Biological Vision Systems

Introduction and HVS overview

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Seminar 1: Contents

1. Overview of the Human Visual System
2. Discussion of the course format
3. Assignment of presenters and reviewers

Overview of the Human Visual System

This course looks at vision from a systems perspective

We consider both perception and action

Both hardware and wetware matter

A HVS overview in two parts

1. Systems perspective

2. Visual perception

A HVS overview in two parts

1. Systems perspective

   Based on Michael Land 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

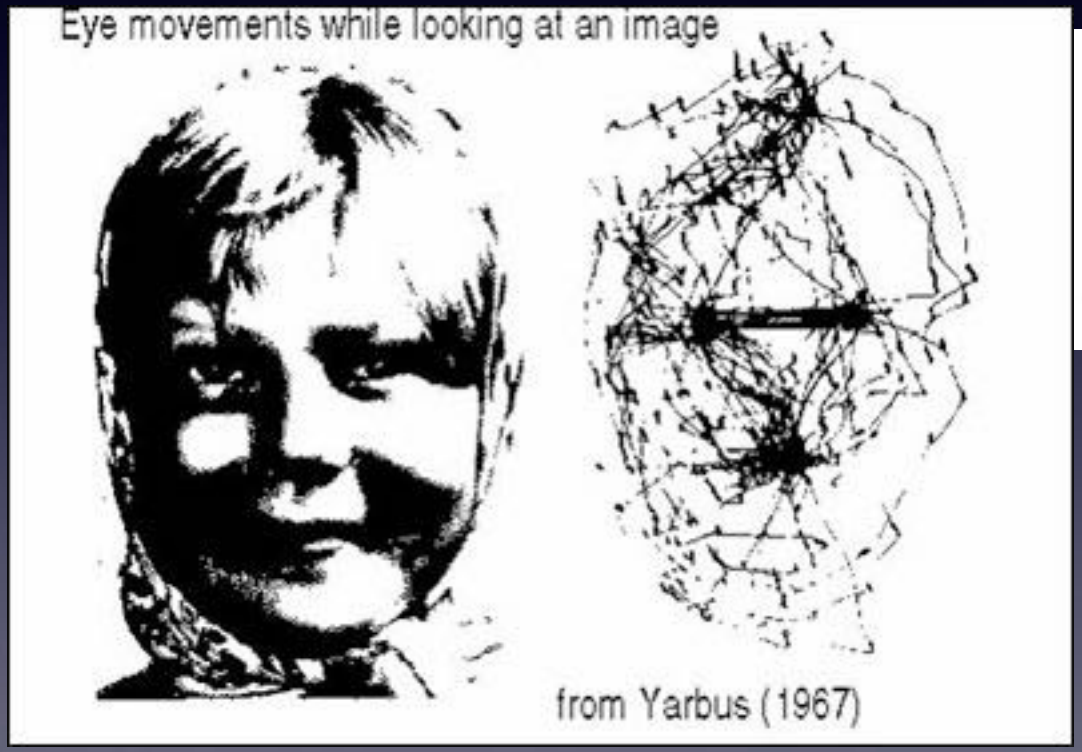
Vision Systems

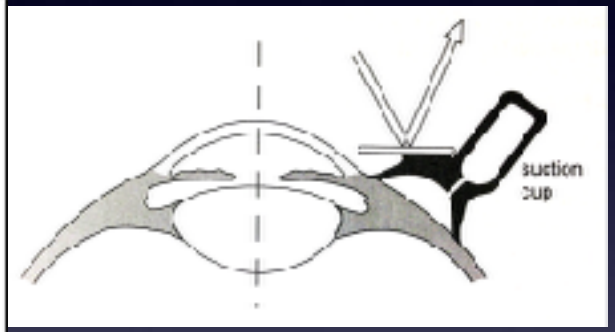
What a camera sees

Vision Systems

What the human eye sees

Vision Systems





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

Vision Systems

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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

Examples of visual behaviours:

1. **Fixate moving targets**
2. **Compensate for head and body movement**

3. **Grasp object**
4. **Recognize object**

Visual Behaviours

Examples of visual behaviours:

1. **Fixate moving targets -** Optokinetic Reflex (OKR)
2. **Compensate for head and body movement** - Vestibulo - Ocular Reflex (VOR)
3. **Grasp object**
4. **Recognize object**

Visual Behaviours

Experiment:
Hold out your hand and raise a finger:

1. move 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)?

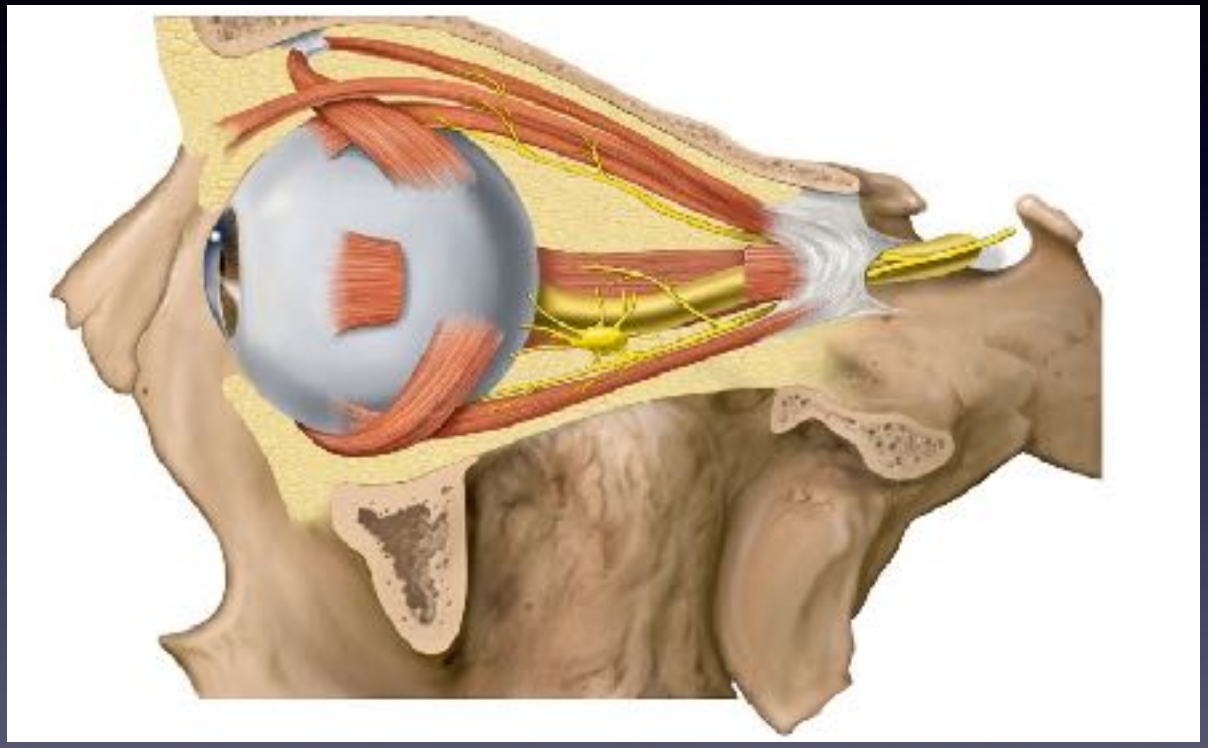
- Optical flow (dense over entire visual field)

Visual input for OKR (tracking)?

