

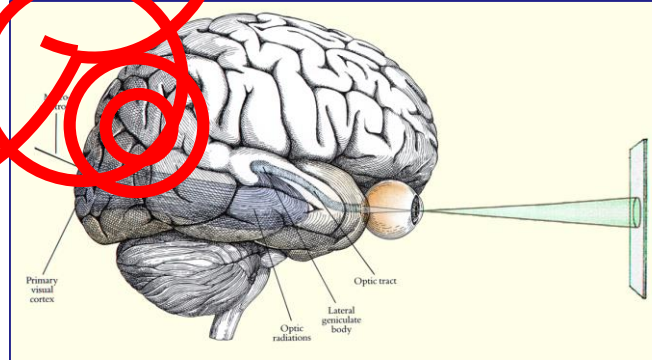
Introduction to Neuroscience:
Systems Neuroscience

Central visual processes

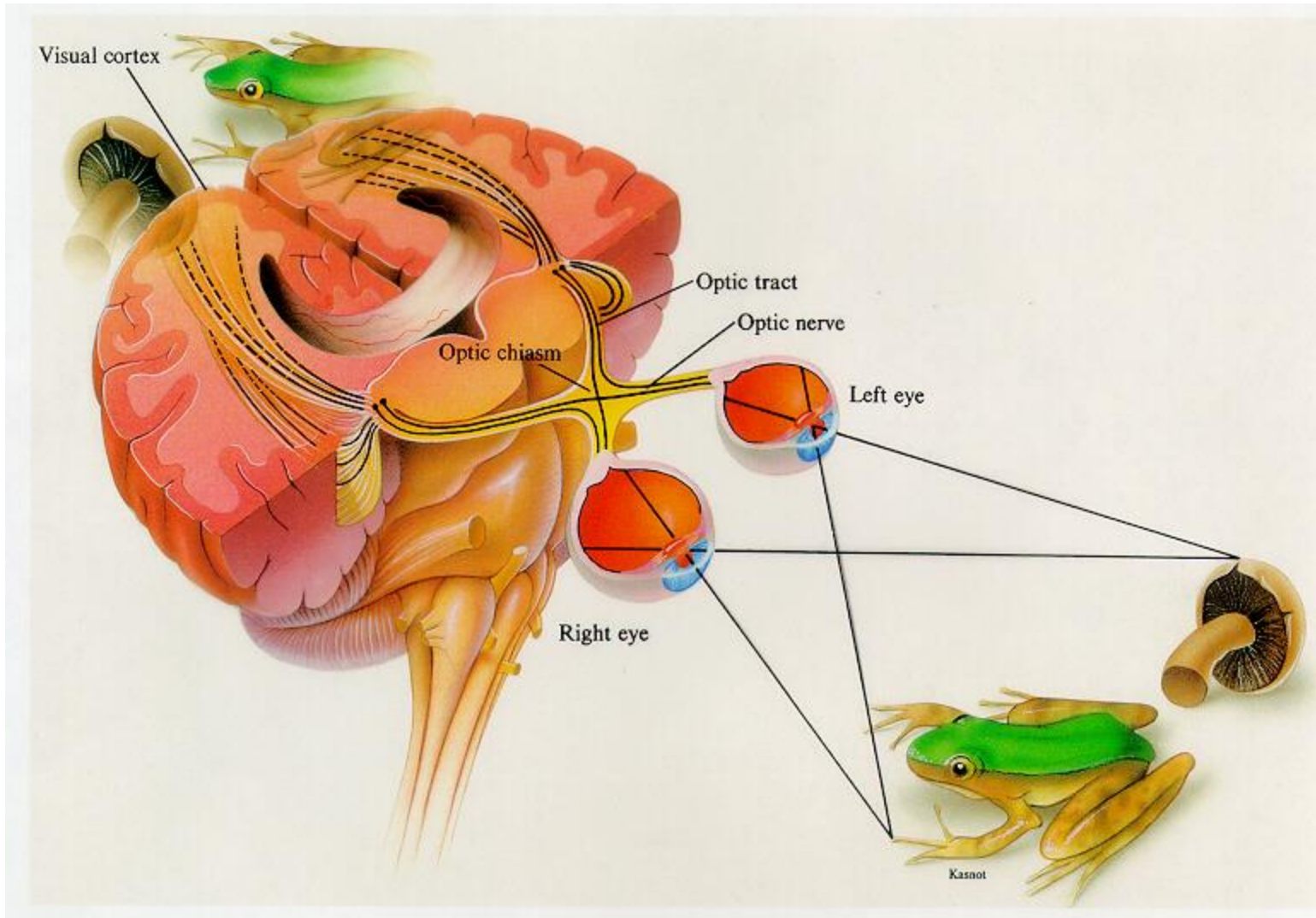
Rafi Malach

Department of Neurobiology

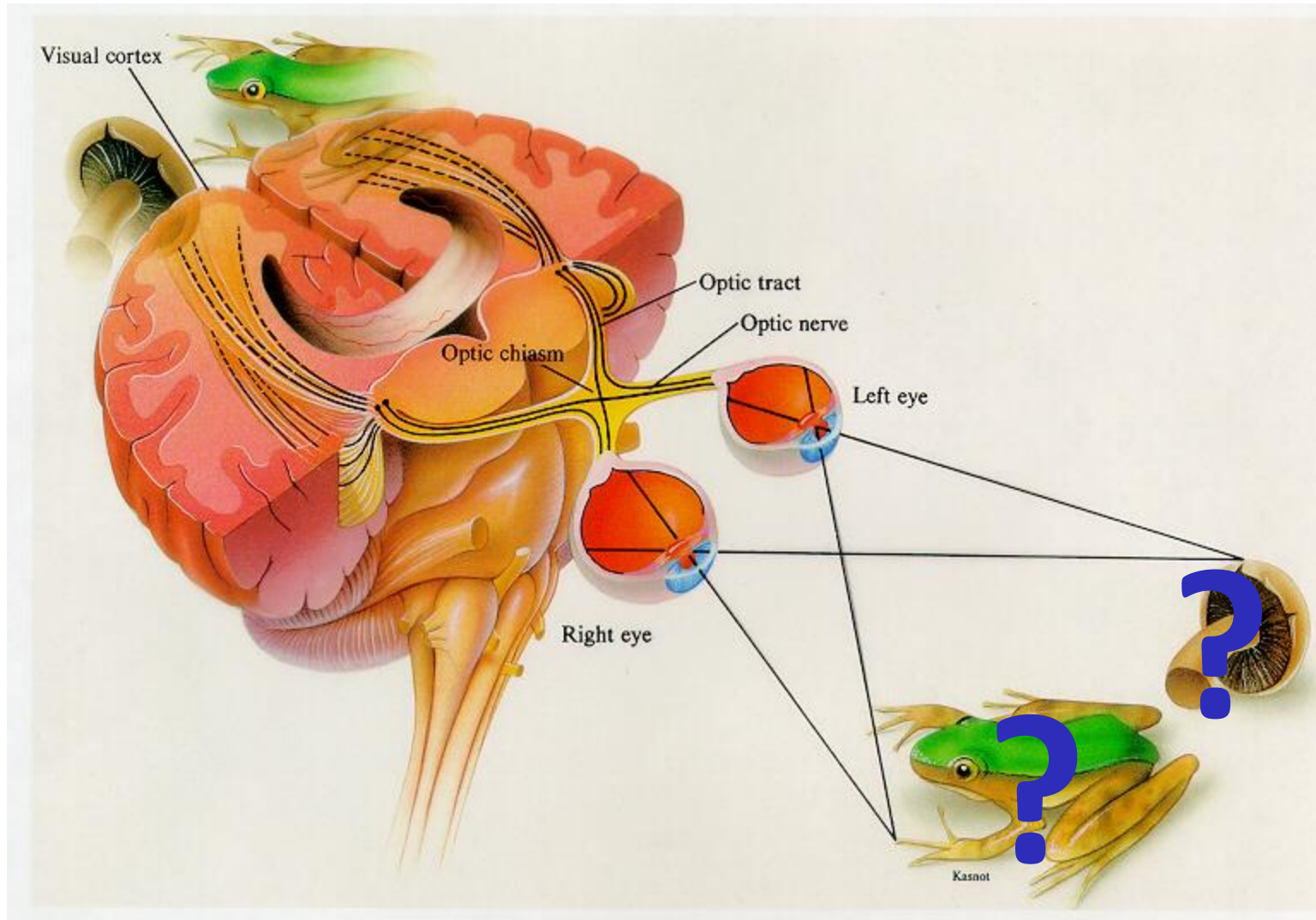
What is the function of the visual system? Creating an adaptive model of the environment



The representation model of visual perception



We do not see the external environment- only the model our visual system generates



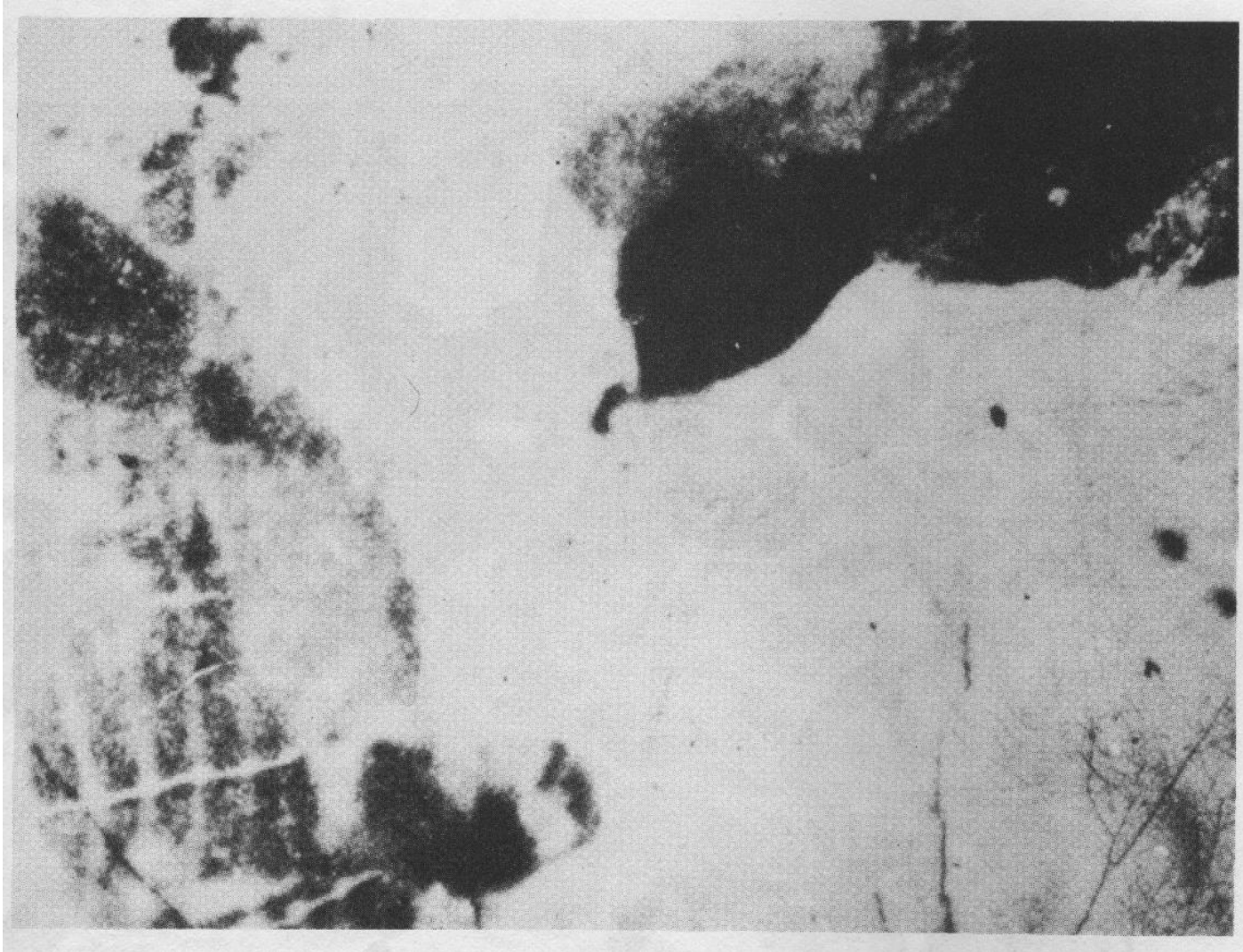
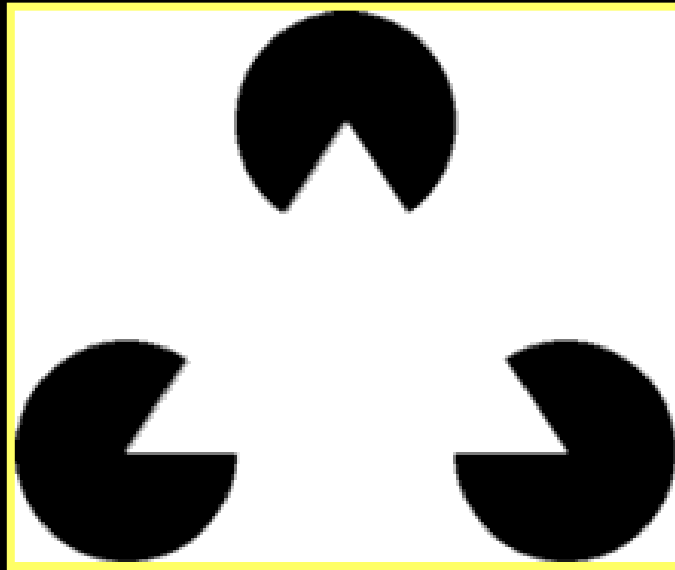


Illustration of the adaptive nature of vision



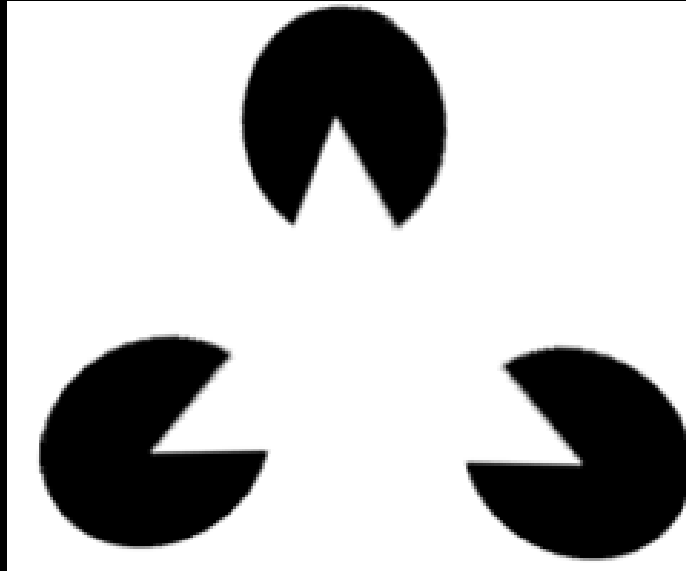
Illustrating the role of attention in visual model creation

Illusory Shapes contradict external information

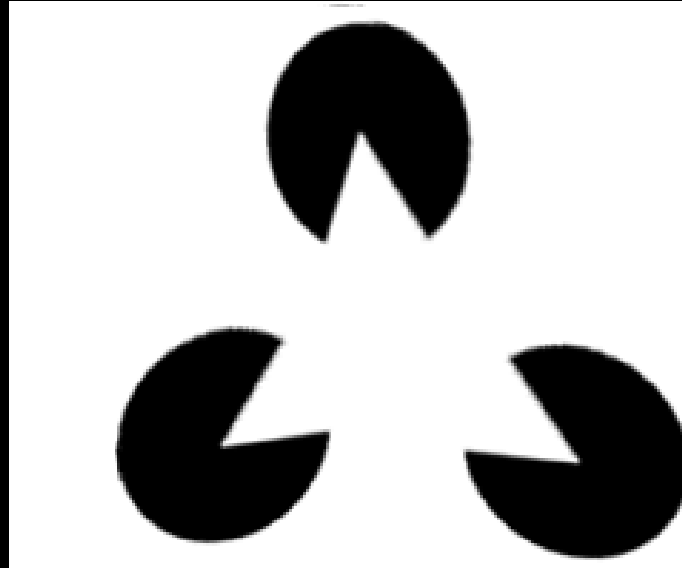


The Kanizsa Triangle

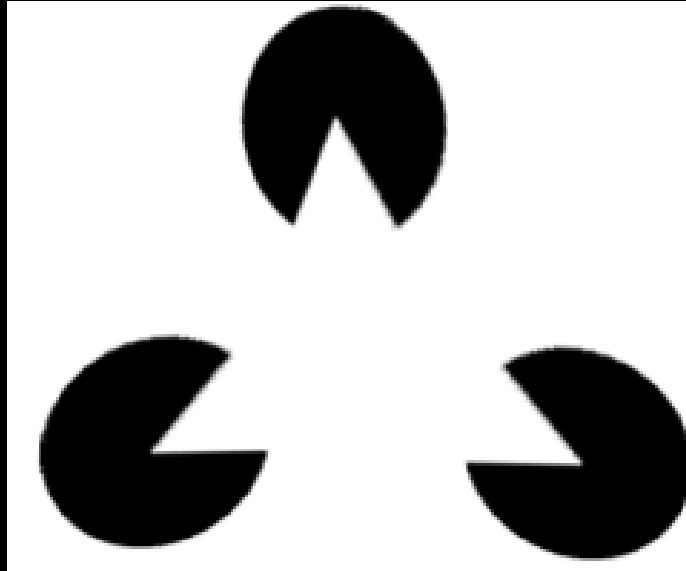
The motion illusion



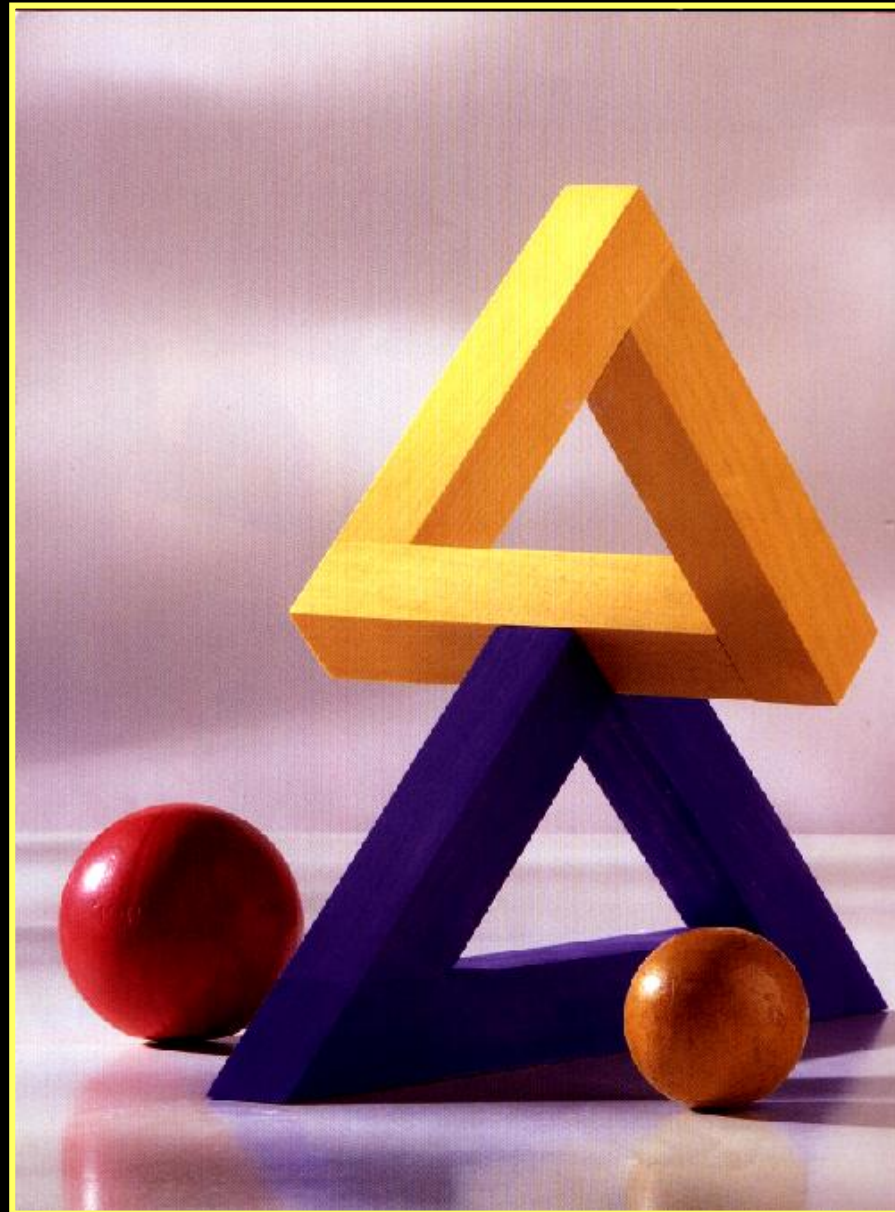
The motion illusion



The motion illusion

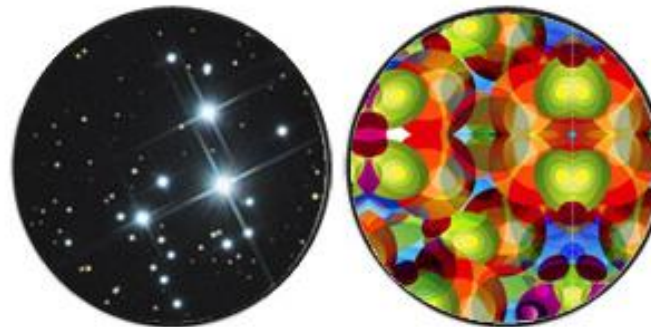


The visual system can create models of objects that can not possibly exist



Vivid visual images can be perceived by blind individuals

The Charles Bonnet Syndrome

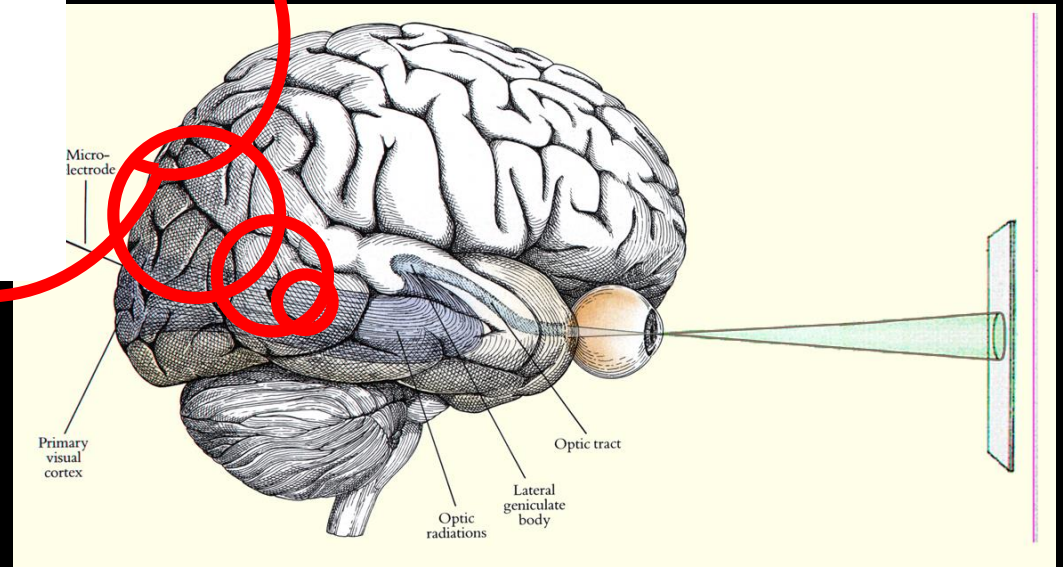


Examples of Charles Bonnet Hallucinations

Interim Summary

- Sensory perception is not the formation of a copy or representation of the external world
- The purpose of perception is to create a model of the world that helps us function effectively

