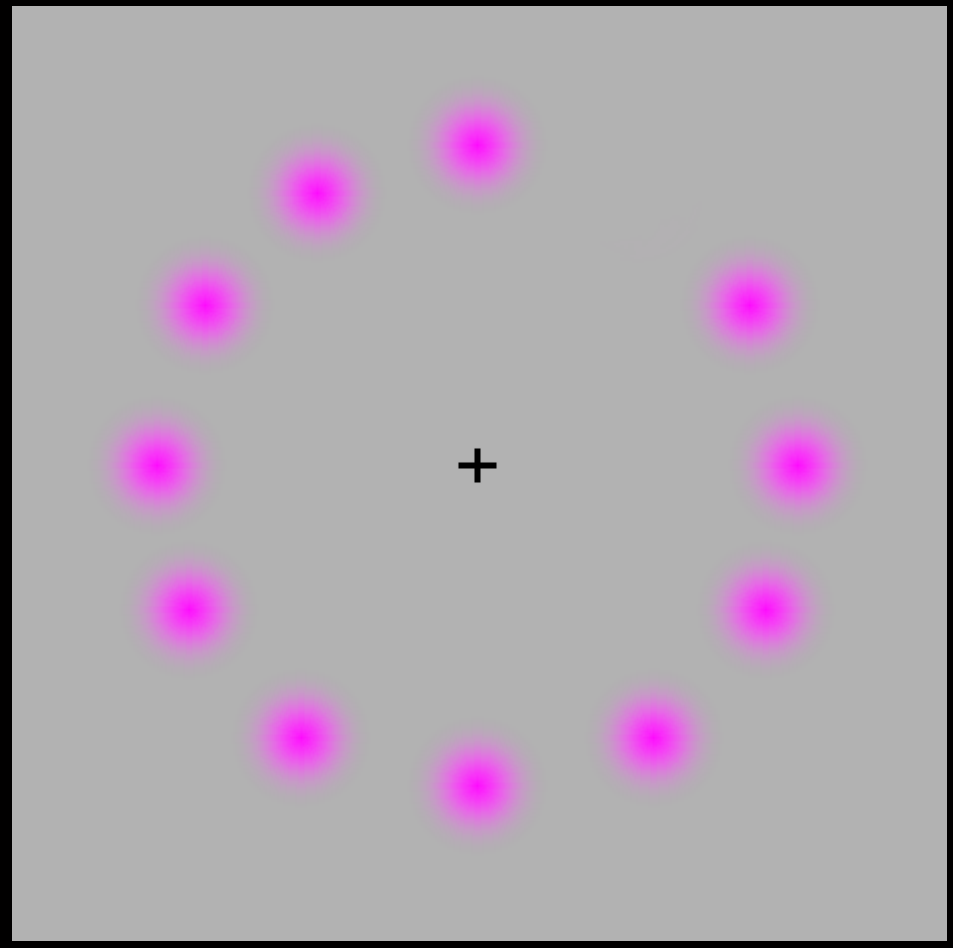
NEUR0017: Visual Neuroscience

INTRODUCTION

Andrew Stockman



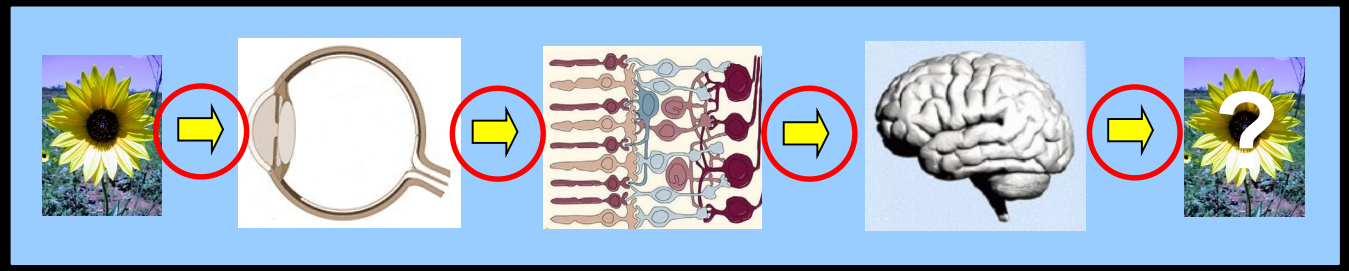
VISUAL NEUROSCIENCE

What is visual neuroscience?

Essentially what we're trying to do is to understand:

How the visual system works!

INPUT



OUTPUT

Using any available technique...

PSYCHOPHYSICS

PHYSICAL STIMULUS → PERCEPTION

Study of the relationship between physical stimulus and perception…

From which we try to infer what is going on inside the black box.

PSYCHOPHYSICS

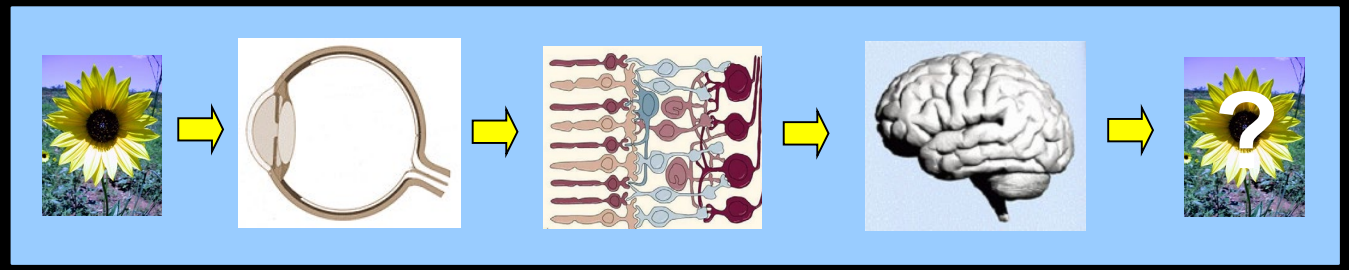
PHYSICAL STIMULUS → PERCEPTION

Can you think of some examples of psychophysical experiments?

And what they might tell us about visual processing?

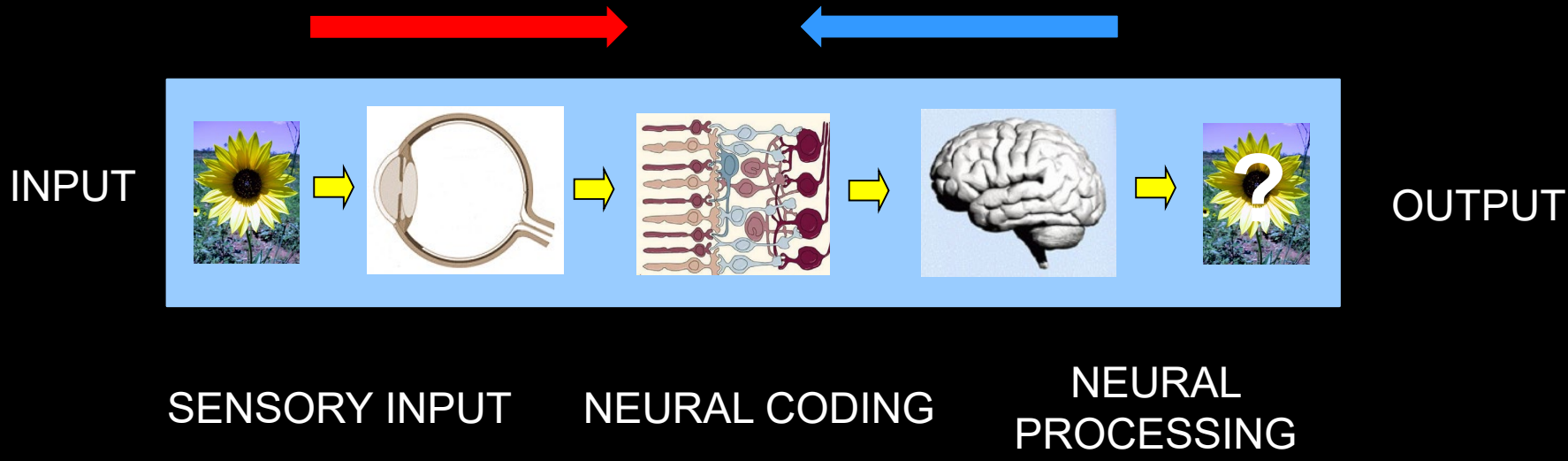
NEUROSCIENCE

Study the relationship between sensory input and the neural coding at different stages of the visual system and from that infer the neural processing.



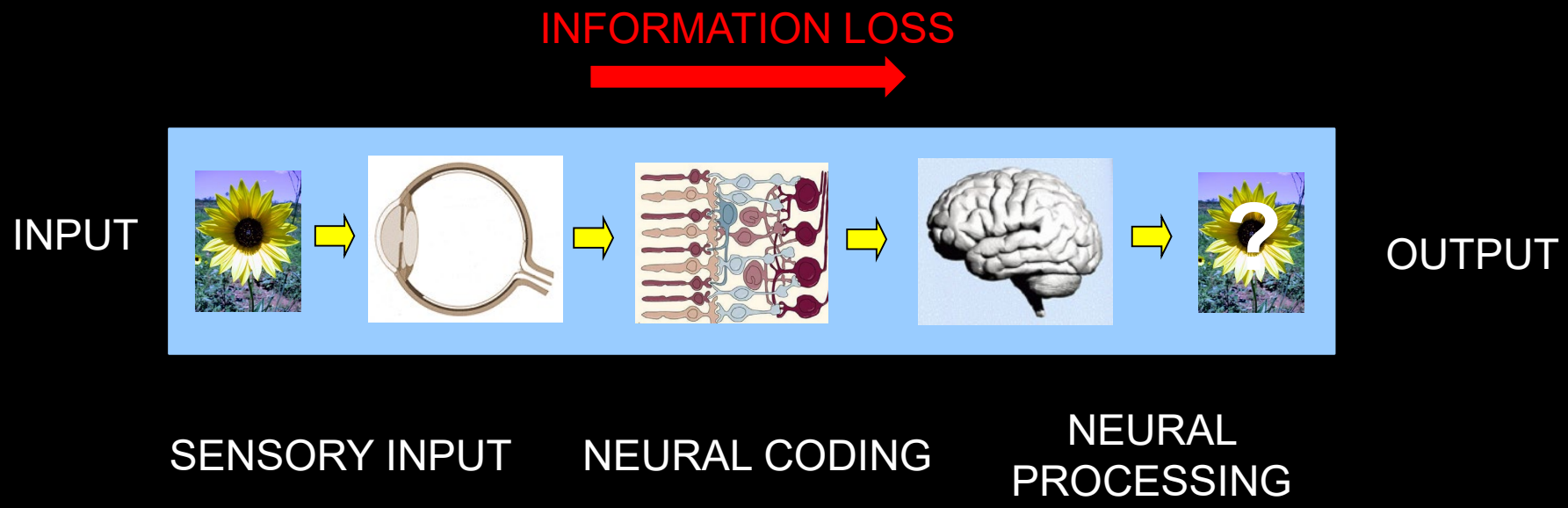
NEUROSCIENCE

- Bottom-Up Processing: information processing beginning at the “bottom” with raw sensory data sent “up” to the brain for higher-level analysis.
- Top-Down Processing: information processing is modified by higher level processes from the “top” working “down”.



NEUROSCIENCE

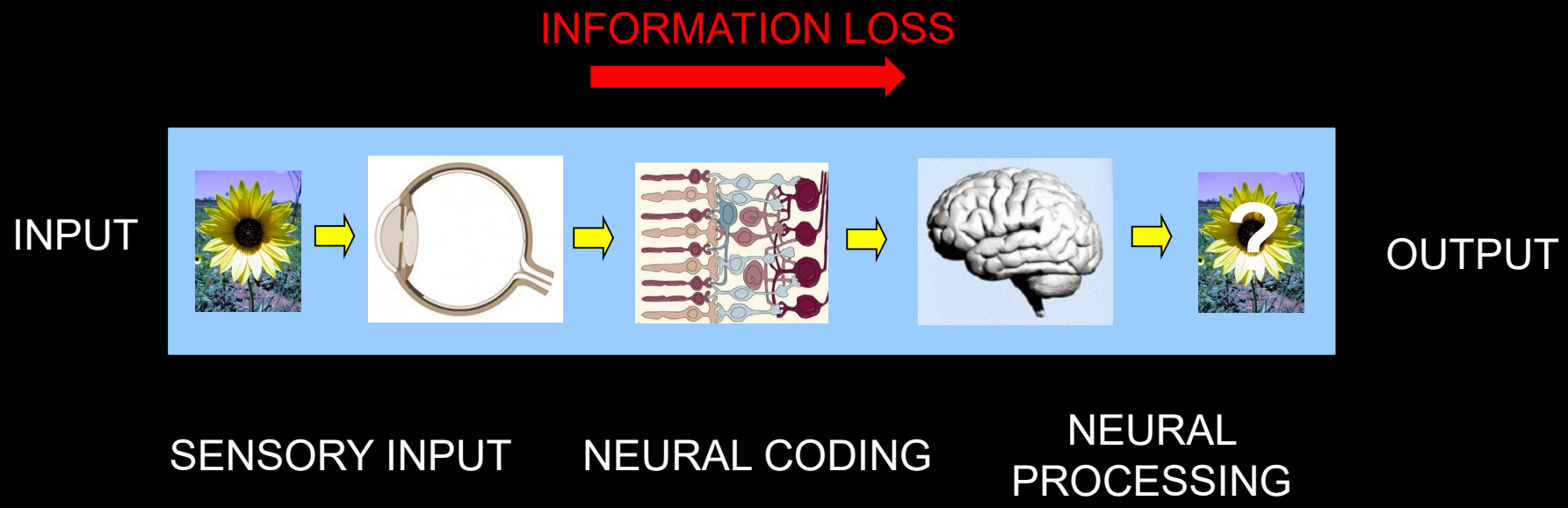
- Information loss: information is lost as visual signals are encoded and processed by successive stages of the visual system.



Think of examples: What is lost?

NEUROSCIENCE

- Information loss: information is lost as visual signals are encoded and processed by successive stages of the visual system.

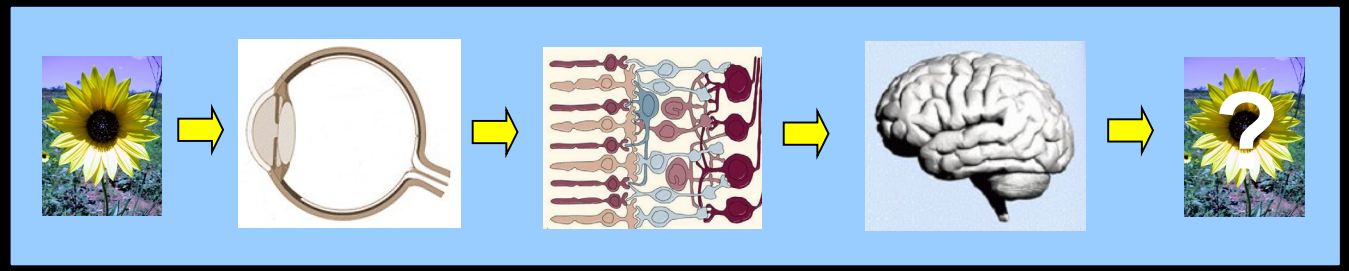


Lost information cannot be retrieved, although some aspects can be *inferred* by top-down processing (e.g., inference of 3D depth from a 2D monocular image).

