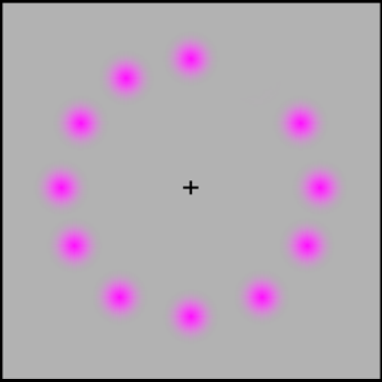


NEUR3001: Advanced Visual Neuroscience

Introduction



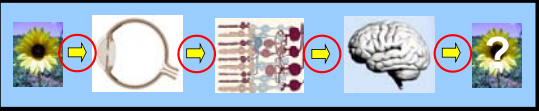
Andrew Stockman

VISUAL NEUROSCIENCE

What is it?

Essentially what we're trying to understand is:

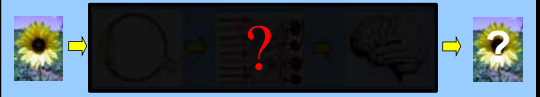
How the visual system works.



Using any technique available to us.

### PSYCHOPHYSICS

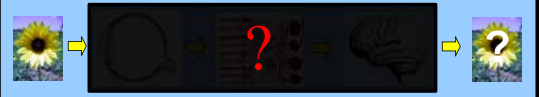
PHYSICAL STIMULUS → PERCEPTION

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

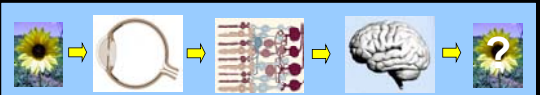
PHYSICAL STIMULUS → PERCEPTION

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.

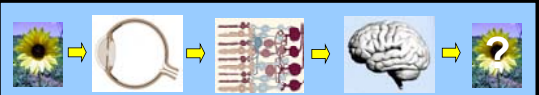
INPUT  OUTPUT

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.

INFORMATION LOSS

INPUT → SENSORY INPUT → NEURAL CODING → NEURAL PROCESSING → OUTPUT

Think of examples: What is lost?

Detailed description: This slide illustrates the concept of information loss in neuroscience. It features a central horizontal flowchart with five stages: a sunflower image, a magnifying glass, a neural circuit diagram, a brain, and a sunflower image with a question mark. Below these stages are labels: 'SENSORY INPUT', 'NEURAL CODING', and 'NEURAL PROCESSING'. A red arrow labeled 'INFORMATION LOSS' points from left to right above the flowchart. The word 'INPUT' is on the far left and 'OUTPUT' is on the far right.

### NEUROSCIENCE

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

INFORMATION LOSS

INPUT → SENSORY INPUT → NEURAL CODING → NEURAL PROCESSING → OUTPUT

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).

Detailed description: This slide is identical to the one above but includes a concluding sentence: '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

PHYSICAL STIMULUS → PERCEPTION

INPUT → SENSORY INPUT → NEURAL CODING → NEURAL PROCESSING → OUTPUT

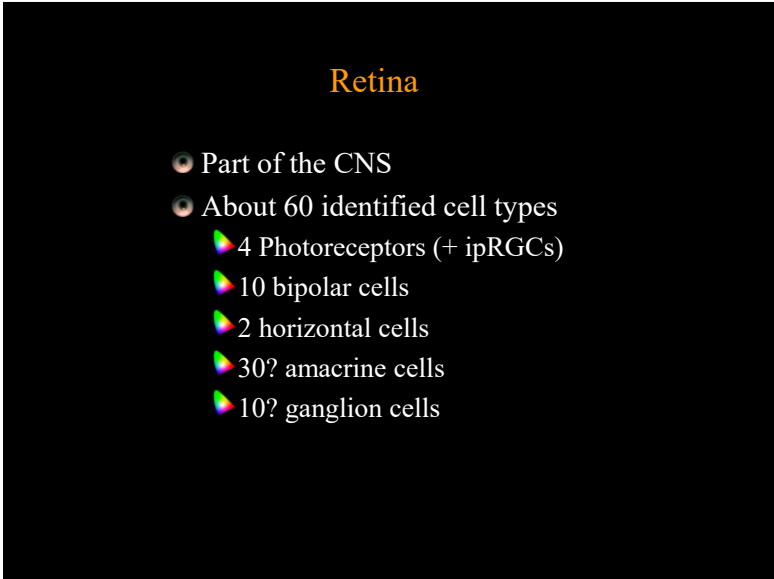
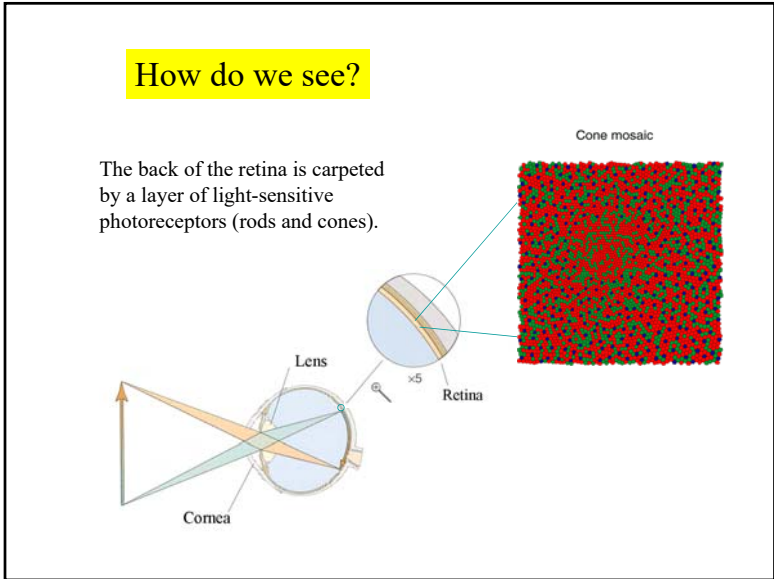
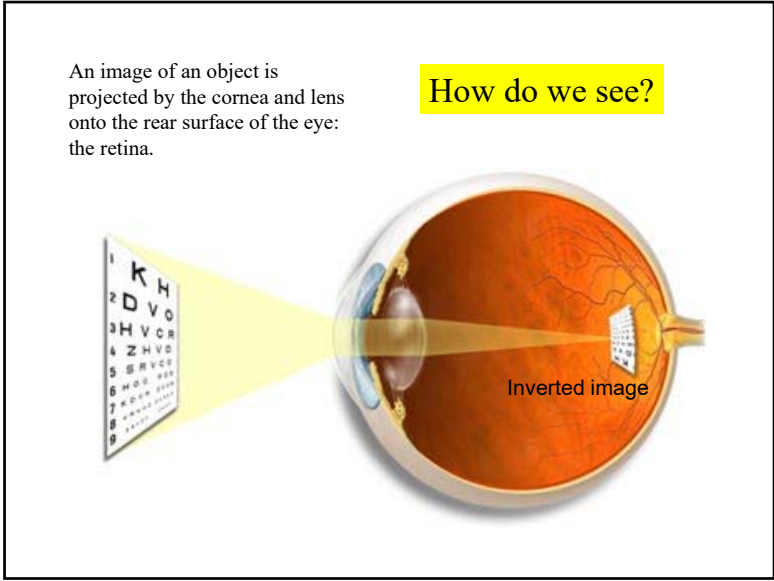
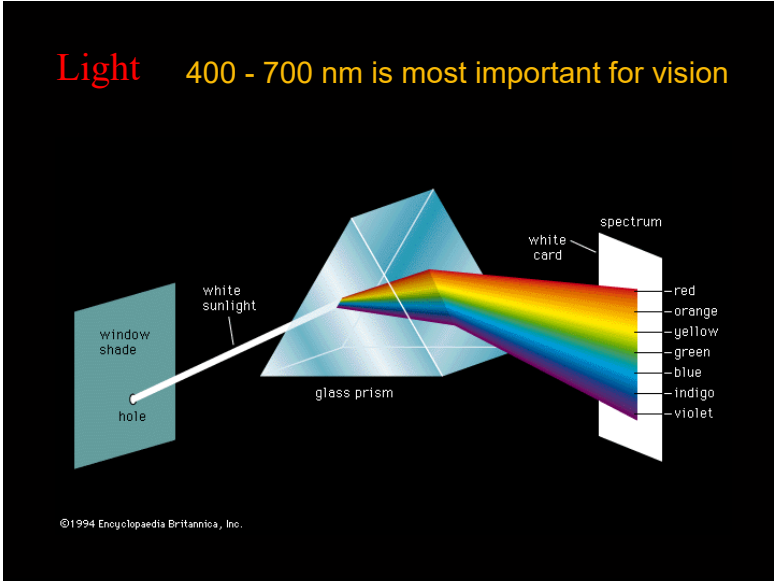
Detailed description: This slide highlights the complementarity of psychophysics and neuroscience. It shows a large white arrow pointing from 'PHYSICAL STIMULUS' to 'PERCEPTION'. Below this, the same visual processing stream diagram as in the previous slides is shown, with 'INPUT' on the left and 'OUTPUT' on the right.