- Tracking (region around fovea)

Note: VOR also receives input from the vestibular system (OF 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

Weka VCR - YouTube

VCR in Chicken

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

Chicken VCR - YouTube

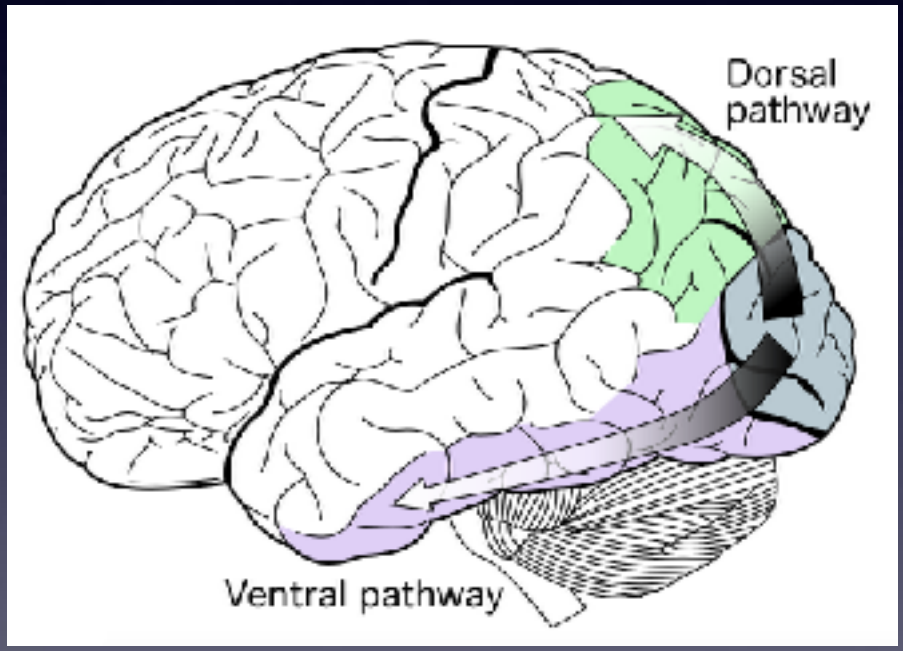
Visual Behaviours

Examples of visual behaviours:

1. **Fixate moving targets** - OKR
2. **Compensate for head and body movement** - VOR,VCR
3. **Grasp object**
4. **Recognize object**

Visual Perception

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



- Dorsal pathway
  controls actions
  e.g. gaze and grasping

- Ventral pathway
  handles visual perception

Complex problem

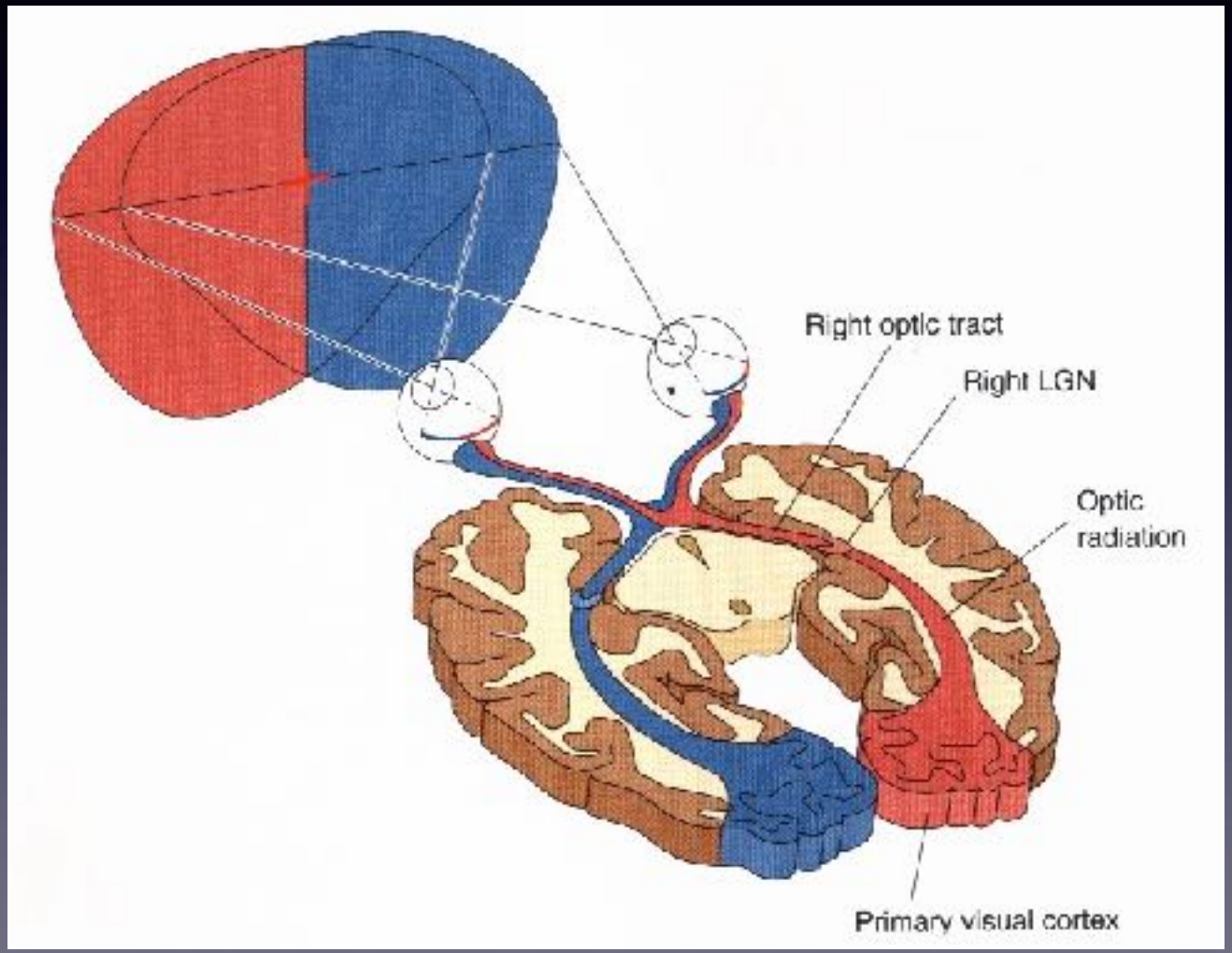
- Recognition using direct matching to prototype images is untenable
  - Large number of objects
  - Large number of variations