PSYCHOPHYSICS AND NEUROSCIENCE CAN BE COMPLEMENTARY

PHYSICAL STIMULUS → PERCEPTION

INPUT



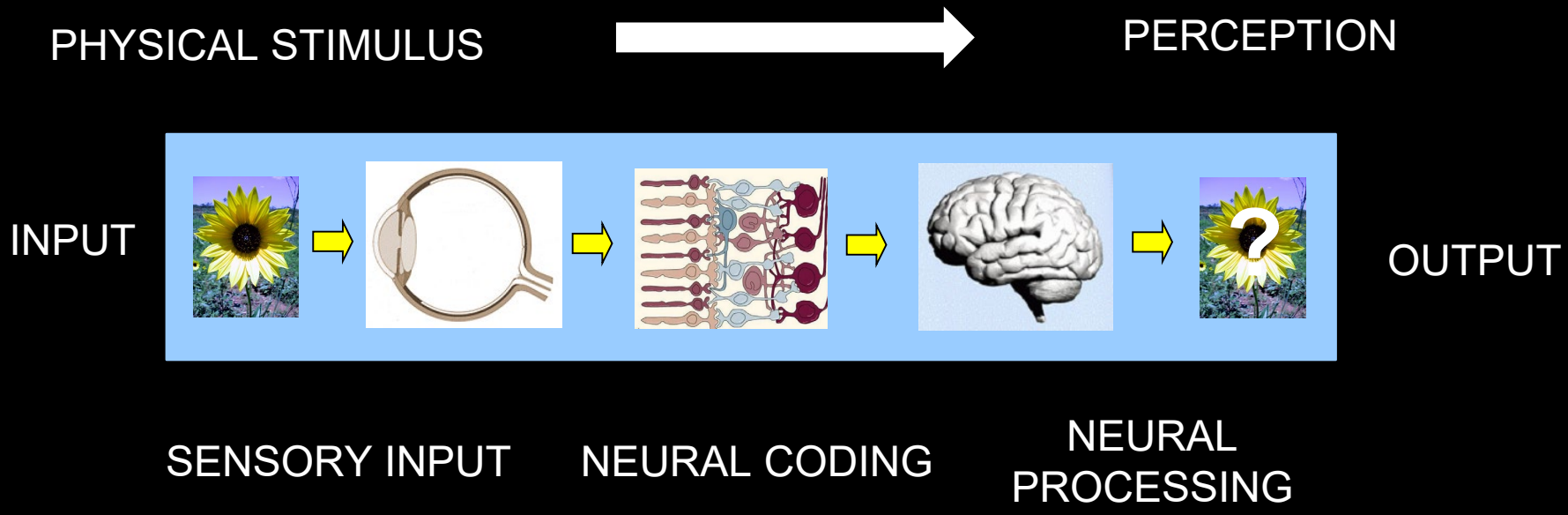
OUTPUT

SENSORY INPUT

NEURAL CODING

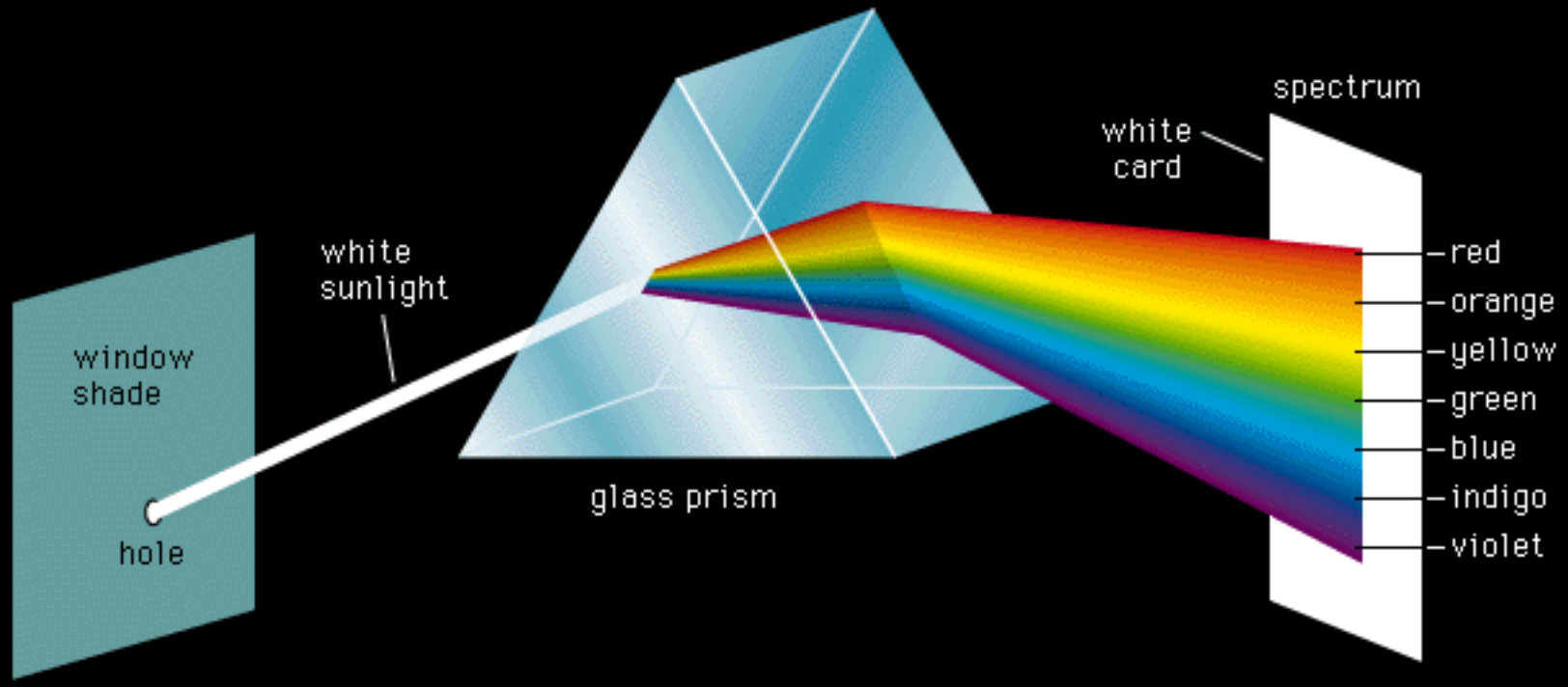
NEURAL PROCESSING

Let’s now step through this processing stream, beginning with…



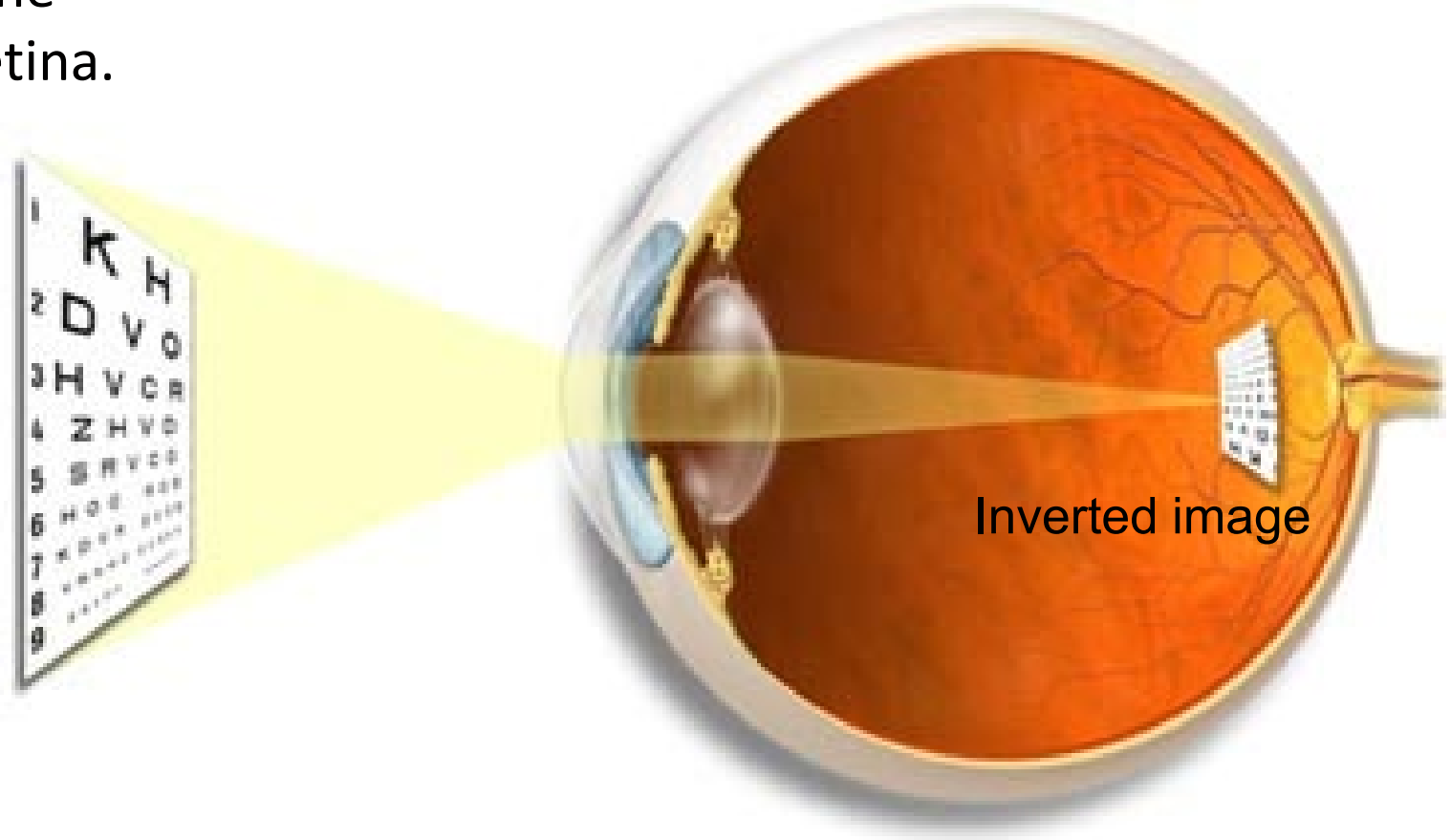
Light

400 - 700 nm is most important for vision



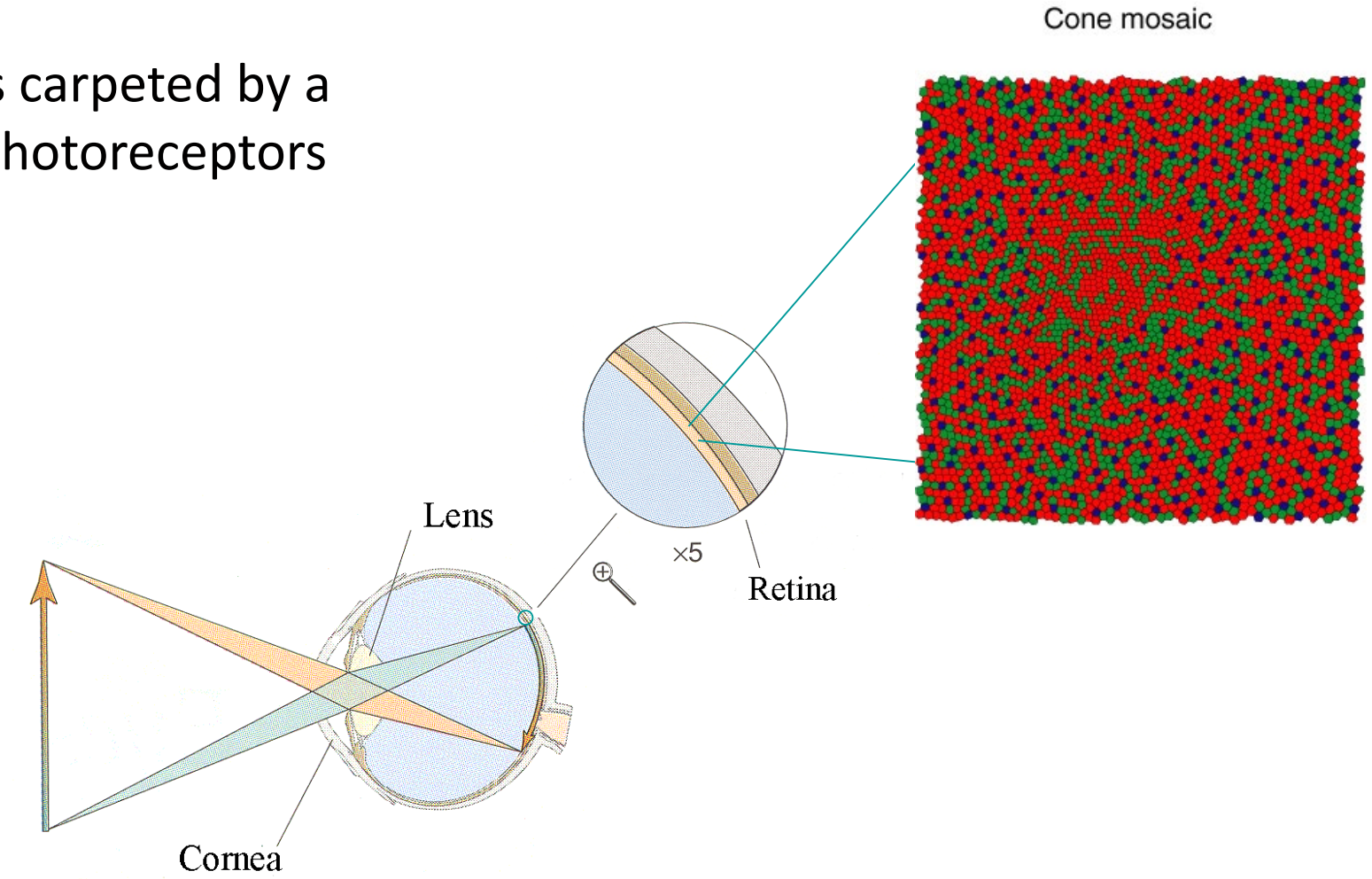
How do we see?

An image of an object is projected by the cornea and lens onto the rear surface of the eye: the retina.



How do we see?

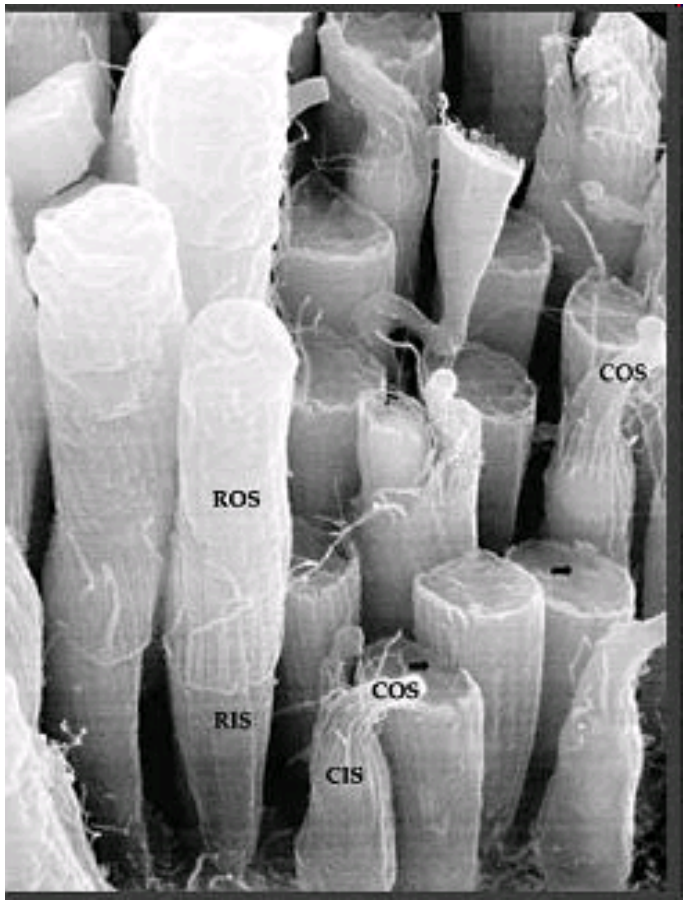
The back of the retina is carpeted by a layer of light-sensitive photoreceptors (rods and cones).



Retina

- An (accessible) part of the CNS
- About 60 identified cell types:
  - 4 Photoreceptors (+ ipRGCs)
  - 10 bipolar cells
  - 2 horizontal cells
  - 30? amacrine cells
  - 10? ganglion cells