The neuronal process underlying visual perception

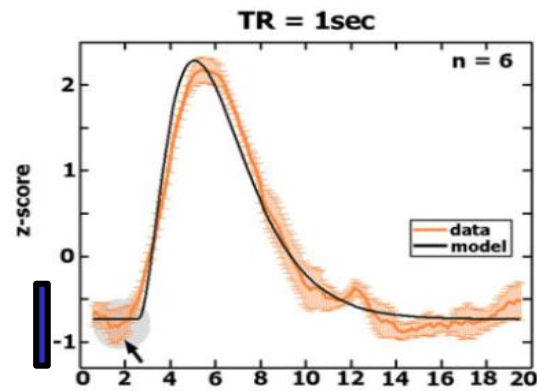
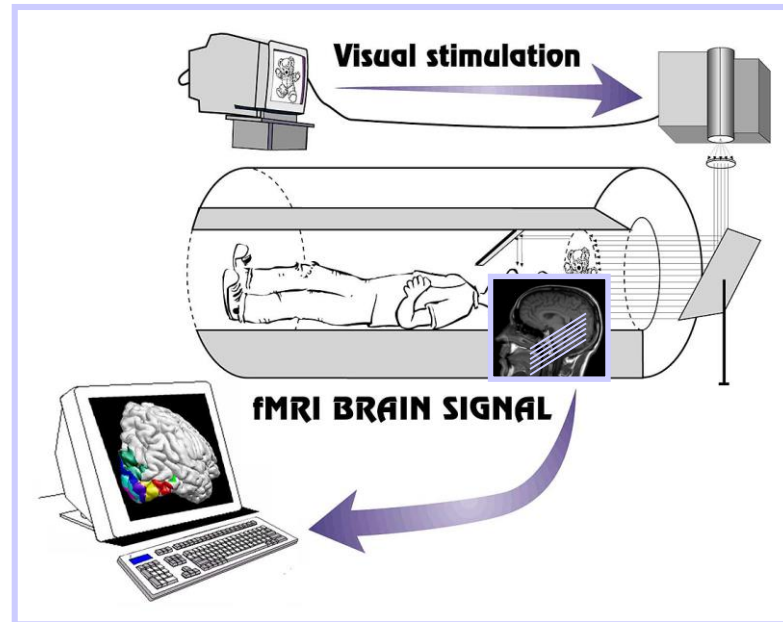


The Methods

Functional Magnetic Resonance Imaging

10^5 - 10^6 neurons

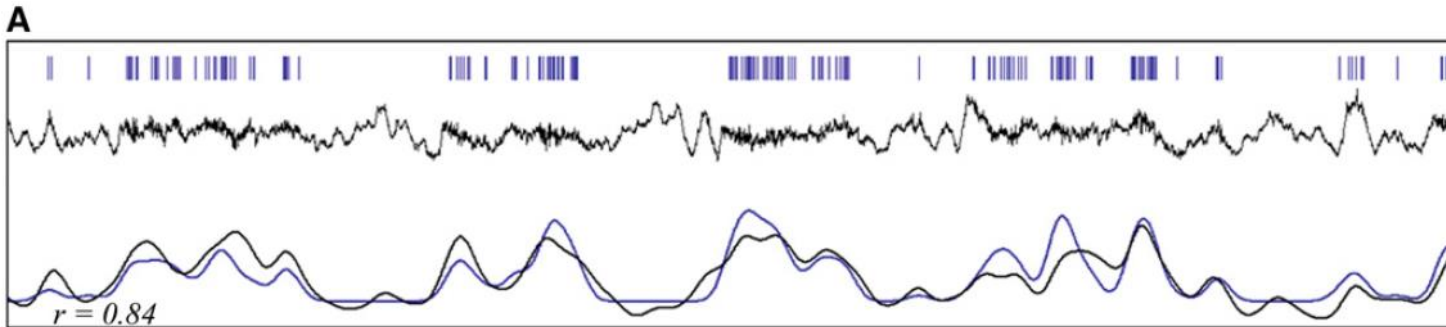
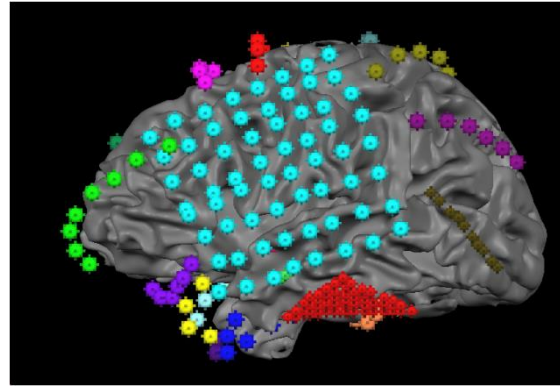
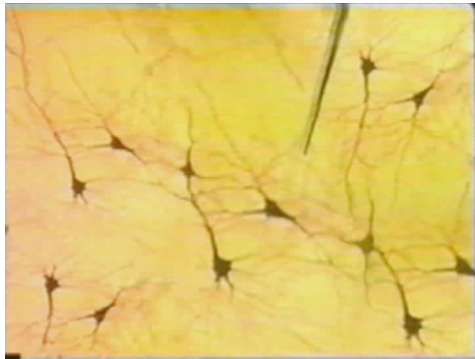
Hemodynamic Signal



Electrophysiology

Micro-electrodes
1-10 neurons
Firing rate

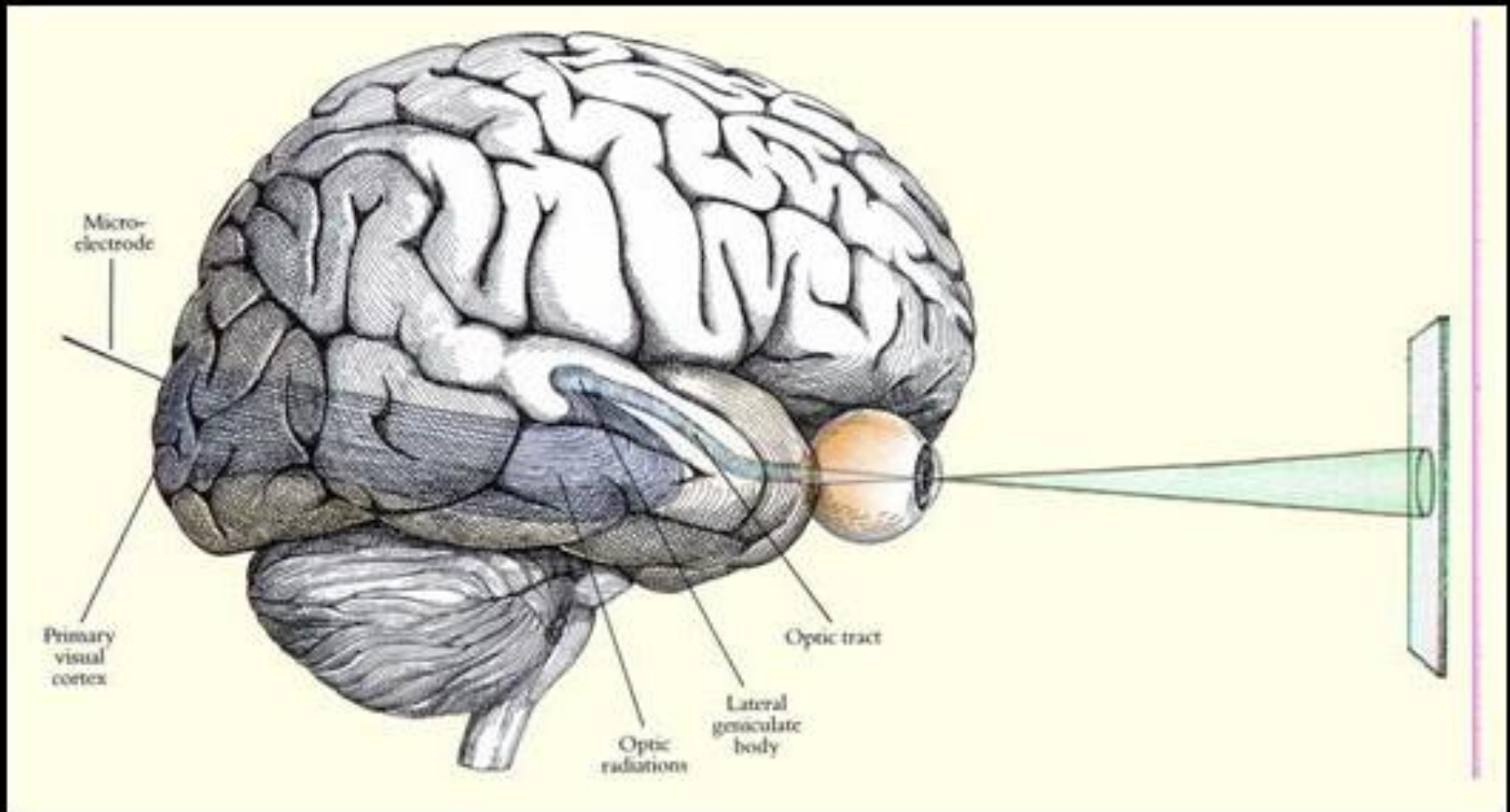
Contacts
 10^4 - 10^6 neurons
Broad band Gamma Power

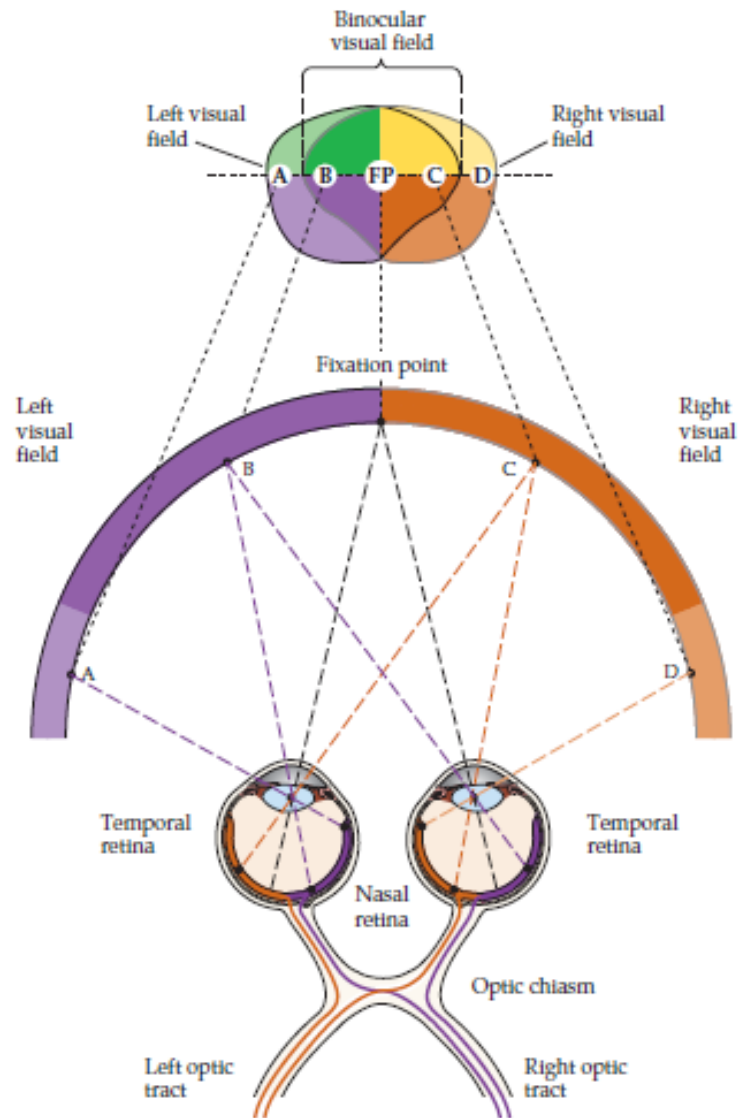


Spikes
LFP
Spikes/
Gamma

Firing rate = amplitude of fast (Gamma) fluctuations

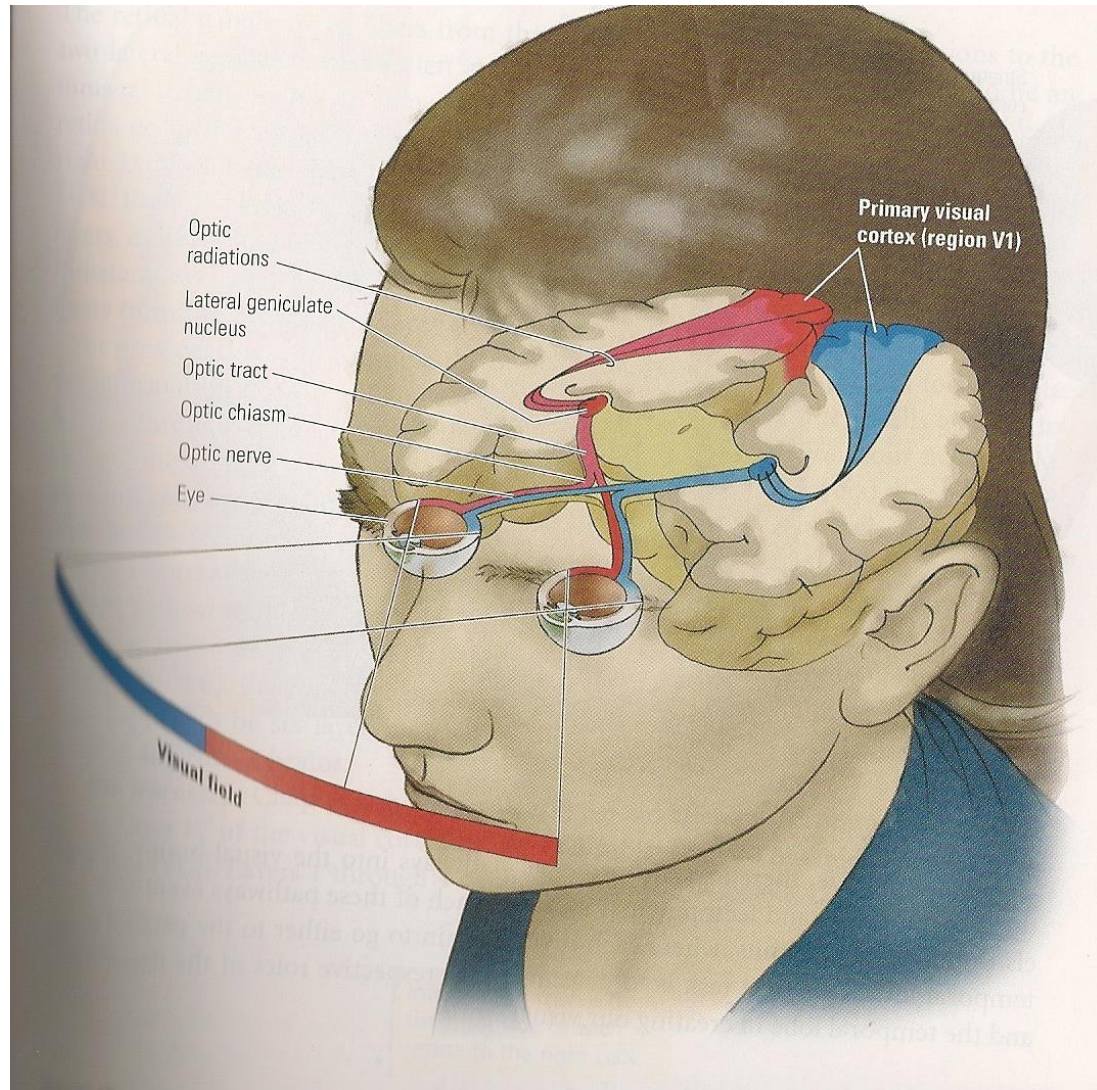
The flow of visual information in the human brain





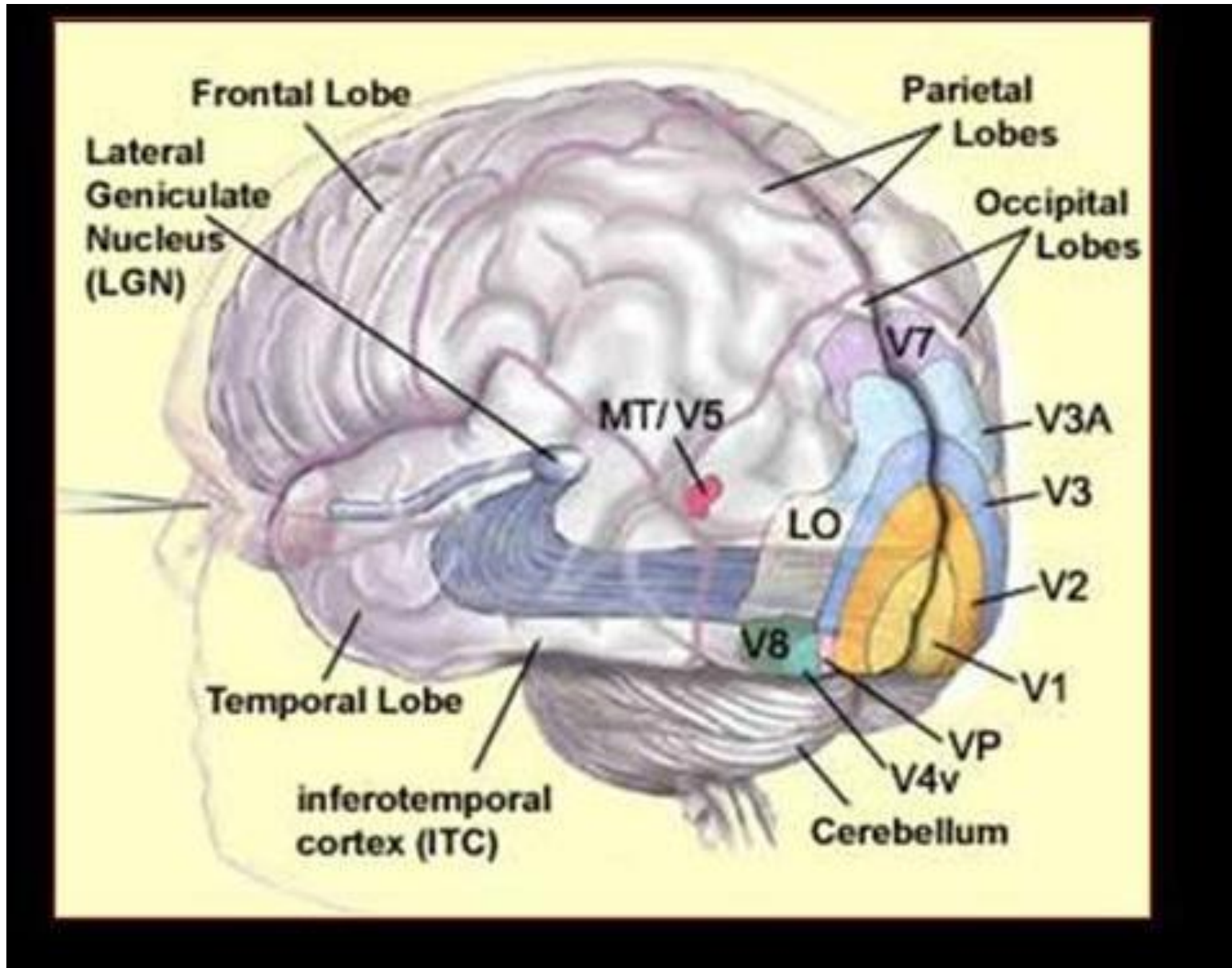
retinotopy, visual field, contra- ipsi, fixation point, vertical meridian
Horizontal meridian