Complex problem

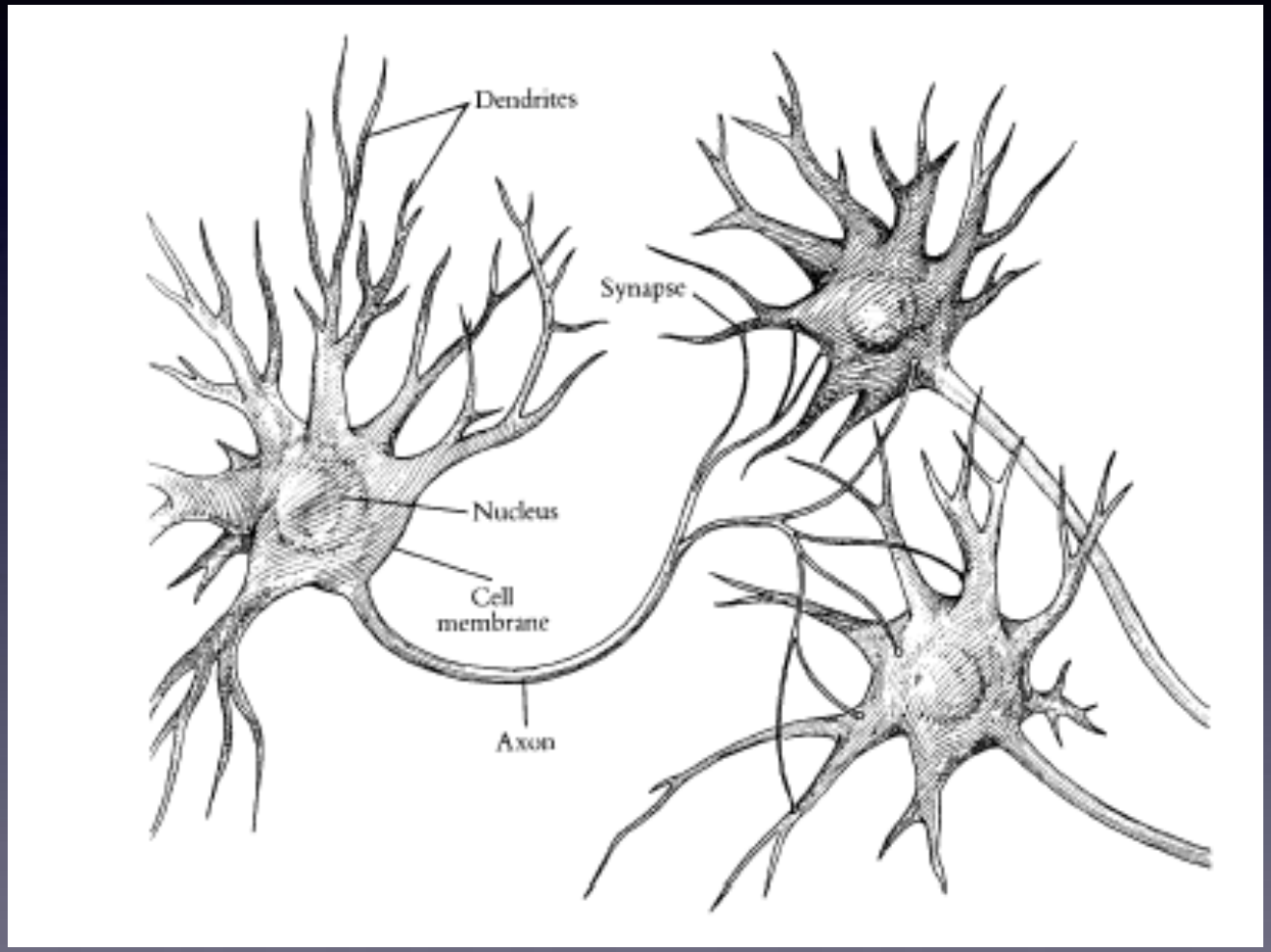
- Recognition using direct matching to prototype images is untenable
  - Large number of objects
  - Large number of variations

Abstraction is necessary!

The visual pathway



Principal parts of a nerve cell



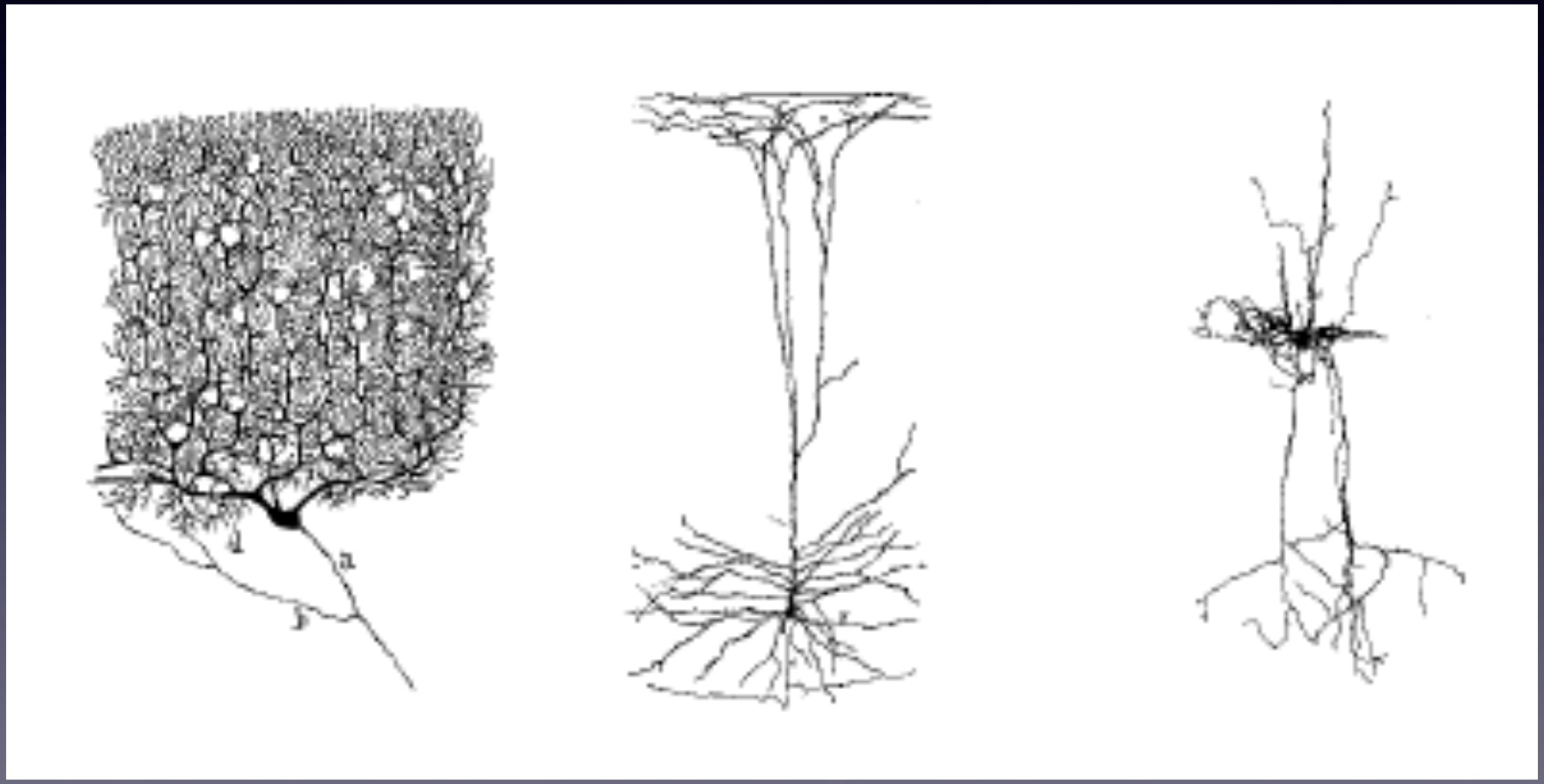
Signals of neurons

- 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
- Normally all-or-nothing
- A few types have ***graded*** signals

