Introduction to Cognitive Neuroscience

Sensory systems

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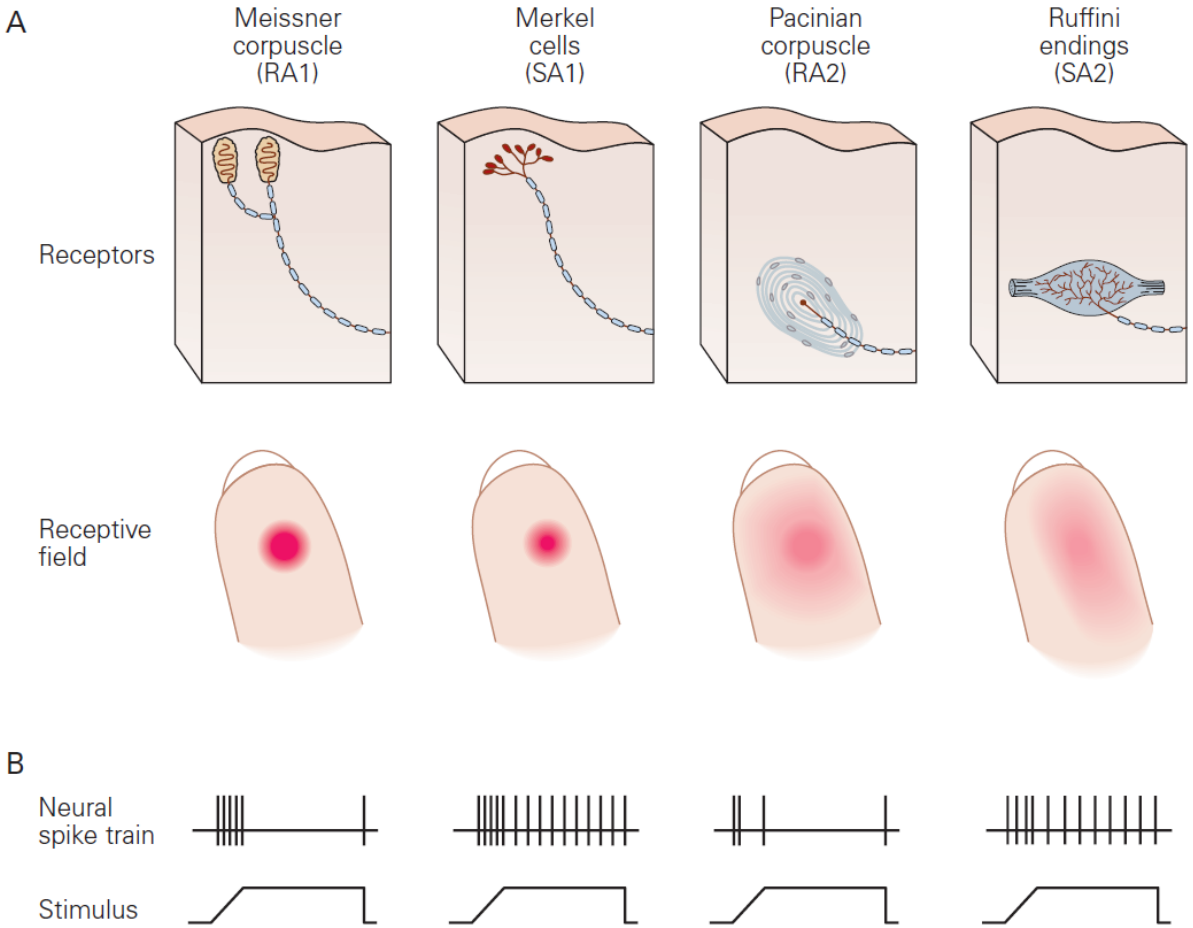
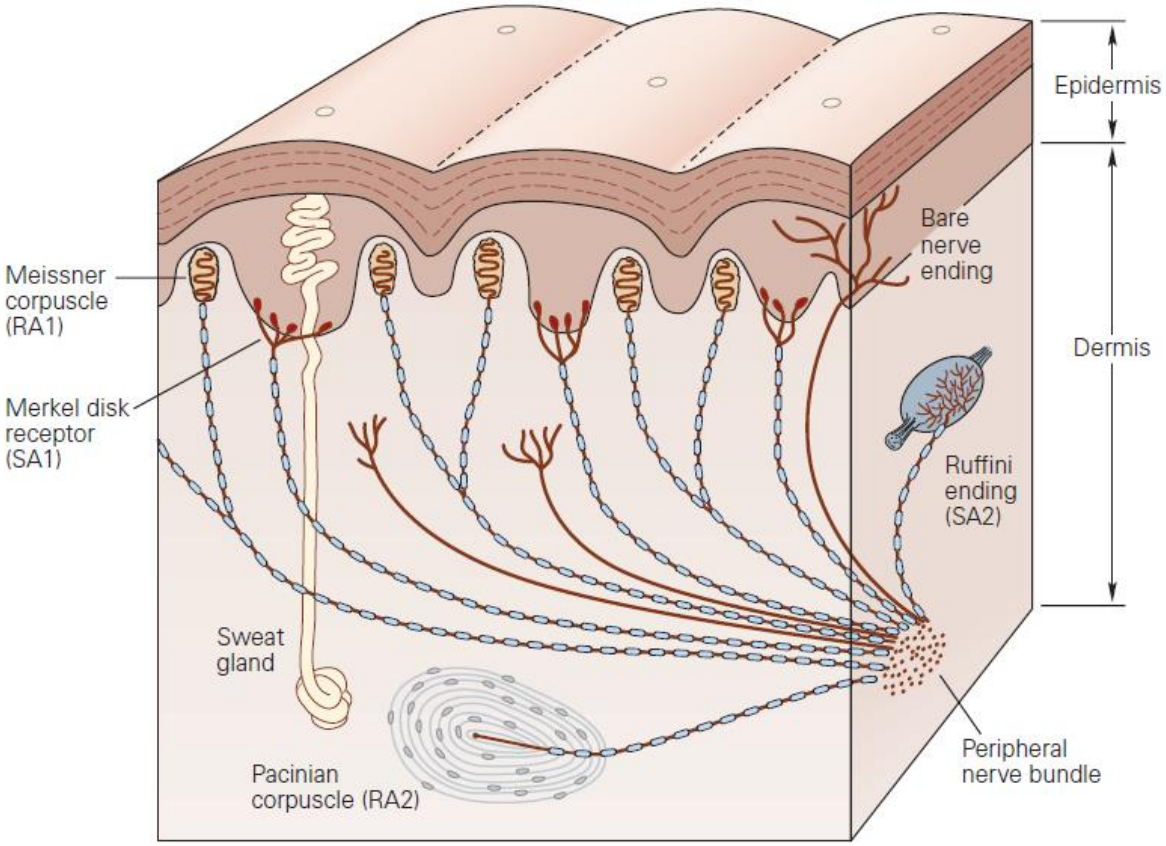
Somatosensory receptors

RA1, rapidly adapting type 1;
RA2, rapidly adapting type 2;
SA1, slowly adapting type 1;
SA2, slowly adapting type 2;

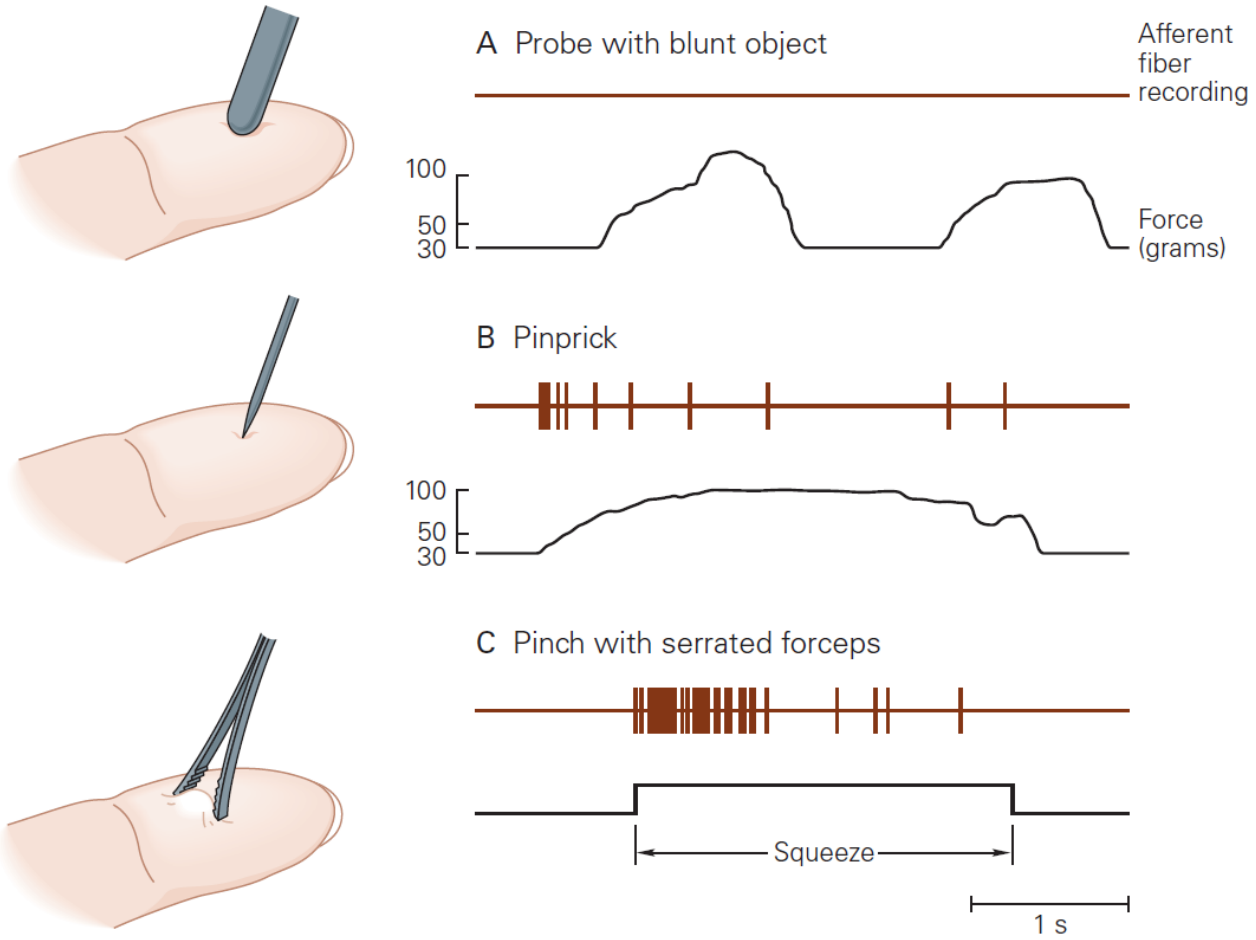



Epidermis
Dermis
Meissner corpuscle (RA1)
Merkel disk receptor (SA1)
Bare nerve ending
Ruffini ending (SA2)
Sweat gland
Pacinian corpuscle (RA2)
Peripheral nerve bundle

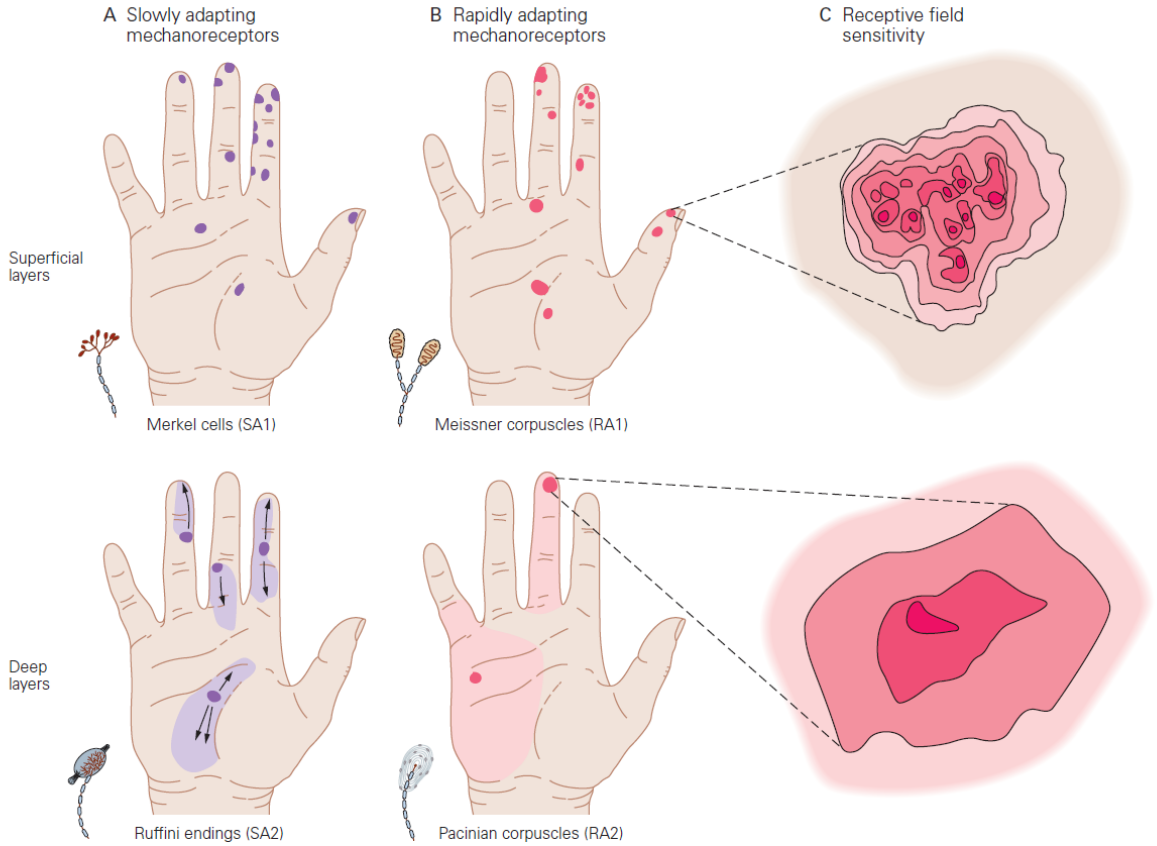
Cutaneous Mechanoreceptor Systems

	Type 1		Type 2	
	SA1	RA1[1]	SA2	RA2[2]
Receptor	Merkel cell	Meissner corpuscle	Ruffini ending	Pacinian corpuscle
Location	Tip of epidermal sweat ridges	Dermal papillae (close to skin surface)	Dermis	Dermis (deep tissue)
Axon diameter (μm)	7–11	6–12	6–12	6–12
Conduction velocity (ms)	40–65	35–70	35–70	35–70
Best stimulus	Edges, points	Lateral motion	Skin stretch	Vibration
Response to sustained indentation	Sustained with slow adaptation	None	Sustained with slow adaptation	None
Frequency range (Hz)	0–100	1–300		5–1,000
Best frequency (Hz)	5	50		200
Threshold for rapid indentation or vibration (best) (μm)	8	2	40	0.01

Mechanical nociceptors respond to stimuli that puncture, squeeze, or pinch the skin

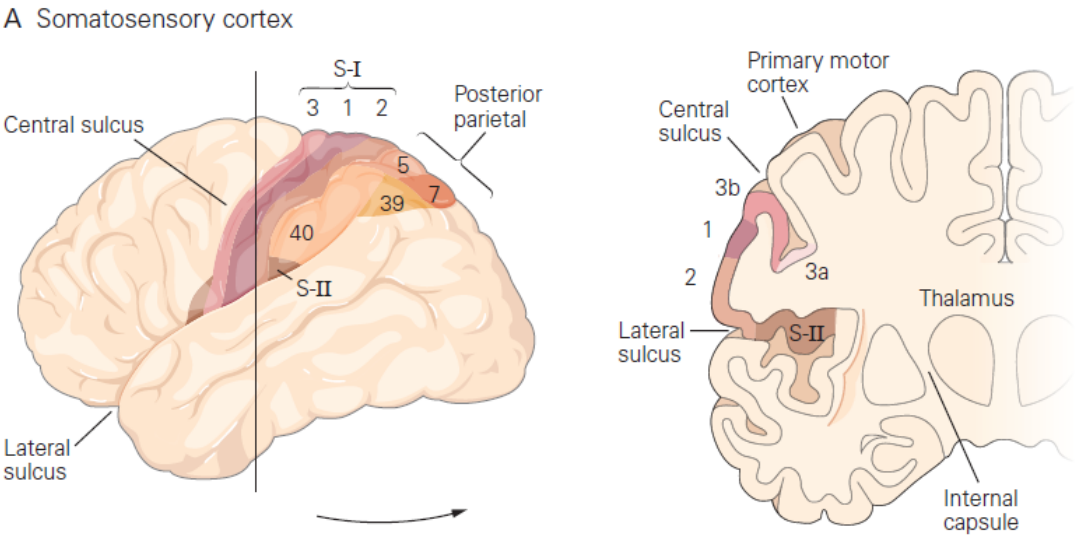


Receptive fields in the human hand are smallest at the fingertips



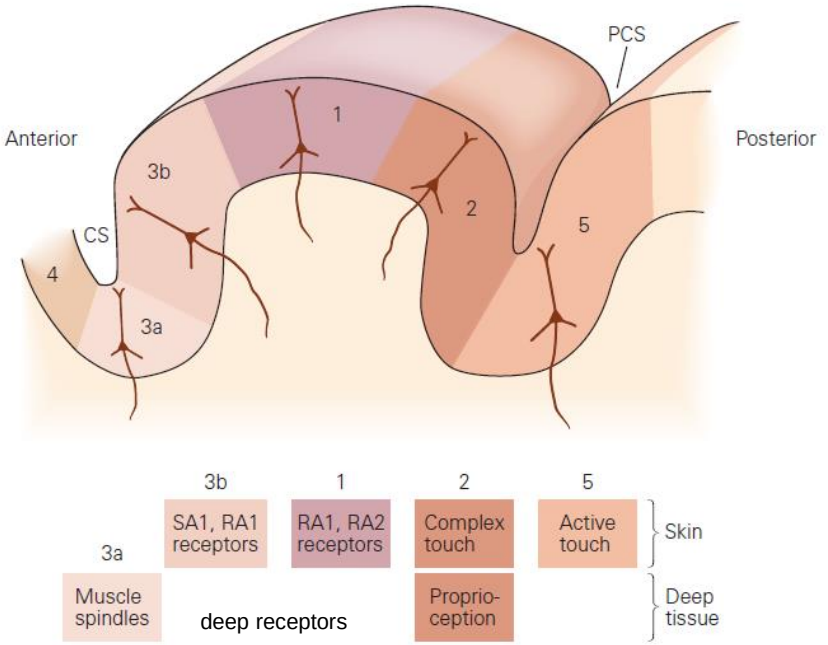
Those of receptors in the deep layers extend across wide regions of skin (light shading), but responses are strongest in the skin directly over the receptor (dark pots).

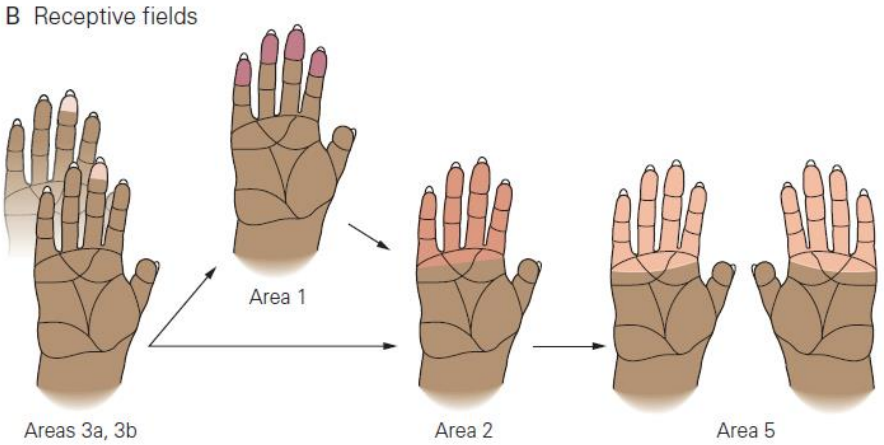
The somatosensory areas of the cerebral cortex.



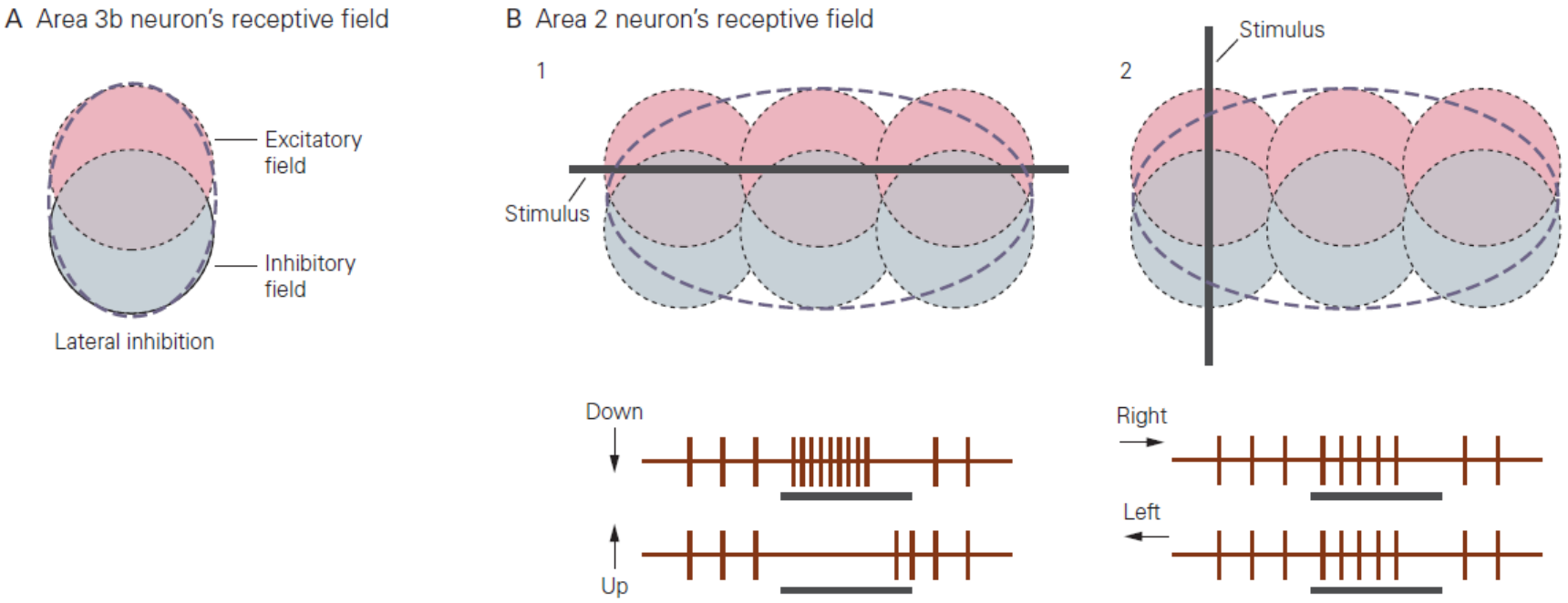
PR, parietal rostroventral cortex;
PV, parietal ventral cortex;
VPL, ventral posterior lateral nuclei;
VPM, ventral posterior medial nuclei;
VPS, ventral posterior superior nuclei

The receptive fields of neurons in the primary somatic sensory cortex.

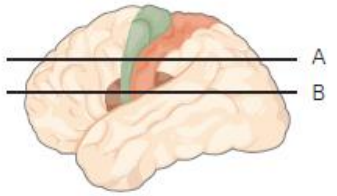




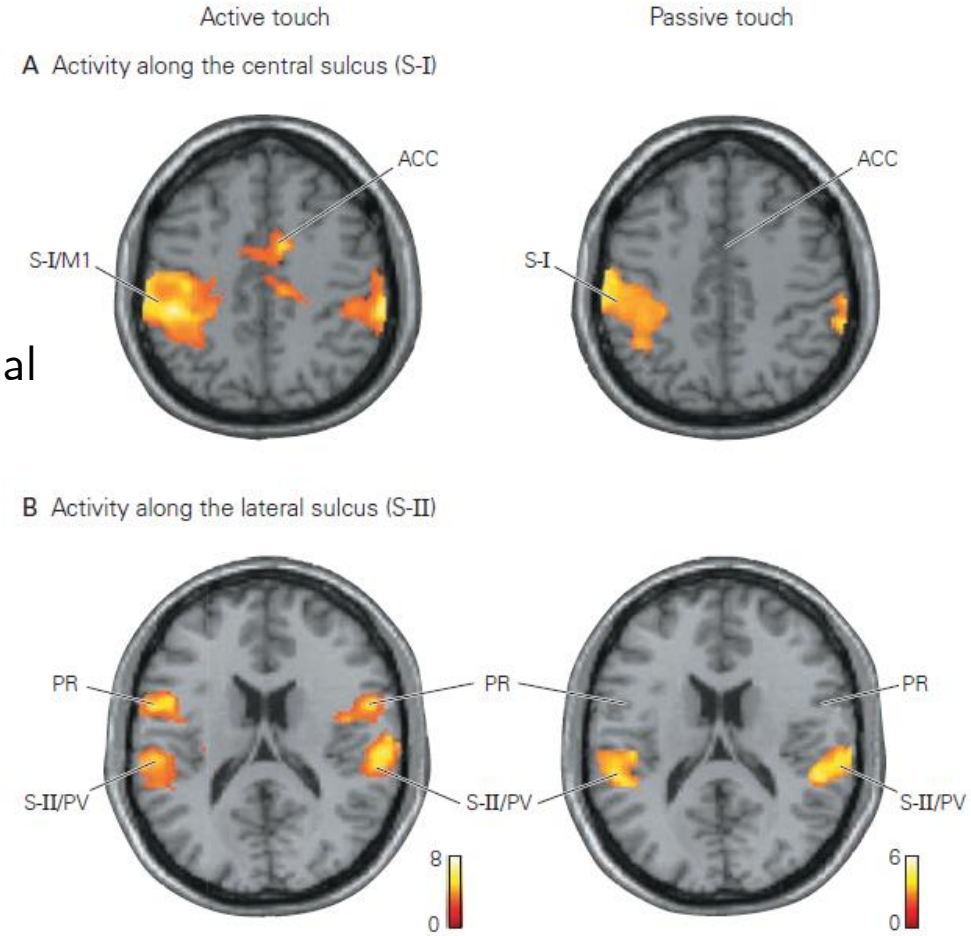
The spatial arrangement of excitatory and inhibitory inputs to a cortical neuron determines which features of a stimulus will be encoded by the neuron.



Active touch evokes more complex responses in S-I and S-II than passive touch



Cortical regions in the human brain stimulated by passive and active touch are localized using functional magnetic resonance imaging (fMRI).

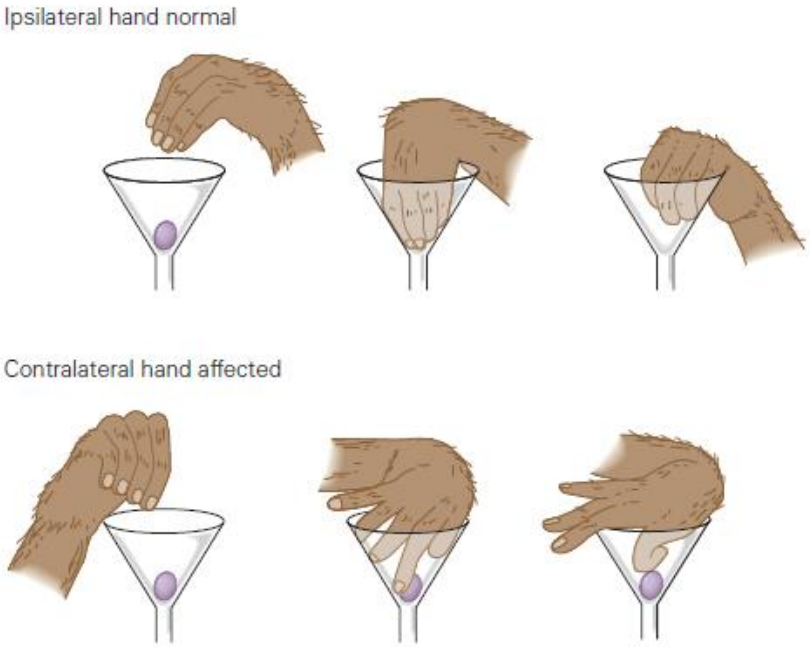


Finger coordination is disrupted when synaptic transmission in the somatic sensory cortex is inhibited in a monkey.

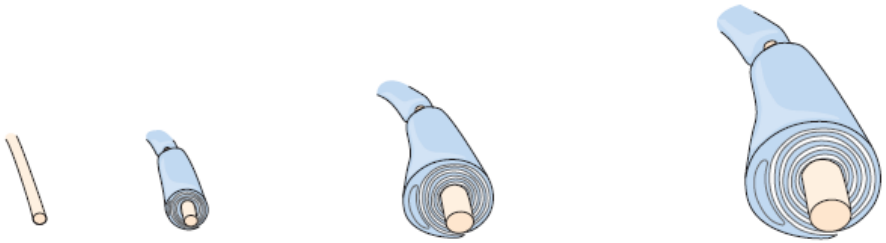
Muscimol, a (GABA) agonist that inhibits cortical cells, was injected into Brodmann's area 2 on the left side of a monkey's brain.

Within minutes after injection the finger coordination of the right hand (contralateral) was **severely disrupted**;

the monkey was unable to pick up a grape from a funnel. The injection effects are known to be specific to the injected hemisphere because the left hand (ipsilateral) continues to perform normally.