Photoreceptors

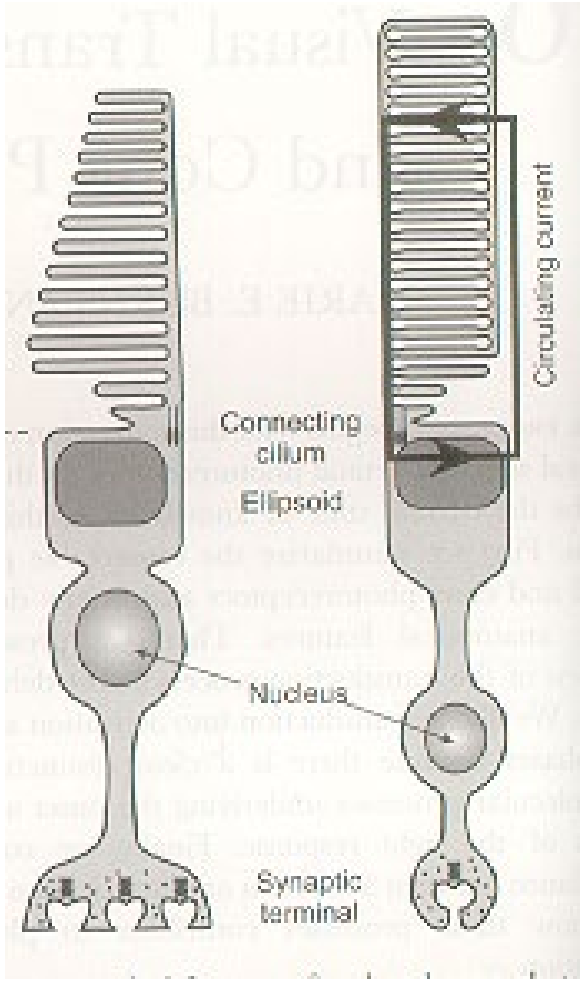


Electron-micrograph 800 ×

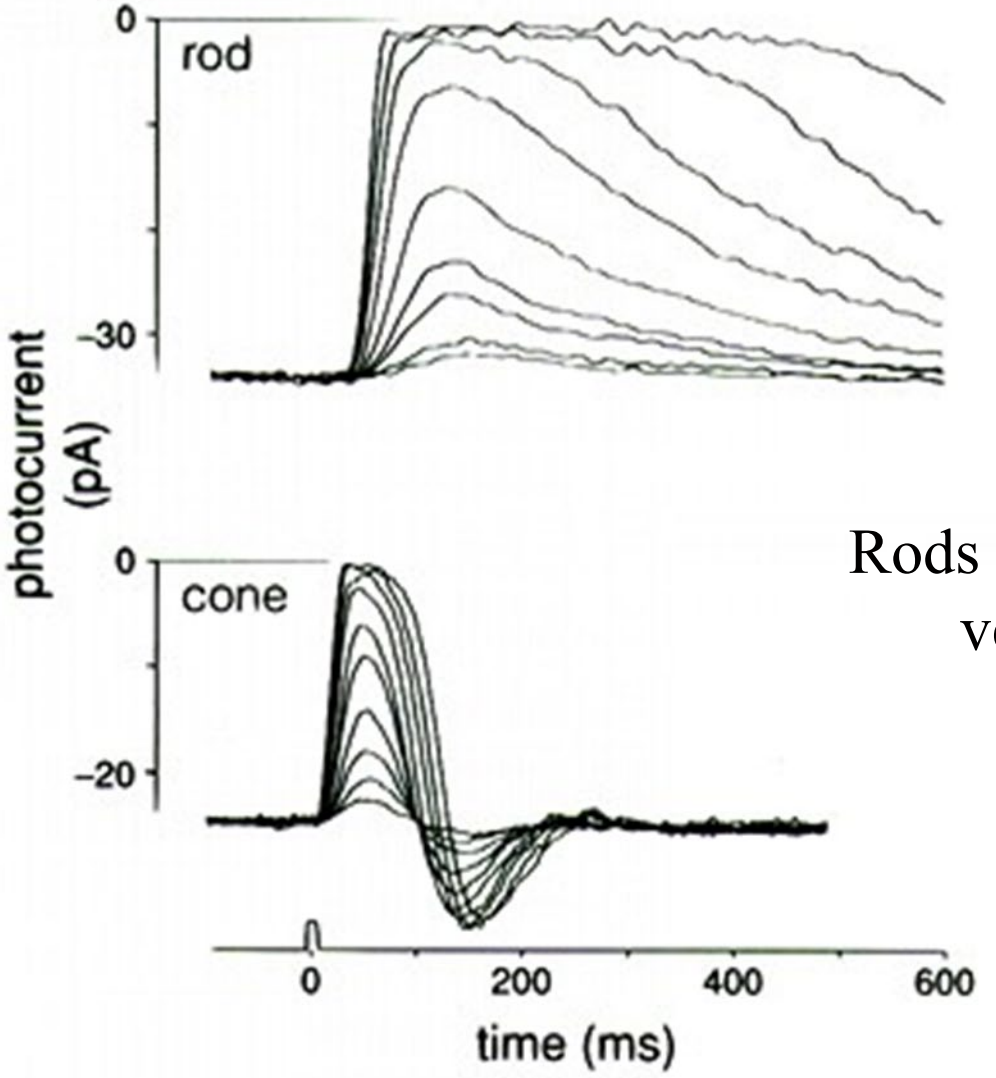
cone

rod

inner segment | outer segment



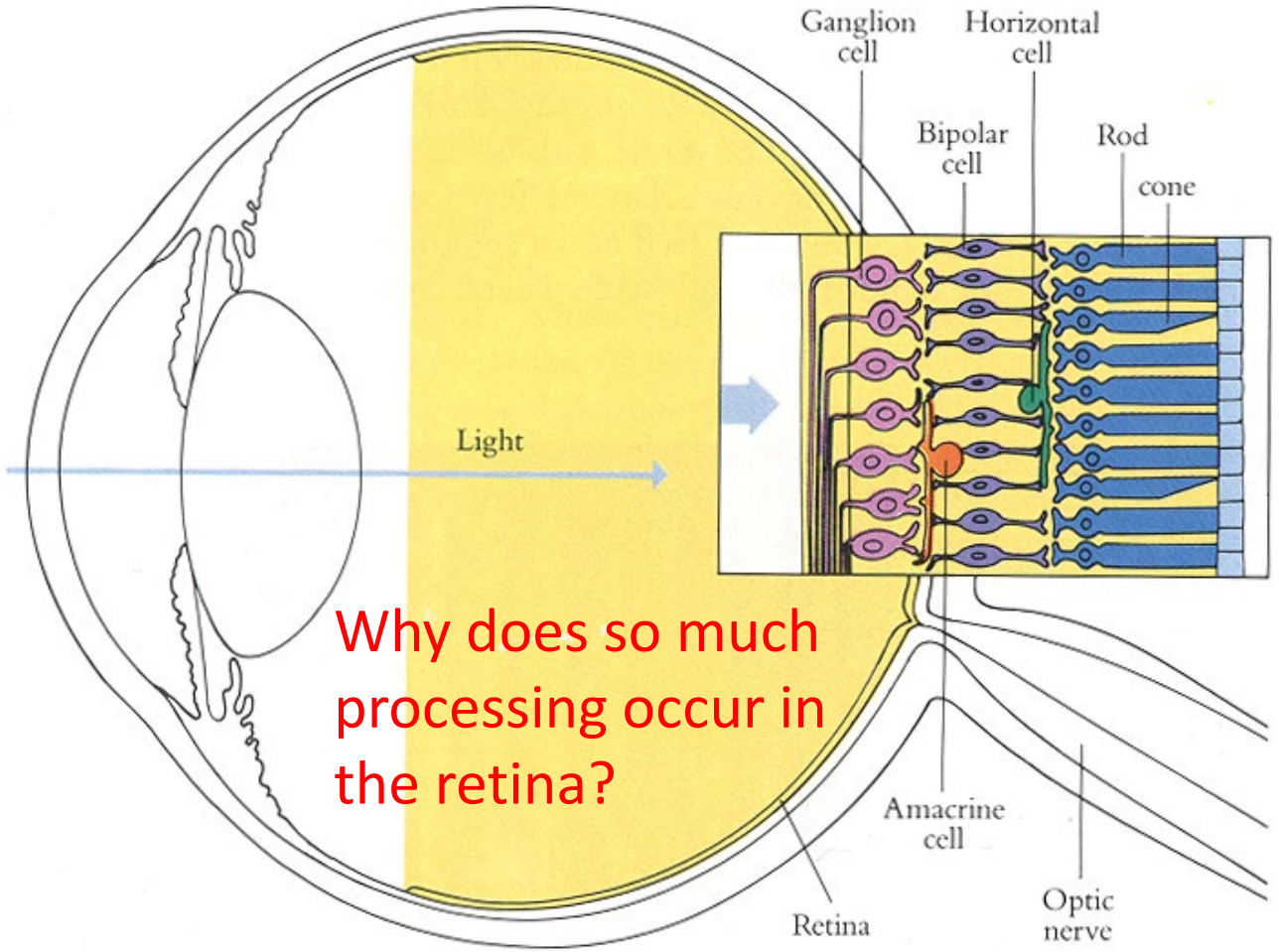
Initial encoding



Rods and cones respond very differently

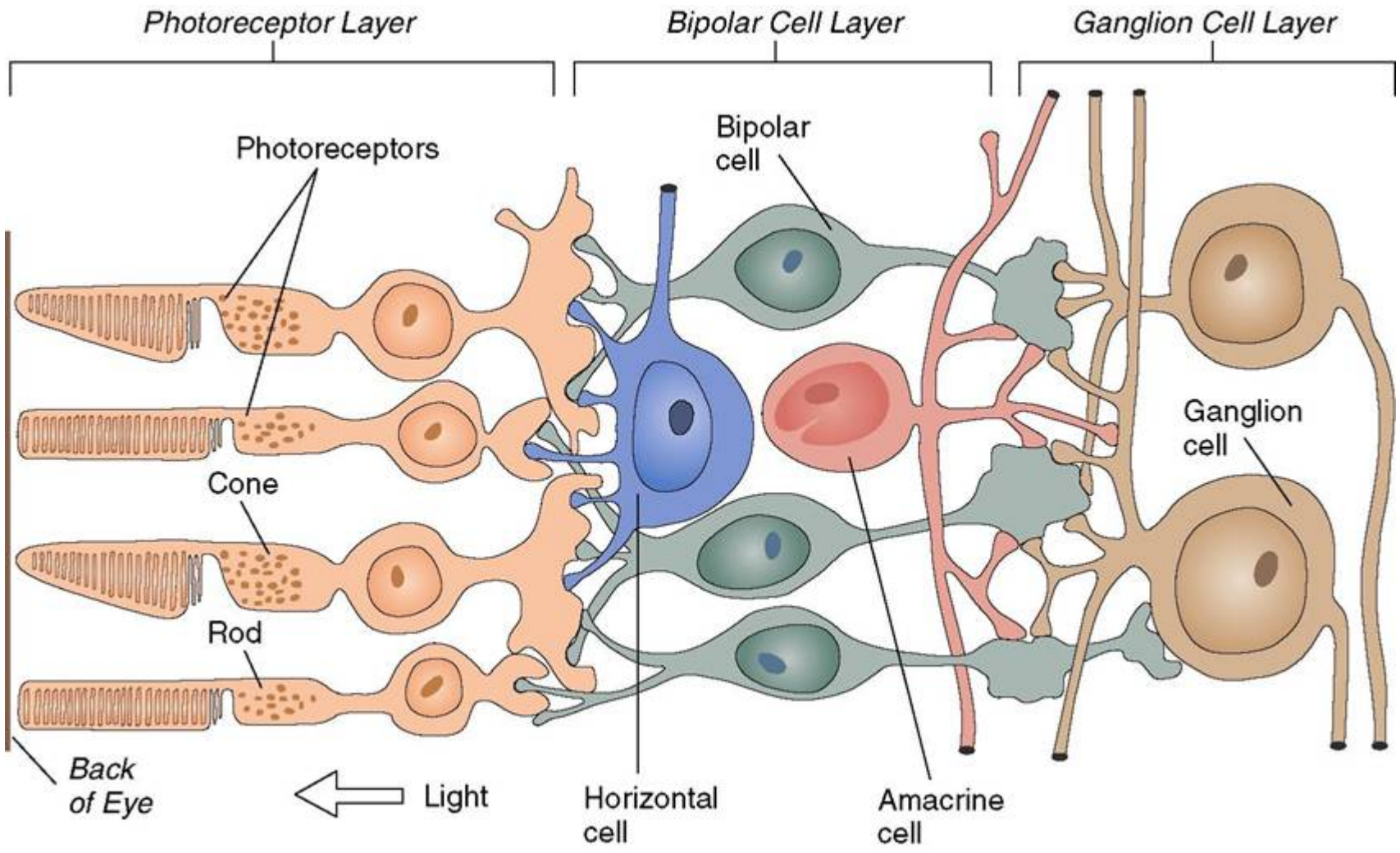
source: Baylor, 1987

Other retinal cells



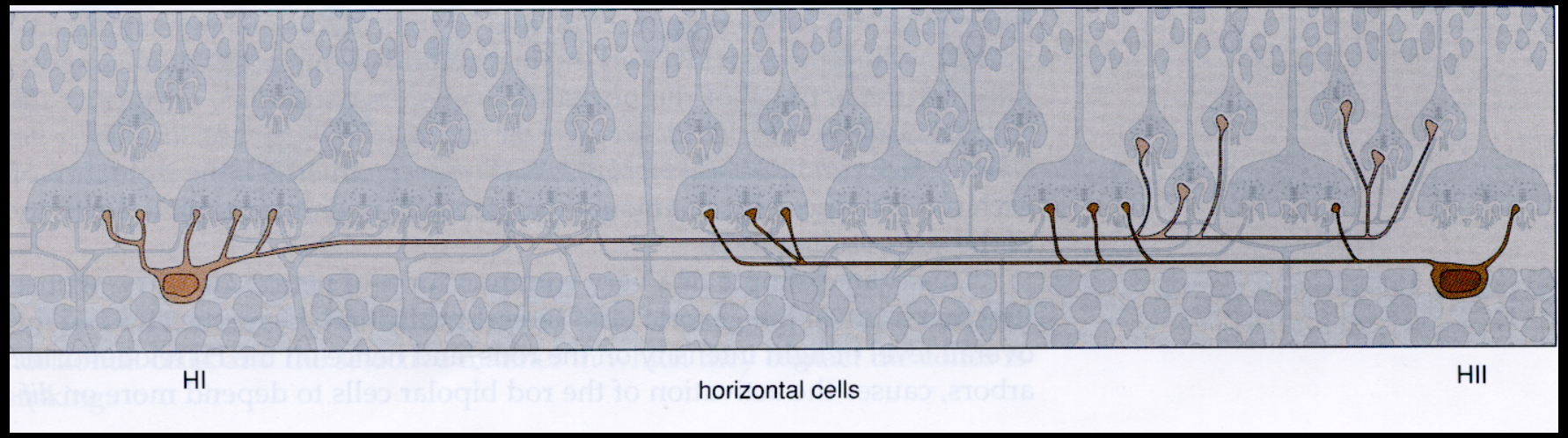
Why does so much processing occur in the retina?

Main cell types in retina



Horizontal cells

Lateral interactions

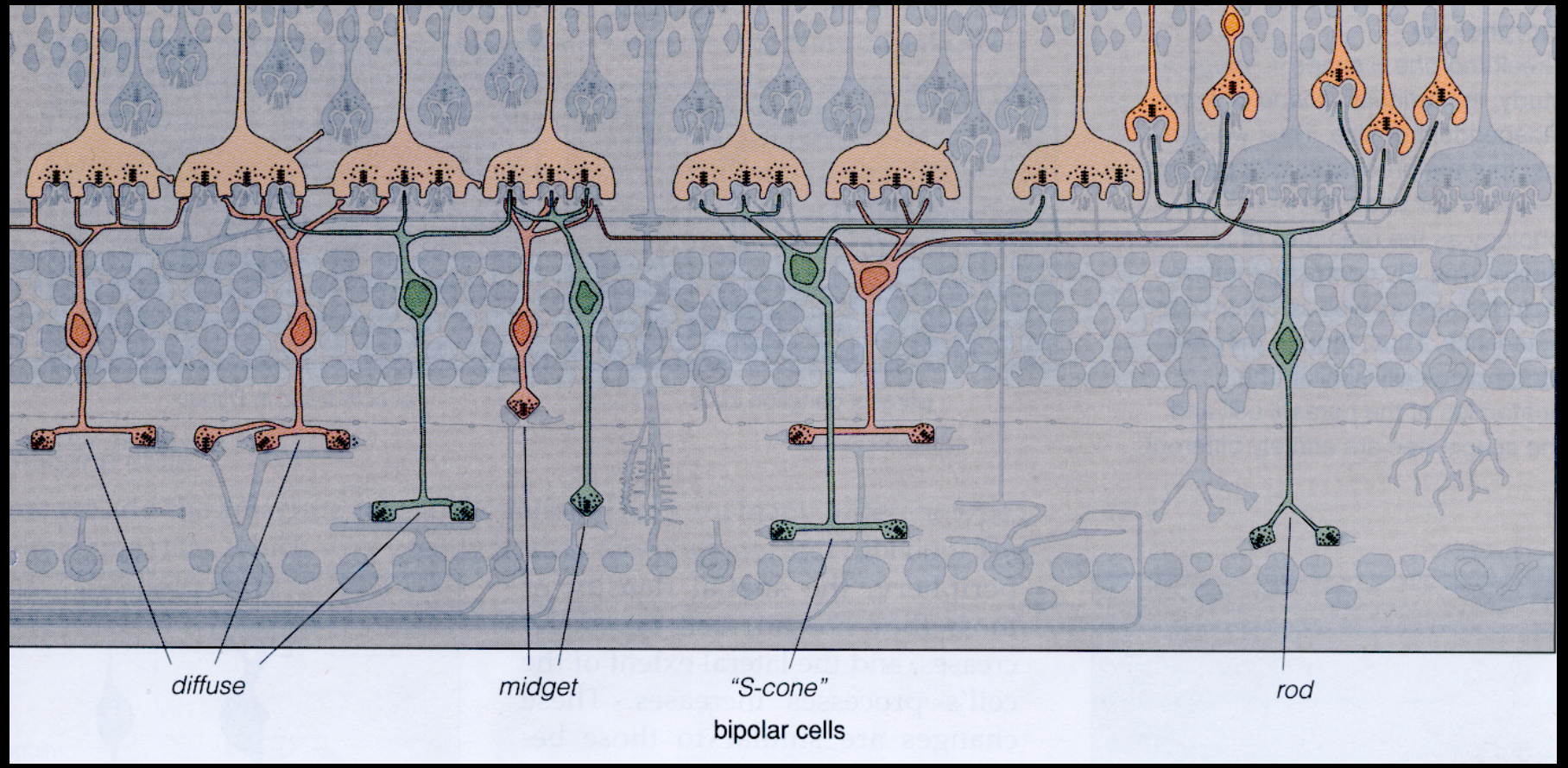


What sort of processing can be achieved by lateral interactions?

From Rodieck (1998)

Bipolar cells

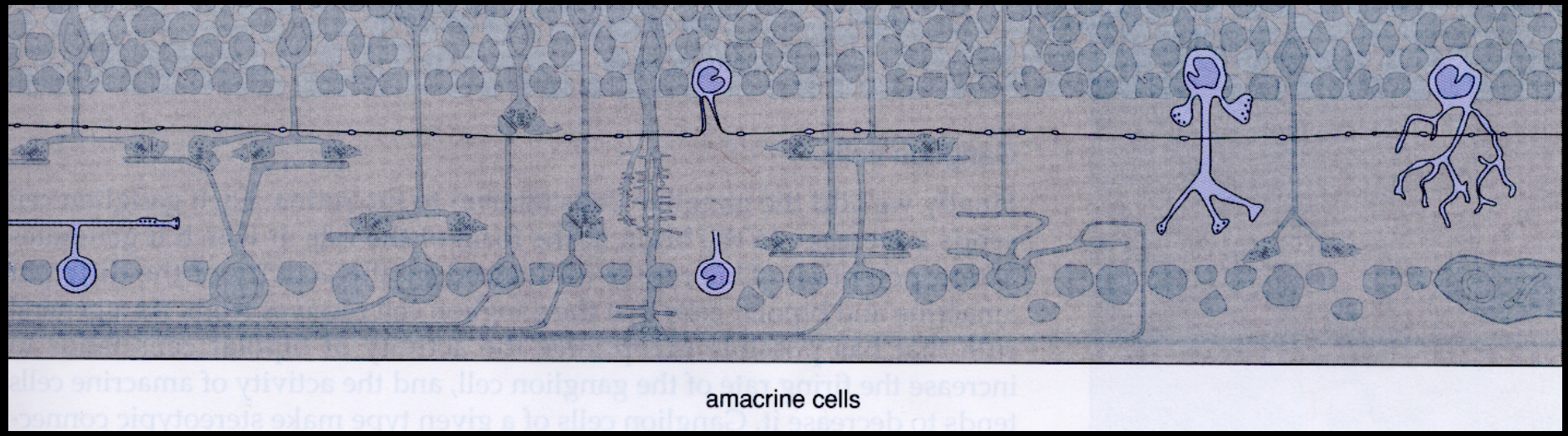
ON (green shading) and
OFF (red shading) varieties



Parallel processing?

From Rodieck (1998)

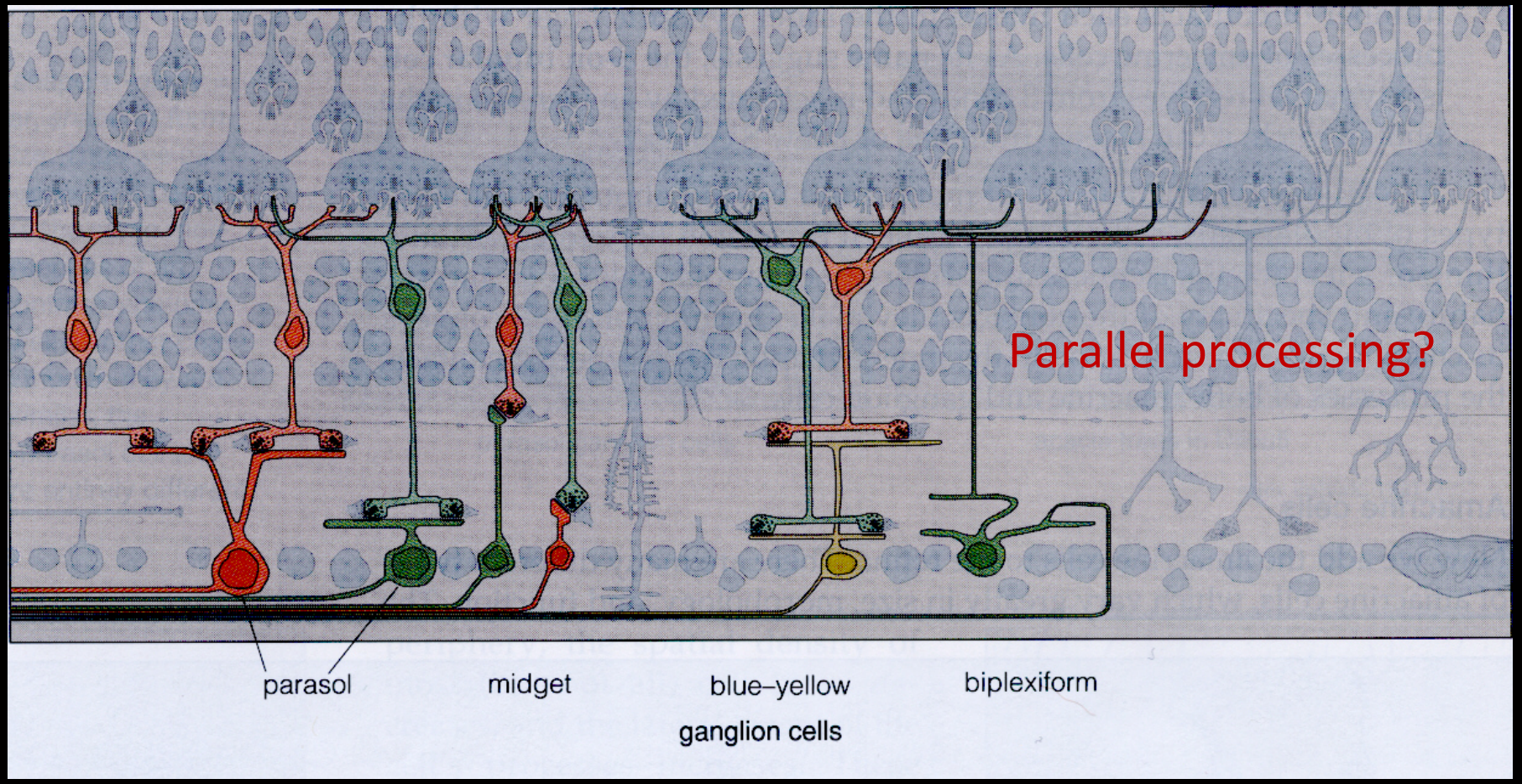
Amacrine cells



From Rodieck (1998)

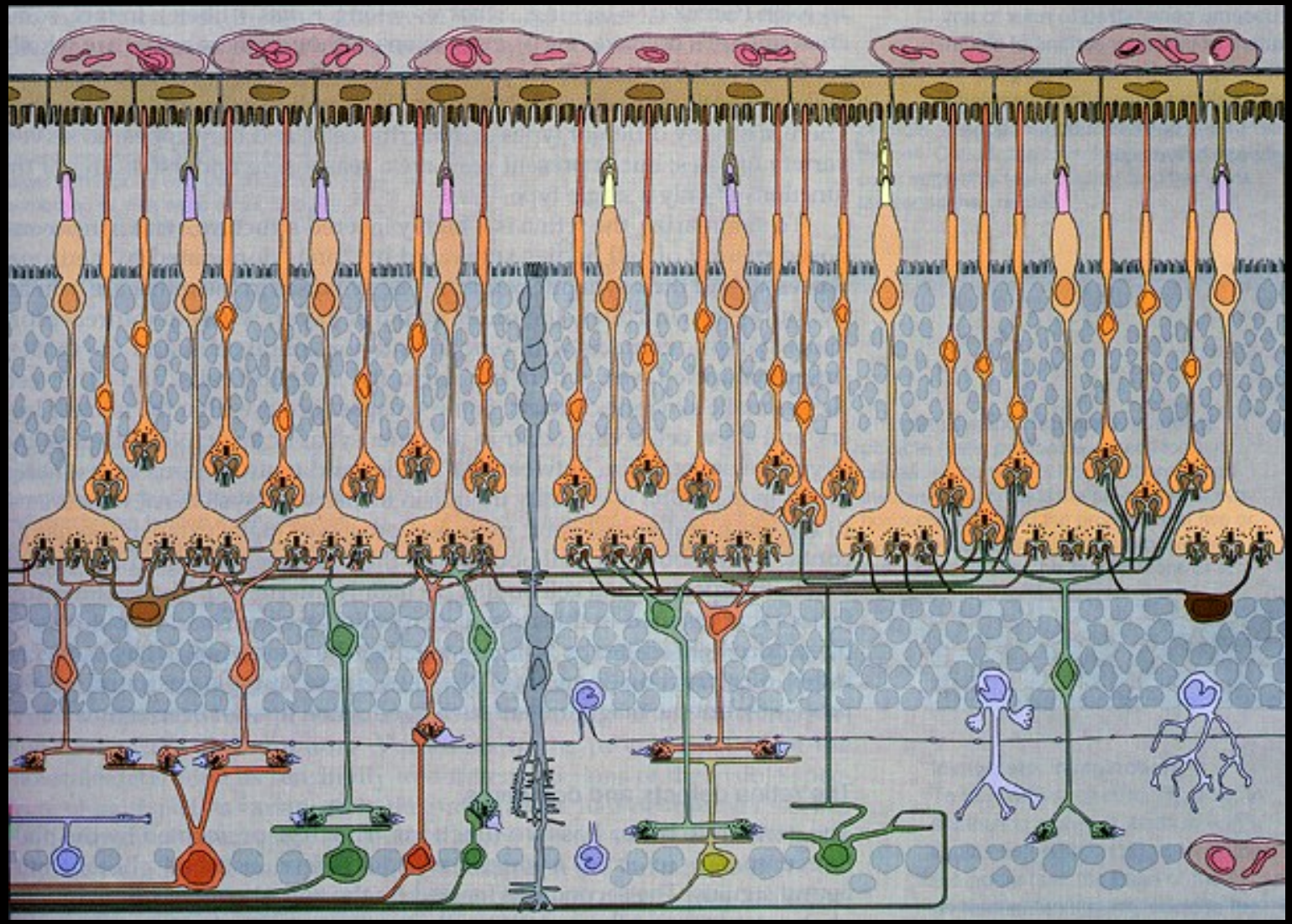
Ganglion cells

ON and OFF varieties



From Rodieck (1998)