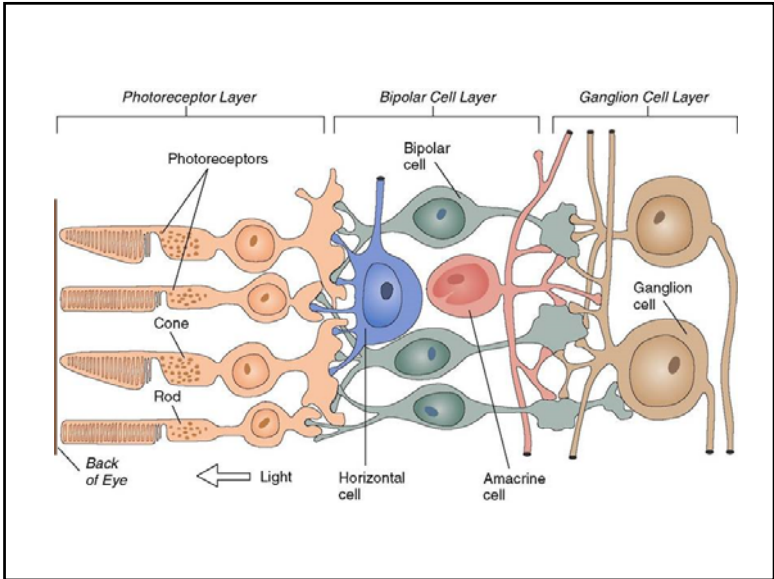
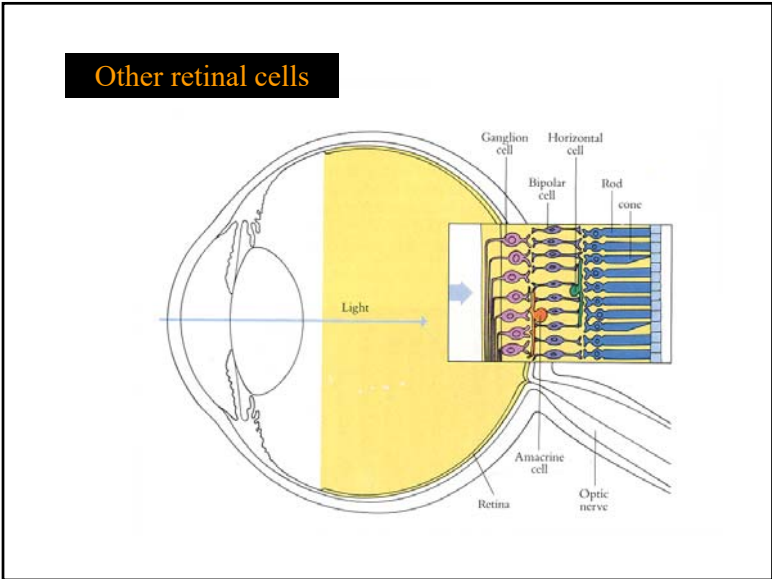
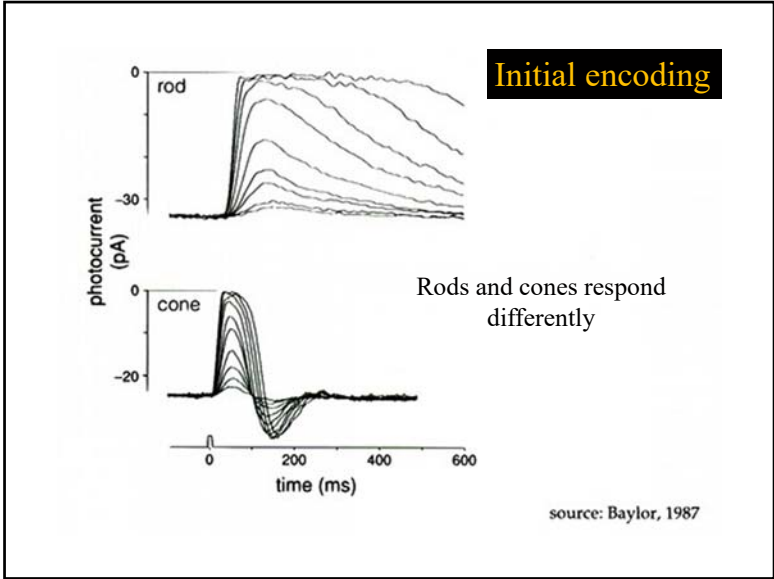
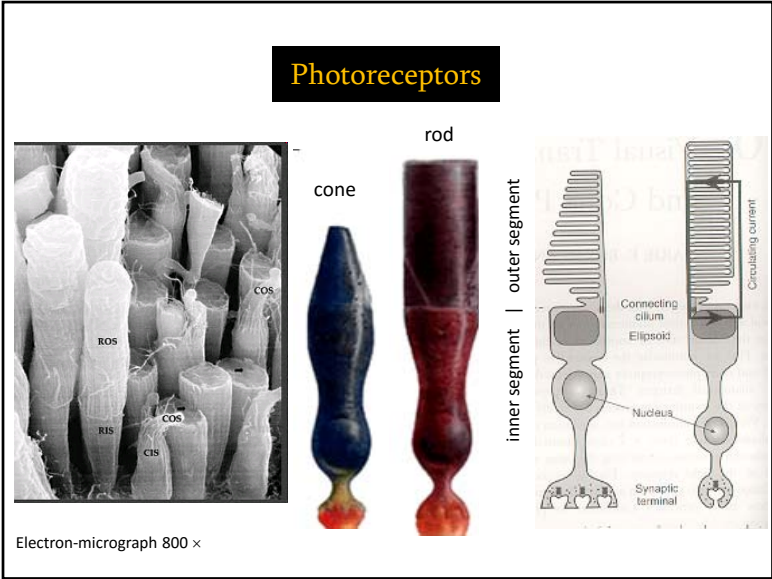
Let's now step through this processing stream, beginning with...

