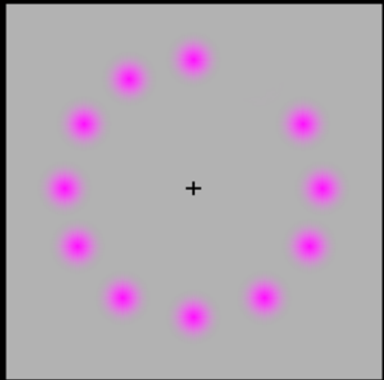
NEUR3001: Advanced Visual Neuroscience

Introduction



Andrew Stockman

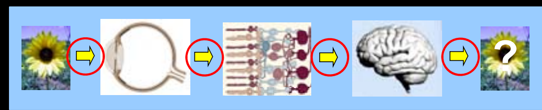
VISUAL NEUROSCIENCE

What is it?

Essentially what we're trying to understand is:

How the visual system works.

INPUT



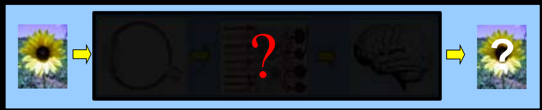
OUTPUT

Using any technique available to us.

PSYCHOPHYSICS

PHYSICAL STIMULUS → PERCEPTION

INPUT



OUTPUT

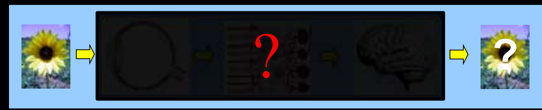
Study the relationship between physical stimulus and perception…

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

PSYCHOPHYSICS

PHYSICAL STIMULUS → PERCEPTION

INPUT



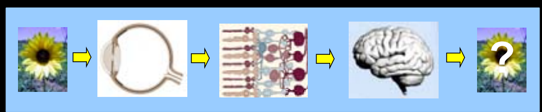
OUTPUT

Can you think of some examples of psychophysical experiments
And what they might tell us about visual processing?

NEUROSCIENCE

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

INPUT



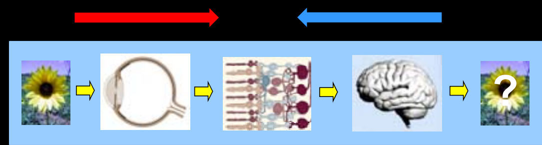
OUTPUT

SENSORY INPUT NEURAL CODING 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".

INPUT

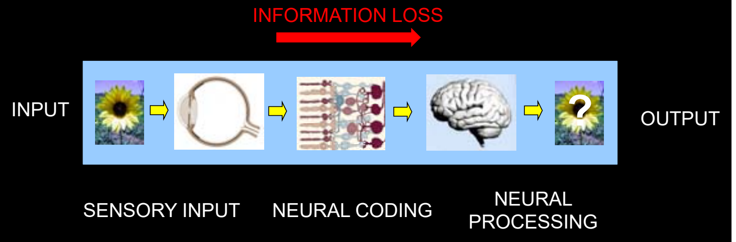


OUTPUT

SENSORY INPUT NEURAL CODING NEURAL PROCESSING

NEUROSCIENCE

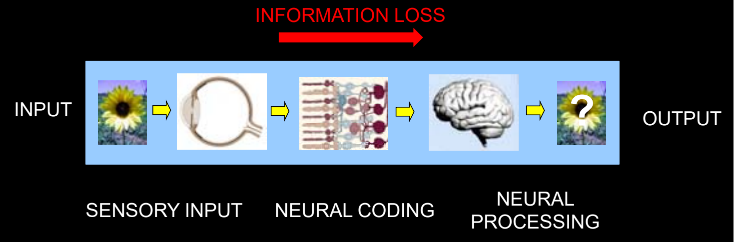
- Information loss: information is lost as visual signals are encoded and processed by successive stages of the visual system.



Think of examples: What is lost?

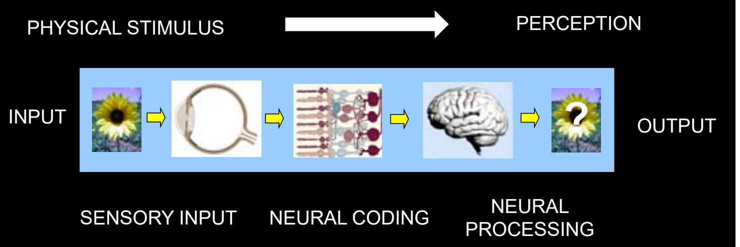
NEUROSCIENCE

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

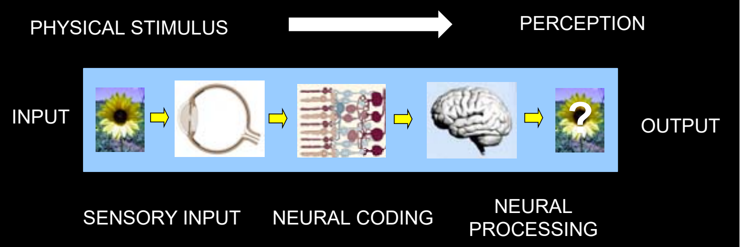


Lost information cannot be retrieved, although some aspects can be *inferred* by top-down processing (e.g., inference of 3D depth from a monocular image).

