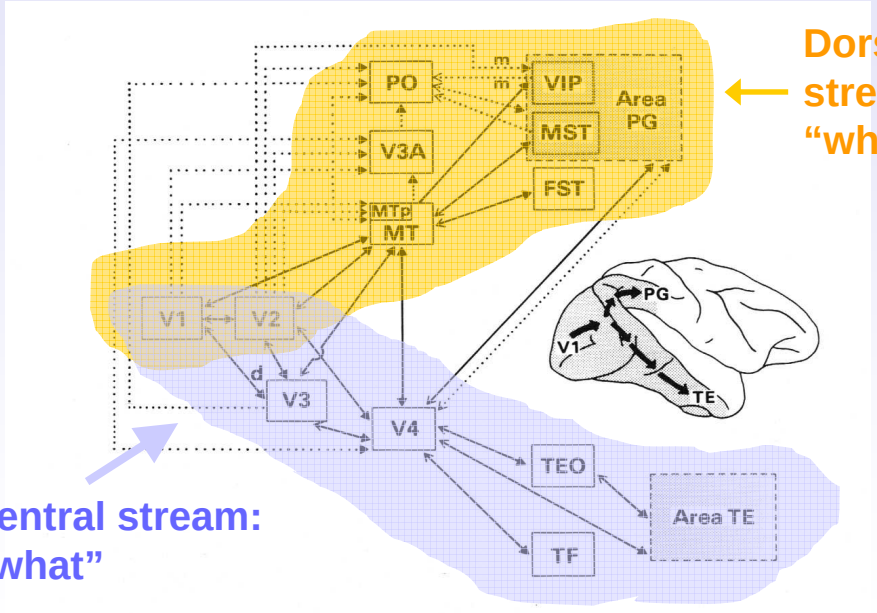
Dorsal lesion



Ventral lesion



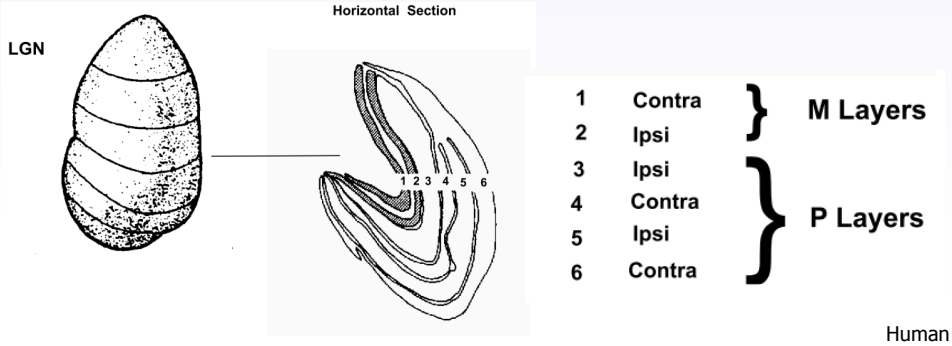
Visual Areas



Magnocellular(M) and parvocellular(P) pathways

- Retinal ganglion cells can be differentiated into M and P cells
- Depends on the projection to LGN

Property	P cells	M cells
Contrast Sensitivity	lower	higher
Receptive field size	smaller	higher
Temporal resolution	lower	higher
Conduction velocity	lower	higher
Response to luminance contrast	tonic (sustained)	phasic (transient)
Spectral selectivity	yes	no



Magnocellular(M) and parvocellular(P) pathways

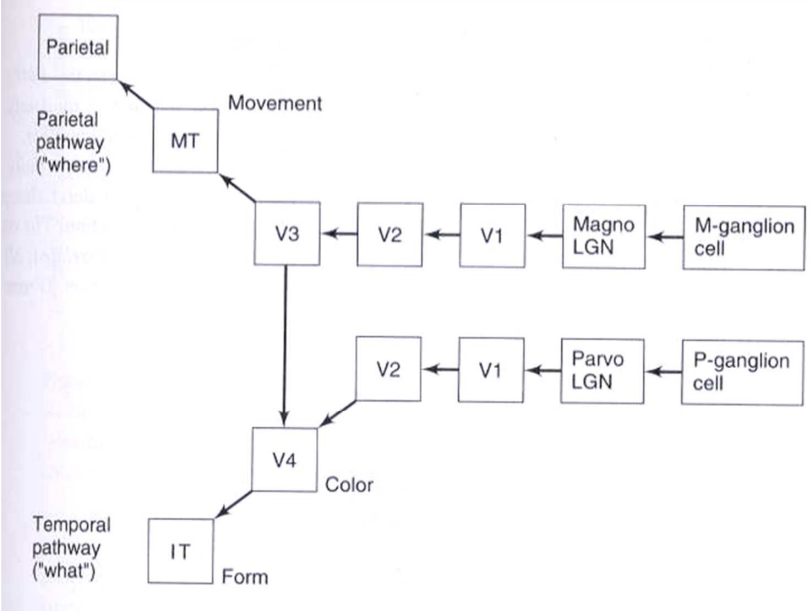
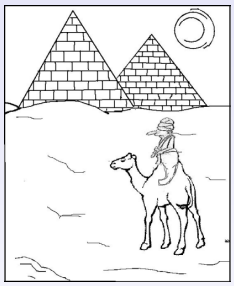


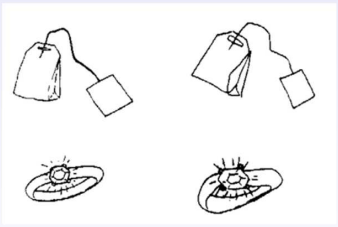
Figure 3.20
Simplified diagram of the visual pathways. Signals flow from right to left, starting with the M and P ganglion cells on the far right, which feed into the parietal and temporal pathways, respectively. V1 is the striate cortex, and V2, V3, and V4 are extrastriate visual areas; other extrastriate areas are IT, inferotemporal cortex; MT, medial temporal cortex; and Parietal, which refers to other areas in the parietal lobe. The visual qualities most strongly associated with areas MT, V4, and IT are indicated.