PHYSICAL STIMULUS → PERCEPTION

INPUT → SENSORY INPUT → NEURAL CODING → NEURAL PROCESSING → OUTPUT

Detailed description: This slide is identical to the one above but includes the introductory text: 'Let's now step through this processing stream, beginning with...'





### Horizontal cells

Lateral interactions

From Rodieck (1998)

What sort of processing can be achieved by lateral interactions?

Detailed description: This diagram illustrates the structure of horizontal cells in the retina. A long, thin cell body is shown with numerous dendrites extending laterally across the outer plexiform layer. The dendrites are labeled 'horizontal cells' and are shown interacting with other cells. The diagram is labeled 'HII' and 'HIII' at the ends, indicating the extent of these lateral interactions. The text 'Lateral interactions' is positioned to the right of the title.

### Bipolar cells

ON (greener) and OFF (redder) varieties

From Rodieck (1998)

Parallel processing?

Detailed description: This diagram shows several types of bipolar cells in the retina. The cells are color-coded: green for ON varieties and red for OFF varieties. The types shown are 'diffuse', 'midget', 'S-cone bipolar cells', and 'rod'. Each type is shown with its characteristic dendritic branching pattern and its connection to a rod or cone photoreceptor. The text 'ON (greener) and OFF (redder) varieties' is positioned to the right of the title.

### Amacrine cells

From Rodieck (1998)

Detailed description: This diagram shows several types of amacrine cells in the retina. The cells are shown with various dendritic branching patterns and are labeled 'amacrine cells'. The diagram illustrates the diverse morphology and connectivity of these cells.

### Ganglion cells

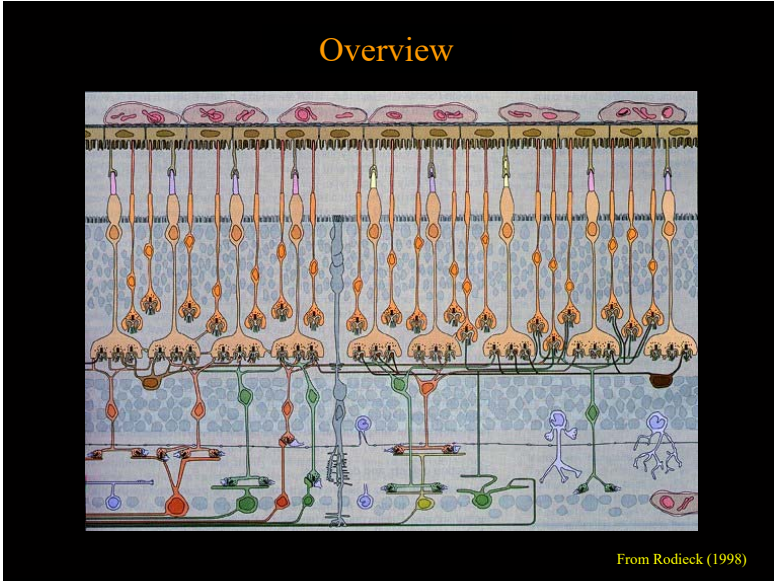
ON and OFF varieties

From Rodieck (1998)

Parallel processing?

Detailed description: This diagram shows several types of ganglion cells in the retina. The cells are color-coded: green for ON varieties and red for OFF varieties. The types shown are 'parasol', 'midget', 'blue-yellow ganglion cells', and 'bipelexiform'. Each type is shown with its characteristic dendritic branching pattern and its connection to a bipolar cell. The text 'ON and OFF varieties' is positioned to the right of the title.