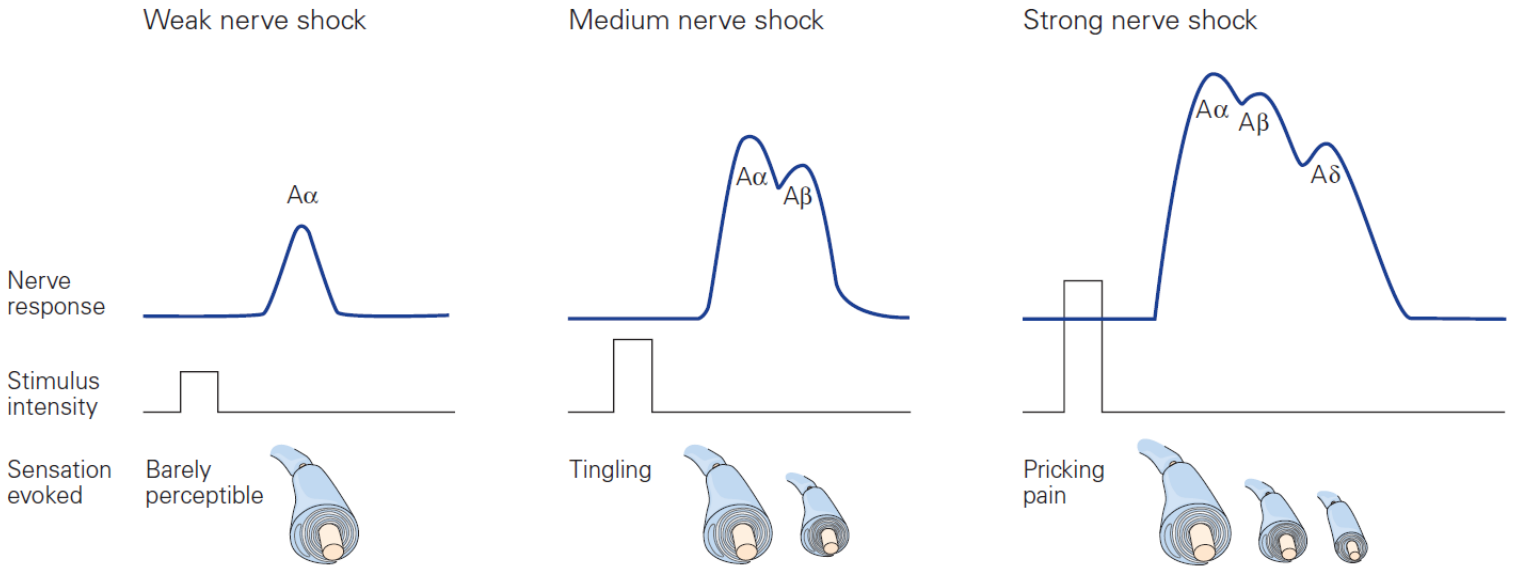


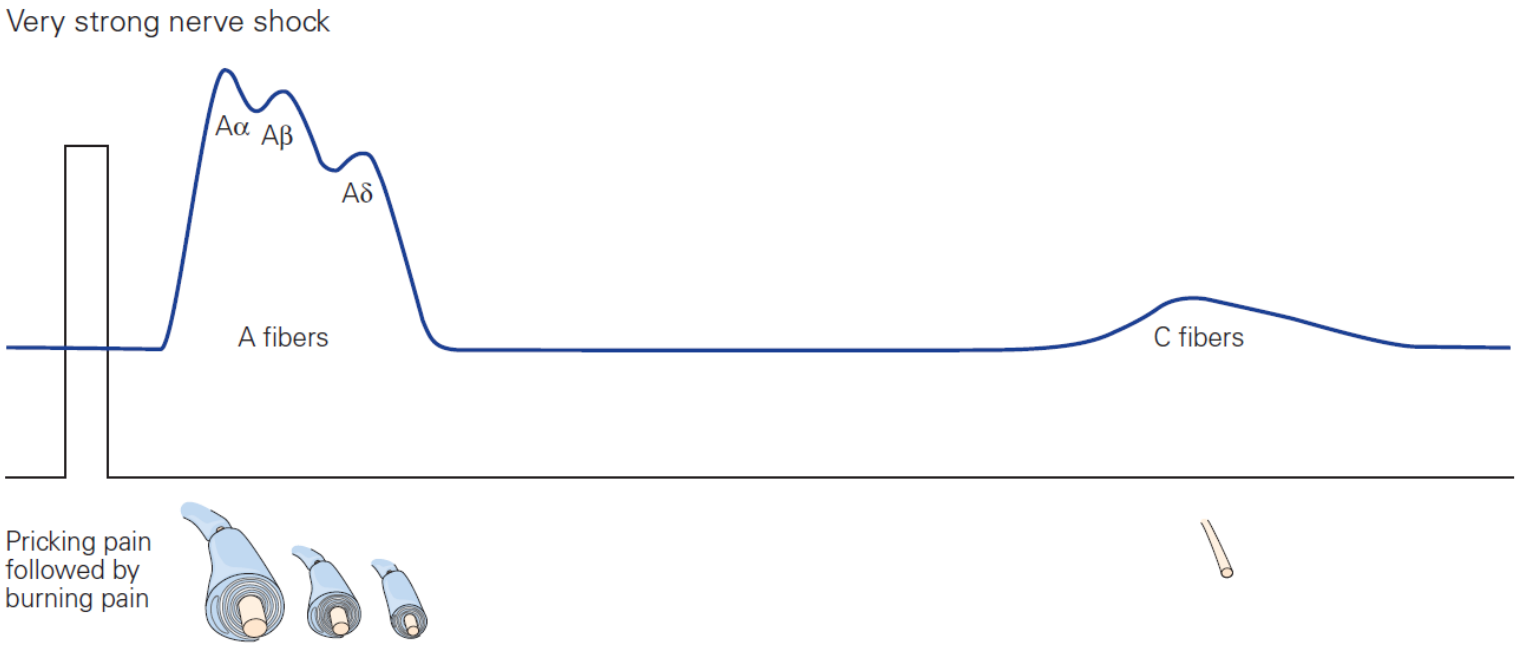
Several types of sensory nerve fibers



Axon diameter (μm)	1	5	12	20
Conduction velocity (m/s)	1	30	72	120

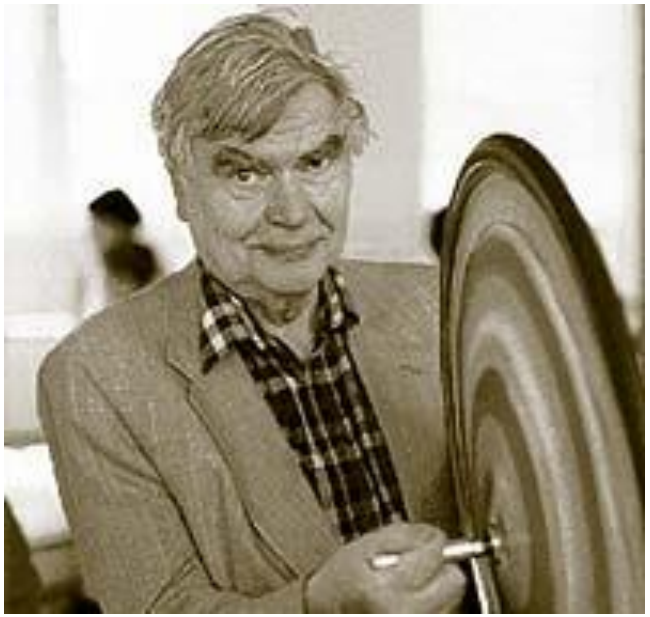
Compound action potentials

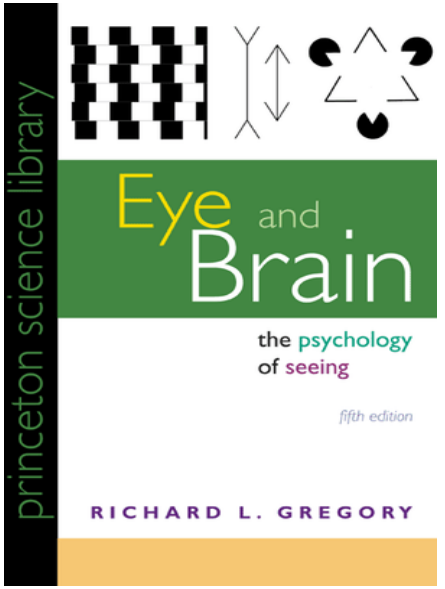




The distinct conduction velocities of different classes of sensory and motor axons produce multiple deflections.

The Constructive Nature of Visual Processing





From the patterns of stimulation on the retina we perceive the world of objects and this is **nothing short of a miracle**.

-Richard L. Gregory, Eye and Brain, 1966

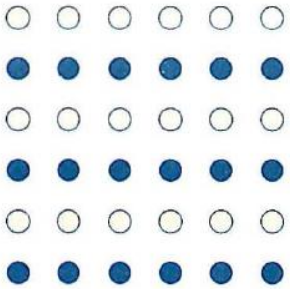
Visual perception is a constructive process

- Vision is often incorrectly compared to the operation of a **camera**
- Old view: **(Jolm Locke, David Hume, and George Berkeley)**
  - **perception as an atomistic process vs. component based sensory**
- Modern view: (Immanuel Kant)
  - Perception is an active and creative process

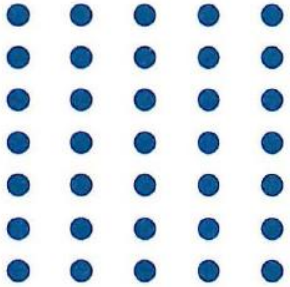
Gestalt means configuration

- Perception depends not just on the **properties** of the stimulus but also on its **context**
- The brain **has a way** of looking at the world
- Law of perception: **similarity, proximity, and good continuation**
- brain's **tendency to impose a pattern**

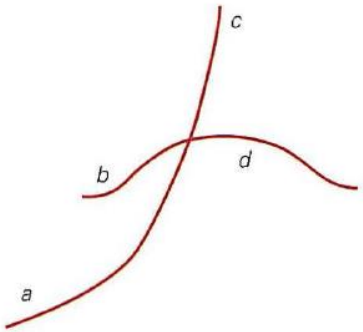
A Similarity

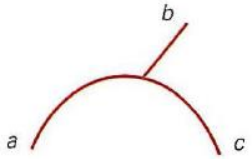


B Proximity

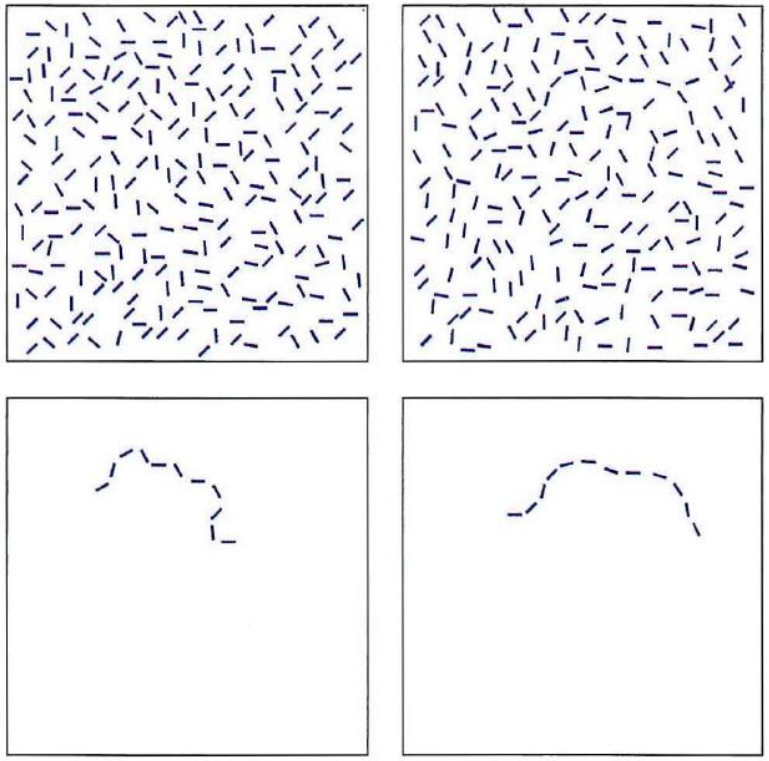


C Good continuation

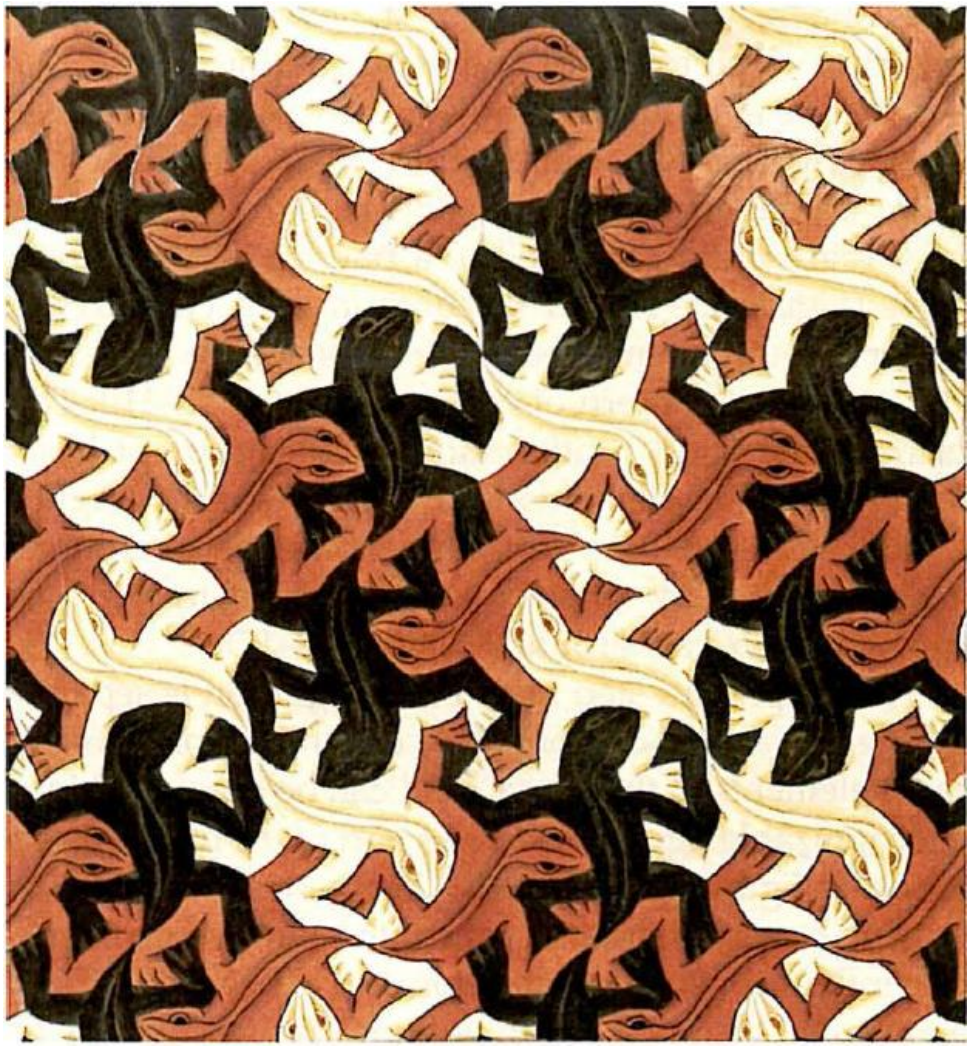




D Contour saliency



maintain the same curvature



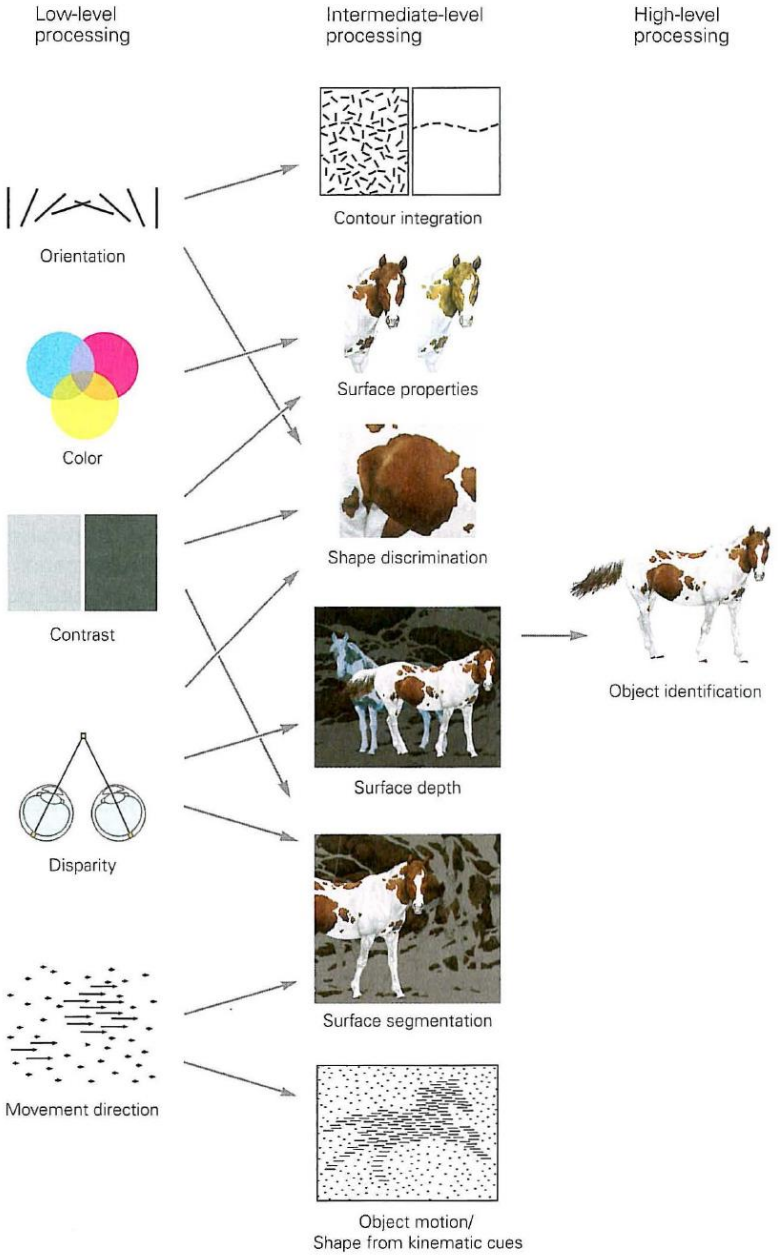
Object recognition depends on the separation of **foreground** and **background** in a scene

Expectation and perceptual task play a critical role in what is seen

higher-order representations of shape guide lower-order processes of segmentation

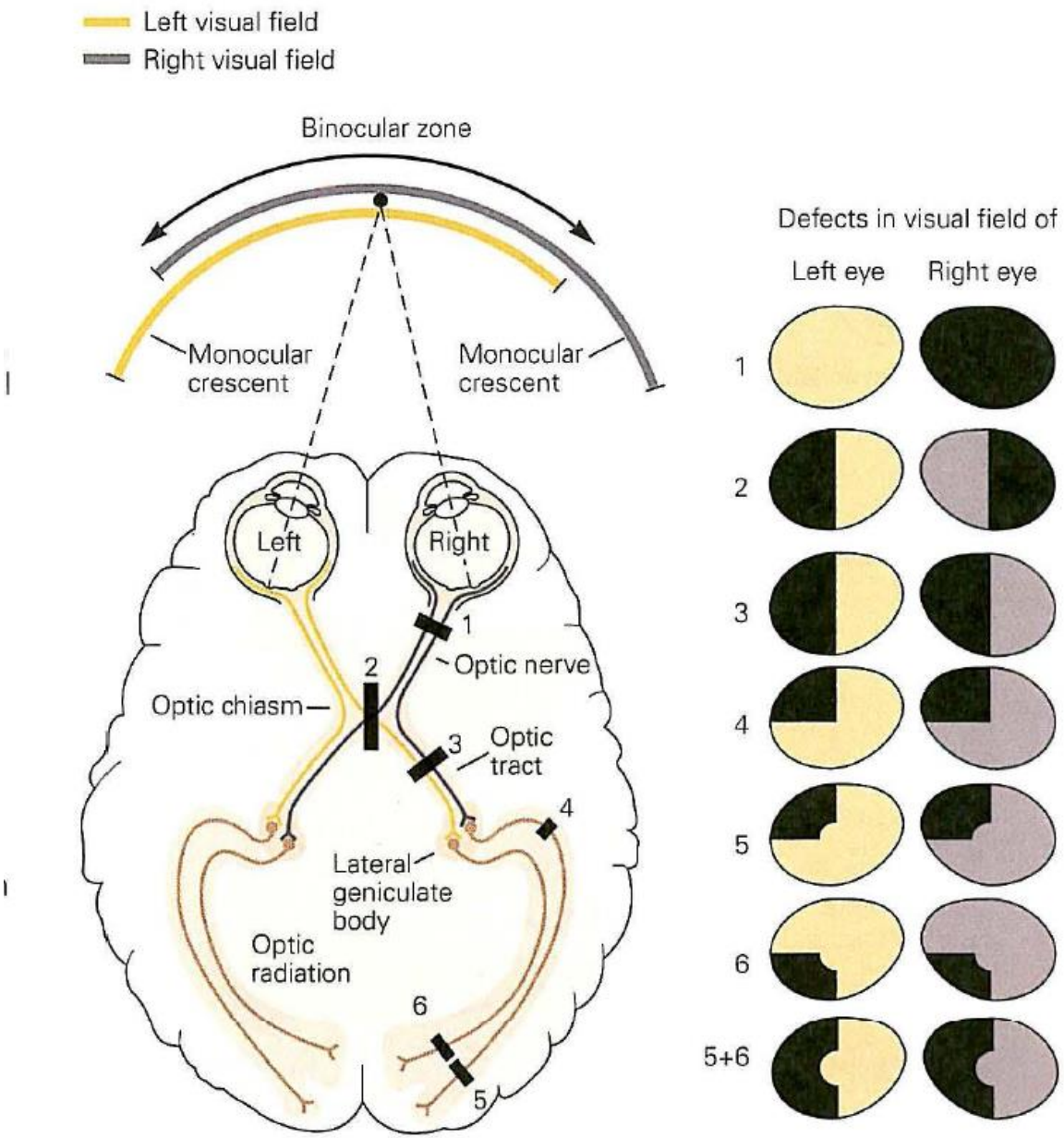
Priming image

Three-level processing



Representation of the visual field along the visual pathway

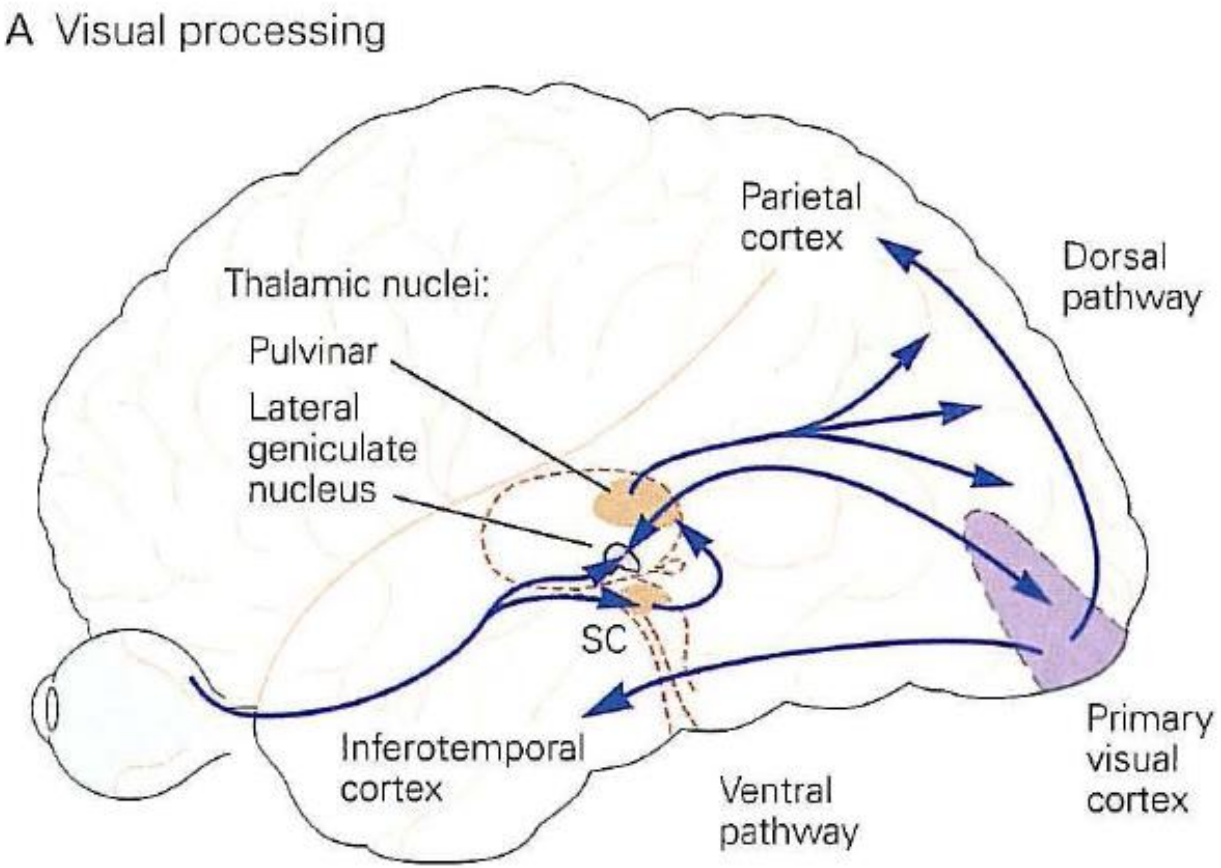
Visual perception is mediated by the **geniculostriate** pathway



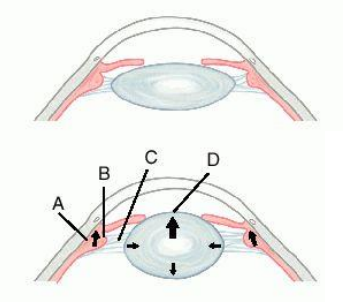
Retinotopy

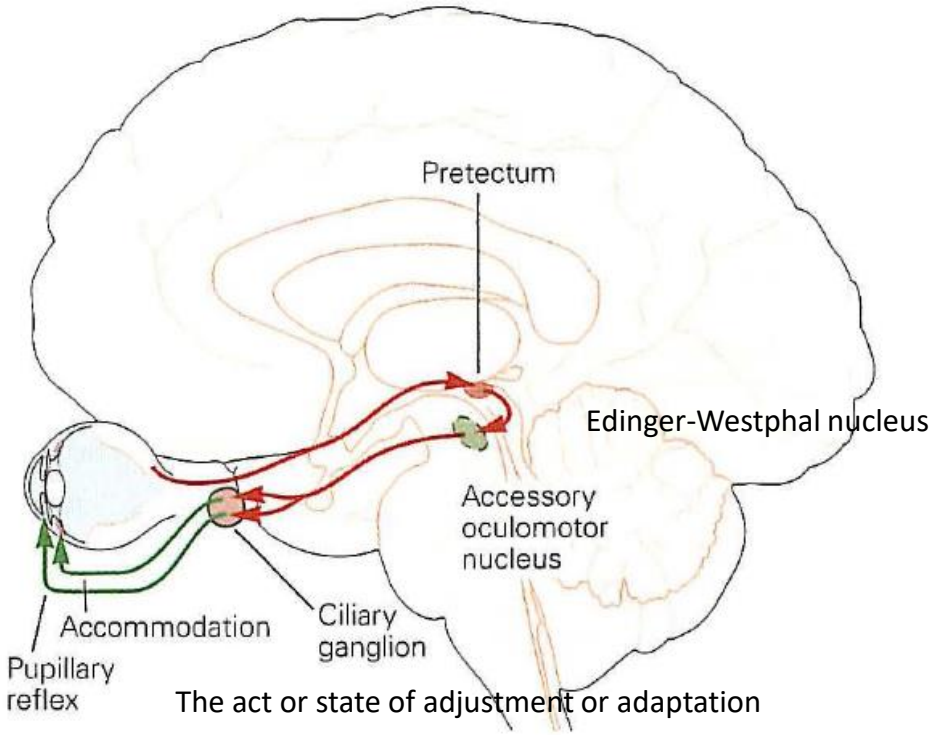
- The preservation of the spatial arrangement of inputs from the retina is called **retinotopy**
- Visual pathwasys:
  - Retin → LGN → Cortex: **geniculostriate**,
  - Retina → superior colliculus → pontine formation
  - Retina → pretectal area of the midbrain (pupillary)