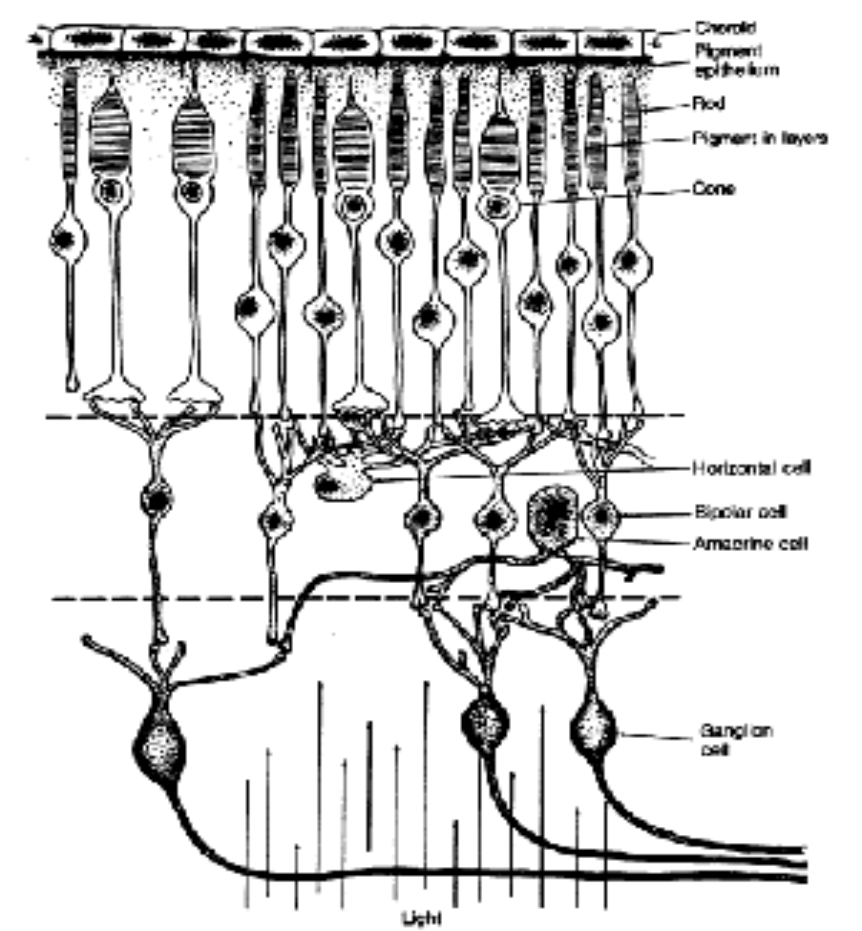
Neurons

- Axons can be < 1 mm to > 1 m
- Synapses can be excitatory or inhibitory
- 50 – 100 neurotransmitters

