TSBB15
Computer Vision

Lecture 9
Biological Vision Systems

Two parts

1. Systems perspective

2. Visual perception

Two parts

1. Systems perspective

   Based on Michael Land's and
   Dan-Eric Nilsson's work

2. Visual perception

   Based on Slides from

   Gösta Granlund

Vision Systems

Camera vs. eye

Vision Systems

≠

Purpose:

Reproduce the world
as accurately as possible

Purpose:

Sensing device for
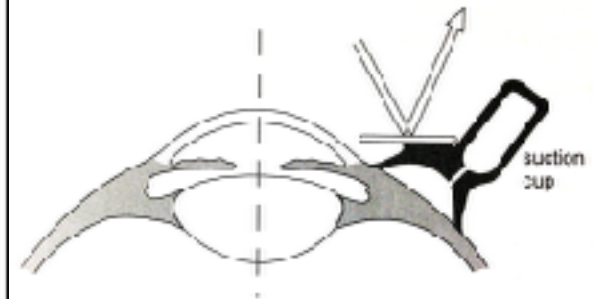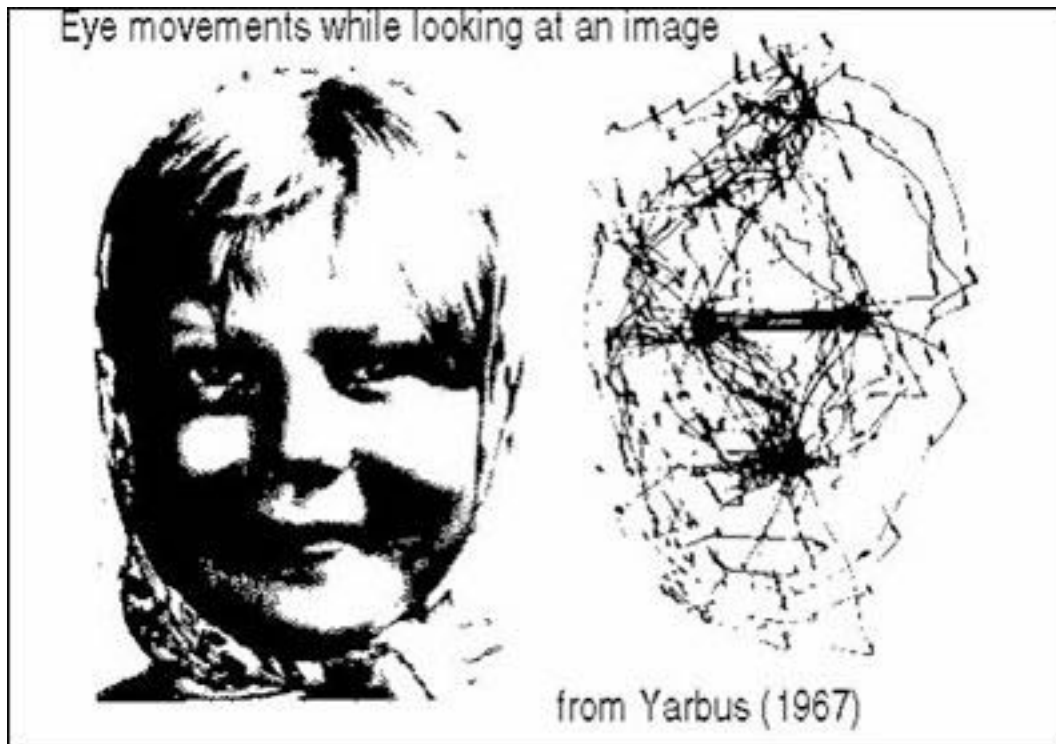visual behaviours

Vision Systems

What a camera sees

Vision Systems

What the human eye sees

Vision Systems

Eye movements while looking at an image

from Yarbus (1967)

Device used by Yarbus
Illustration from:
M. F. Land "Looking and Acting"

Vision Systems

≠

Uniform resolution
Smooth motion

just central 2° are sharp
saccadic motions (avg. 3Hz,
around 700°/s)

Vision Systems

Peripheral view

Foveal view

What a robot sees

Visual Behaviours

Saccadic motion is an example of a visual behaviour

Purpose?

Visual Behaviours

Other examples of visual behaviours:

1. Fixate moving targets

2. Compensate for head and body movement

3. Change detection

4. Recognition

Visual Behaviours

Other examples of visual behaviours:

1. Fixate moving targets - Optokinetic Reflex (OKR)

2. Compensate for head and body movement
 - Vestibulo - Ocular Reflex (VOR)

3. Change detection

4. Recognition

Visual Behaviours

Experiment:

Hold out your hand and raise a finger:

1. turn head while looking at finger (VOR)
2. move hand while looking at finger (OKR)

Which reflex is faster?

Visual Behaviours

Visual input for VOR (stabilization)?

Visual input for OKR (tracking)?

Visual Behaviours

Visual input for VOR (stabilization)?
 - Optical flow (dense over entire visual field)

Visual input for OKR (tracking)?
 - Tracking (region around fovea)

Visual Behaviours

Visual input for VOR (stabilization)?
 - Optical flow (dense over entire visual field)

Visual input for OKR (tracking)?
 - Tracking (region around fovea)

Note: VOR mainly uses input from the vestibular system (optical flow is used for learning).

Visual Behaviours
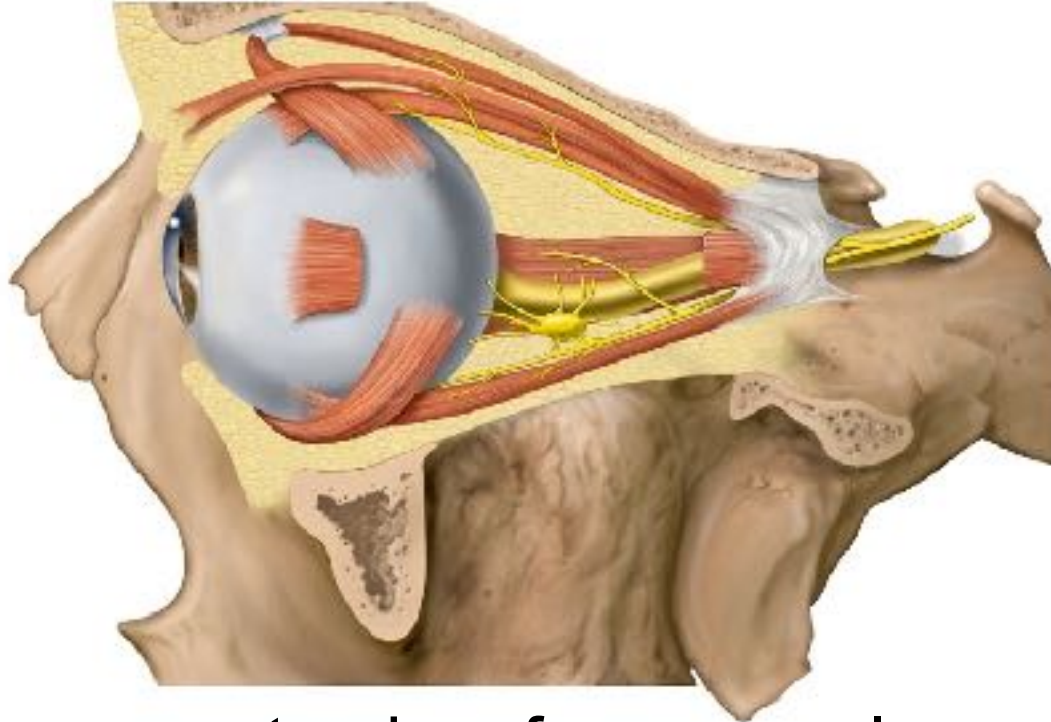
- Three opponent pairs of eye muscles
- Whole neck-eye system is involved in gaze control

VCR in Weka bird

Whole head has to move in birds - Vestibulo-Collic Reflex

<u>Weka VCR - YouTube</u>

VCR in Chicken

Whole head has to move in birds - Vestibulo-Collic Reflex

Chicken VCR - YouTube

VCR on Robot

Boston Dynamics version of VCR
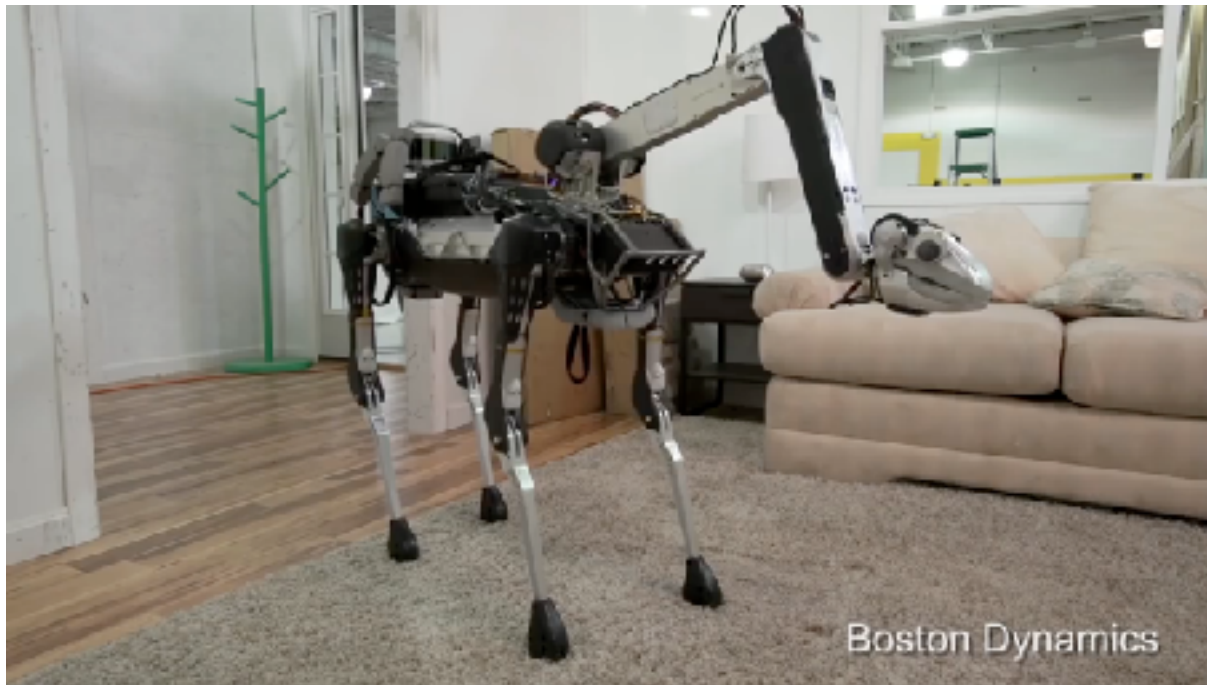
Boston Dynamics - YouTube

Visual Behaviours

Examples of visual behaviours:

1. Fixate moving targets - OKR

2. Compensate for head and body movement - VOR,VCR

3. Change detection - 1&2 + time difference

4. Recognition - Saccadic motions + 1&2 + Perceptual hierarchy

Visual Perception

- How and what separation
  [Godale & Milner, Trends Neuroscience 92]

Dorsal pathway

Ventral pathway

- Dorsal pathway controls gaze and action

- Ventral pathway handles visual recognition
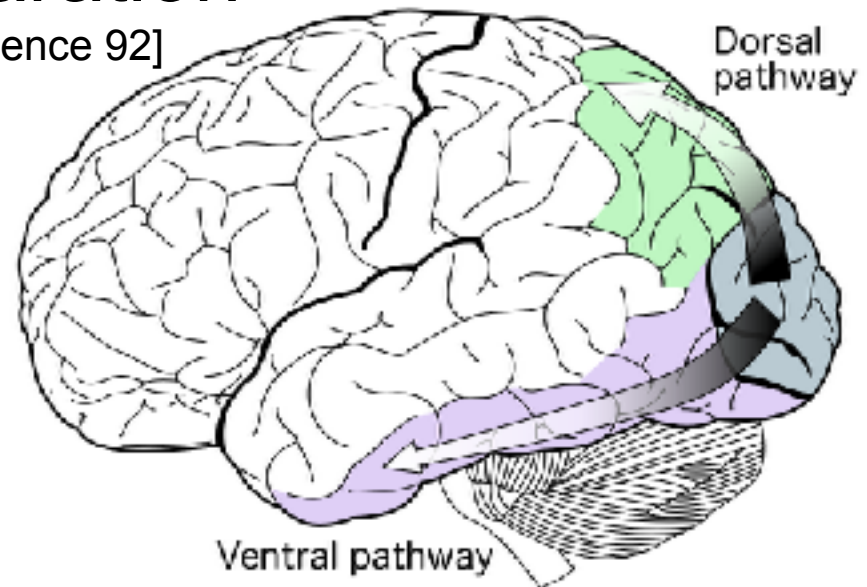
Complex problem

Recognition using direct matching to prototype images is untenable:

- Large number of objects
- Large number of variations

Complex problem

Recognition using direct matching to prototype images is untenable:

• Large number of objects

• Large number of variations

Abstraction is necessary!

The visual pathway

Right optic tract

Right LGN

Optic radiation

Primary visual cortex
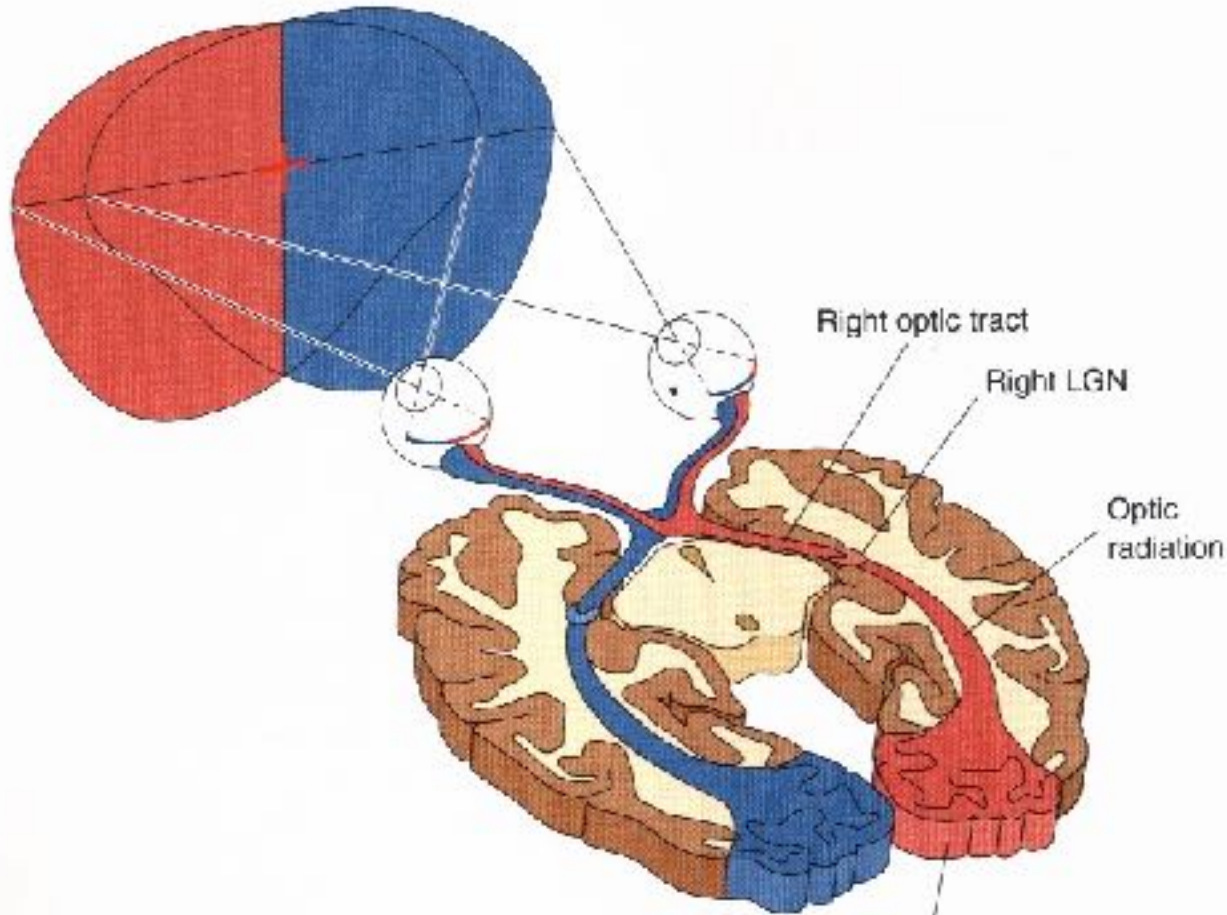
Principal parts of a nerve cell
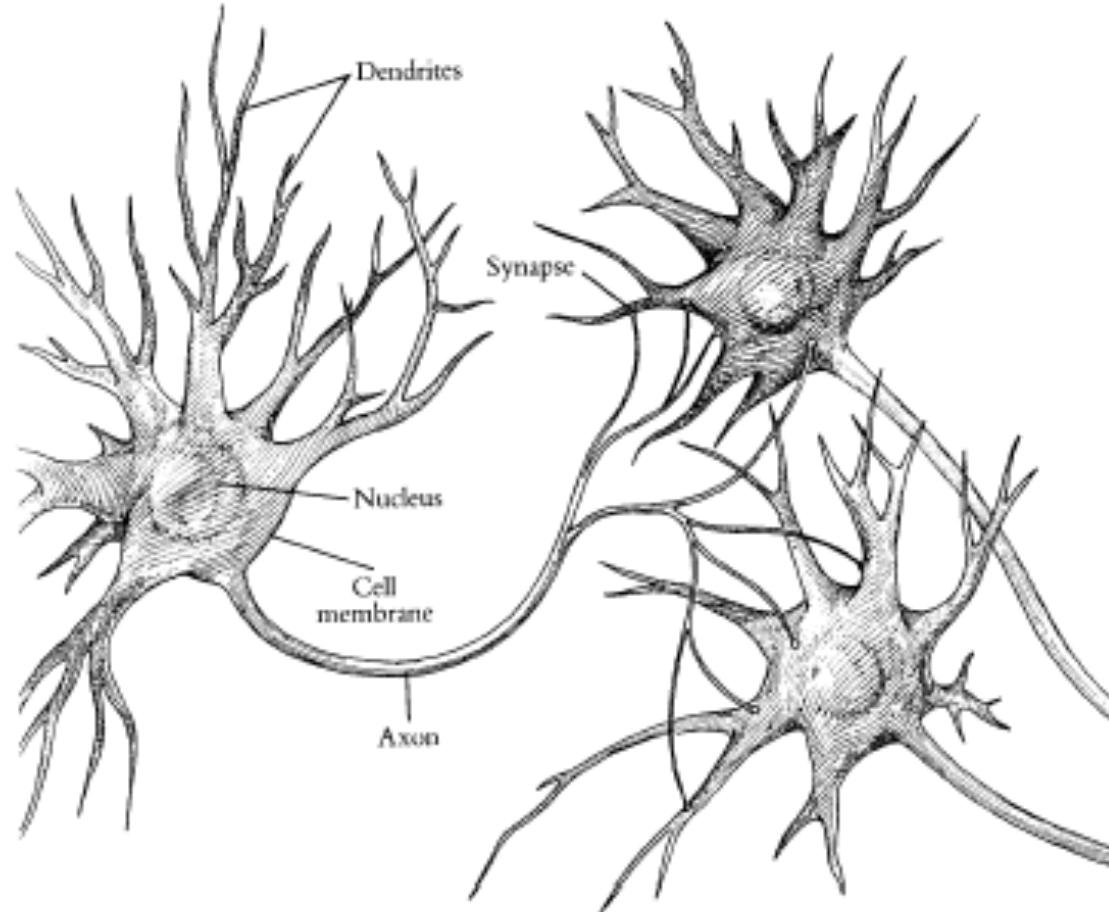
Signals of neurons