Pathways for visual processing,



Pupillary reflex accommodation

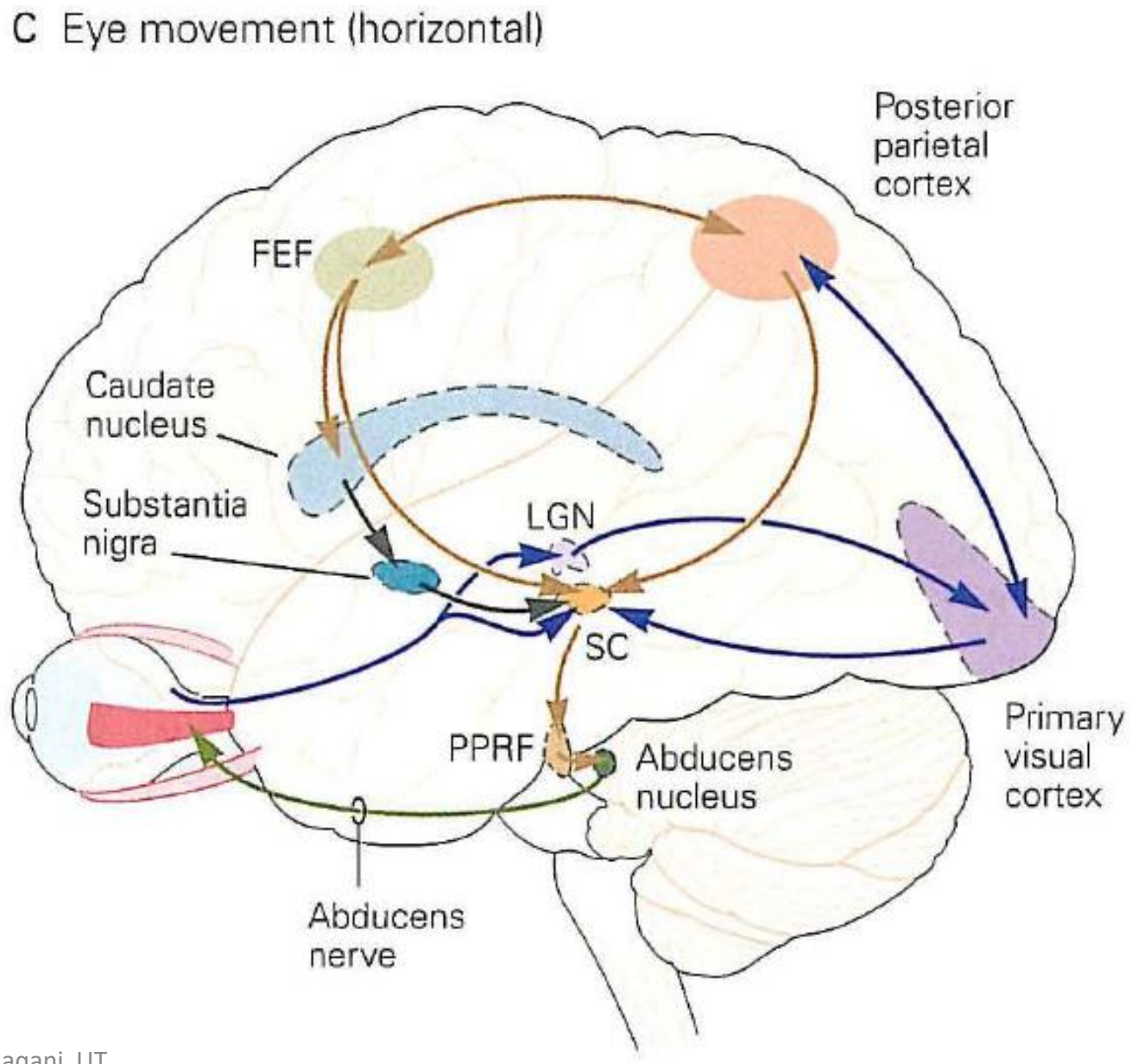




pupillary sphincter

The act or state of adjustment or adaptation

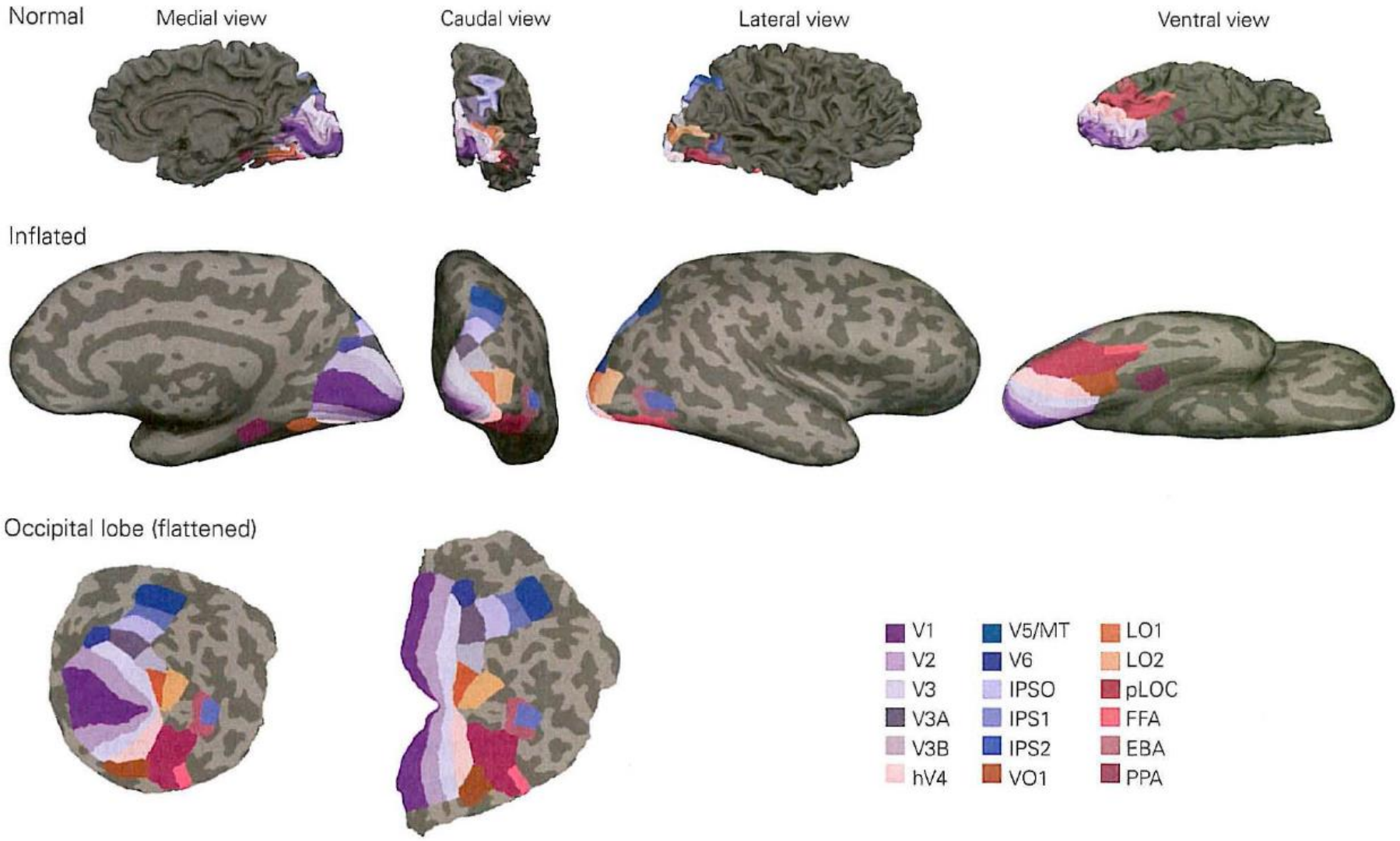
Eye movement



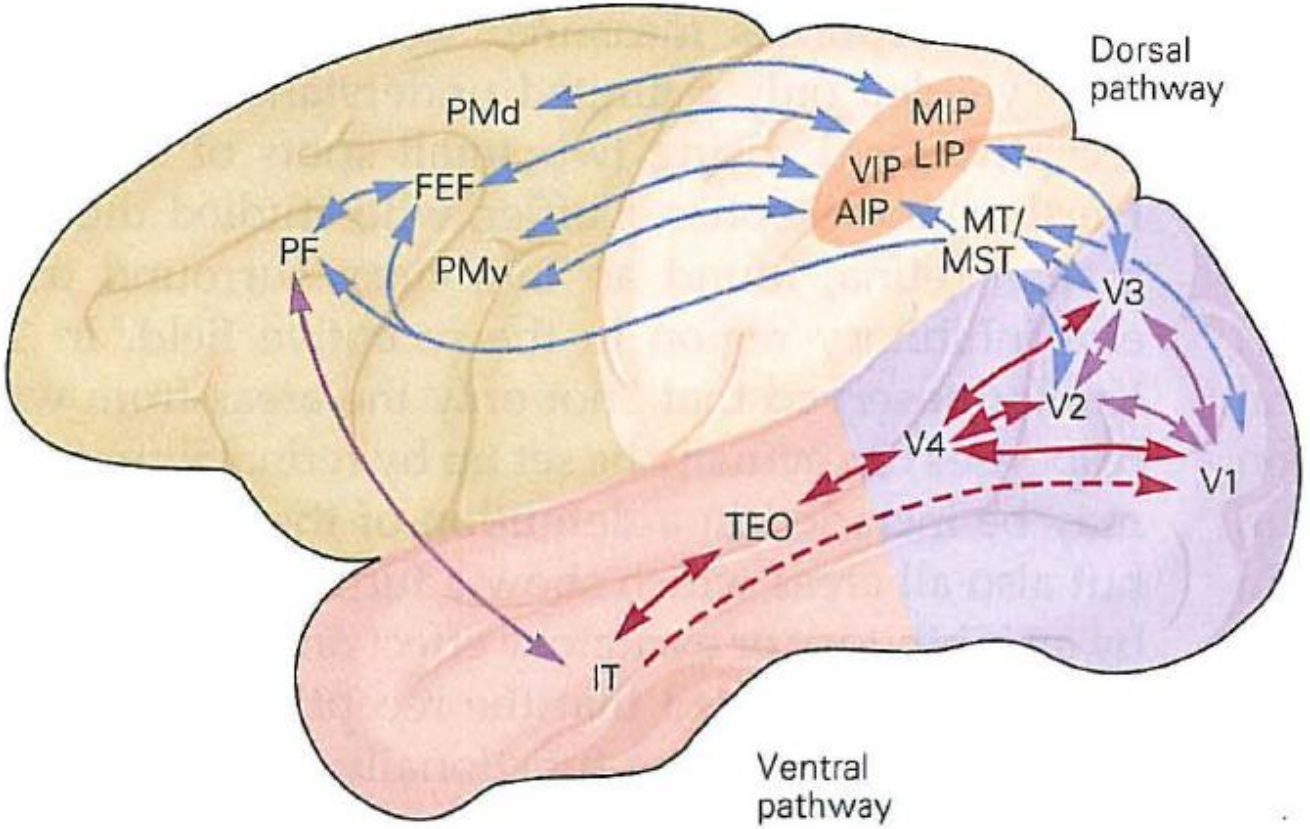
Form, color, motion, and depth are processed in discrete areas of the cerebral cortex

- **Anatomical** vs **functional** division
- Almost **half of** the cerebral cortex is involved with vision.
- Two criteria for division:
  - representation of visual space, known as a visuotopic (or retinotopic) map,
  - functional properties of their neurons.
- **Two major** pathway
- **Reciprocity** is an important feature of the connectivity between cortical areas.

Cortical visual areas in humans

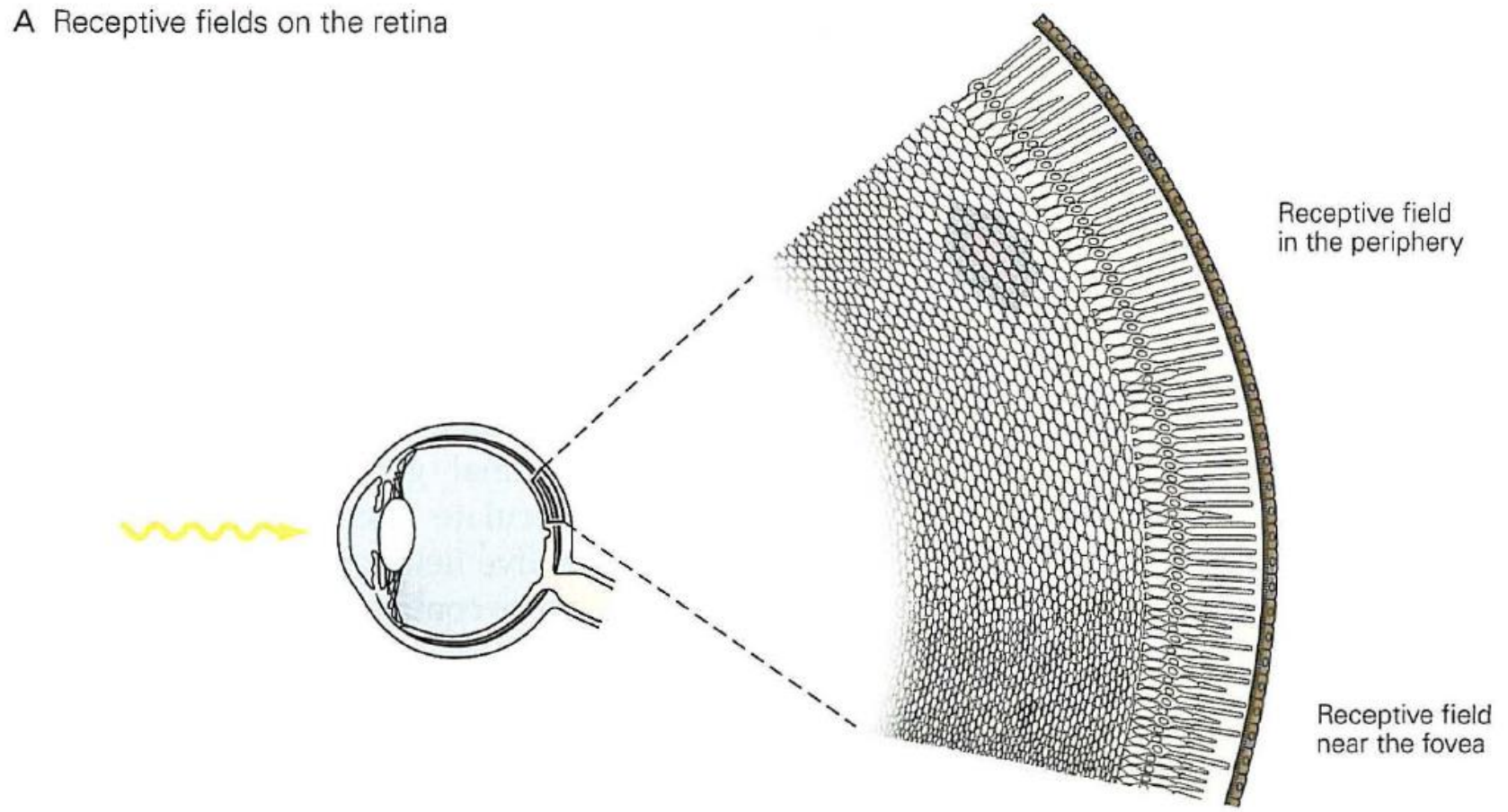


Visual pathways in the macaque monkey



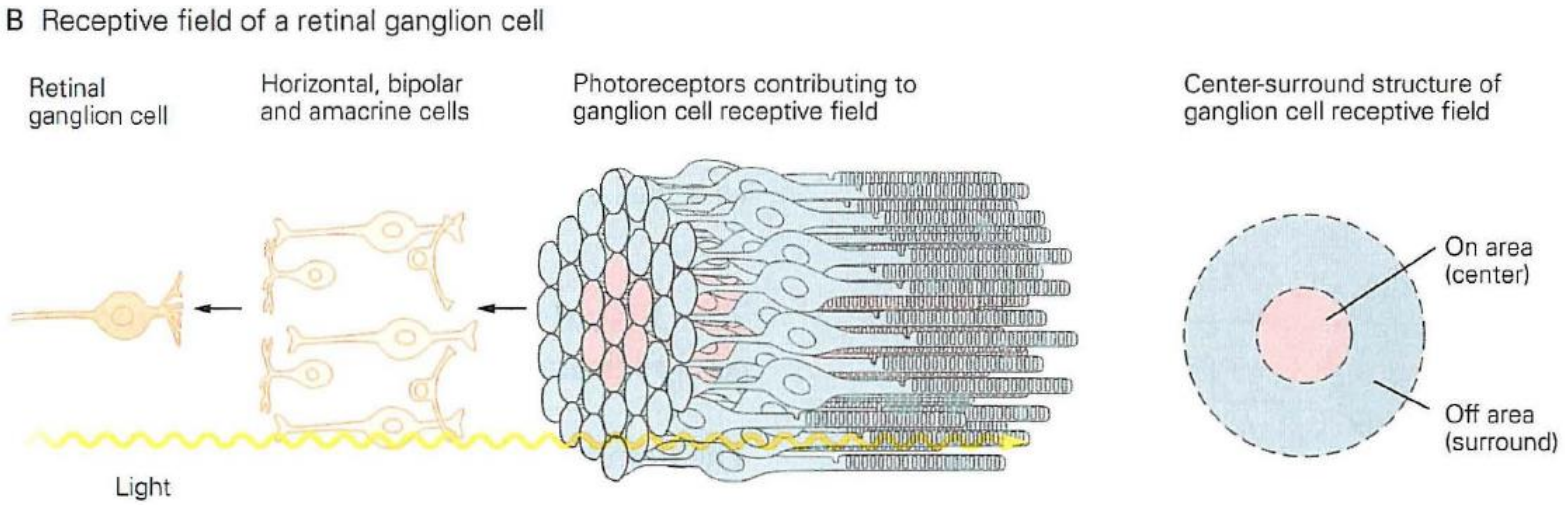
- **Reciprocal** or feedback pathways running in the opposite direction
- The **receptive fields** of neurons at **successive relays** in an afferent pathway provide clues to how the brain analyzes visual form

Receptive fields on the retina

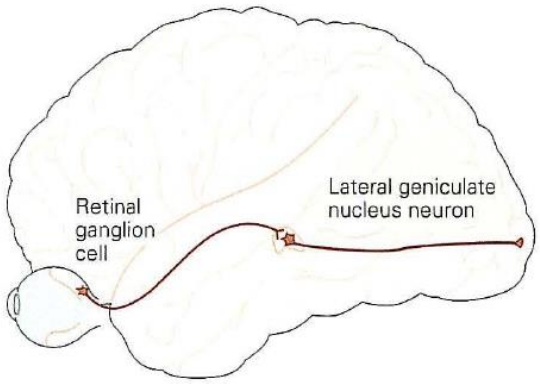


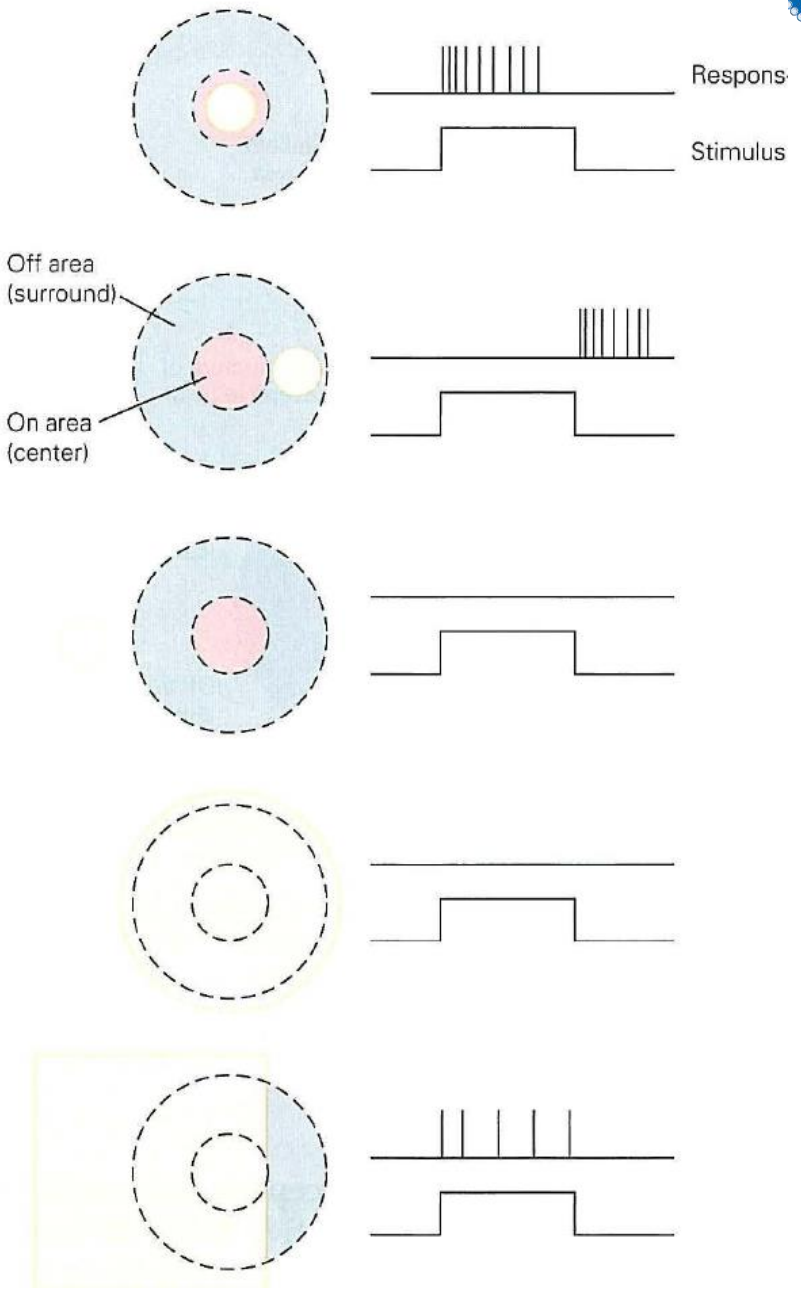
Retinal RF

- Neuron's receptive field represents a small window on visual space
- On center and off center most **sensitive to borders and contours**
- ***Eccentricity: its*** position relative to the fovea, index for size of RF; 0.1 to 10 degree
- More cortical space is dedicated to the central part of vision



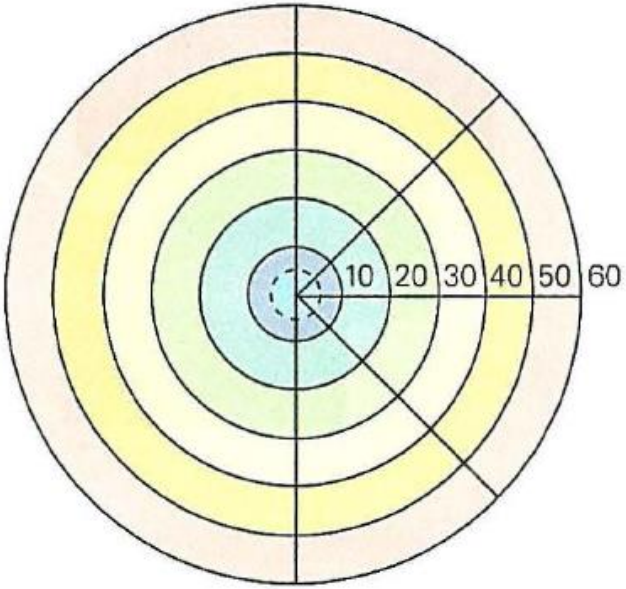
Center-surround structure



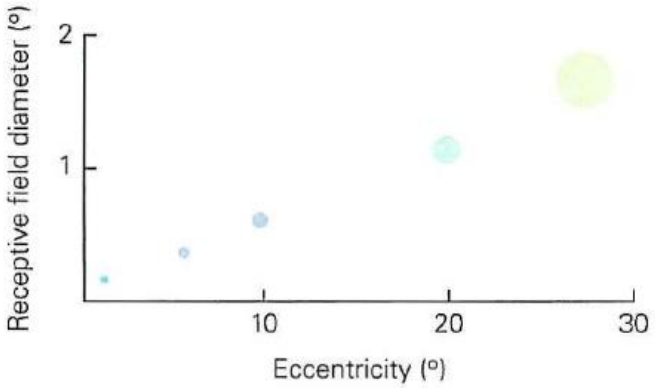


Magnification factor

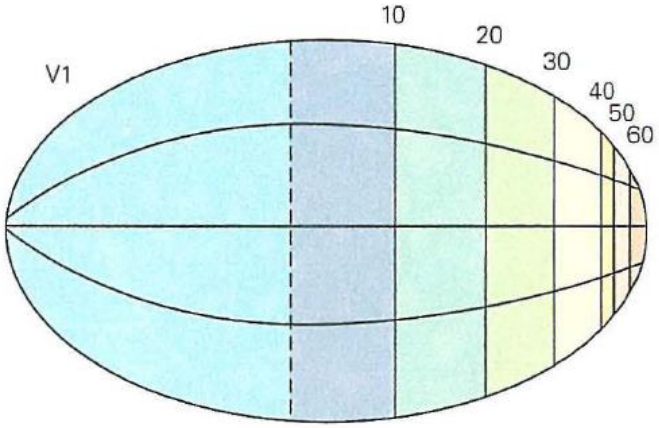
A Map of retinal eccentricity



B Receptive field size varies systematically with eccentricity

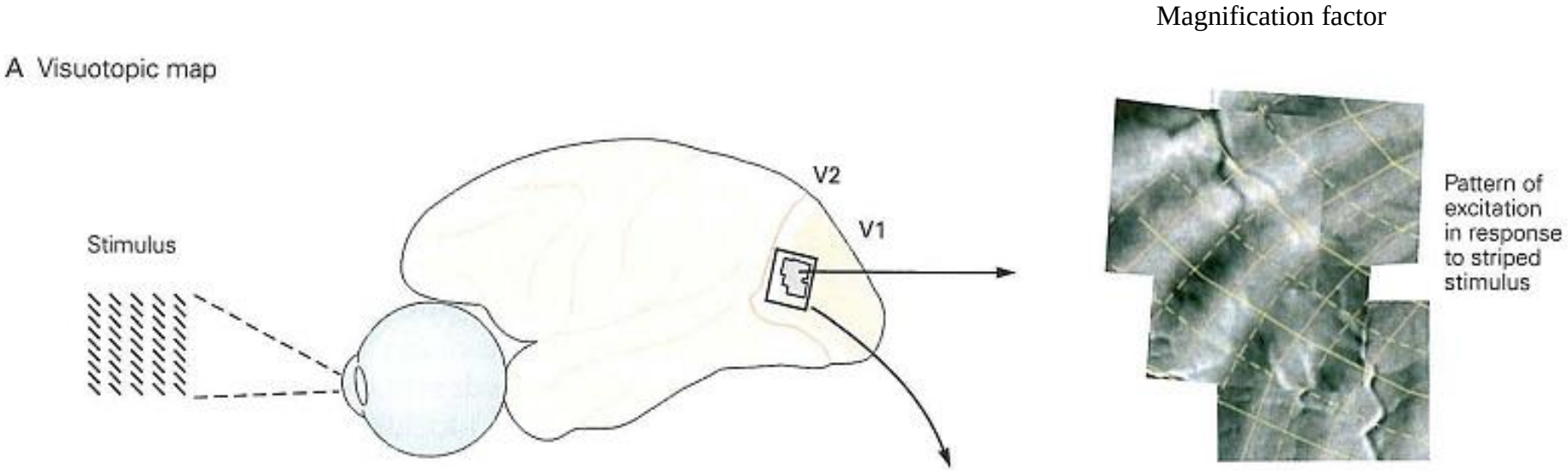


C Cortical magnification varies with eccentricity



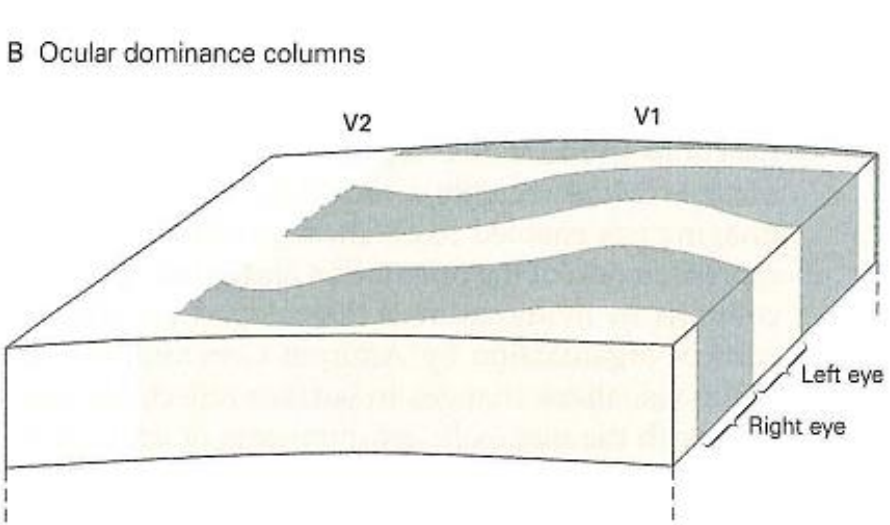
Visuotopic map

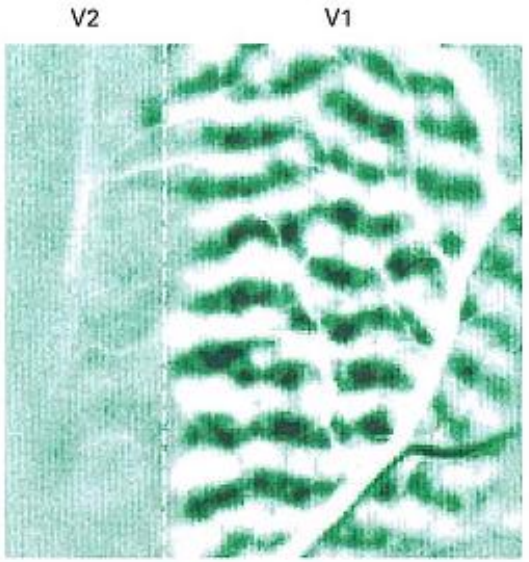
Visualized with intrinsic-signal optical imaging



Surface of the primary visual cortex is functionally organized in a map of the visual field