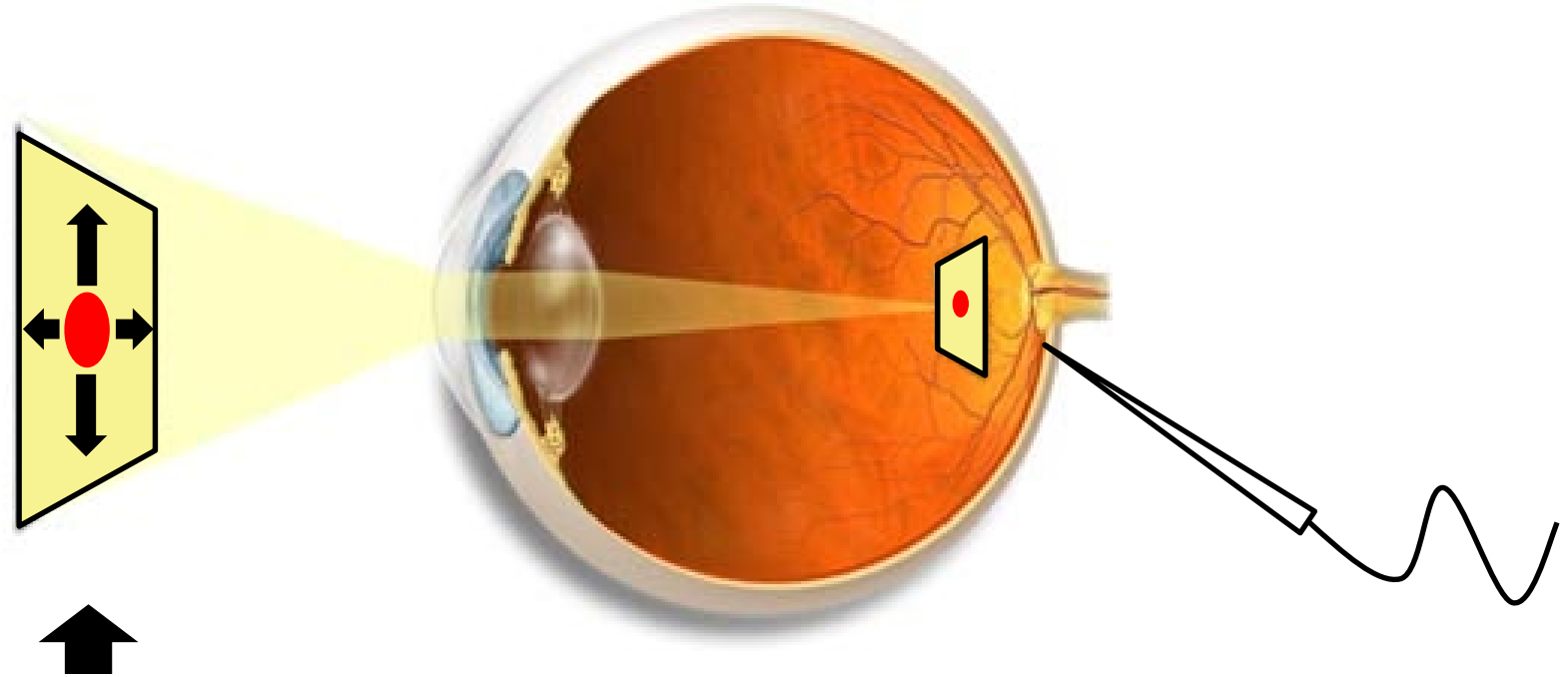
Overview



From Rodieck (1998)

Receptive field

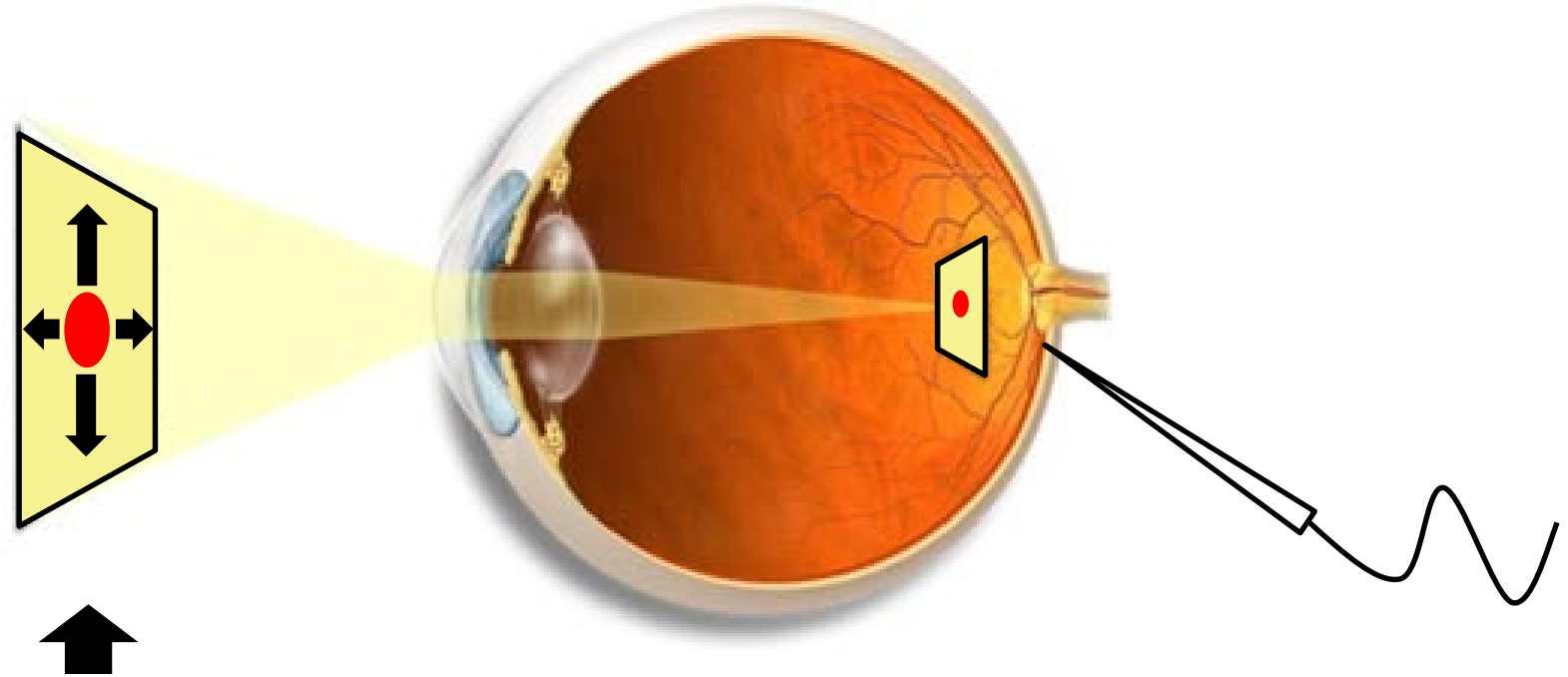
We can investigate what a cell encodes by recording its response to visual stimulation and so “map” its receptive field



Find the area in visual space to which the cell responds.

Receptive field

We can investigate what a cell encodes by recording its response to visual stimulation and so “map” its receptive field



And find out which types of stimuli optimally stimulate the cell.

Neural codes and signal processing

Early measurements

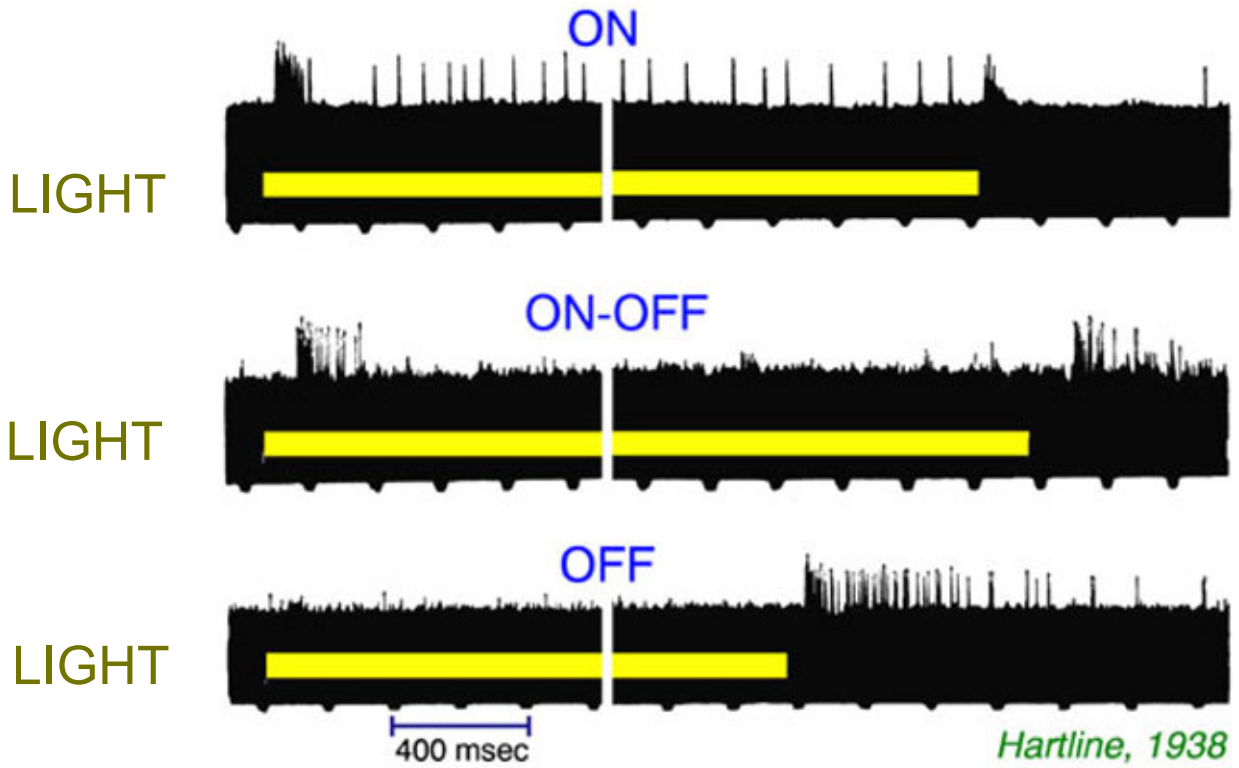
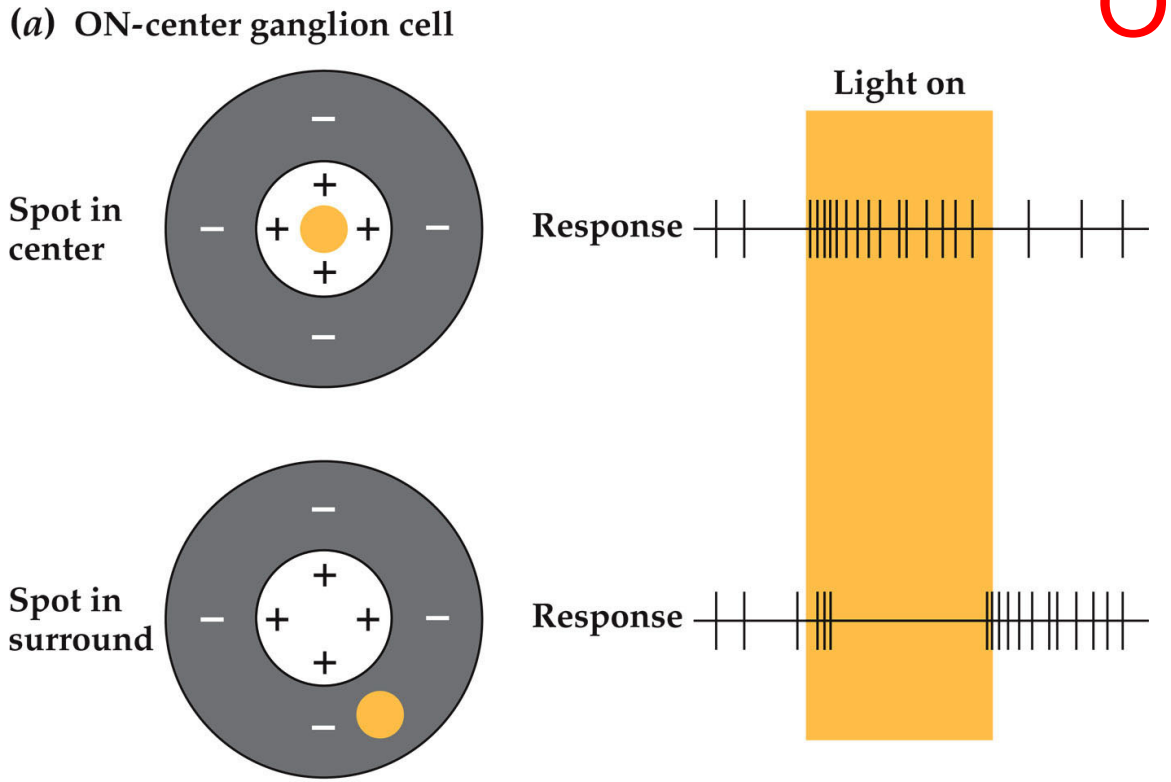


Fig. 3. ON, OFF and ON-OFF ganglion cells (after Hartline, 1938; 1967).

Neural codes and signal processing (centre-surround)

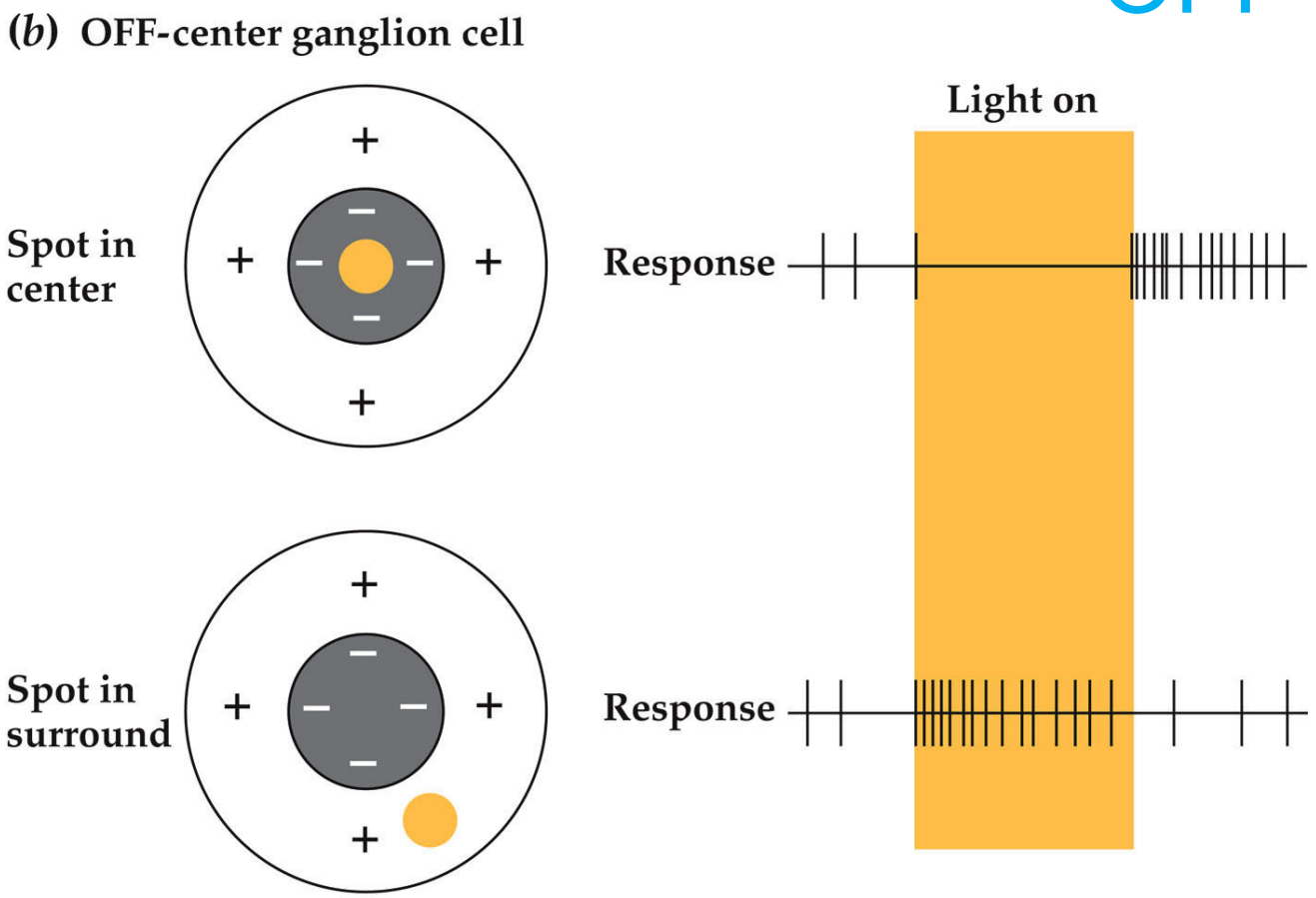
ON cell



SENSATION & PERCEPTION 3e, Figure 2.14 (Part 1)

Neural codes and signal processing (centre-surround)

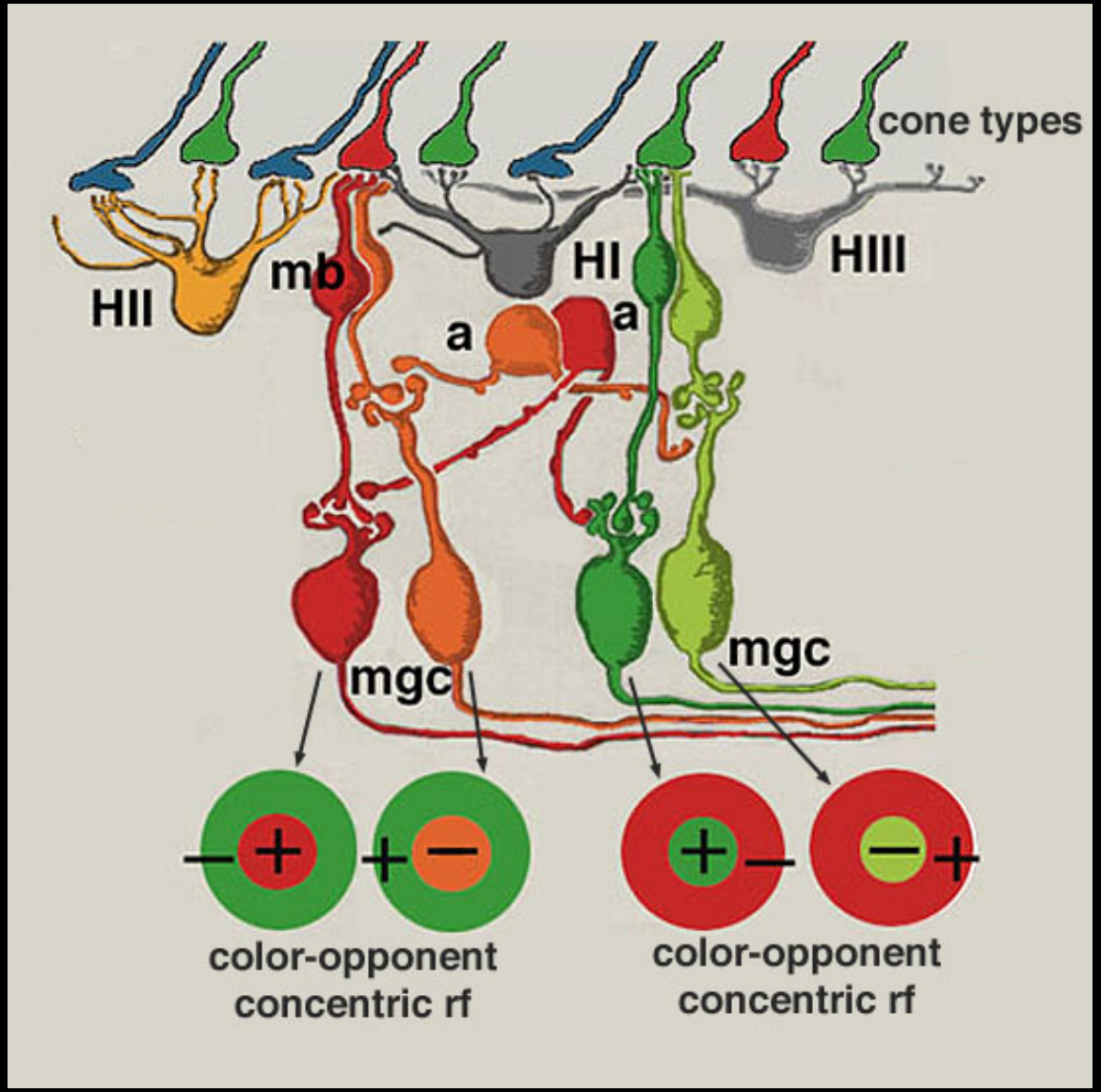
OFF cell



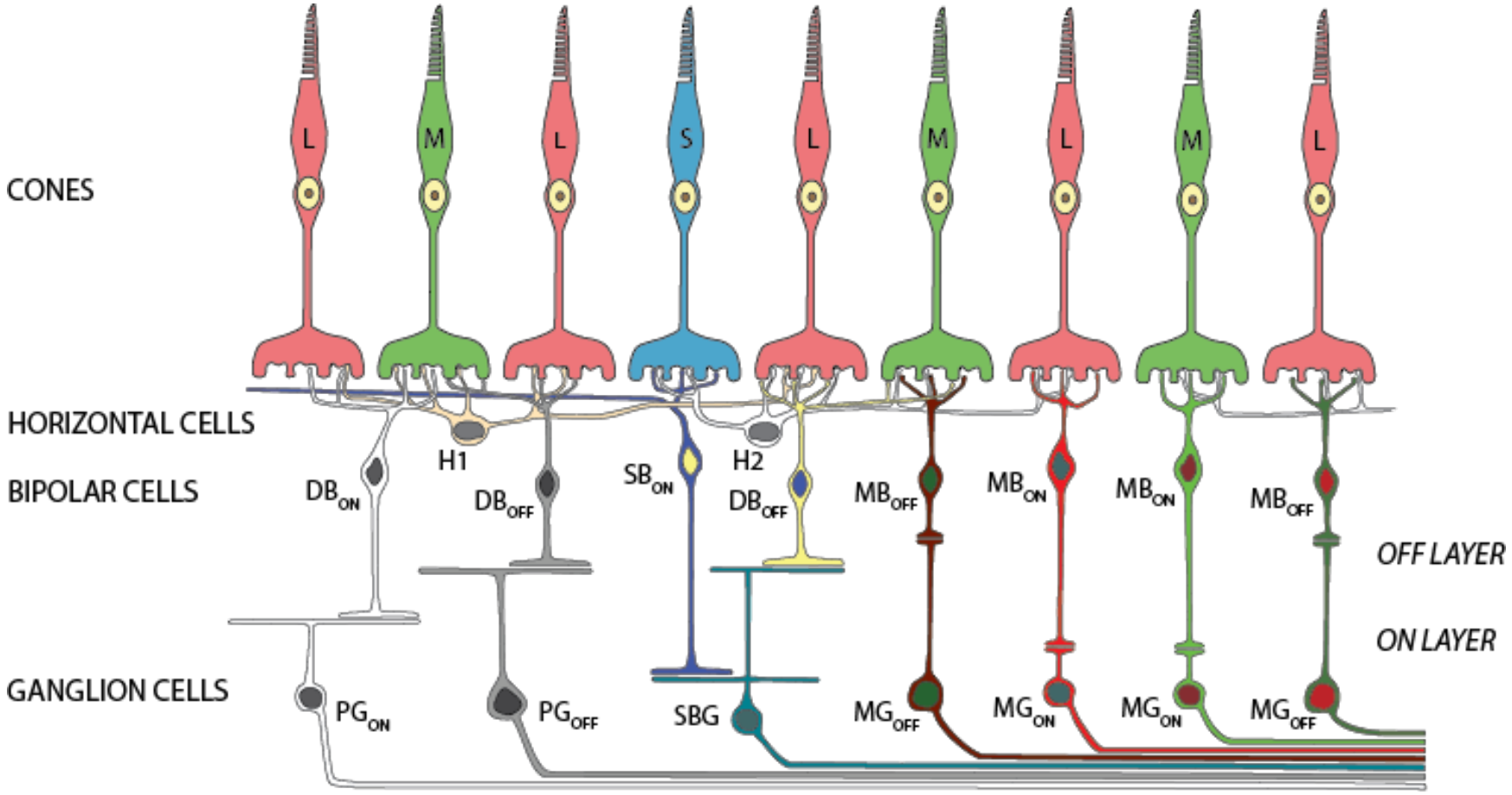
SENSATION & PERCEPTION 3e, Figure 2.14 (Part 2)