Flow of information from the eye to the brain

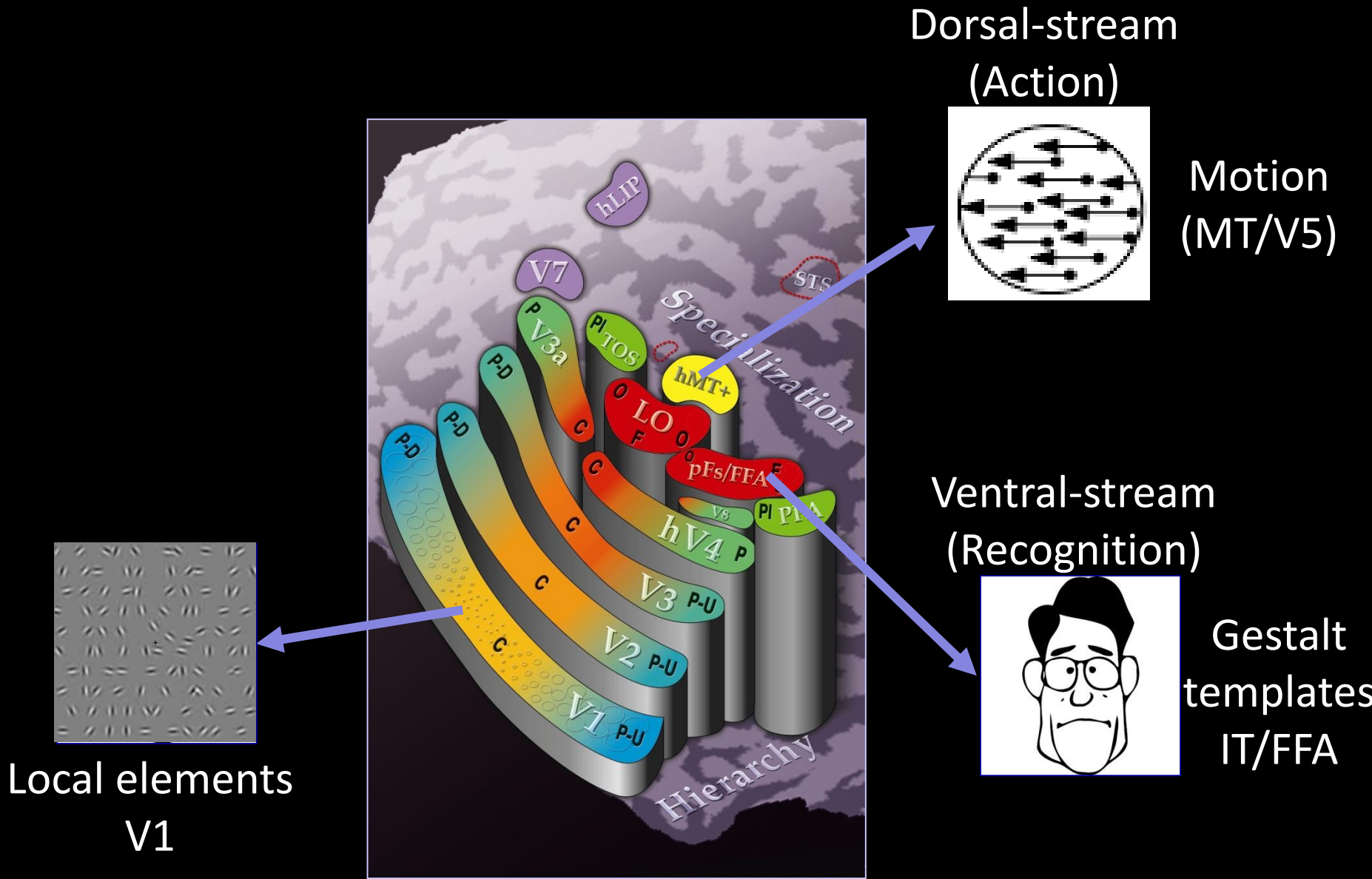


Optic nerve, chiasm, partial crossing, tract and radiation

Atlas of human visual areas

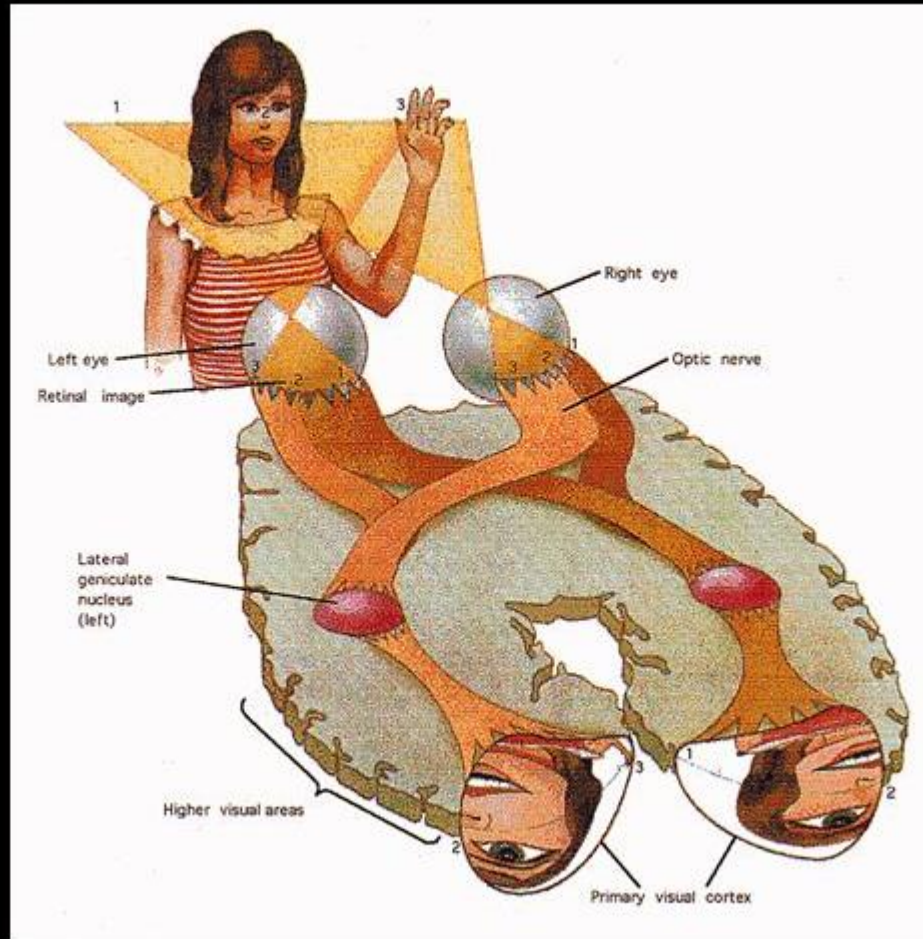


Functional Selectivity in the Human Visual Cortex



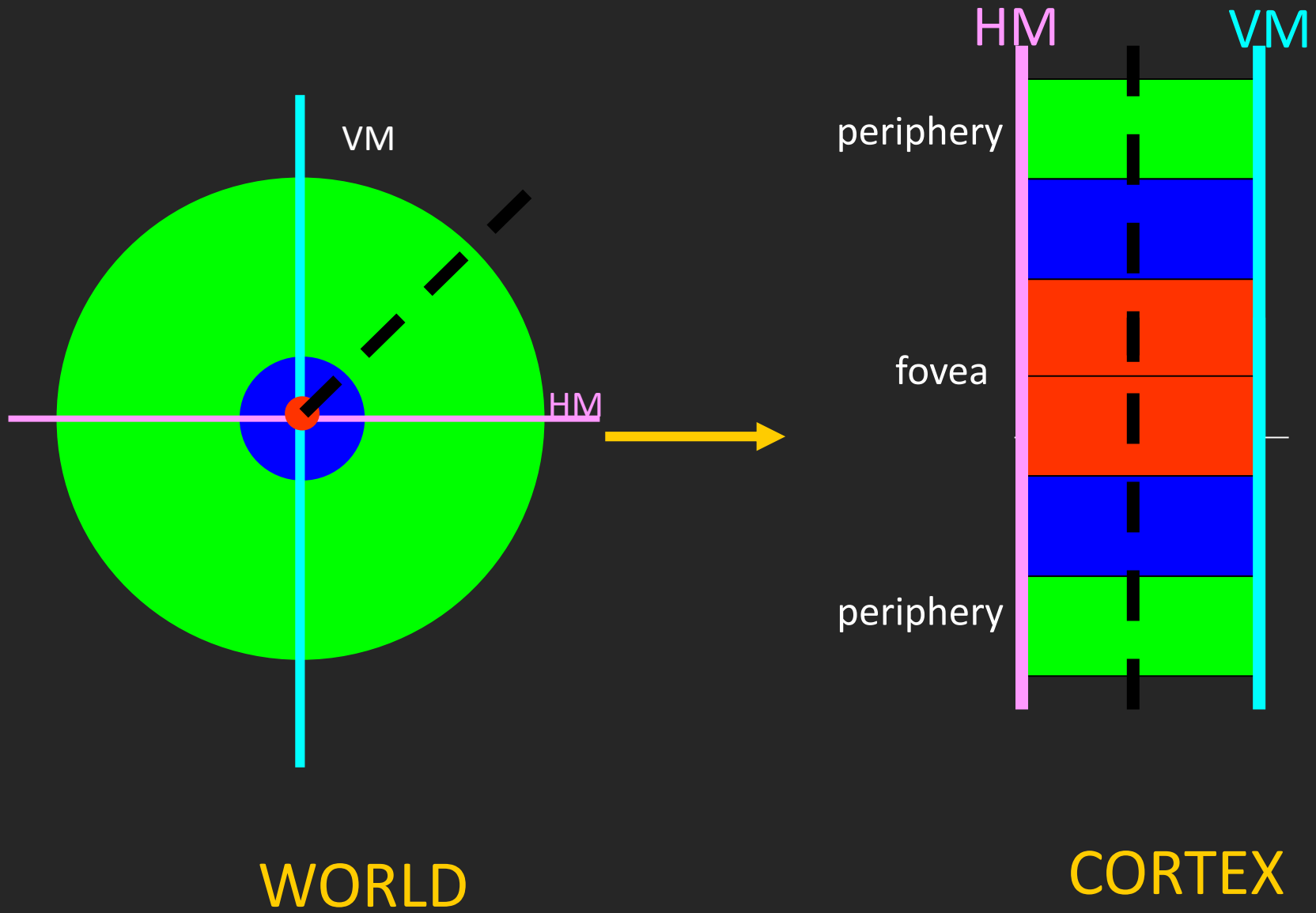
Large scale organizational principles of V1

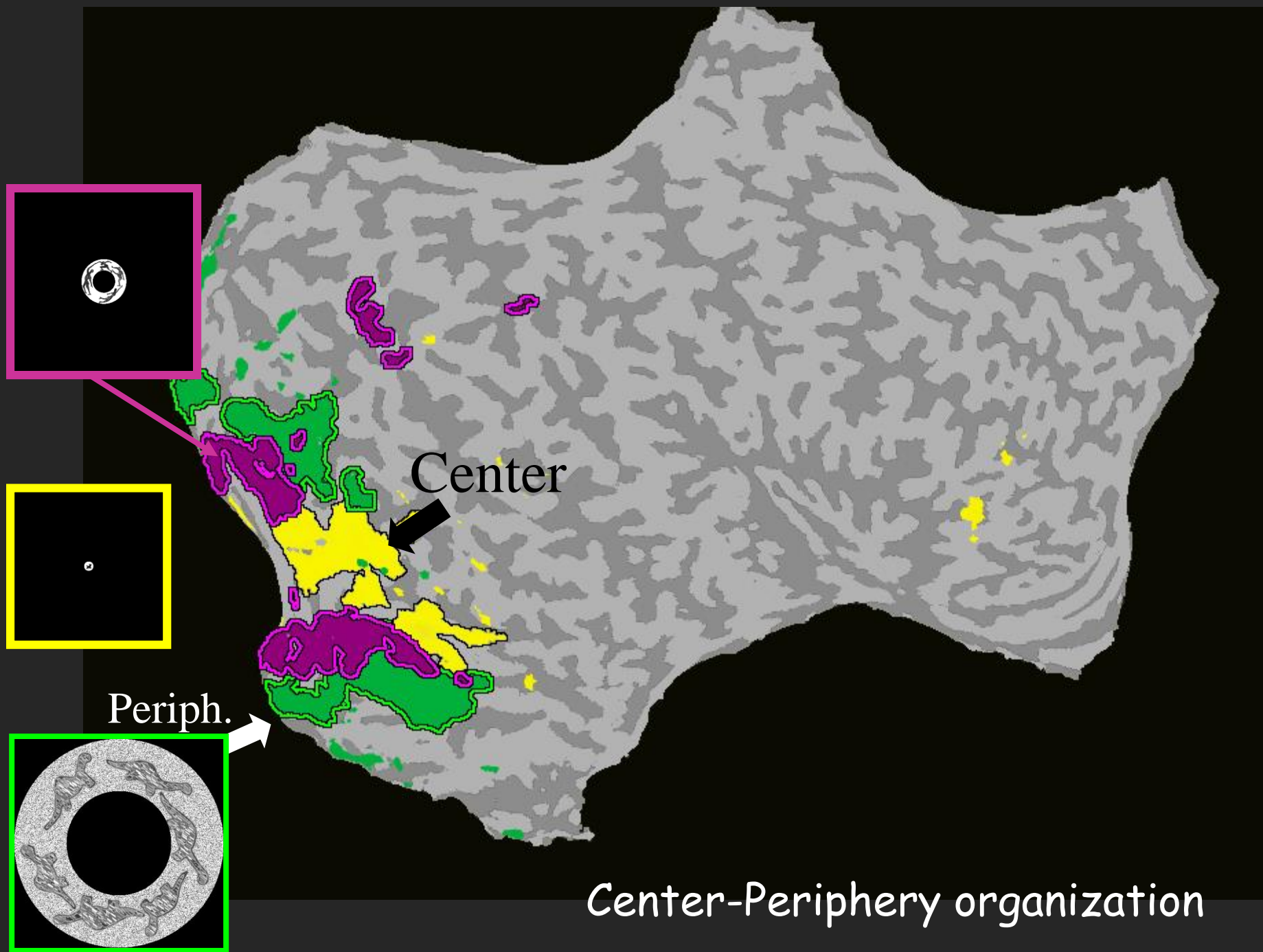
Retinotopy



Magnification factor- $\text{mm cortex} / \text{visual angle}$

Polar Retinotopic organization of visual cortex





Center

Periph.

Center-Periphery organization

Interim Summary

- The early, retinotopic, stages in the visual system consist of multiple representations of the visual field- organized as parallel bands on unfolded cortex

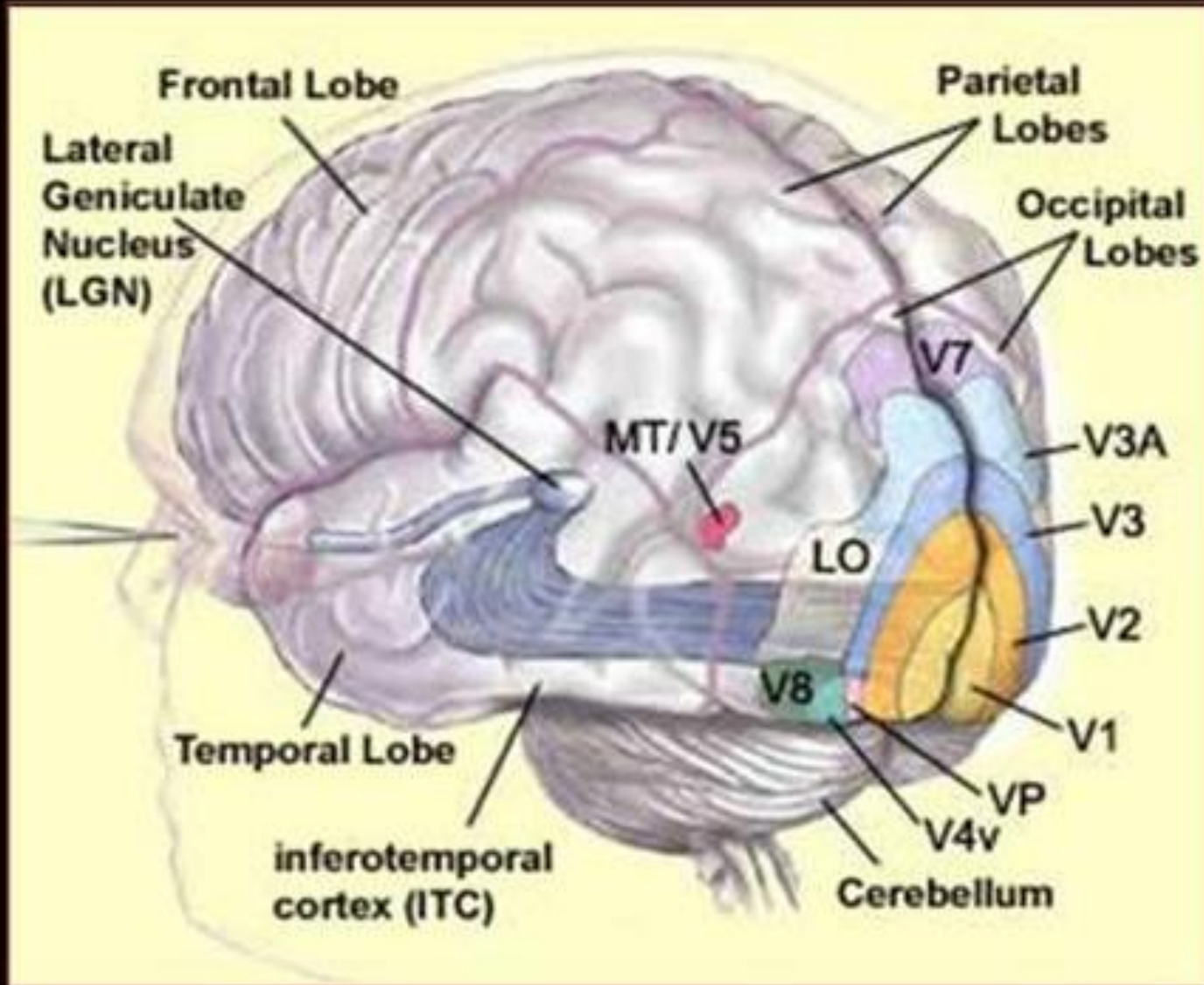
Three major principles of organization:

1) Magnification factor- the central visual field activates a larger number of neurons

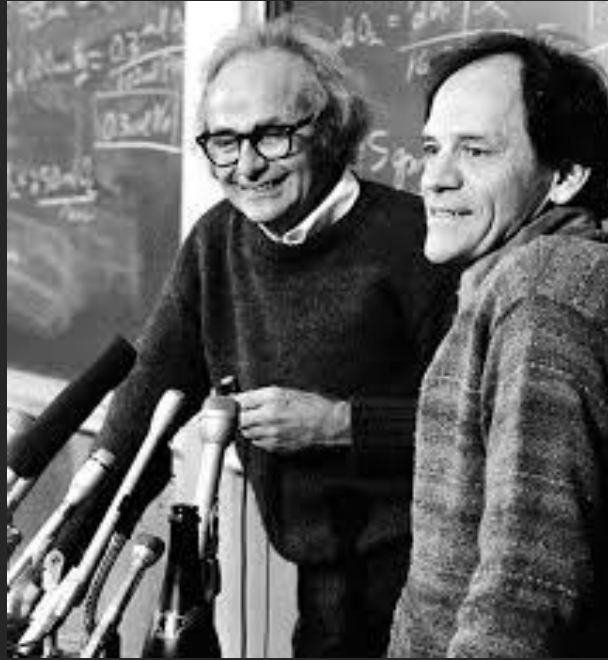
2) Center-periphery organization- central vision is in the center

3) Polar angle organization- right visual field in the left hemisphere, upper visual field – in ventral cortex

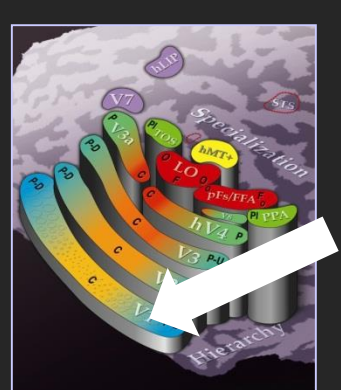
The functional transformations along the visual pathways



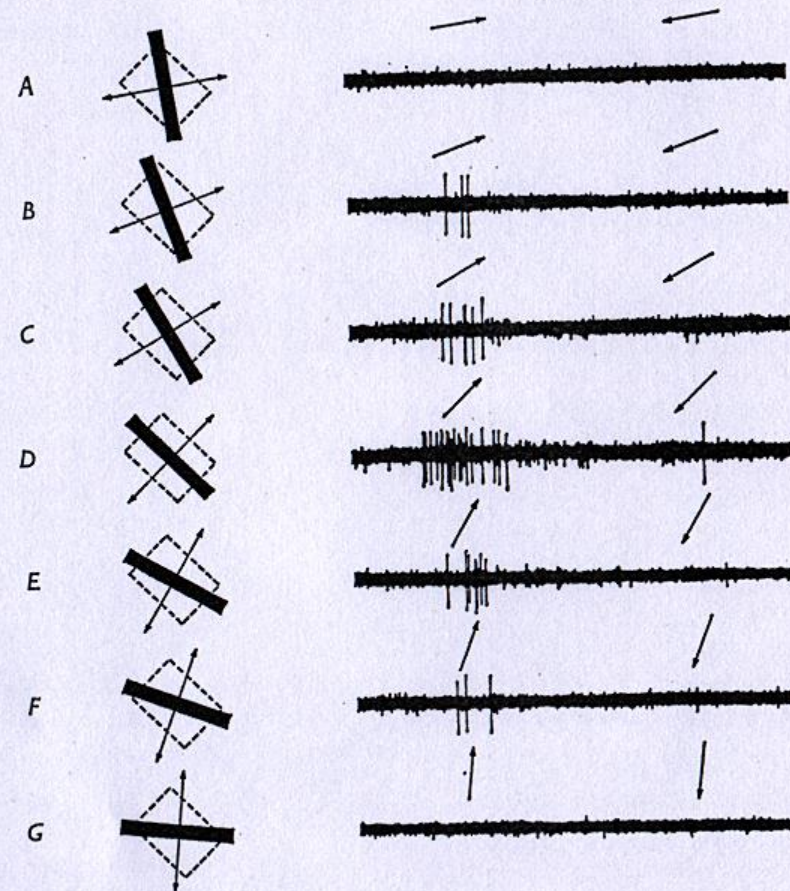
The properties of single neurons in area V1



David Hubel and Torsten Wiesel



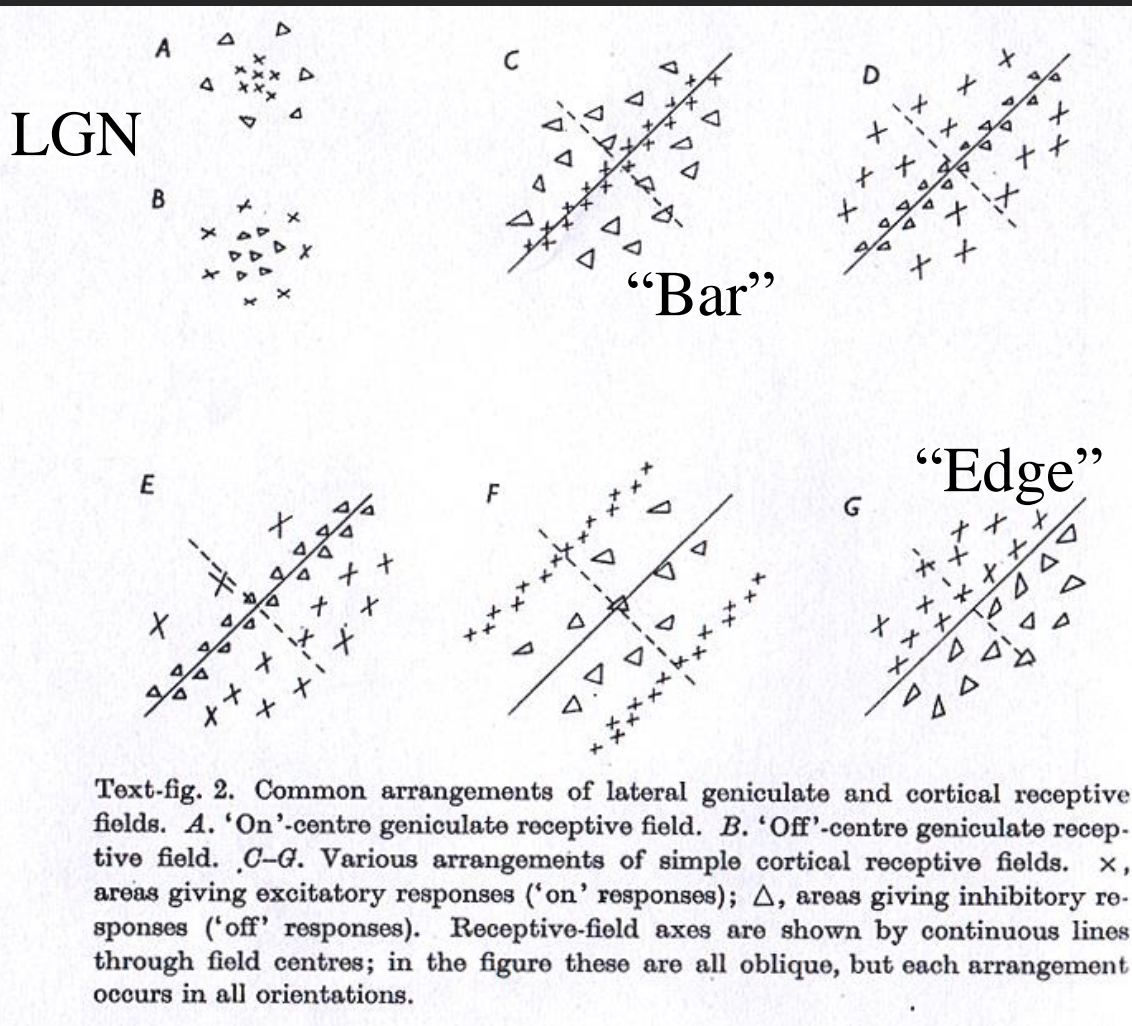
Receptive field of a visual neuron in area V1



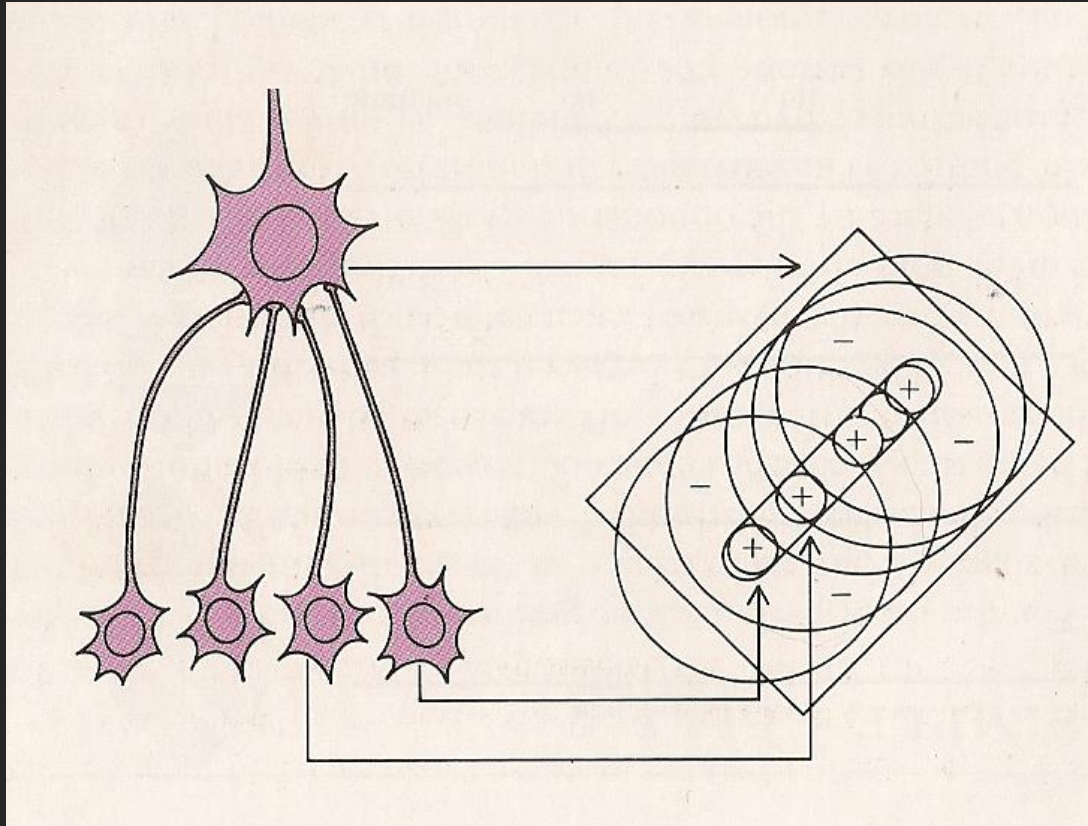
Text-fig. 2. Responses of a complex cell in right striate cortex (layer IV A) to various orientations of a moving black bar. Receptive field in the left eye indicated by the interrupted rectangles; it was approximately $\frac{1}{3} \times \frac{1}{3}^\circ$ in size, and was situated 4° below and to the left of the point of fixation. Ocular-dominance group 4. Duration of each record, 2 sec. Background intensity $1.3 \log_{10} \text{ cd/m}^2$, dark bars $0.0 \log \text{ cd/m}^2$.