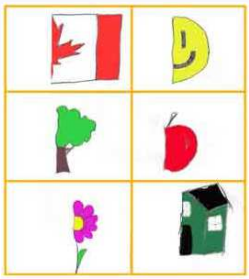
Visual Agnosias: Evidence for visual modularity

- Agnosia: Loss of the ability to recognize objects/scenes/people although the initial visual sensory processing is intact
- Simultanagnosia: Inability to see more than one object at the same time
- Prosopagnosia: Inability to recognize faces
- Associative visual agnosia: Inability to recognize objects
- Hemineglect: Lack of spatial attention
- Blindsight: Response to visual stimuli without awareness

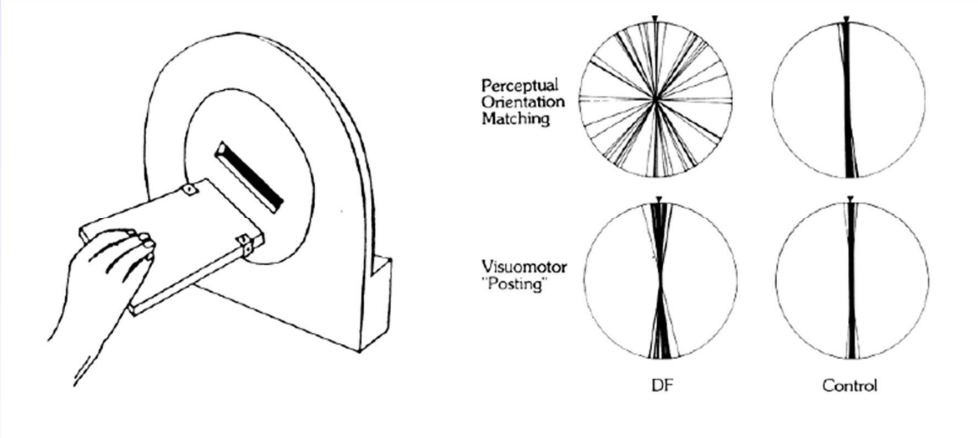


"a man looking at mountains"





Acting without "recognizing"



Visual Form Agnosia – DF

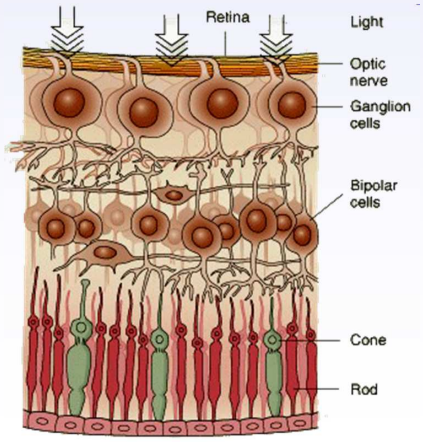
Deficit in 'seeing' but 'action' intact

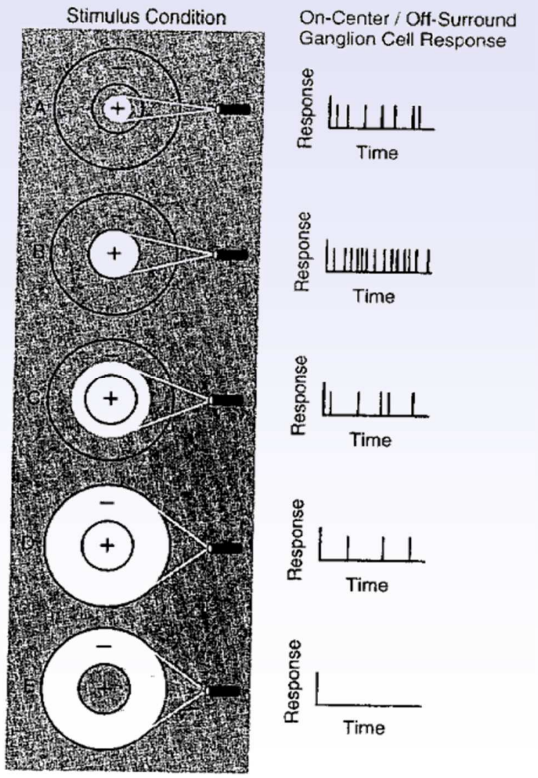
Parietal pathway is serving motor-guided behavior "how vs. where" (Milner & Goodale 1995)

Early feature processing

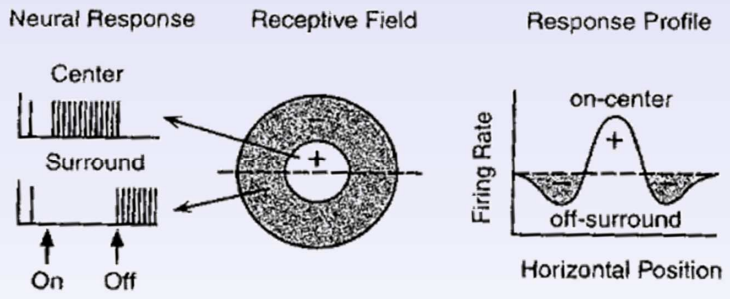
- How does the visual cortex compute/generate visual information ?
- How can we understand the basic visual processing principles ?
- What determines the "usefulness" of a visual representation ?