Colour coding

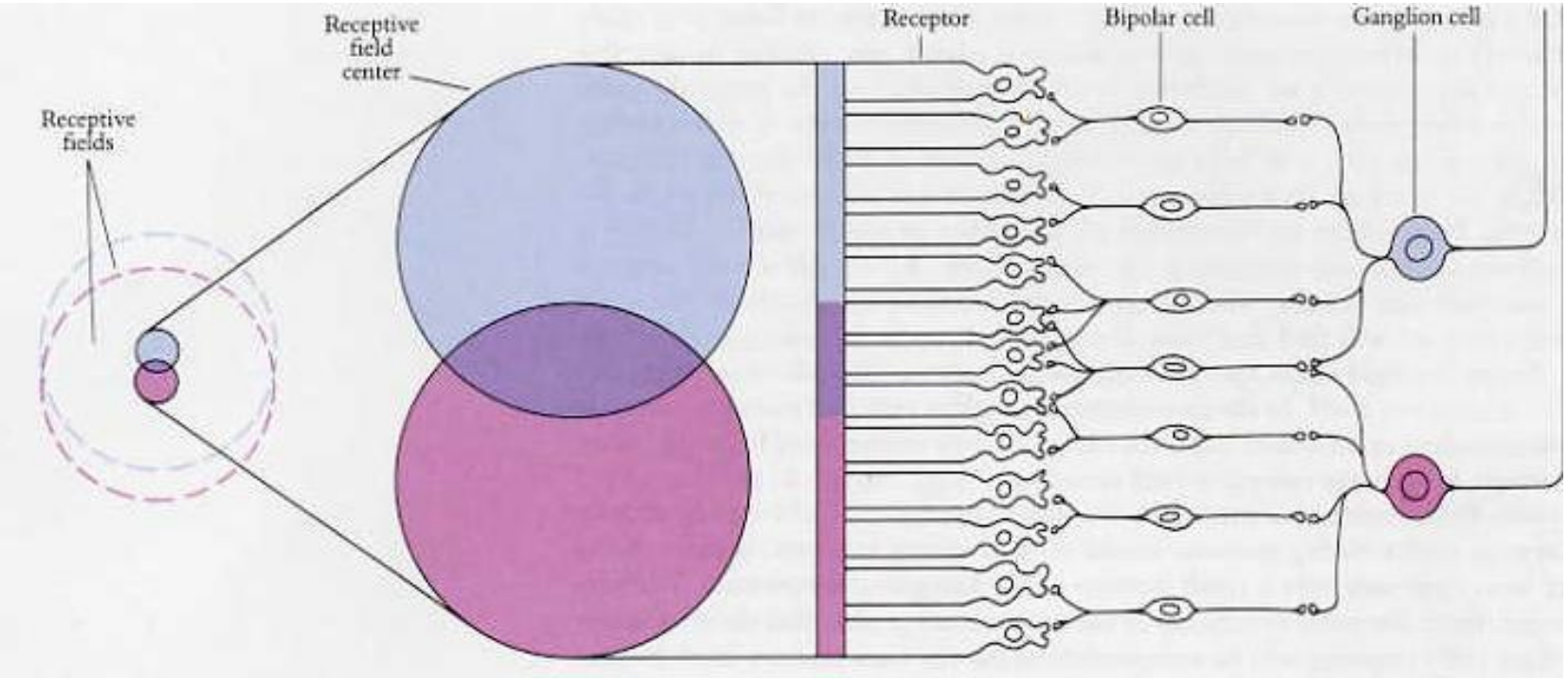
Red-green colour opponency



Parallel and serial processing in the retina

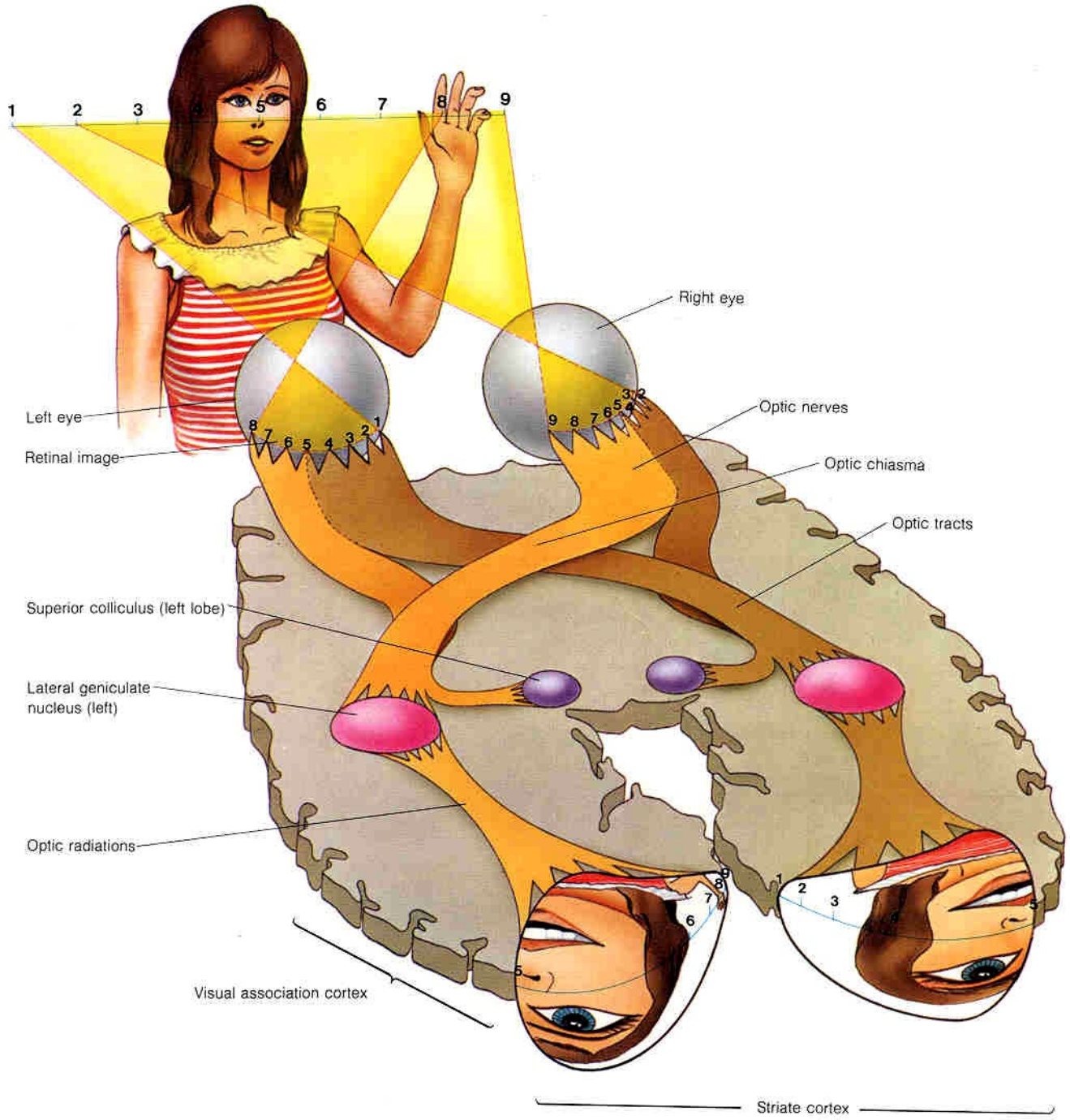


Retinotopic maps

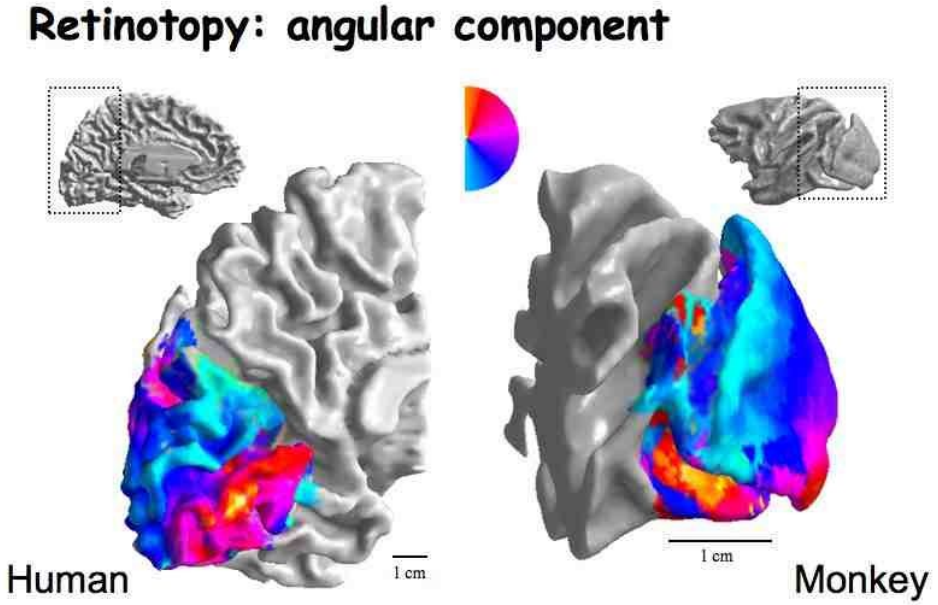


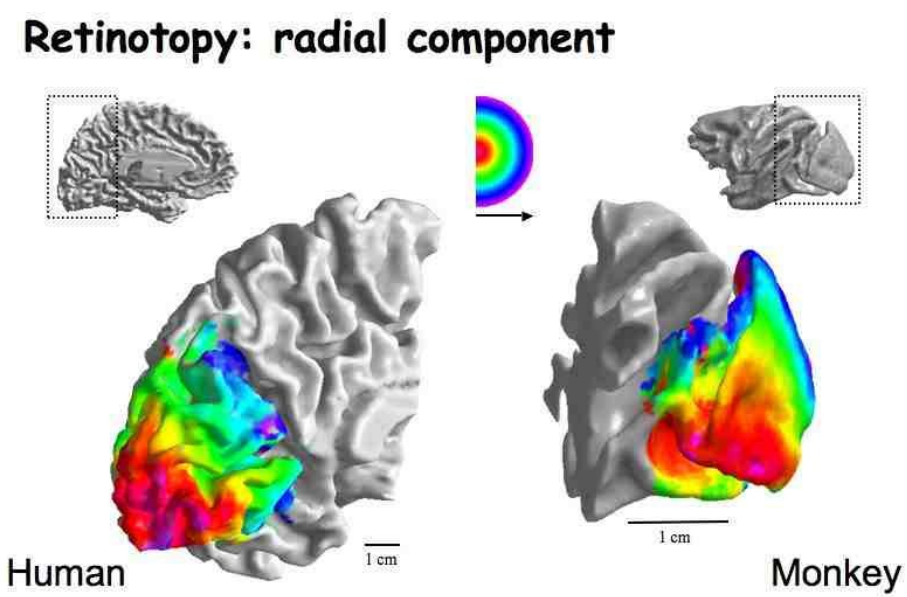
David Hubel

Retinotopic maps



Retinotopic maps





David Heeger

Neural Coding

Johannes Peter Müller (1801-1858)

Law of Specific Nerve Energies

Stimulation by any cause has the same effect.

Neurons code information by virtue of their connections not their biological structure.

For example, electrical stimulation of your auditory nerve will cause you to hear sounds. Pressure applied to the eye causes phospenes.

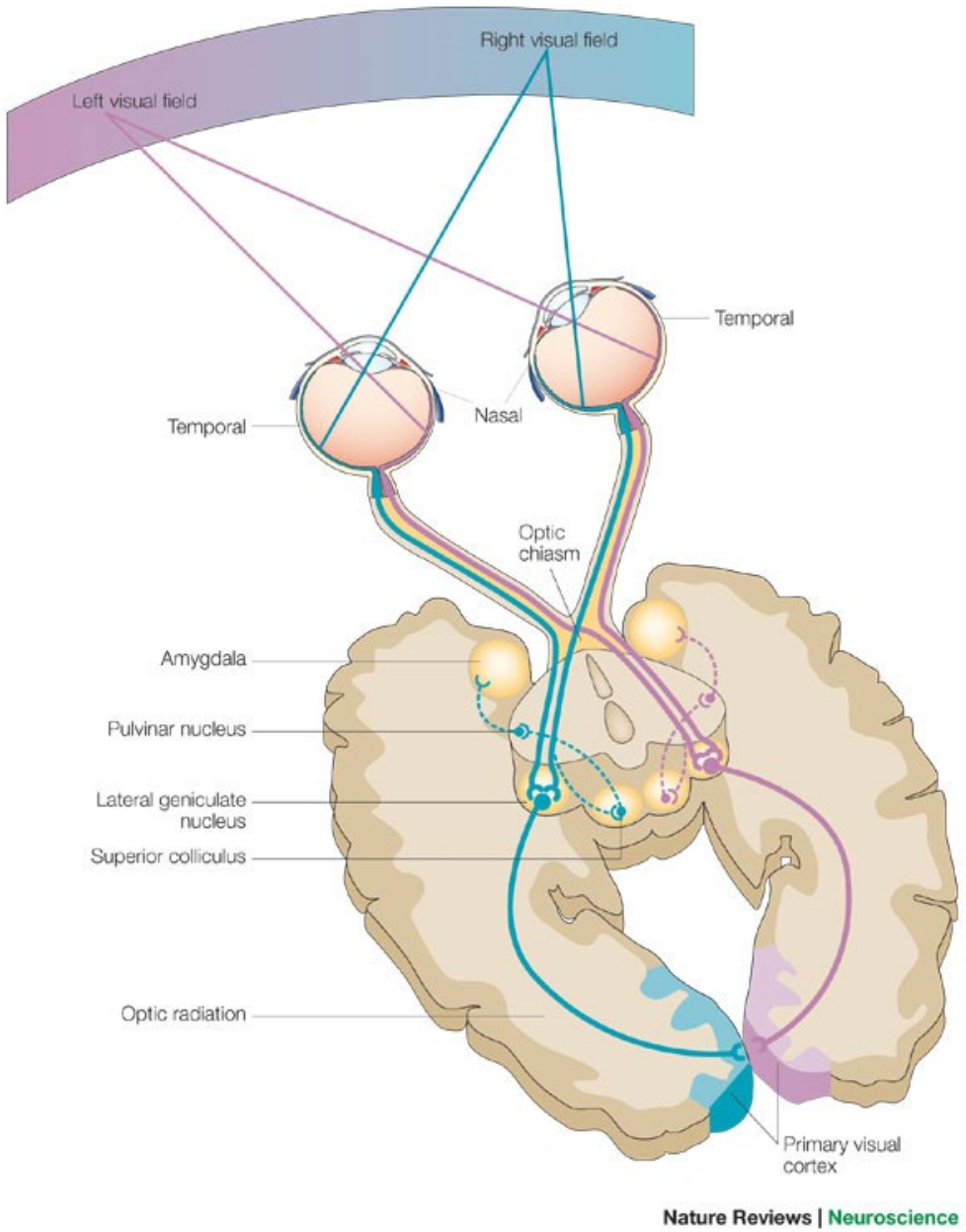
Electrical stimulation of human cortex during neurosurgery causes hallucinatory perceptions (Penfield experiments).

Neural Coding

- Single neurons represent sensory stimulus parameters with their rate or timing of action potential firing.
- Will fire more spikes to some stimuli than others.
- Information might be contained in timing of spikes.
- Relationship between stimulus parameters and neural responses is called the **neural code**