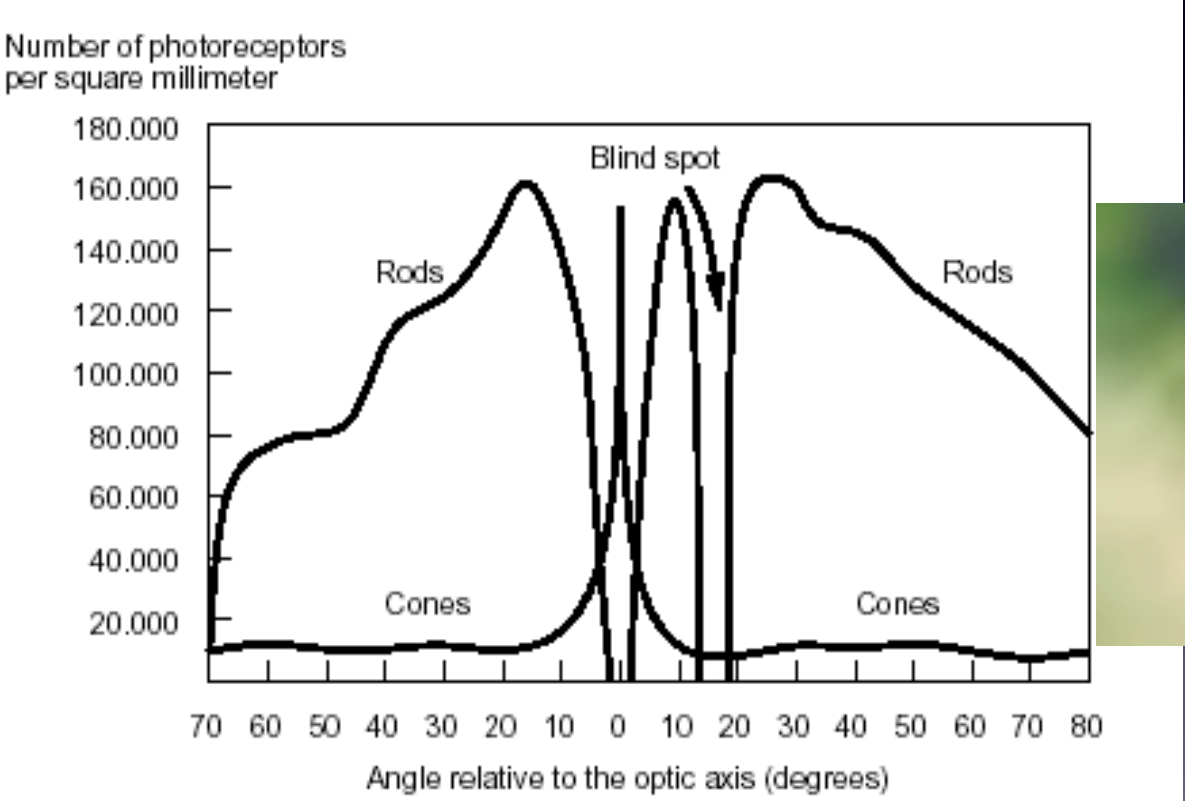
> 100 different types of nerve cells



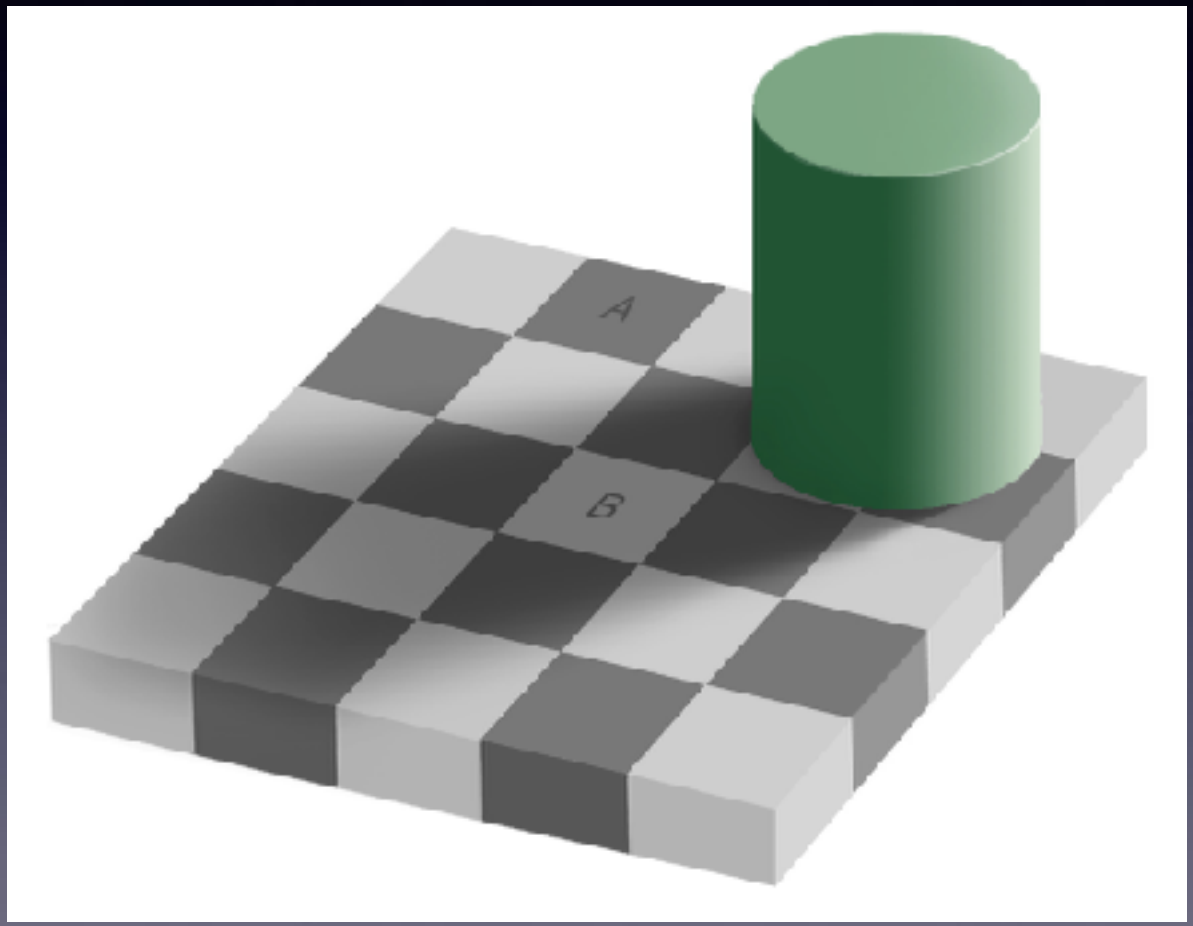
The retina



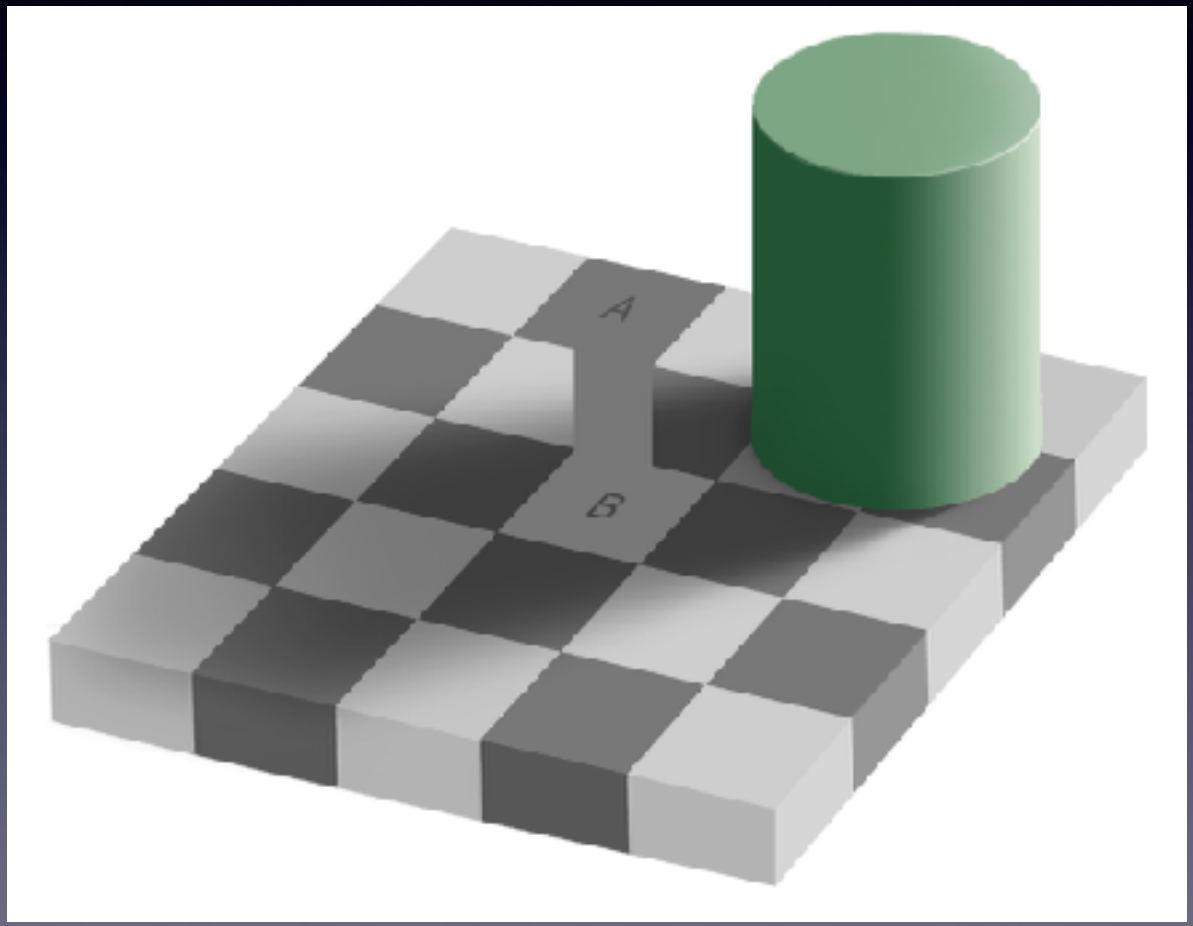
Density of photoreceptors