PSYCHOPHYSICS AND NEUROSCIENCE CAN BE COMPLEMENTARY

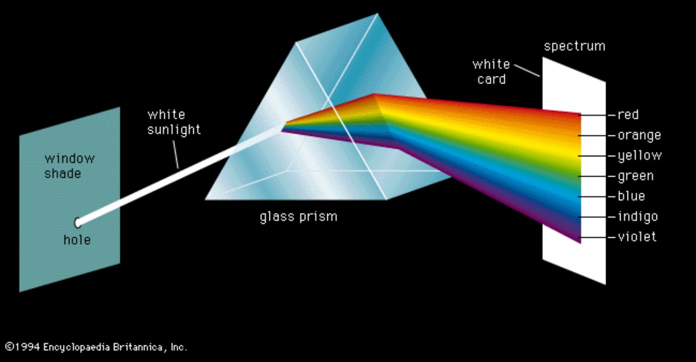


Let’s now step through this processing stream, beginning with…



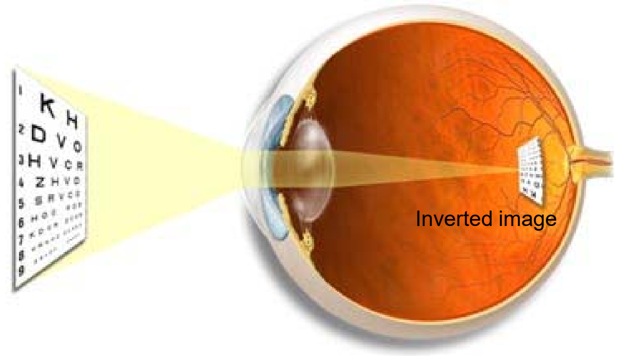
Light

400 - 700 nm is most important for vision



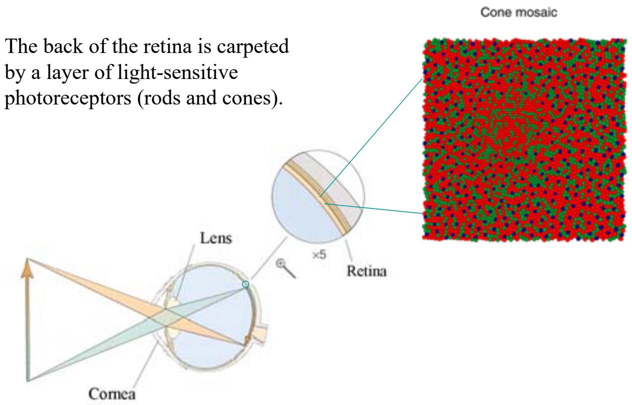
How do we see?

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



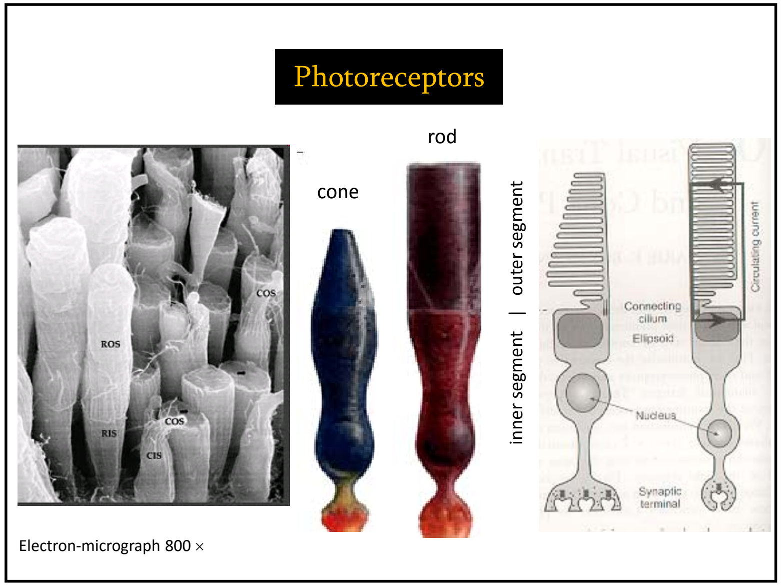
How do we see?

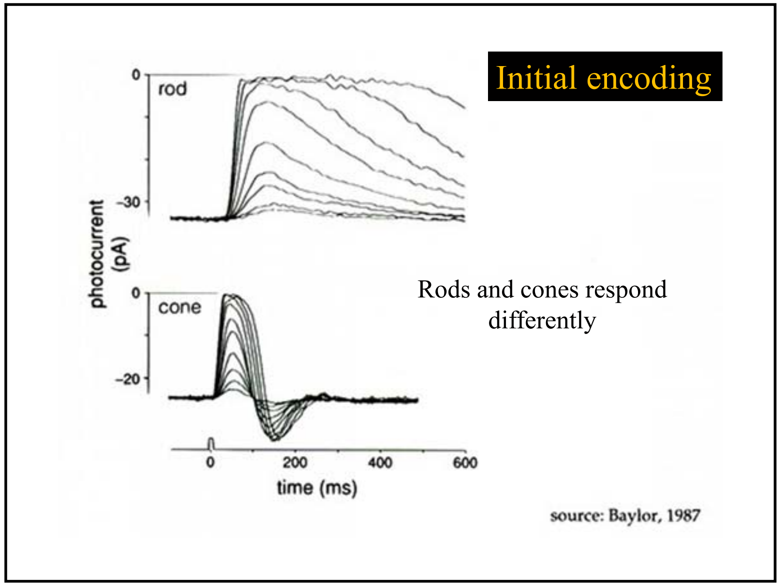
The back of the retina is carpeted by a layer of light-sensitive photoreceptors (rods and cones).