- Carried through a chemical process
- Resting potential -70 mV inside axon
- Reversal to +40 mV inside axon
- Refractory time about 1 msek
- A few to > 1000 impulses per second
- Most neurons use **pulse frequency coding**
- A few types have **graded** signals

Neurons

Axons can be < 1 mm to > 1 m

Synapses can be excitatory or inhibitory

50 – 100 neurotransmitters

> 100 different types of neurons

The retina
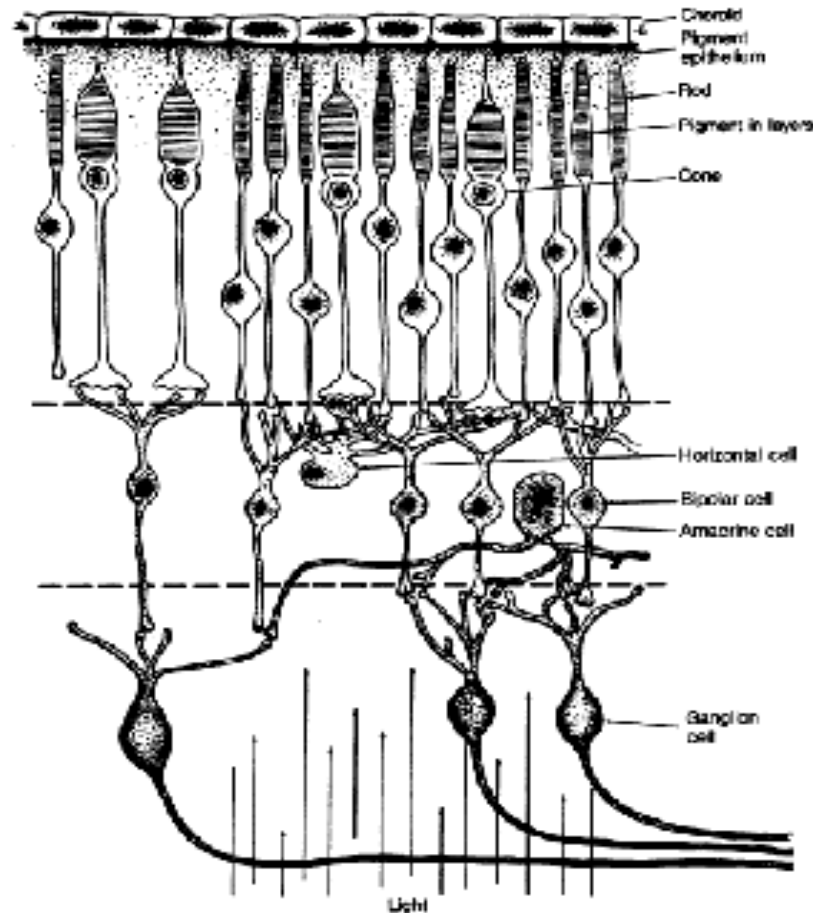
Density of photoreceptors
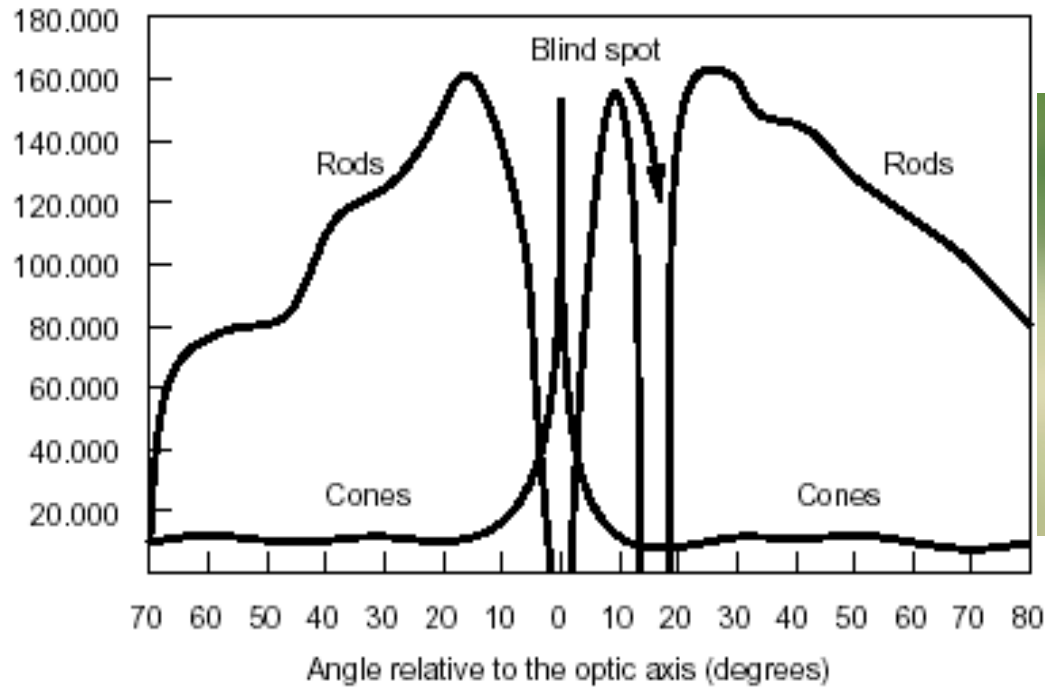
Stability with respect to illumination
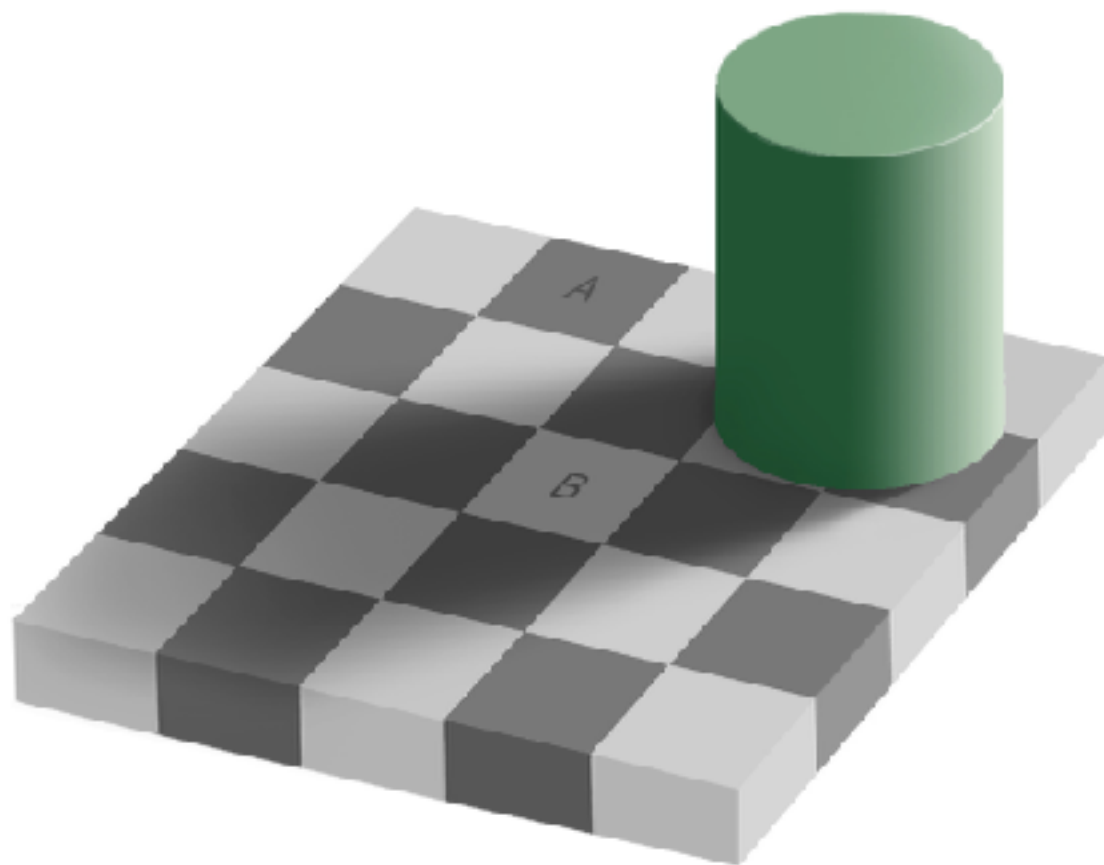
Stability with respect to illumination
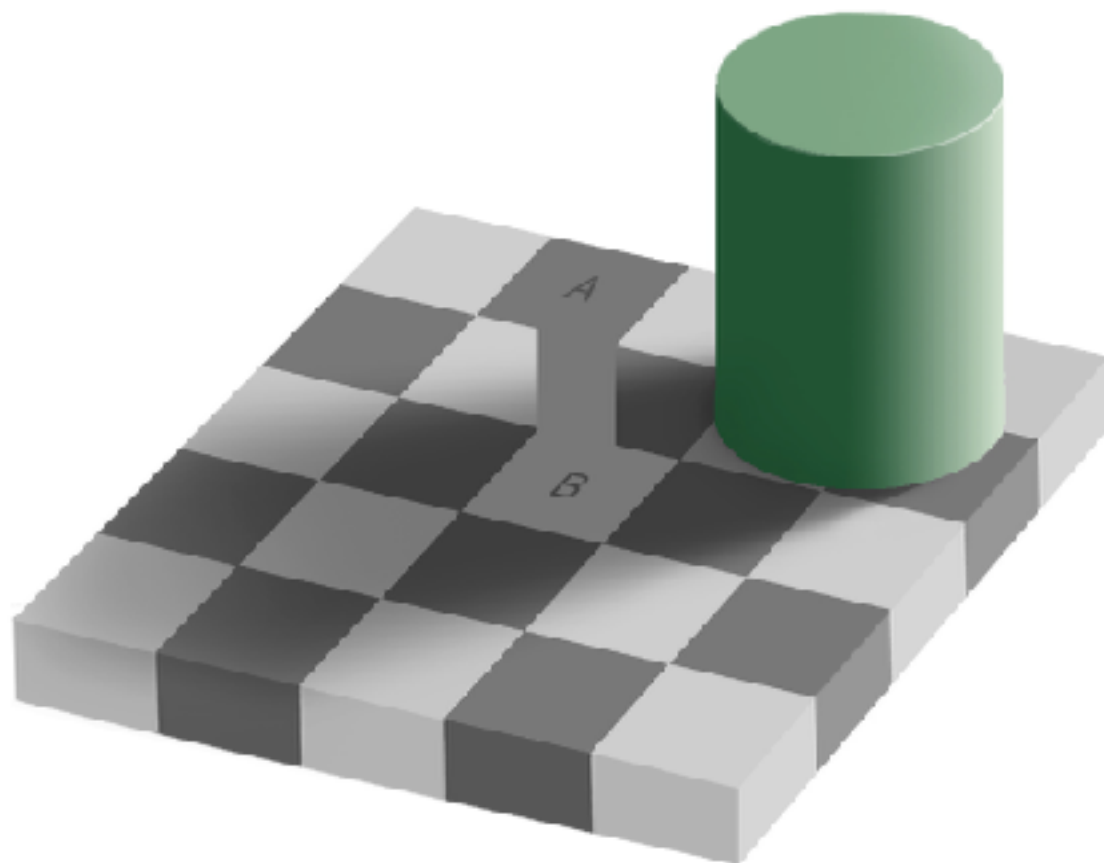
Center-surround receptive fields