Ocular dominance columns

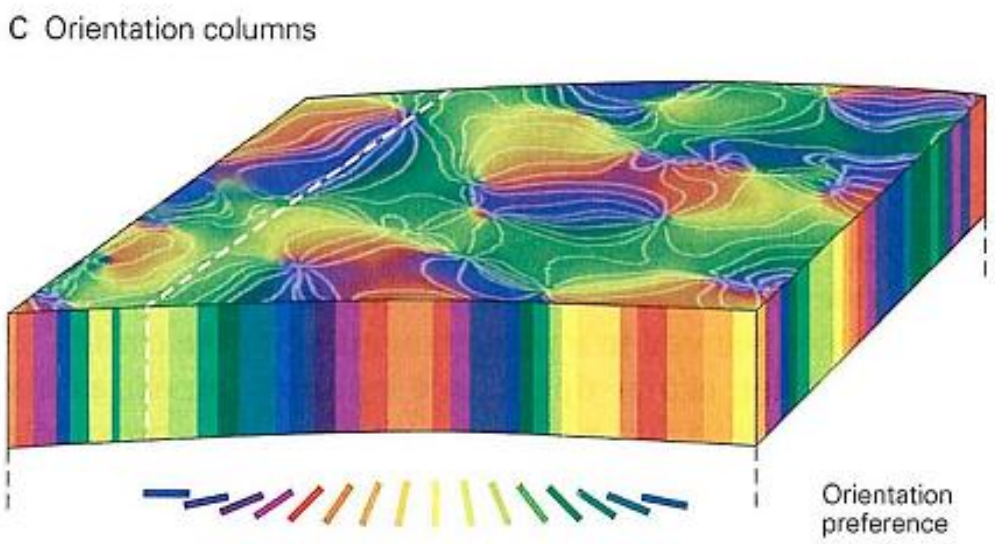


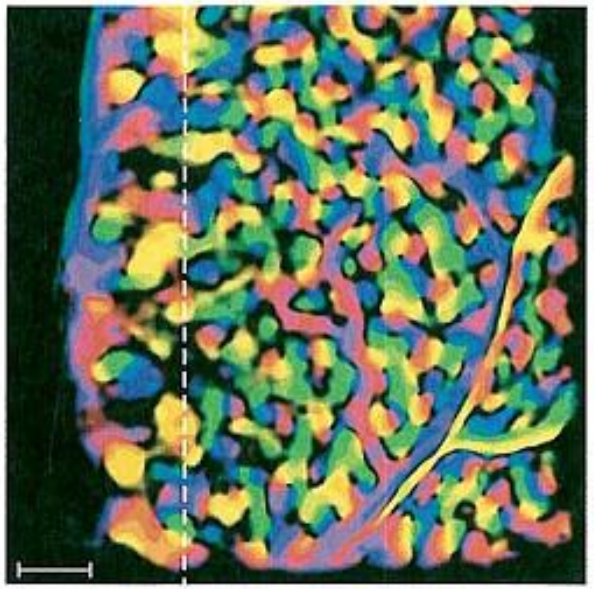


Left-and right-eye stripes, each approximately 750 in width

Orientation columns

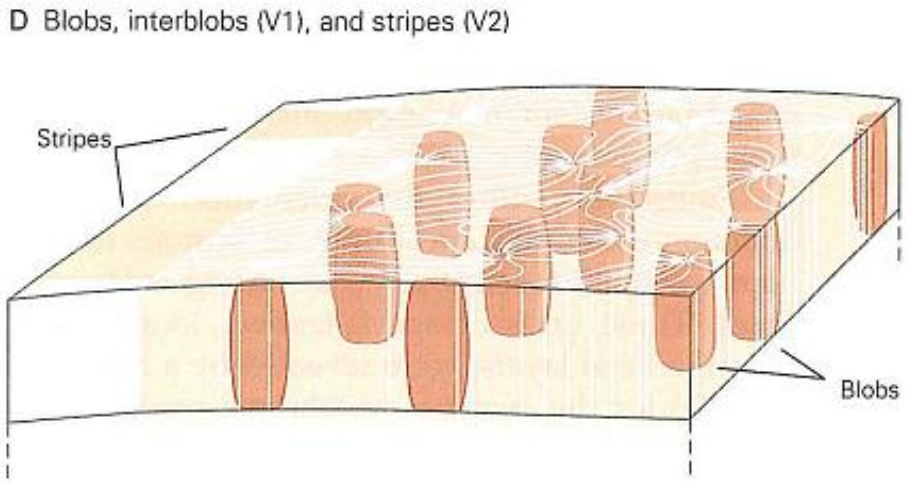
- Sudden changes in orientation
  - Fractures in the orientation map
- Pinwheels surrounding

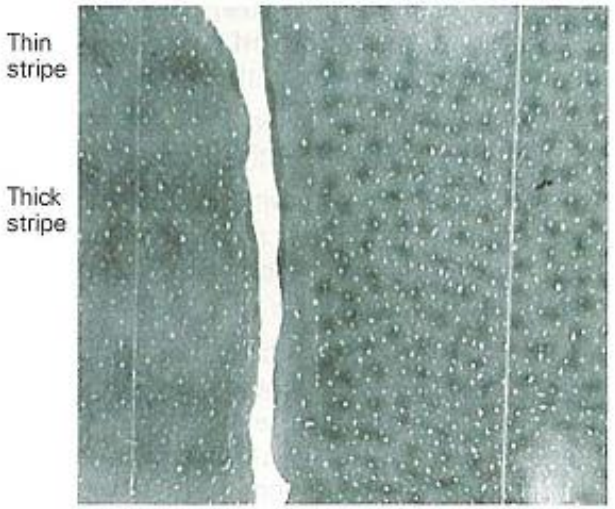




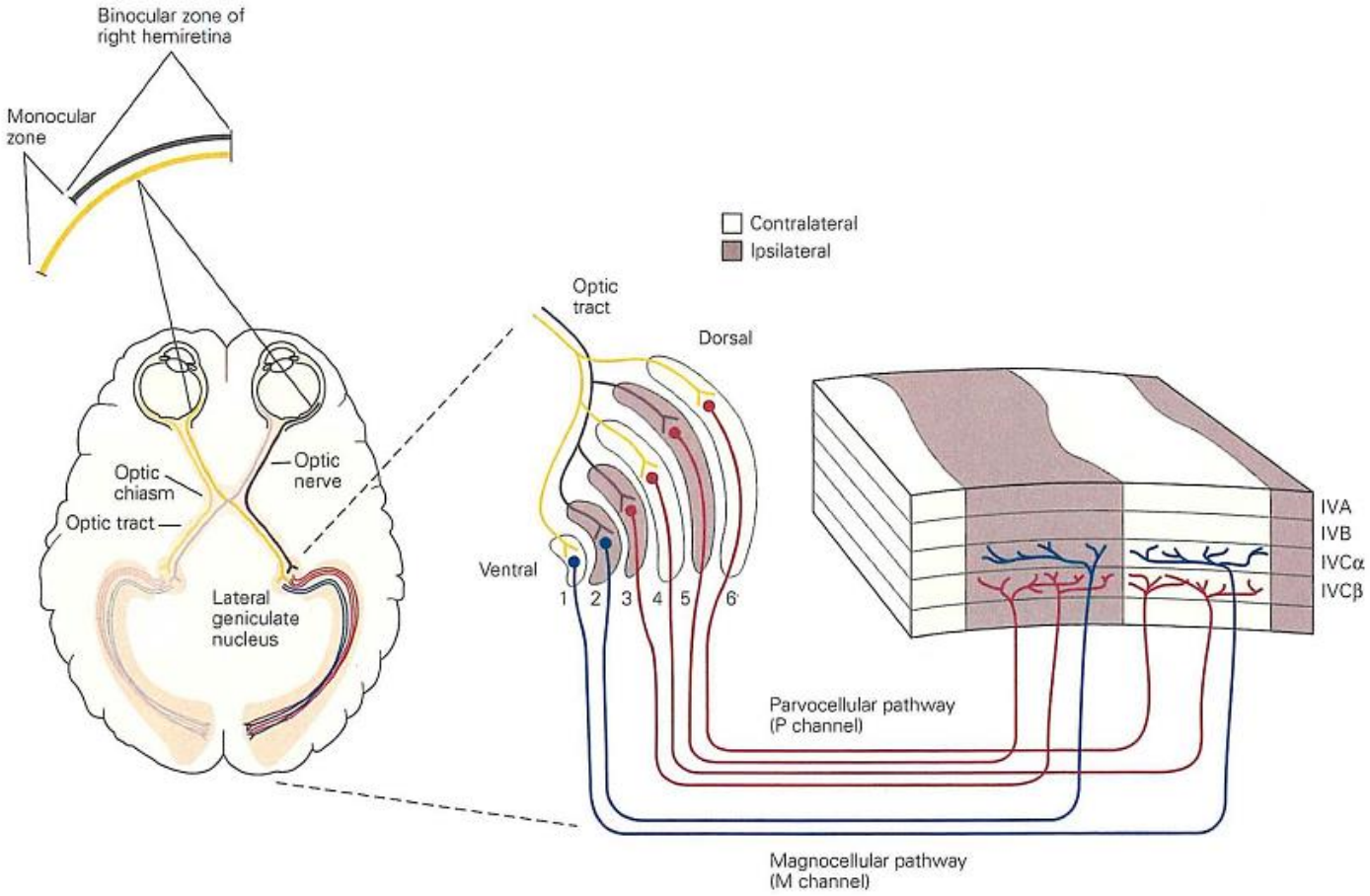
Blobs, interblobs (V1), and stripes (V2)

- Modules of **functional organization**
- Clusters of color-selective neurons
- **Thick** stripes contain neurons selective for **direction of movement**
- **Thin** stripes contain neurons selective for **color**
- Pale for **orientation**



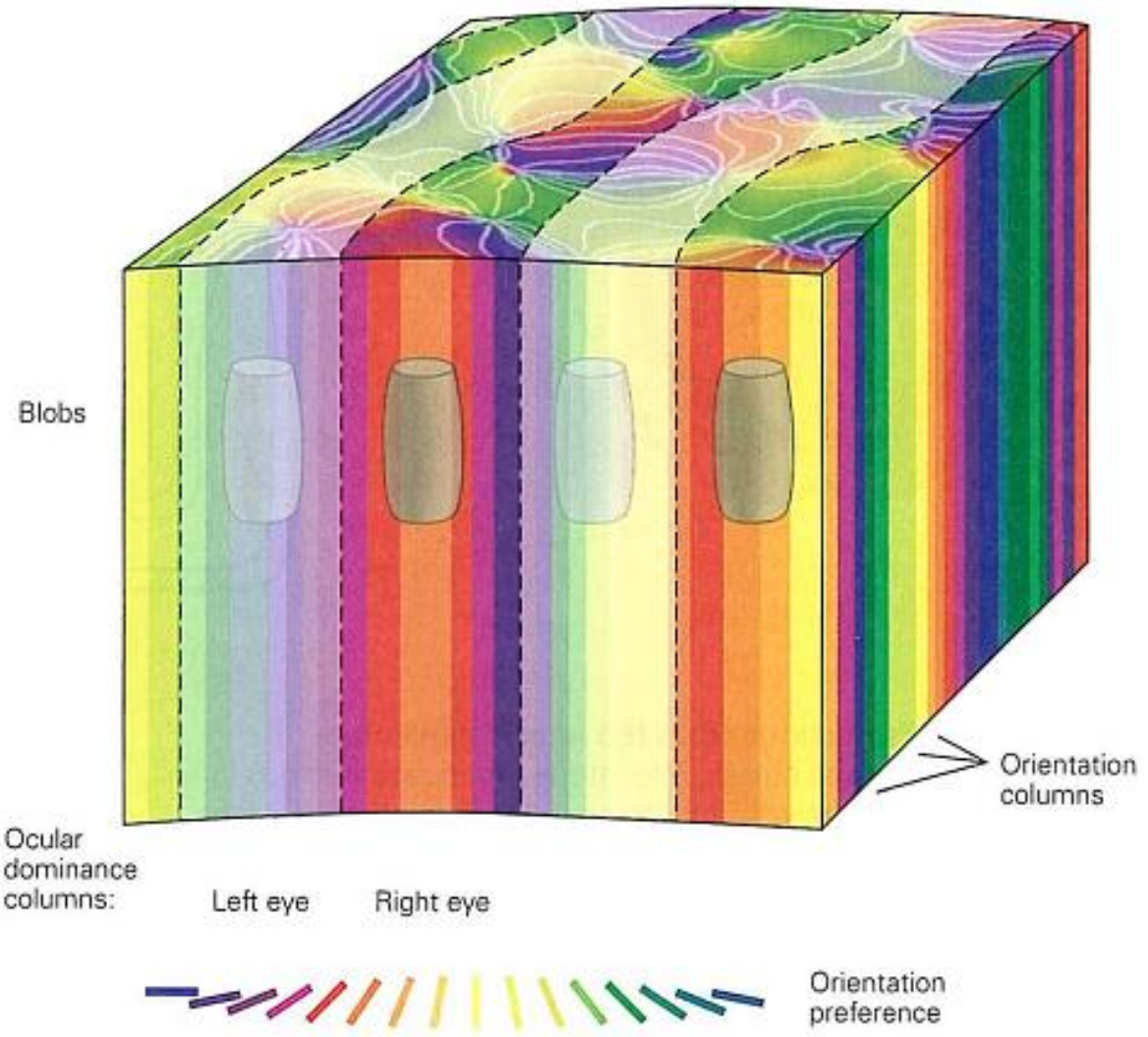


Projections from the lateral geniculate nucleus to the visual cortex



A cortical computational module

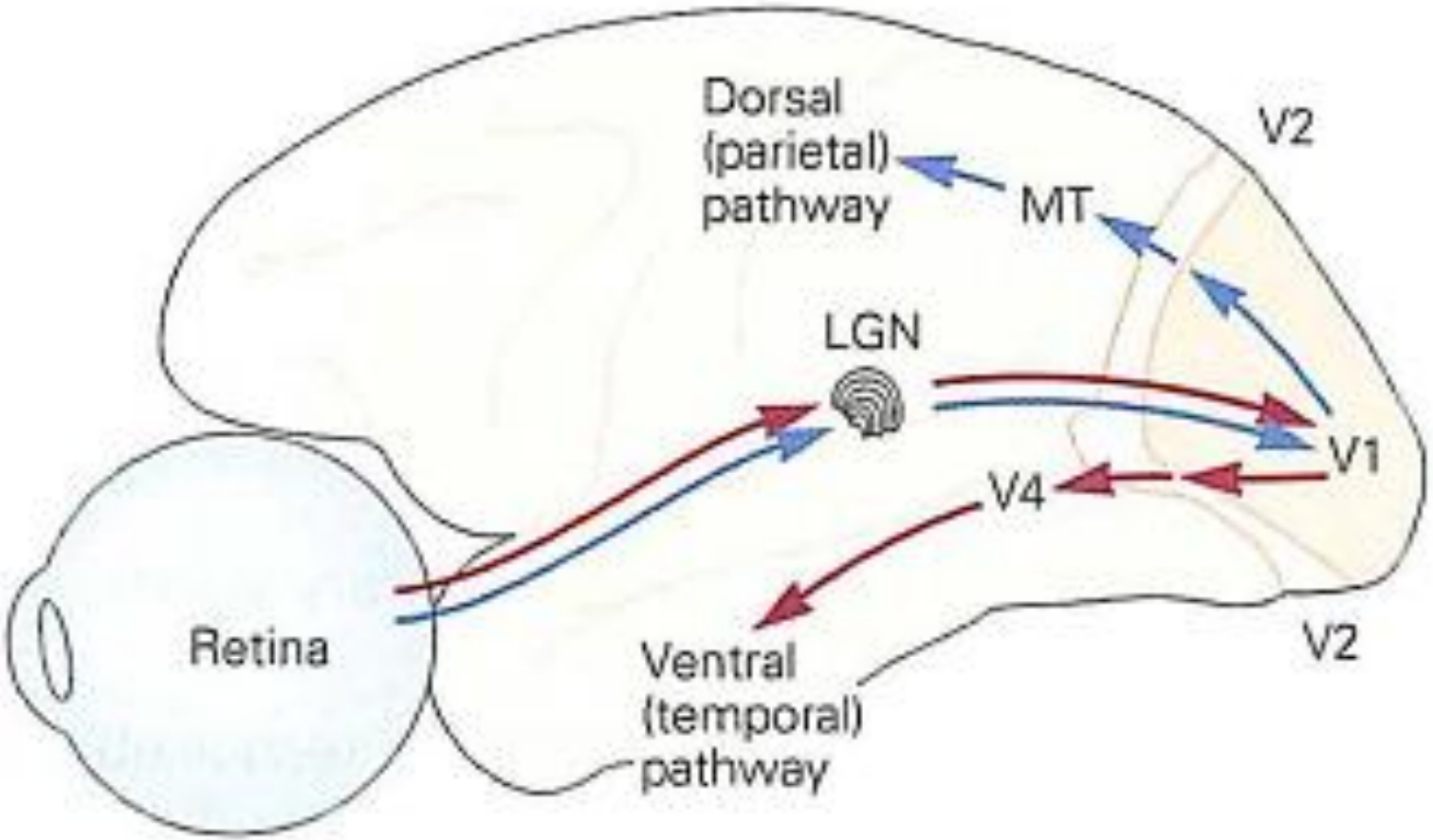
- Functional and anatomical cell types of primary visual cortex
- Would be repeated hundreds of times to cover the visual field



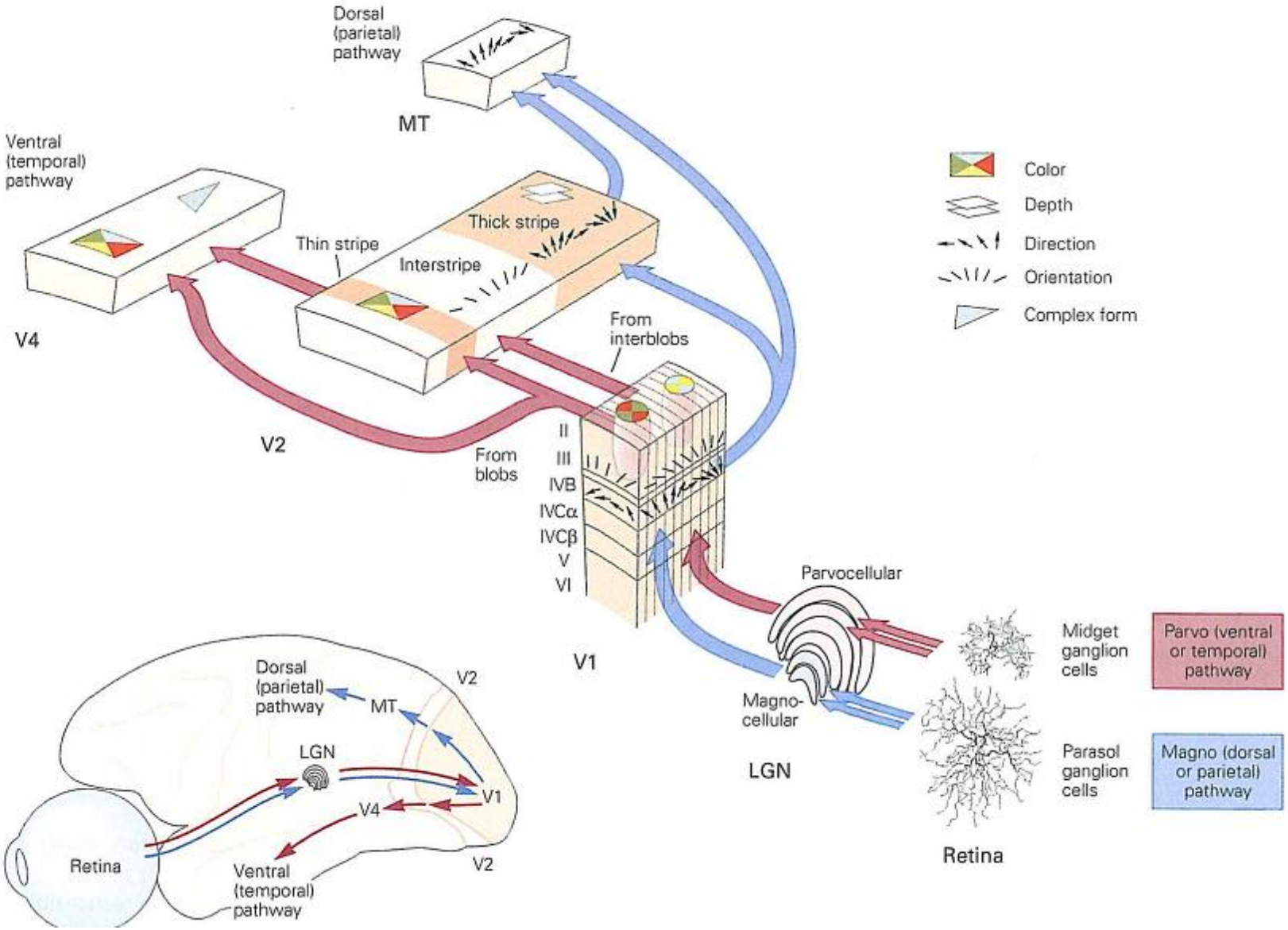
Visual processing

- **Serial processing** occurs in the successive connections between cortical areas
- **Parallel processing** occurs simultaneously in sub-sets of fibers that process different submodalities
- Pathways are not absolutely segregated
- Columnar organization
  - Efficient connectivity
  - Share inputs
  - Minimize the number of neurons required for analyzing different attributes

Parallel processing in visual pathways.

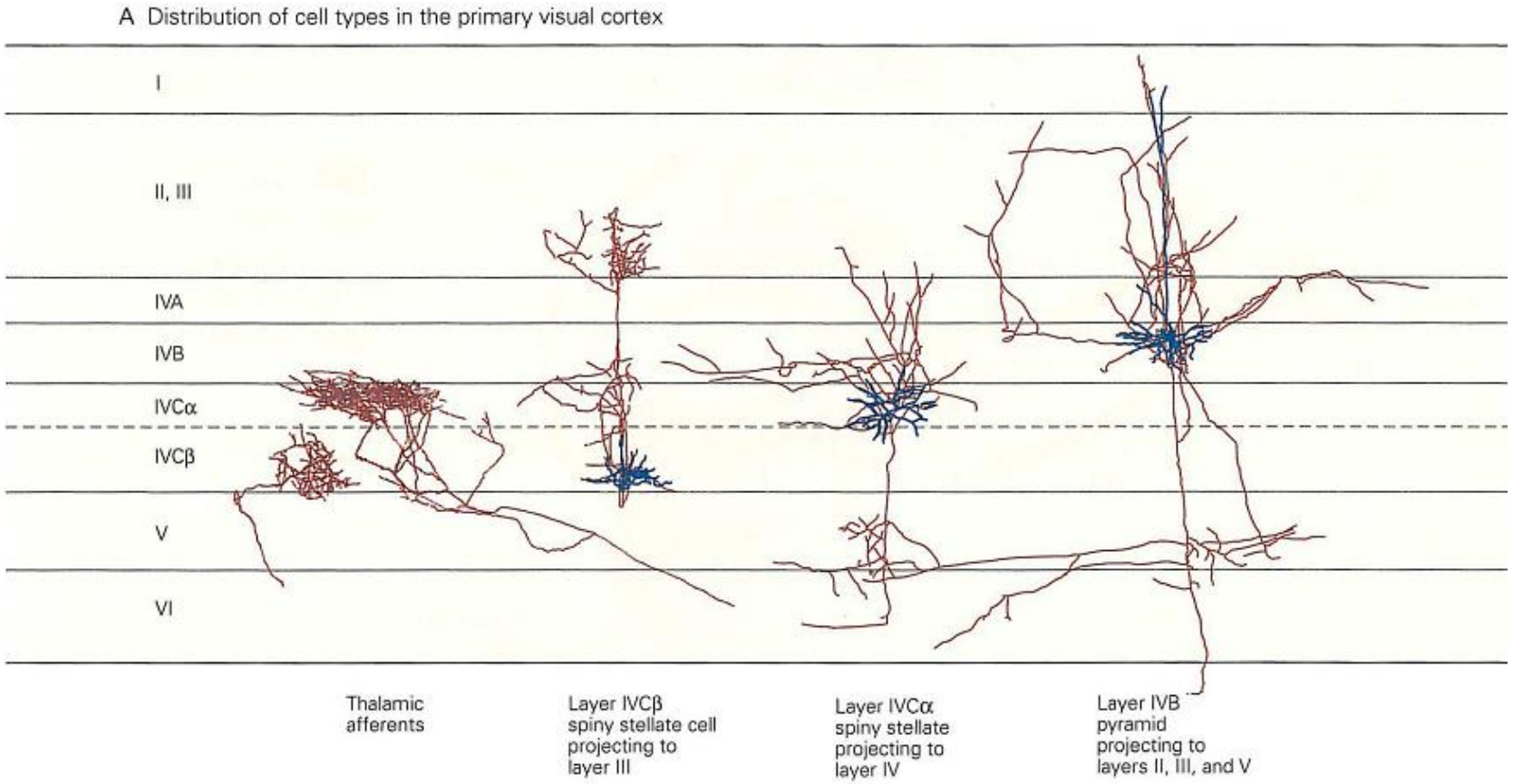


There are substantial interconnections between them

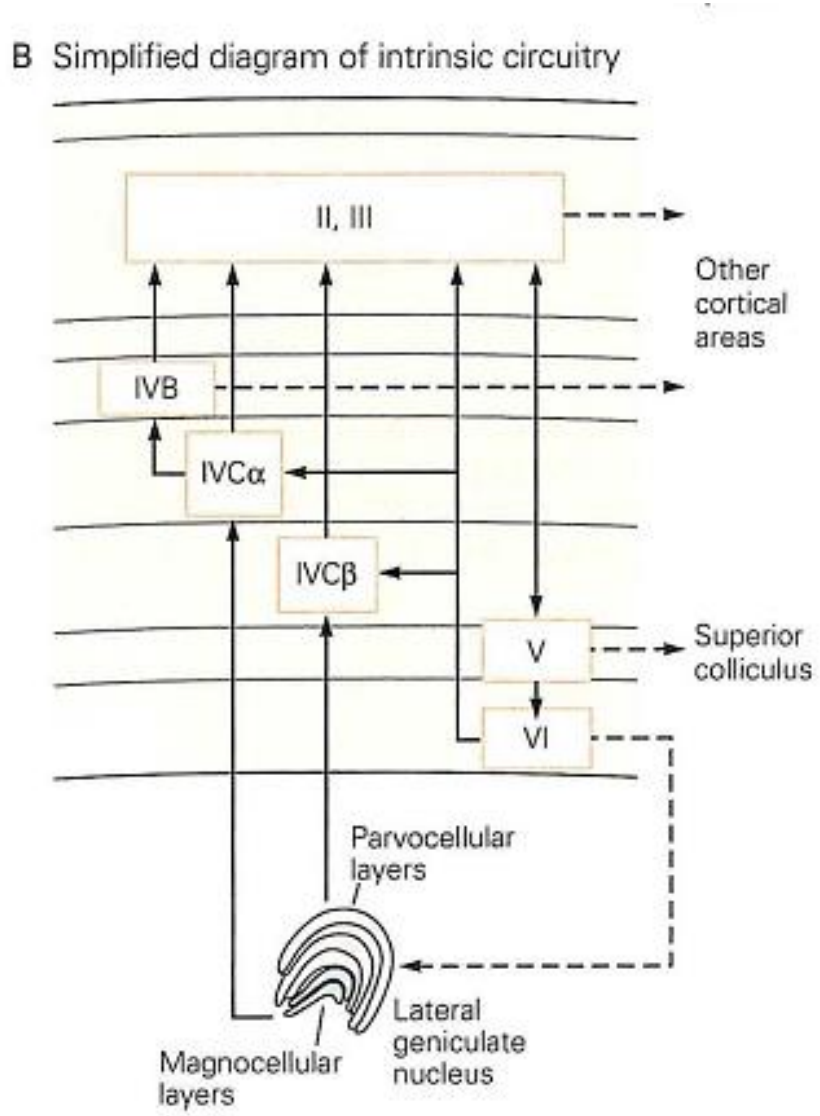

Dorsal (parietal) pathway
MT
Ventral (temporal) pathway
Thin stripe
Thick stripe
Interstripe
V4
V2
From interblobs
From blobs
II
III
IVB
IVCα
IVCβ
V
VI
V1
Color
Depth
Direction
Orientation
Complex form
Parvocellular
Magno-cellular
LGN
Midget ganglion cells
Parvo (ventral or temporal) pathway
Parasol ganglion cells
Magno (dorsal or parietal) pathway
Retina
Dorsal (parietal) pathway
MT
V2
LGN
V1
V4
Retina
Ventral (temporal) pathway
V2

Intrinsic cortical circuits transform neural information

Examples of neurons in different cortical layers



Schematic diagram of excitatory connections within the primary visual cortex



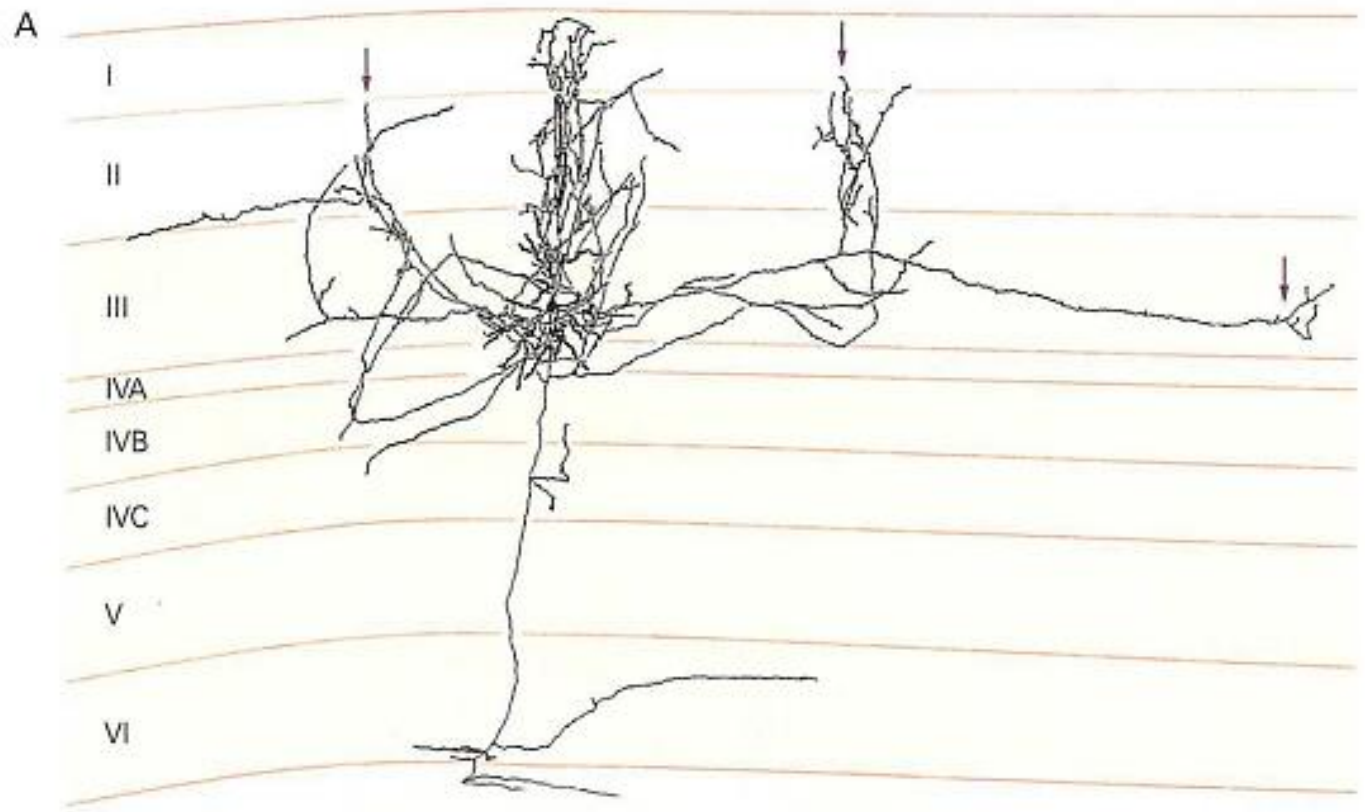
Neurons in the superficial layer of IV have small receptive fields whereas deeper-layer neurons have large ones.