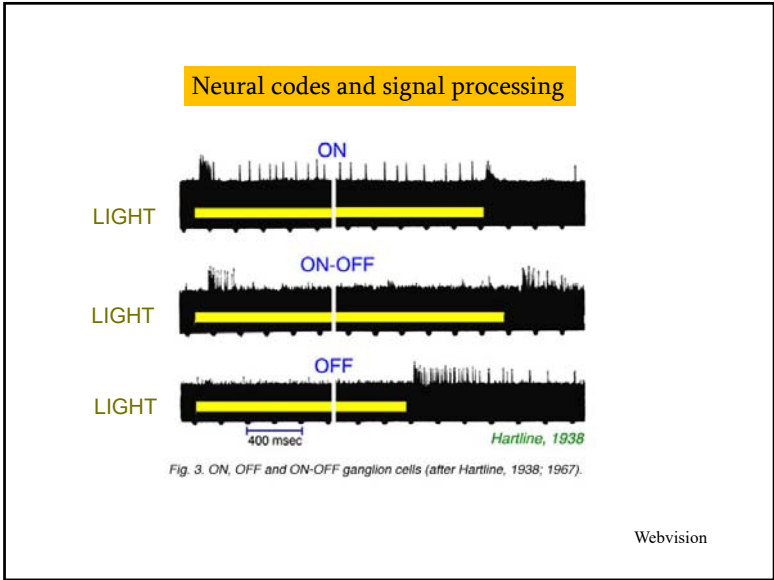


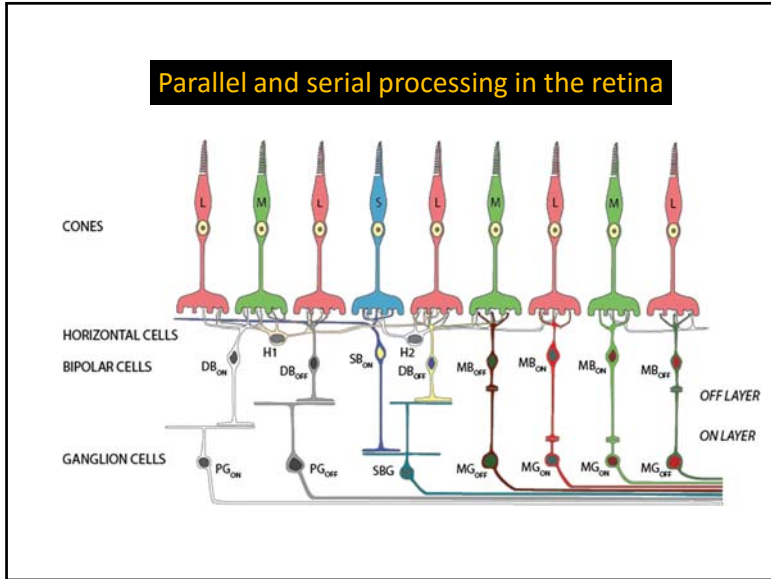
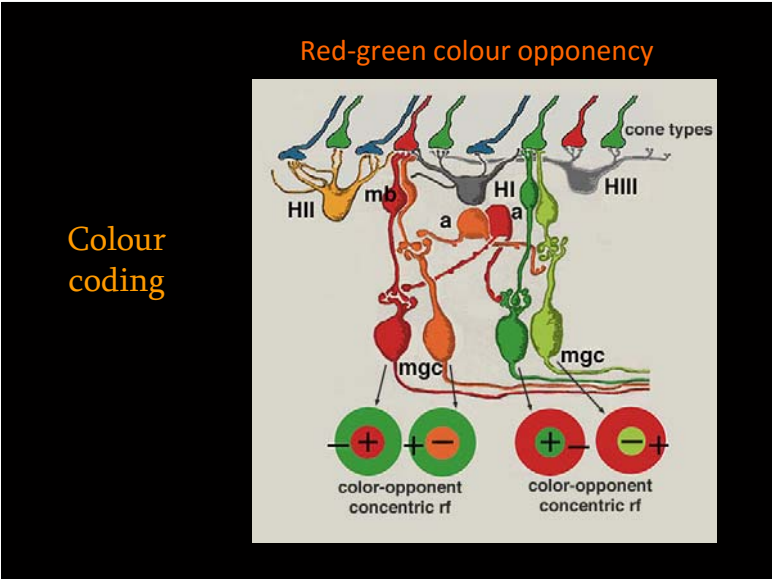
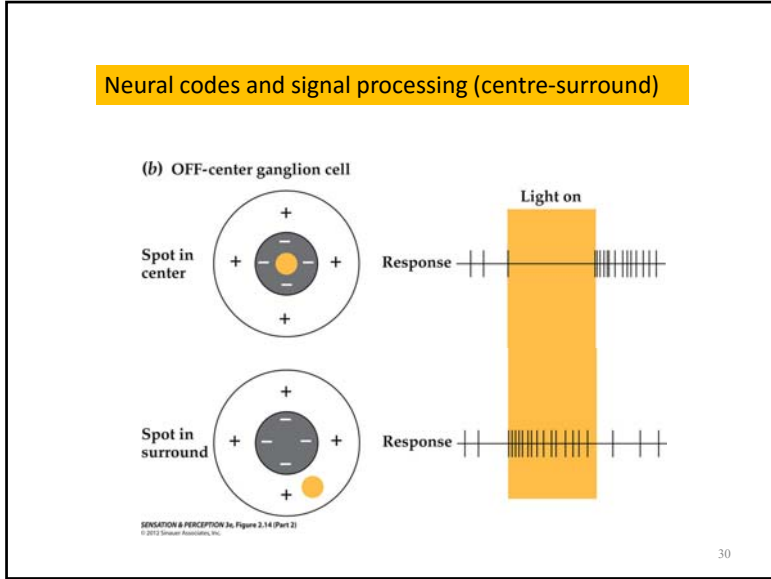
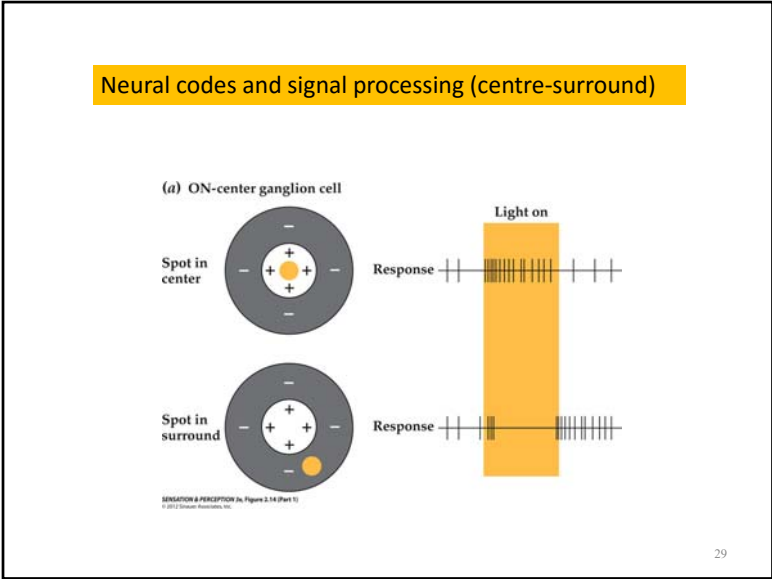
We can investigate what a cell encodes by “mapping” its receptive field