On responses

Off responses

On–off responses at transition
zone between on and off areas

On–center
receptive
field

Off–center
receptive
field
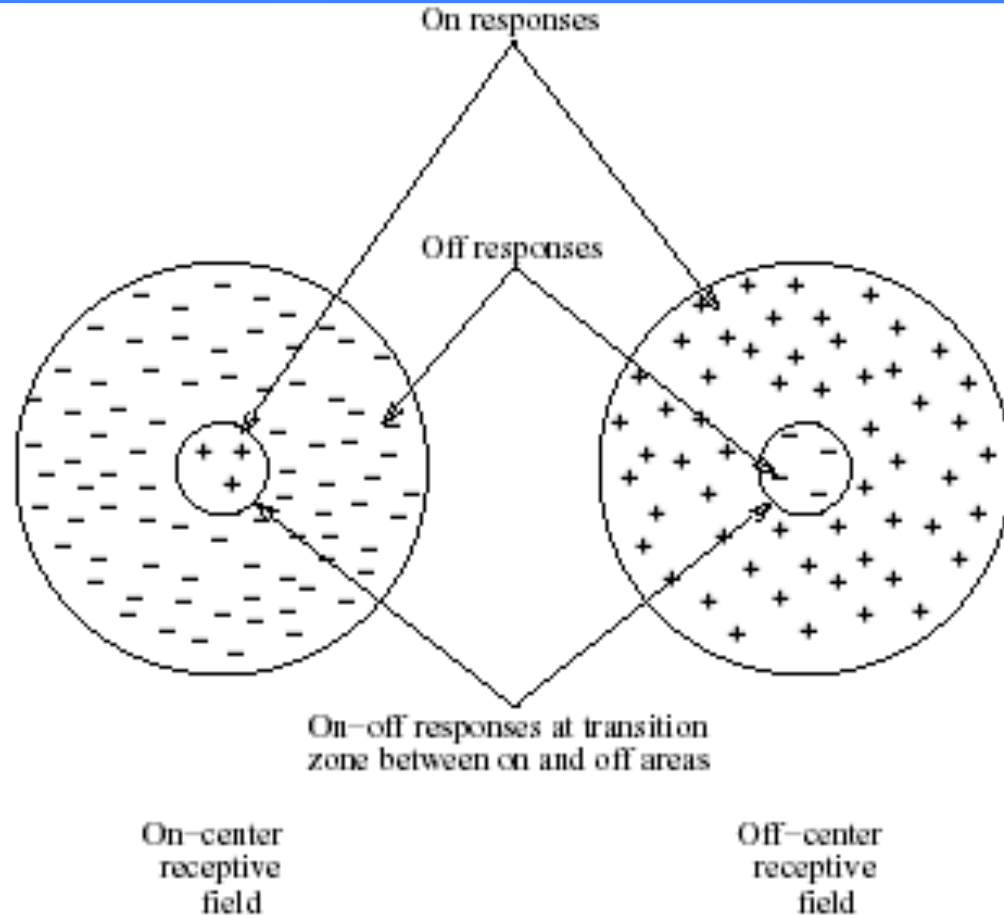
Generation of center-surround fields
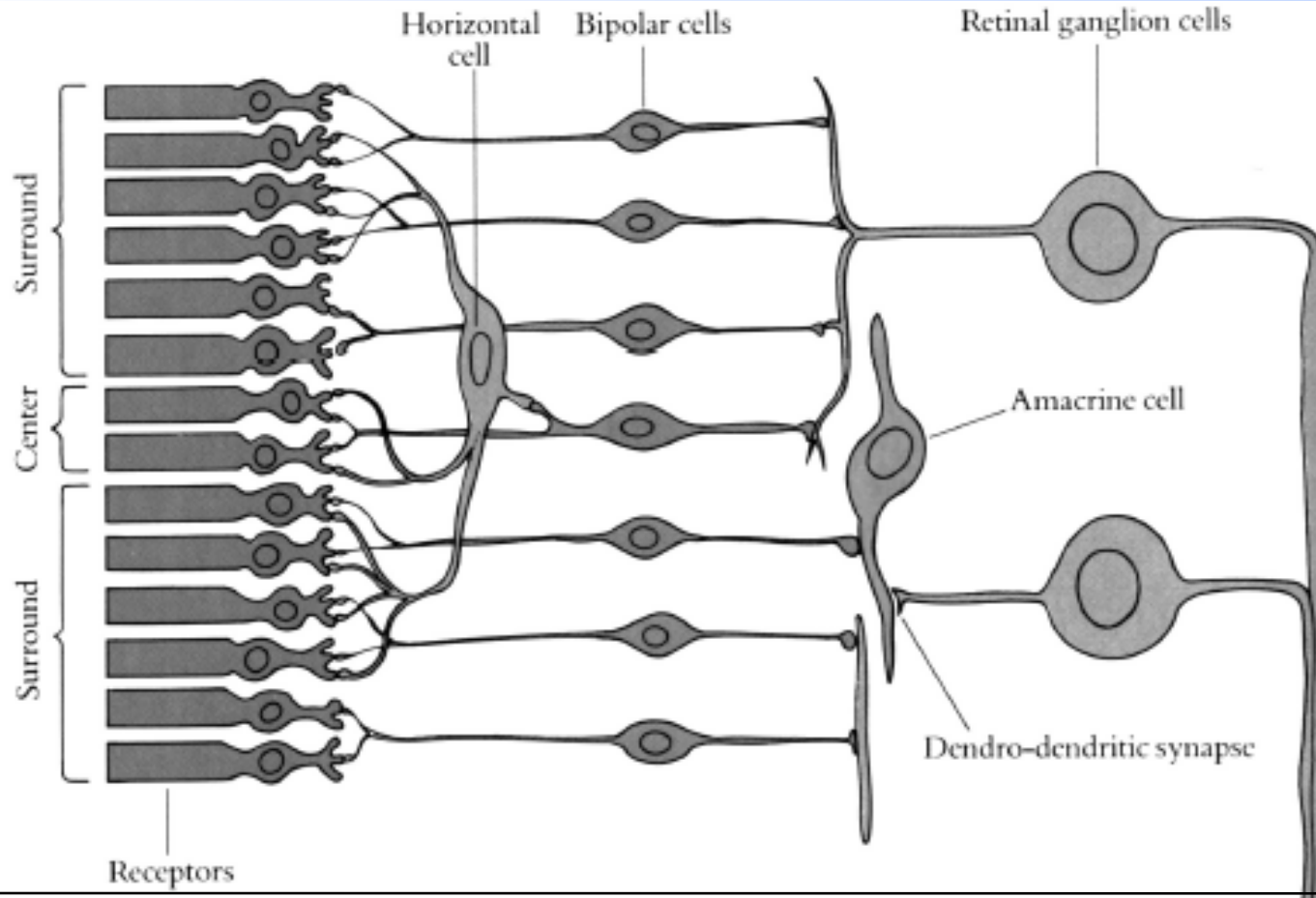
Absorbance spectra of photo pigments
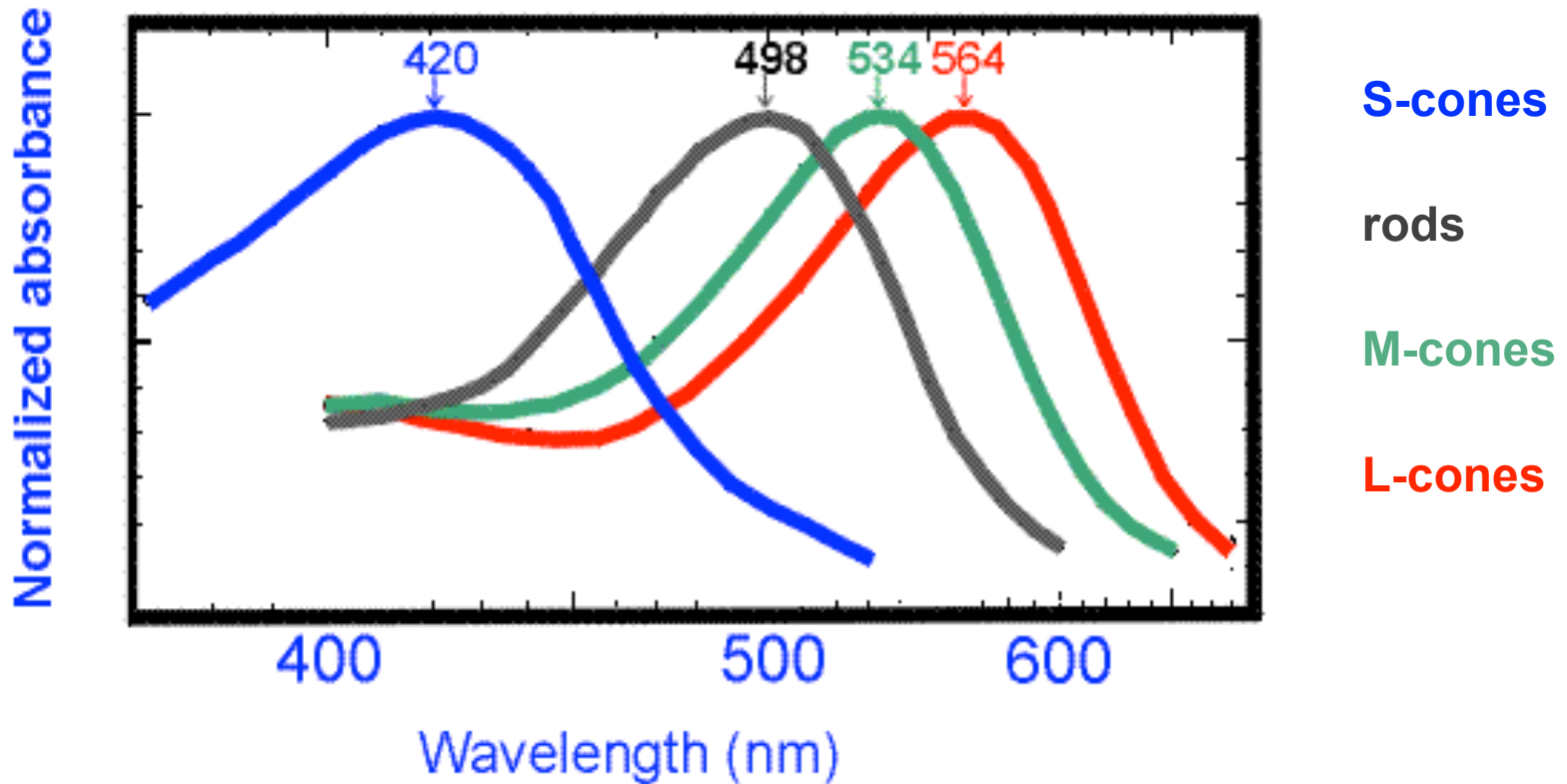
After Bowmaker & Dartnall, 1980

Colour vision theories

The **trichromatic** theory operates at the receptor level

The **opponent processes** theory applies to the subsequent neural level of colour vision processing

Additive colour mixing

Green projector

Red Projector

Blue Projector
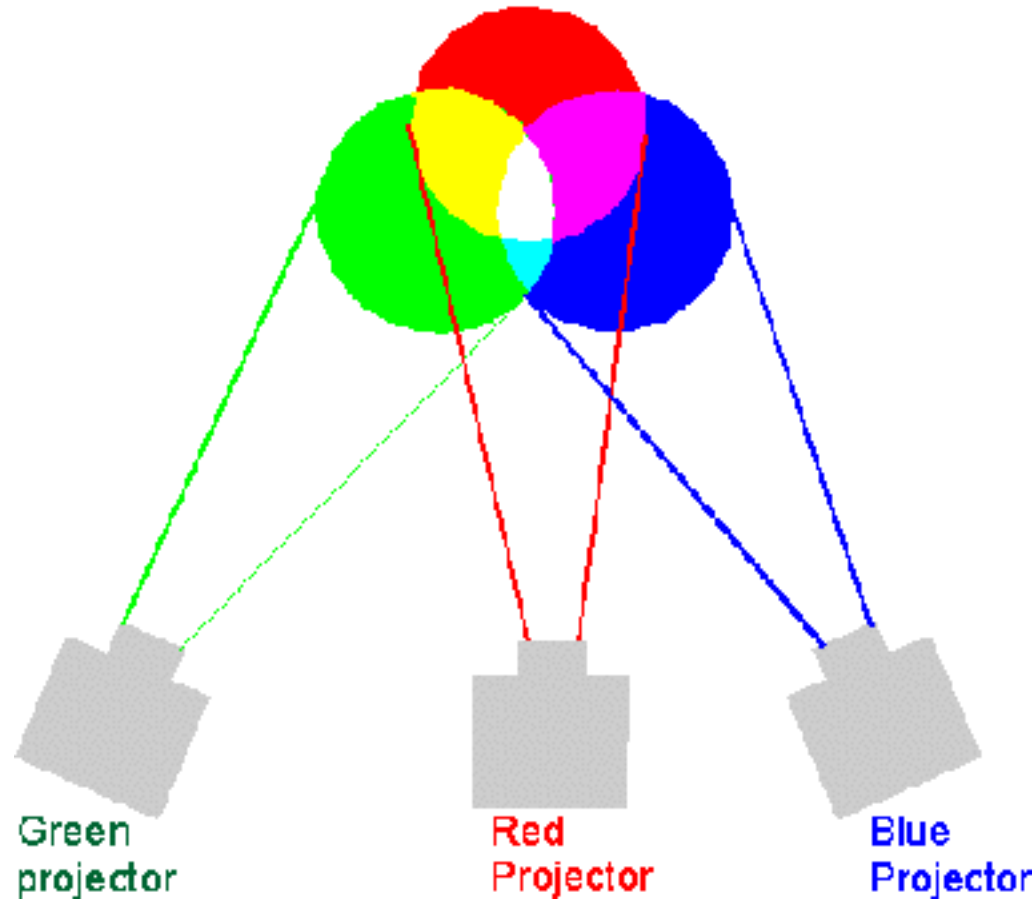
The CIE colour diagram

The visual pathway

Right optic tract

Right LGN

Optic radiation

Primary visual cortex

Cortical maps

Forward

Posterior parietal cortex (PP)

7

V3, V4, V5

19

V2

41   22

38

18

V1

21

17

20

Inferior temporal cortex (IT)
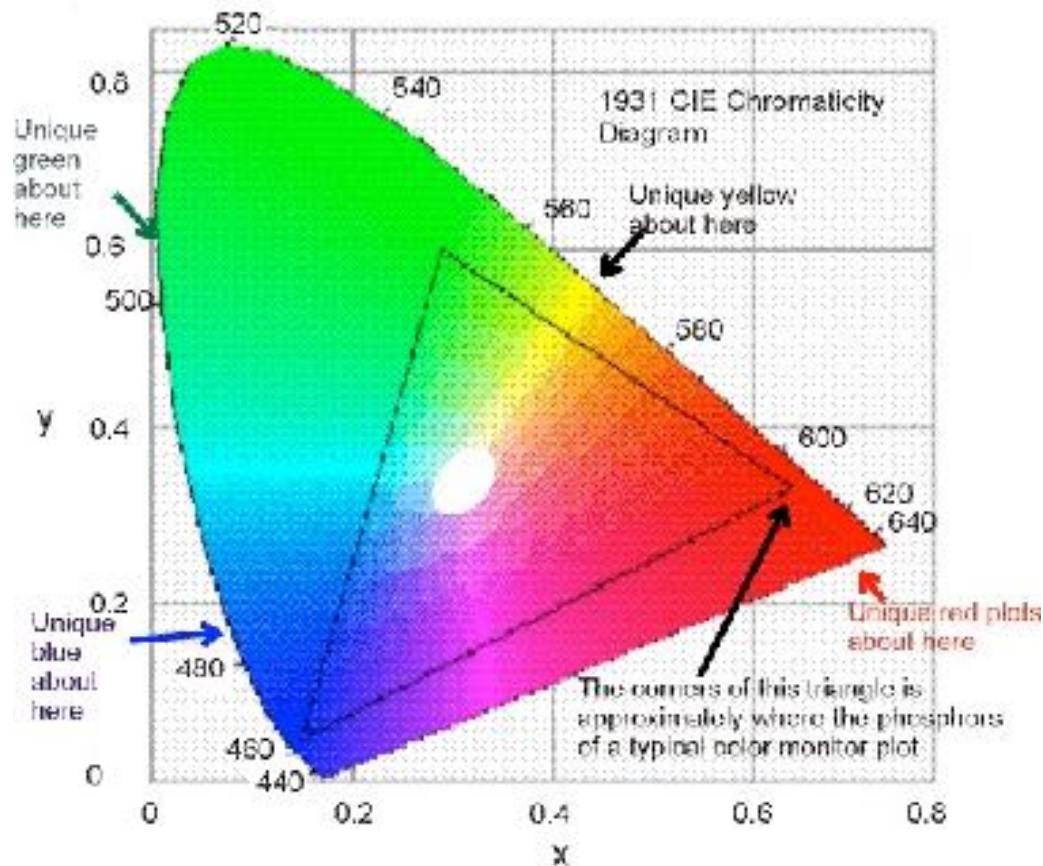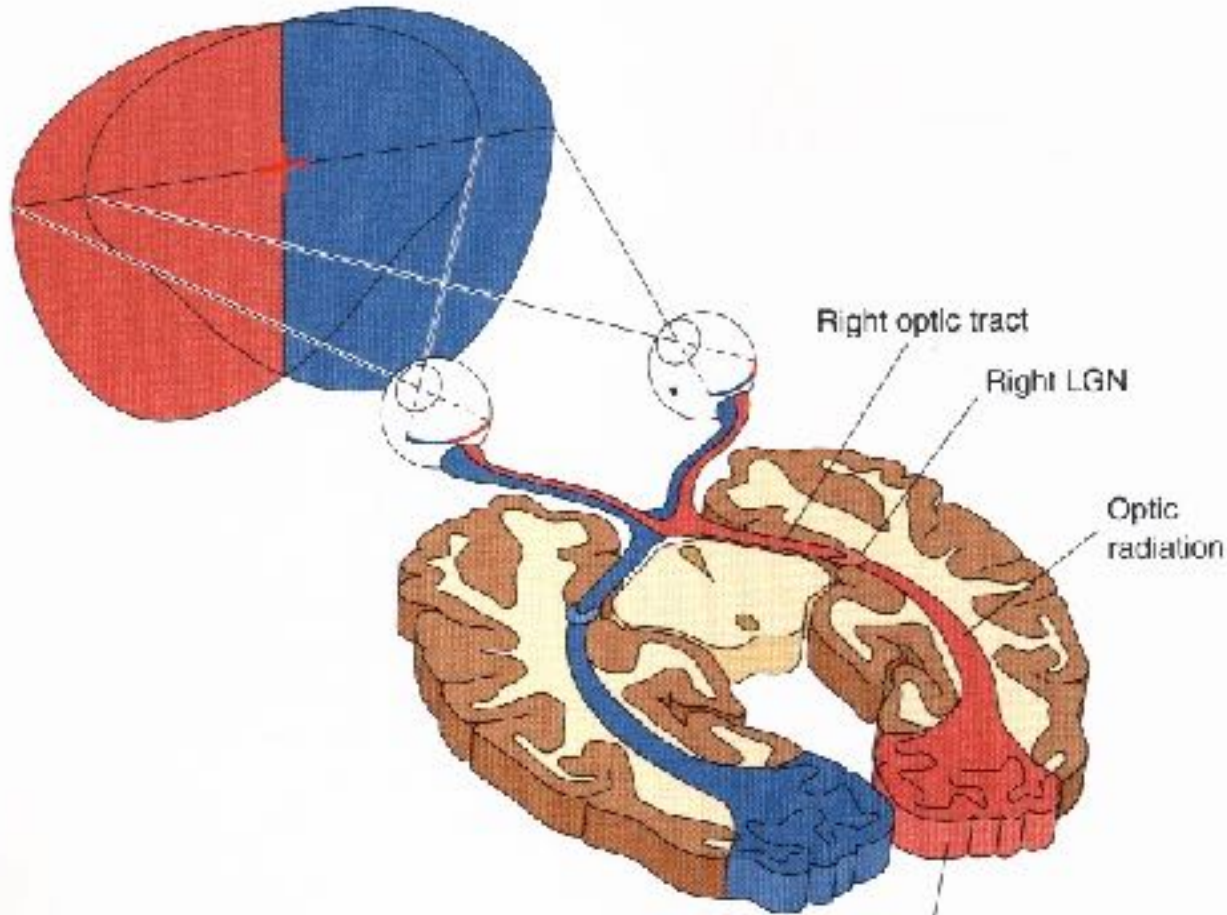
Primary visual cortex
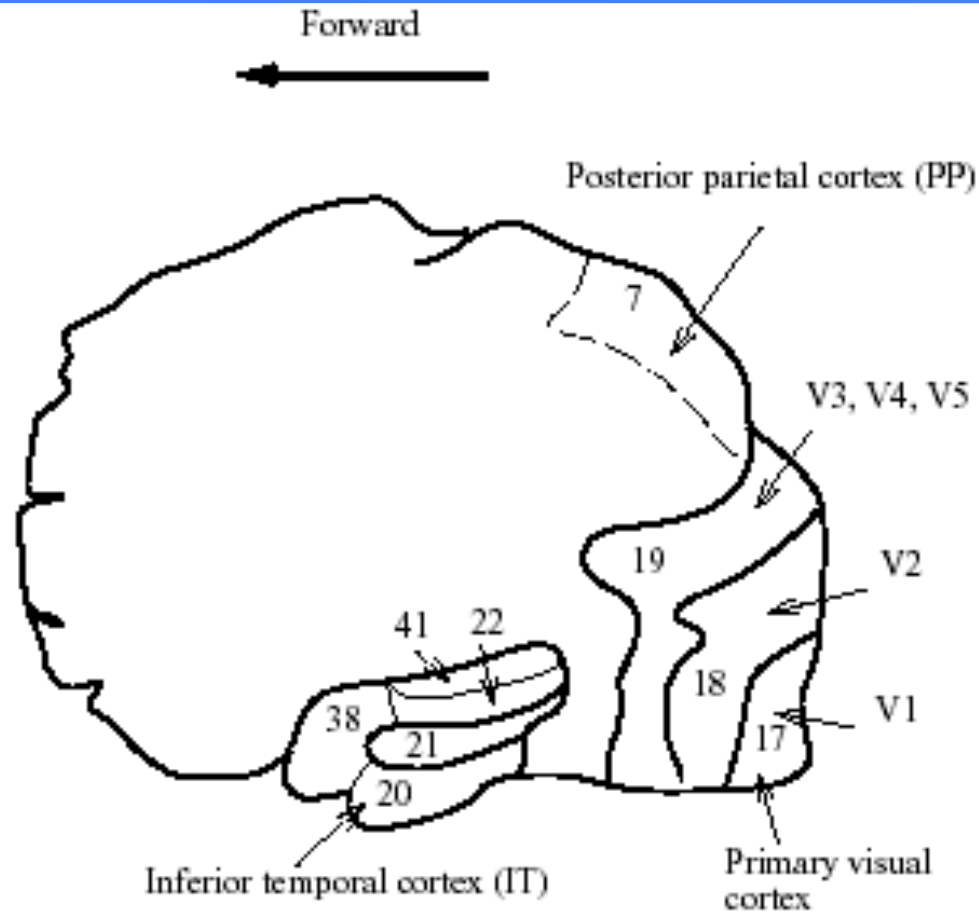
1981 Nobel prize in Medicine

David Hubel, Harvard

Torsten Wiesel, Harvard (initially KI)

- Microelectrodes in primary visual cortex of anasthesized cats
- What visual patterns are a particular cell sensitive to?