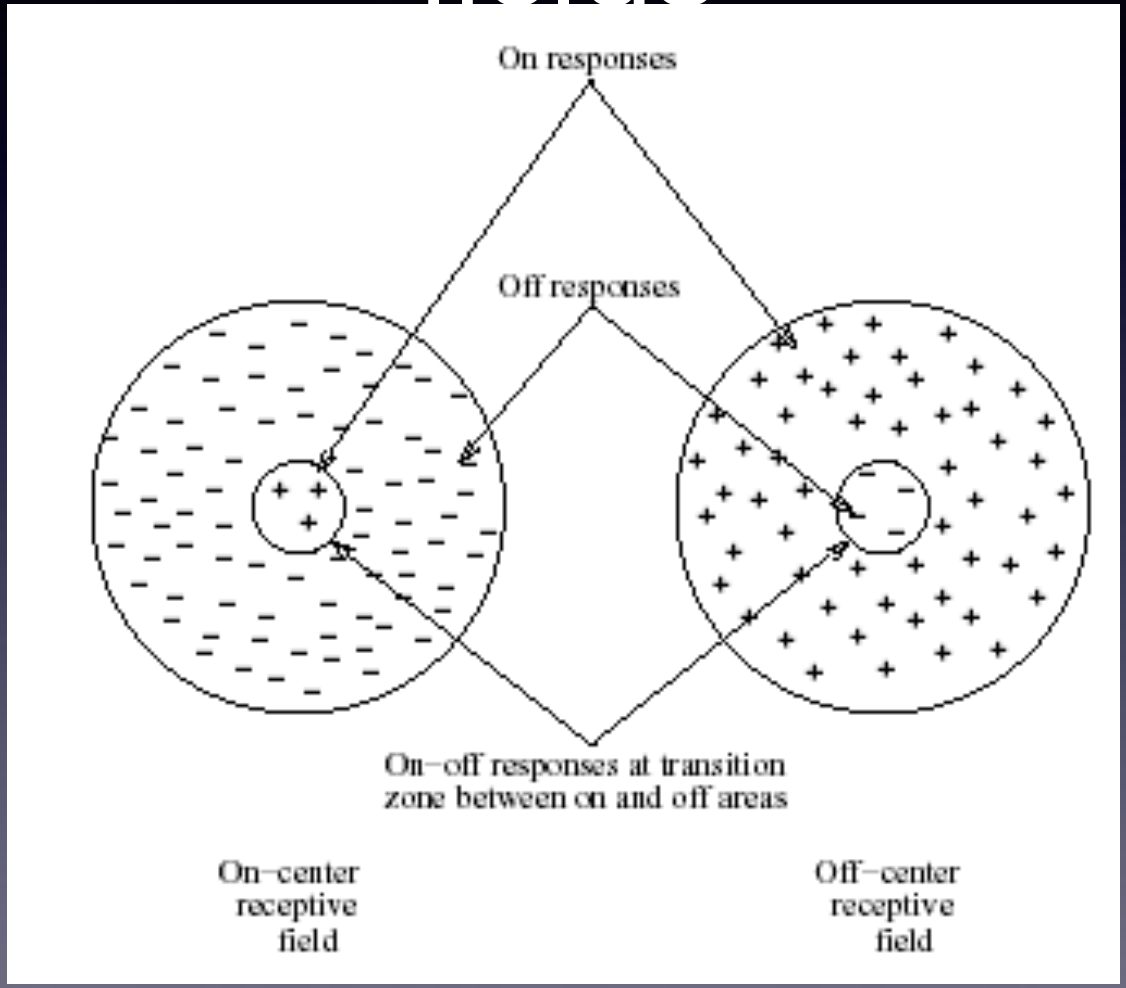
Stability with respect to illumination



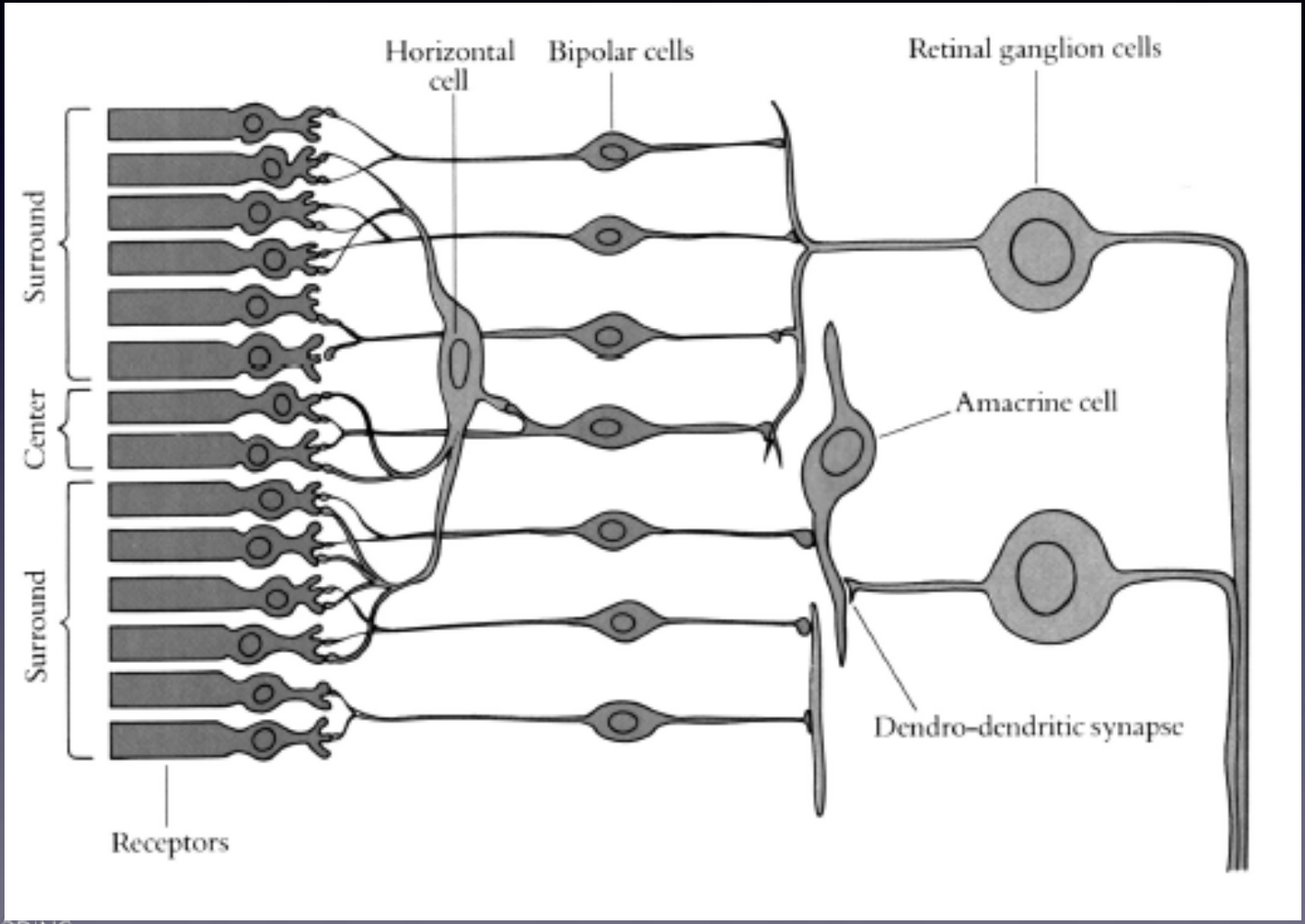
Stability with respect to illumination



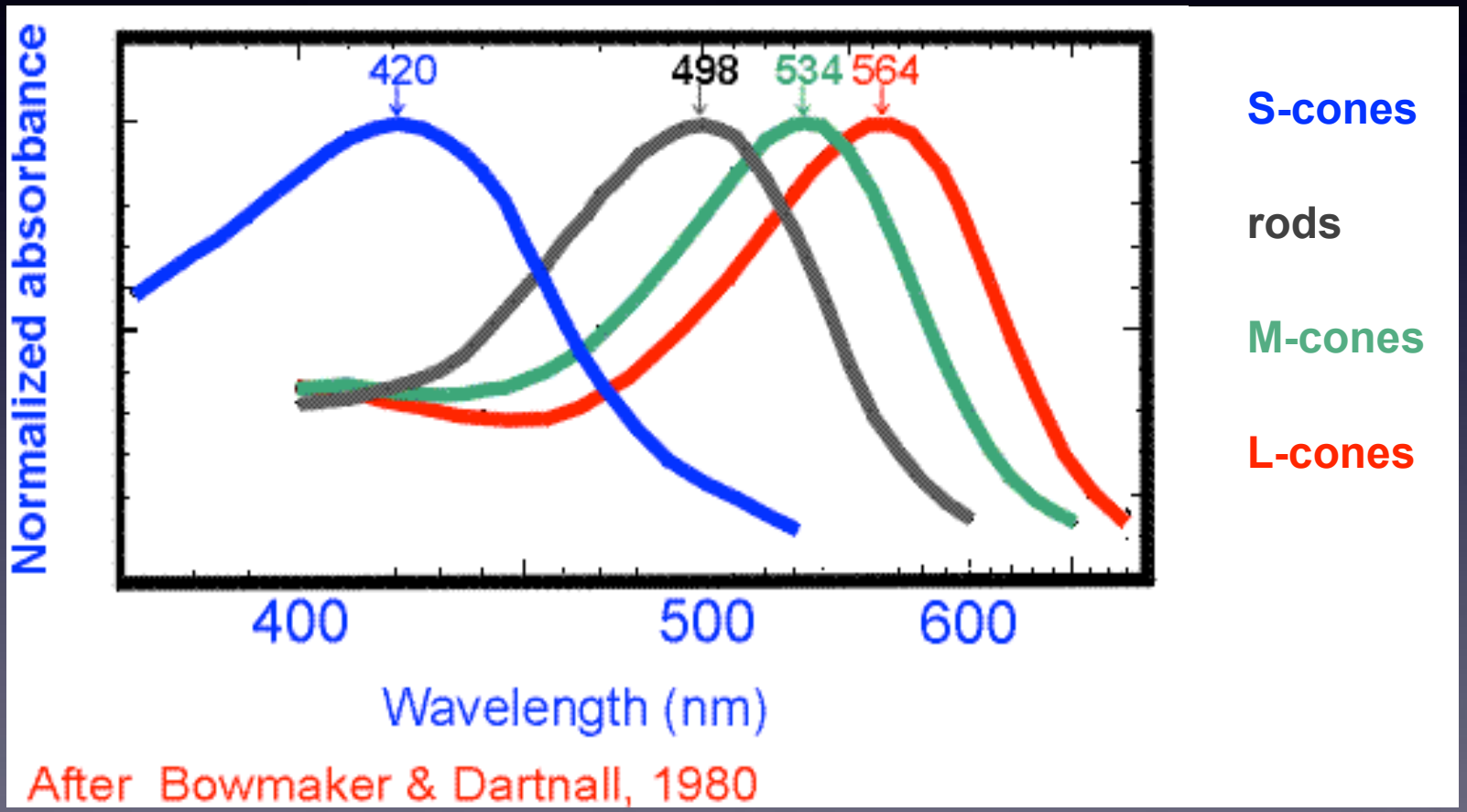
Center-surround receptive fields