Ganglion cell responses

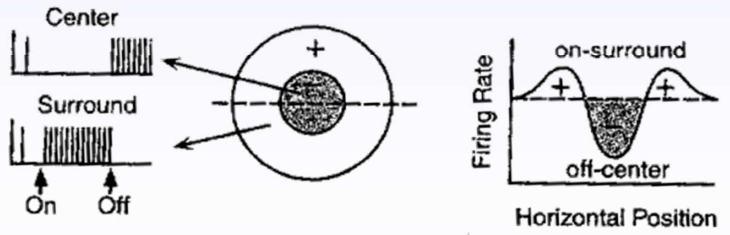




Receptive field structure of ganglion cells

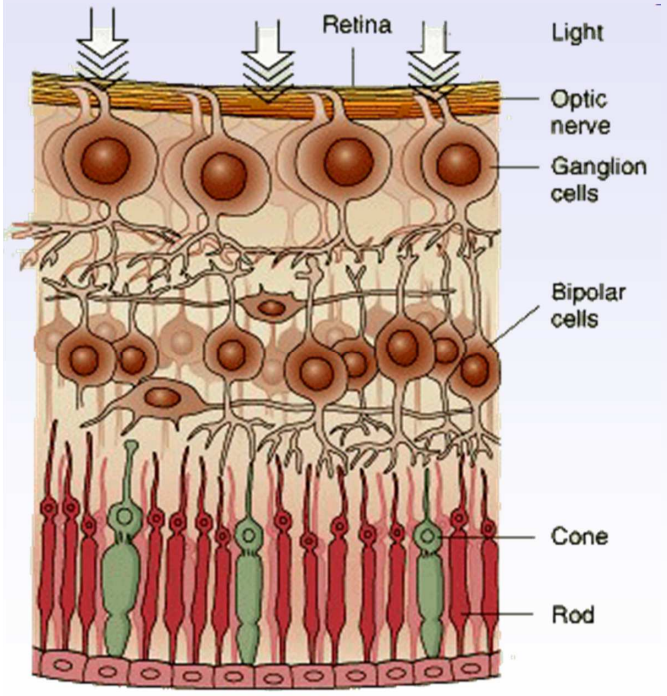


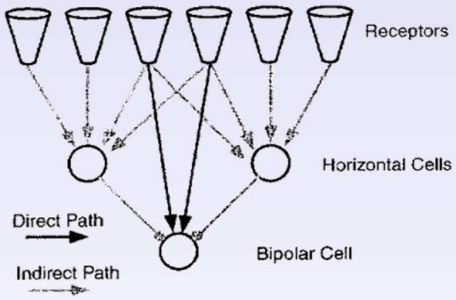
A. ON-CENTER OFF-SURROUND CELLS



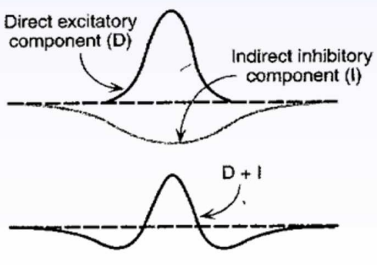
B. OFF-CENTER ON-SURROUND CELLS

Wiring for Mexican-hat response





A. WIRING DIAGRAM



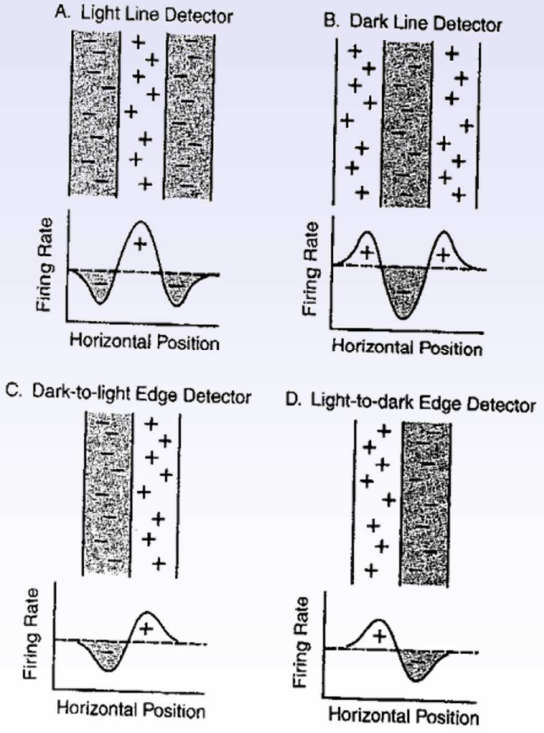
B. RECEPTIVE FIELD PROFILES

Hubel and Wiesel's discovery

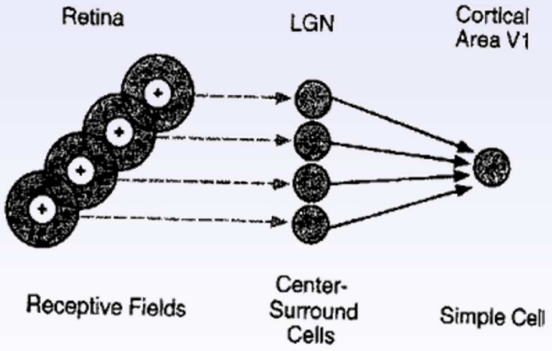
- "Simple" and "complex" cells in the cat visual cortex