Feed-forward and feedback connections,

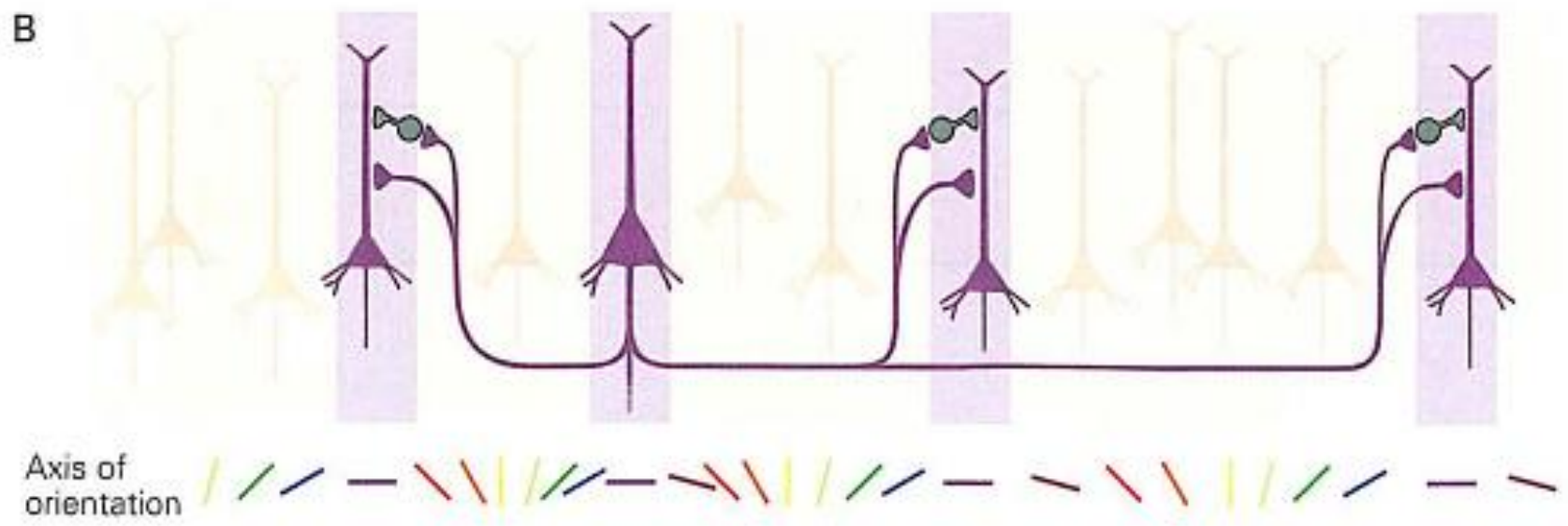
Long-range horizontal connections

Convergence and divergence of connections

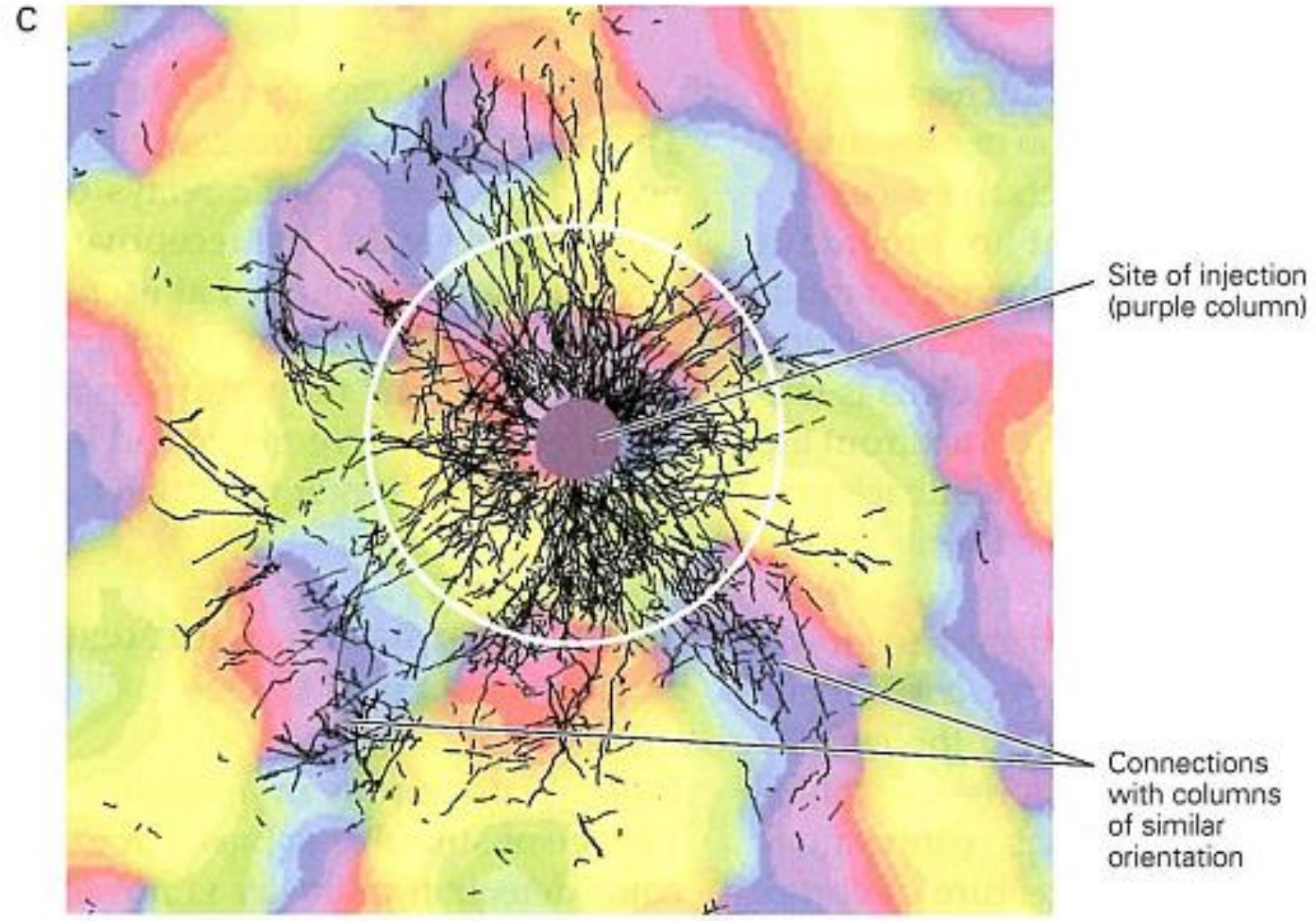
Long-range horizontal connections integrate information from different parts of the visual field



Link columns of cells with similar orientation specificity



Pattern of horizontal connections



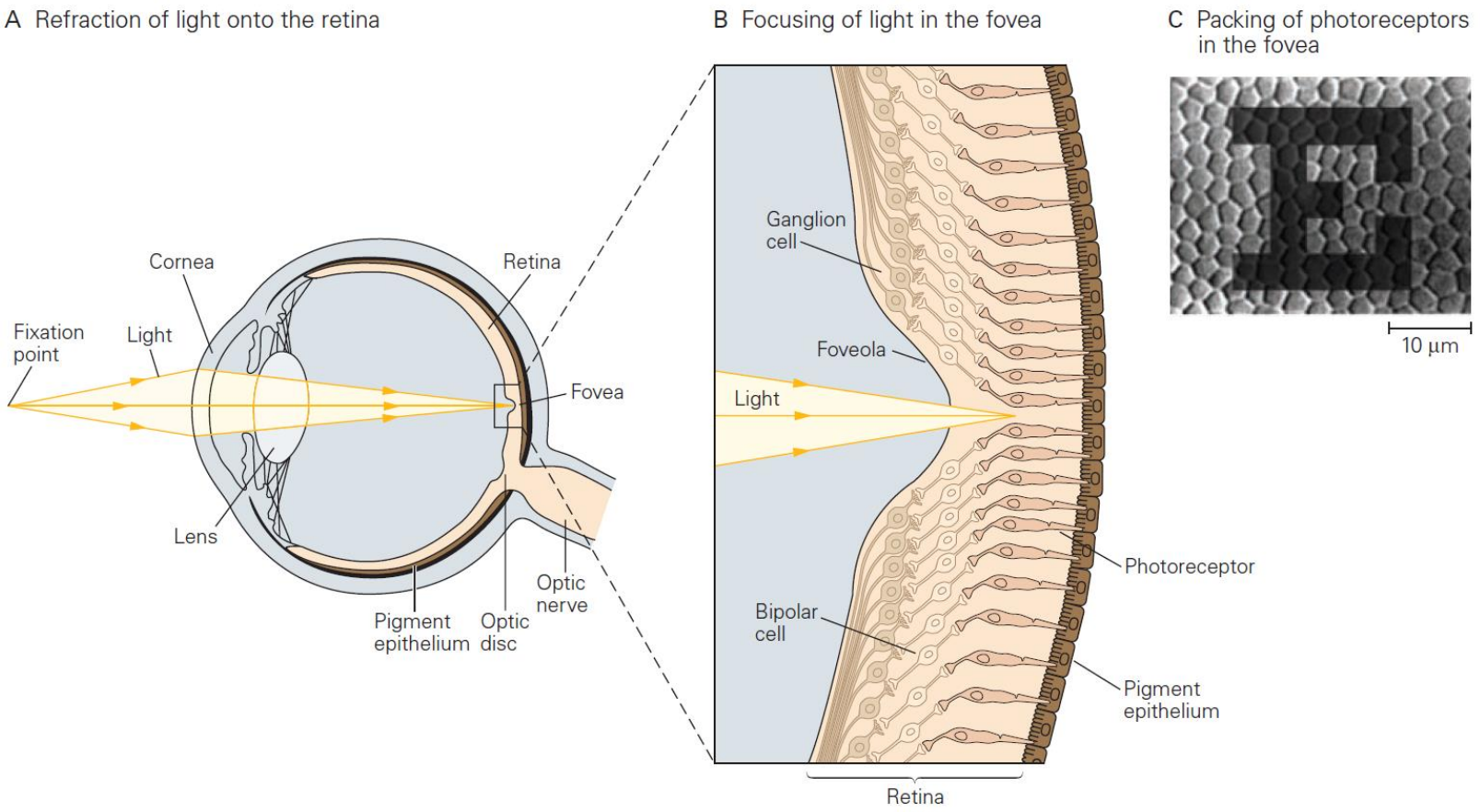
Gene encoding green fluorescent protein into one orientation column

Visual information is represented by a variety of neural codes

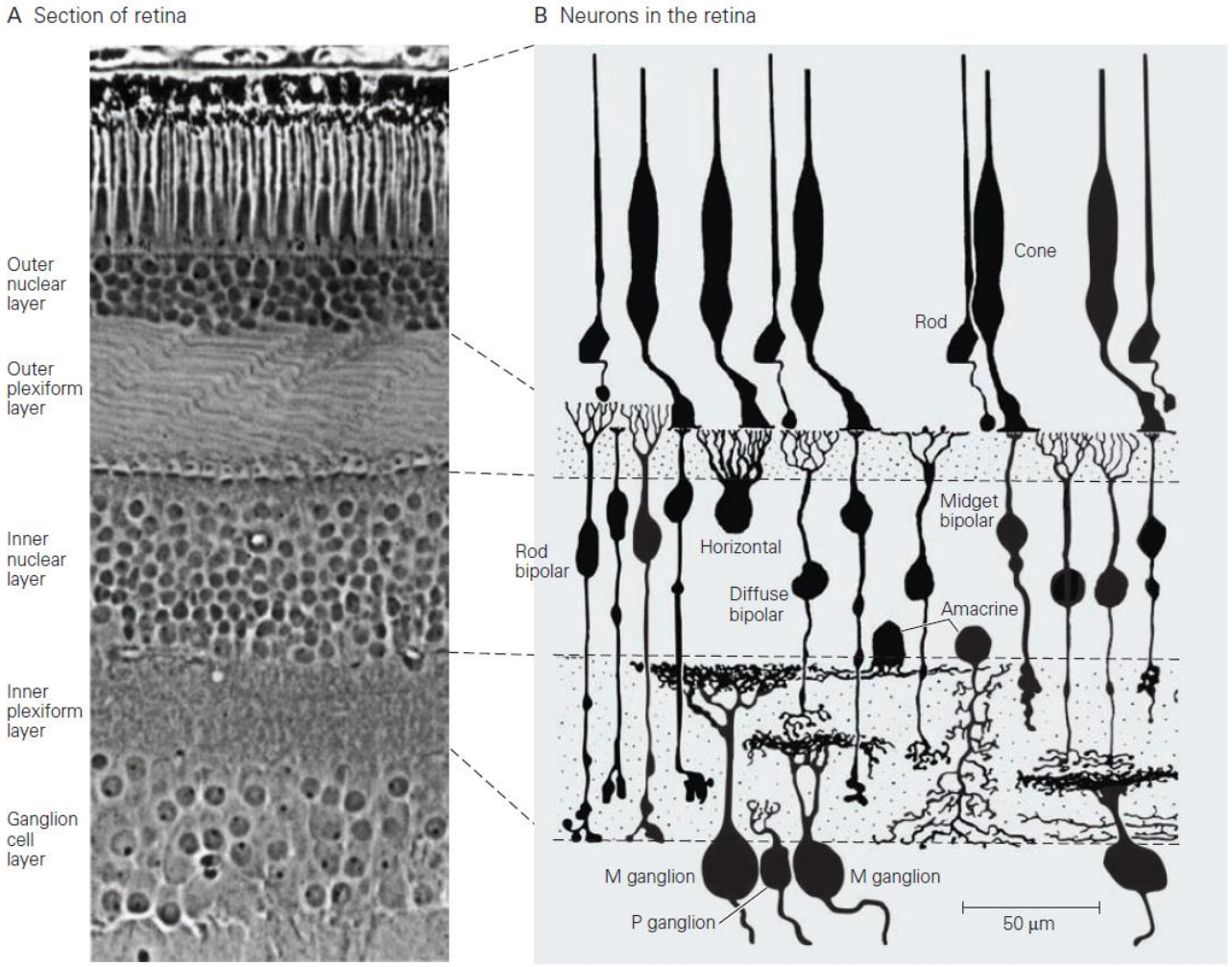
- **Labeled line** in which activity signals a stimulus with a given value
- **Population code:**
  - **Vector averaging**
- **Gaussian tuning curve**
- **Variability of a neuron's response**
  - **Signal-to-noise**
- Distributed code vs. Grandmother cell
- Firing rate vs timing of action potential
  - Synchronous firing

Low-level visual processing

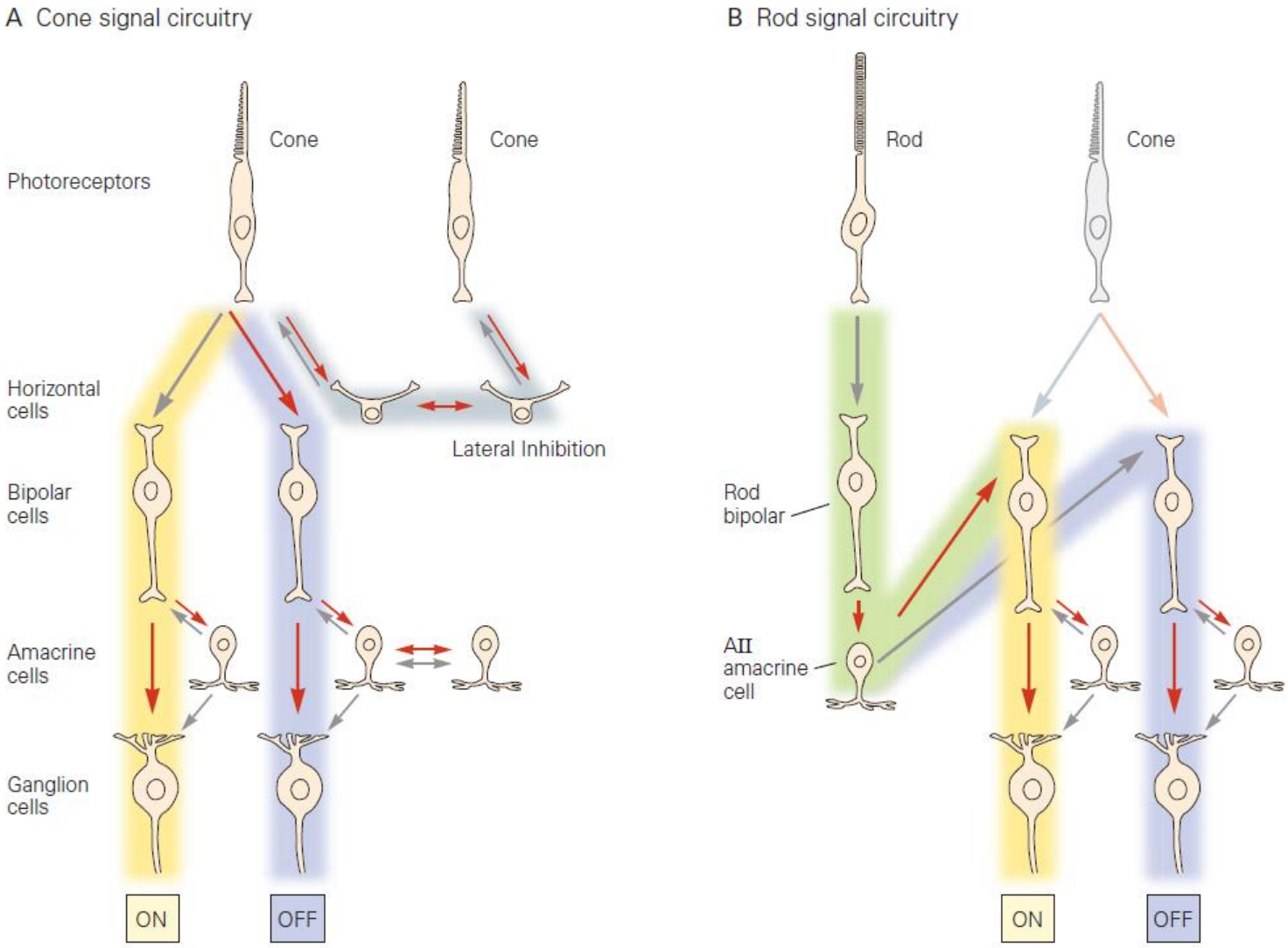
The eye projects the visual scene onto the retina's photoreceptors



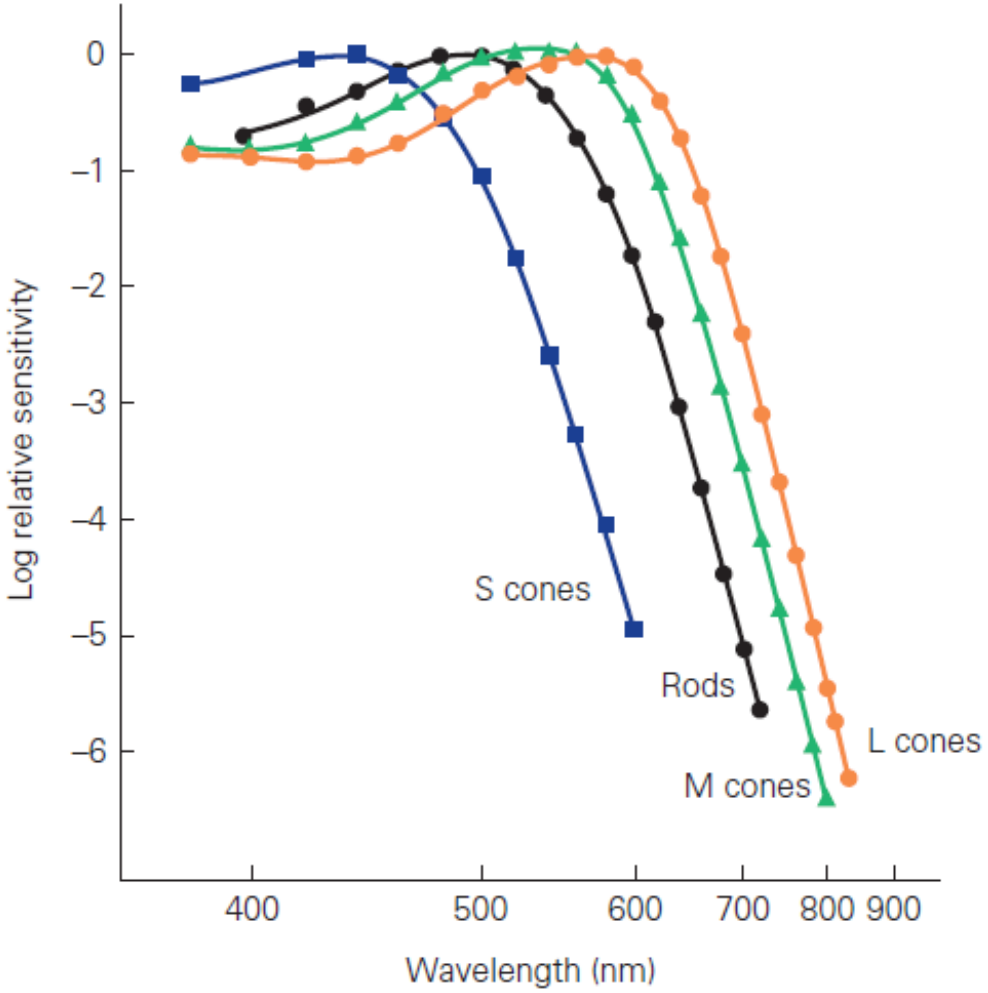
The retina comprises five distinct layers of neurons and synapses.