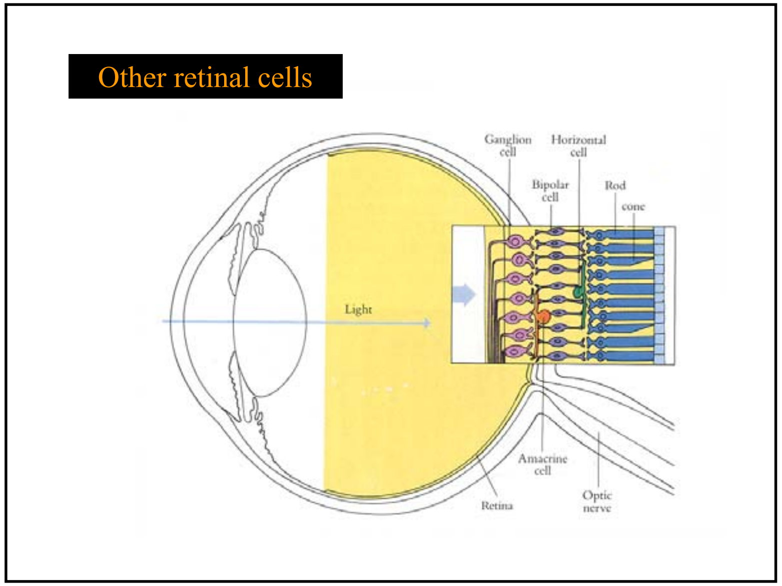


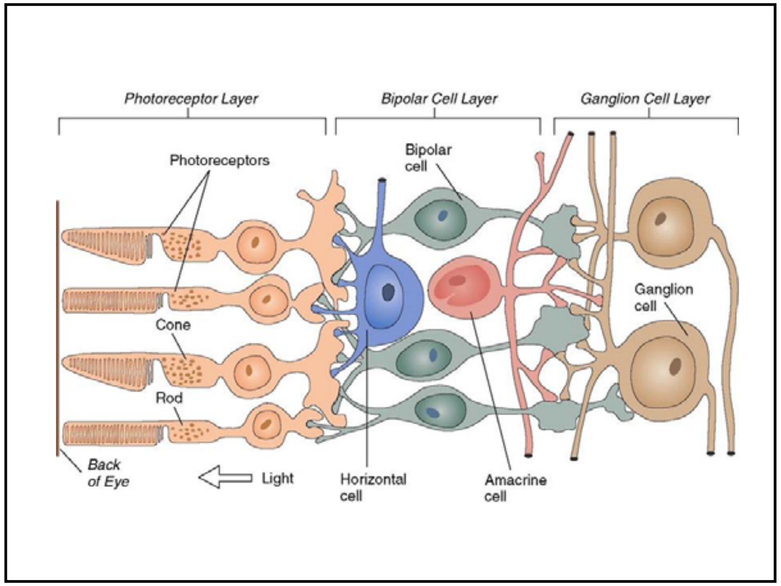
Retina

- 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
rod
cone
outer segment | inner segment
Connecting cilium
Ellipsoid
Nucleus
Synaptic terminal
Circulating current
COS
ROS
RIS
CIS
Electron-micrograph 800 ×

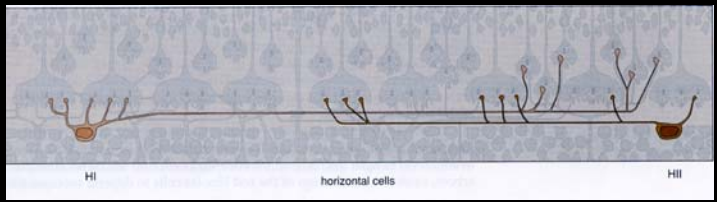

Initial encoding
rod
cone
photocurrent (pA)
0
-30
-20
0
200
400
600
time (ms)
Rods and cones respond differently
source: Baylor, 1987


Other retinal cells
Ganglion cell
Horizontal cell
Bipolar cell
Rod
cone
Light
Amacrine cell
Retina
Optic nerve


Photoreceptor Layer
Bipolar Cell Layer
Ganglion Cell Layer
Photoreceptors
Bipolar cell
Cone
Rod
Ganglion cell
Back of Eye
Light
Horizontal cell
Amacrine cell

Horizontal cells

Lateral interactions

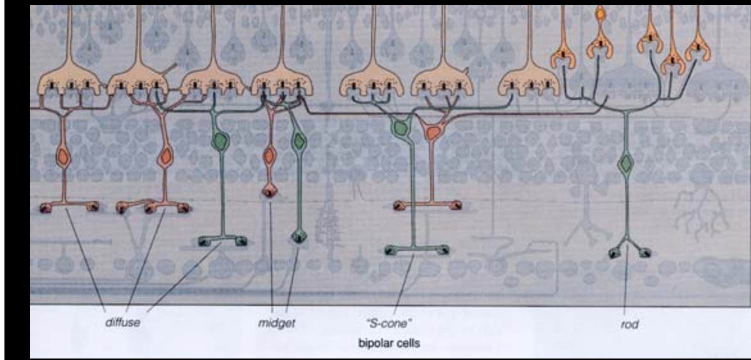


From Rodieck (1998)

What sort of processing can be achieved by lateral interactions?

Bipolar cells

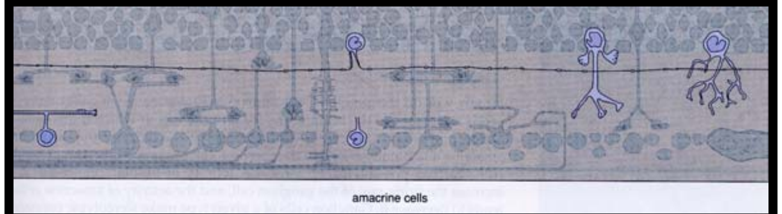
ON (greener) and
OFF (redder) varieties



Parallel processing?

From Rodieck (1998)

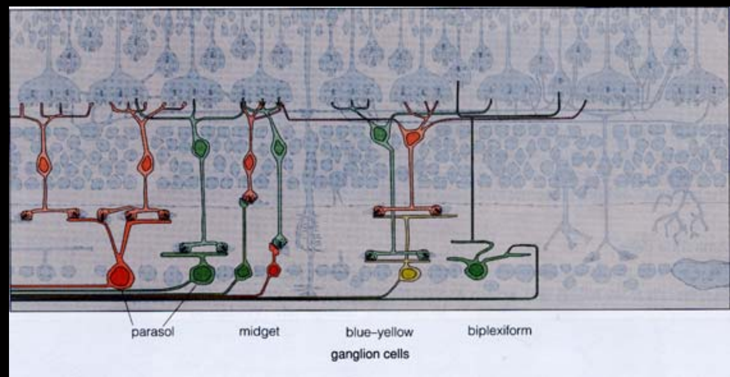
Amacrine cells



From Rodieck (1998)