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

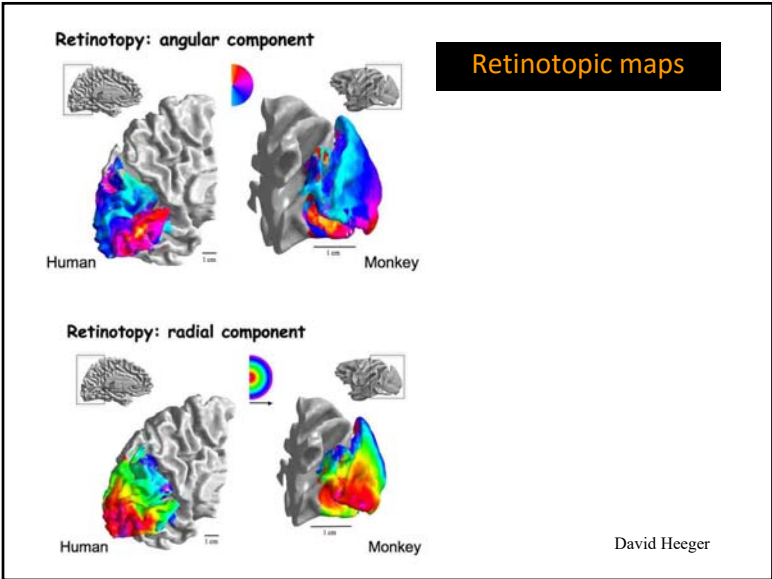
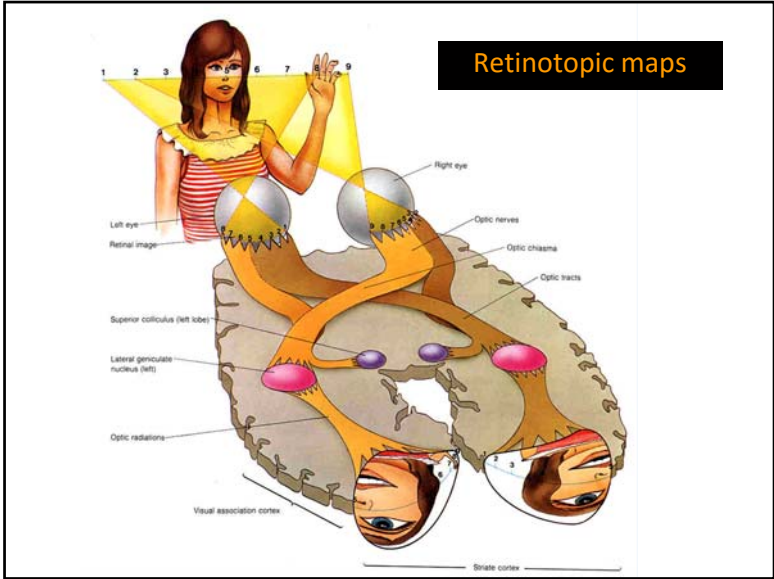
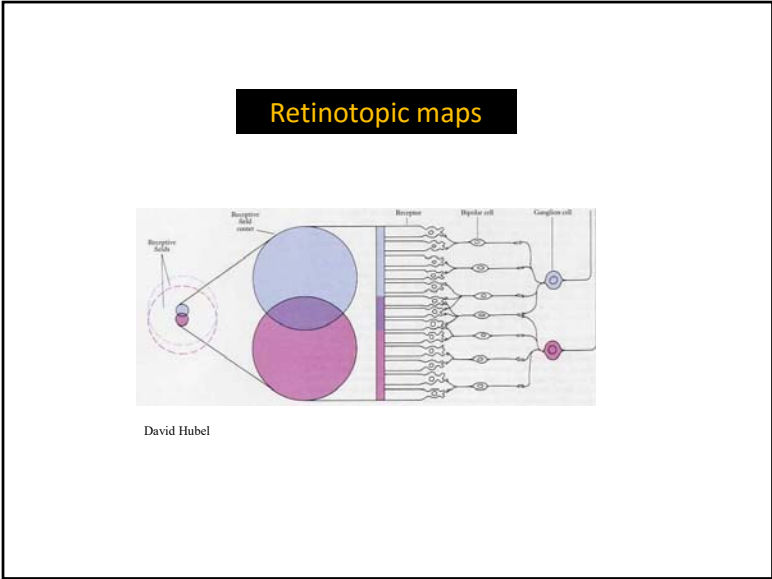
We can investigate what a cell encodes by “mapping” its receptive field

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









### Neural Coding

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, or phosphenes.