Receptive fields of simple cells
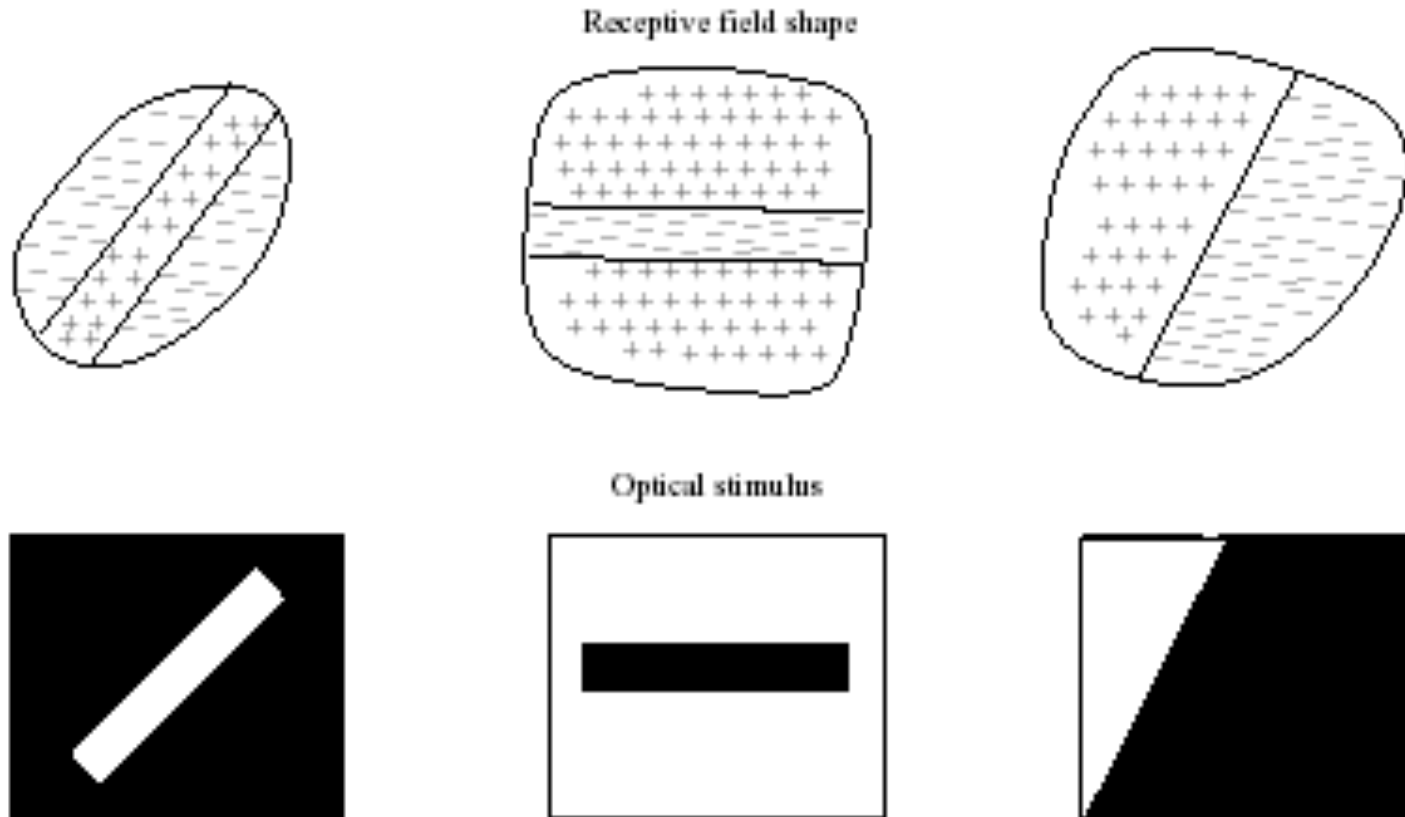
Preference of orientation and direction