Ganglion cells

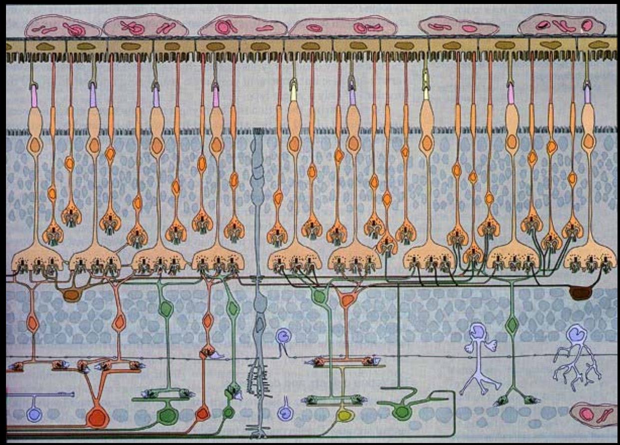
ON and OFF varieties



Parallel processing?

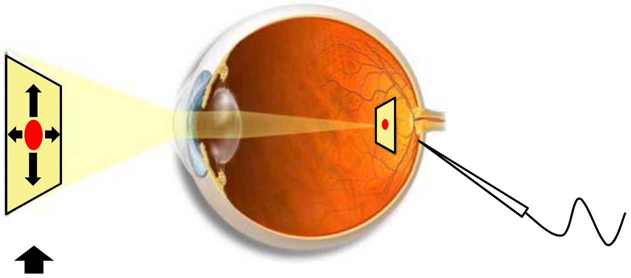
From Rodieck (1998)

Overview



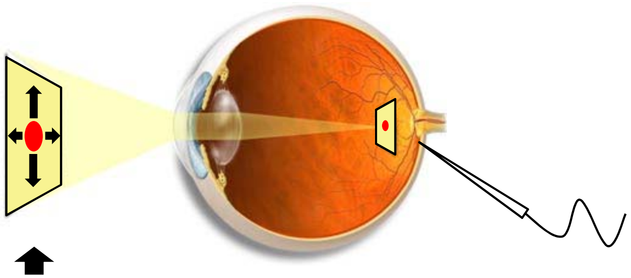
From Rodieck (1998)

We can investigate what a cell encodes by “mapping” its receptive field



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

We can investigate what a cell encodes by “mapping” its receptive field



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

Neural codes and signal processing

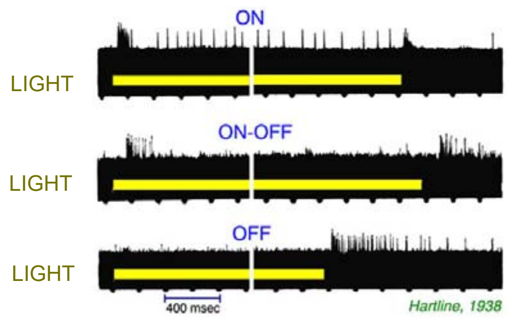
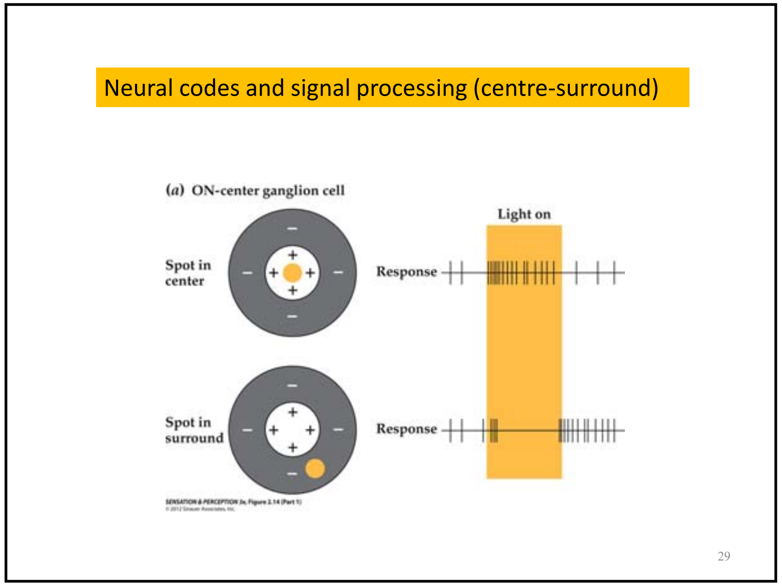
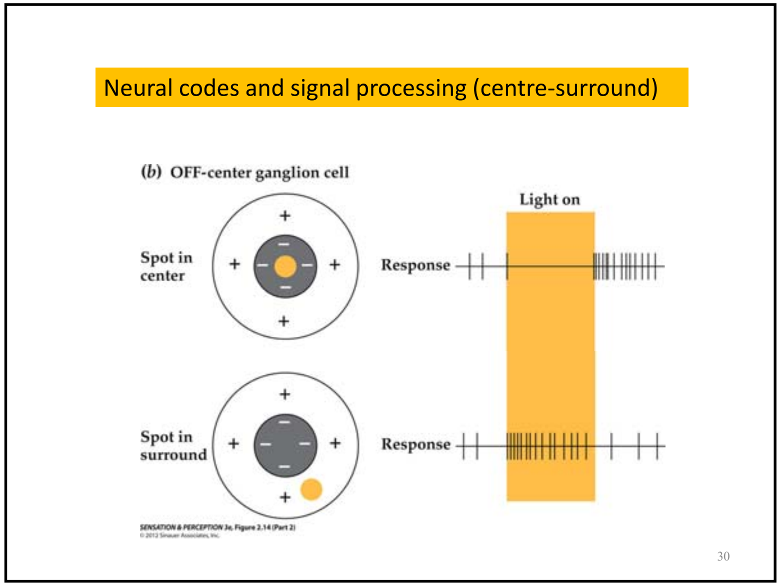
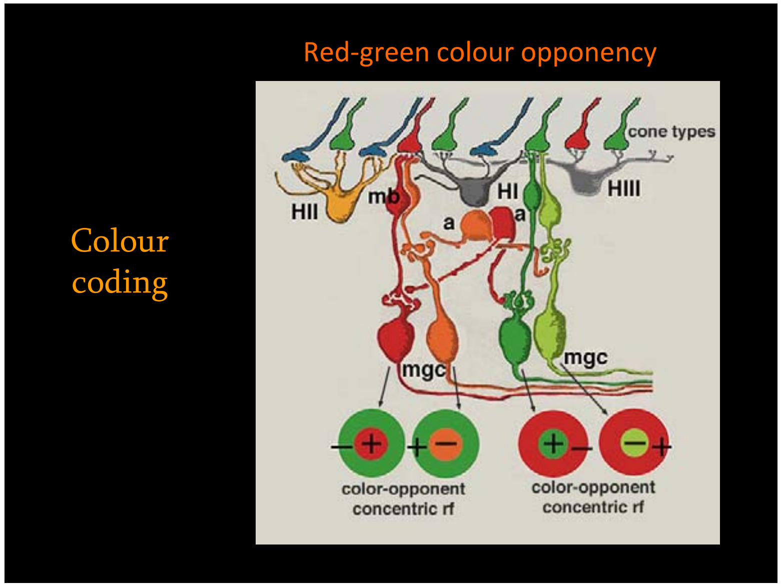