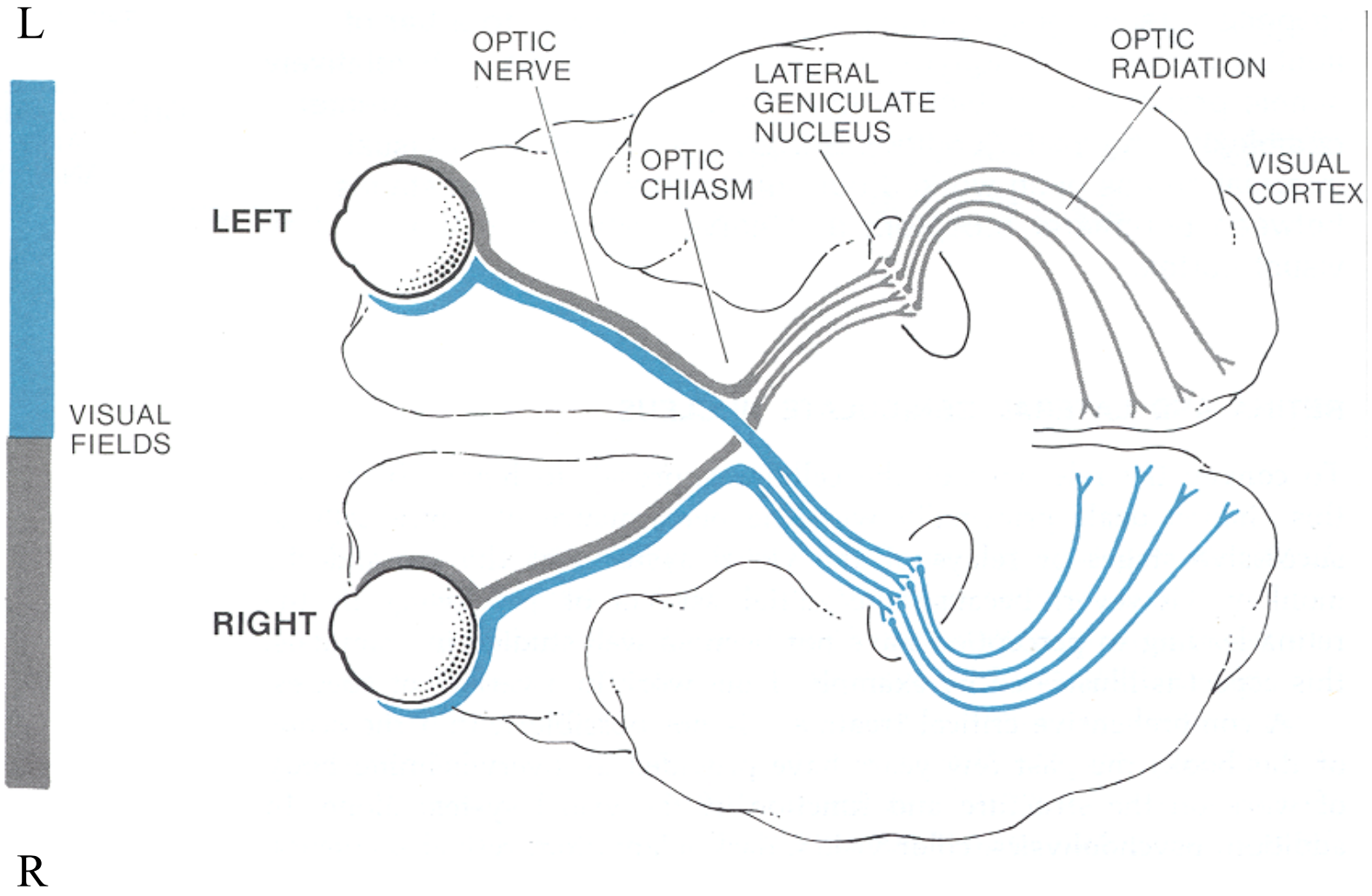
From retina to brain…

Geniculo-striate pathway



Hannula, Simons & Cohen, 2005

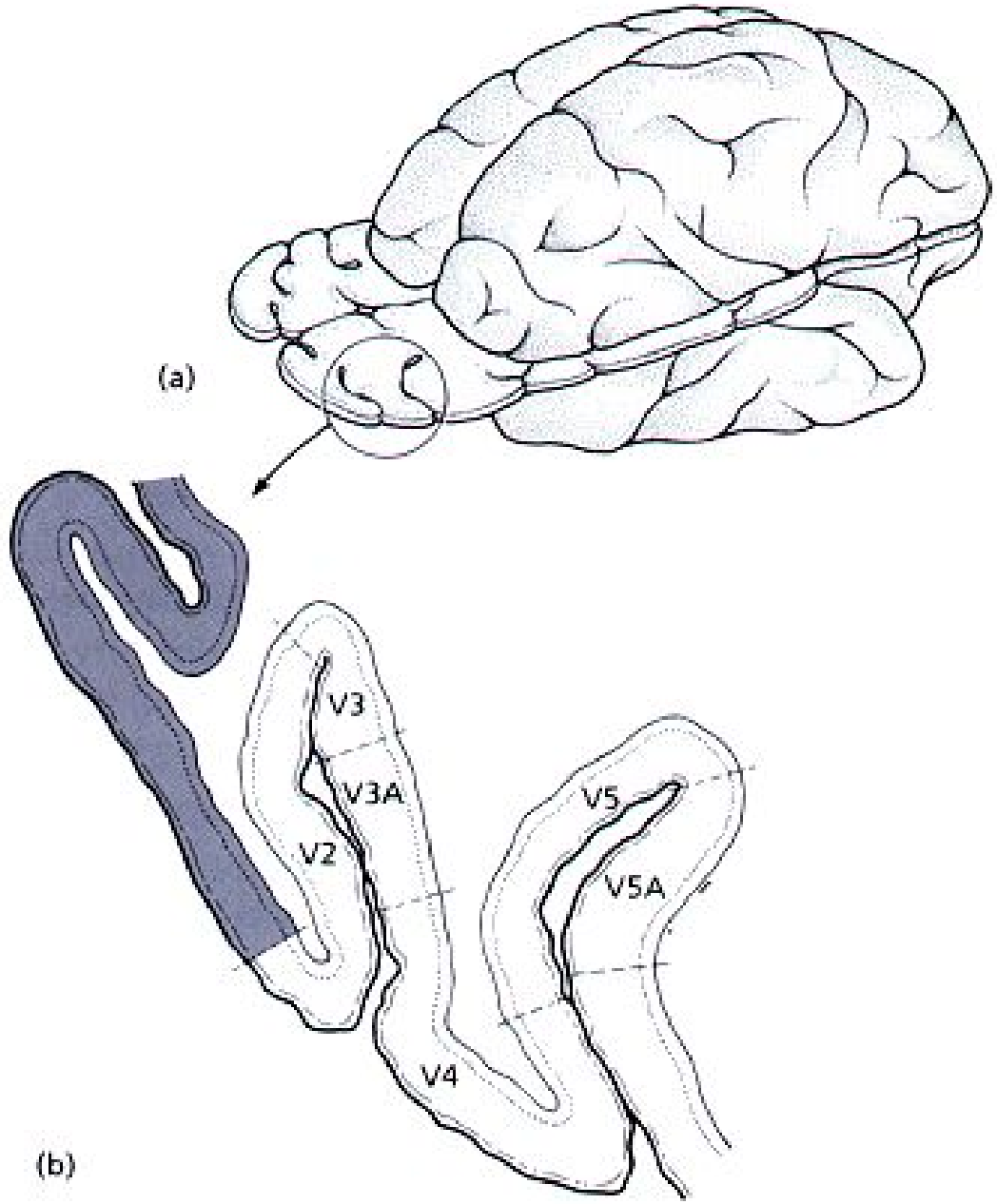
Visual pathways



From below

Cortical level

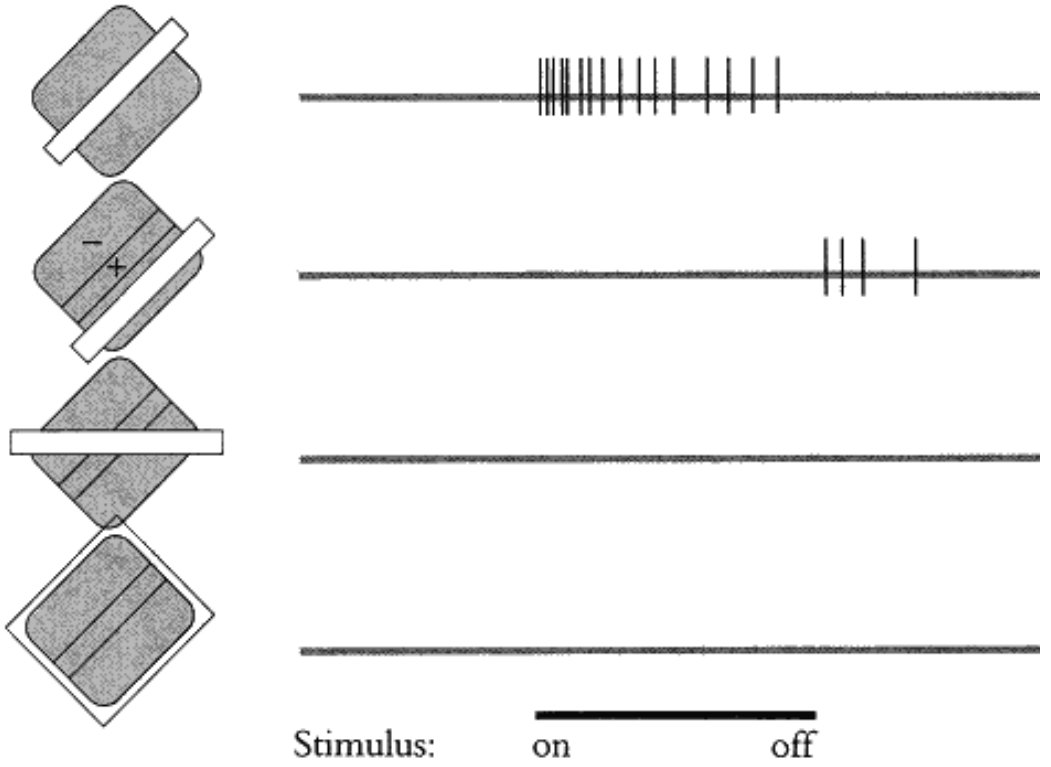
V1-V5



Neural codes and signal processing

Simple cells

V1, layers 4 & 6

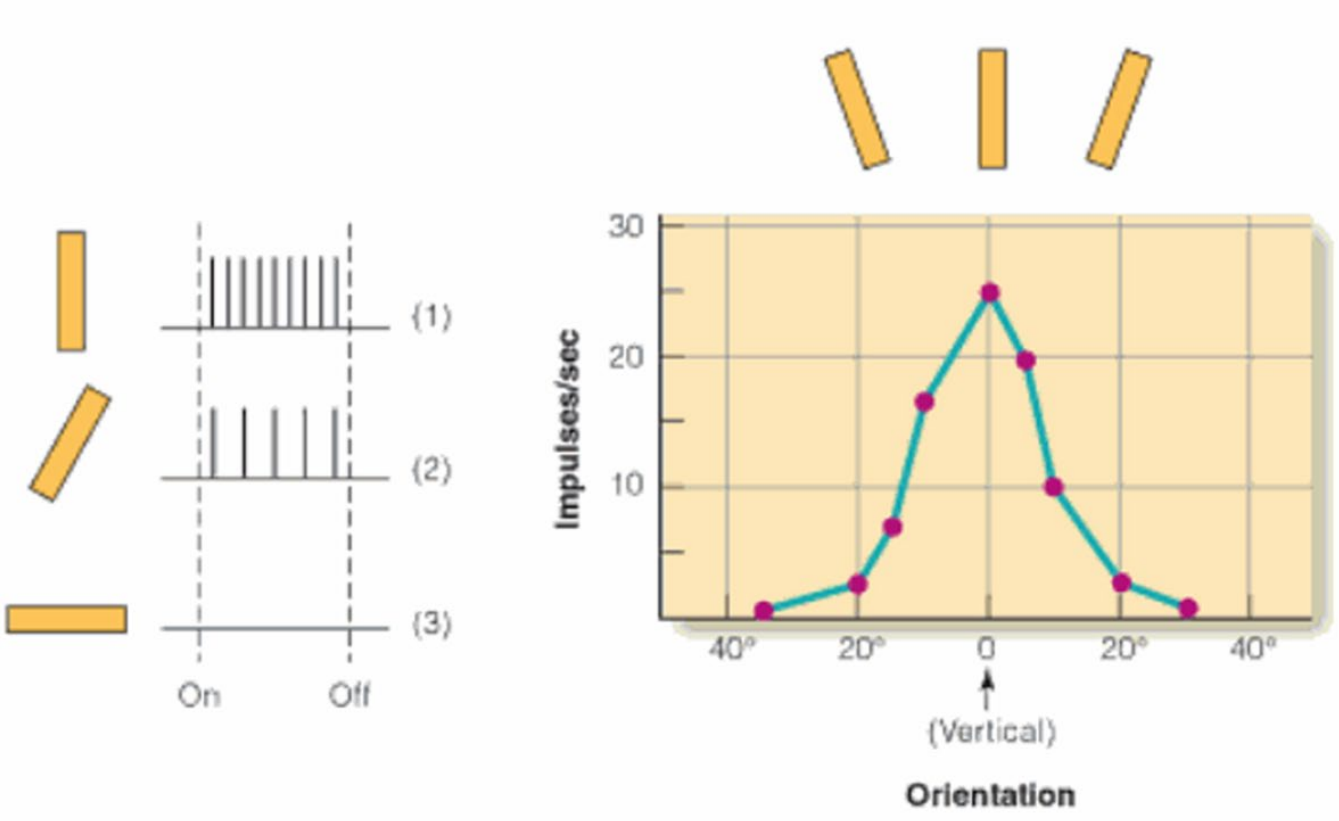


Simple cells have narrow, elongated excitatory and inhibitory zones that have a specific orientation. These cells are “line detectors”. Their receptive fields can be built from the convergent connections from lateral geniculate nucleus cells.

Neural codes and signal processing

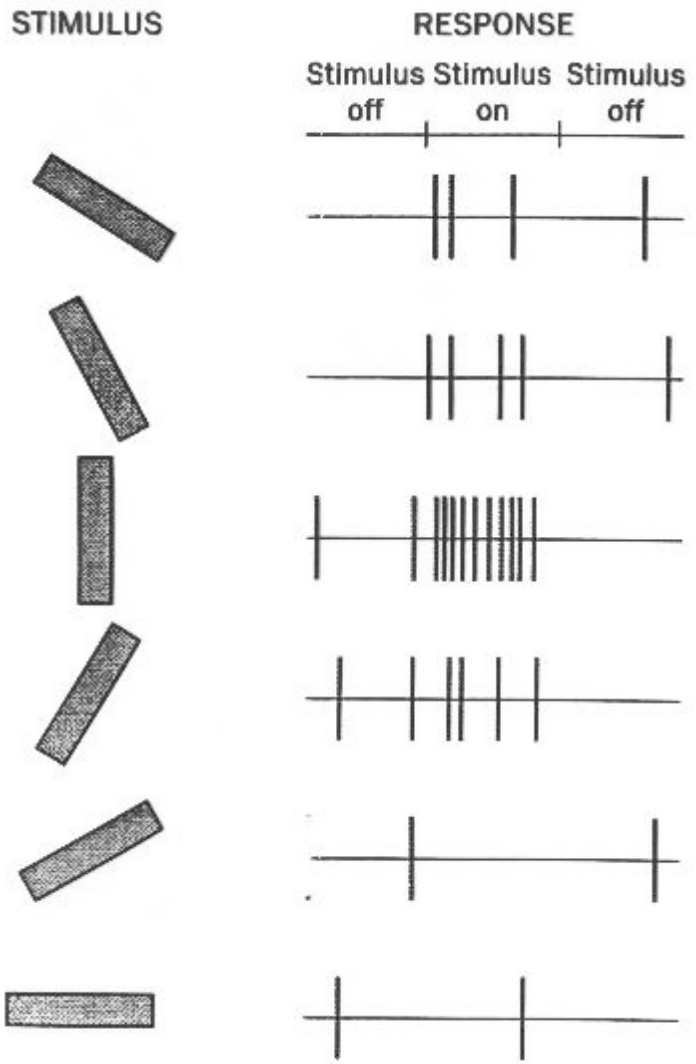
A **tuning curve** relates the response of a neuron to varied stimulus parameters.

Feature extraction: orientation



Neural codes and signal processing

V1 – primary visual cortex



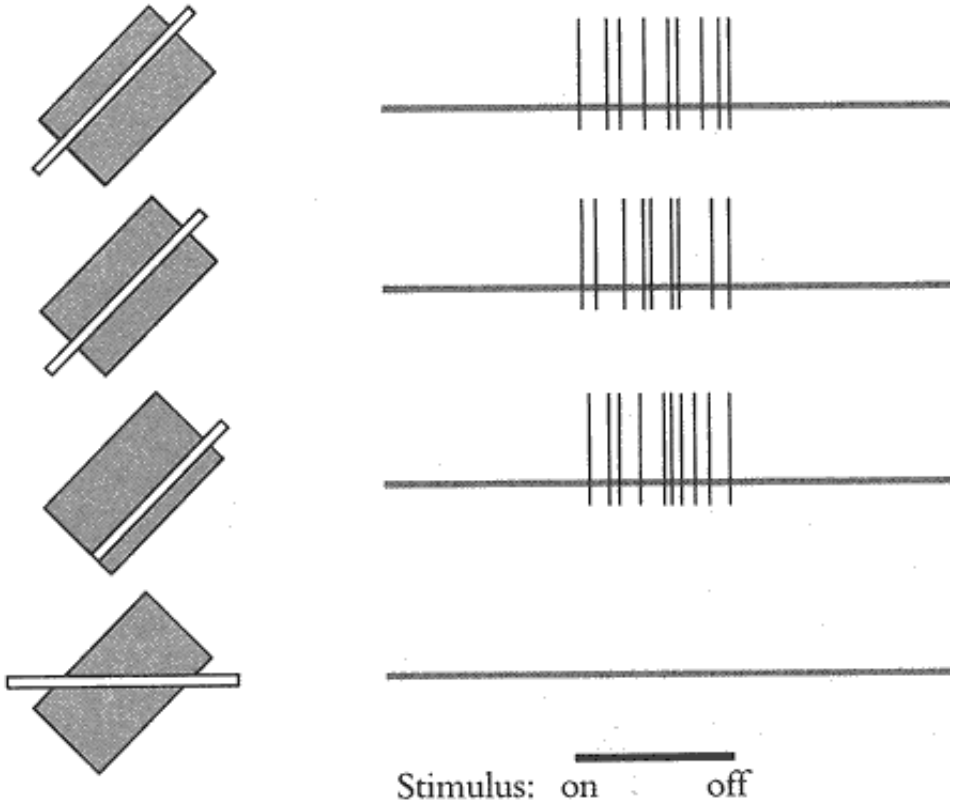
Simple cells

Feature extraction: orientation

Neural codes and signal processing

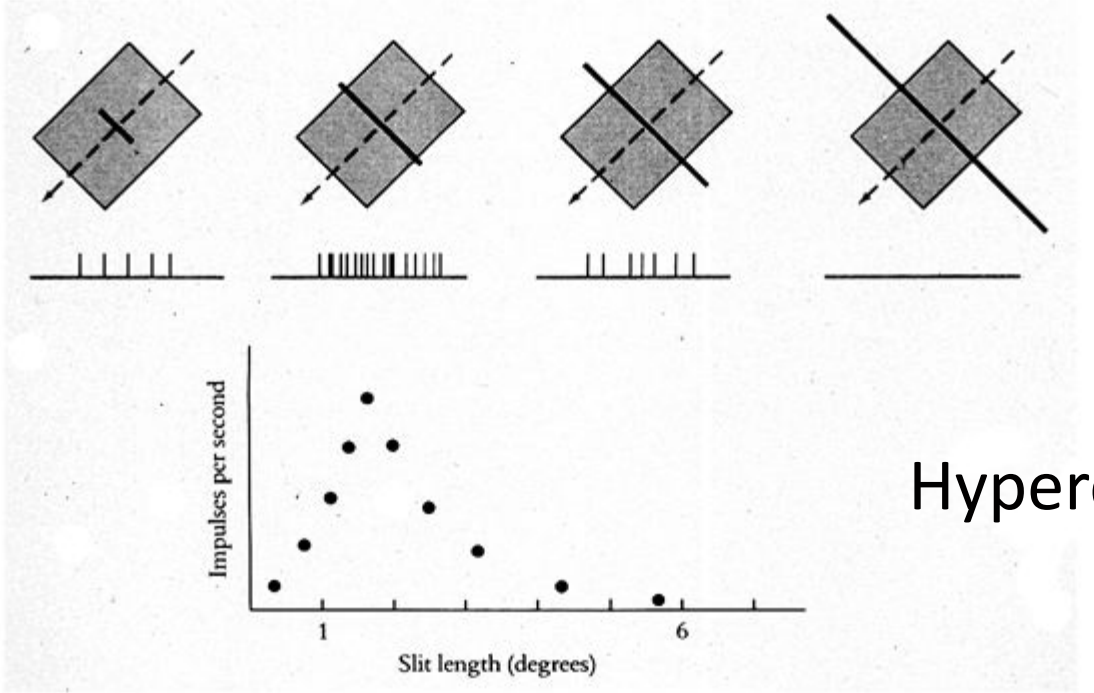
Complex cells

V1, layers 2, 3 & 5



Complex cells have large receptive fields without clear excitatory or inhibitory zones. They respond best to a moving edge of specific orientation and direction of motion. They are powerful “motion detectors”. Their receptive fields could be built from the convergent connections of simple cells.

Neural codes and signal processing



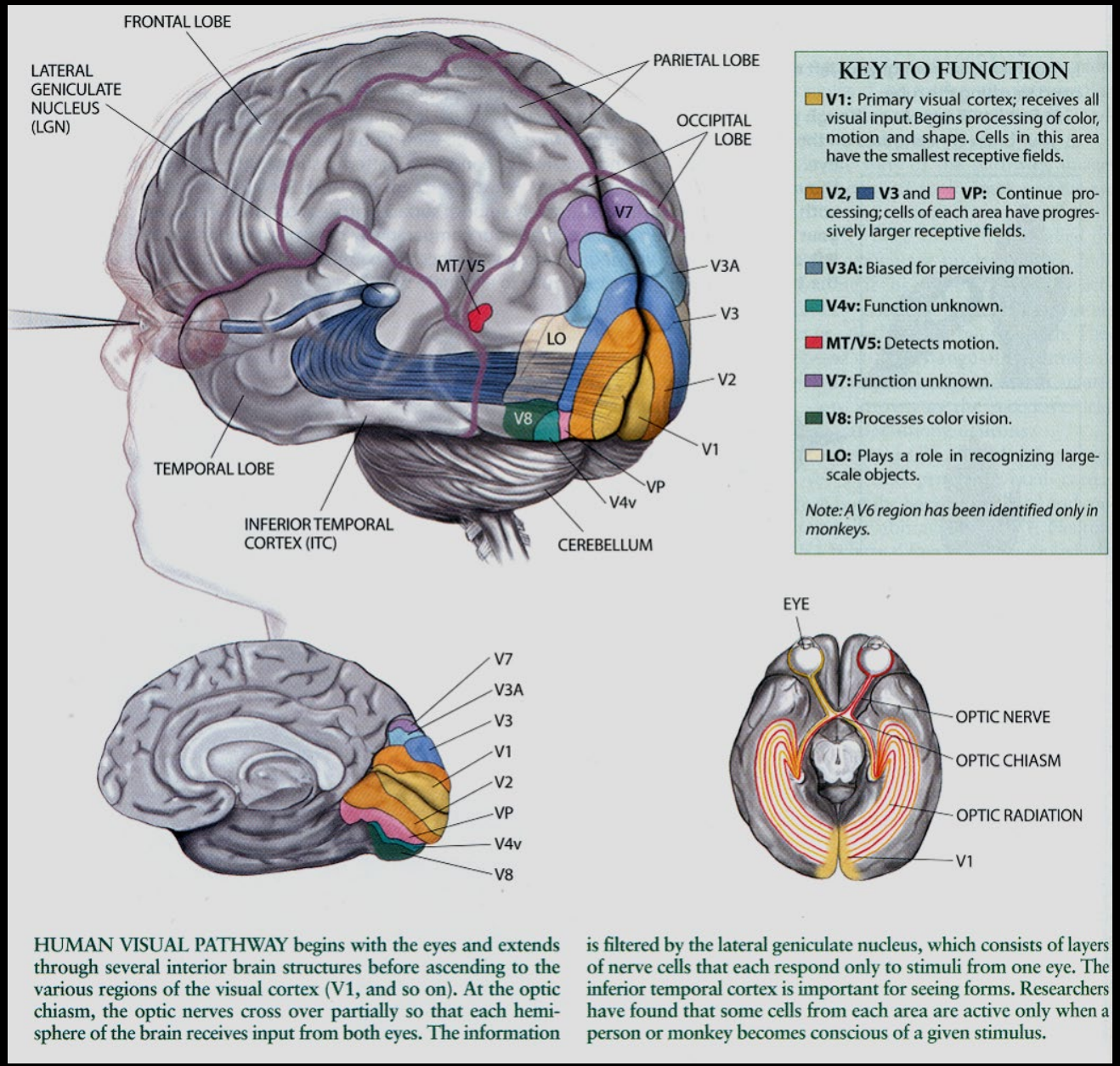
Hypercomplex cells

www.cns.nyu.edu

Hypercomplex cells are like complex cells except for inhibitory flanks on the ends of the receptive field, so that response increases with increasing bar length up to some limit, but is then inhibited. This property is called *end-stopping*.