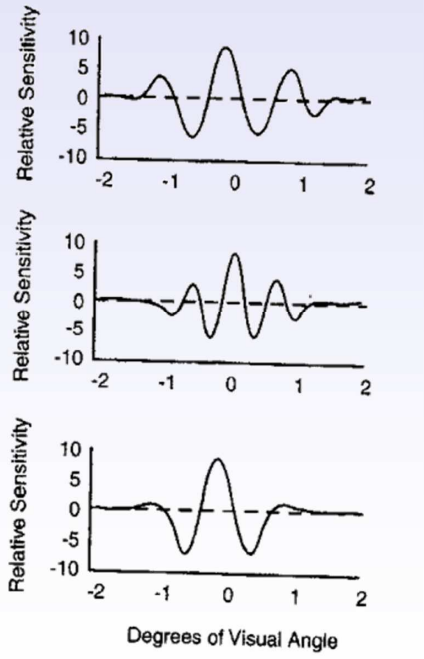
Hubel and Wiesel, 1981 Nobel prize

→Video



Simple cells continued

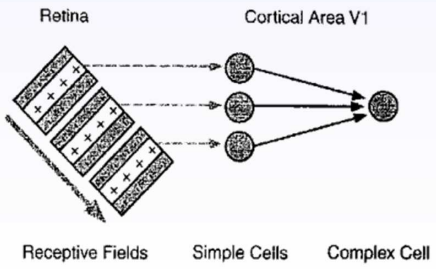


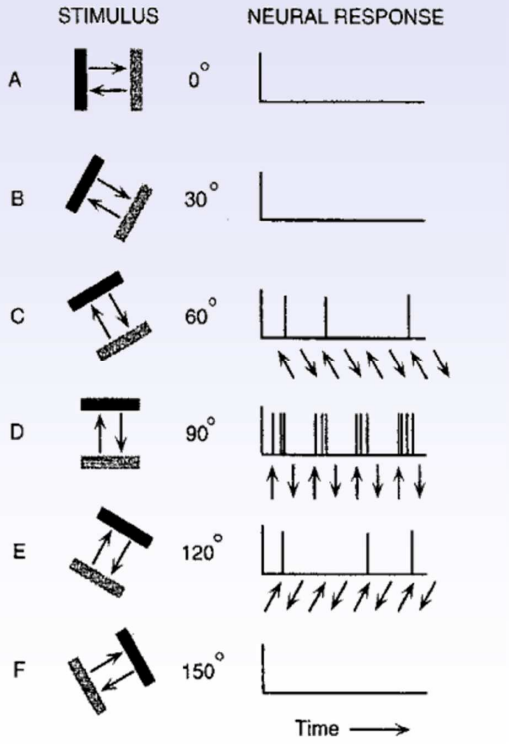


Complex cells

Properties of complex cells

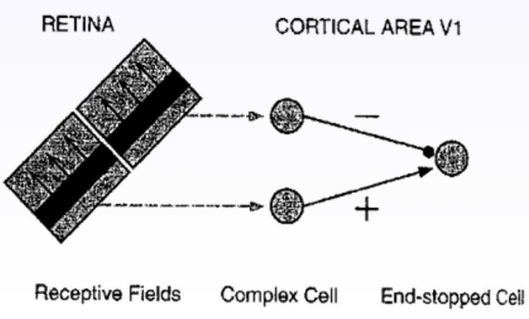
- Nonlinearity
- Motion sensitivity
- Position insensitivity
- Spatial extension