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

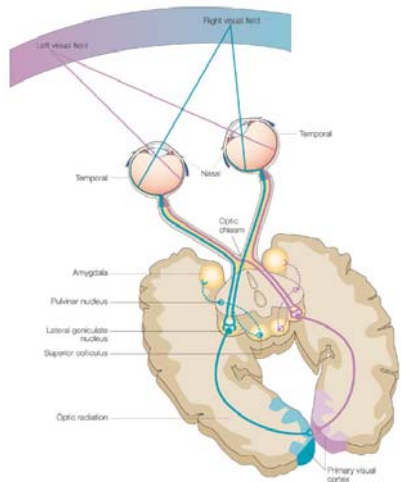
**Johannes Peter Müller (1801-1858)**

### 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...

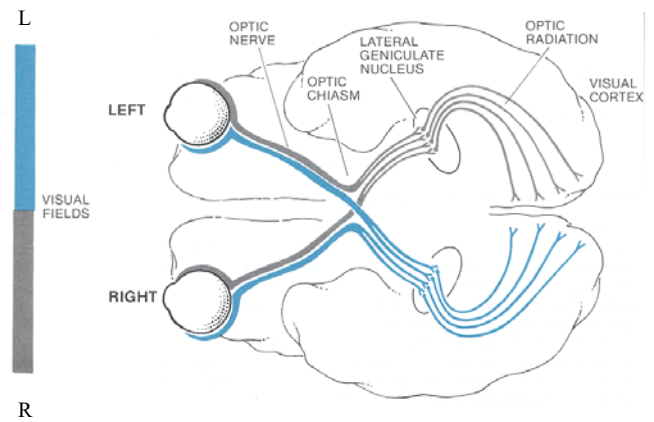
### Geniculo-striate pathway



Hannula, Simons & Cohen, 2005

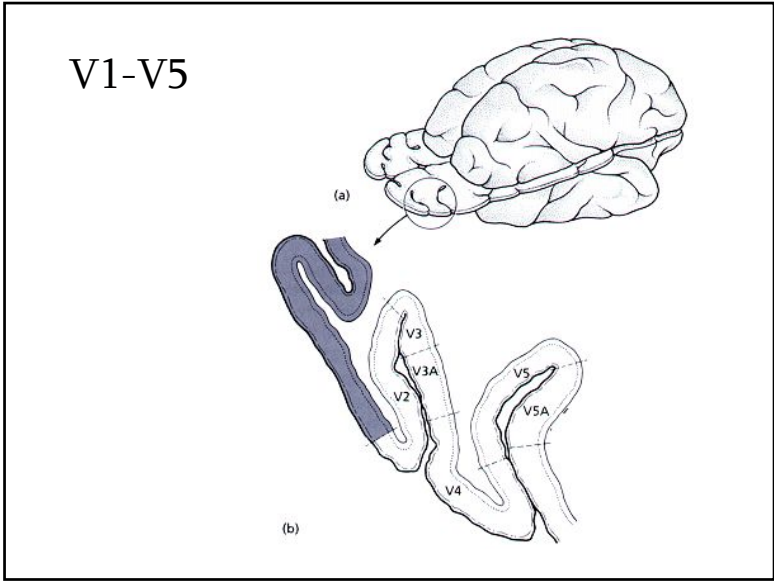
Nature Reviews | Neuroscience

### Visual pathways



From below

# Cortical level



Neural codes and signal processing

Simple cells

V1, layers 4 & 6

Stimulus: on off

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

Stimulus: on off

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

The diagram shows four receptive fields of increasing size, each with a bar stimulus. Below them are raster plots showing the neural response. A graph plots 'Impulses per second' against 'Bar length (degrees)'. The response increases with bar length up to about 4 degrees and then decreases, illustrating end-stopping.

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

The diagram shows five horizontal bars of varying lengths and orientations. To the right, corresponding neural response patterns are shown, with spikes occurring at the onset and offset of the stimulus, and a sustained response during the 'on' period.

Feature extraction:  
orientation

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

The graph plots 'Impulses/sec' on the y-axis (0 to 30) against 'Orientation' on the x-axis (-40° to 40°). The curve is bell-shaped, peaking at 0° (vertical). Three bars of different orientations are shown above the graph, corresponding to points on the curve.

Feature extraction:  
orientation

## Visual areas

The diagram shows a lateral view of the brain with color-coded visual areas: V1 (purple), V2 (orange), V3 (yellow), V3A (green), V4 (blue), V4v (light blue), V5 (red), V5A (pink), V6 (light purple), V6A (light green), V7 (light blue), V7A (light orange), V8 (light yellow). It also shows the optic chiasm, optic nerves, and optic radiations.

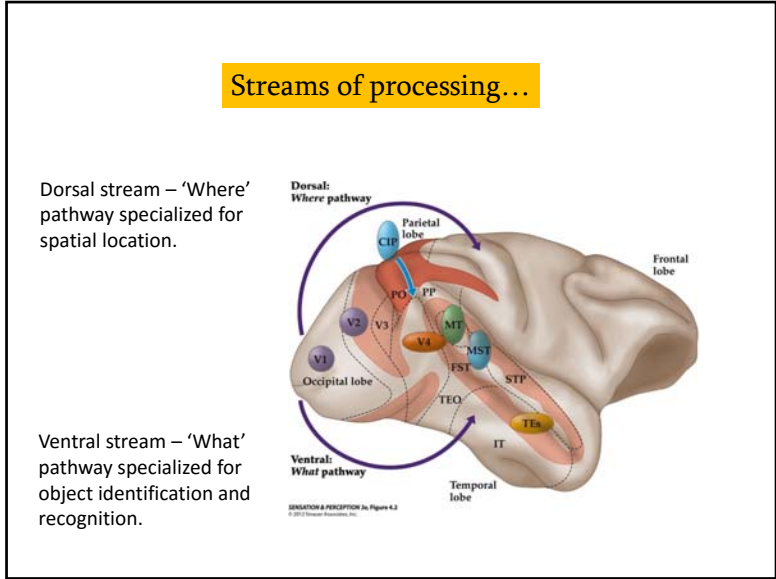
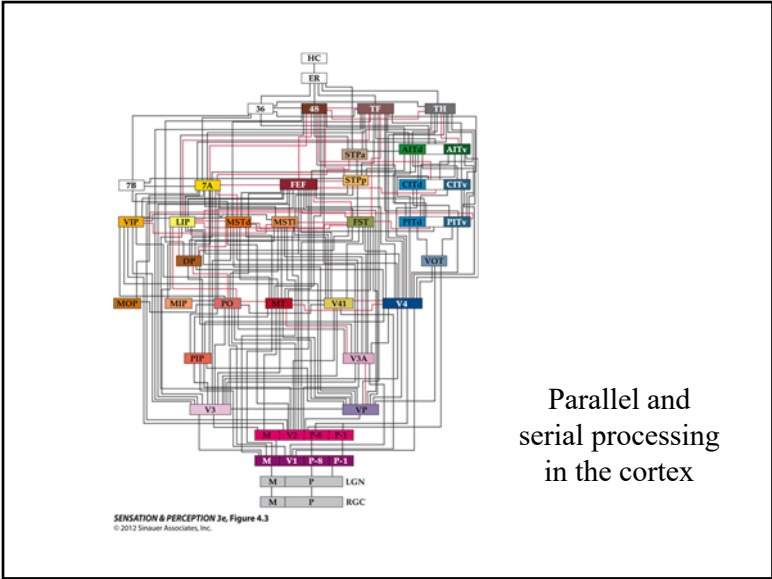
**KEY TO FUNCTION**