Stimulus selectivity of receptive fields

Receptive field of a "Simple" cell in area V1

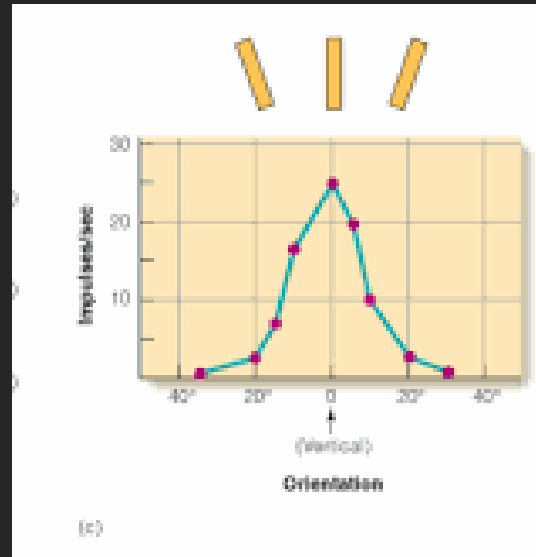


The simple cell model

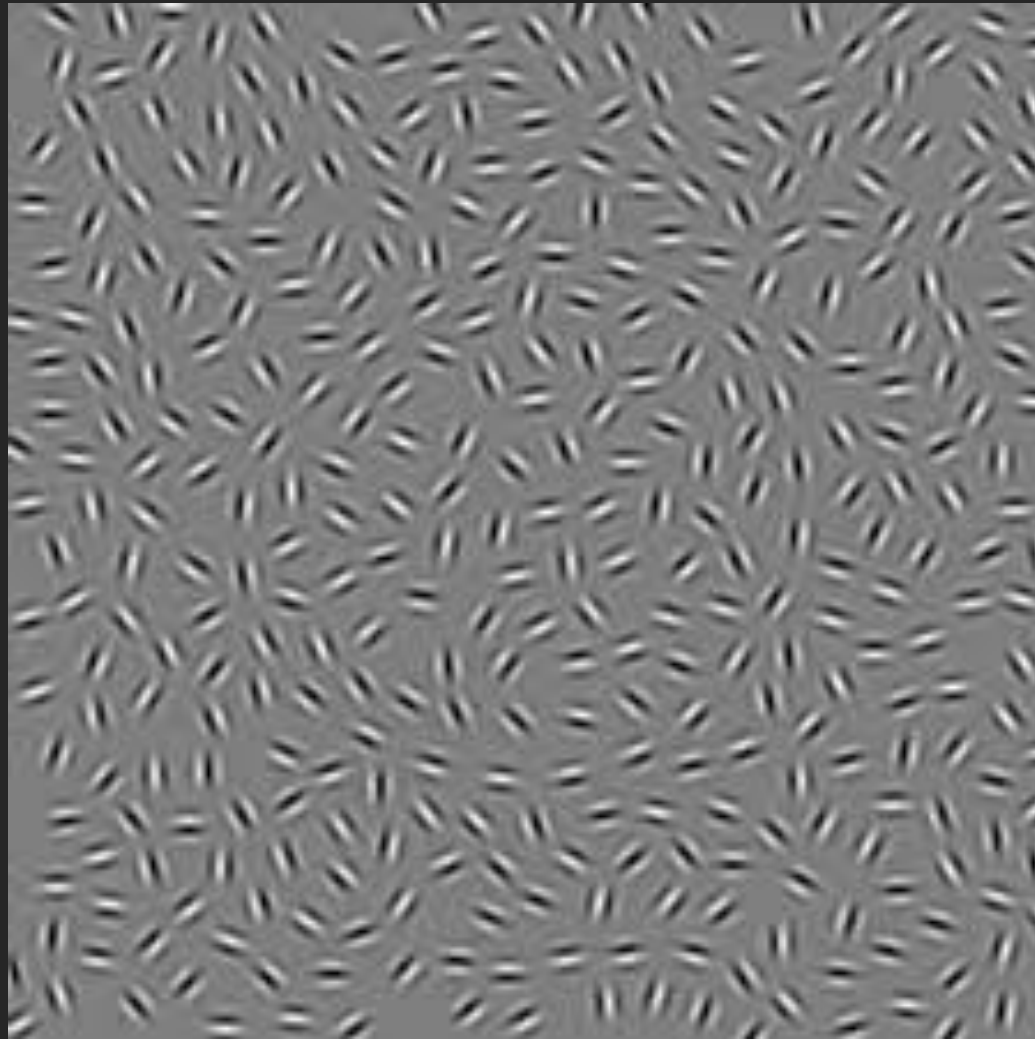


Convergence, threshold, synchrony
an "and" function

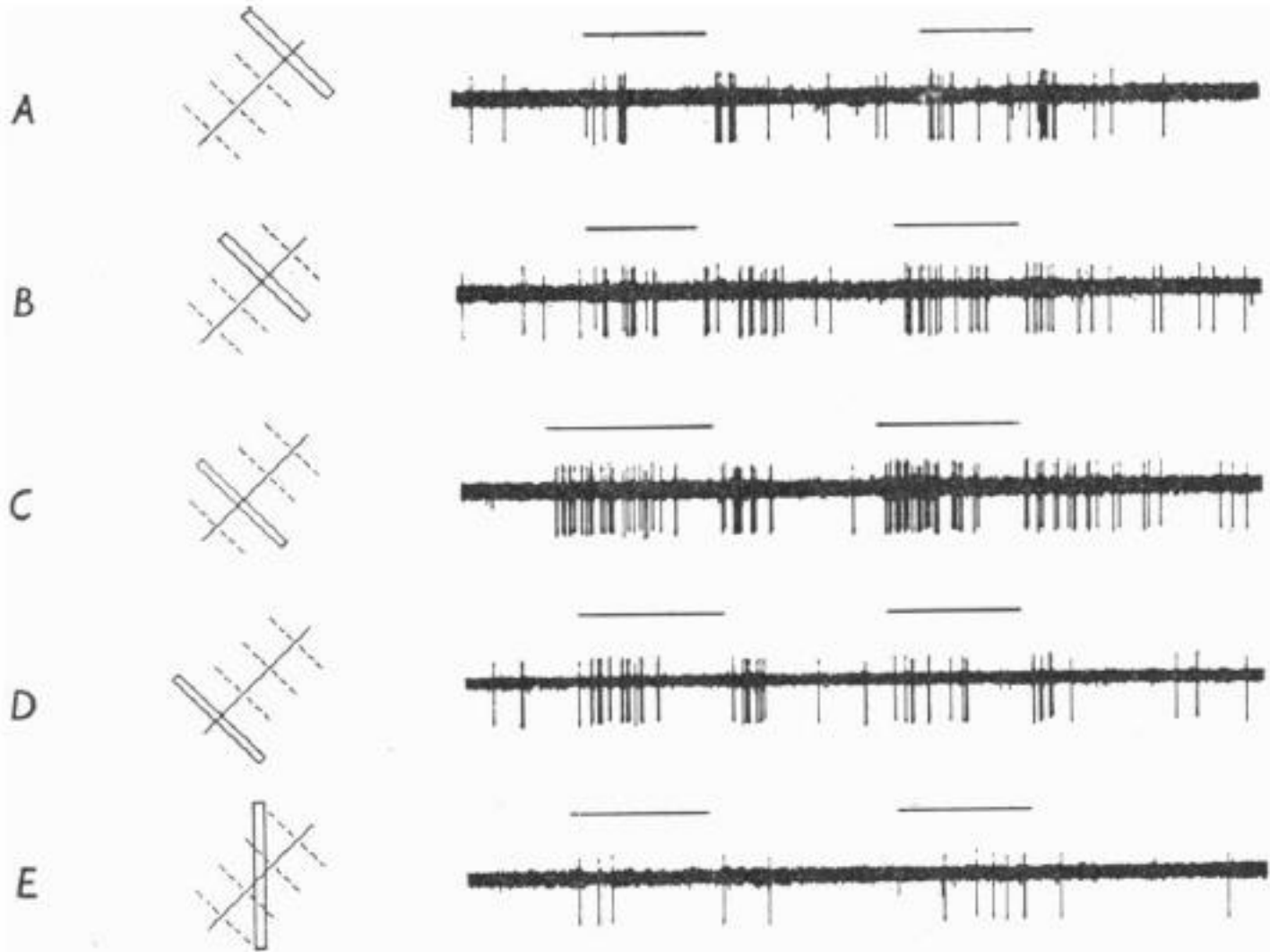
What is the function of the oriented line detectors?



Perceptual saliency of line detection



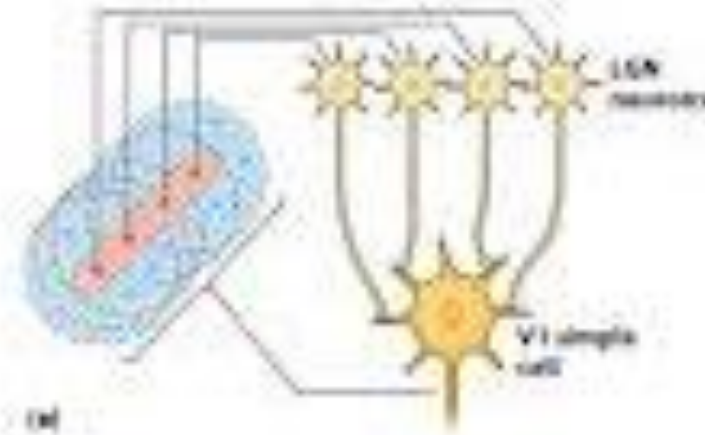
Functional Hierarchy within V1



complex cells

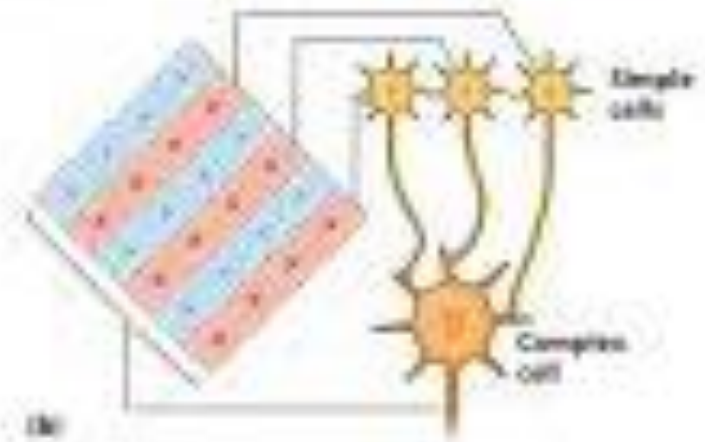
Functional hierarchy within V1

Simple cells



“And” function

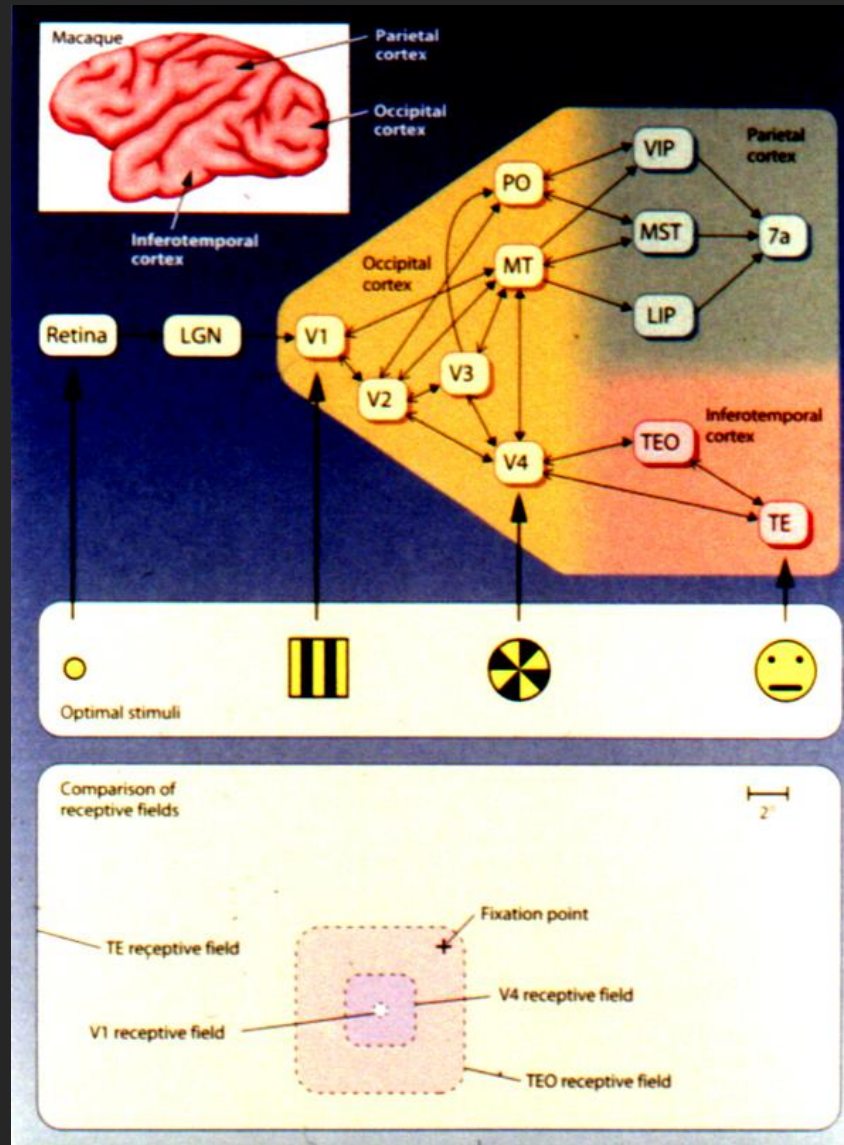
Complex cells



“Or” function

The transformation from simple to complex cells

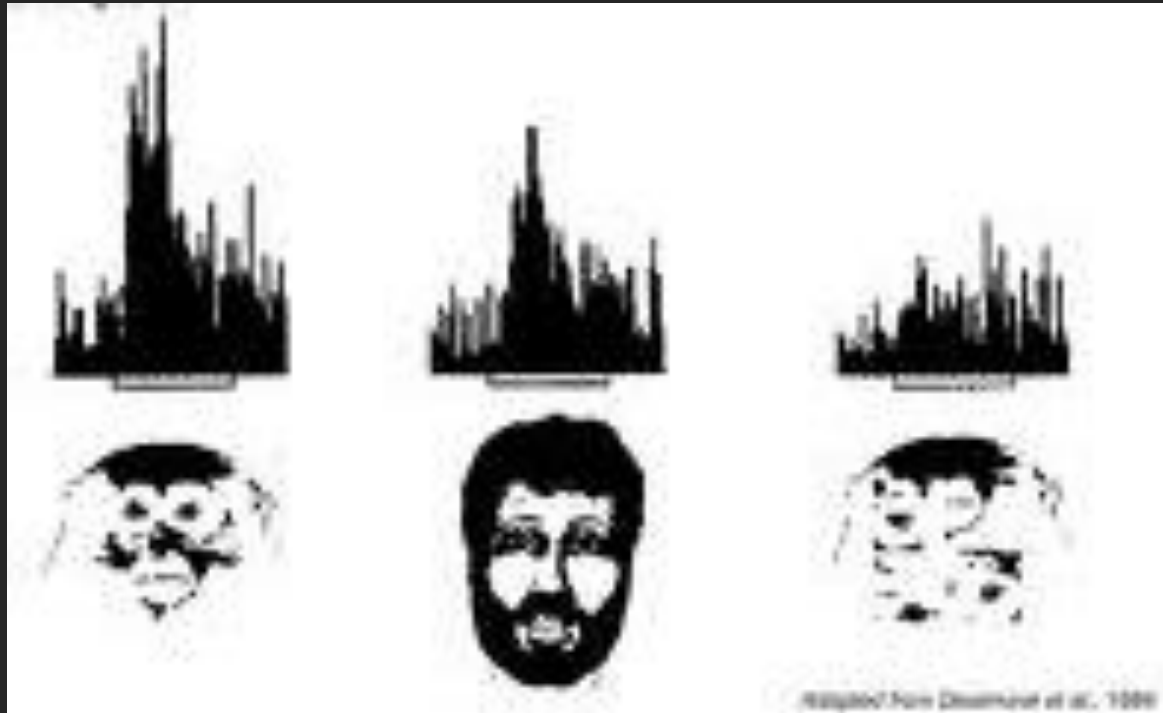
Growing “abstraction” along the visual hierarchy



Increased complexity

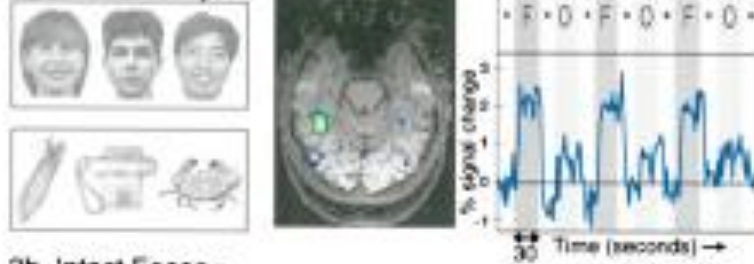
Increased RF size

Complex templates at the top of the VENTRAL stream

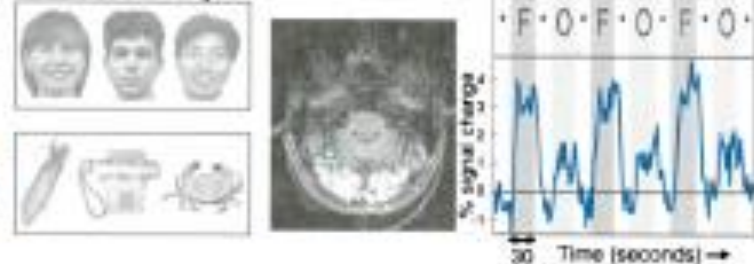


"Face" neurons

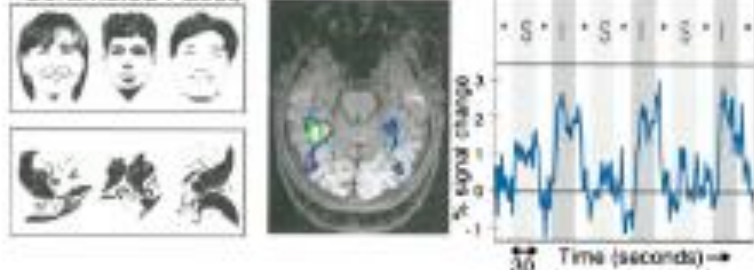
3a. Faces > Objects



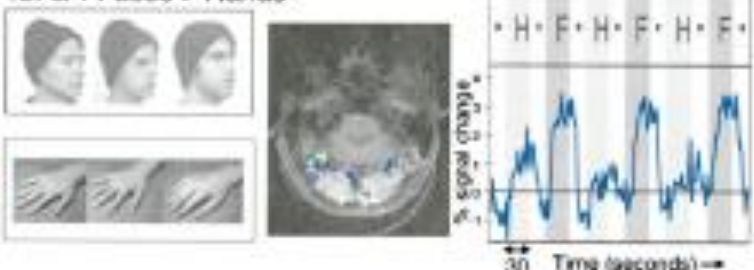
4a. Faces > Objects



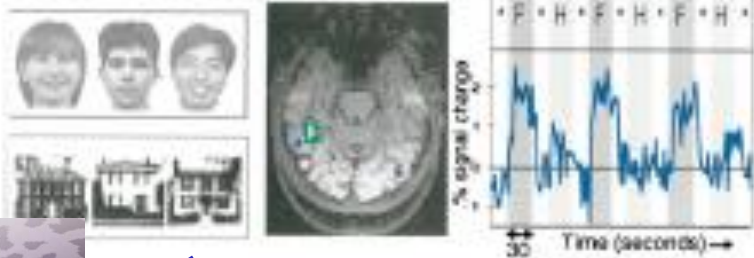
3b. Intact Faces > Scrambled Faces



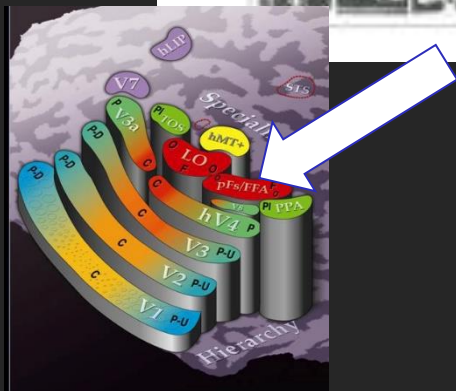
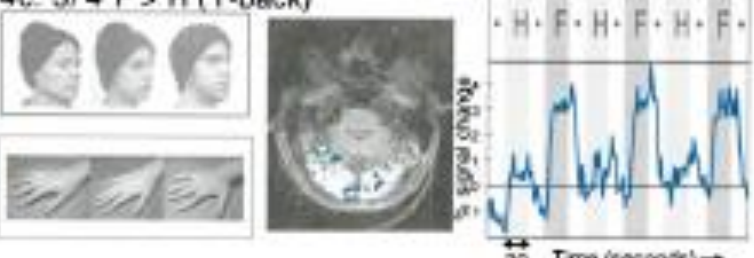
4b. 3/4 Faces > Hands



3c. Faces > Houses



4c. 3/4 F > H (1-back)