Preferred orientation and direction

Preferred orientation and non-preferred direction

Length detector

Length detector
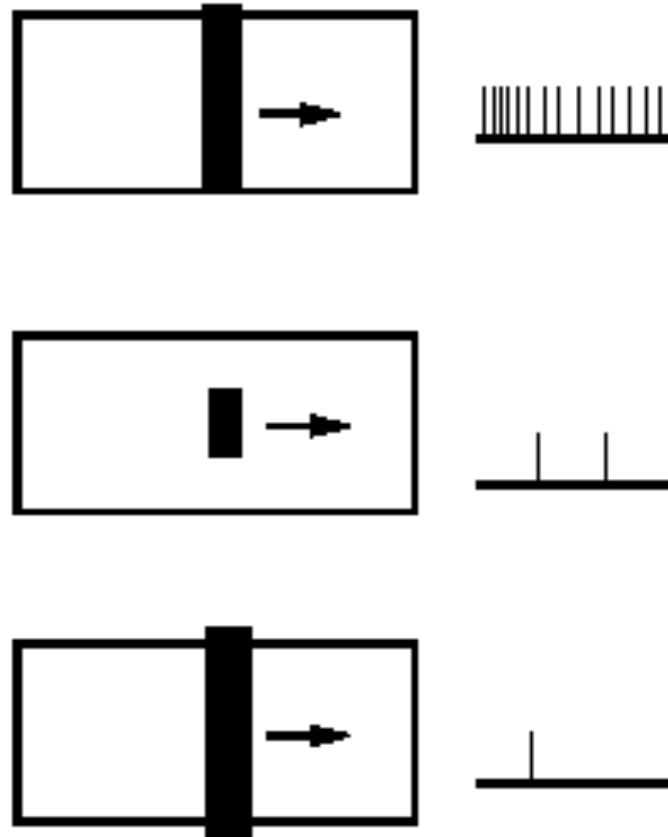
Width detector

Width detector

Angle detector

Angle detector

Stimulus　　　　　　　　　Response
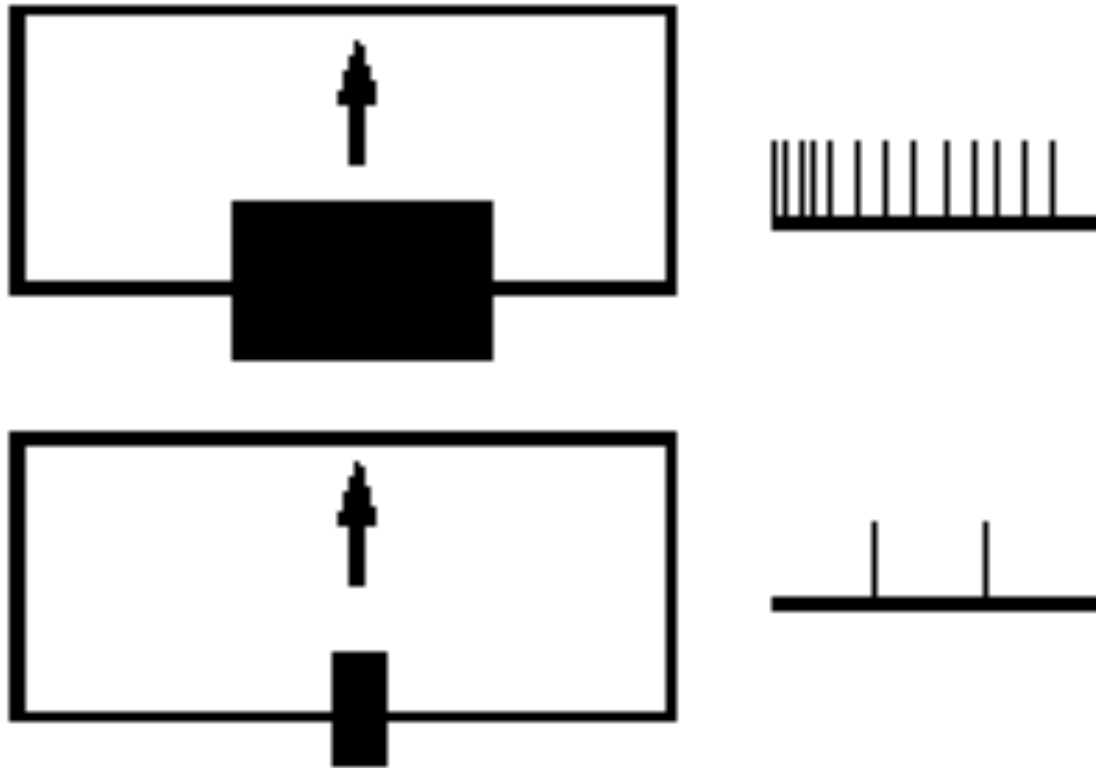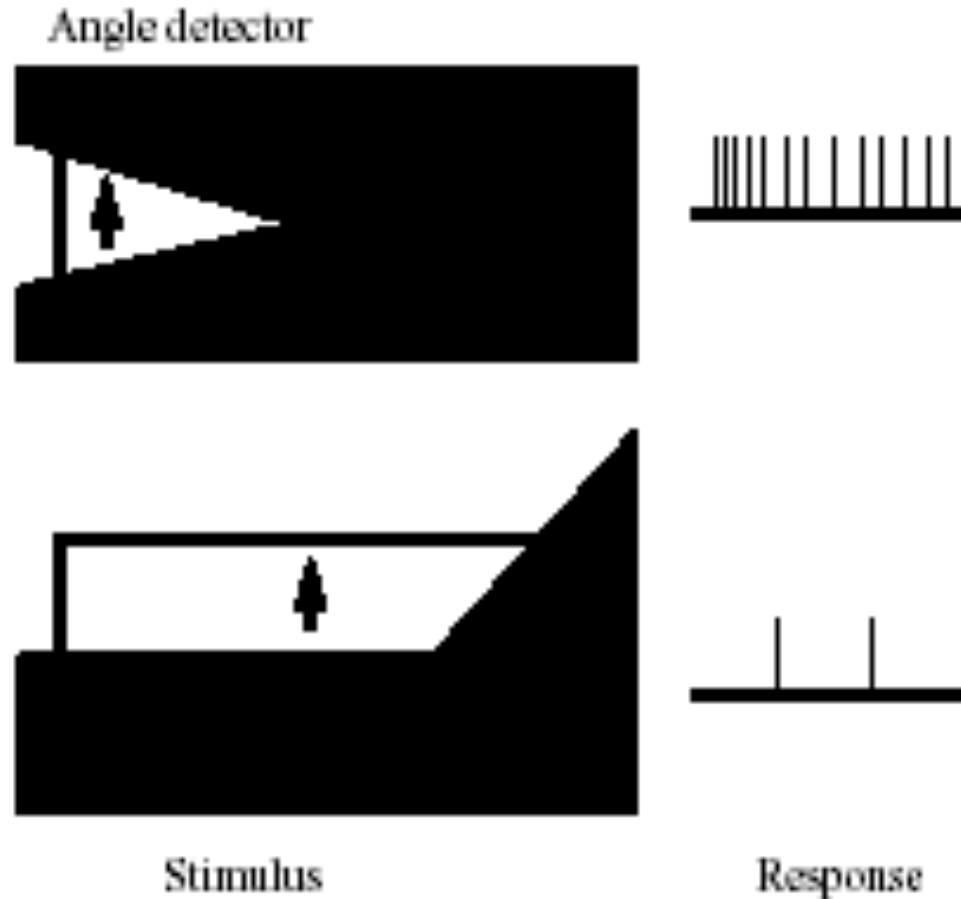
Orientation tuning
Simple cell of cat
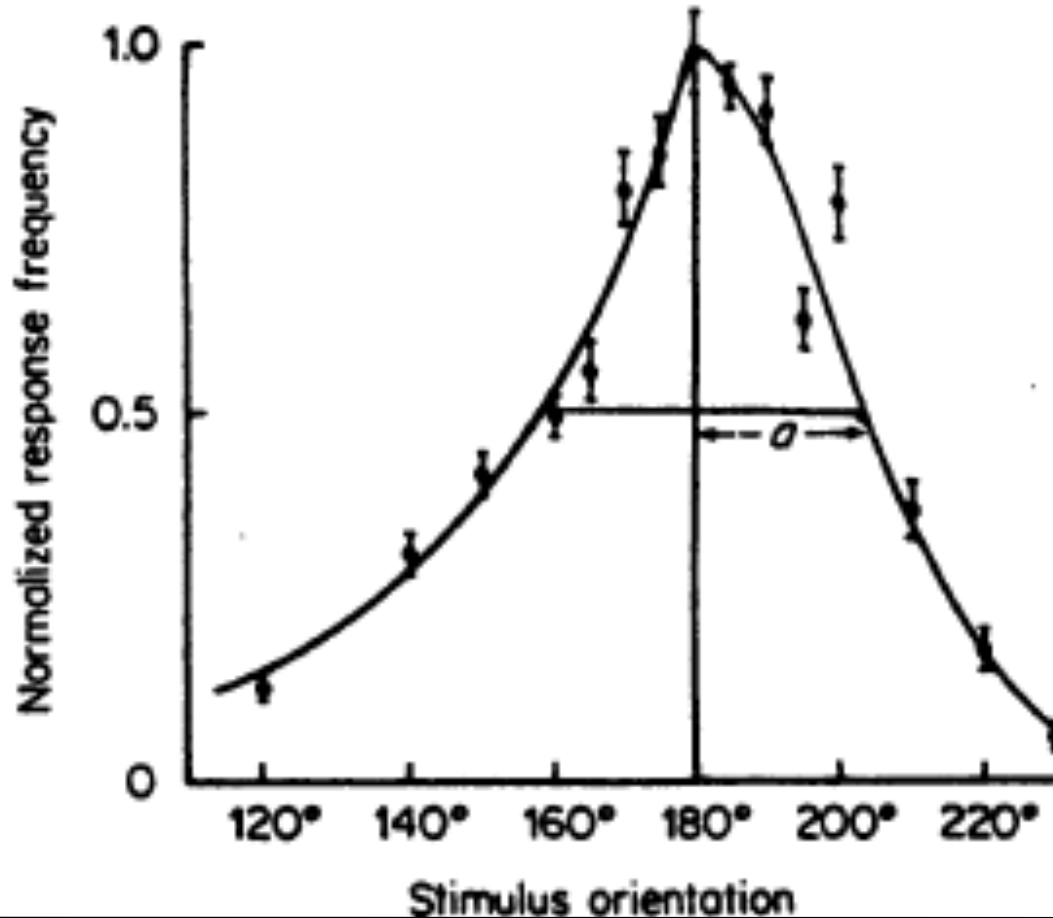
Sensitivity profiles of simple cells a)Bisymmetrical b)Antisymmetrical
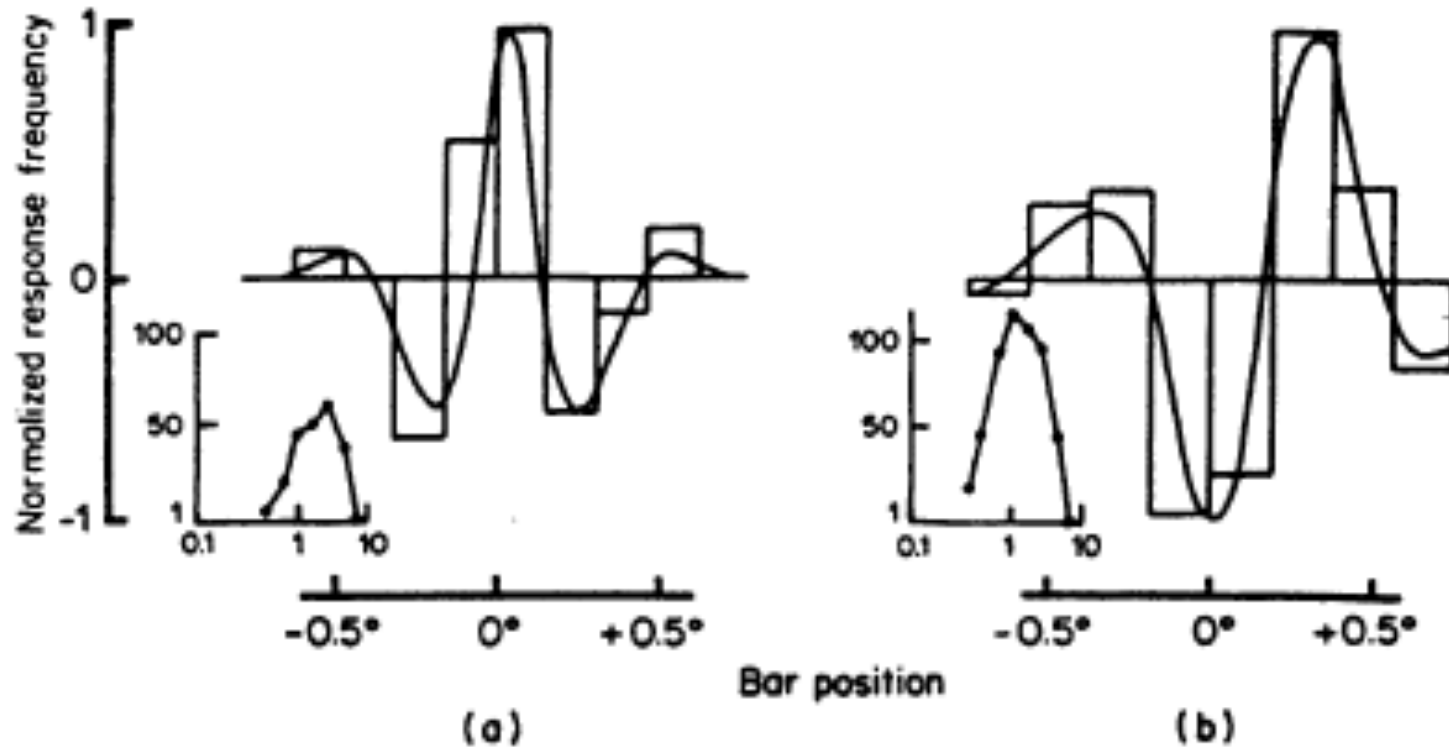
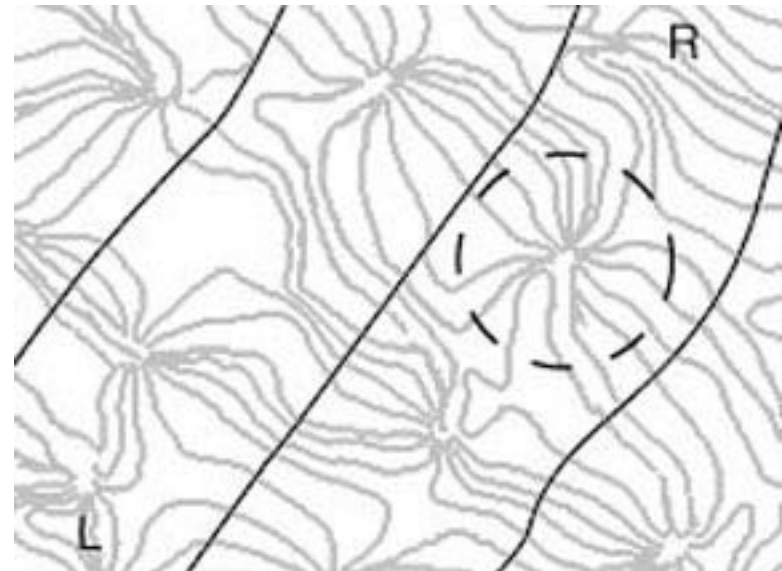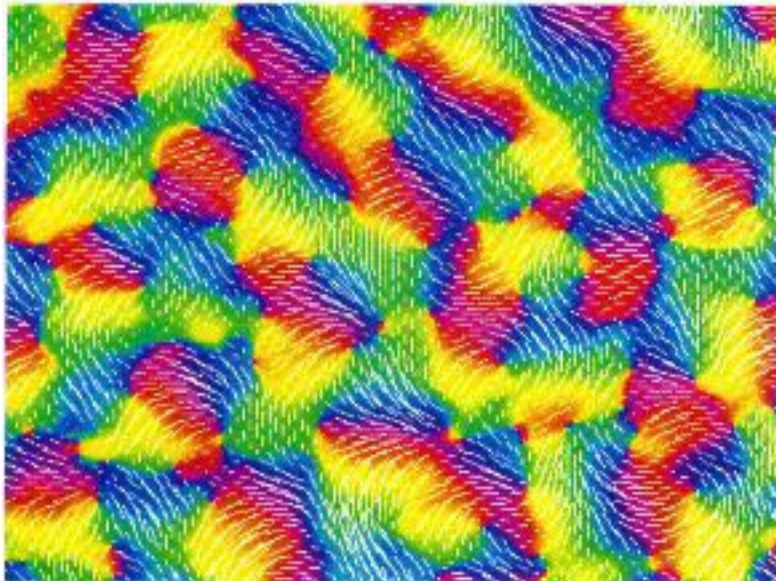# Implementation of simple cell receptive fields
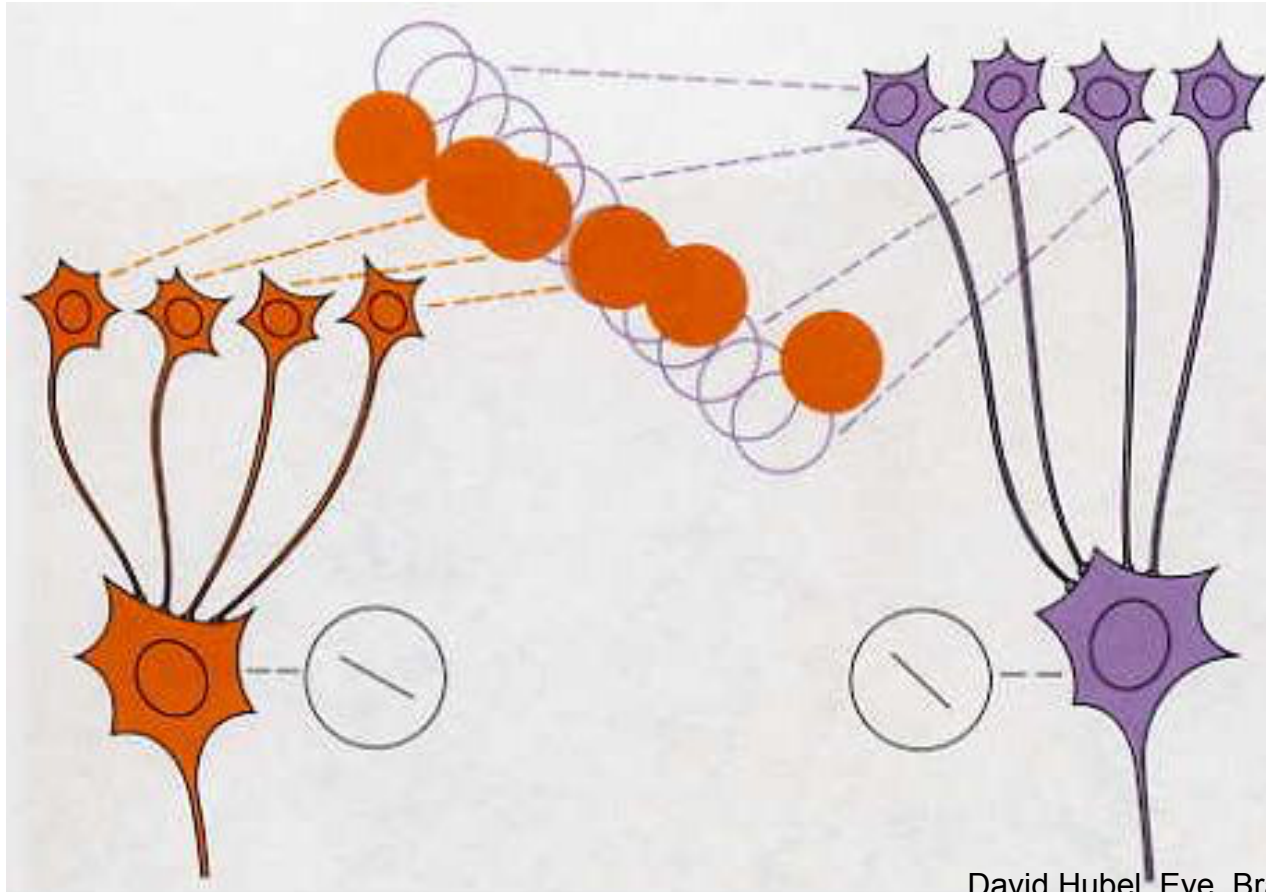
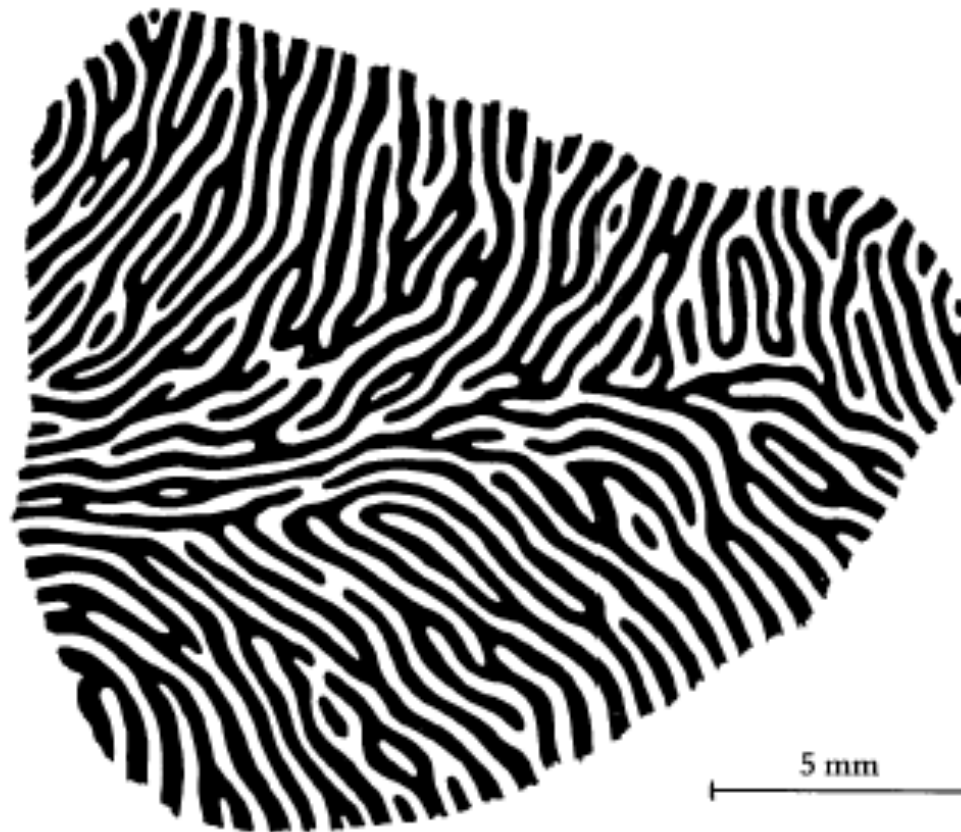David Hubel, Eye, Brain and Vision

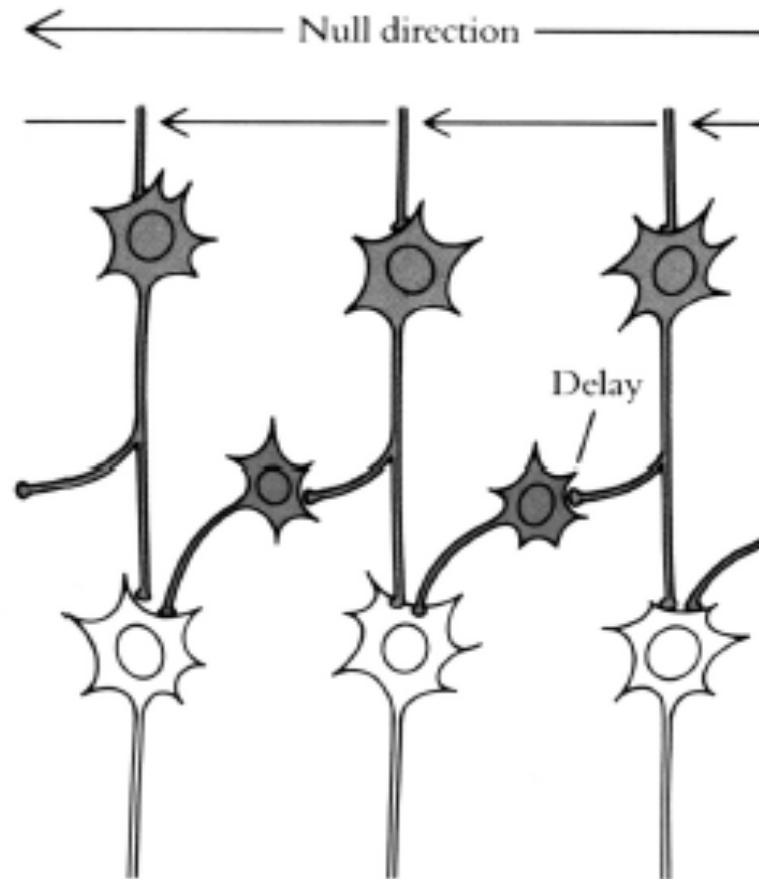# Orientation and ocular dominance columns
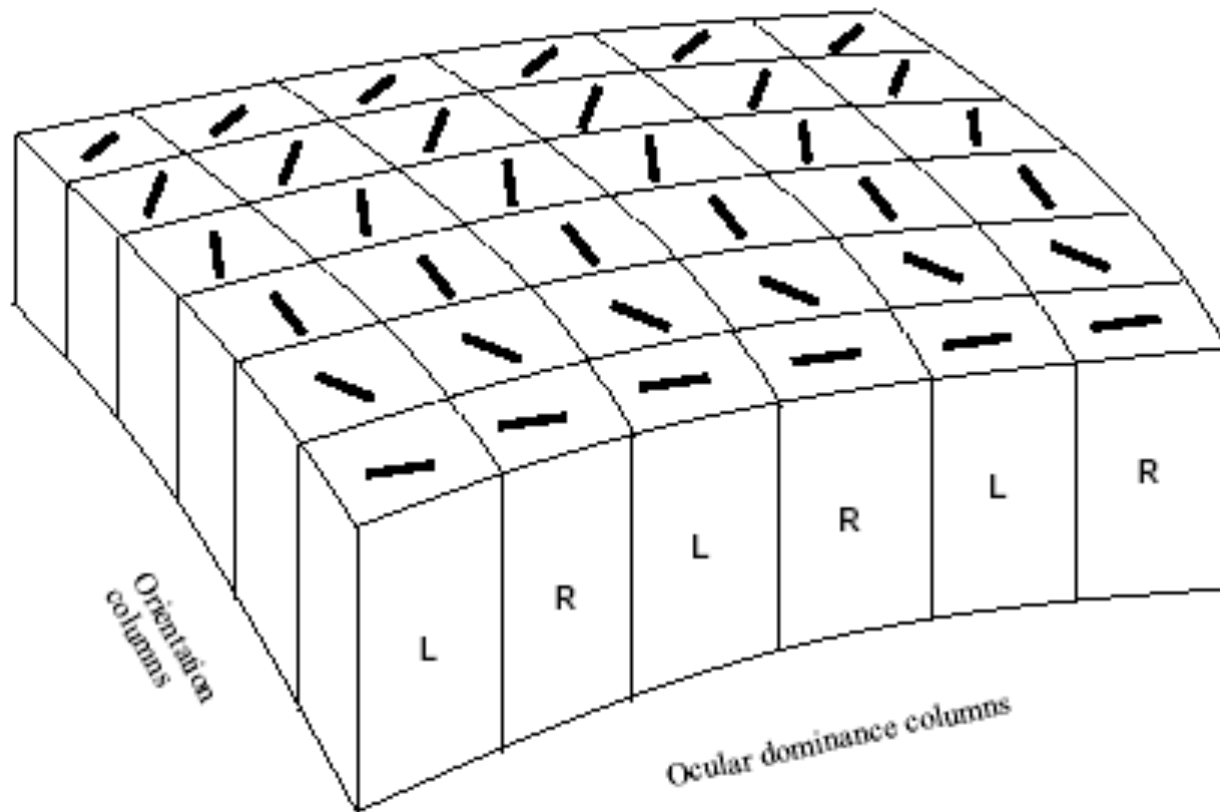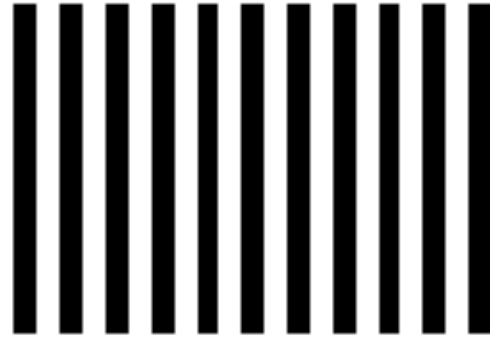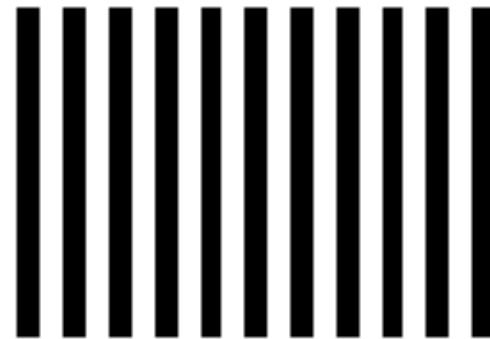
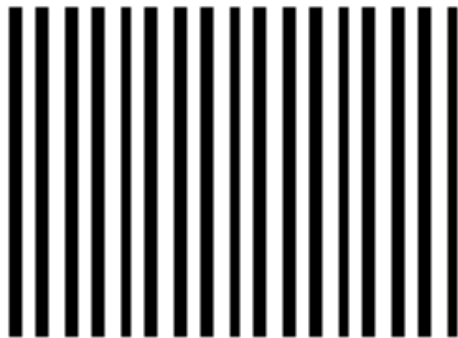# Orientation dominance