- V1: Primary visual cortex; receives all visual input. Begins processing of color, motion and shape. Cells in this area have the smallest receptive fields.
- V2, ■ V3 and ■ VP: Continue processing cells of each area have progressively larger receptive fields.
- V3A: Based for perceiving motion.
- V4v: Function unknown.
- MT/V5: Detects motion.
- V7: Function unknown.
- V8: Processes color vision.
- LO: Plays a role in recognizing large-scale objects.

Note: A (V) region has been identified only in monkeys.

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.



### Ventral stream – ‘What’

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

(a)

(b)

Border-ownership neuron

SENSATION & PERCEPTION 3e, Figure 4.4  
© 2012 Sinauer Associates, Inc.

### Ventral stream – ‘What’

- V1 → V2 → V4 → IT

Face cell

SENSATION & PERCEPTION 3e, Figure 4.5  
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# Processing strategies

Features (Pandemonium model, Selfridge 1959)

The diagram illustrates the Pandemonium model of perception. At the top is a purple **Decision Demon** labeled 'A!'. Below it are five red **Cognitive Demons** labeled 'A', 'O', 'X', 'R', and 'H'. At the bottom are eight red **Feature Demons**, each associated with a specific feature: a vertical line, a horizontal line, a diagonal line, and two curved lines (concave up and concave down).

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)

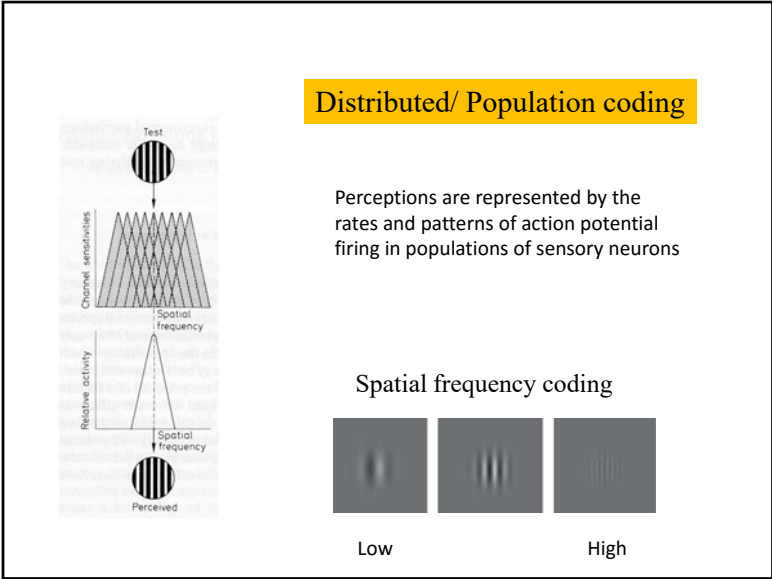
The illustration shows a grandmother with glasses reading a book to a young child. To the right is a diagram of a neuron with several dendrites, labeled '(1234)' and 'Grandmother!'. Below the diagram is the text 'Localist coding schemes'.

## 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 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.

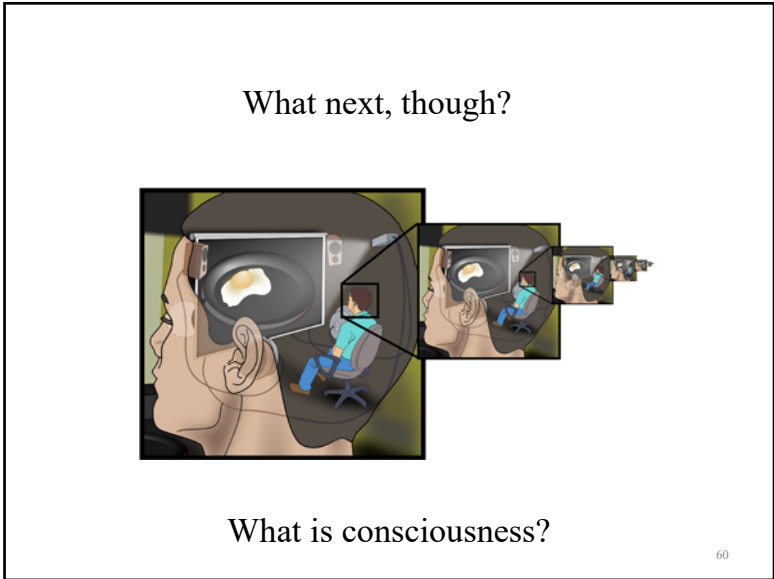
Each concept is represented by many neurons.

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.

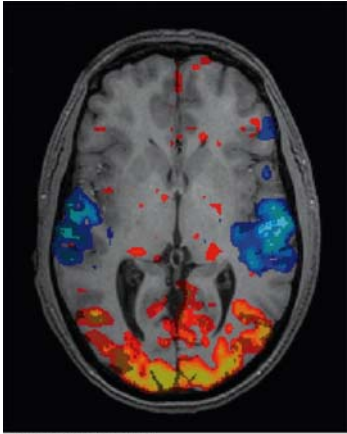


**fMRI**

### Other methods

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



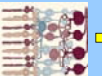


Measure localized brain activity by measuring localized increases in blood flow  
Measures changes of oxygenated and deoxygenated blood to strong magnetic fields (BOLD signal).



SENSATION & PERCEPTION 4e, Figure 1.36  
© 2013 Sinauer Associates, Inc.

### 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.

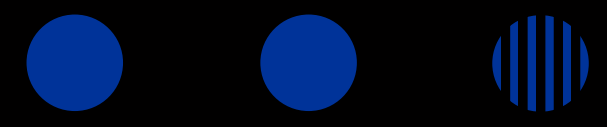
Crucially, though, we can use knowledge from neuroscience to guide our experiments and models.