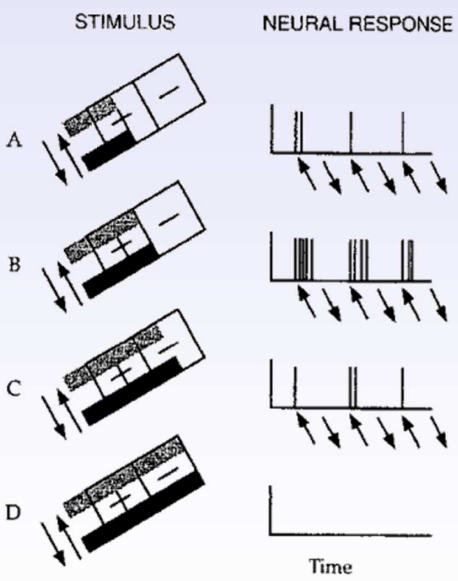




Hypercomplex cells

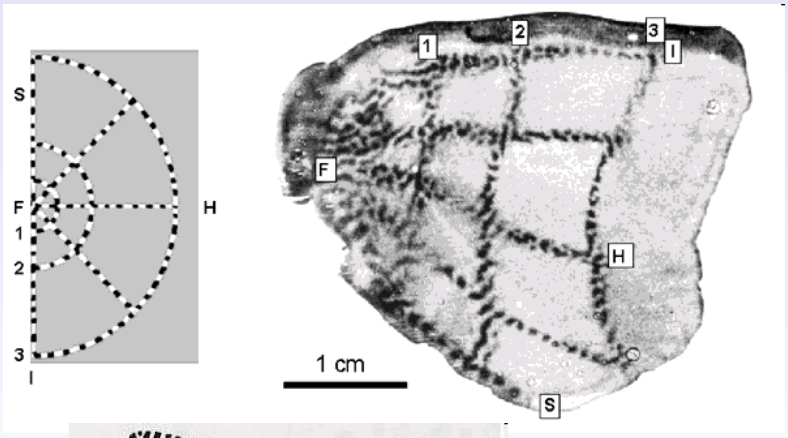
- End-stopping

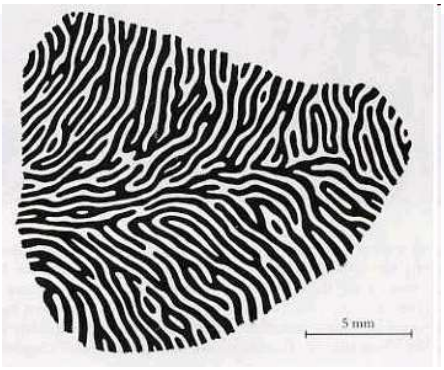




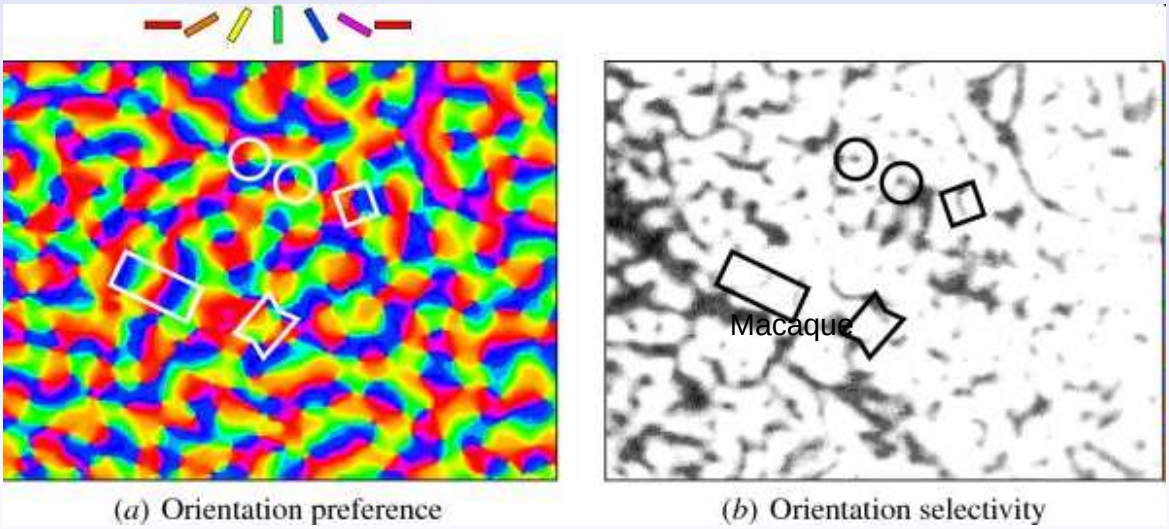
Architecture of V1 – Striate cortex

- Retinotopic mapping
- Ocular dominance stripes

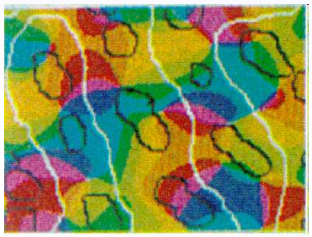




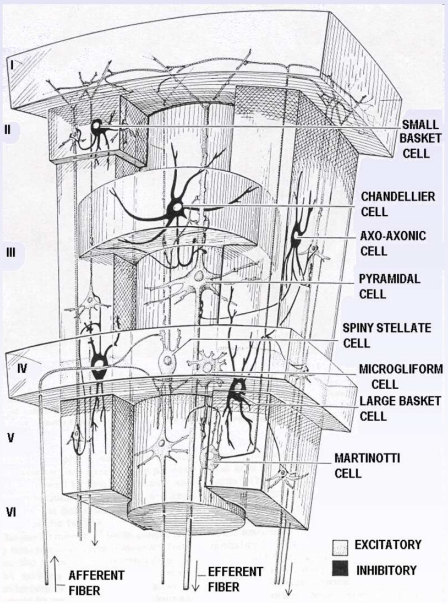
Ocular Dominance and Orientation Selctivity

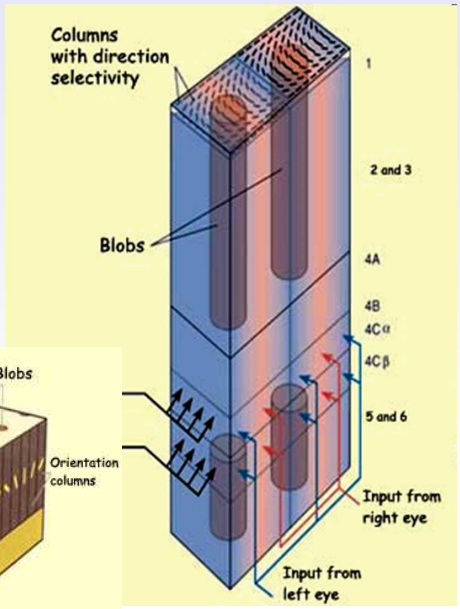


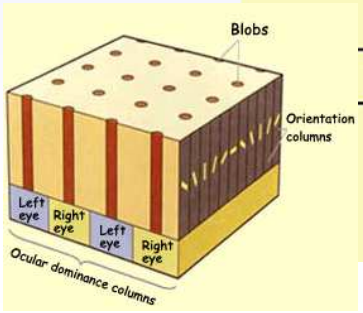
(*a*) Orientation preference (*b*) Orientation selectivity