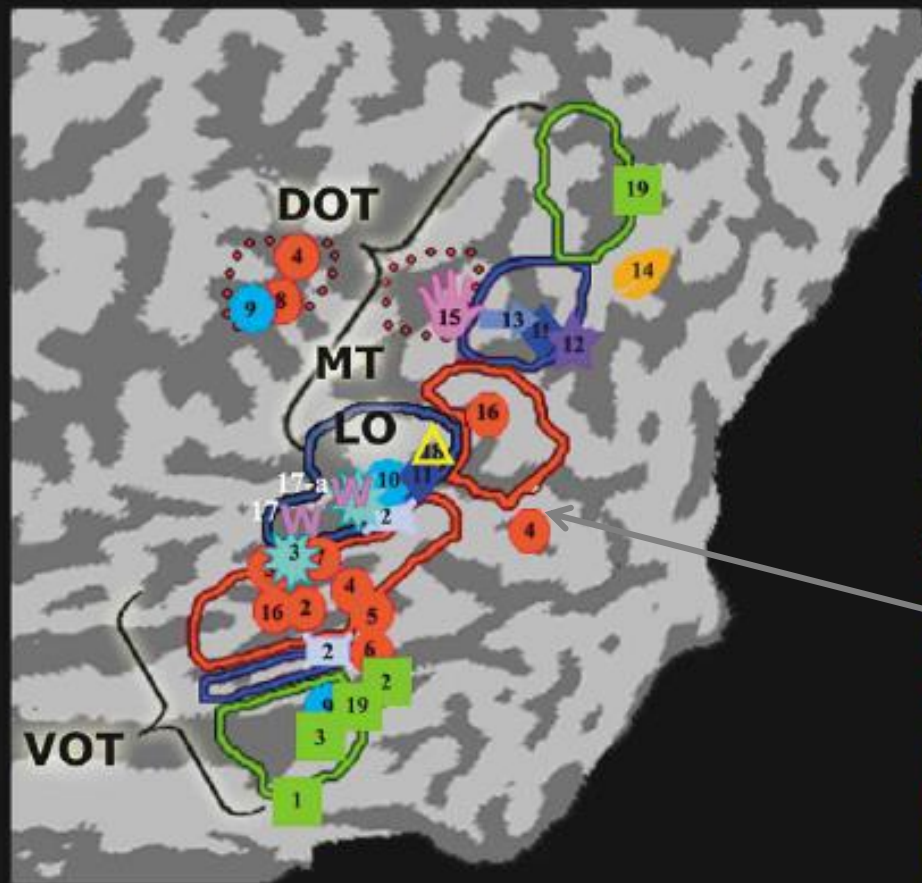
Fusiform "Face" Area

Electrical stimulation of the fusiform face area



Mosaic of category-selective cortical regions

Left Hemisphere

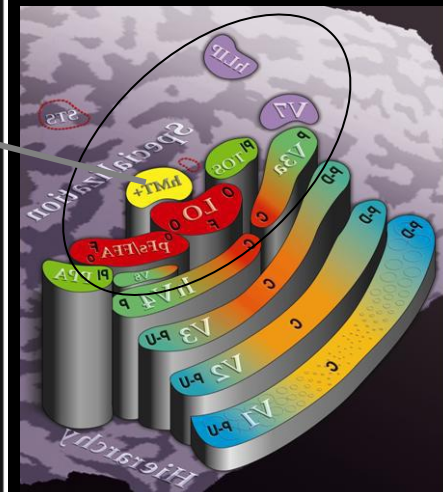


- △ Somatosensory
- ☆ Illusory contours
- ➔ Motion
- ✋ Body parts
- 🍌 Kinetic
- W Words
- ✨ Animals
- ◆ Objects
- Tools
- ▭ Chairs
- Faces
- Buildings

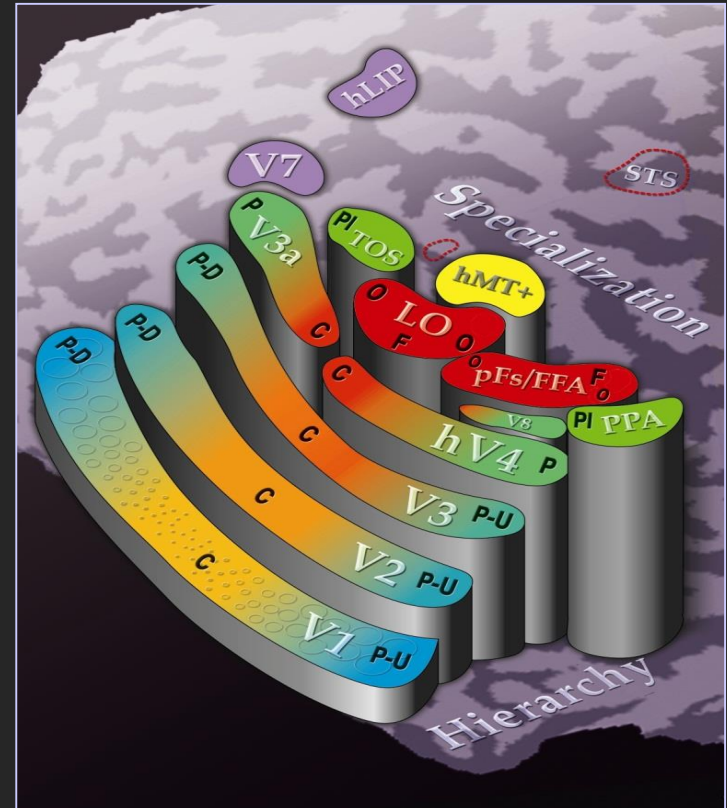
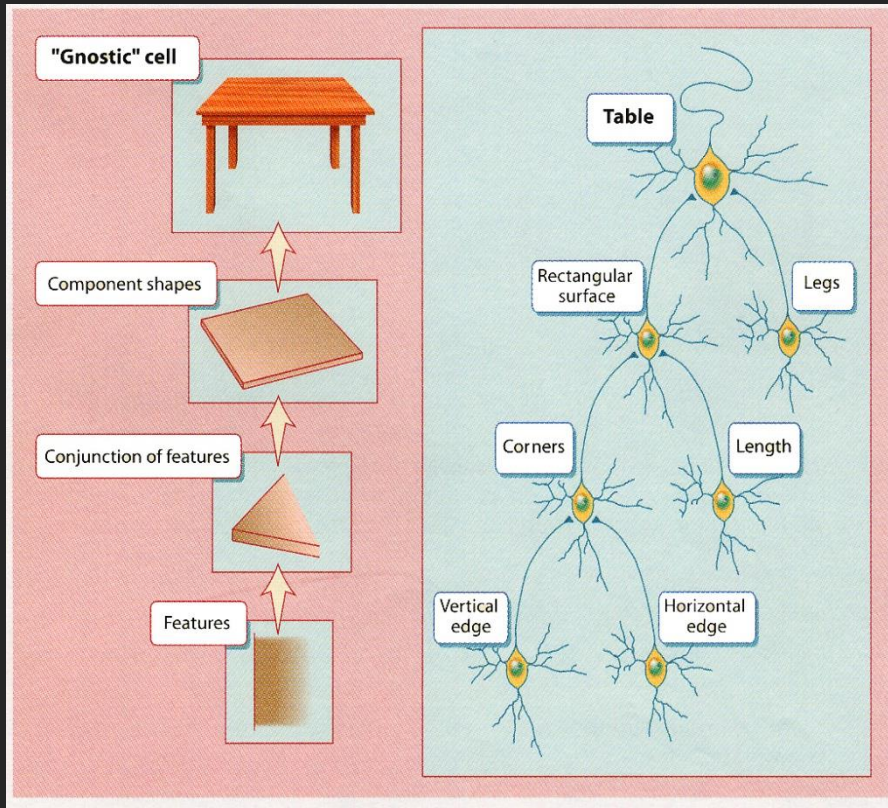
Anterior



Posterior

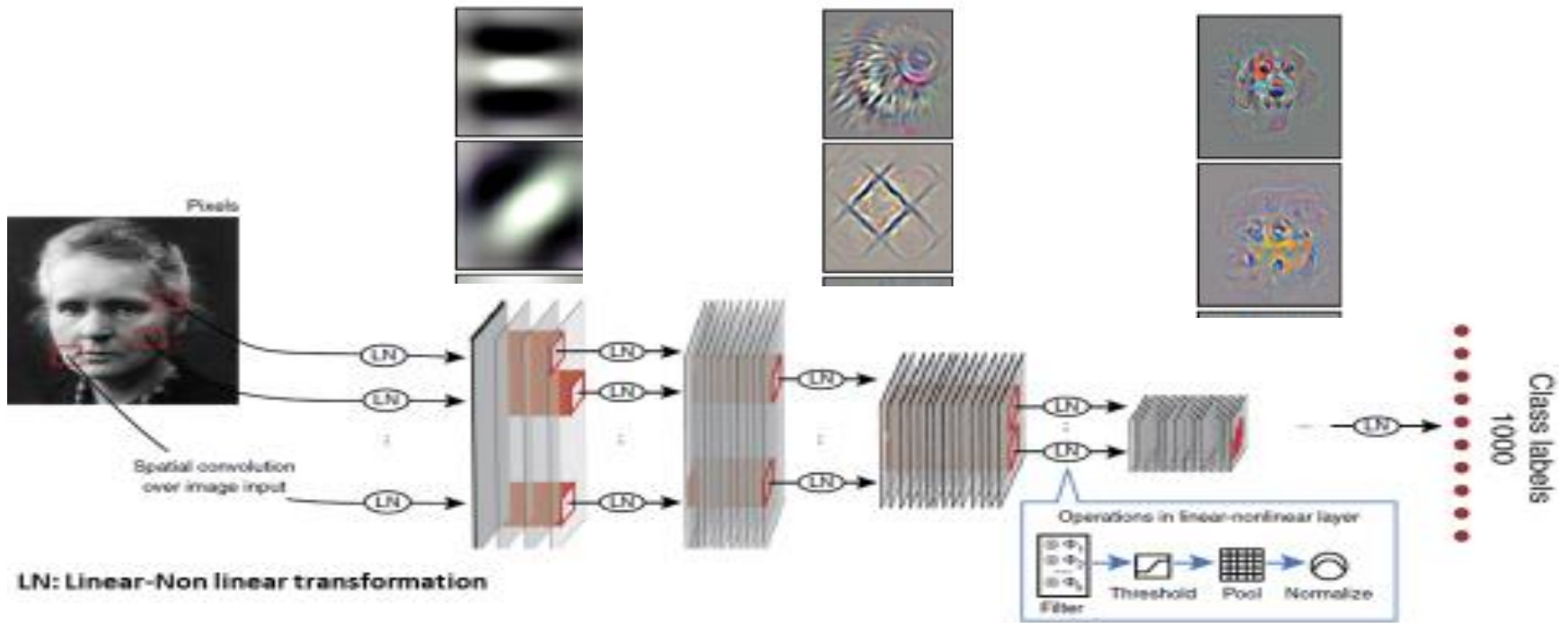


How are the functional transformations implemented?



Repeating the feed-forward simple cell model along the hierarchy

Deep Convolutional Neural Network: A successful hierarchical model of human visual performance

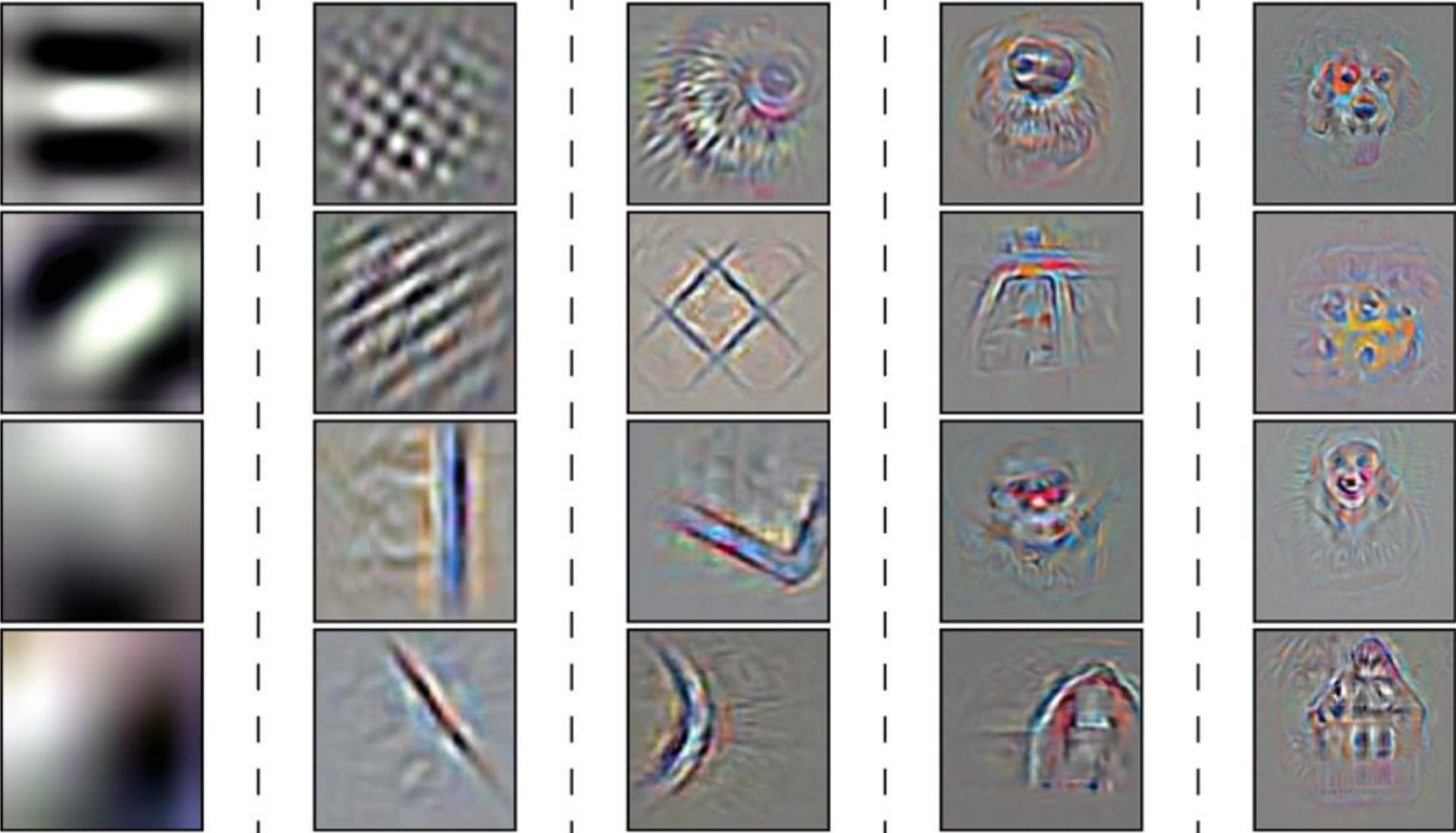


Yamin and DiCarlo, 2016

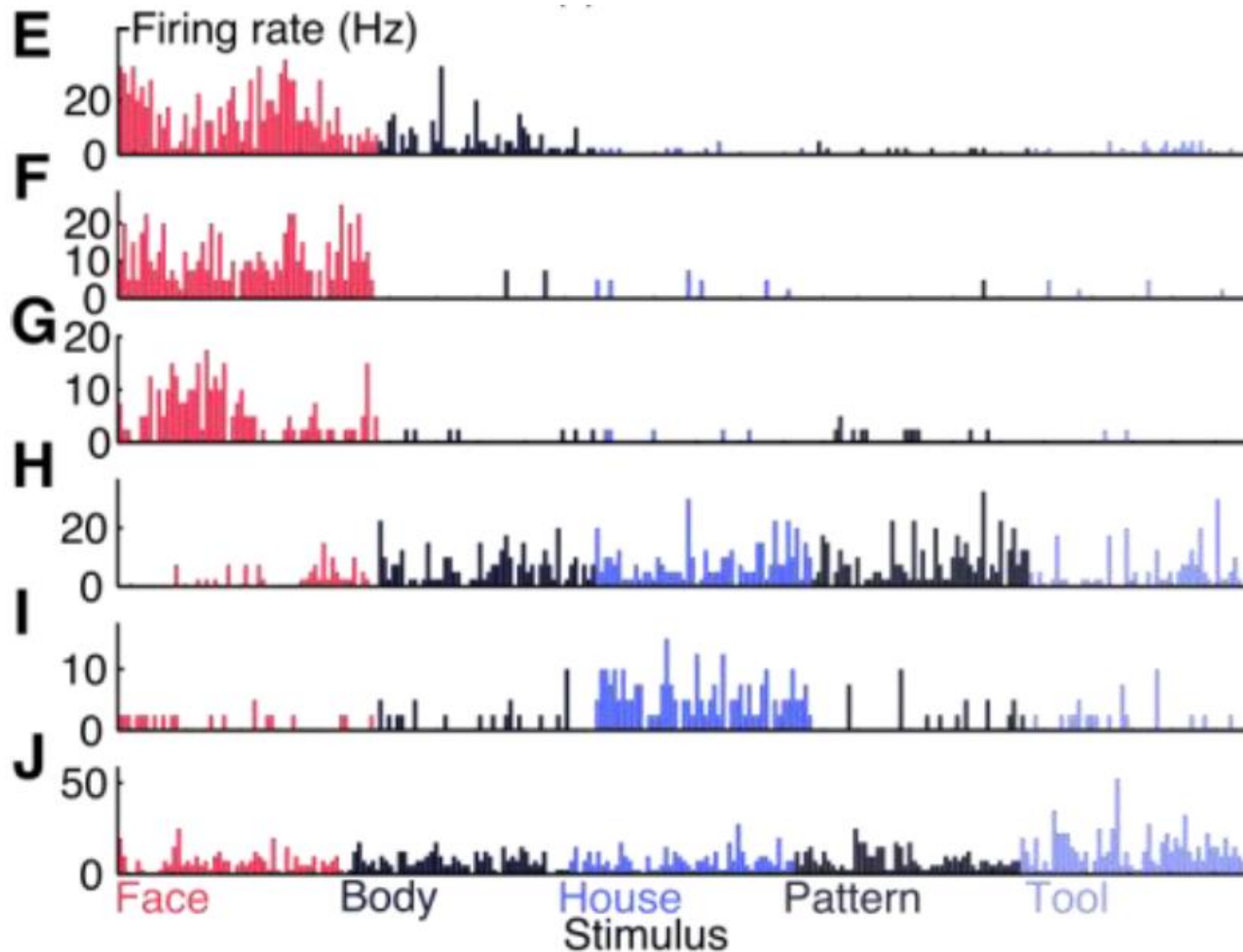
Guculu and Van Gerven, 2015

Artificial networks now out-perform human visual recognition capabilities

Receptive fields of artificial neurons along the hierarchy



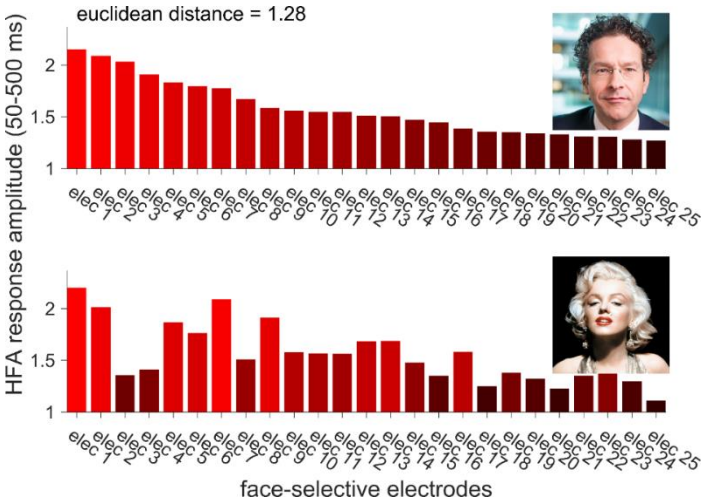
Distributed and selective responses to single face exemplars in human face-selective neurons



- 1) Wide-distribution: every face activates
- 2) Selectivity: each face activates to a different degree

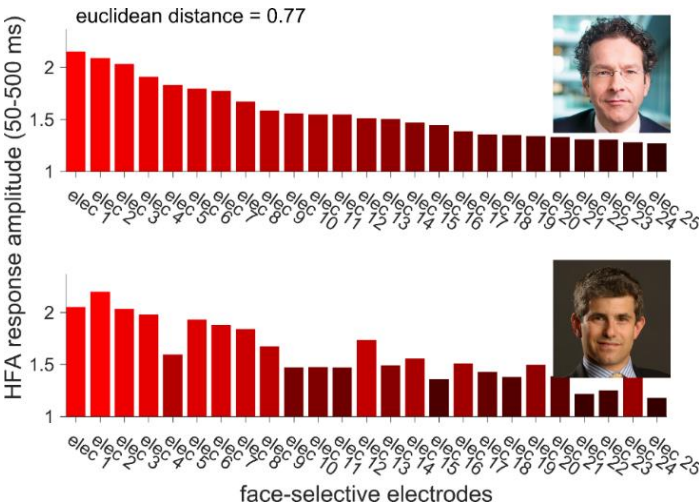
Visual images are represented through patterns of neuronal activity

Dissimilar activation patterns



Long distance (ED=1.28)

Similar activation patterns



Short distance (ED=0.77)

Mapping all face pair-distances in the human cortex

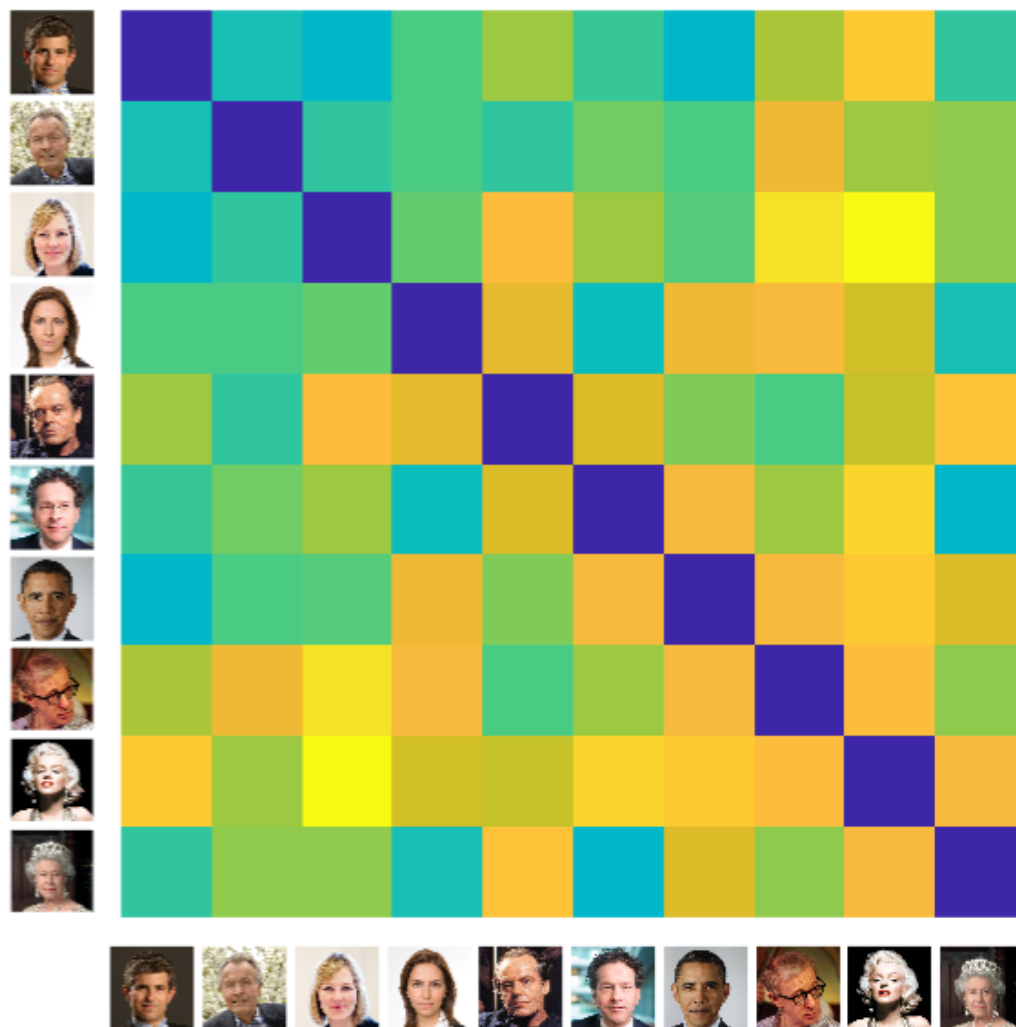
Representational Similarity Analysis (RSA)