Ocular dominance map

5 mm

Implementation of direction-sensitive cell

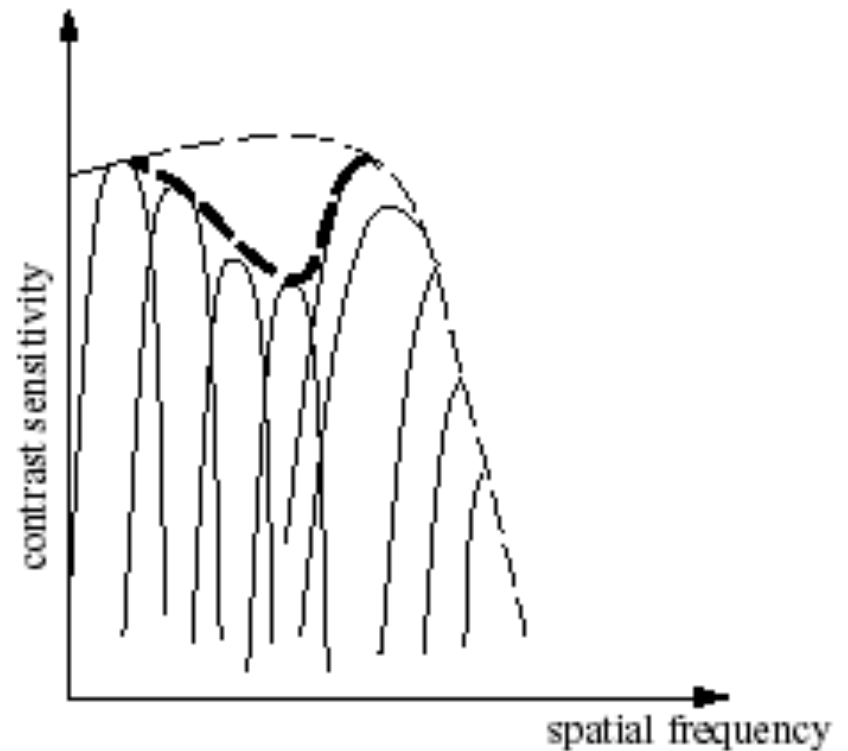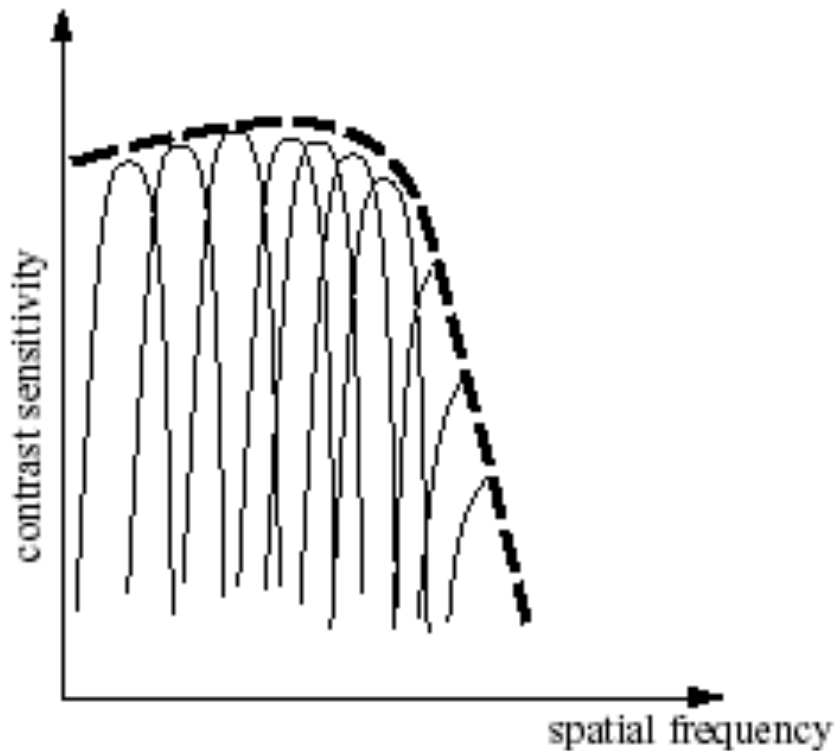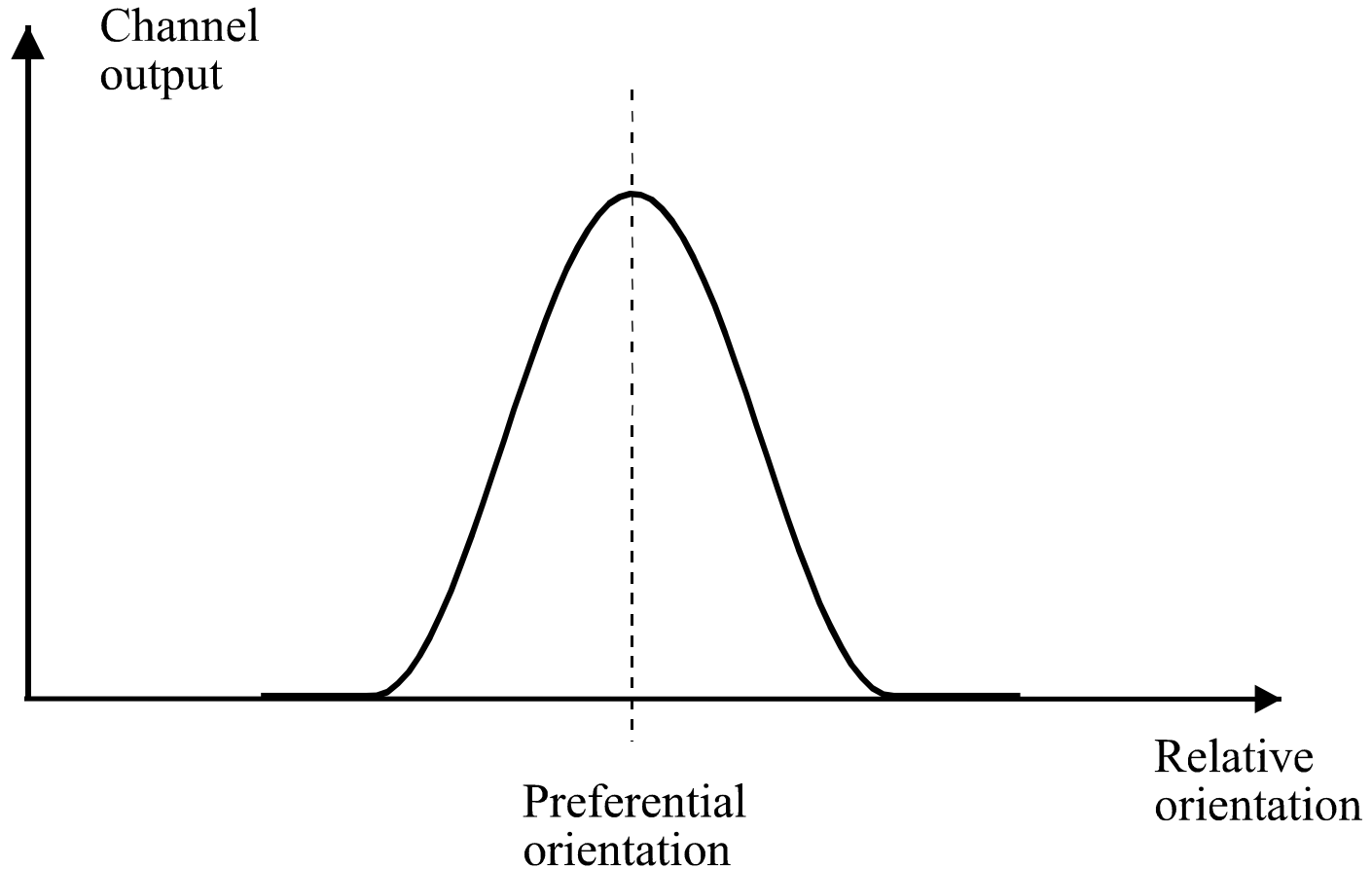# Spatial frequency adaptation

Adapted from Blakemore & Sutton, 1969

Build-up from separate channels Effect on sensitivity of channels

Channel representation

Channel Information Representation

$$\mathbf{x} = [\ 0\ \ 0.25\ \ 1.0\ \ 0.25\ \ 0\ \ \ \ 0\ \ \ \ 0\ \ 0.25\ \ 1.0\ \ 0.25\ \ 0\ \ \ \ 0\ \ \ \ 0\ ]^T$$
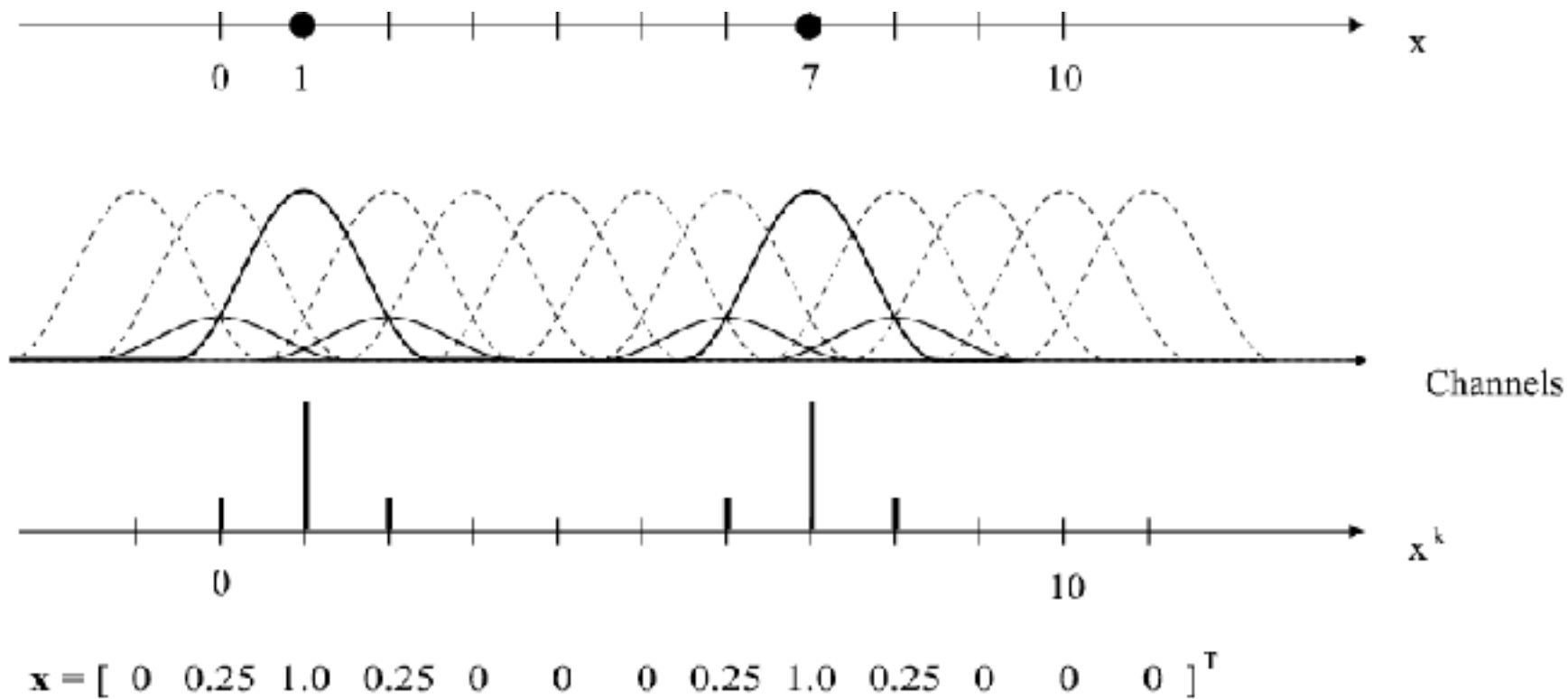
Advantages of channel representation

- Several values can be represented for a variable, allowing support to alternative hypotheses

- Locality allows a fast optimization in learning

- Locality allows implementation of non-linear models using linear mappings

- Allows representation of confidence or certainty

- Monopolarity allows **zero** to represent **no information** (i.e. "I don't know")

- Sparse representation

Local versus global properties
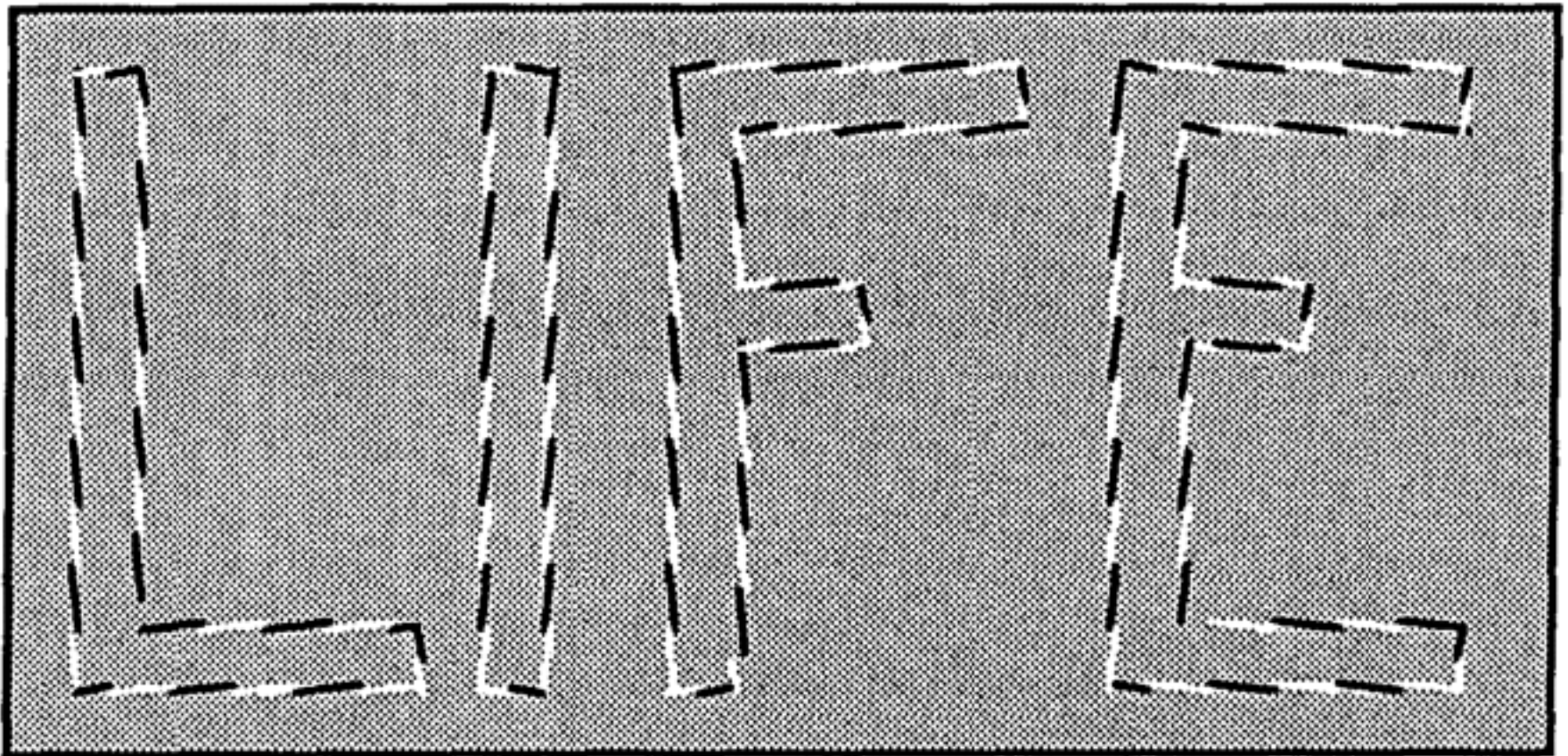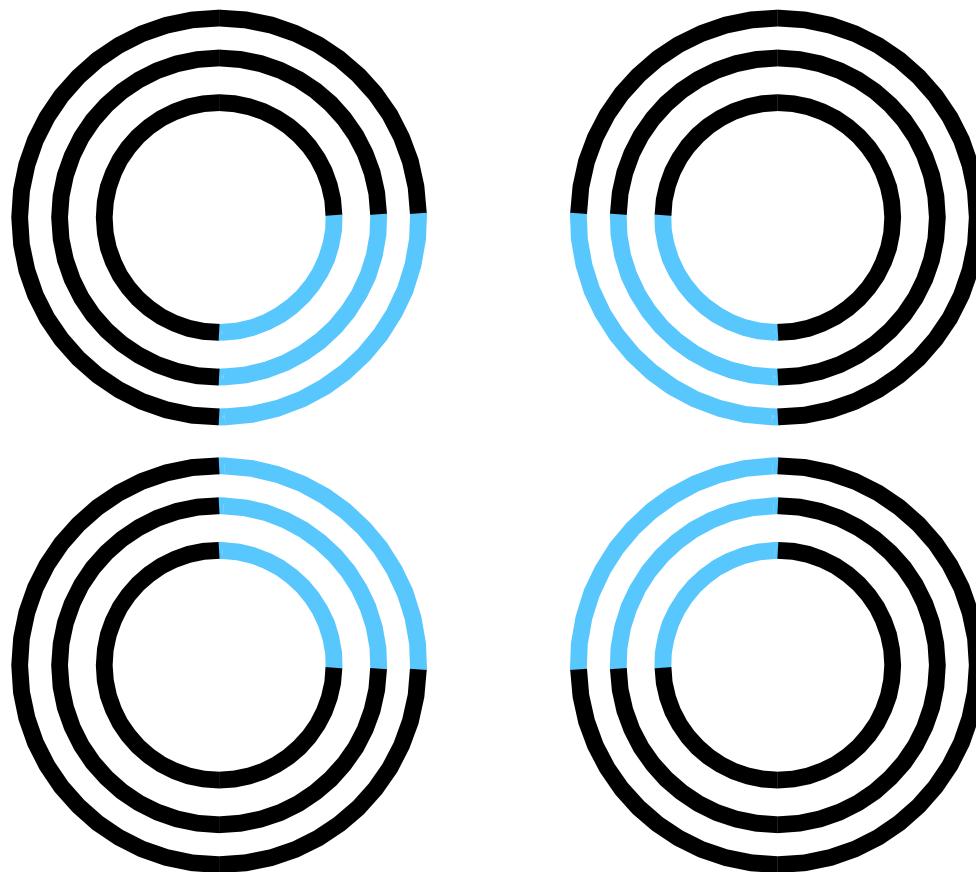
Conflicting interpretations