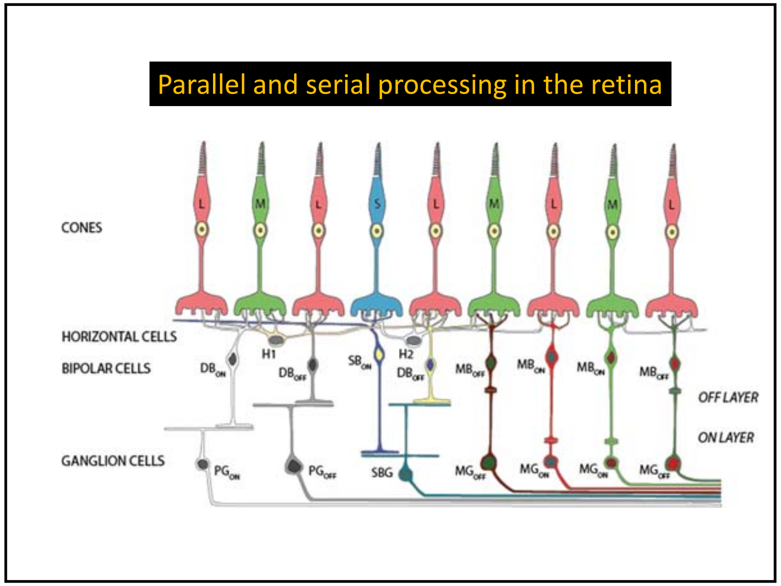
Fig. 3. ON, OFF and ON-OFF ganglion cells (after Hartline, 1938; 1967).

Webvision

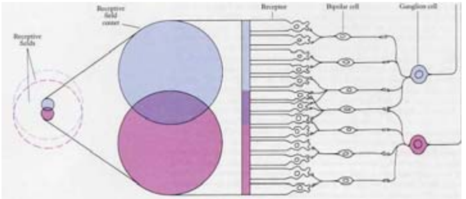

Neural codes and signal processing (centre-surround)
(a) ON-center ganglion cell
Light on
Spot in center
Response
Spot in surround
Response
29


Neural codes and signal processing (centre-surround)
(b) OFF-center ganglion cell
Light on
Spot in center
Response
Spot in surround
Response
30


Red-green colour opponency
Colour coding
cone types
HII
mb
HI
HIII
a
a
mgc
mgc
color-opponent concentric rf
color-opponent concentric rf

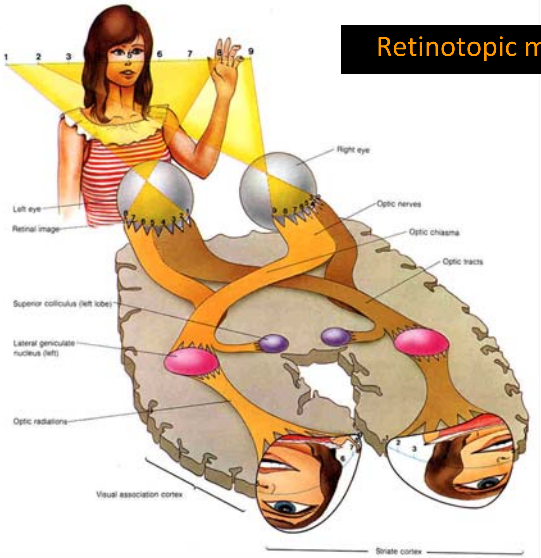

Parallel and serial processing in the retina
CONES
HORIZONTAL CELLS
BIPOLAR CELLS
GANGLION CELLS
H1
H2
OFF LAYER
ON LAYER
SBG

Retinotopic maps

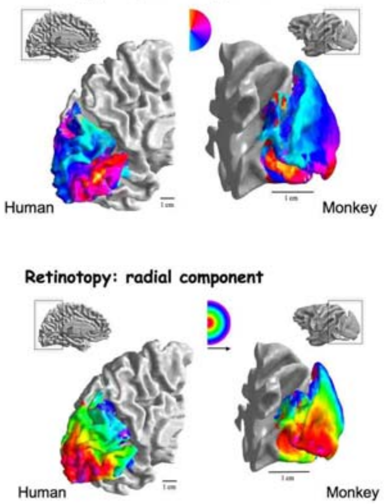


David Hubel

Retinotopic maps



Retinotopic maps



David Heeger

Neural Coding

Law of Specific Nerve Energies

Stimulation by any cause has the same effect.

Neurones 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, or phospenes.