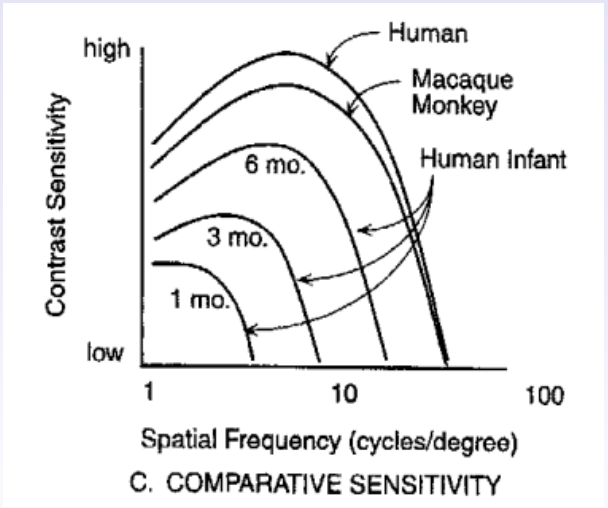
Cortical Column



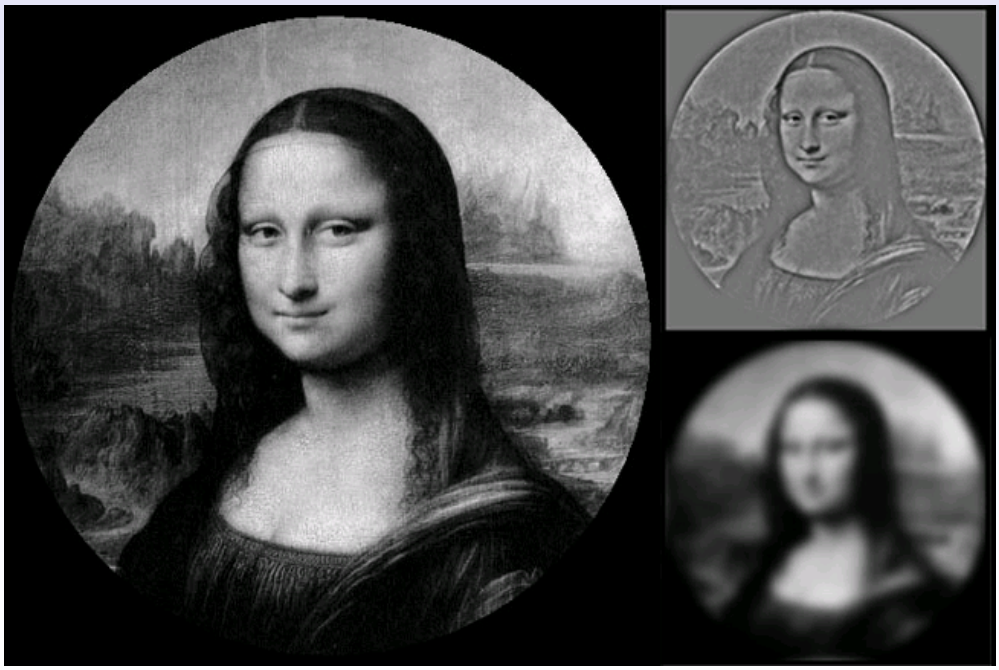




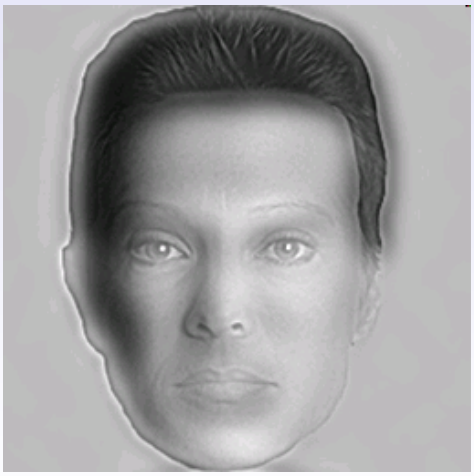
Spatial frequencies



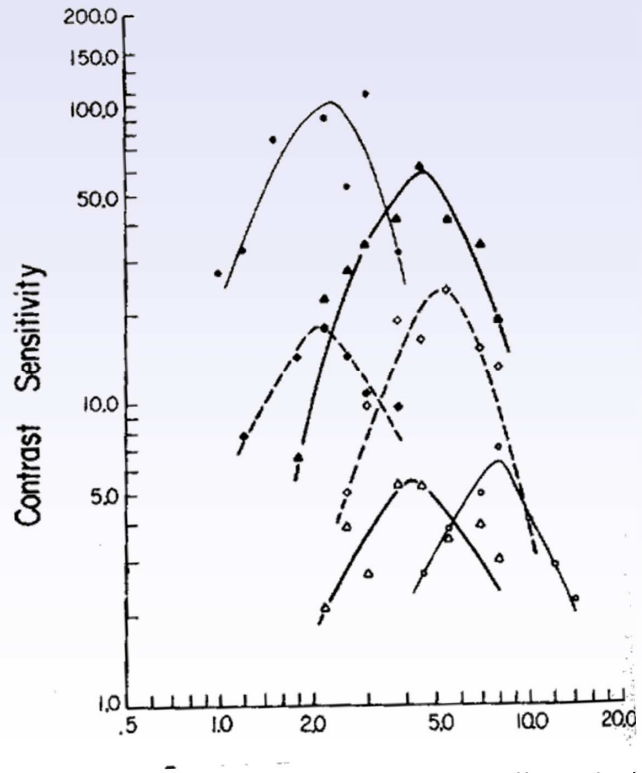
Spatial frequency-based image decomposition