Parallel interpretation
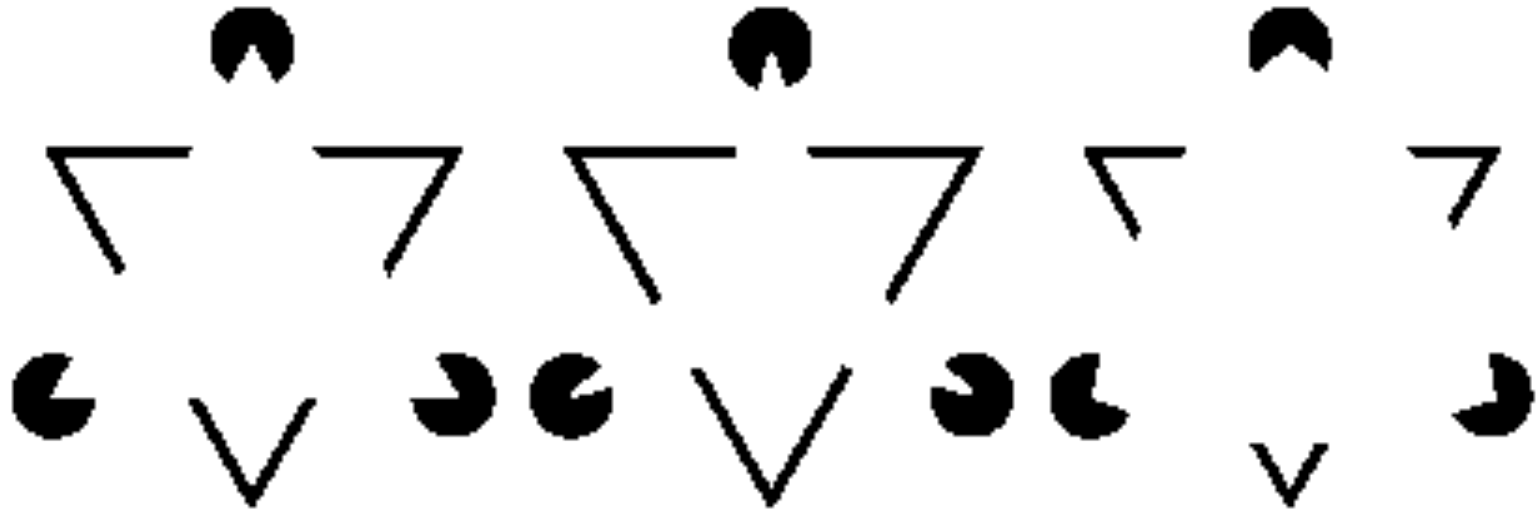
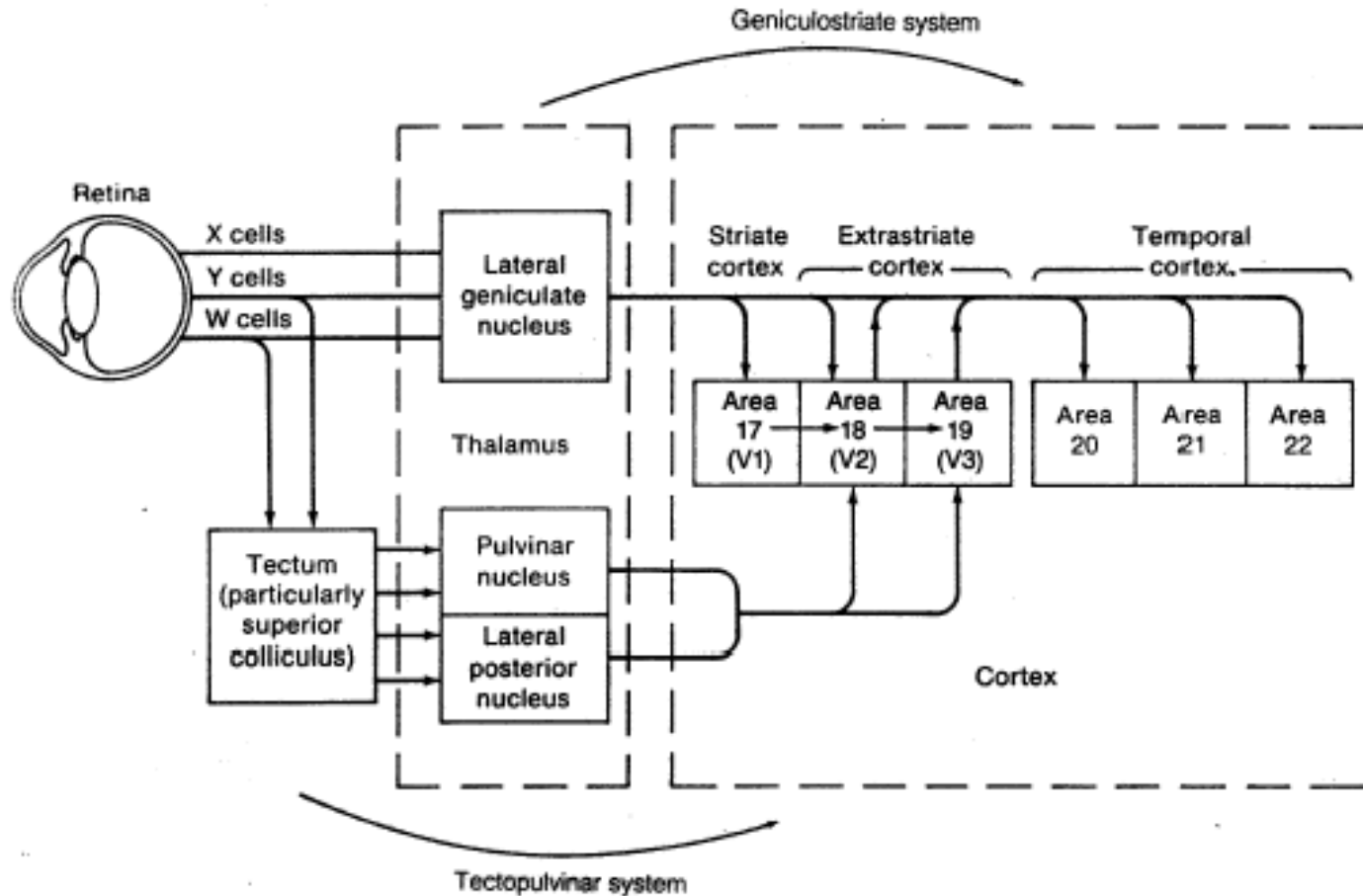# Sequential interpretation

Extrapolations forming illusions

The Kanitza triangle

Part of processing pathway

Computation times

On average 150ms to recognition. S. Thorpe et al. 1996
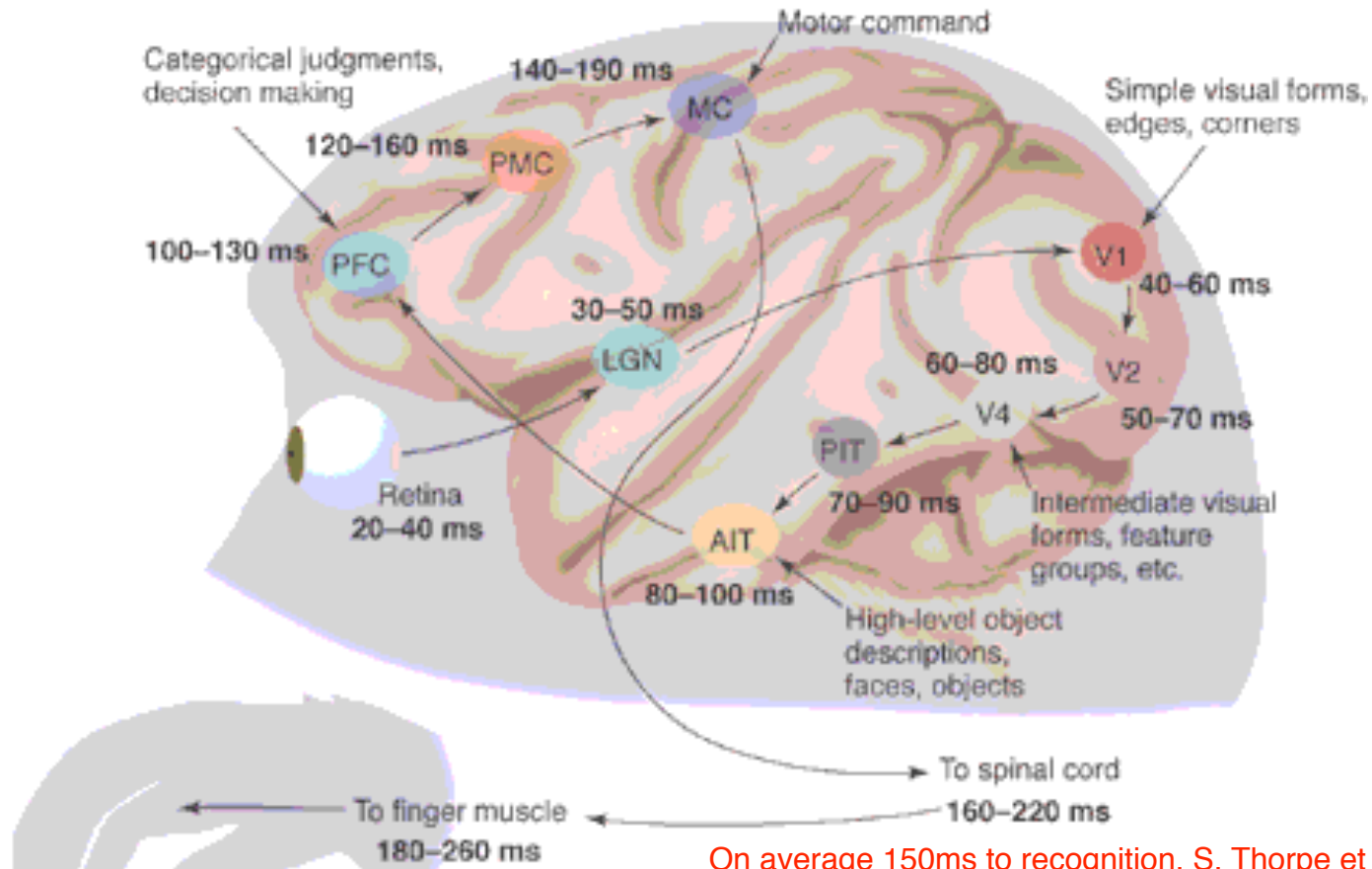
A conventional robotics structure

Feature input → **Scene description** → **Action generation** → Output
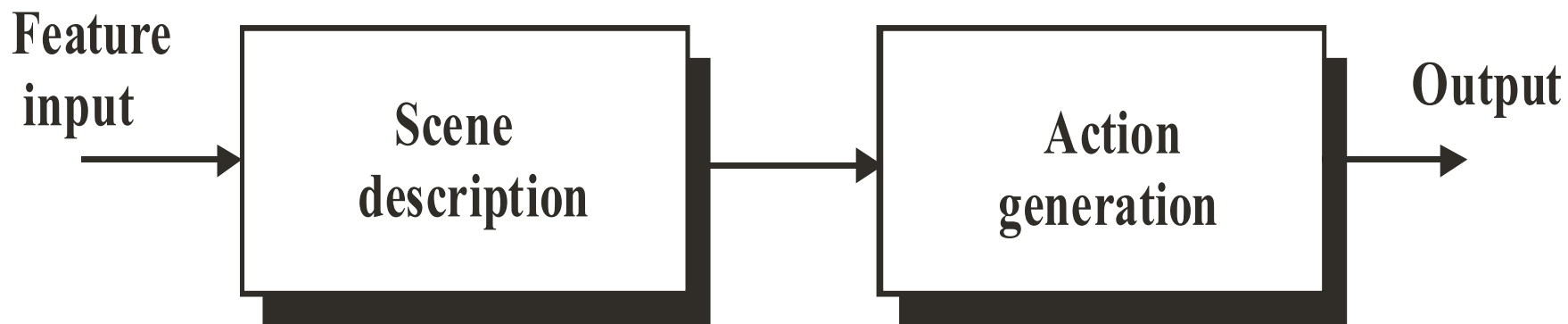
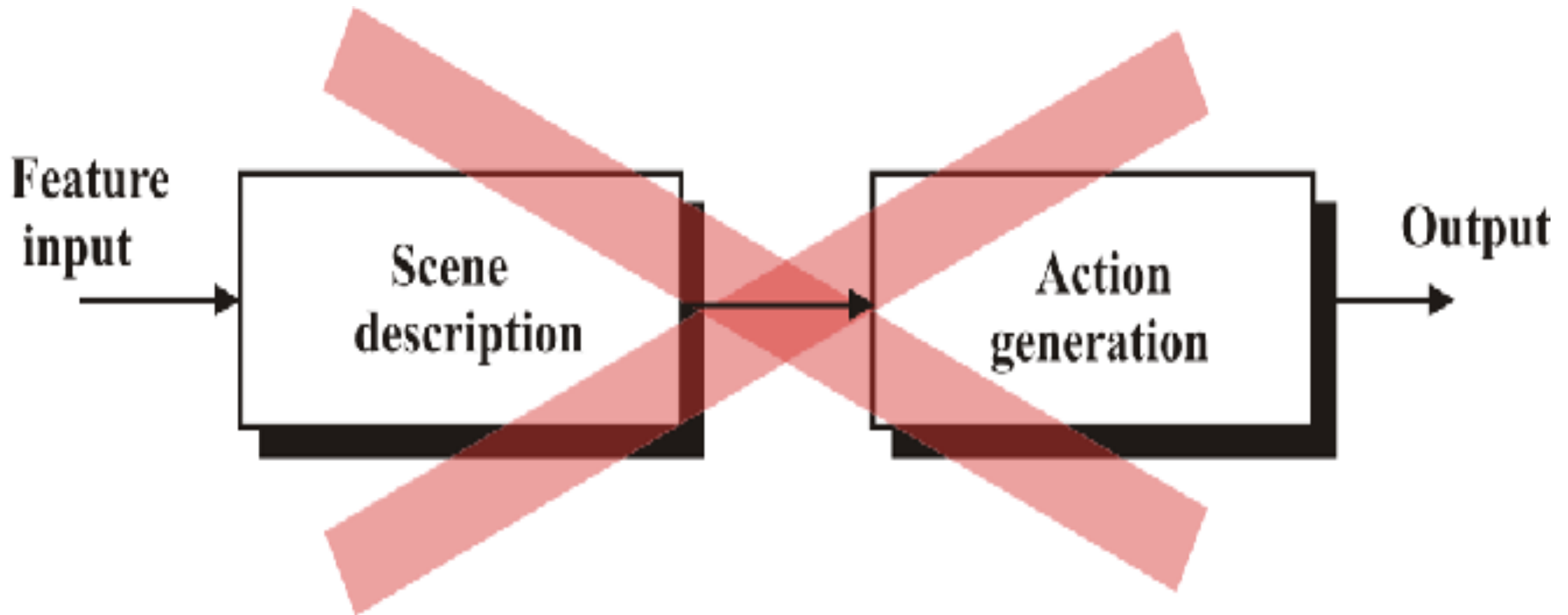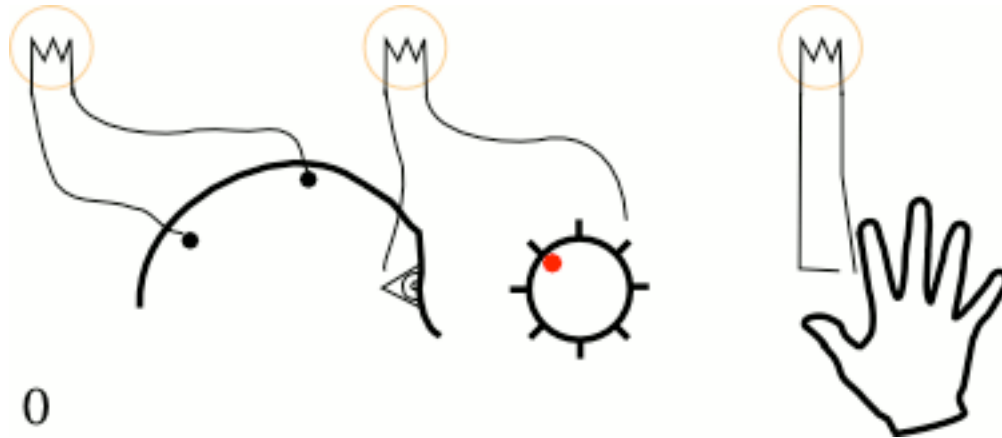# Not done in biological vision