### 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.

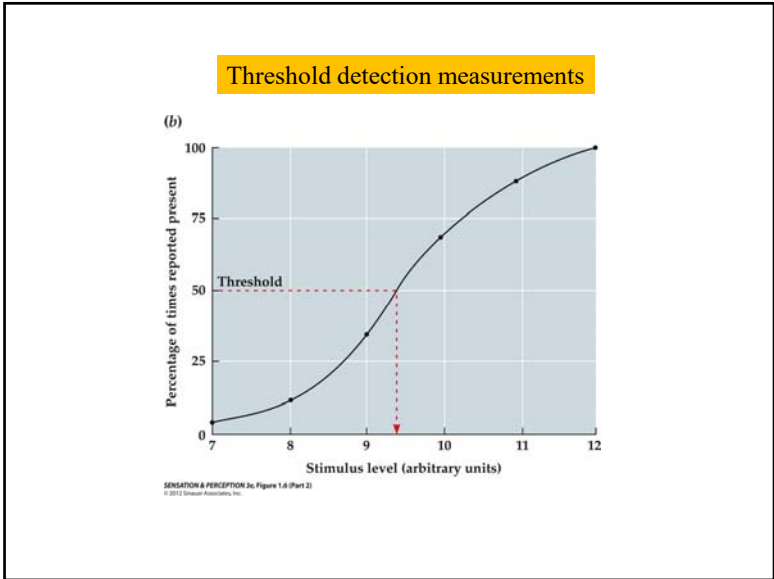
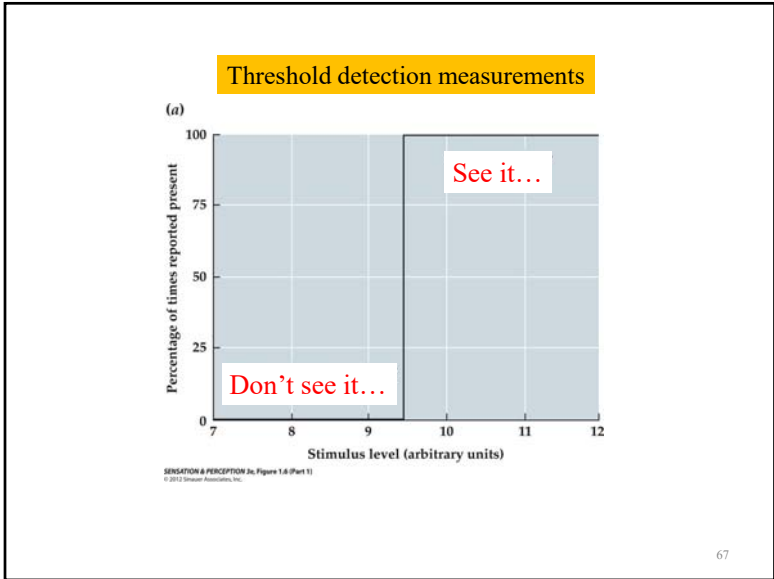
### Which psychophysical tasks provide useful information?

DETECTION TASKS



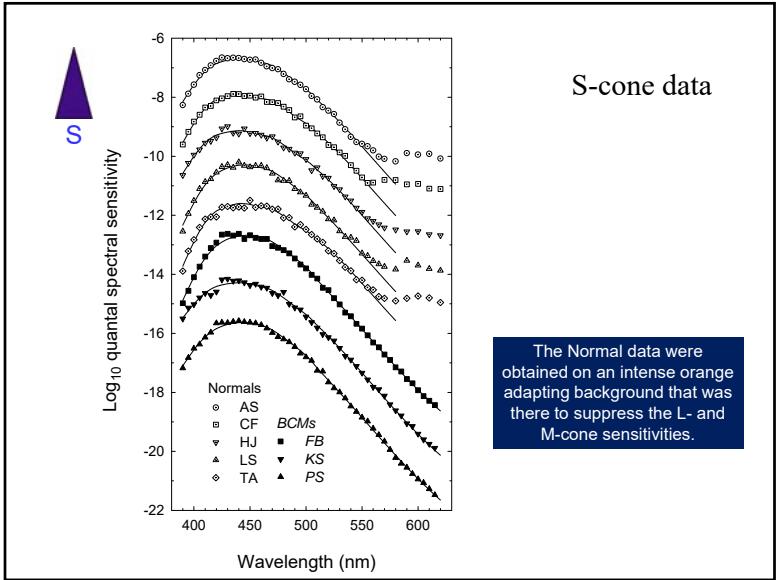
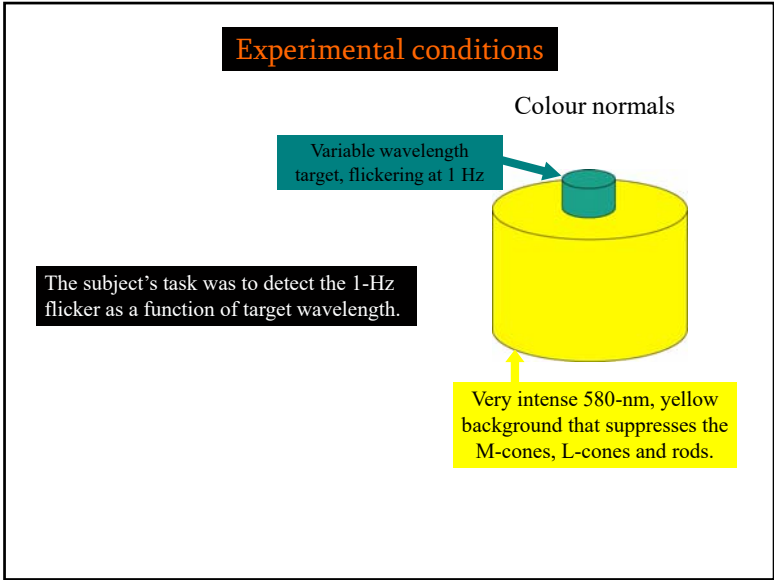
*Is a circle present?*      *Is the circle flickering or steady?*      *Is the pattern (grating) visible?*

In general, we use simple tasks.      Can you think of other tasks?



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.



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?