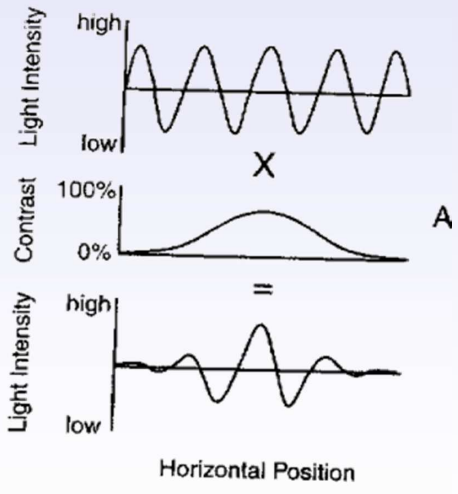
Hybrid images



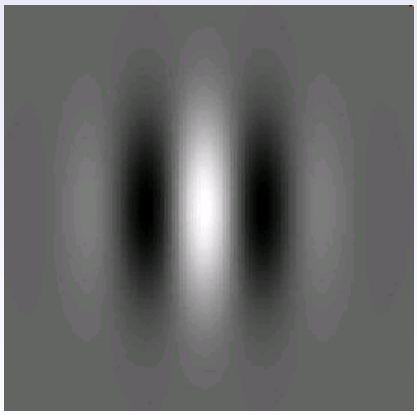
Contrast sensitivity functions



Two-dimensional Gabor function



$$f(x) = e^{\left(-\frac{x^2}{\sigma^2}\right)} \cos(2\pi\omega x)$$



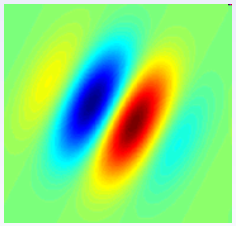
$$f(x, y) = e^{\left(-\left(\frac{x^2+y^2}{\sigma^2}\right)\right)} \cos(2\pi\omega x)$$

General 2D Gabor

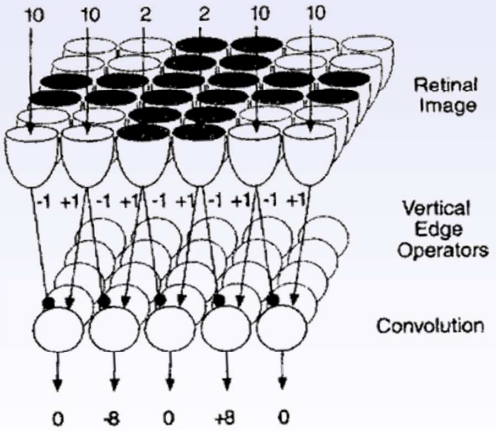
$$g(x, y; \lambda, \theta, \psi, \sigma, \gamma) = \exp\left(-\frac{x'^2 + \gamma^2 y'^2}{2\sigma^2}\right) \cos\left(2\pi \frac{x'}{\lambda} + \psi\right)$$

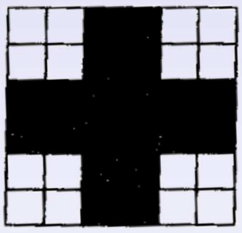
$$x' = x \cos\theta + y \sin\theta$$

$$y' = -x \sin\theta + y \cos\theta$$

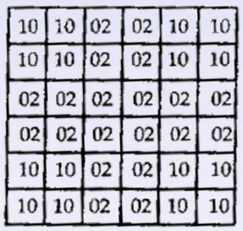


Convolution and receptive fields





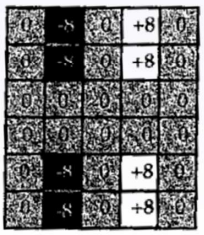
A. Grayscale Image



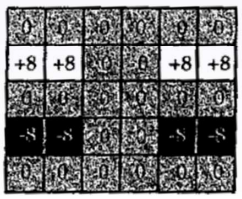
B. Image Intensities

C. Vertical Edge Operator

D. Horizontal Edge Operator

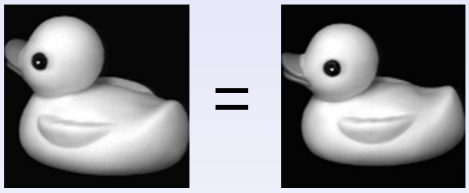


E. Convolution of Image with Vertical Edge Operator

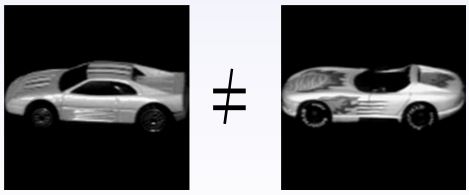


F. Convolution of Image with Horizontal Edge Operator

Basic recognition problem

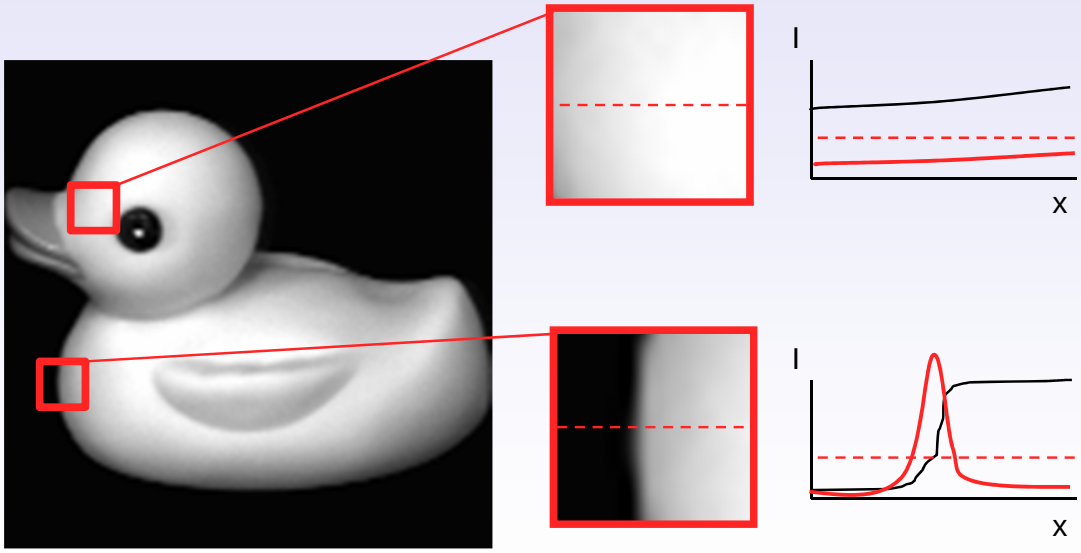


Stability
(invariance)