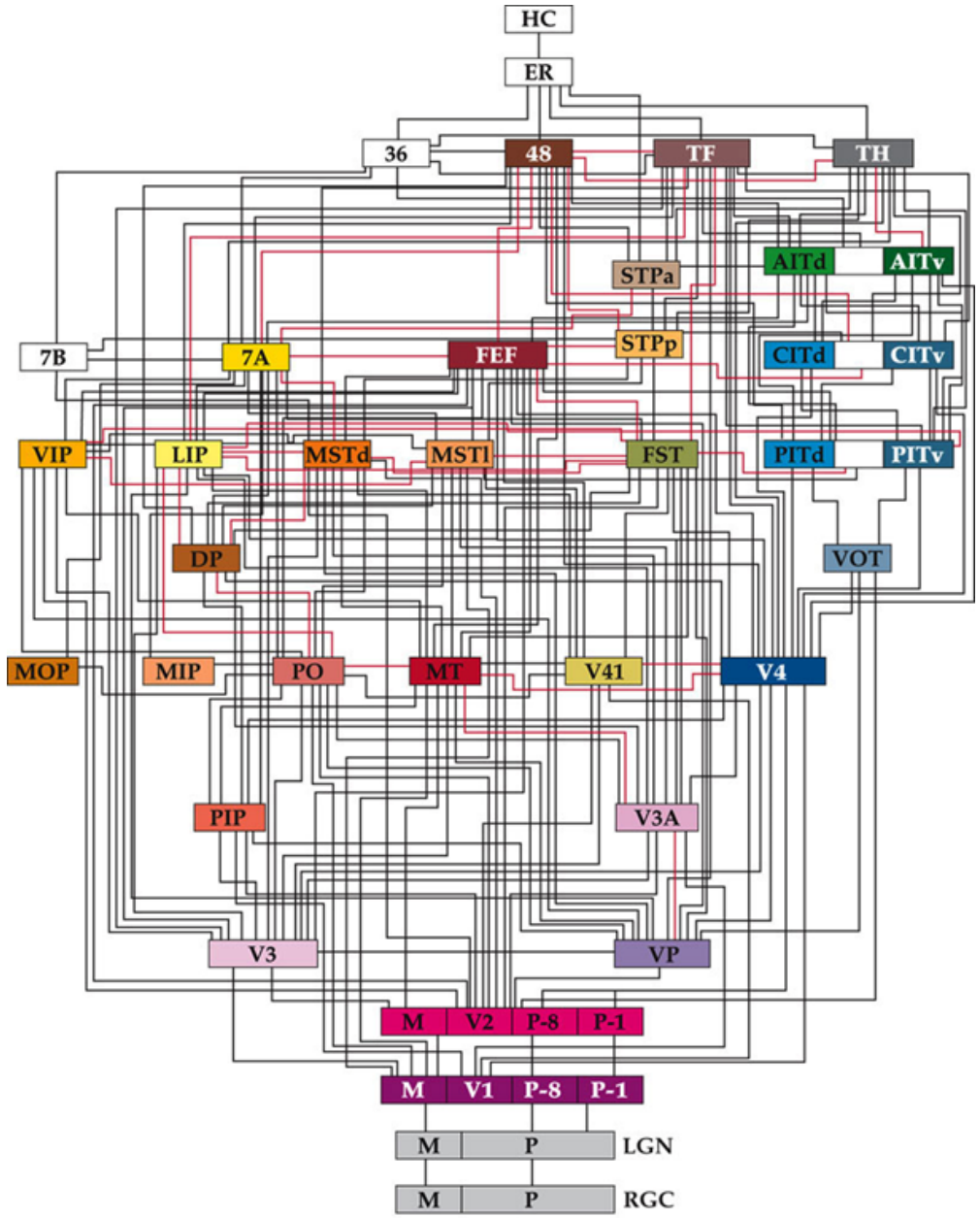
Visual areas

Levels of Processing: Functional Hierarchy



HUMAN VISUAL PATHWAY begins with the eyes and extends through several interior brain structures before ascending to the various regions of the visual cortex (V1, and so on). At the optic chiasm, the optic nerves cross over partially so that each hemisphere of the brain receives input from both eyes. The information is filtered by the lateral geniculate nucleus, which consists of layers of nerve cells that each respond only to stimuli from one eye. The inferior temporal cortex is important for seeing forms. Researchers have found that some cells from each area are active only when a person or monkey becomes conscious of a given stimulus.

Parallel and serial processing in the cortex

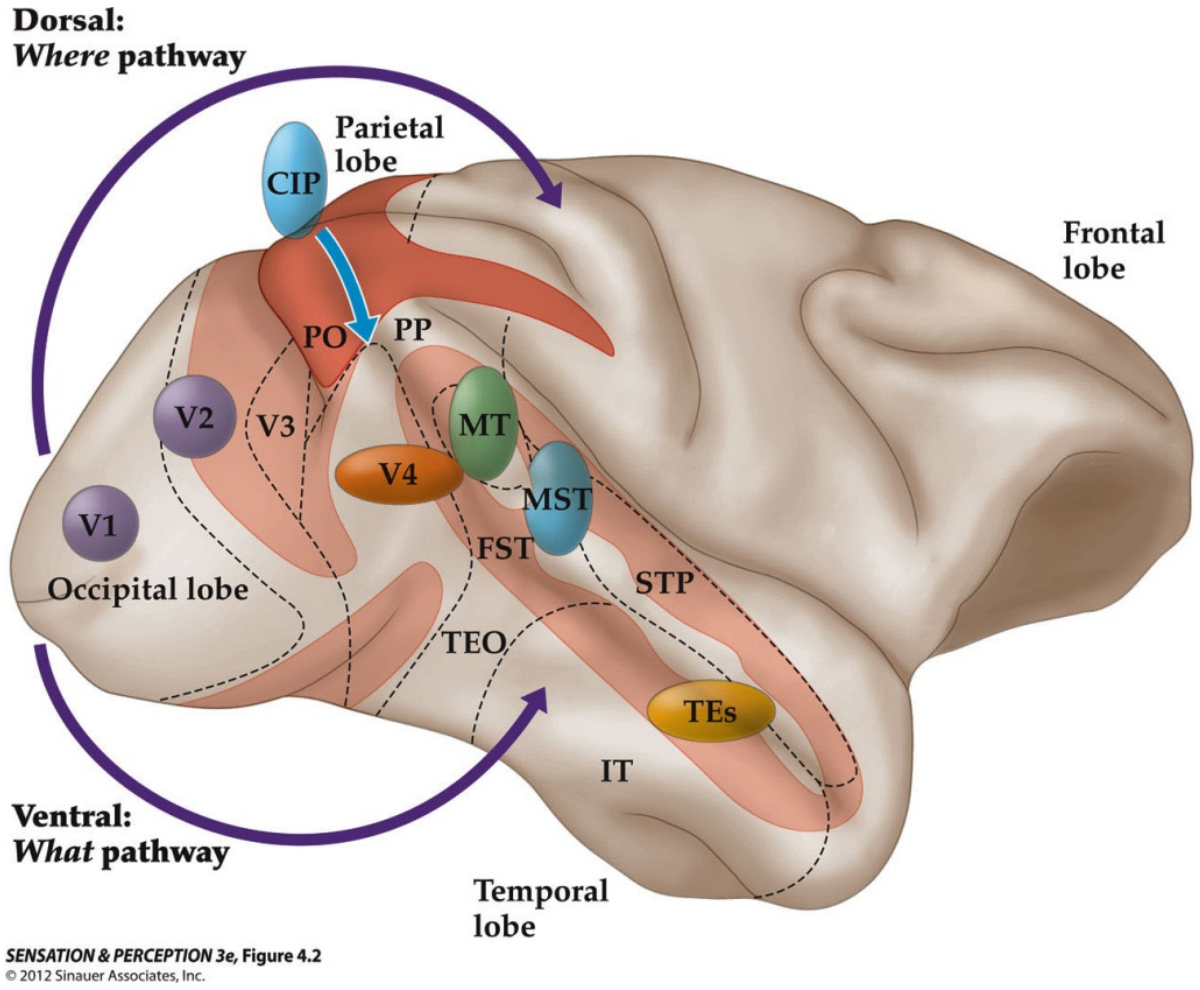


***SENSATION & PERCEPTION 3e*, Figure 4.3**

Streams of processing

Dorsal stream – ‘Where’ pathway specialized for spatial location.

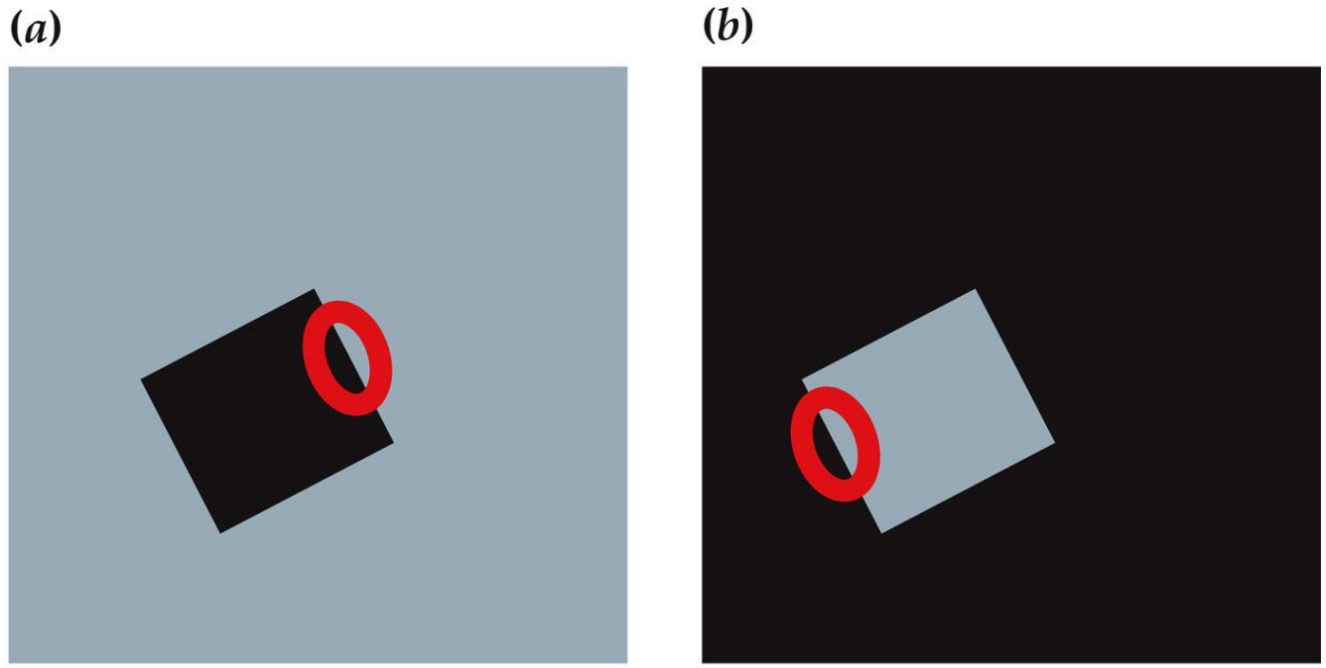
Ventral stream – ‘What’ pathway specialized for object identification and recognition.



SENSATION & PERCEPTION 3e, Figure 4.2

Ventral stream – 'What'

- V1→ V2 → V4 → IT
- Neurons sensitive to features useful for object recognition



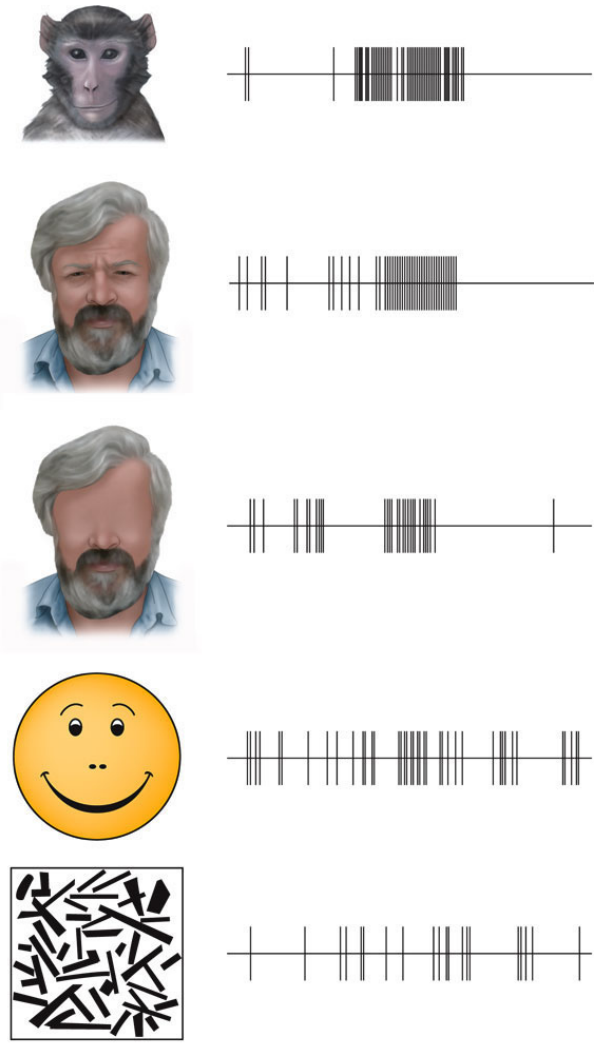
SENSATION & PERCEPTION 3e, Figure 4.4

Border-ownership neuron

Ventral stream – ‘What’

- V1→ V2 → V4 → IT

Face cell

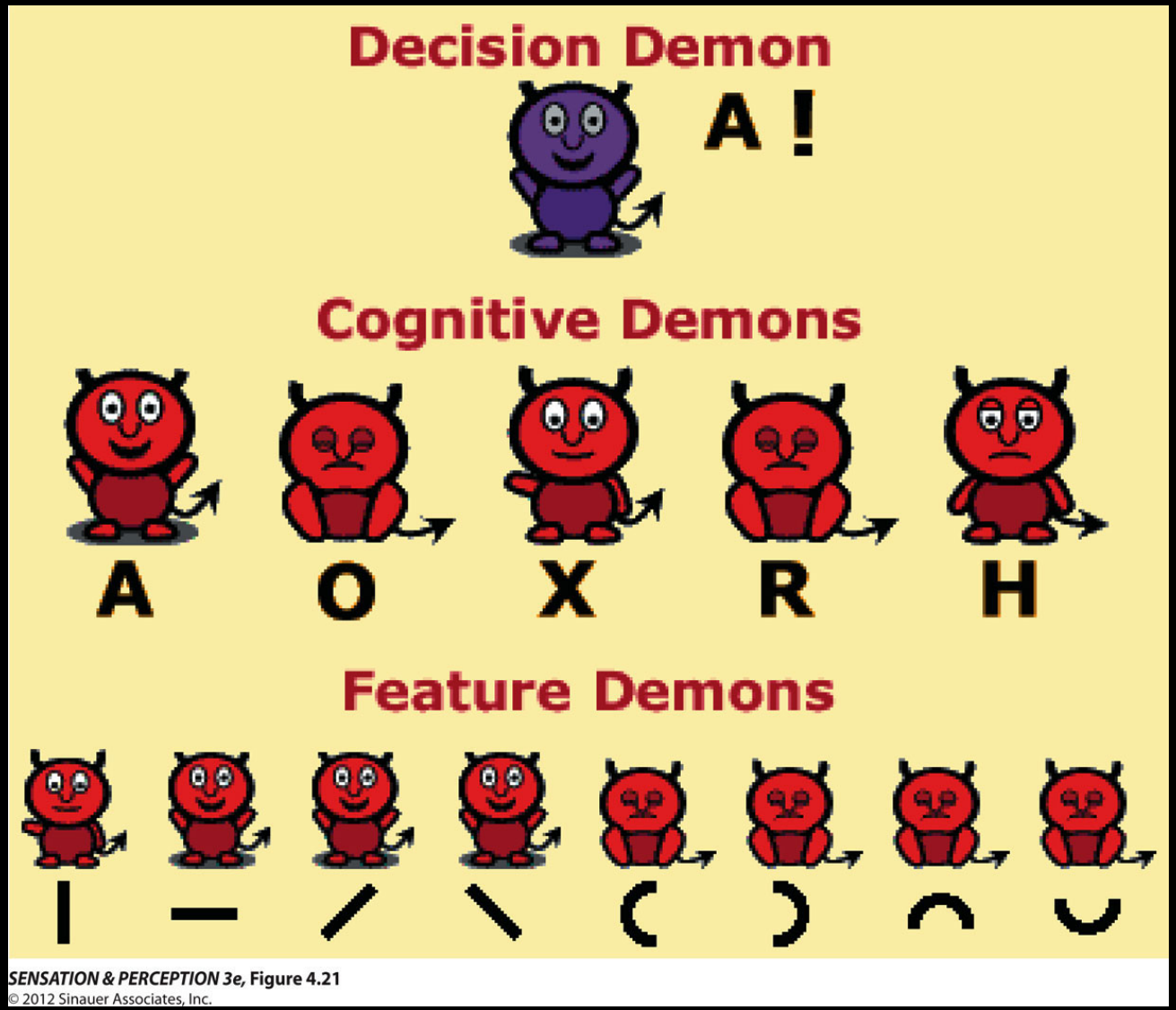


SENSATION & PERCEPTION 3e, Figure 4.5

PROCESSING STRATEGIES

Pandemonium model

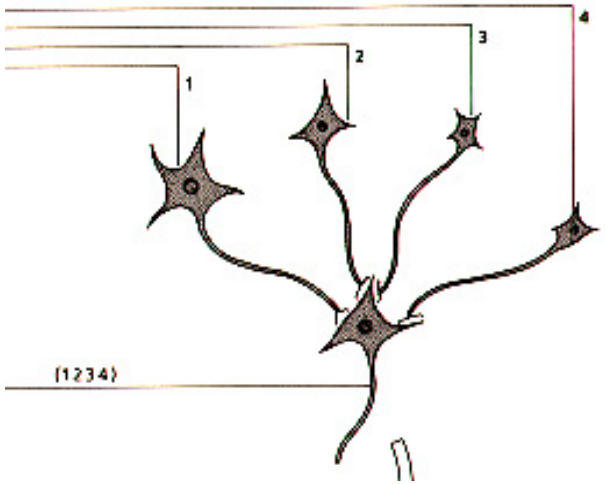
(Selfridge 1959)



The basic idea of the pandemonium architecture is that a pattern is first perceived in its parts before the “whole”: completely bottom-up.