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

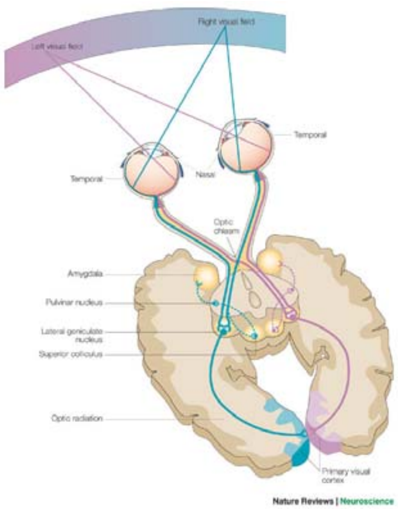
Johannes Peter Müller (1801-1858)

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**

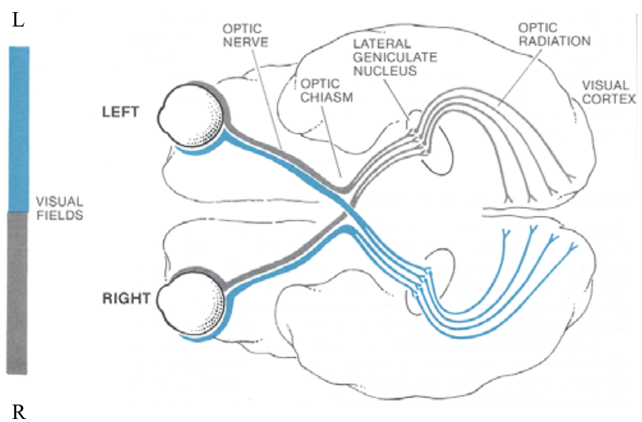
From retina to brain…

Geniculo-striate pathway



Hannula, Simons & Cohen, 2005

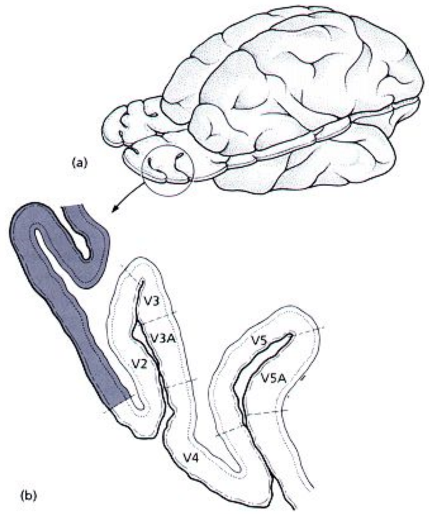
Visual pathways



From below

Cortical level

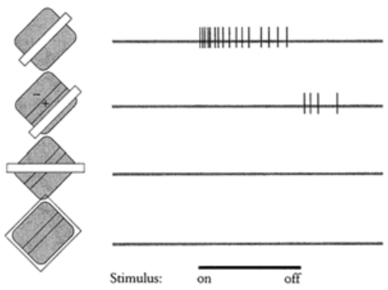
V1-V5



Neural codes and signal processing

Simple cells

V1, layers 4 & 6

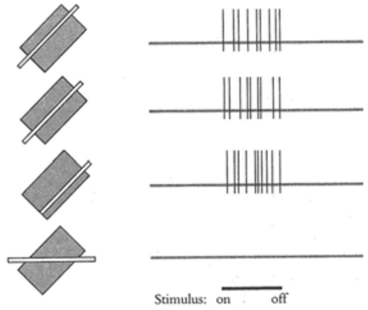


Simple cells have narrow, elongated excitatory and inhibitory zones that have a specific orientation. These cells are “line detectors”. Their receptive fields can be built from the convergent connections from lateral geniculate nucleus cells.

Neural codes and signal processing

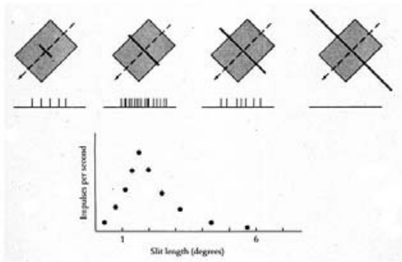
Complex cells

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.

Hypercomplex cell

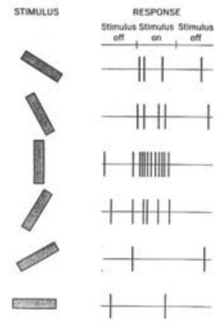


www.cns.nyu.edu

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*.