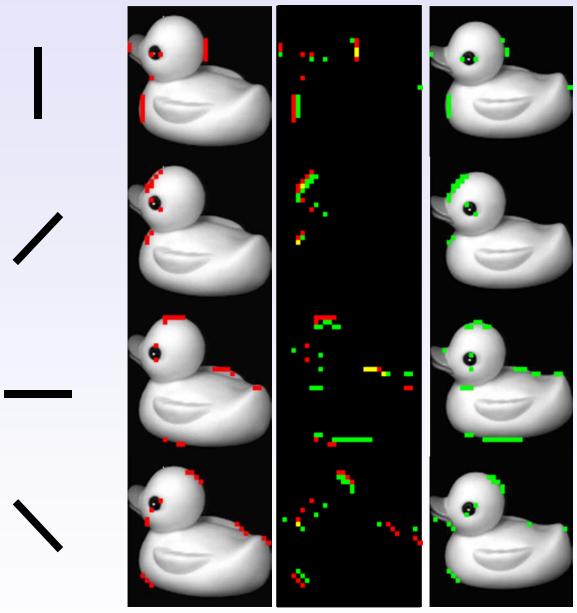


Selectivity

Edge feature detector

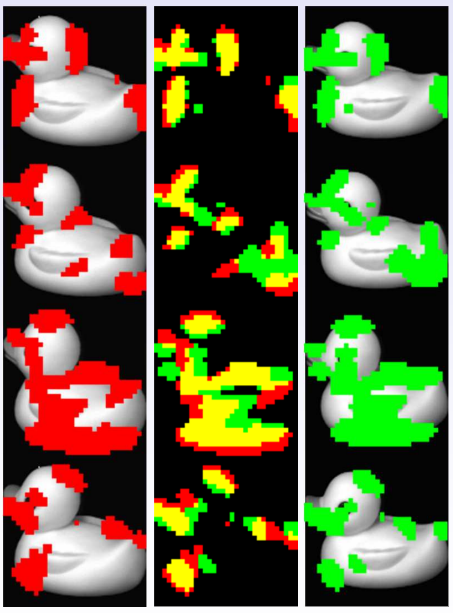


Feature Selectivity – Stability Dilemma



View1 Match View2

High Threshold = High Selectivity Low Stability

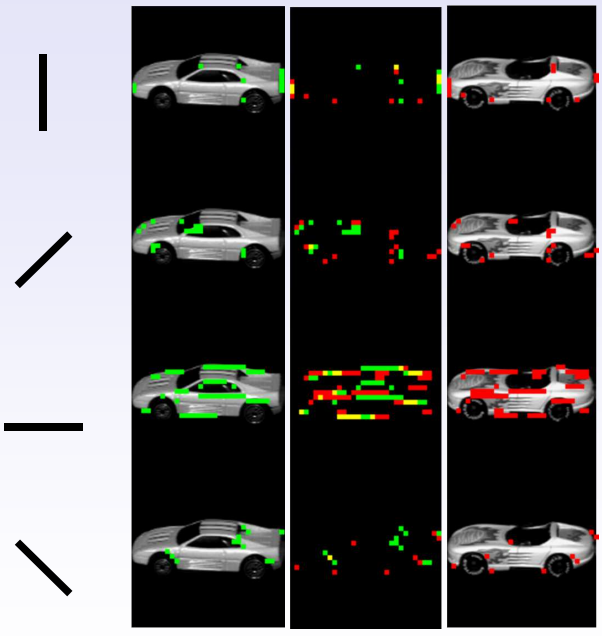


View1 Match View2

Low Threshold = Low Selectivity High Stability

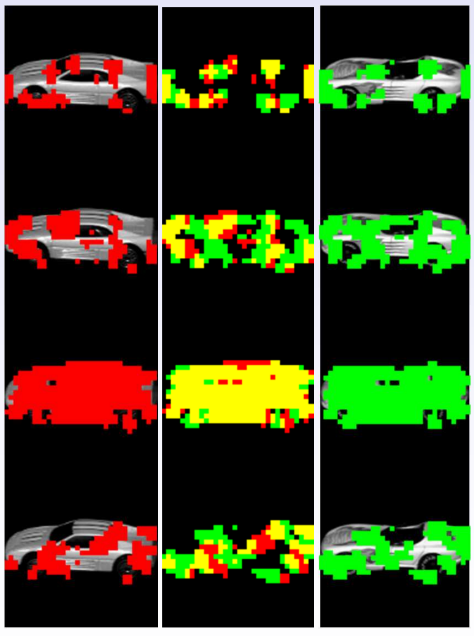
37

Feature Selectivity – Stability Dilemma



View1 Match View2

High Threshold = High Selectivity Low Stability



View1 Match View2

Low Threshold = Low Selectivity High Stability

38

Why does V1 detect “features” ?

- Robust information
- Conservation of information
- Selectivity versus stability
- → Practical tutorial