Neural distances matrix

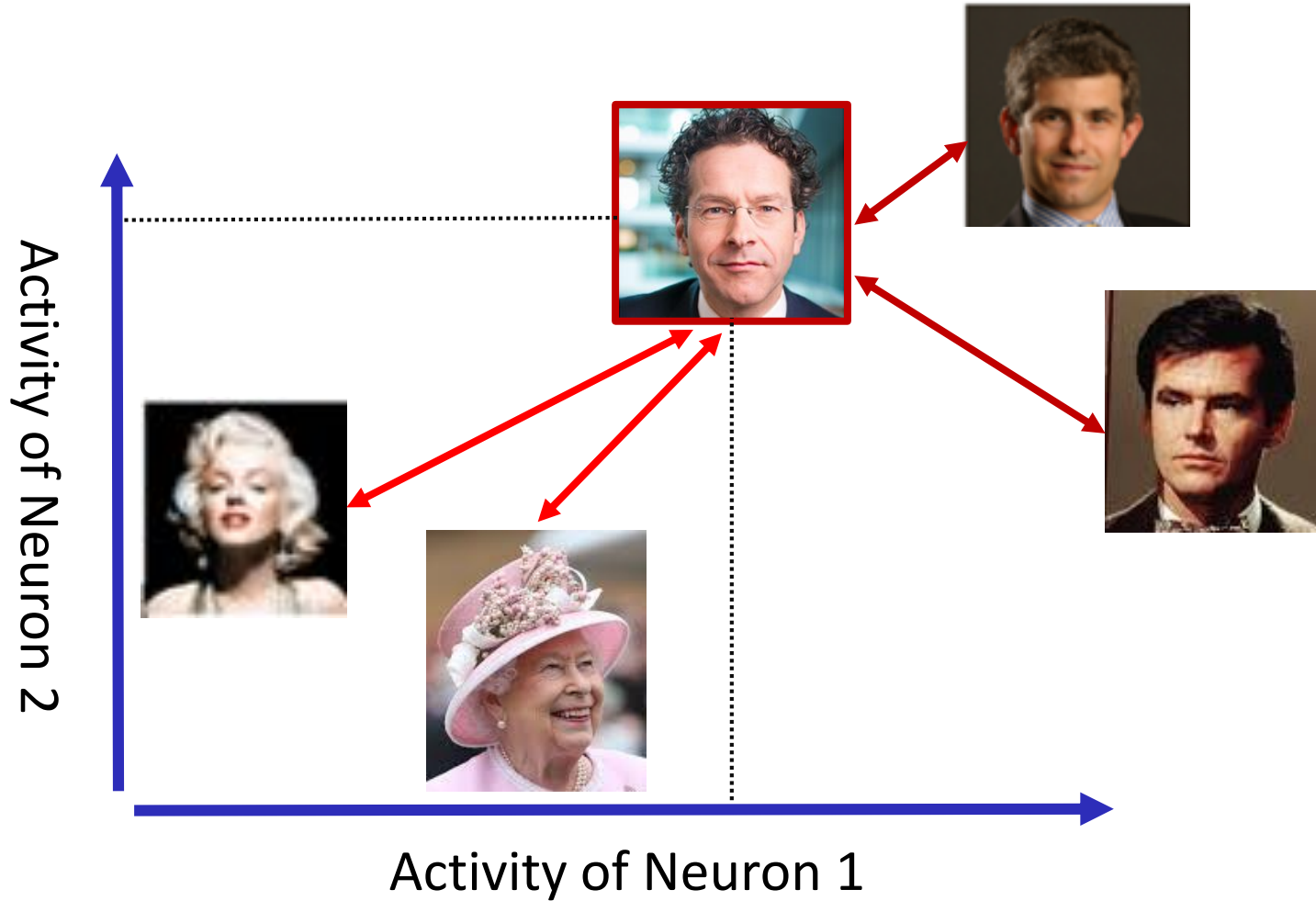
Different activation patterns
(long distance)



Similar activation patterns
(short distance)



Transforming pattern similarity to distances in neuronal-space



Interim Summary

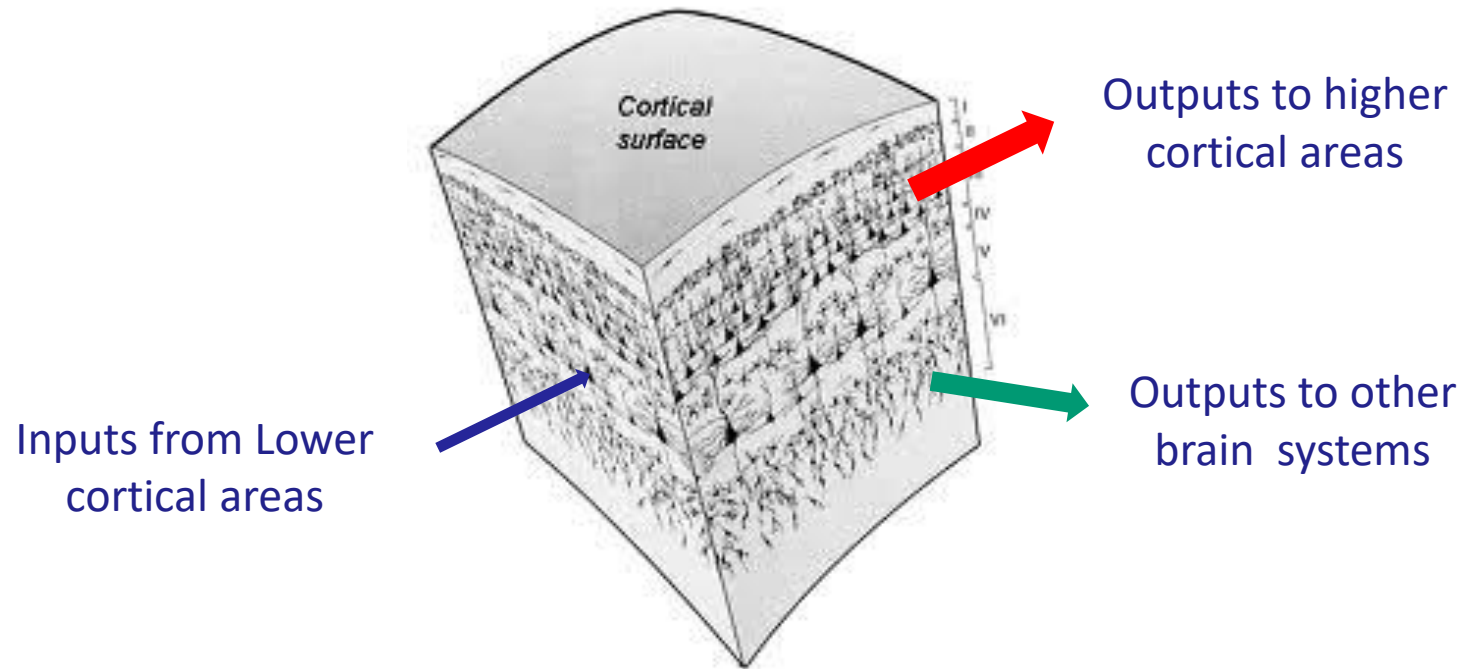
- The visual pathway consists of a series of functional transformations

Characteristics of the transformation:

- 1) Increasingly holistic – from picture elements to entire percepts organized in categories
- 2) Increasingly invariant- reduced sensitivity to position in the visual field
- 3) The transformation is implemented through selective convergence of inputs combined with a decision non-linearity (e.g. the LGN- to simple cell transformation)
- 4) Extending the principle can account for functional properties along the visual hierarchy
- 5) Supported by artificial networks
- 6) Widely distributed representation- no evidence for “grand-mother” cells

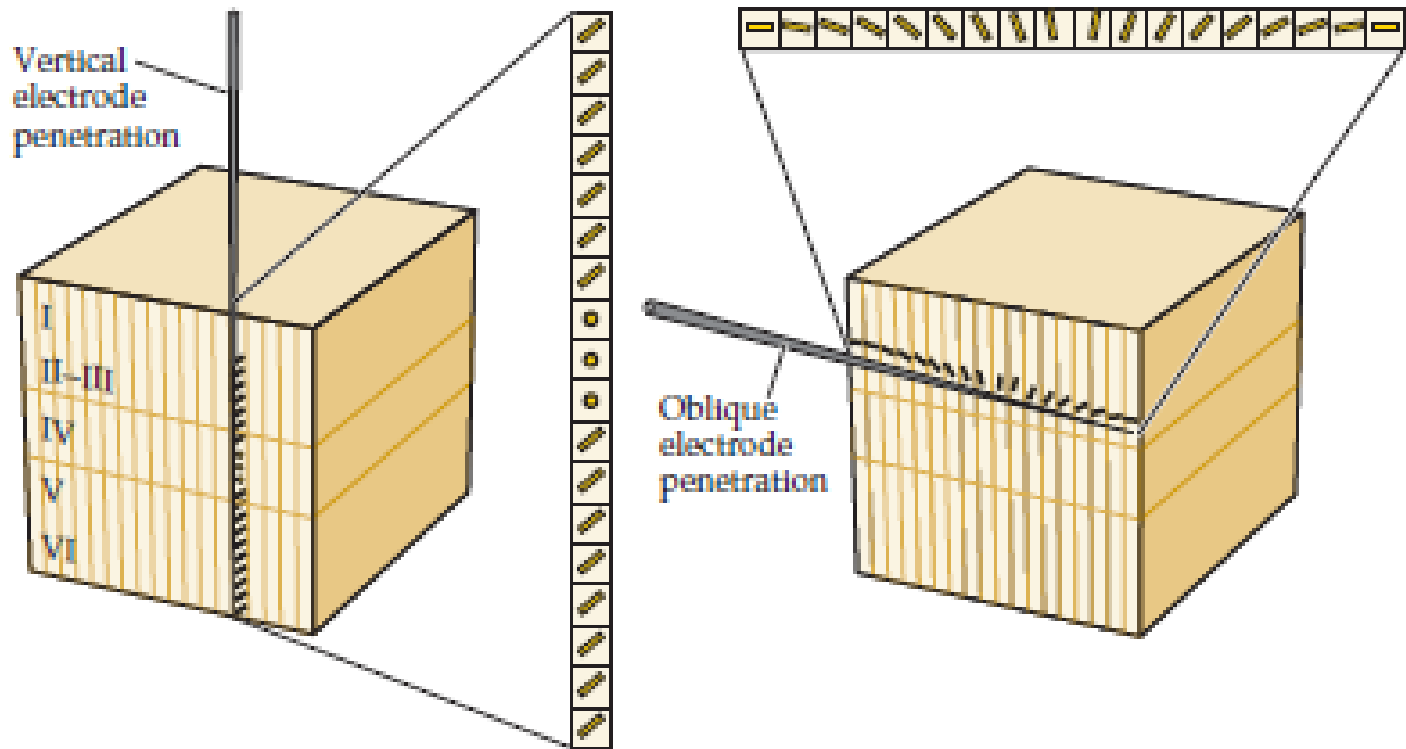
Functional organization of the cortex

Vertical organization: 6 layers

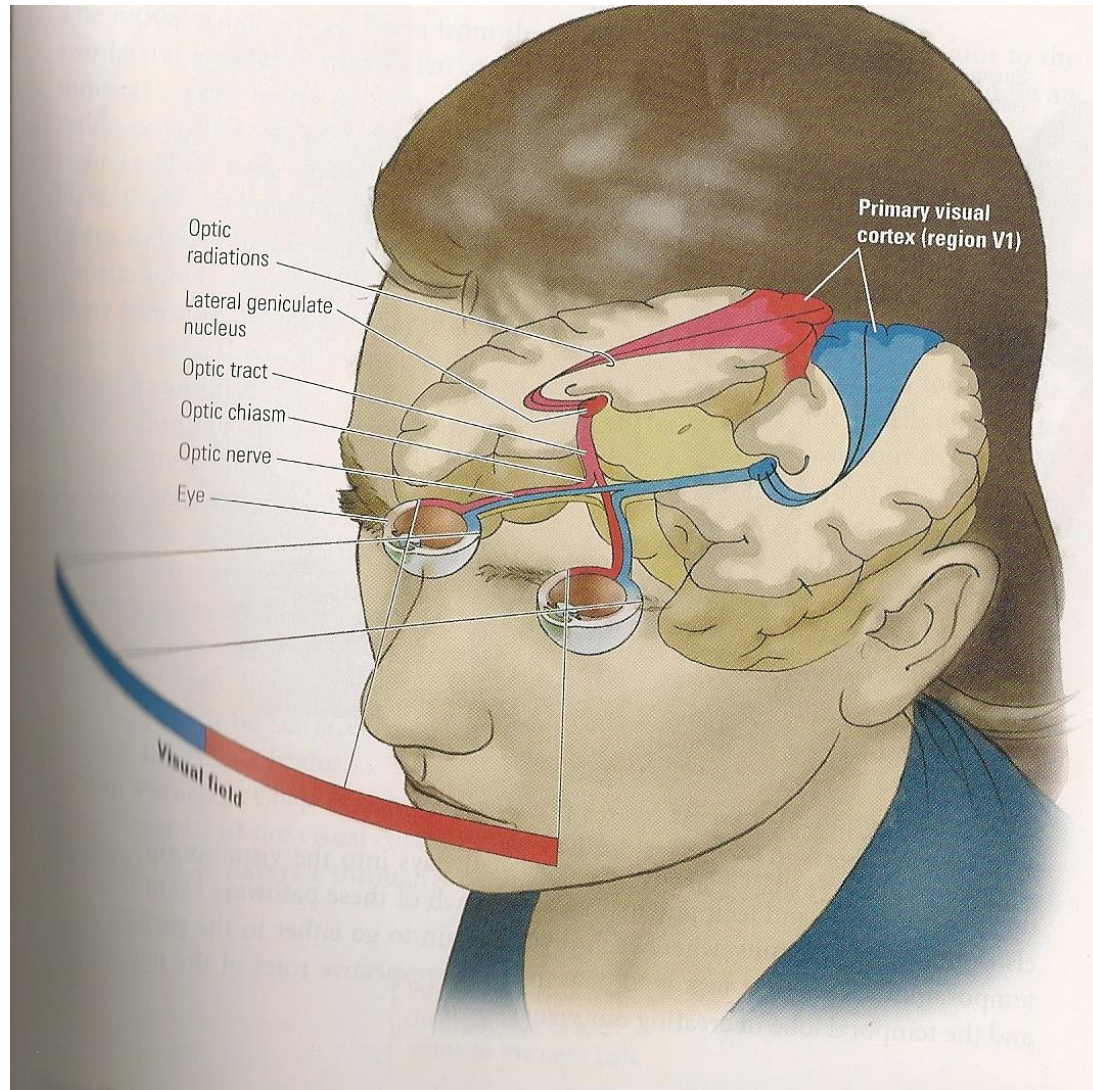


Functional organization of the Area V1

Horizontal organization: “Orientation columns”

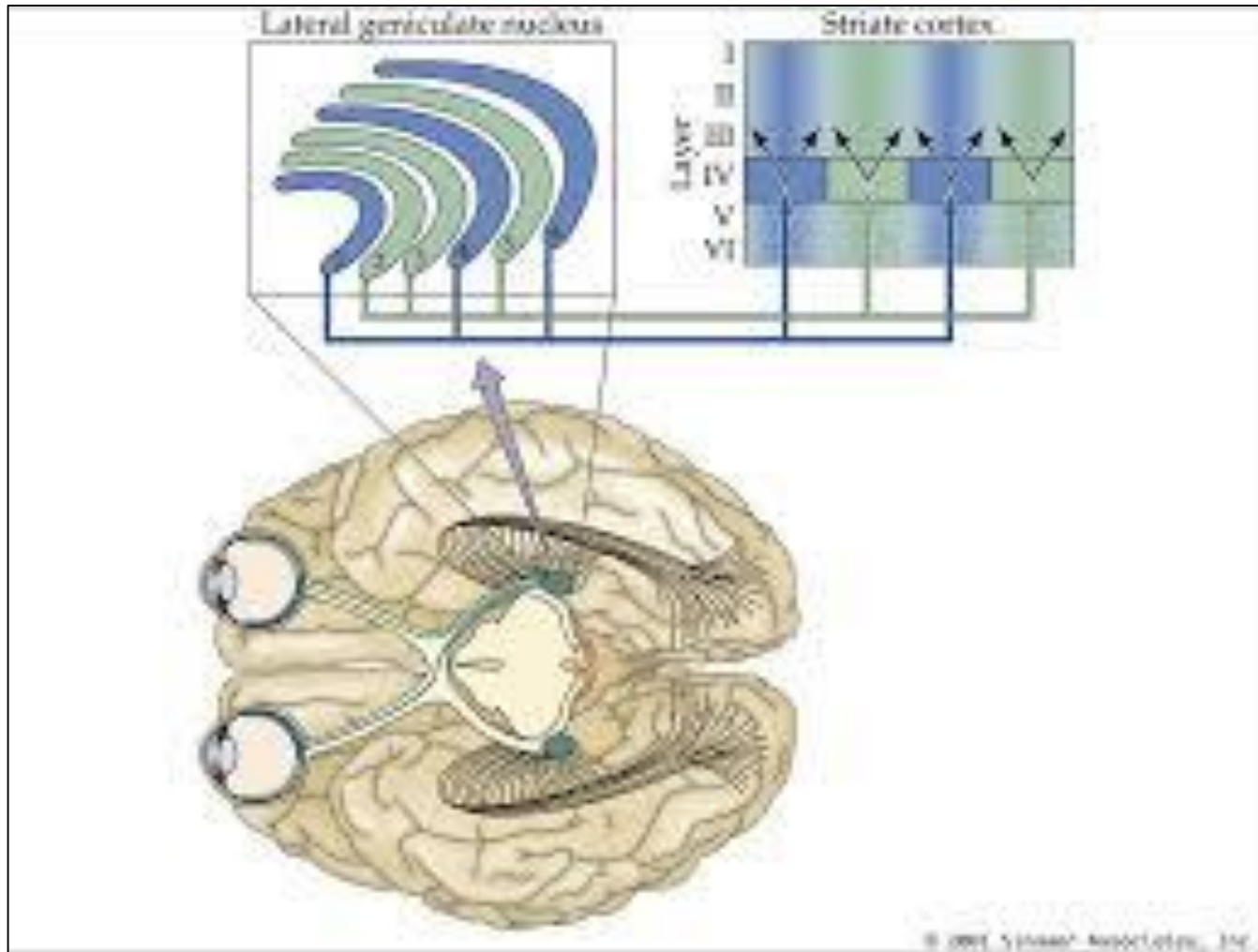


How is the information from the two eyes combined?



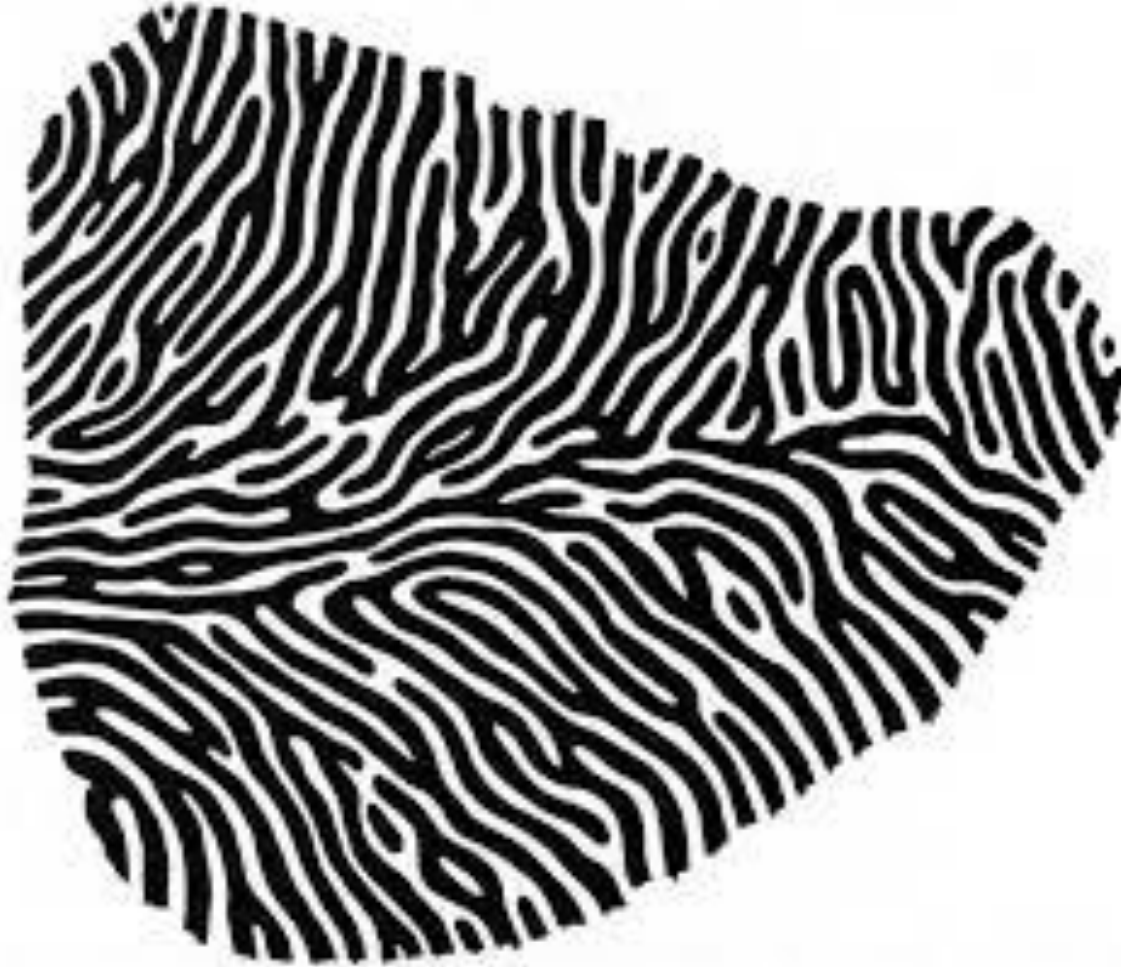
Right and left eyes outputs converge in the LGN

LGN: Ocular outputs are segregated in layers
Cortex: Ocular outputs are segregated in columns