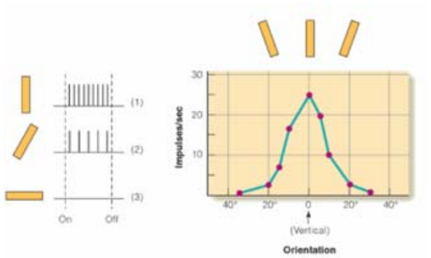
Neural codes and signal processing

V1 – primary visual cortex



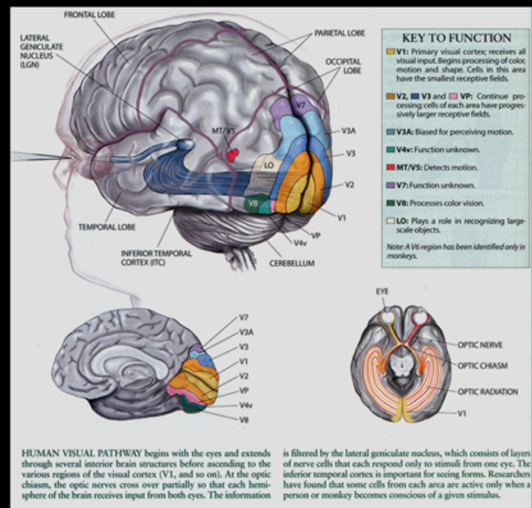
Feature extraction: orientation

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

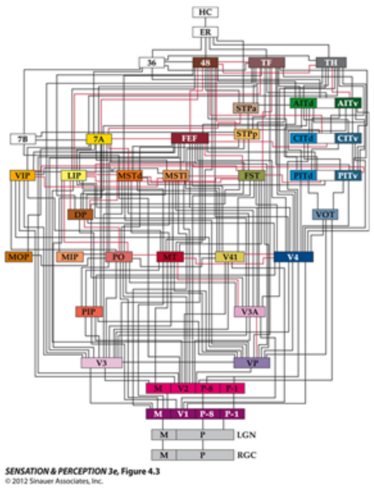


Feature extraction: orientation

Visual areas



Levels of Processing: Functional Hierarchy

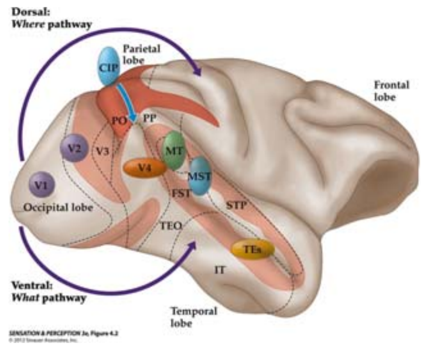


Parallel and serial processing in the cortex

Streams of processing…

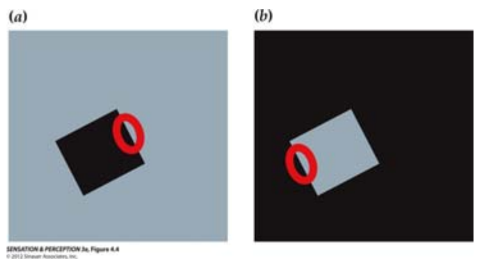
Dorsal stream – 'Where' pathway specialized for spatial location.

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



Ventral stream – 'What'

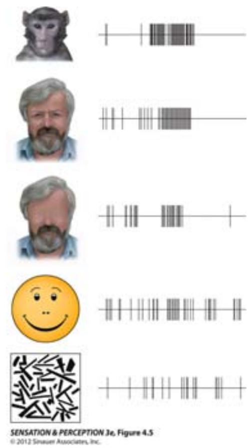
- V1→ V2 → V4 → IT
- Neurons sensitive to features useful for object recognition



Border-ownership neuron

Ventral stream – 'What'

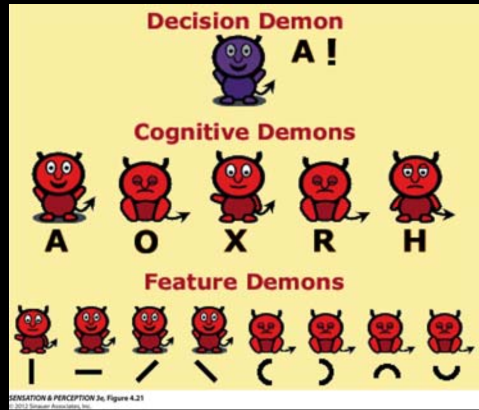
- V1→ V2 → V4 → IT



Face cell

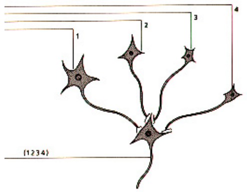
Processing strategies

Features (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.

Grandmother cell (Barlow, 1972)



Grandmother!

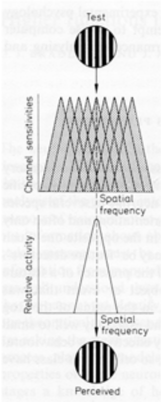
Localist coding schemes

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/ 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.

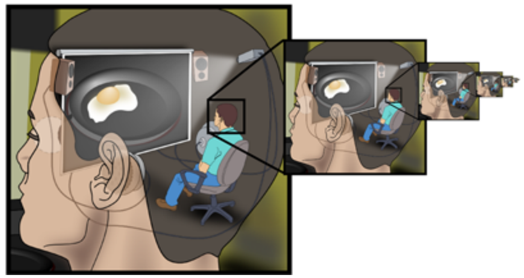
Each neuron participates in the representation of many concepts.

Top-down processing

Beliefs, cognitions, and expectations can drive the pattern recognition process. For example, if you are expecting to come across a certain 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, though?



What is consciousness?

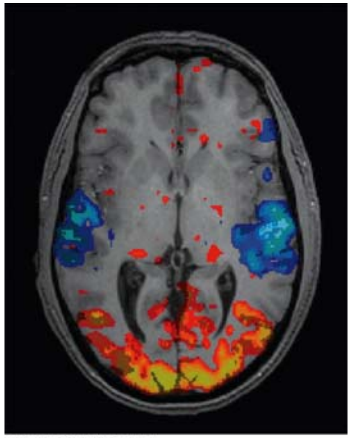
60

fMRI

Other methods

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

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
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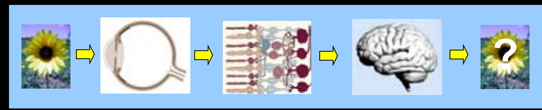
PSYCHOPHYSICS

PHYSICAL STIMULUS → PERCEPTION

INPUT



OUTPUT

Study relationship between physical stimulus and perception..,

PSYCHOPHYSICS

PHYSICAL STIMULUS → PERCEPTION

INPUT

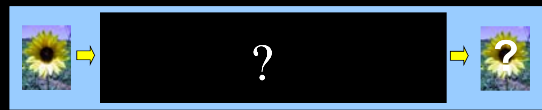
OUTPUT

Study relationship between physical stimulus and perception..,

PSYCHOPHYSICS

PHYSICAL STIMULUS → PERCEPTION

INPUT



OUTPUT

In psychophysics, we have to infer what is going on inside a “black box” just from studying the input and output…

In fact, we can learn a remarkable amount about the internal processing from psychophysical measurements.

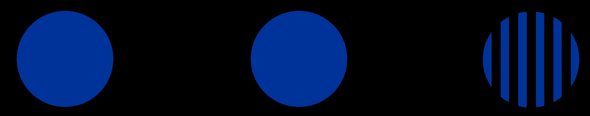
Crucially, though, we can use knowledge from neuroscience to guide our experiments and models.