Generation of center-surround fields



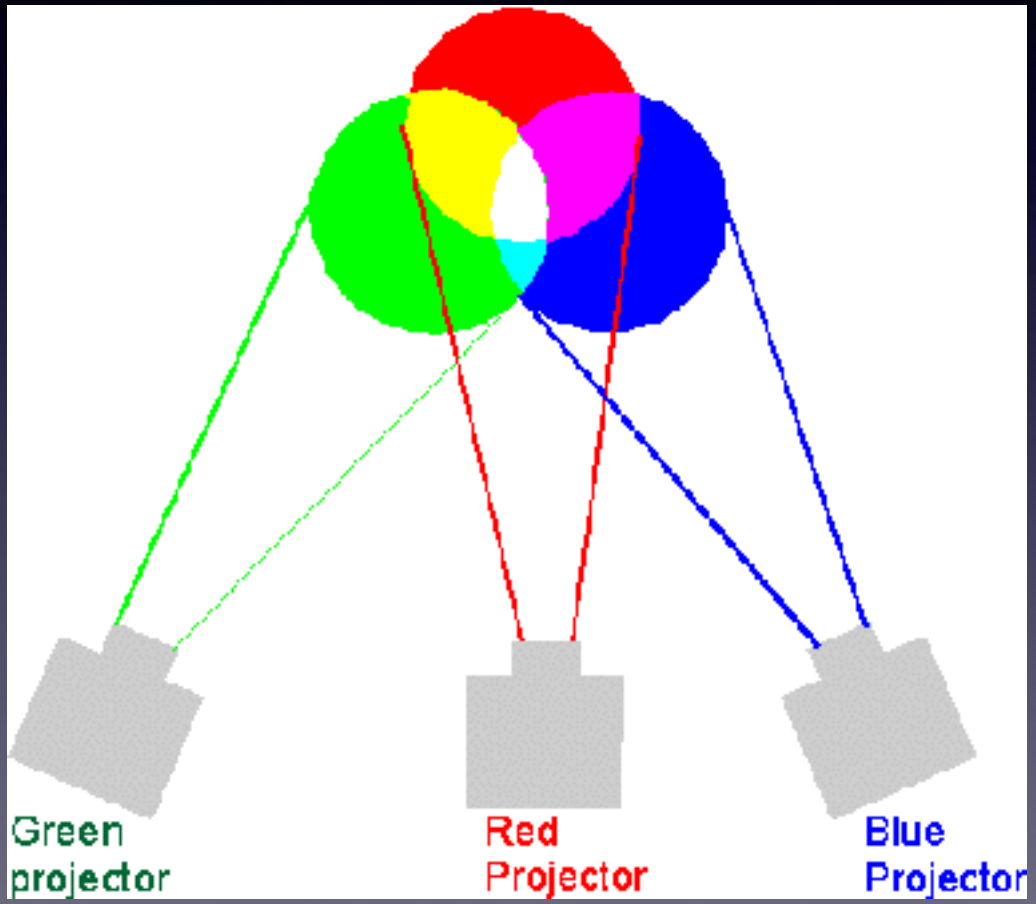
Absorbance spectra of photo pigments



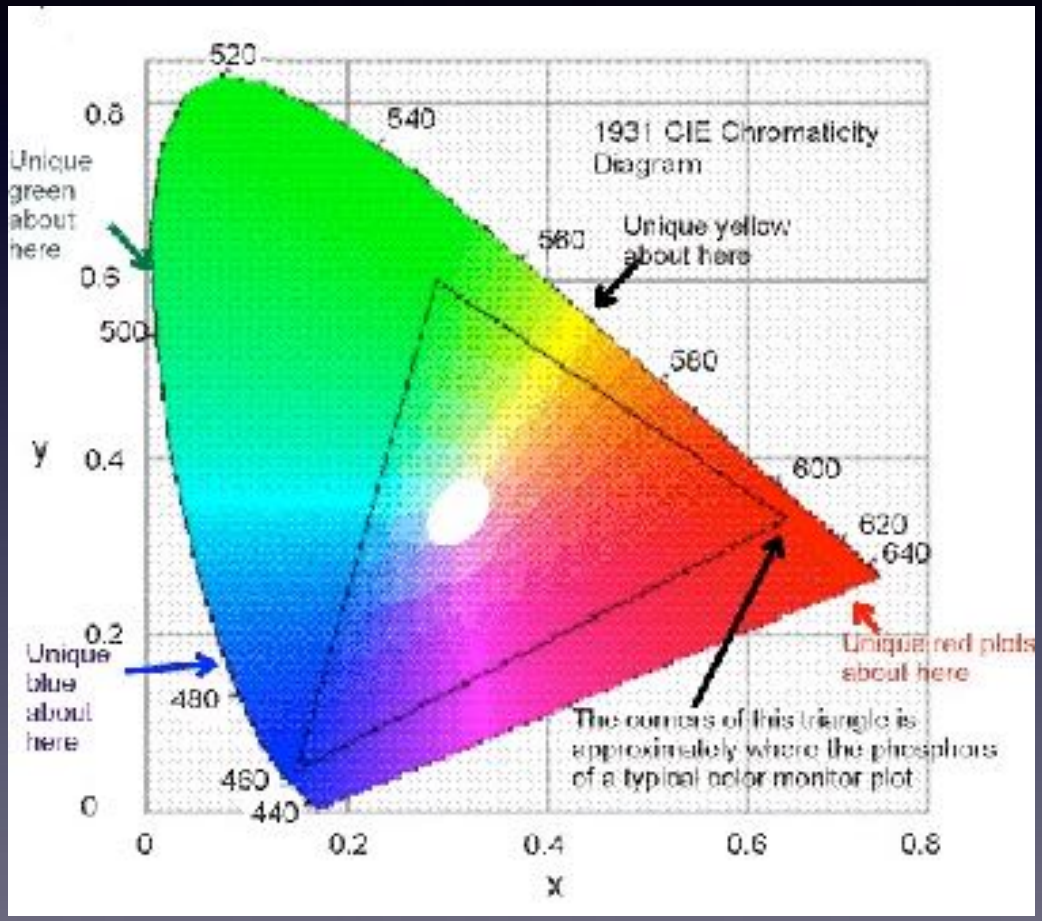
Colour vision theories

- The ***trichromatic*** theory operates at the receptor level