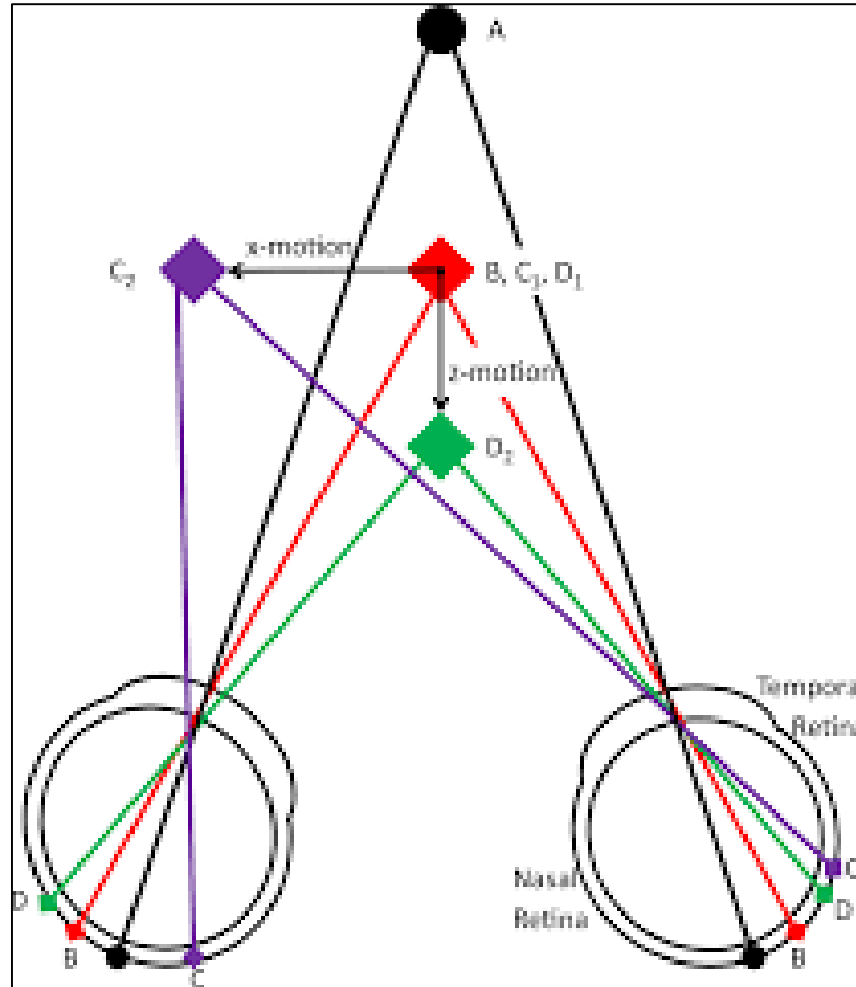
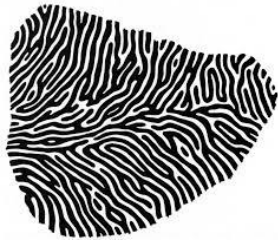
Ocular Dominance Columns

Monkey Ocular Dominance Columns- top view

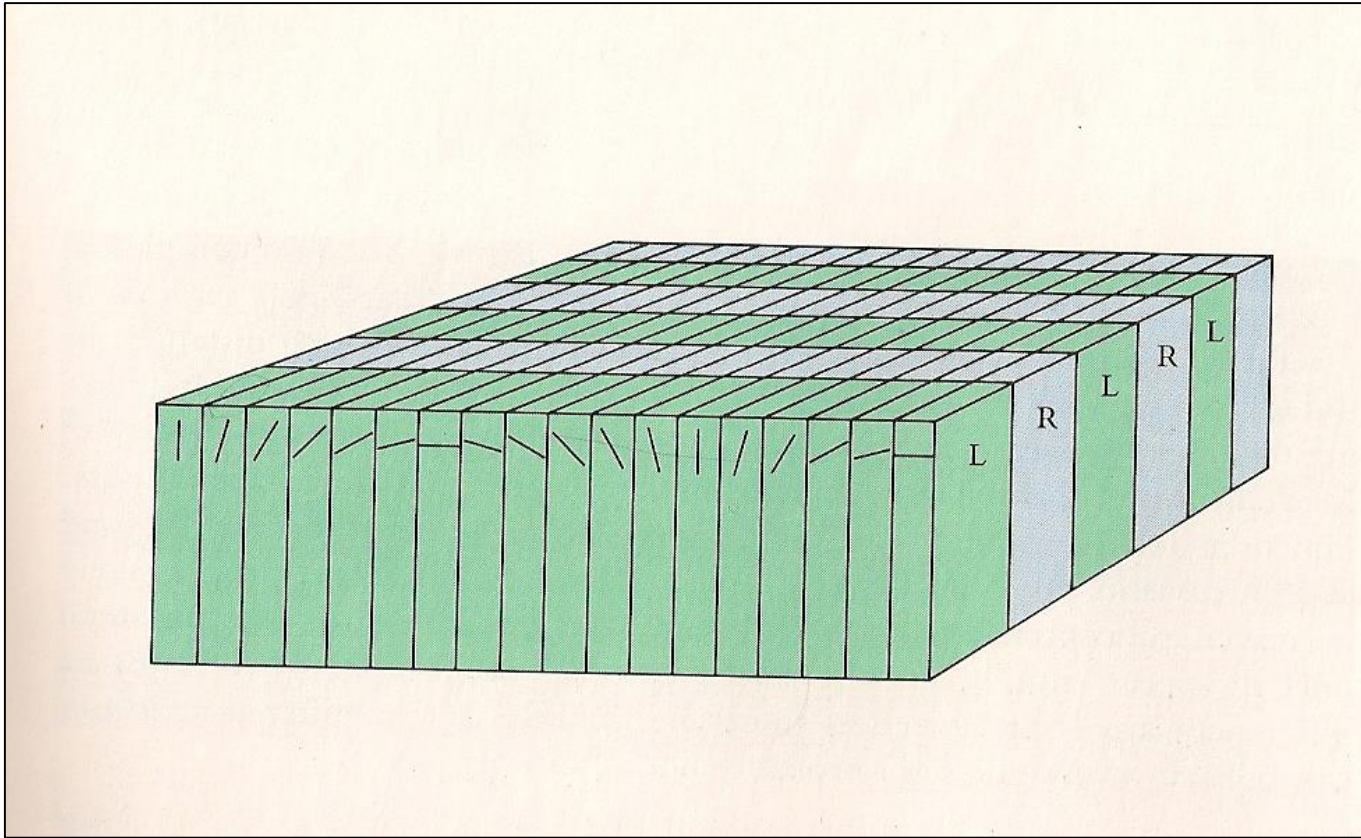


Area V1

What is the function of the ocular selectivity?



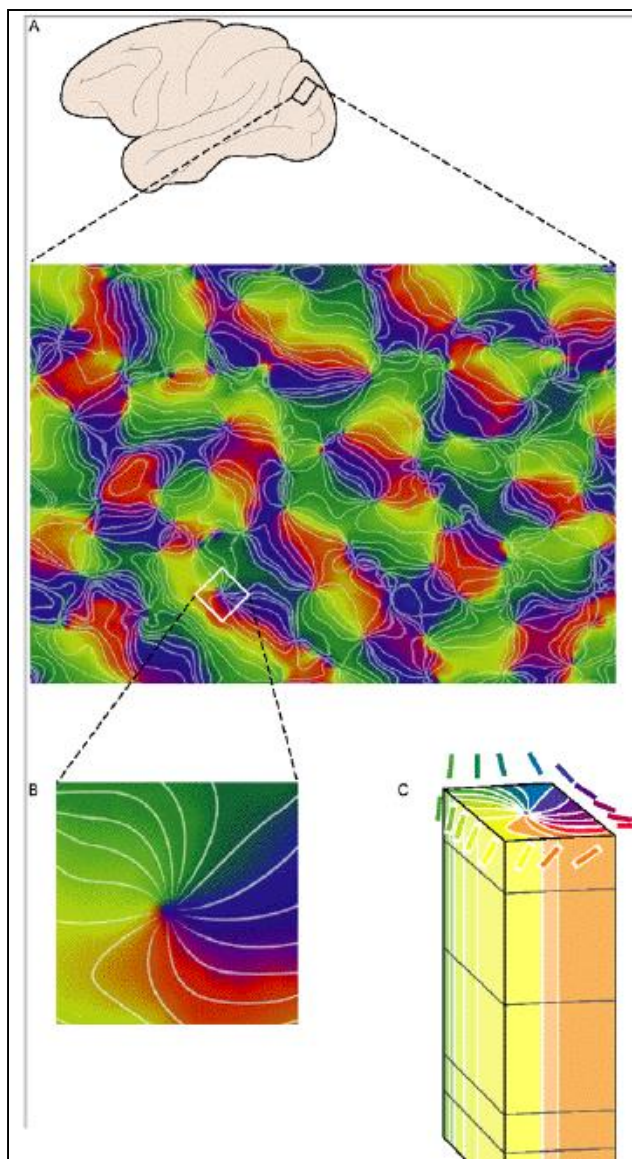
How are the ocular dominance and orientation columns combined?



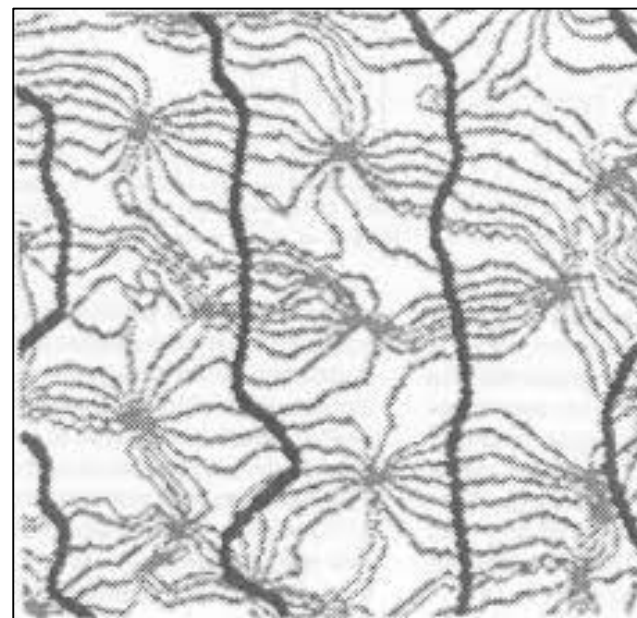
The idealized “hyper-column” model

How are the ocular dominance and orientation columns combined?

Orientation map of V1



Orientation vs. Ocular Dominance

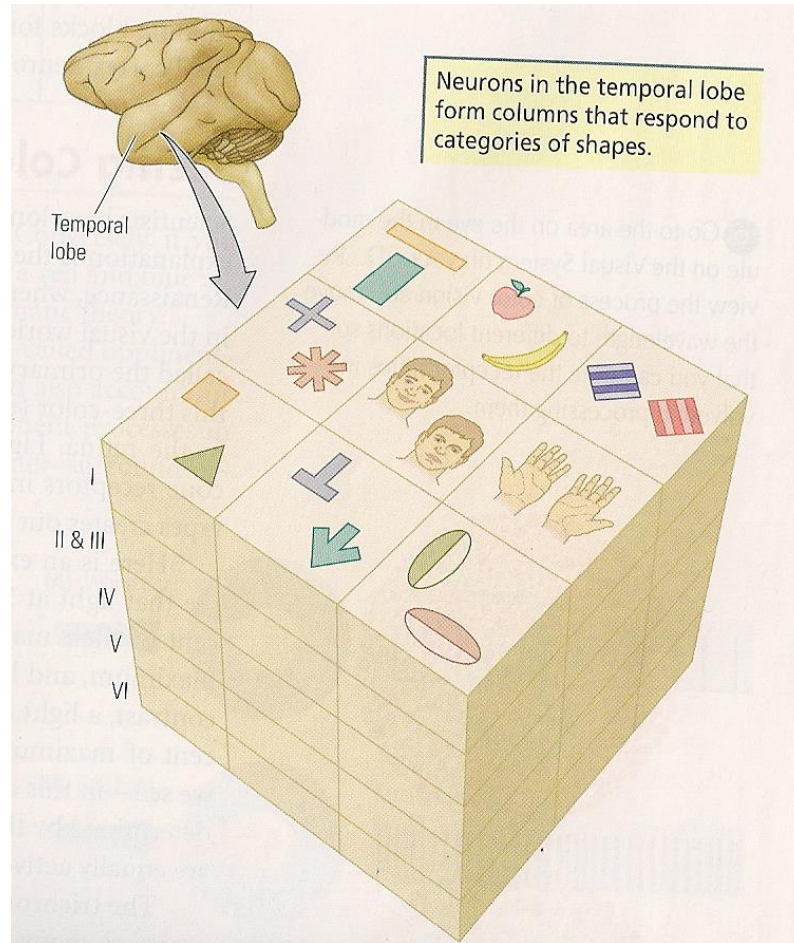


Orientation (thin lines)

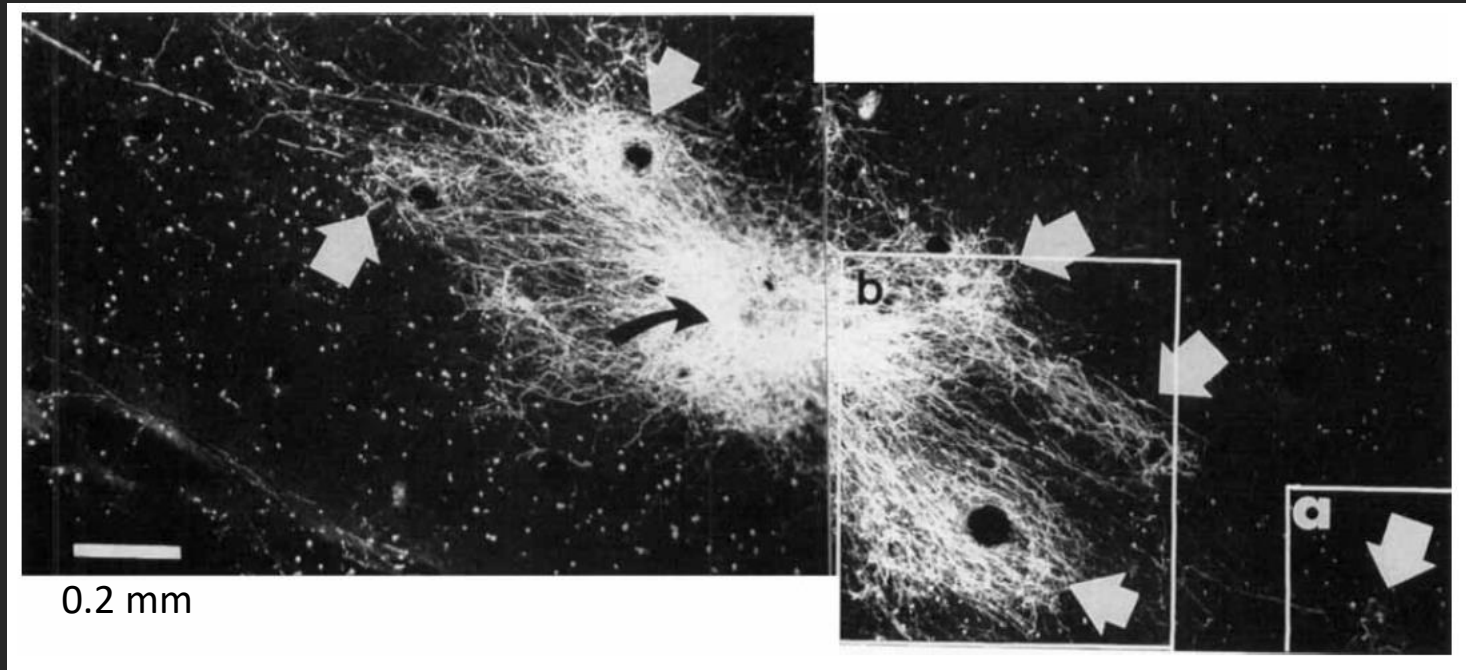
Ocular-Dominance (thick lines)

The hyper-column as revealed by optical imaging

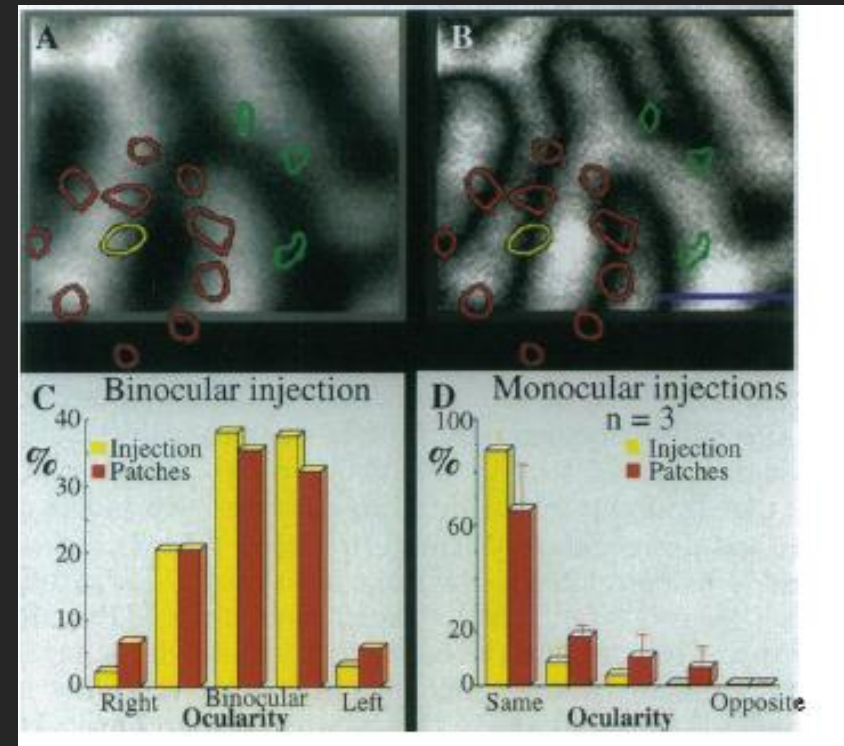
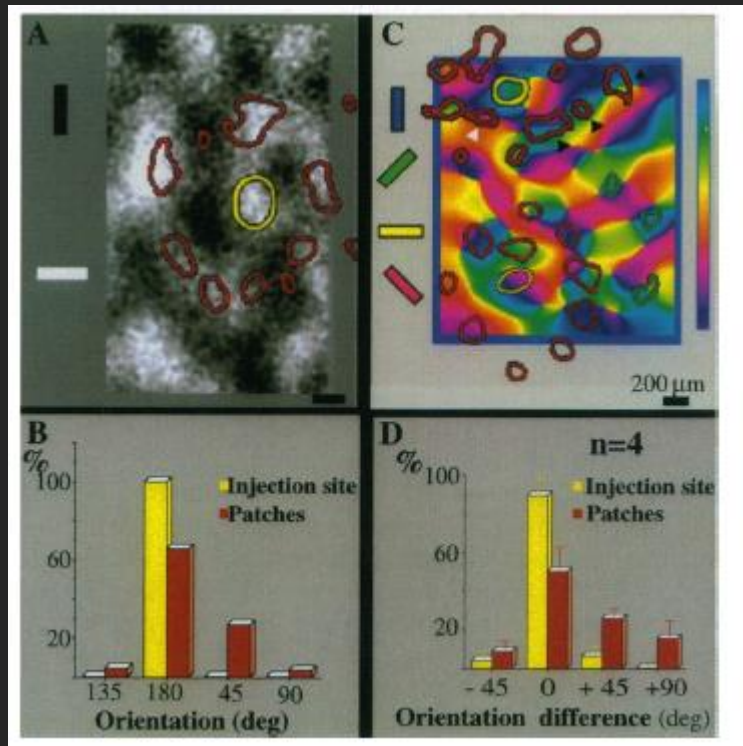
Columnar organization of complex templates in high order Ventral Stream



Lateral Connectivity: massive, local, reciprocal interactions



Lateral Connectivity connects similar-function columns



Interim Summary

- The functional organization of local cortical sites

Along the vertical dimension:

Similar functional selectivities (orientation, ocular dominance)

Six different layers- inputs arrive in middle layers, output leave of outer layers

Along the vertical dimension

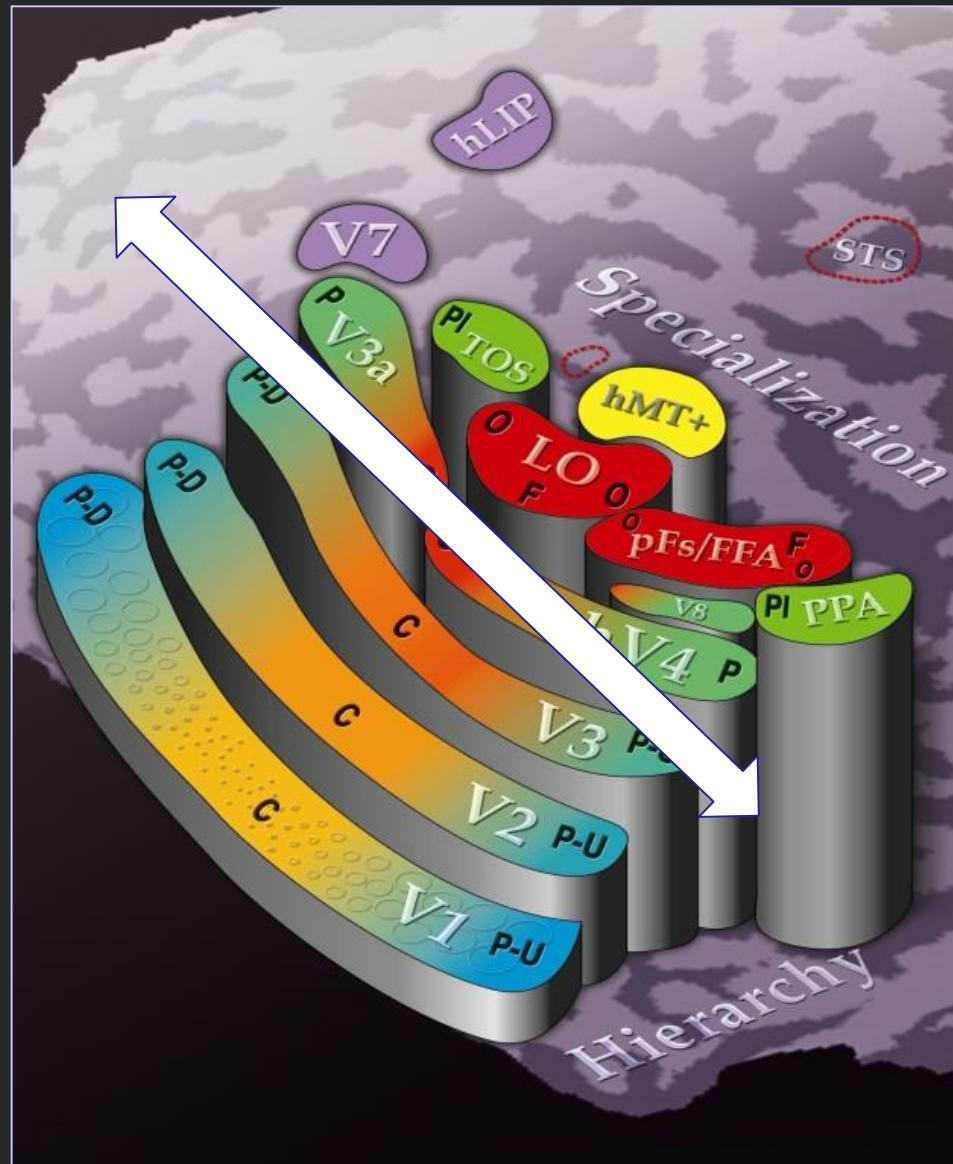
Local transition in orientation and ocular dominance