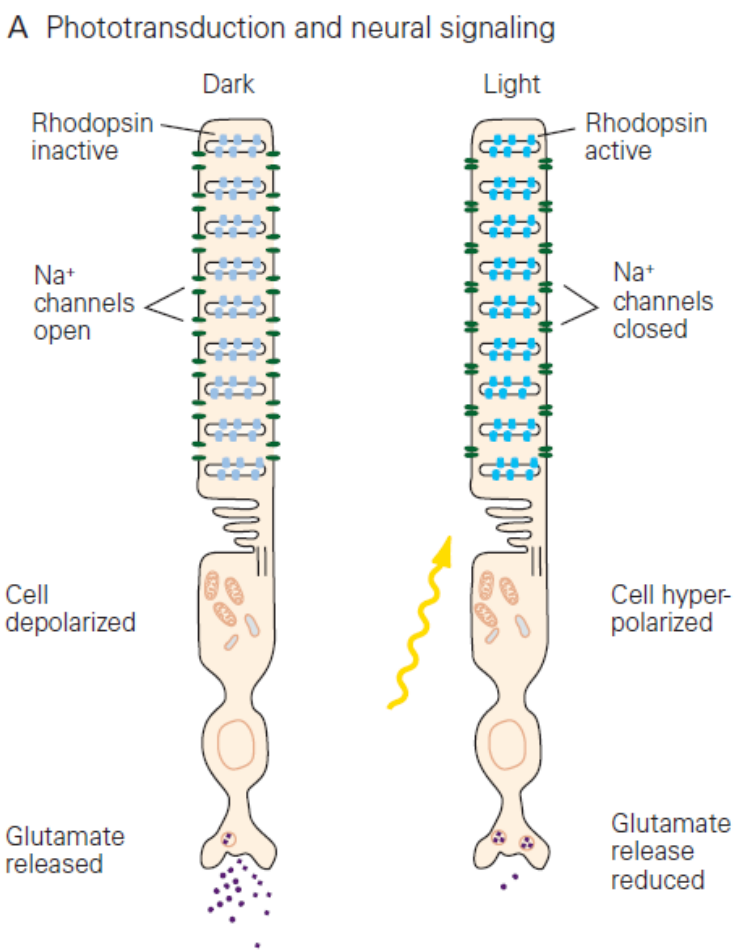
The retinal circuitry

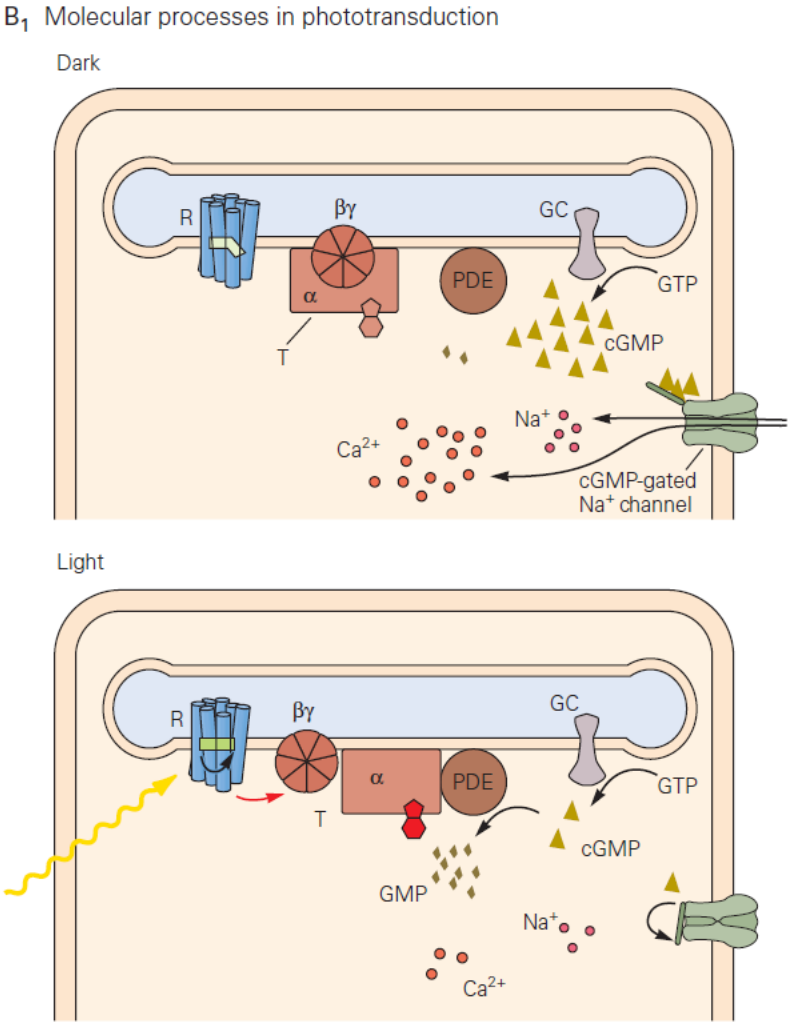


Sensitivity spectra for the three cones and the rod

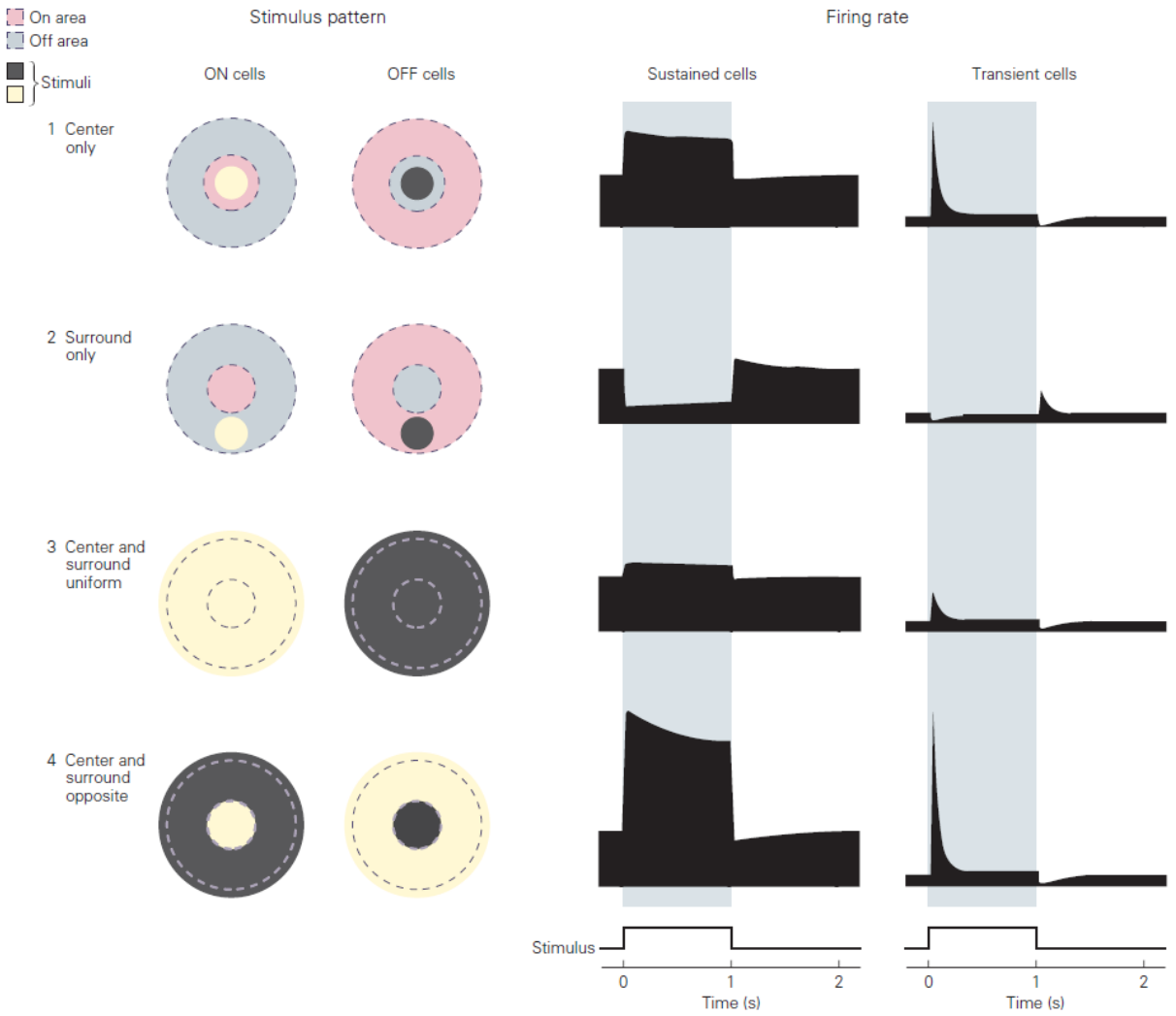


Phototransduction

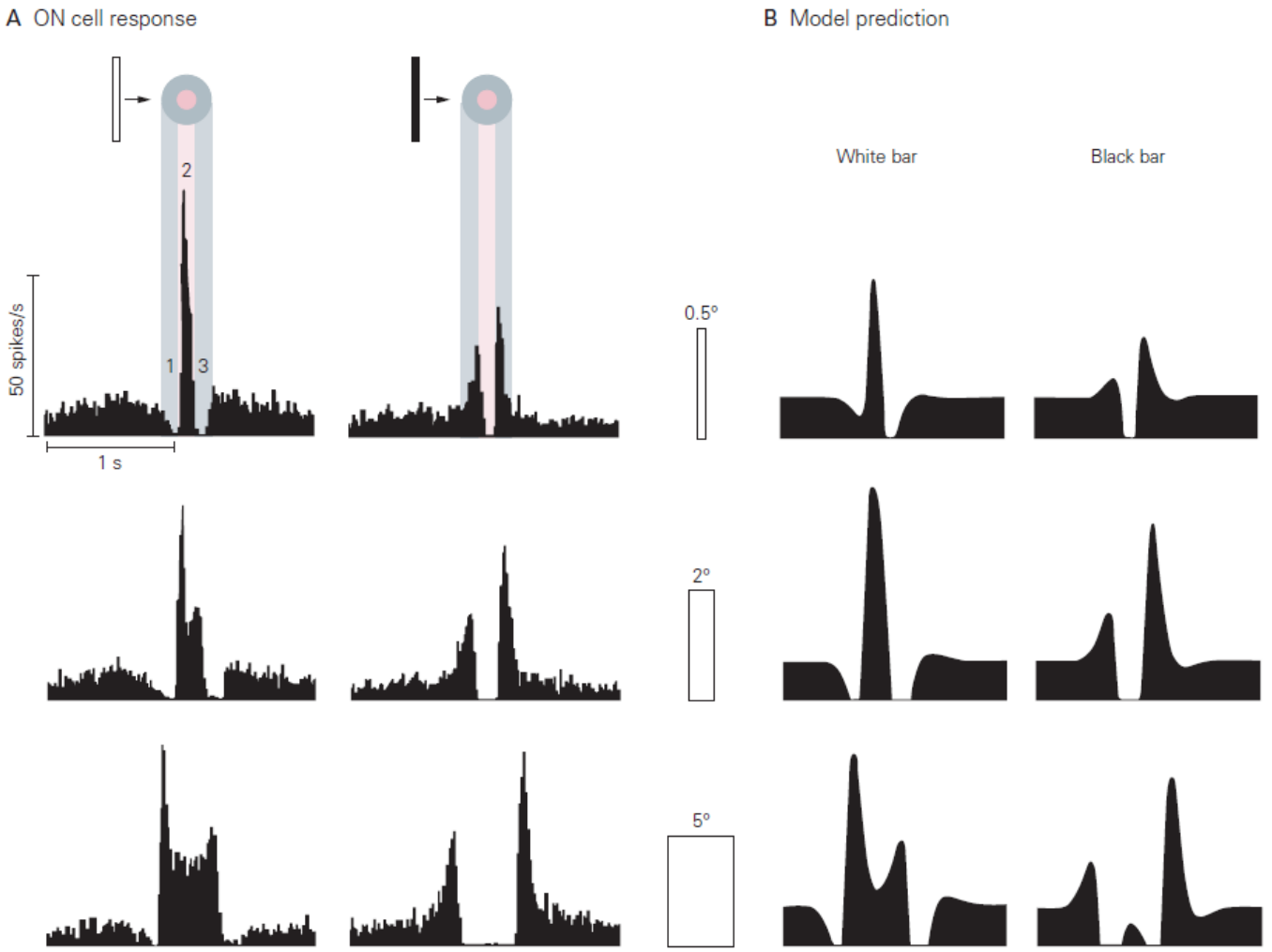




Responses of retinal ganglion cells with center-surround receptive fields



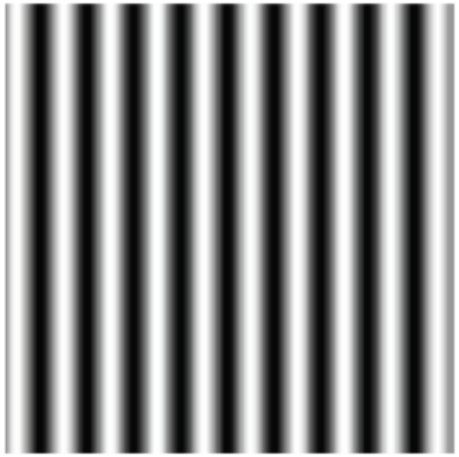
The representation of moving objects by retinal ganglion cells



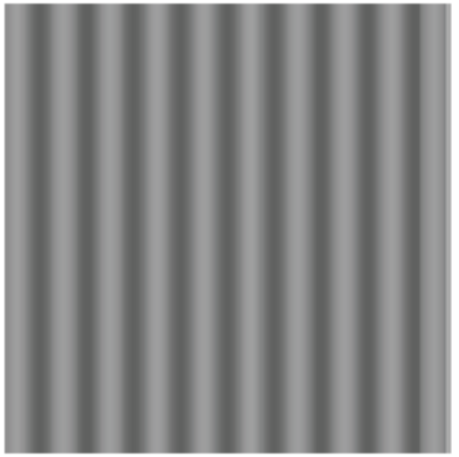
Sinusoid grating displays used in psychophysical experiments with human subjects

Low spatial frequency

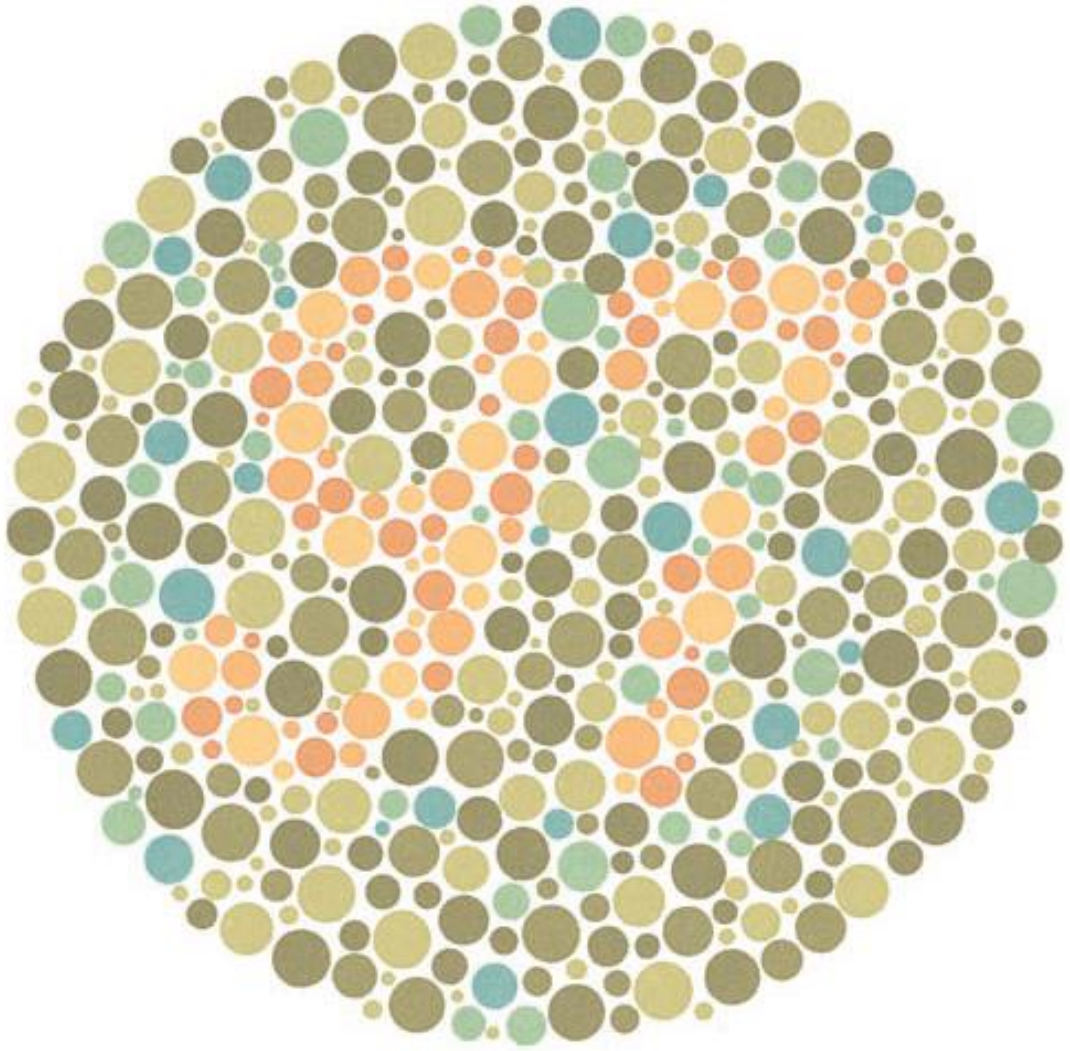
High spatial frequency, high contrast



High spatial frequency, low contrast



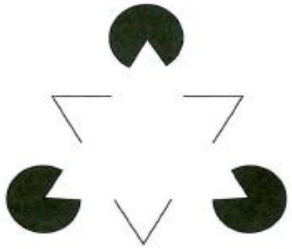
A test for some forms of color blindness. The numerals embedded

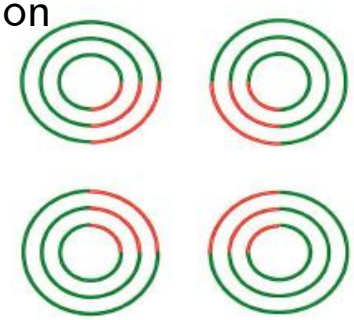


Intermediate-level visual processing and visual primitives

Illusory contours and perceptual fill-in.

Kanizsa triangle illusion

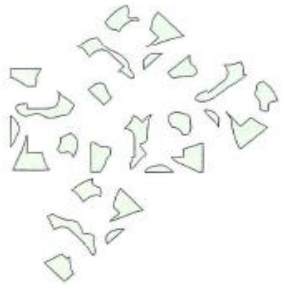


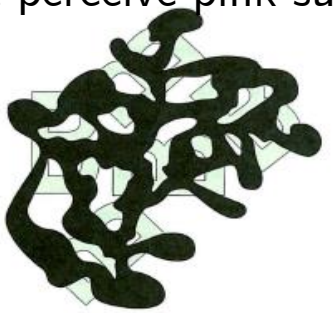


Use **local orientation** and **contrast** to construct the contours and surfaces of objects

Contours and surfaces that **do not appear** in the visual field

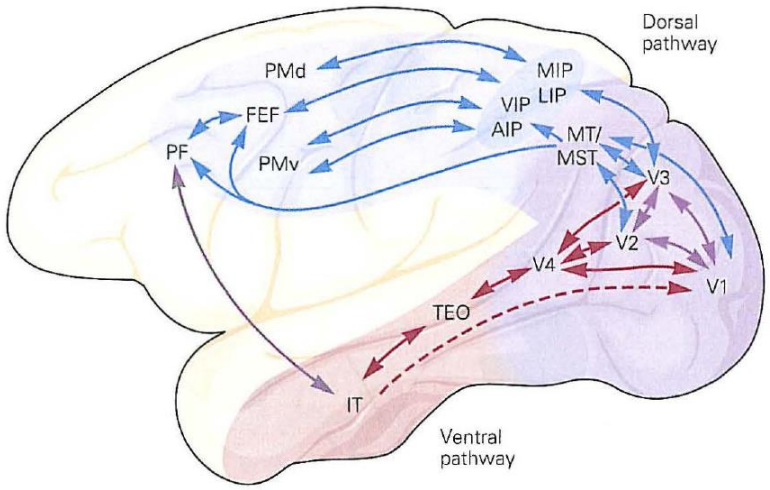
Whit perceive pink surface





Contour integration and surface segmentation can also occur through occluding surfaces.

Cortical areas involved with intermediate- level visual processing



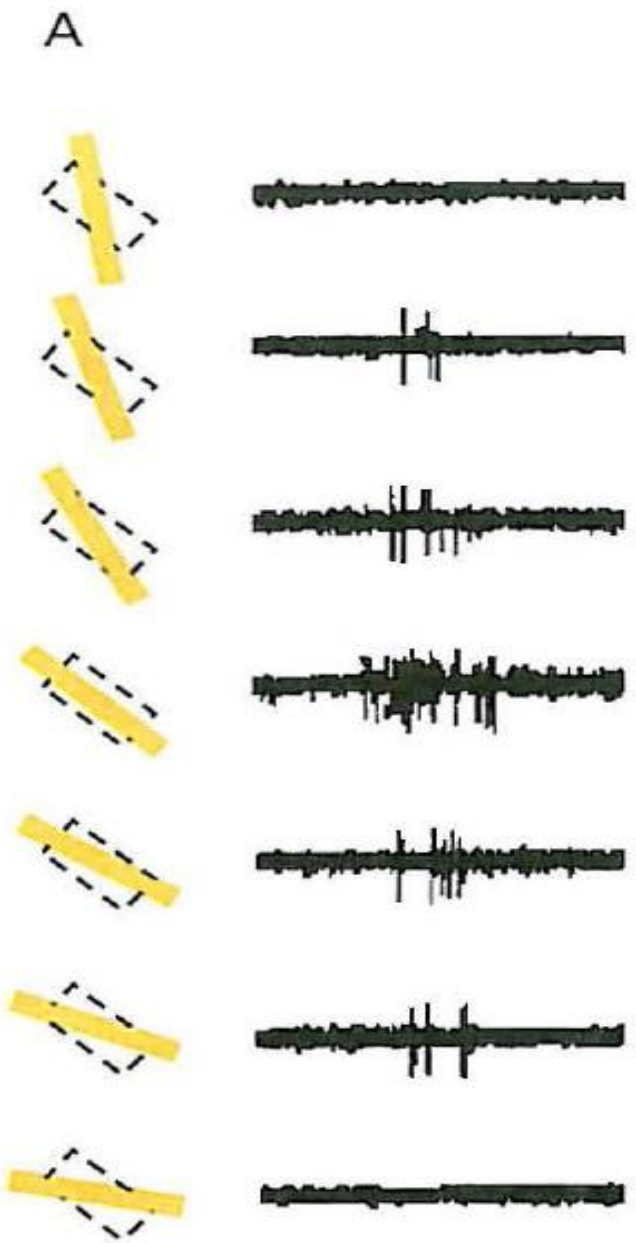
Scene segmentation: Integrating **local cues** to construct **contours** and **surfaces** and **segregating foreground from background**.

ALP, anterior intraparietal cortex; FEF, frontal eye fields; IT, inferior temporal cortex; LIP, lateral intraparietal cortex; MIP, medial Intraparietal cortex; MST, medial superior temporal cortex; MT, middle temporal cortex; PF, prefrontal cortex; Pmd, dorsal premotor cortex; pmv, ventral premotor Cortex; TEO, occipitotemporal cortex; VIP, ventral Intraparietal cortex; V1, V2, V3, V4, primary, secondary, Third, and fourth visual areas.)

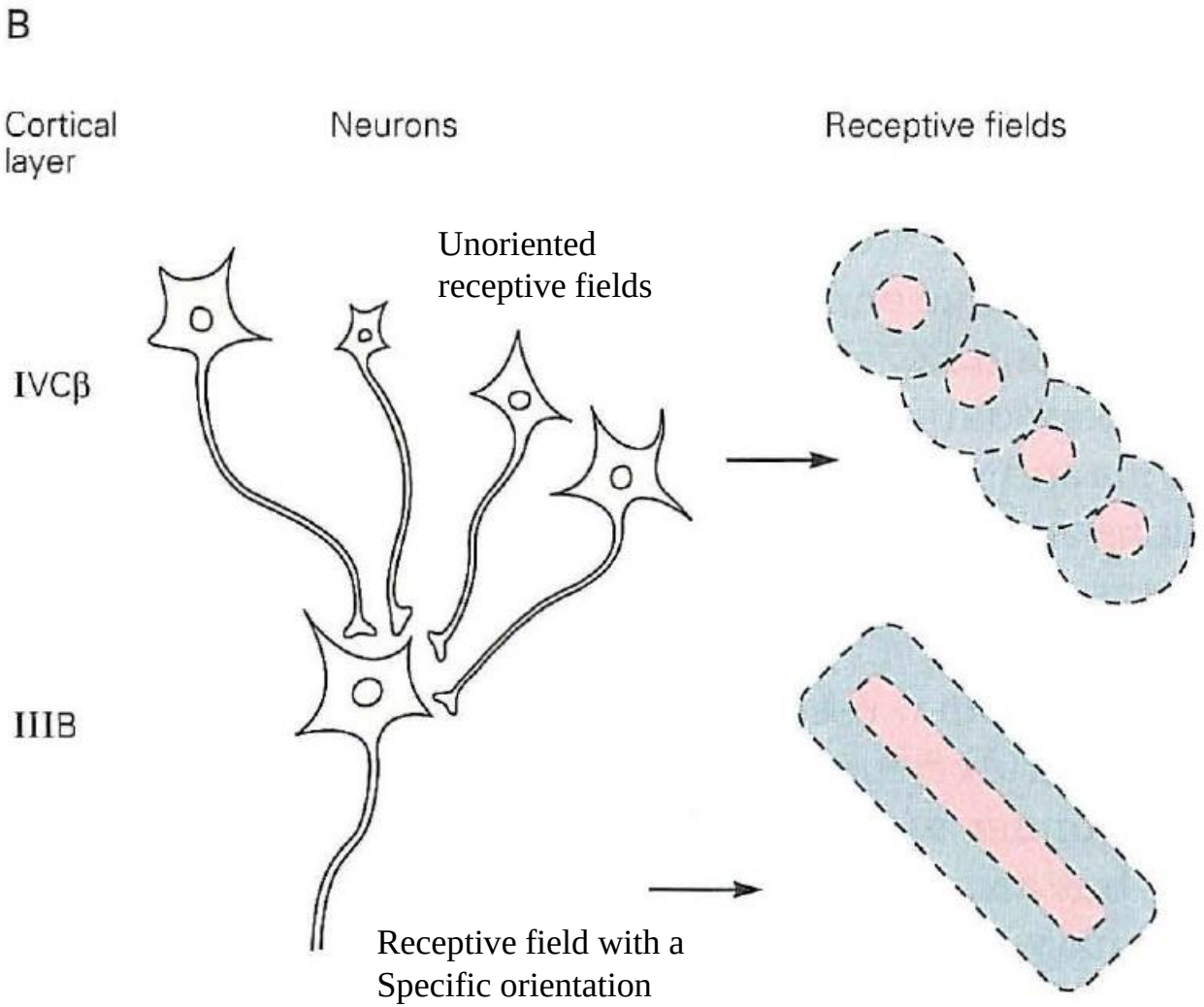
Orientation selectivity and mechanisms

Selectively to line segments that fit the orientation

First step in the brain's analysis of an object's form



Alignment of the circular center-surround receptive fields of several presynaptic cells in the lateral geniculate nucleus

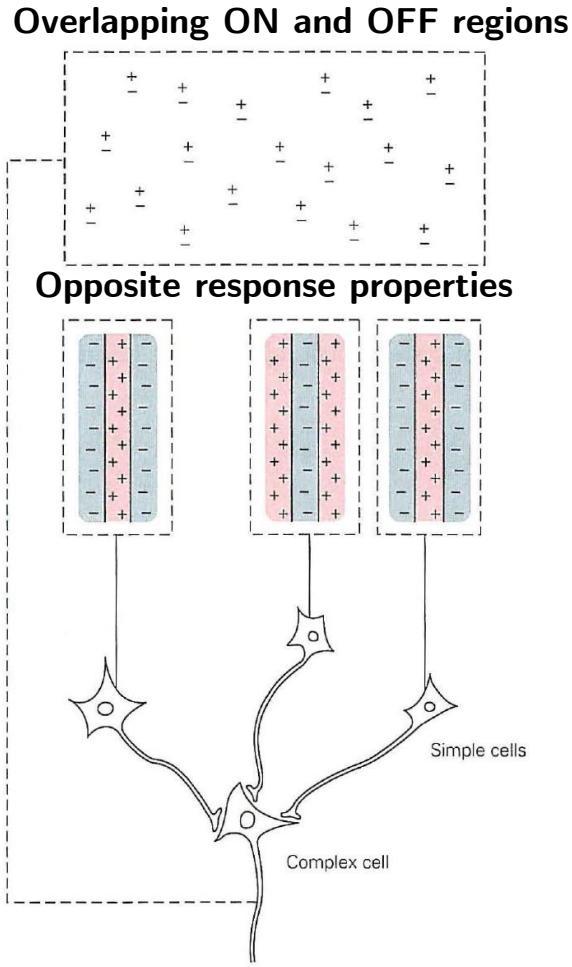


Simple and complex cells in the visual cortex

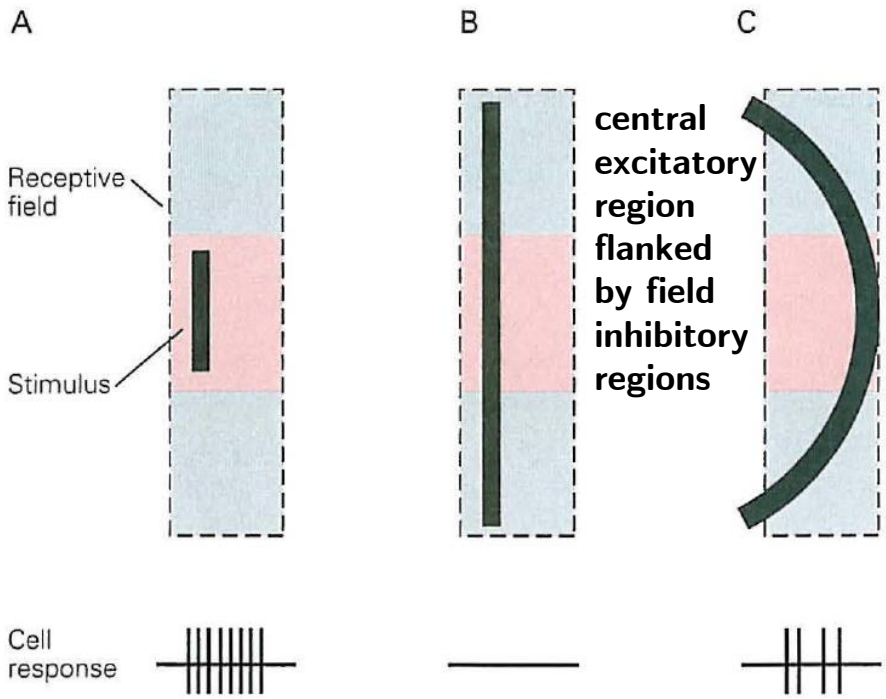
+ : onset of a light

- : extinction of a bar of light

+/-: respond **continuously** as a line or edge **traverses** the receptive field along an axis **perpendicular** to the receptive-field orientation

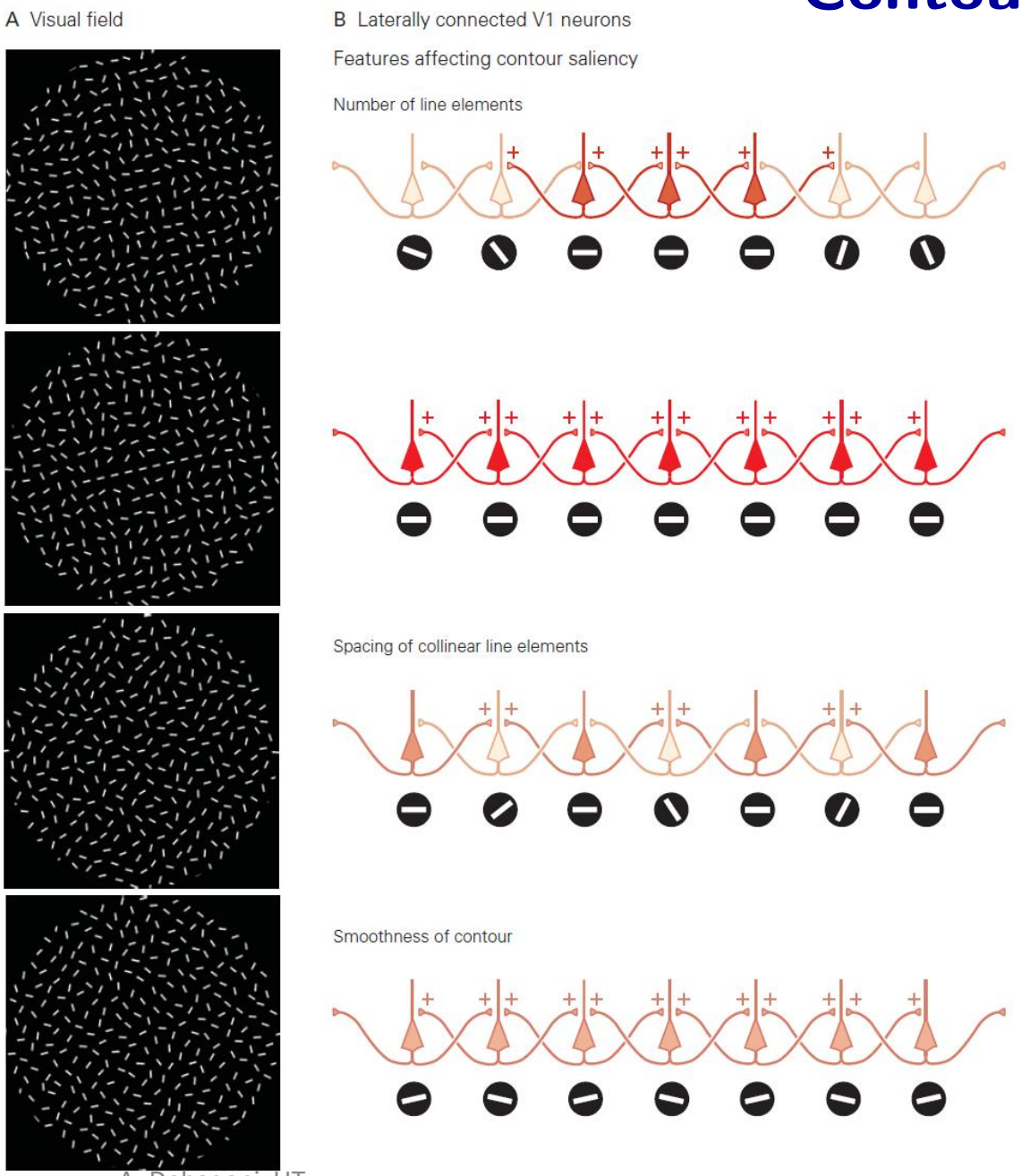


End-inhibited receptive fields



Inhibitory regions have the same orientation selectivity

Contour integration:



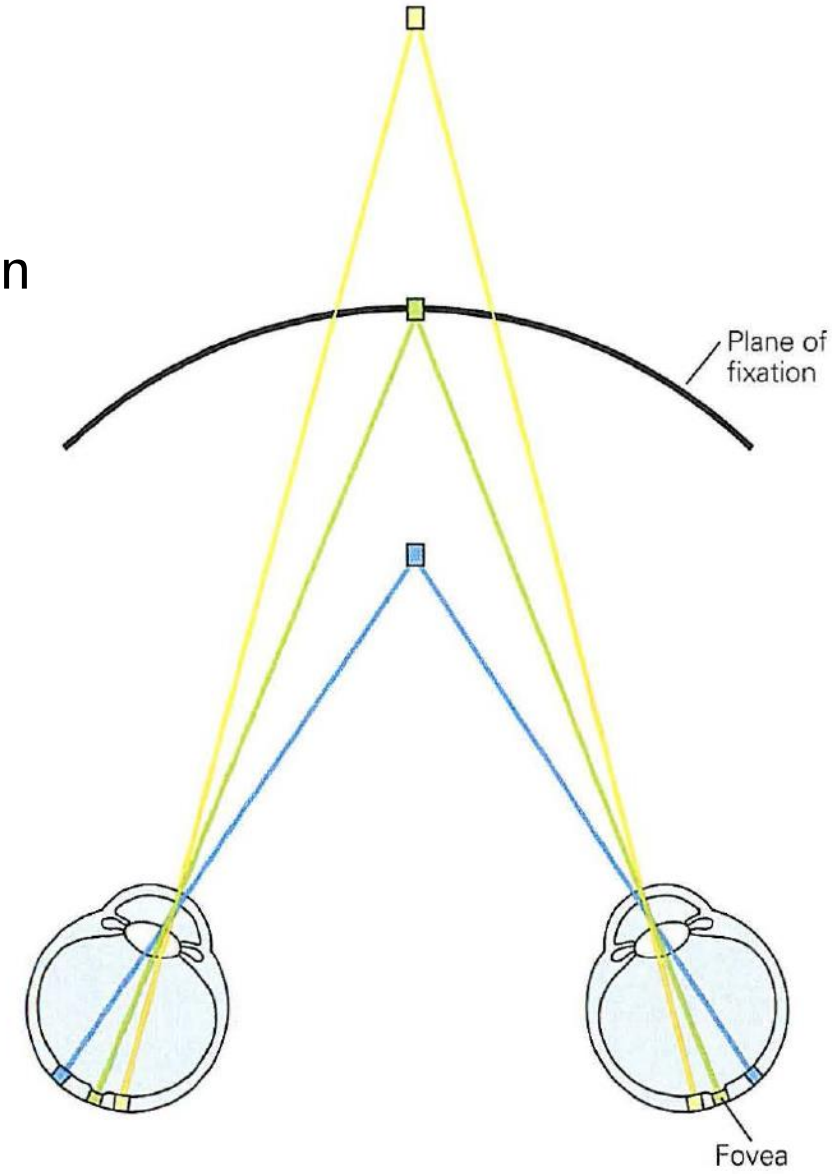
- Perceptual properties are reflected in the **horizontal** connections
- Features affecting contour saliency
- Contour elements are spaced sufficiently close together, excitation can propagate from cell to cell

Binocular disparity of retinal images

Depth is computed from the positions at which images occur in the two eyes.