Consciousness - an afterthought

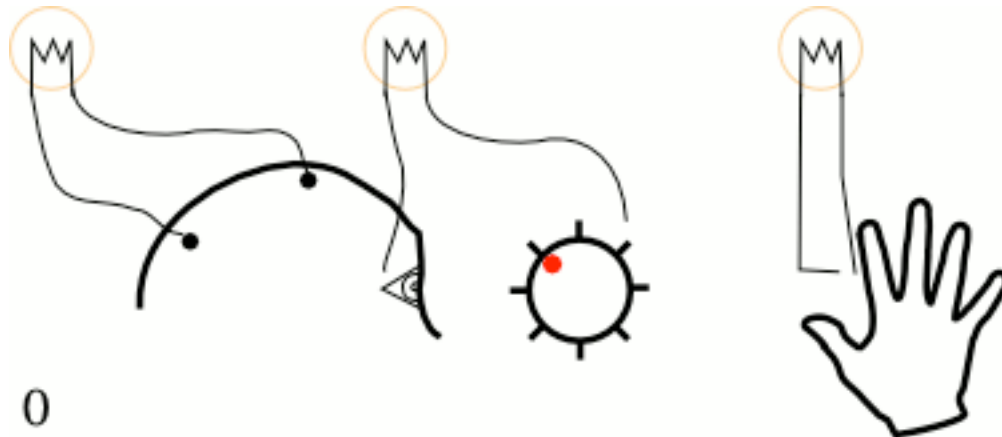Experiments by Benjamin Libet show that:

Action is initiated before it reaches consciousness

0

Consciousness - an afterthought

Synchronized EEG and rotating clock, subjects note position on timer when "they were first aware of the wish or urge to act"
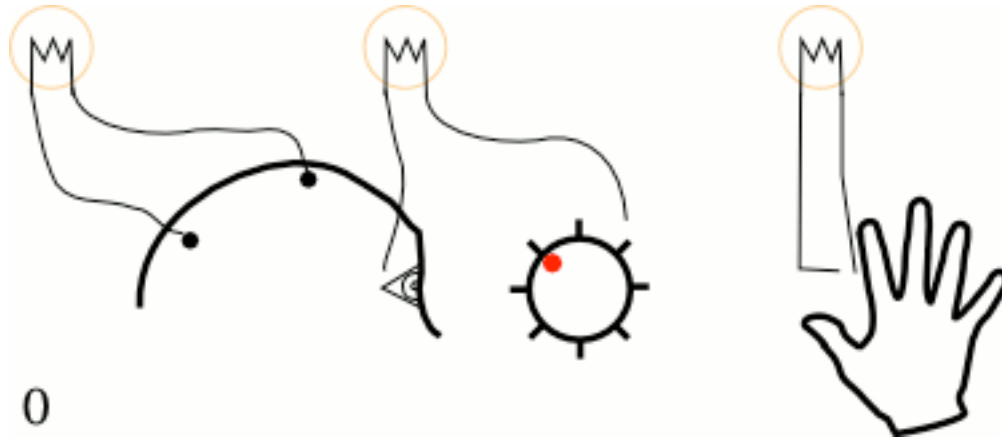
Consciousness - an afterthought

T-500ms: Readiness potential is measured by EEG

T-200ms: Observed time is registered by consciousness
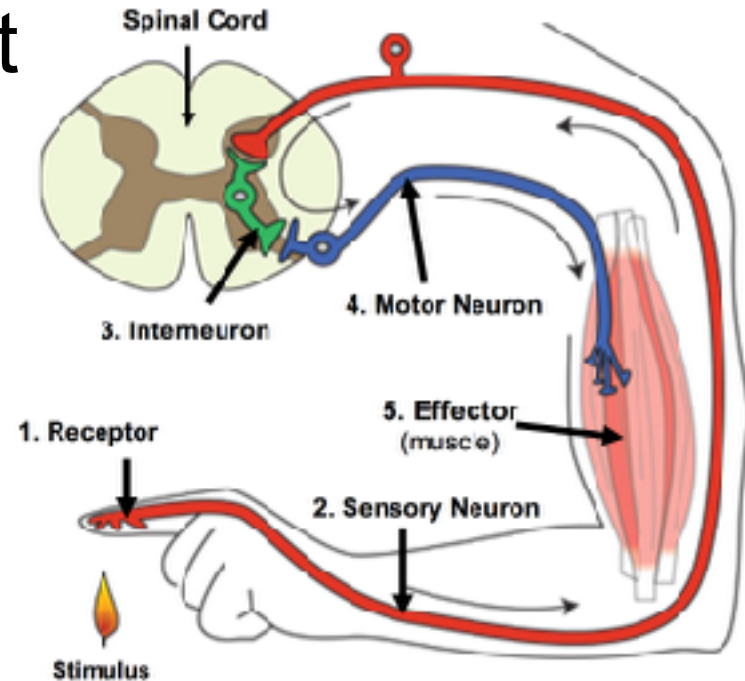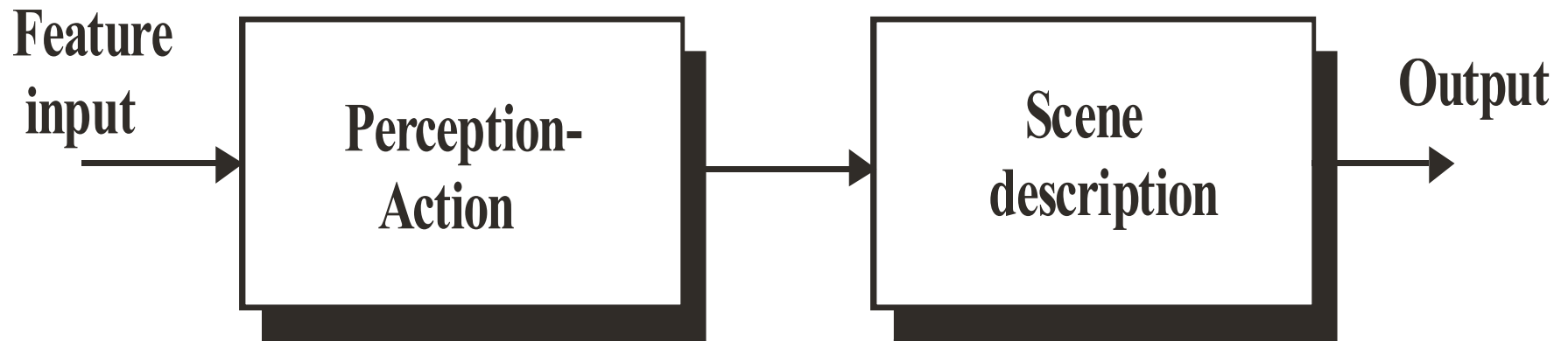by looking at synchronised clock

T: Action takes place

Other examples

1. It is well known that reflex actions are pre-conscious

2. You do not consciously plan all details of e.g. walking pattern

Order is the opposite!

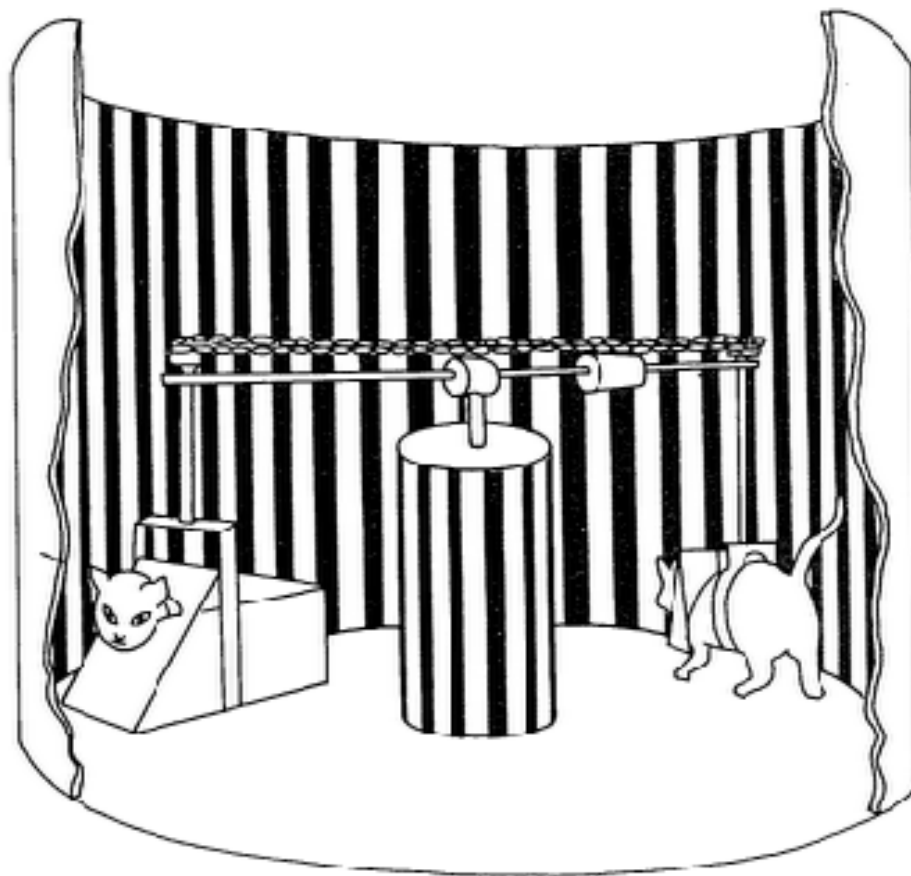**Feature input** → **Perception-Action** → **Scene description** → **Output**
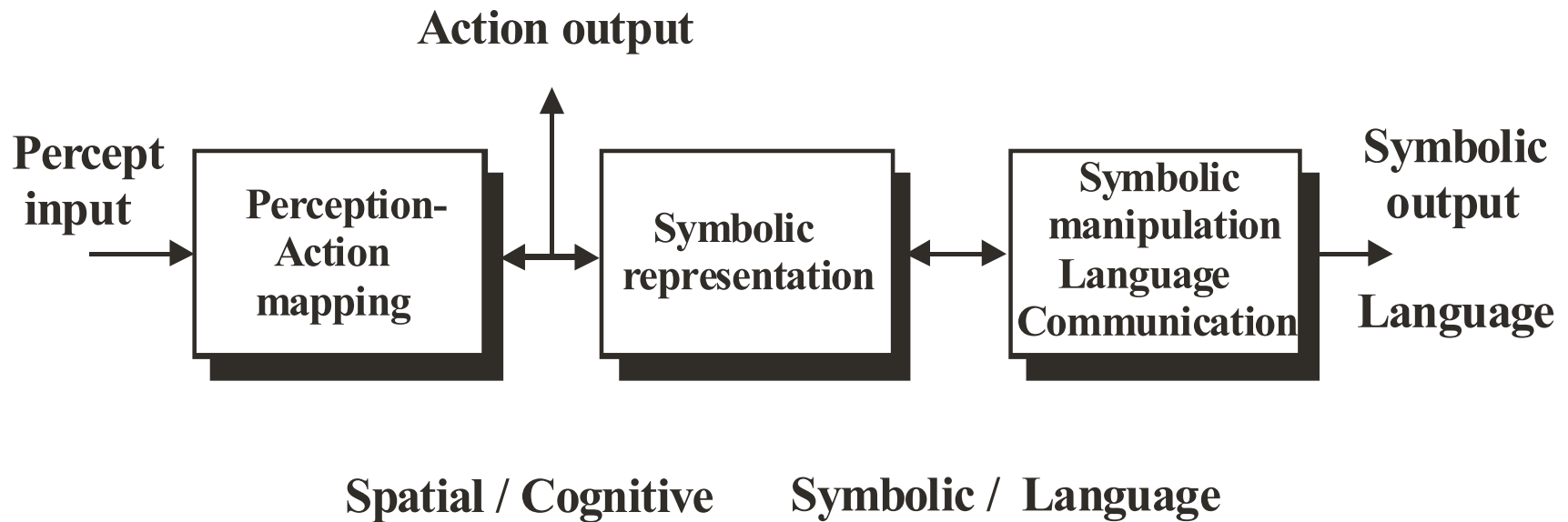
Active versus passive exposure

Why active learning?

Act-perceive-learn cycle

- Only features that change are related to the action or state change

- The action or state space is much less complex than the percept space

- Does not require consciousness (other forms of learning do)

Extended Cognitive Structure

Action output

Percept input → **Perception-Action mapping** ↕ **Symbolic representation** ↕ **Symbolic manipulation Language Communication** → **Symbolic output** **Language**

Spatial / Cognitive   **Symbolic / Language**
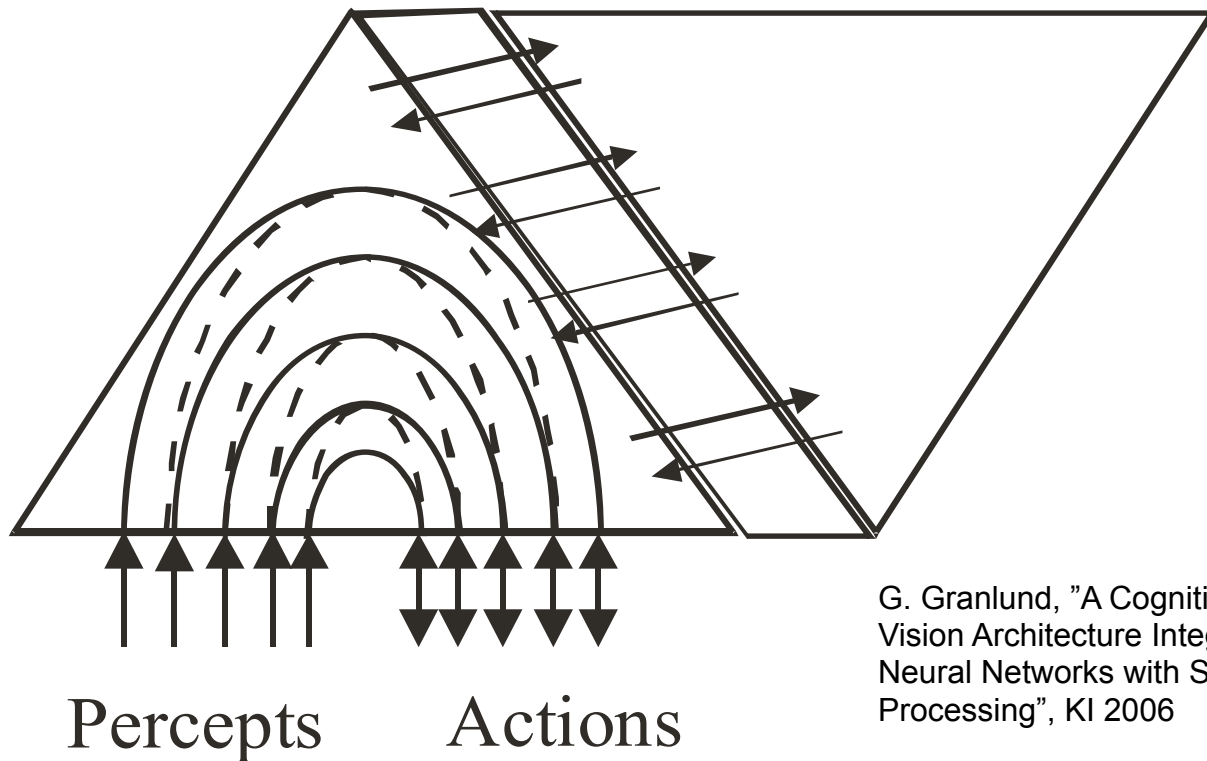
G. Granlund, "A Cognitive Vision Architecture Integrating Neural Networks with Symbolic Processing", KI 2006

Pyramid version

Continuous   Symbolic

Percepts   Actions

G. Granlund, "A Cognitive
Vision Architecture Integrating
Neural Networks with Symbolic
Processing", KI 2006

Summary

- Biological vision systems are not monolithic, but a collection of **visual behaviours**

- Visual perception is done in **cortical maps**, for e.g. colour, edges, and faces

- Much of visual learning is **active**, and pre-conscious