Global transition along retinotopic positions

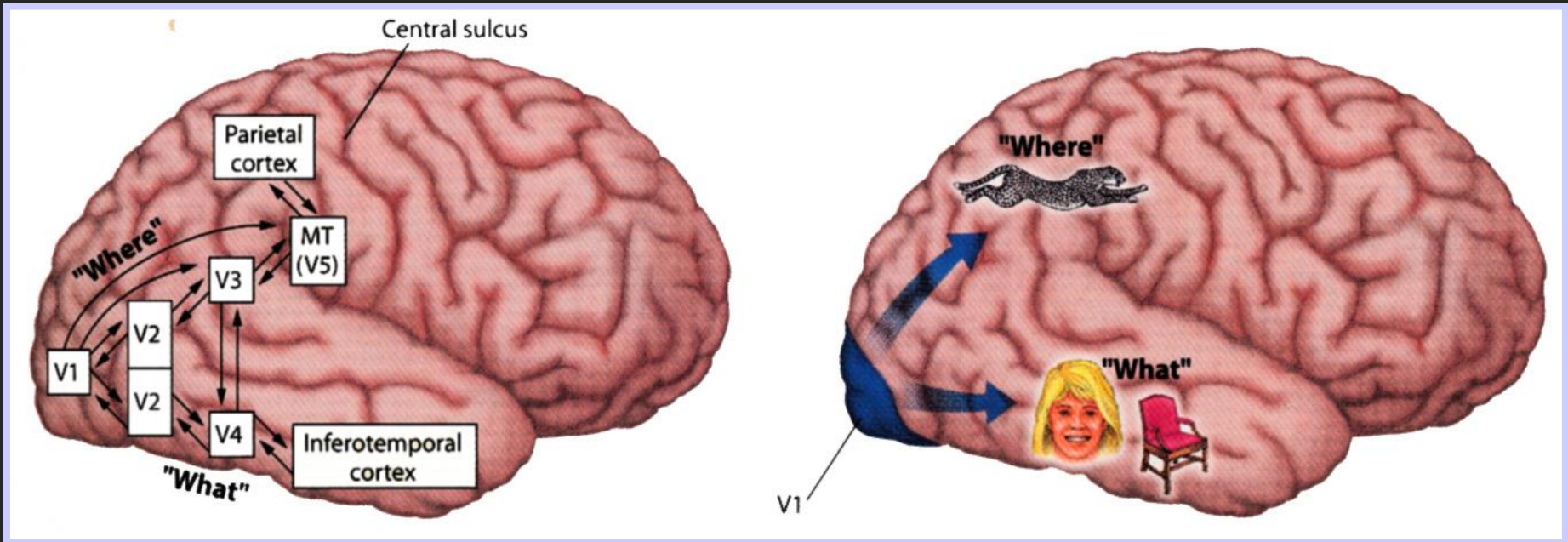
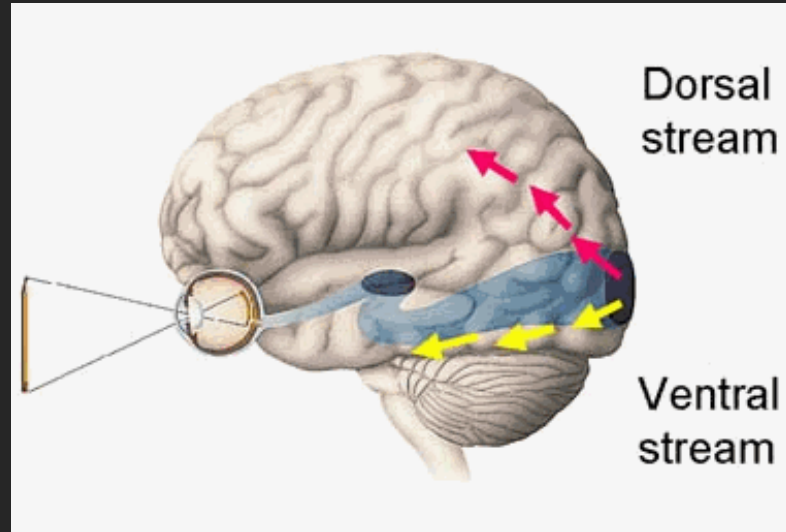
Same organization in higher areas but for complex shapes

Inter-columnar communication through massive lateral connections

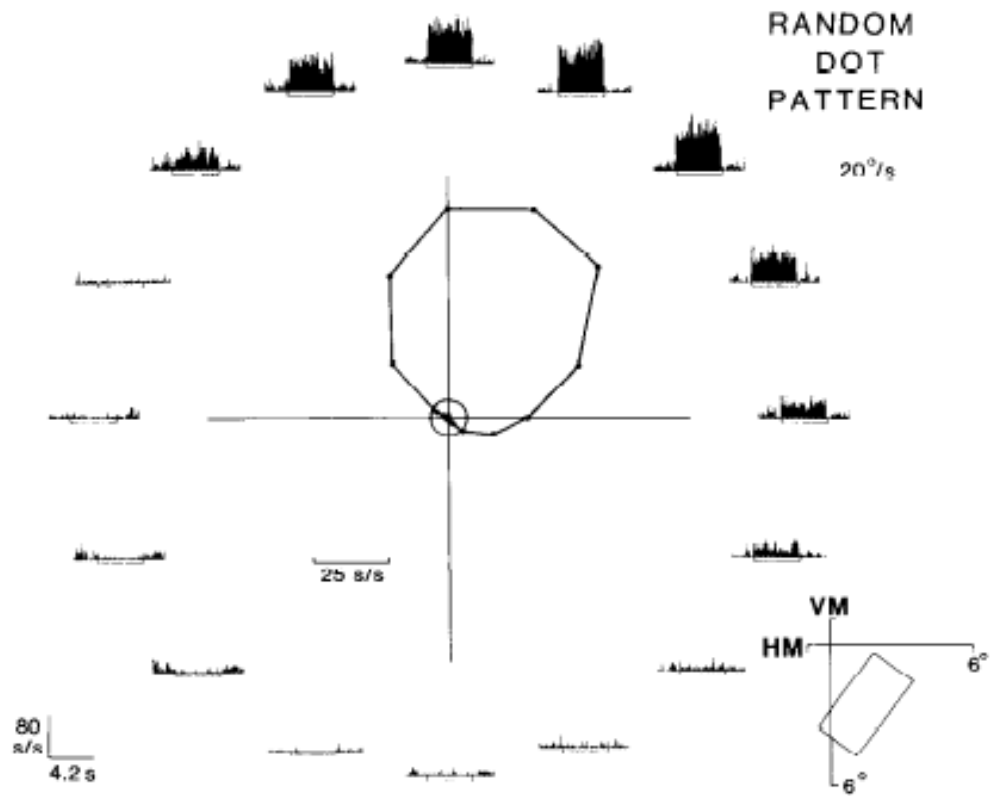
Large scale specialization in the visual system



Two streams in the visual system

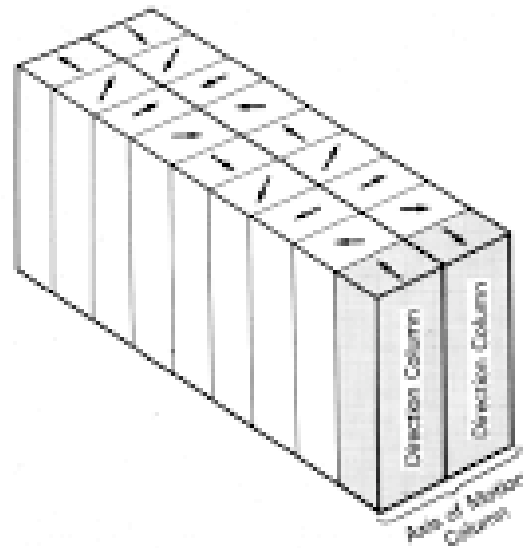


Direction selectivity in area MT- Dorsal stream



Columnar organization for direction and orientation in area MT

Columnar architecture in MT



Motion blindness following dorsal stream lesion



Interim Summary

- On a large scale we find a specialization of the visual system into two streams

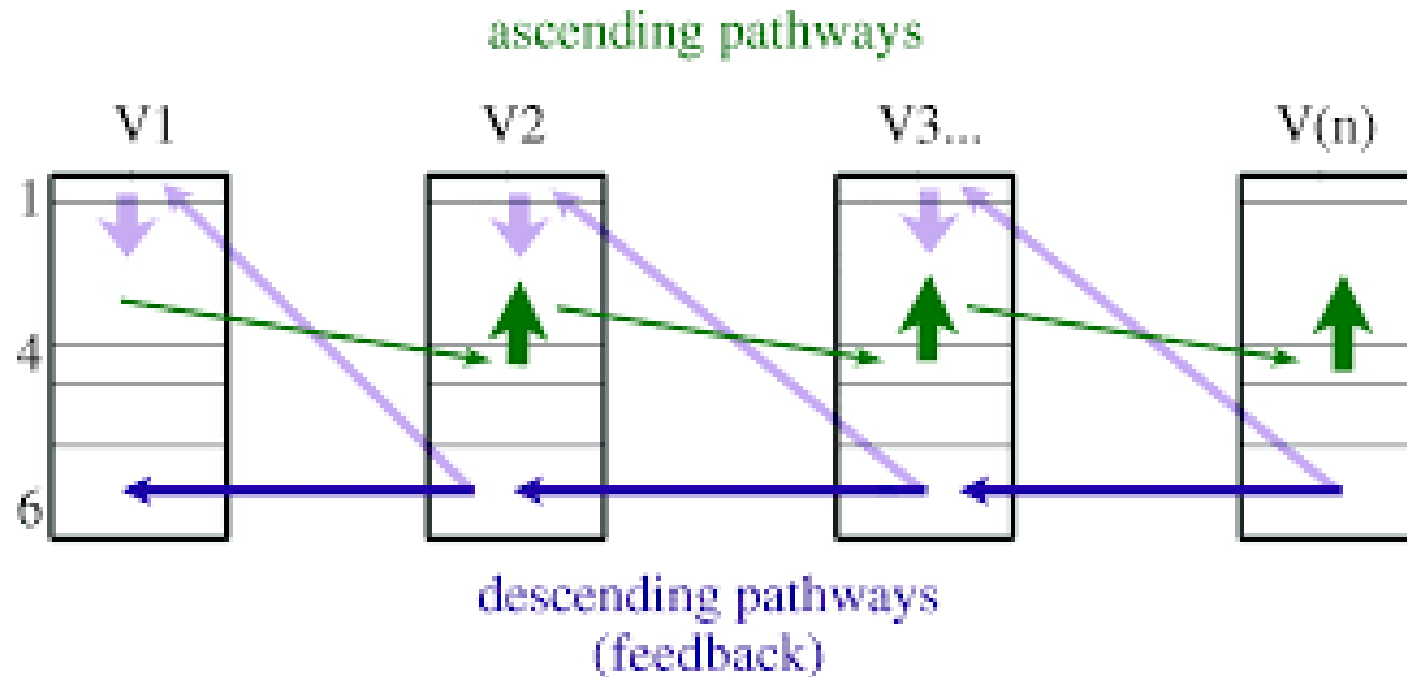
The ventral stream specializes in form perception and recognition

Contains neurons sensitive to static templates of objects insensitive to location

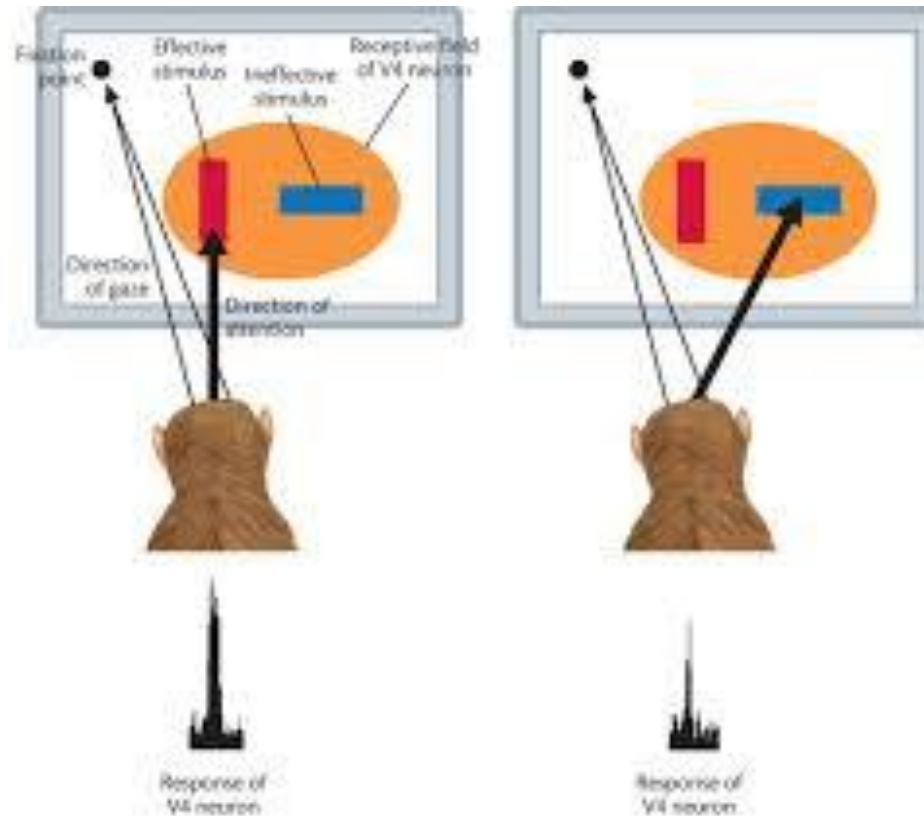
The dorsal stream specializes in motion and action

Contains neurons sensitive to motion direction and speed

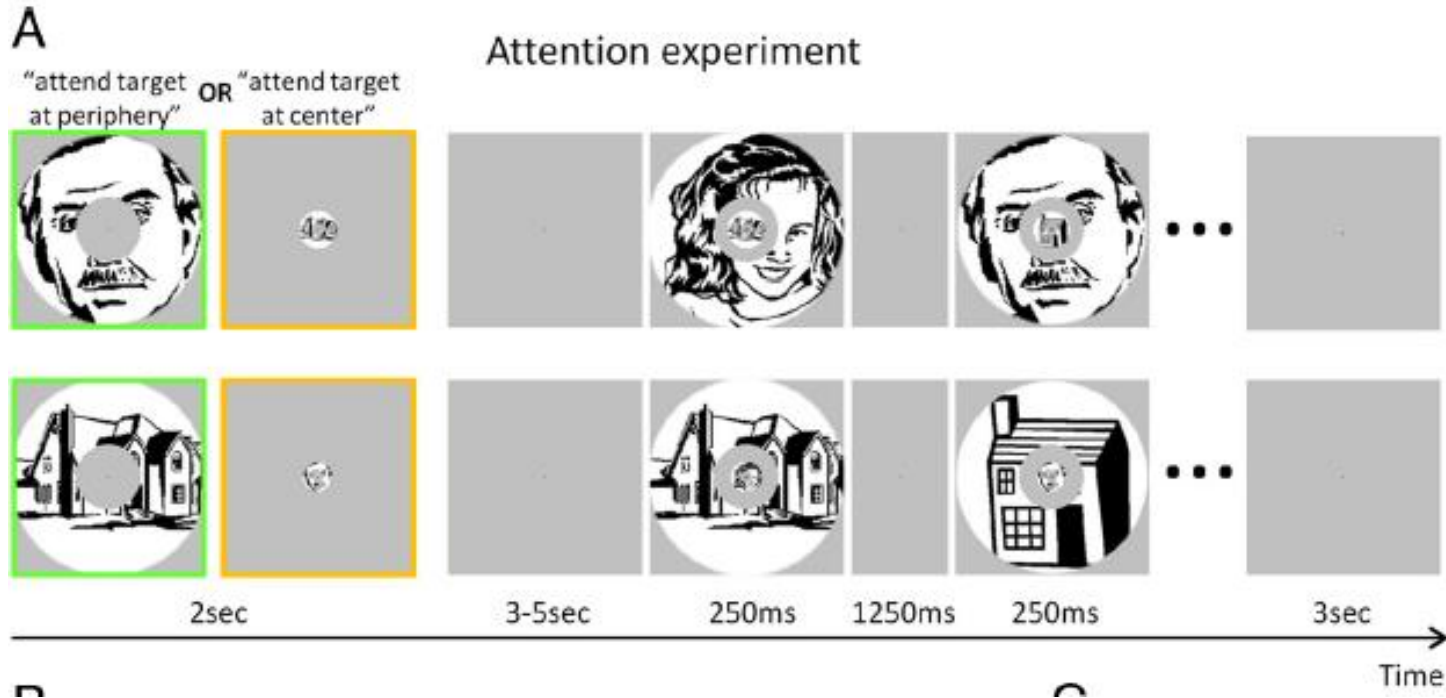
Massive “Top-Down” connections along the visual hierarchy



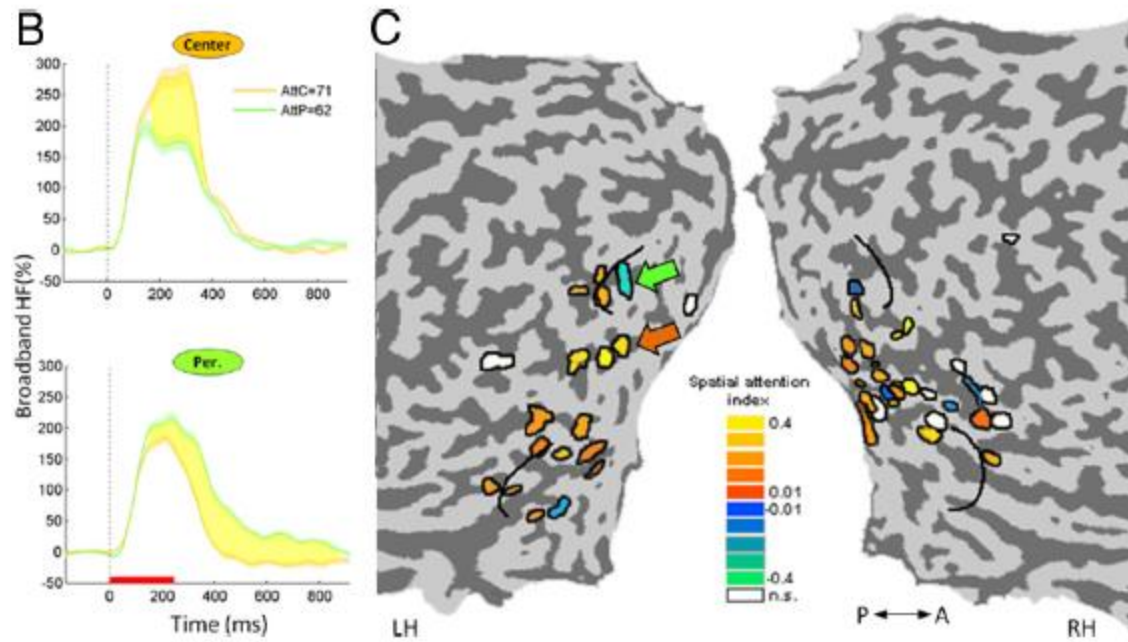
Attention mediated by top-down connections



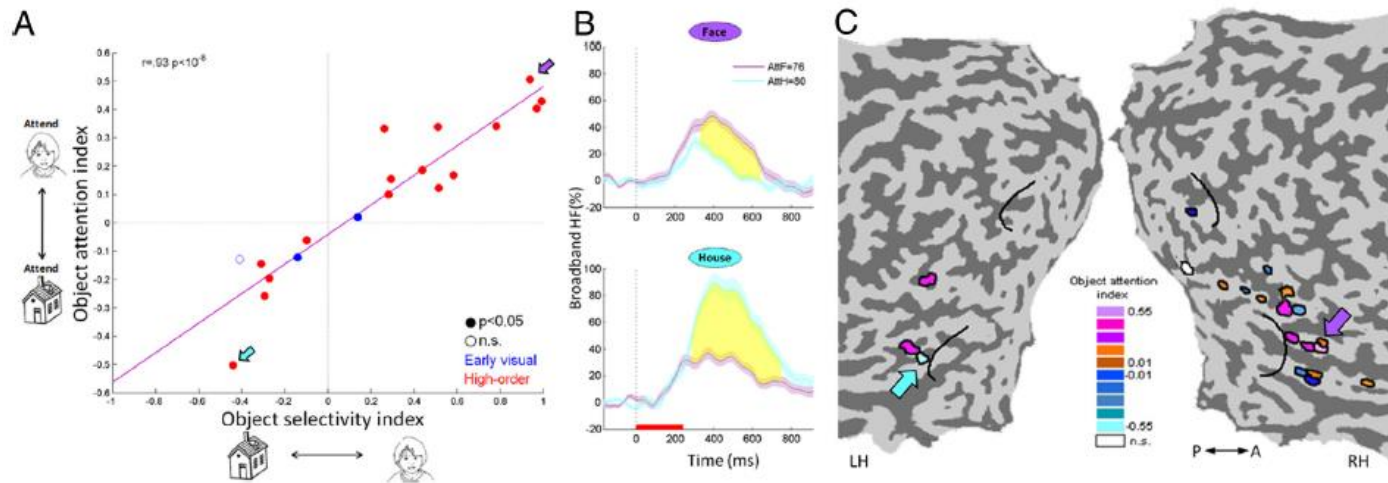
Top down attention in the human visual system



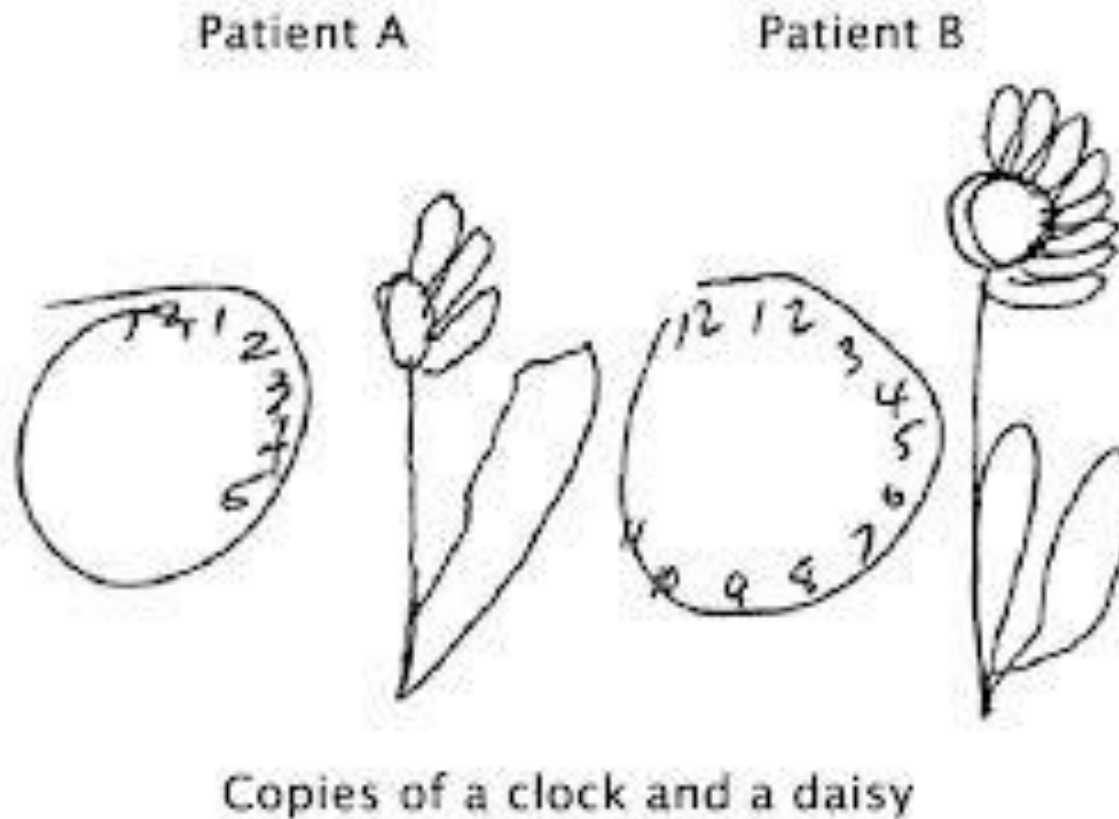
Spatial (“spot-light”)attention in early visual system



Template –selective attention in high order, ventral stream



Spatial attention is mediated via the right dorsal stream



Visual Neglect following right parietal lobe lesion

Summary

Parallel to the feed-forward hierarchical flow there is a massive top-down information flow

The top-down flow implements attentional selection:

Spatial attention:

Enhances activity in attended retinotopic locations

Feature- based/form attention

Enhances activity in attended feature/form representations

Damage to the top-down mechanism results in visual neglect