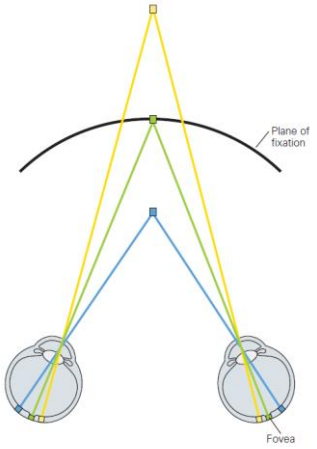
Green falls on **corresponding** points on the two retinas

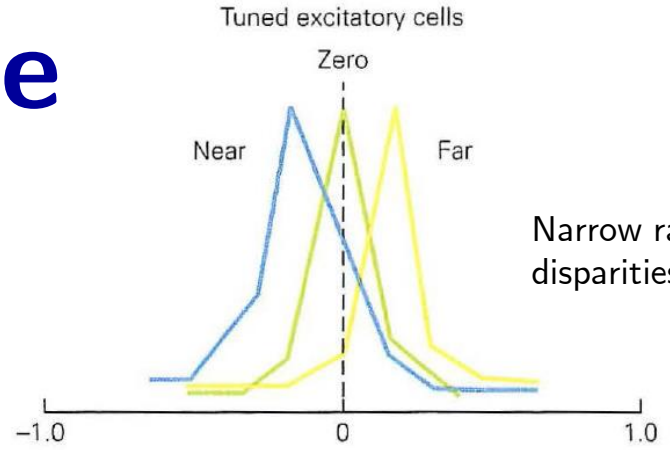
Blue and yellow fall on **non-corresponding**



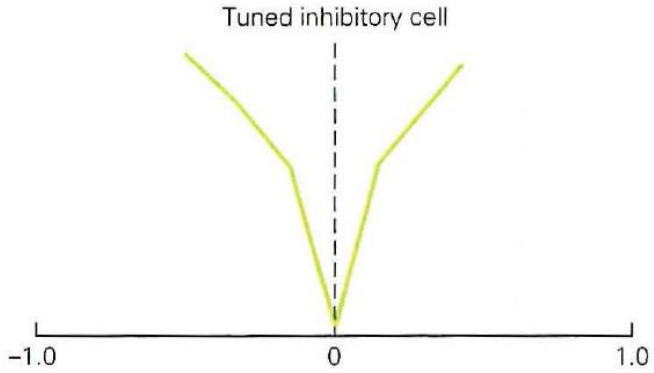
Disparity-selective neurons

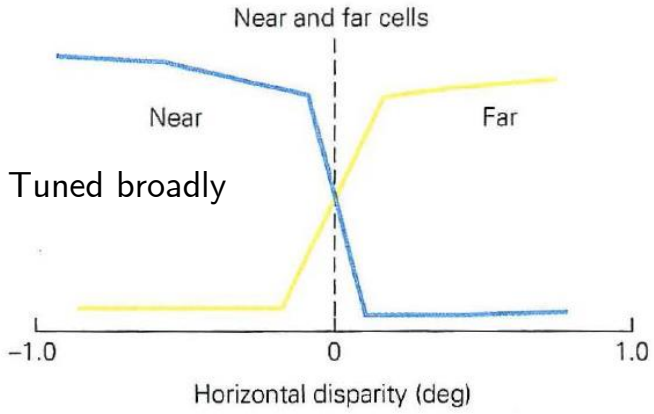
Response of neuron to binocular stimuli with different disparities (abscissa)





Narrow range of disparities





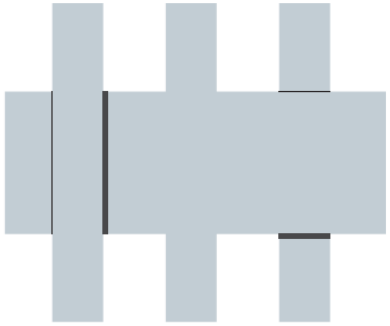
Tuned broadly

Global analysis of binocular disparity

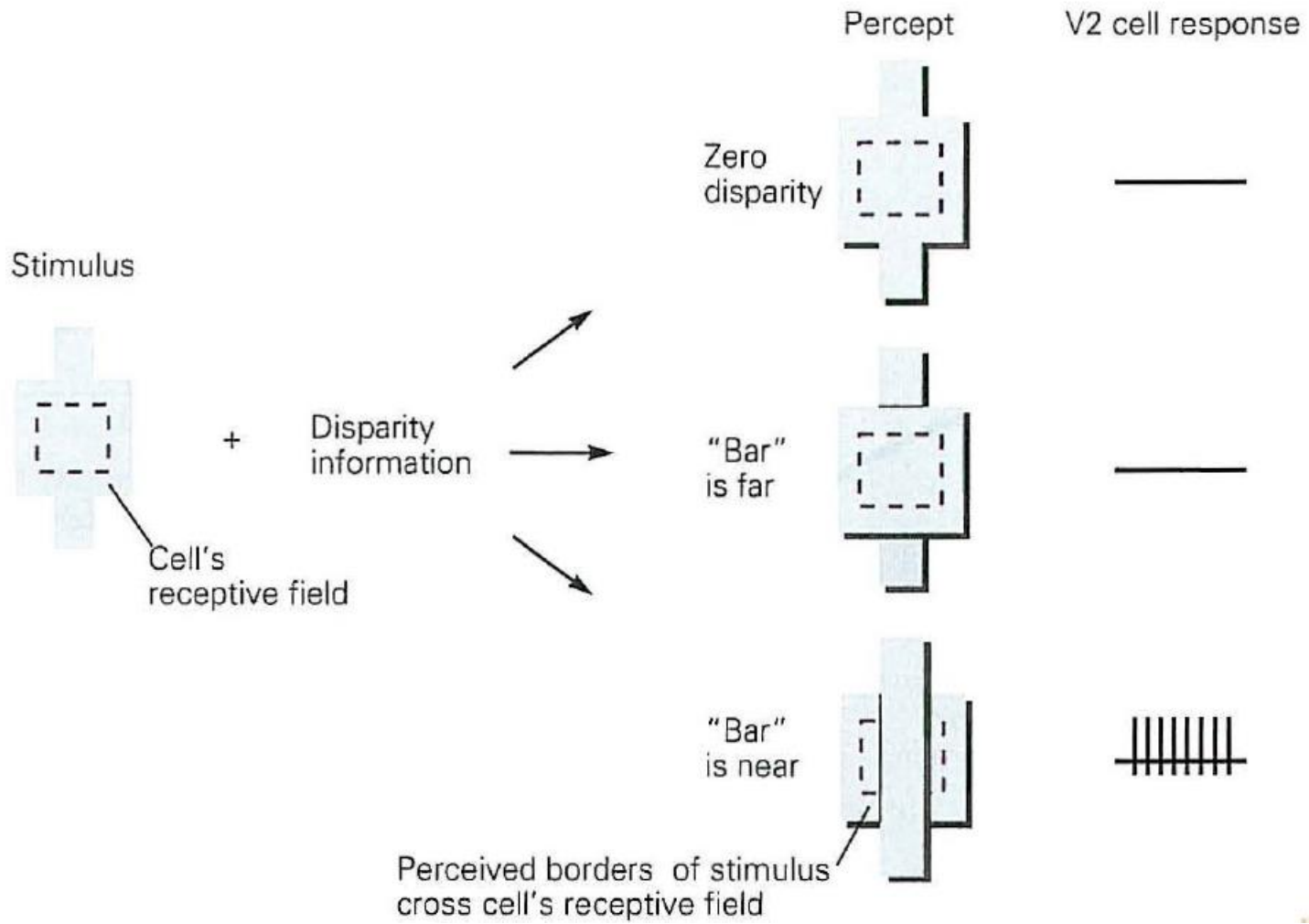
Depth cues contribute to surface segmentation

Fuse the two rectangles in, with diverged eyes

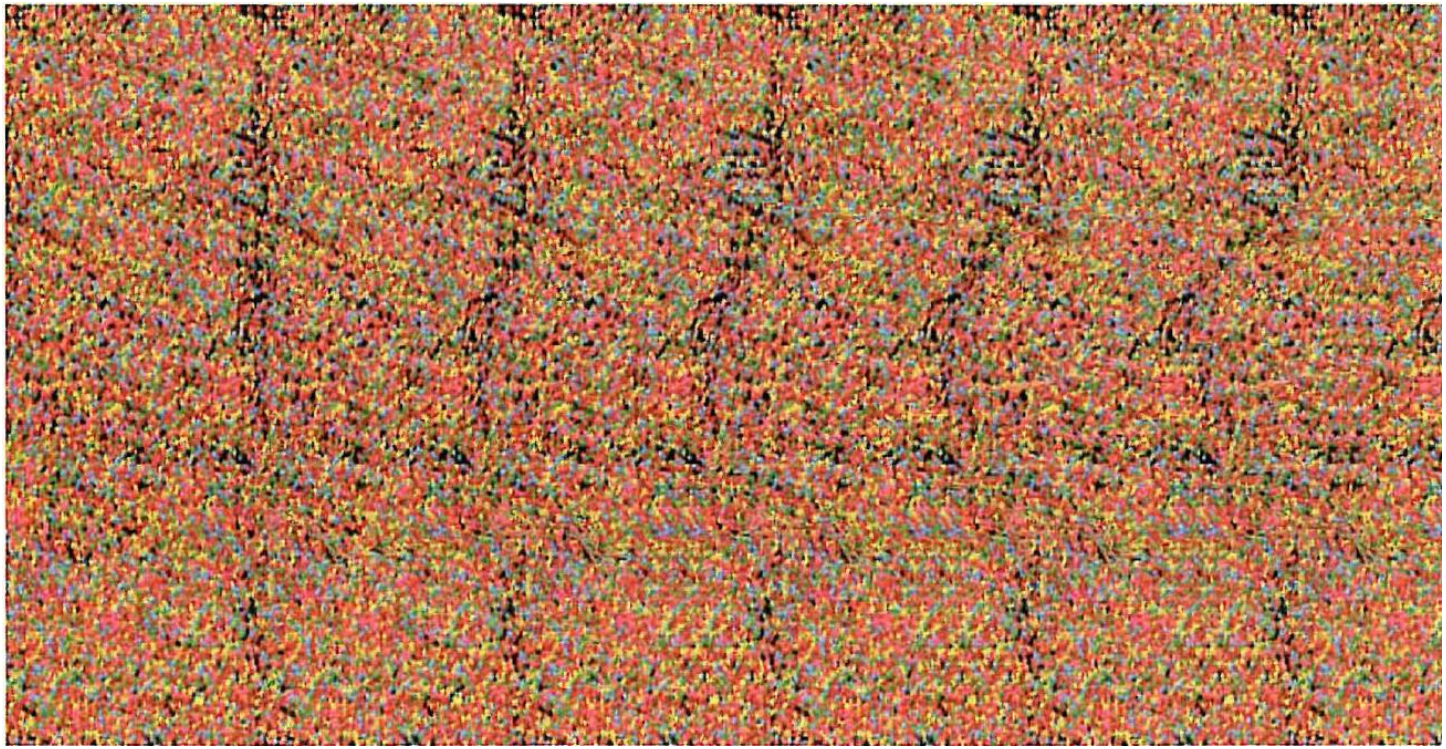
The three vertical bars fall on the two retinas with near, zero, and far disparity, respectively



A neuron in area V2 responds to illusory edges **formed by binocular disparity cues**

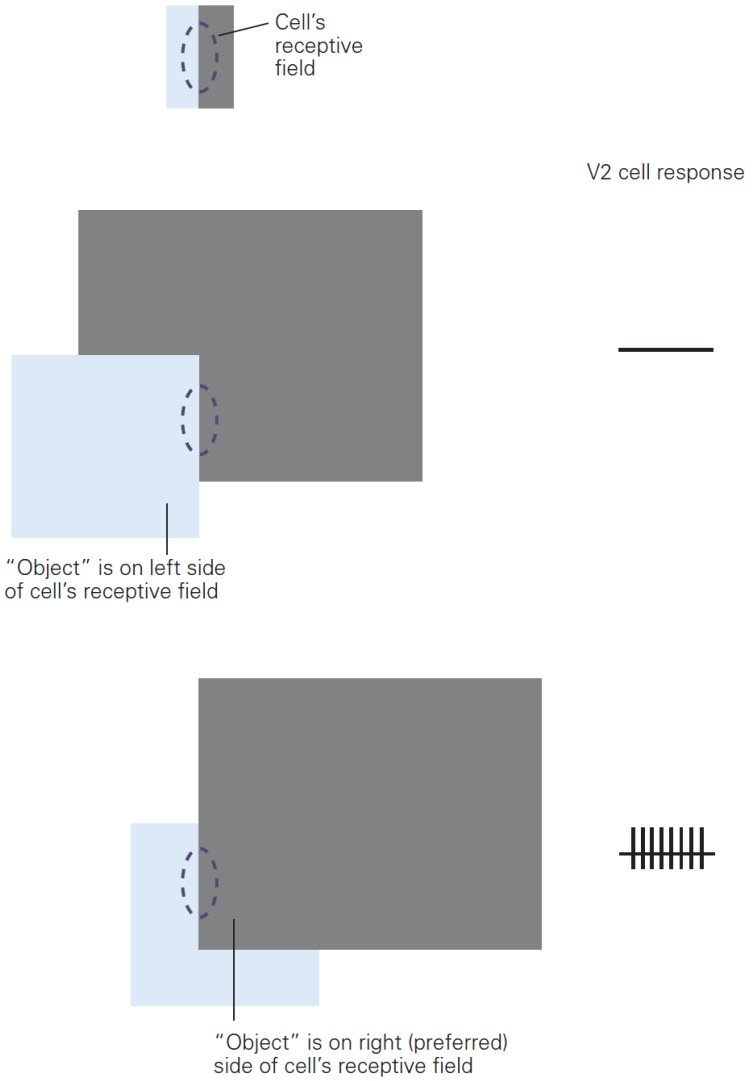


Diverges or converges the eyes on random dots



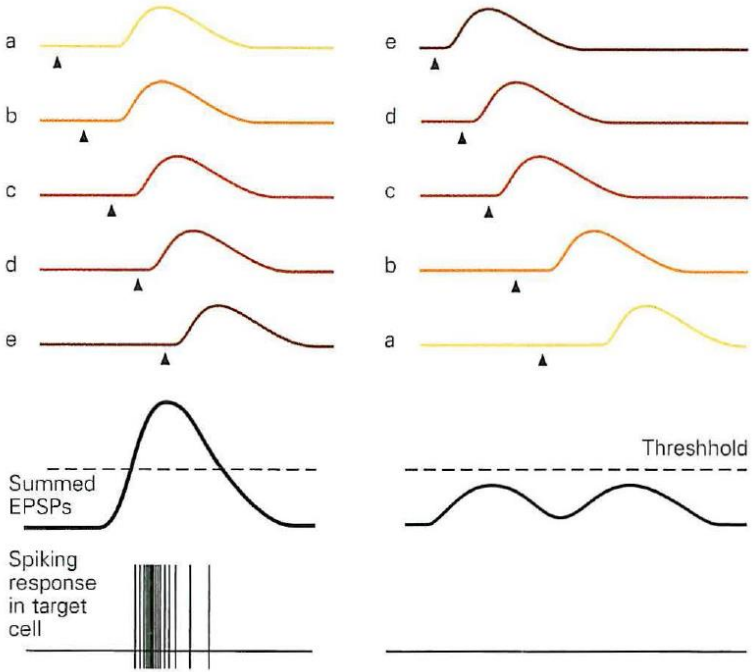
Cells in area V2 are sensitive to the boundaries of whole objects.

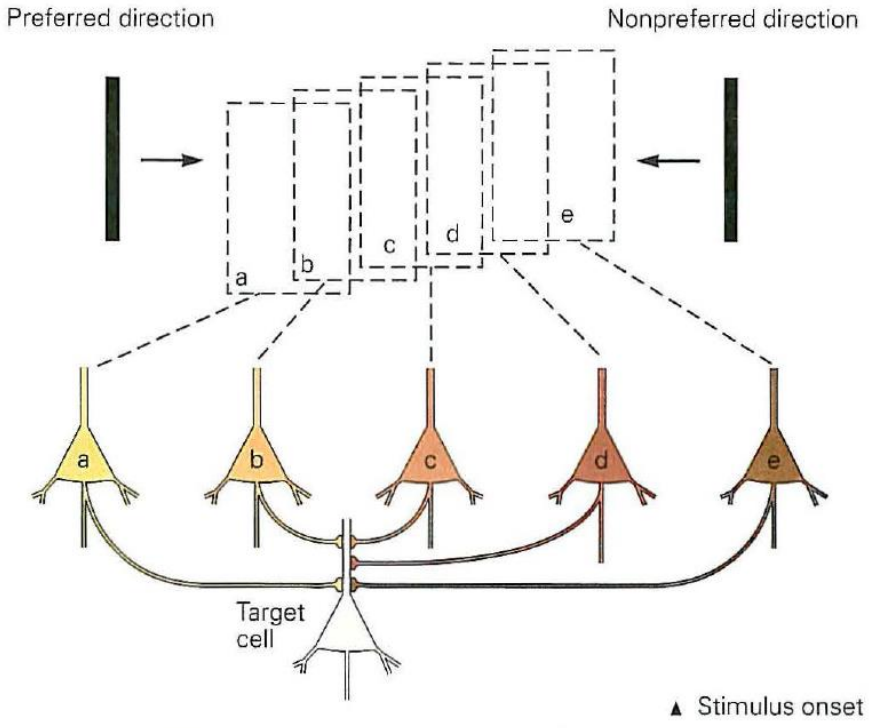
The cell responds only when the boundary is part of a complete surface



Directional selectivity of movement

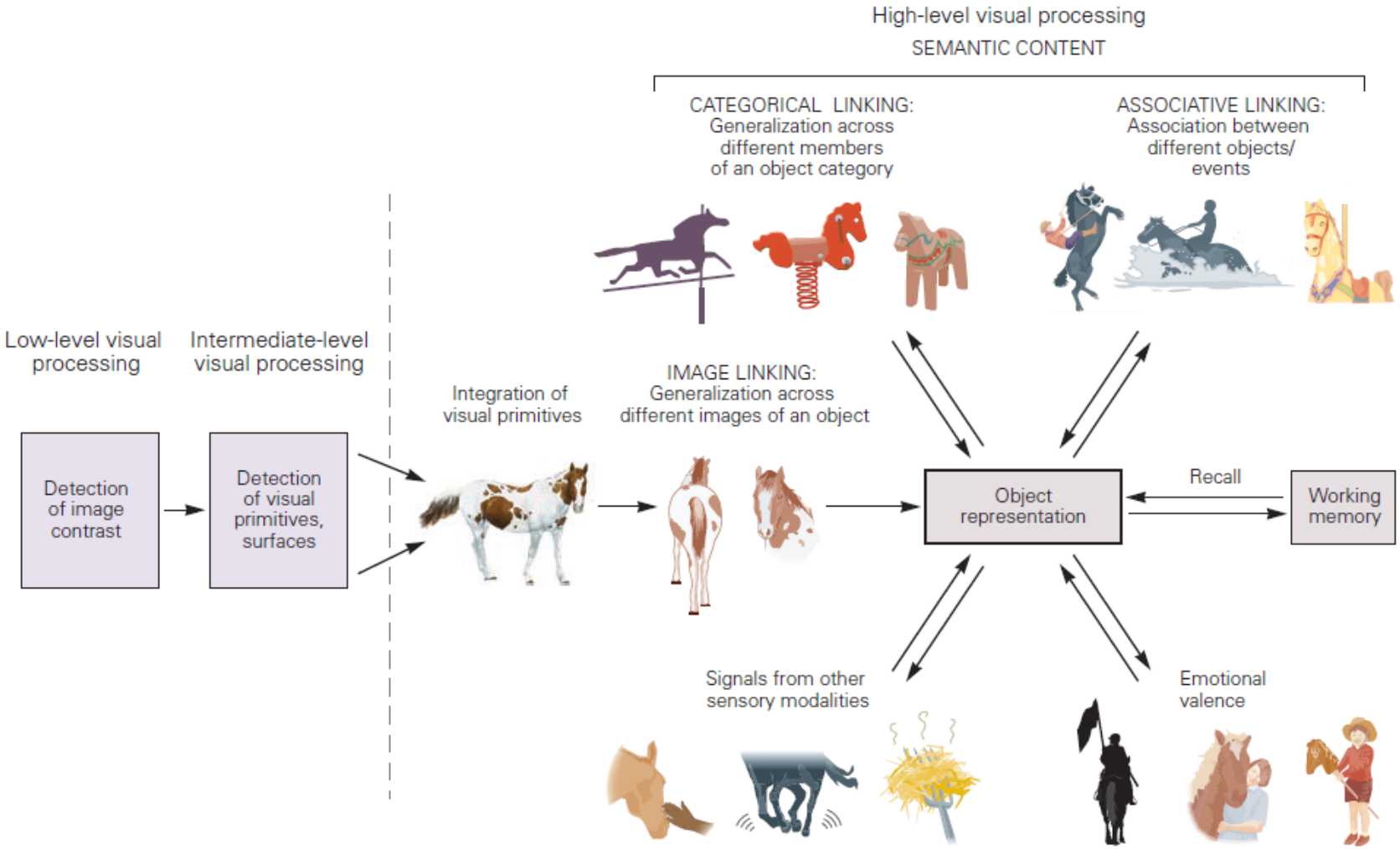
The selectivity of a neuron to the direction of movement depends on the **response latencies of presynaptic neurons.**



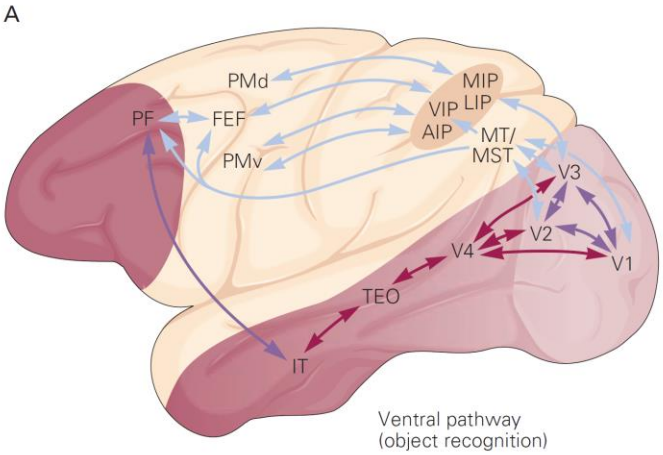


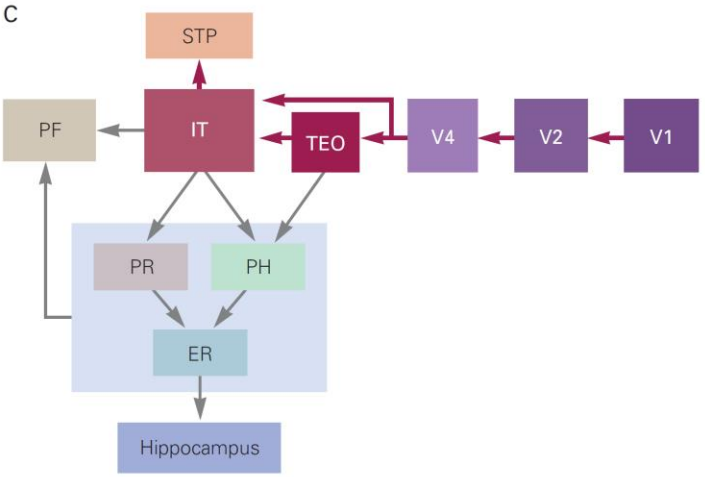
High-Level Visual Processing

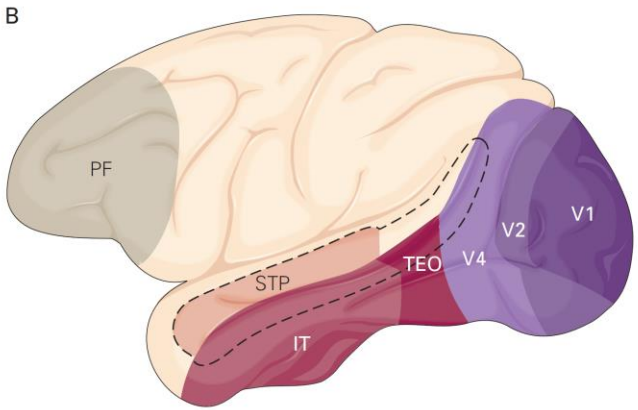
The neuronal representation of entire objects is central to high-level visual processing

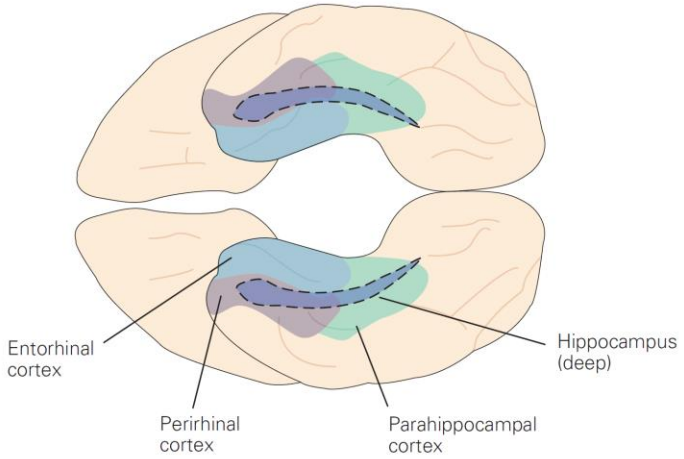


Cortical pathway for object recognition

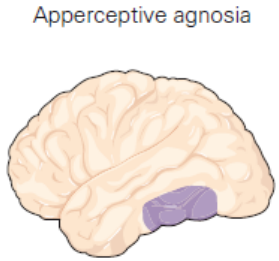


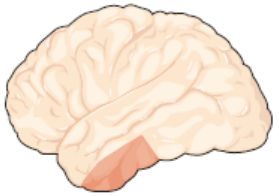






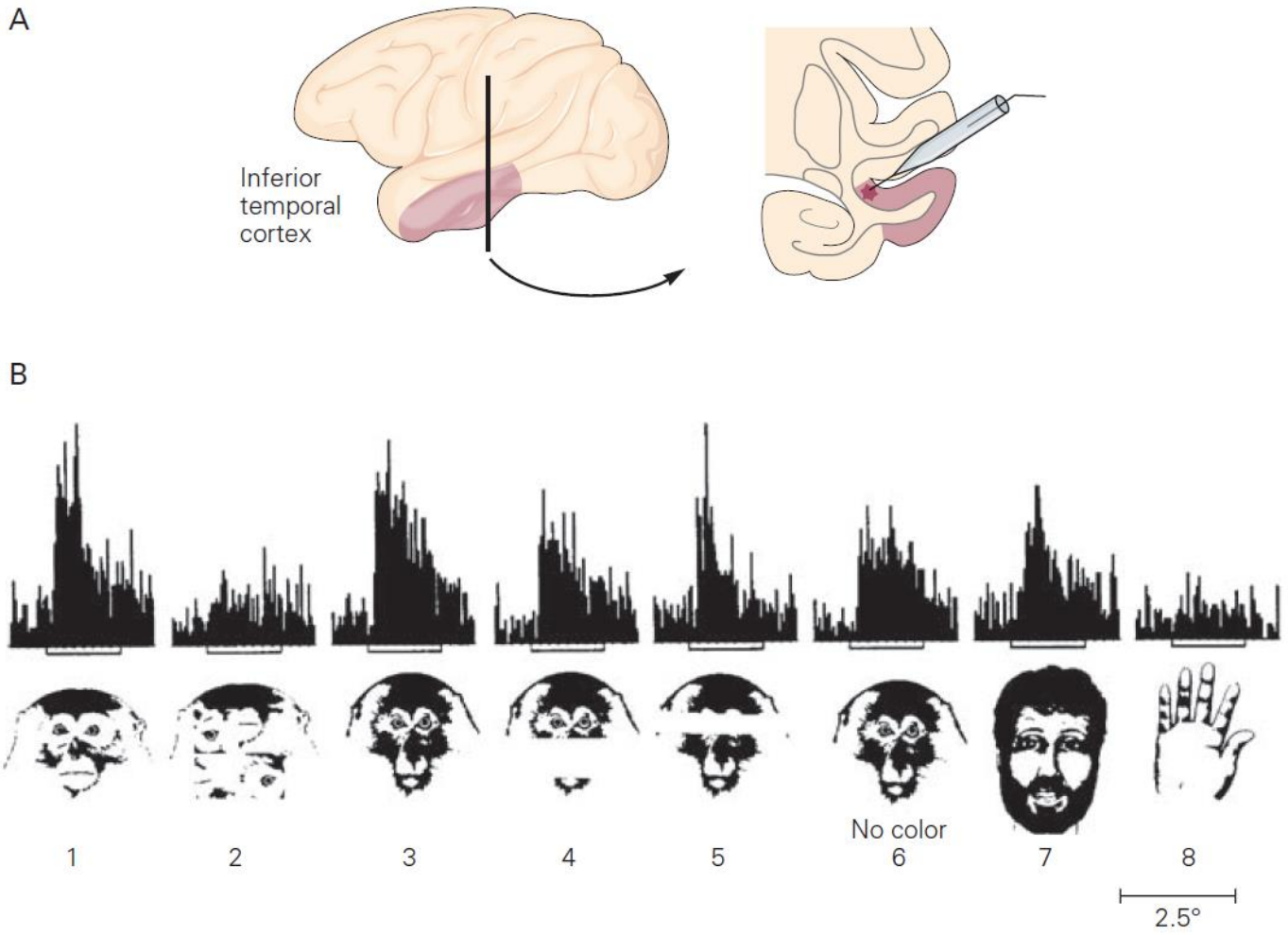
Neuropsychological evidence for the neuronal correlates of object recognition in the temporal lobe