Psychophysics

- Manipulate the properties of simple visual stimuli, and carefully measure the effect of that manipulation on the human subject's response–in an attempt to understand the workings and organization of the human visual system.

Which psychophysical tasks provide useful information?

DETECTION TASKS



Is a circle present?

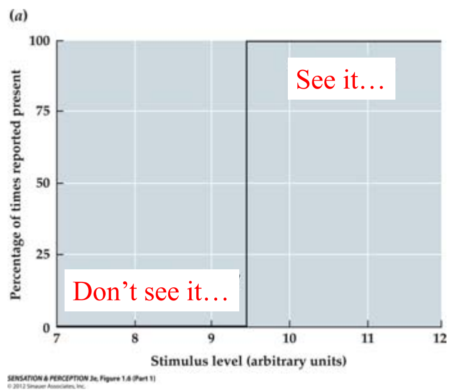
Is the circle flickering or steady?

Is the pattern (grating) visible?

In general, we use simple tasks.

Can you think of other tasks?

Threshold detection measurements



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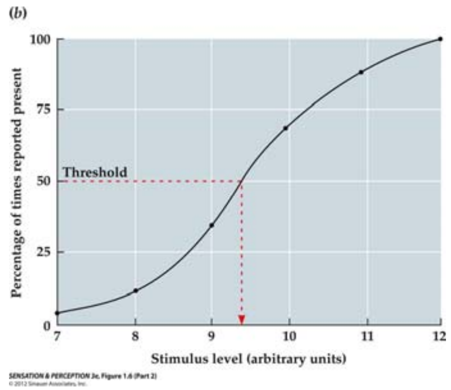
Threshold detection measurements



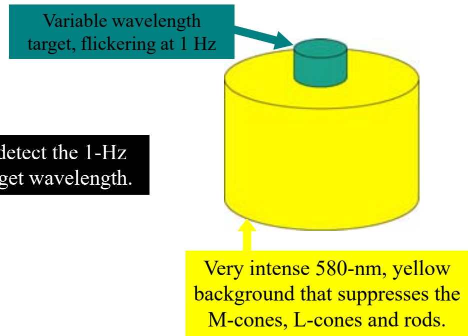
As an example, human spectral sensitivity

Measuring the spectral sensitivity characterizes wavelength-dependence of the visual system from which under some conditions we can infer the spectral properties of the cone photoreceptors.

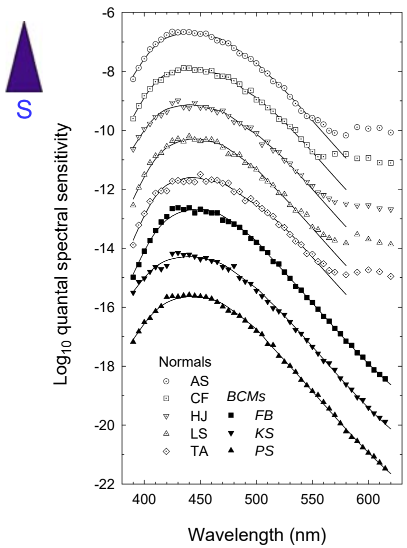
Experimental conditions

Colour normals

The subject's task was to detect the 1-Hz flicker as a function of target wavelength.



S-cone data



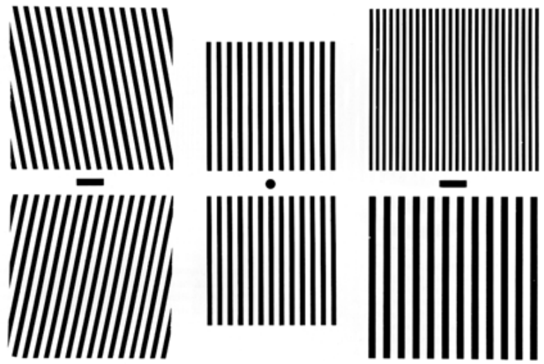
The Normal data were obtained on an intense orange adapting background that was there to suppress the L- and M-cone sensitivities.

Illusions

Why study illusions?

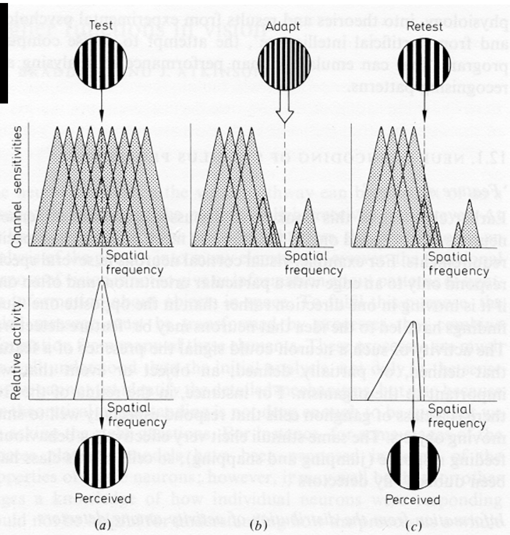
- Seeing is not always believing.
- Illusions can provide insights into how the visual system works

Example: Grating adaptation (population coding)



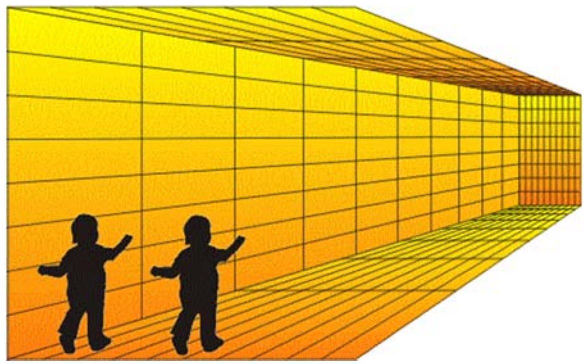
Source: Horace Barlow

Spatial frequency adaptation explained?



Source: Barlow and Mollon, 1982

Visual processing: illusions



Top down?