Localist coding schemes

Grandmother cell (Barlow, 1972)

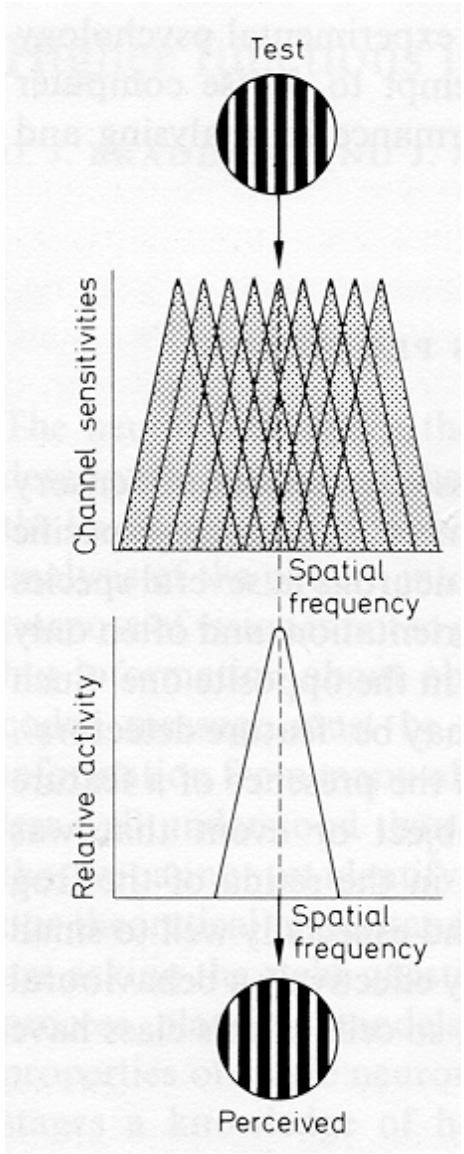


Grandma!

Localist representations

Knowledge is coded in a localist fashion: individual objects, words and simple concepts are coded distinctly with their own dedicated representation.

Easy to understand, but very inefficient. Separate cells for every colour/ property of an object?



Distributed or population coding

Perceptions are represented by the rates and patterns of action potential firing in populations of sensory neurons

Spatial frequency coding

Low

High

Distributed representations

Knowledge is coded as a pattern of activation across many processing units, with each unit contributing to many different representations. As a consequence, there is no one unit devoted to coding a given word, object, or person.

Each concept is represented by many neurons.

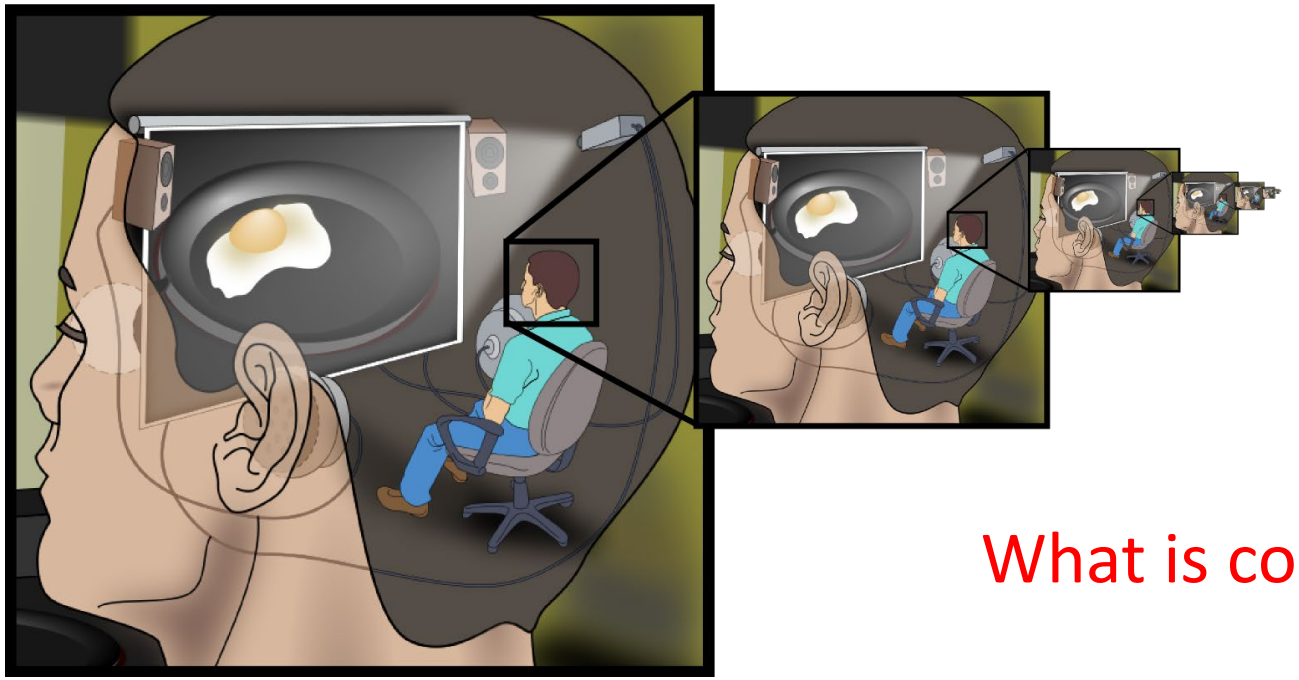
Each neuron participates in the representation of many concepts.

Top-down processing

Beliefs, cognitions, and expectations can drive the pattern recognition process. For example, if you expect to see a particular pattern, then you can focus your attention on looking for evidence consistent with that pattern.

So in the Pandemonium model, instead of all activity travelling up to the decision demon, information or activation can be sent the other way down to the feature demons.

What next?

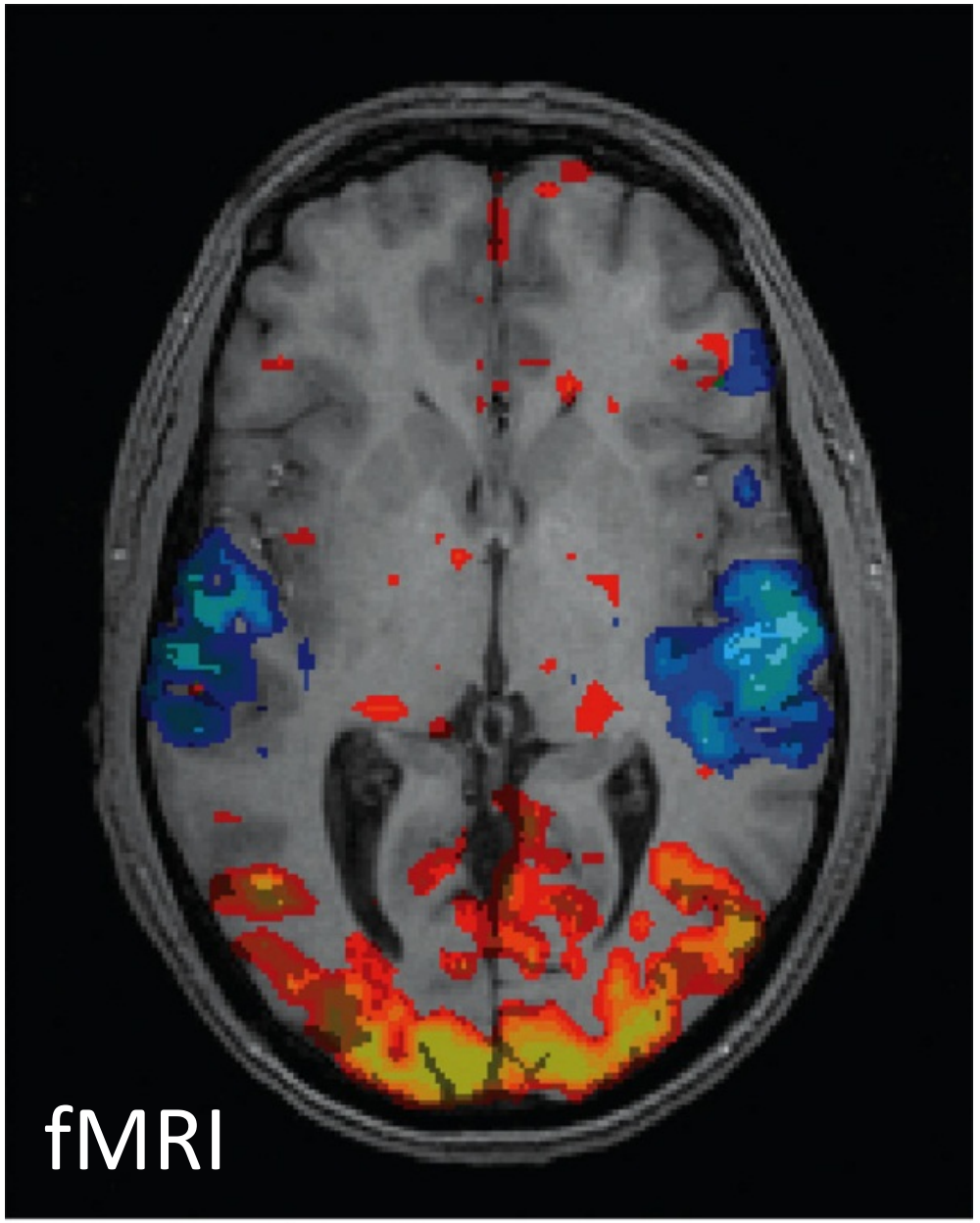


What is consciousness?

Other methods

Measure localized brain activity by measuring localized increases in blood flow.

Measures changes of oxygenated and deoxygenated blood to strong magnetic fields (BOLD signal).



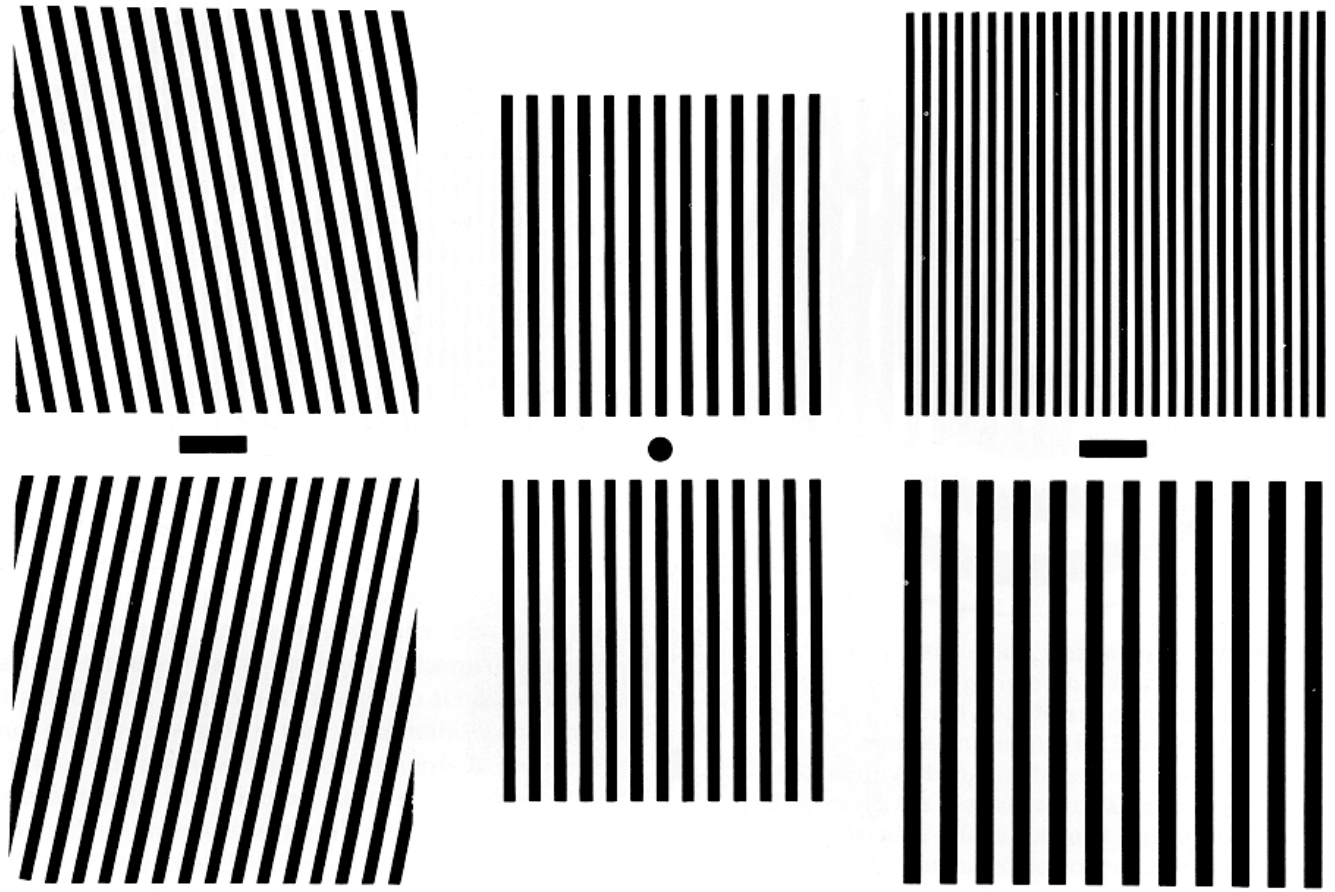
SENSATION & PERCEPTION 3e, Figure 1.36

ILLUSIONS

Why study illusions?

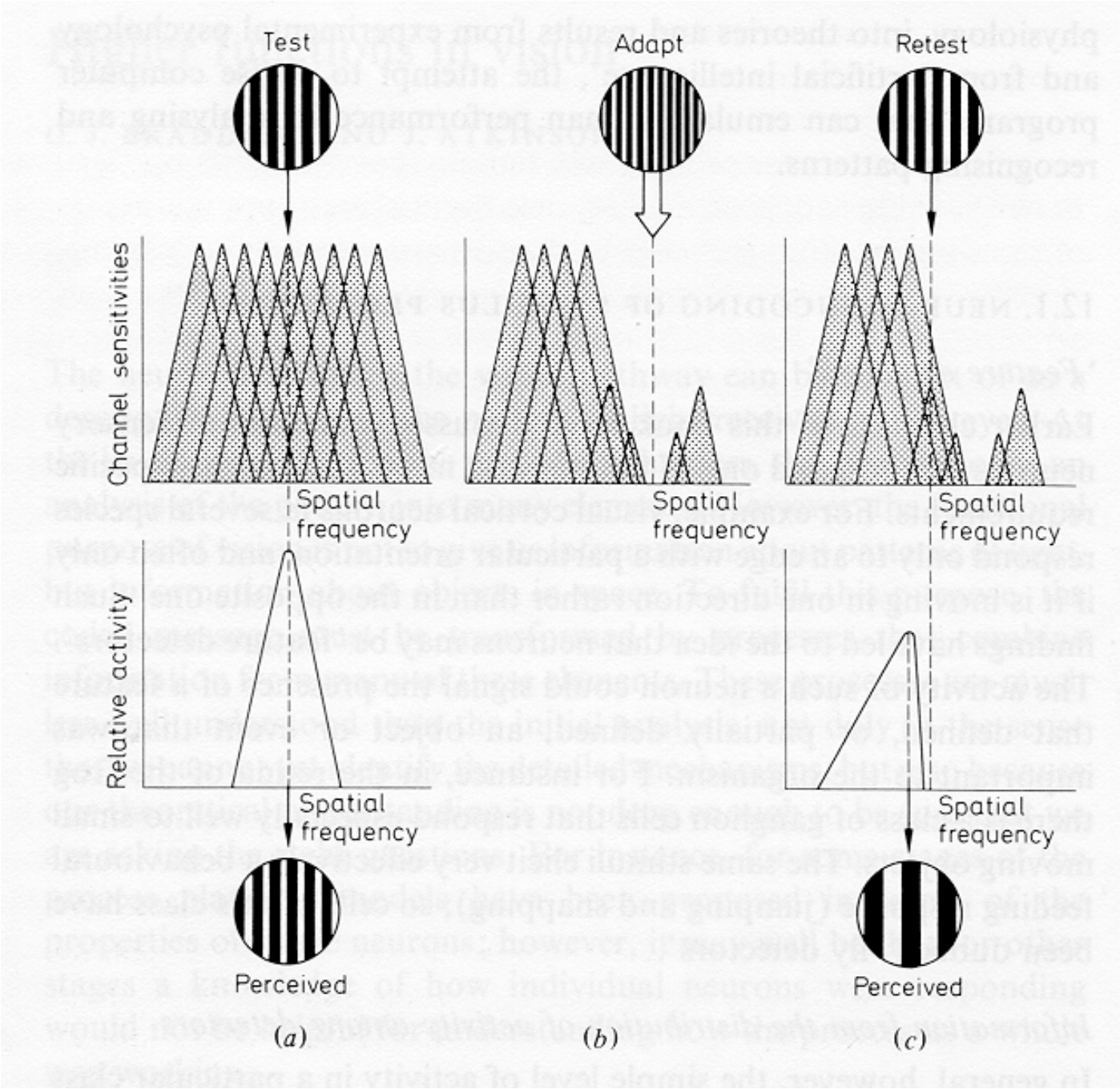
- Seeing is not always believing.
- Illusions can provide insights into how the visual system works

Example: Grating adaptation (population coding)



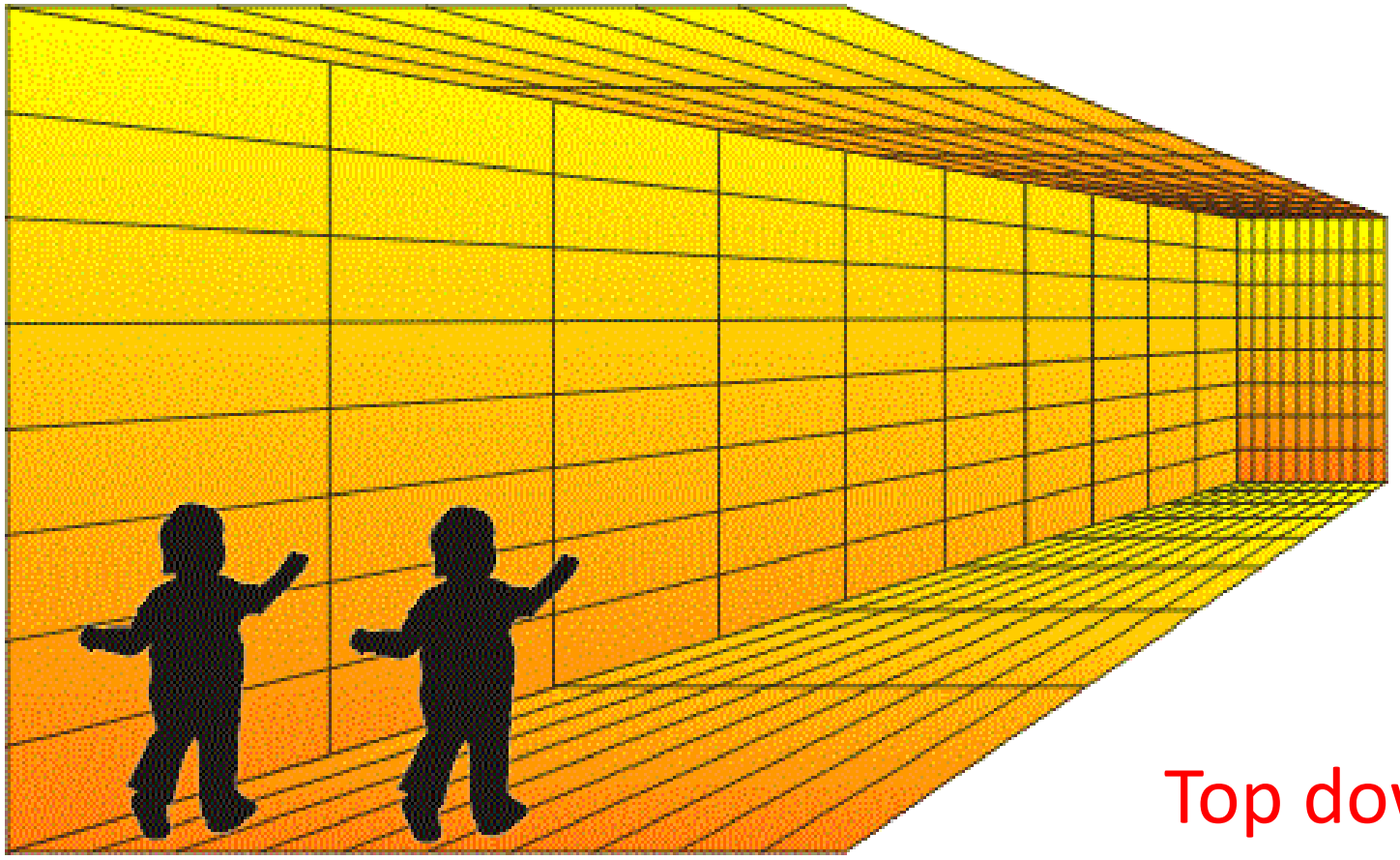
Source: Horace Barlow

Spatial frequency adaptation explained?



Source: Barlow and Mollon, 1982

Visual processing: illusions



Top down?