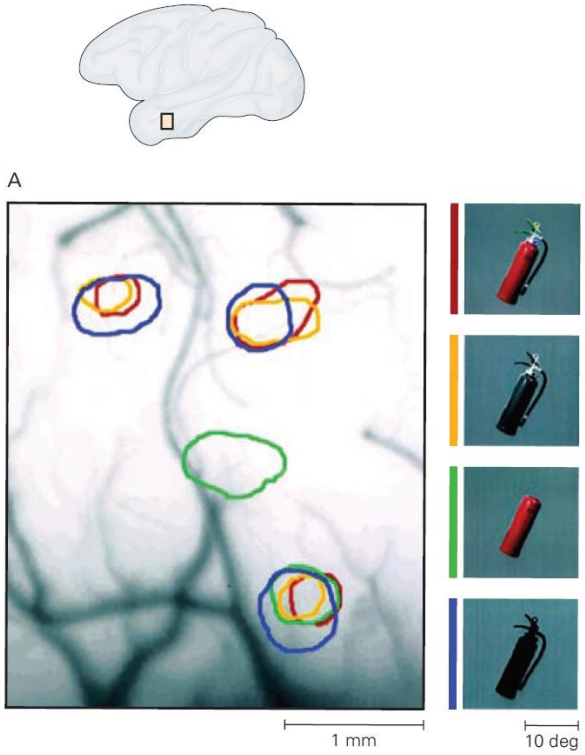


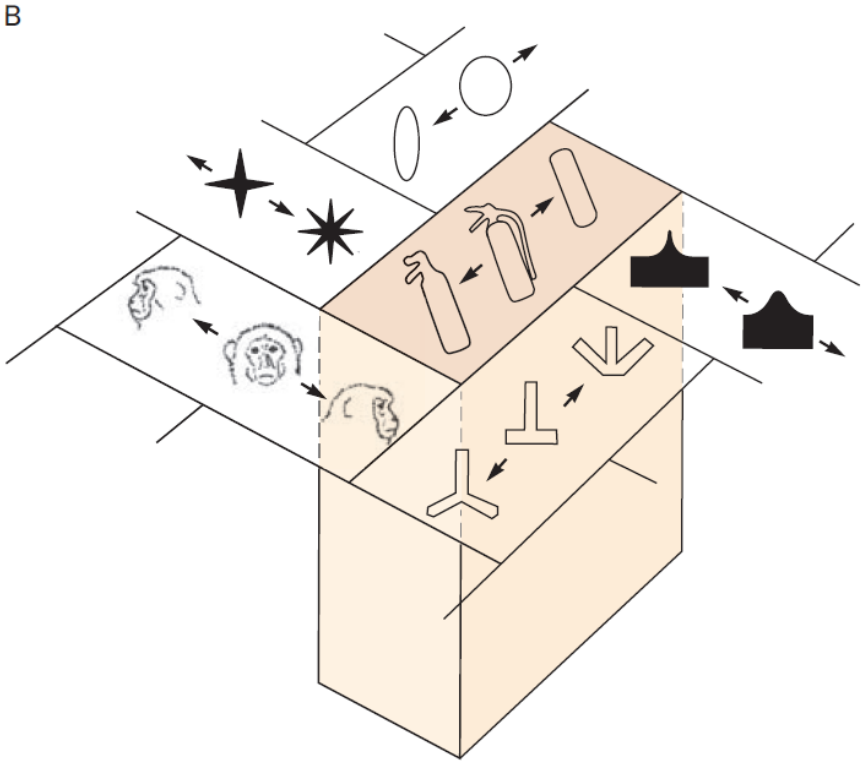
	Apperceptive agnosia			Associative agnosia		
	Model	Patient's drawing	Verbal identification of object	Model	Patient's drawing	Verbal identification of object
Ability to copy or match visual stimuli			"Circle"			—
			"Square"			
			"Diamond"			—
			"Three"			—
			"Four"			
Deficiency of object perception	Cannot see object parts as a unified whole			Cannot interpret, understand, or assign meaning to objects		
Clinical interpretation	Unable to construct sensory representations of visual stimuli			Sensory representation is created normally but cannot be associated with meaning, function, or utility		

Neurons in the inferior temporal cortex of the monkey are involved in face recognition

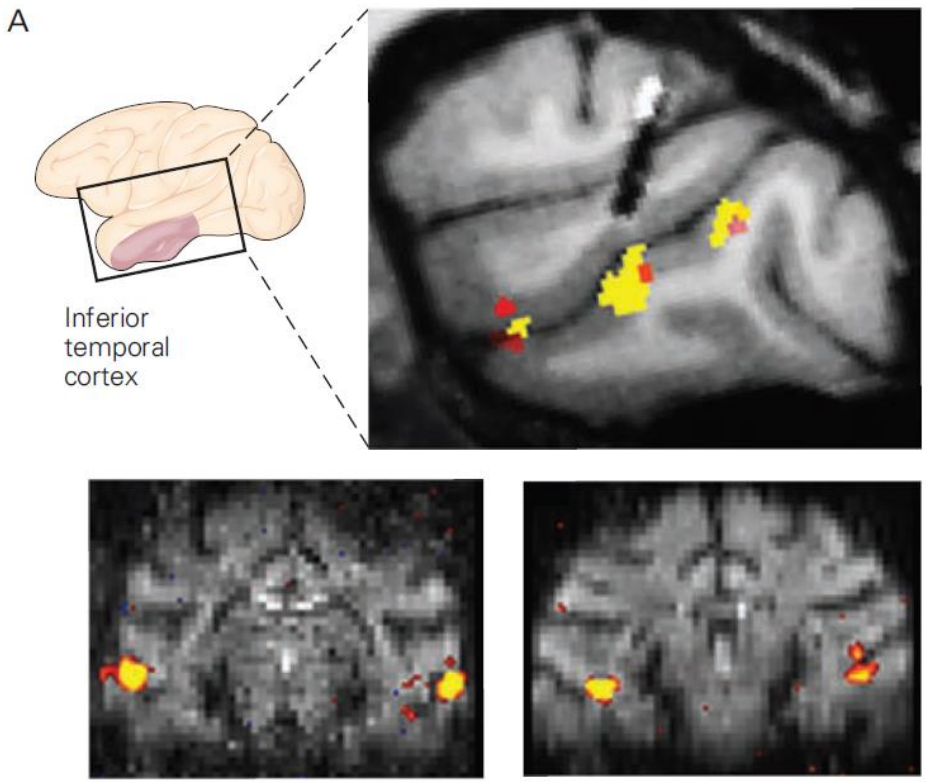


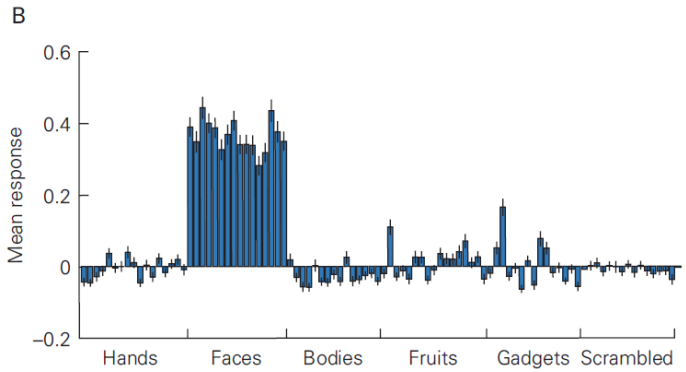
Neurons in the anterior portion of the inferior temporal cortex that represent complex visual stimuli are organized into columns



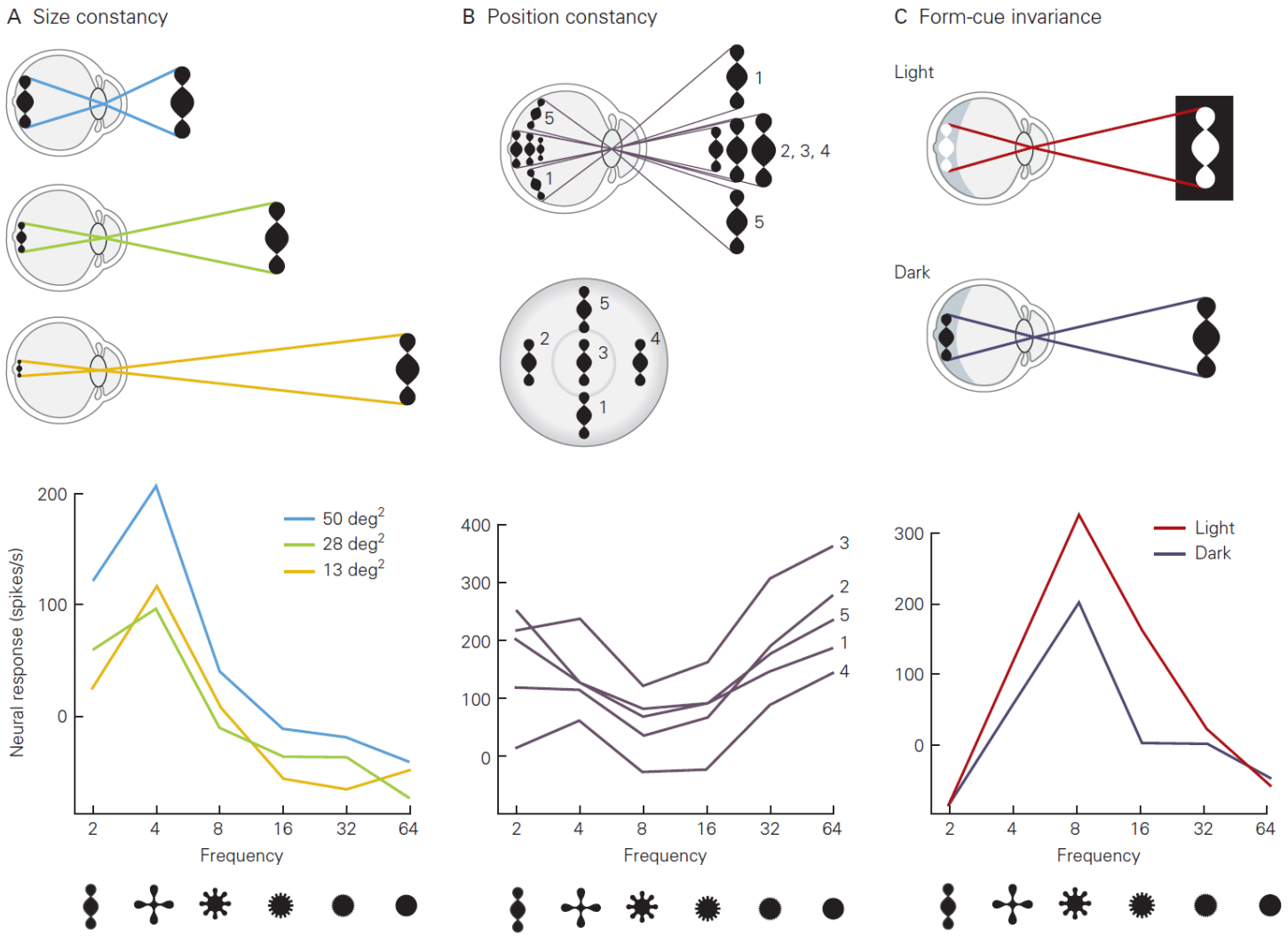


The inferior temporal cortex contains dense clusters of face-selective neurons

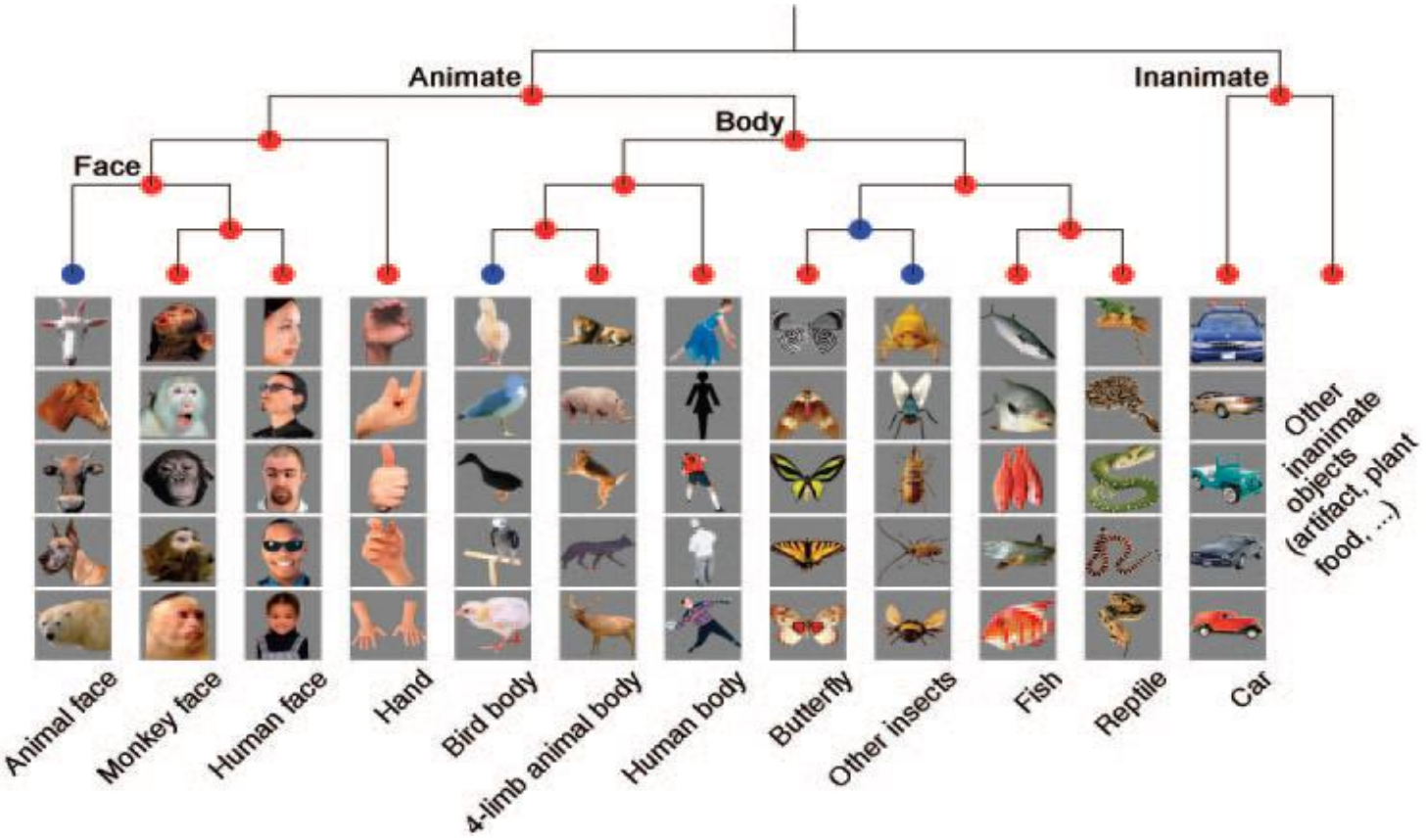




Perpetual constancy is reflected in the behavior of neurons in the inferior temporal cortex

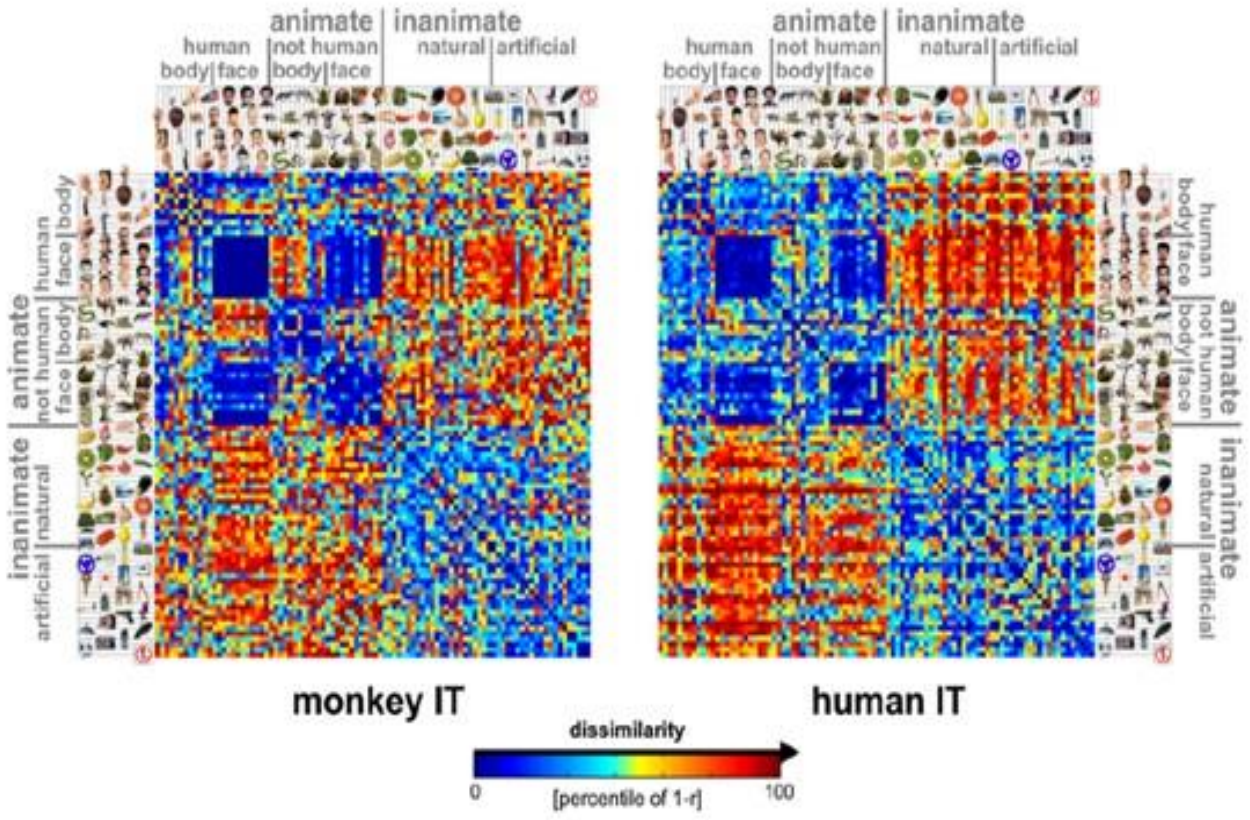


Neural coding for categorical perception
Hierarchical decoding in Kiani et al. (2007)



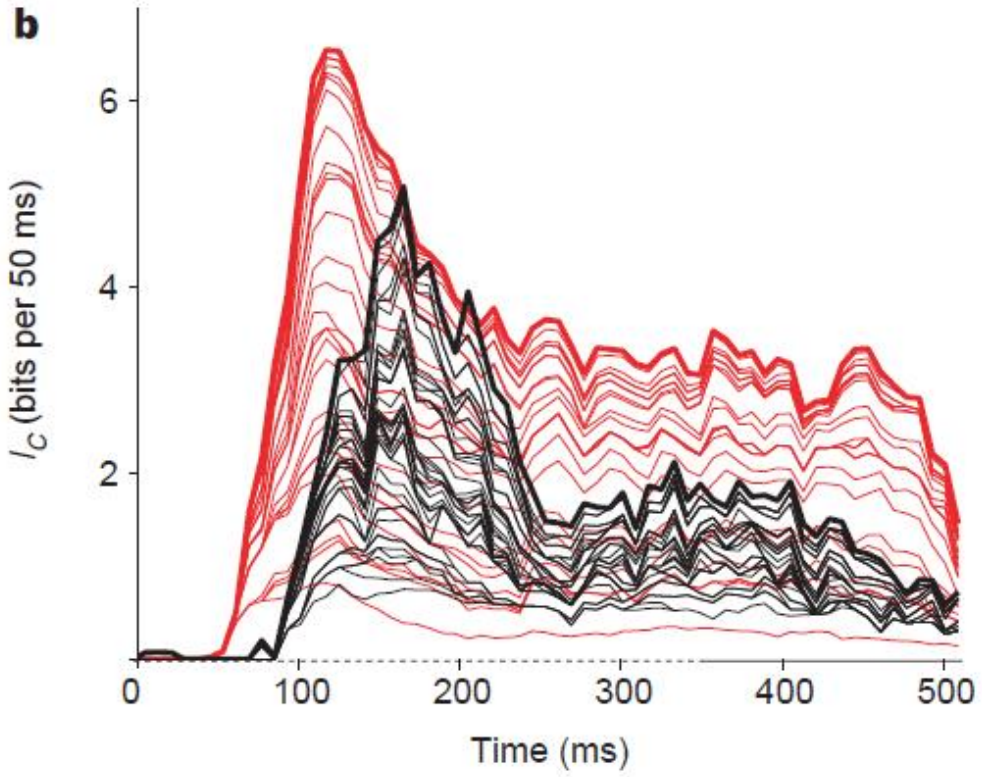
(Roozbeh Kiani 2007)

Representational Dissimilarity Matrix



(M. M. Nikolaus Kriegeskorte 2008)

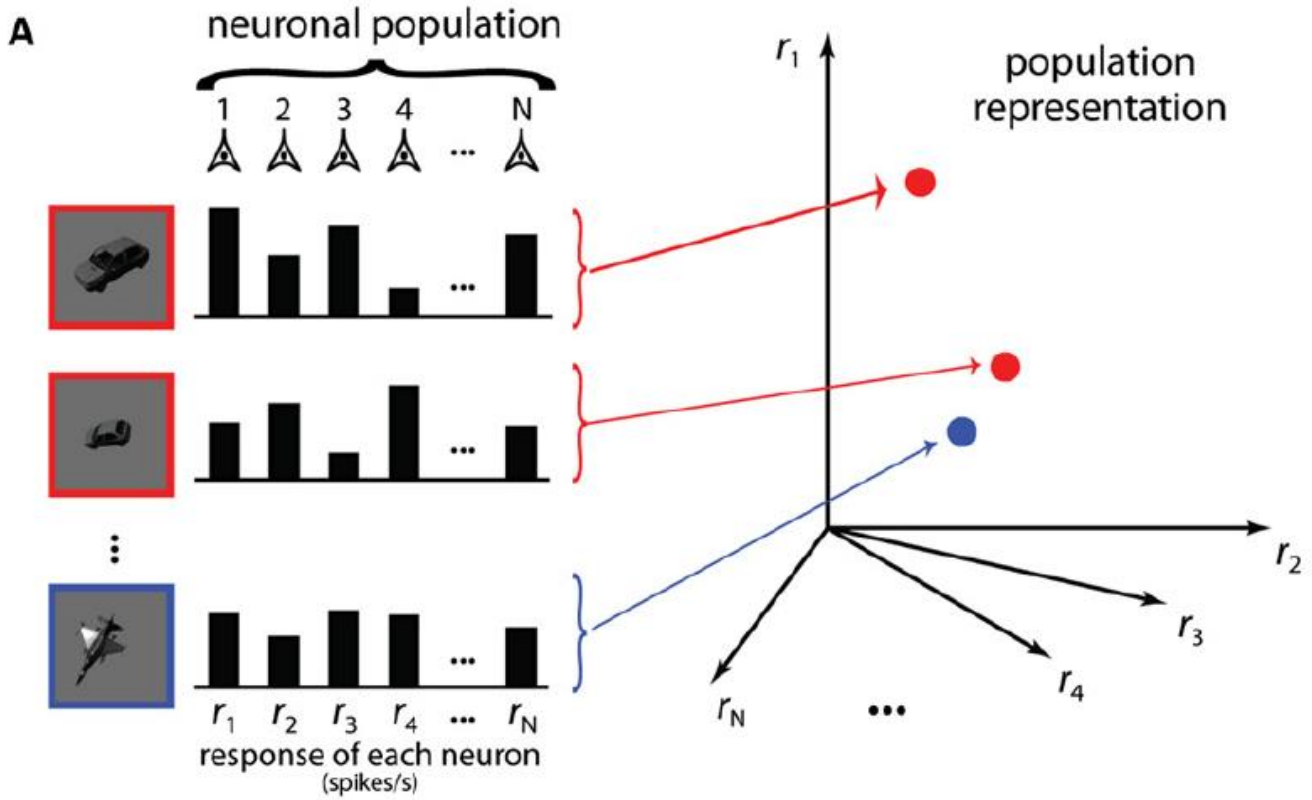
Global and fine information coded by single neurons



Early global information could serve as a 'header' to enhance subsequent processing by switching the processing mode.

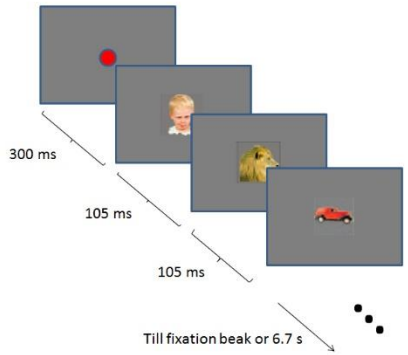
(Yasuko Sugase 1999)

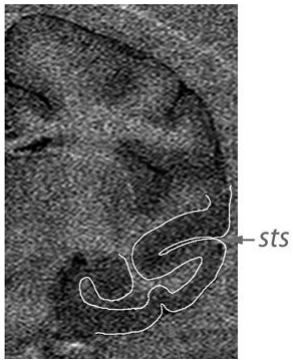
Population response



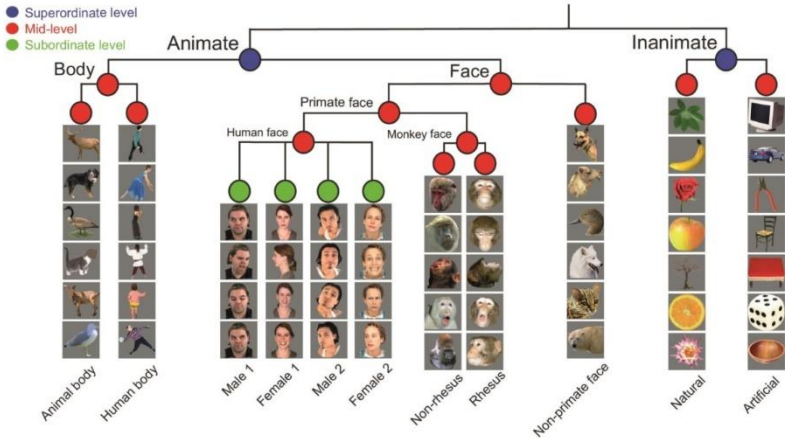
DiCarlo neuron 2012

experimental paradigm

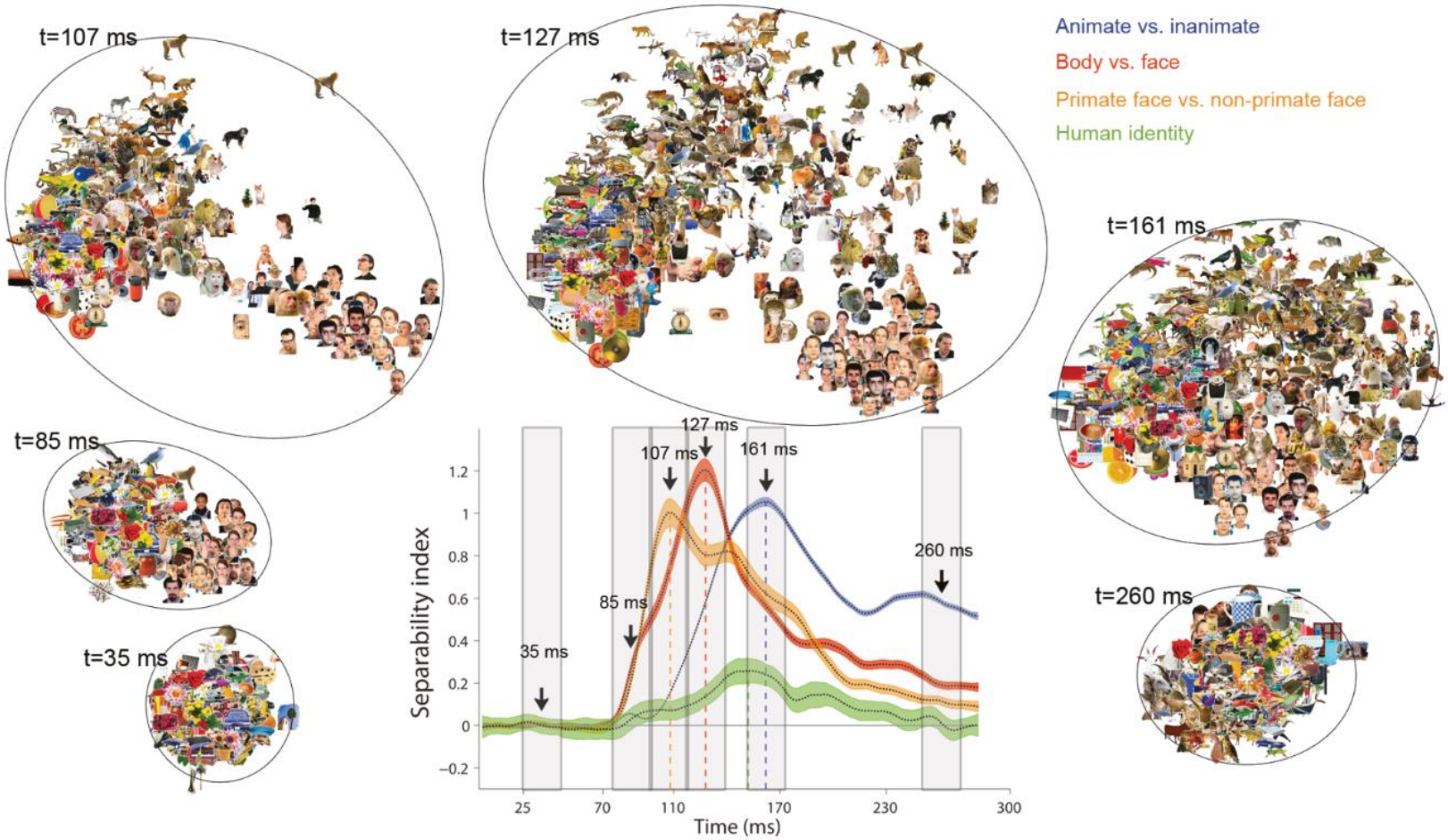




Stimuli



The time course of category representation



Dehaqani et al. 2016