- The ***opponent processes*** theory applies to the subsequent neural level of colour vision processing

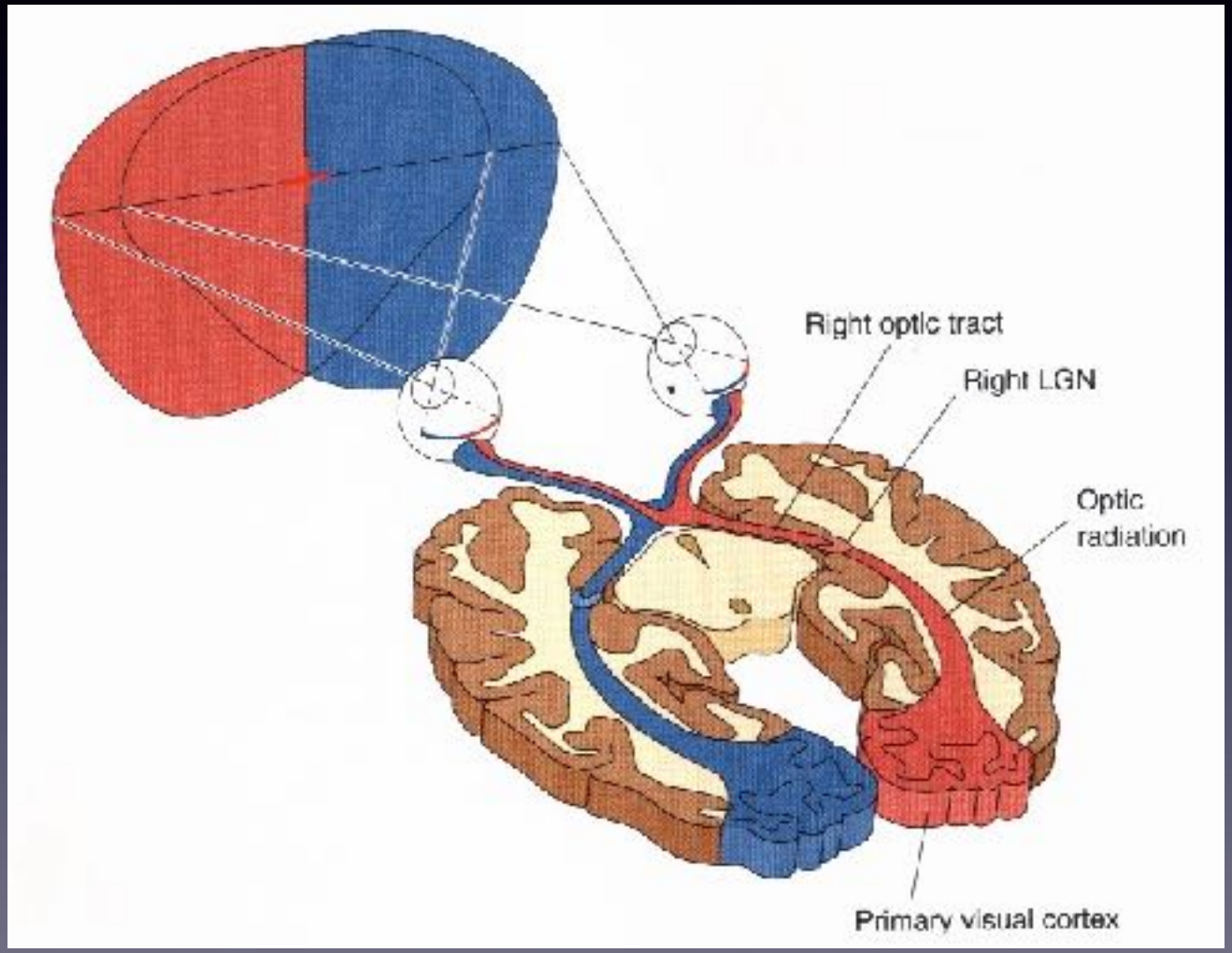
Additive colour mixing



The CIE colour diagram

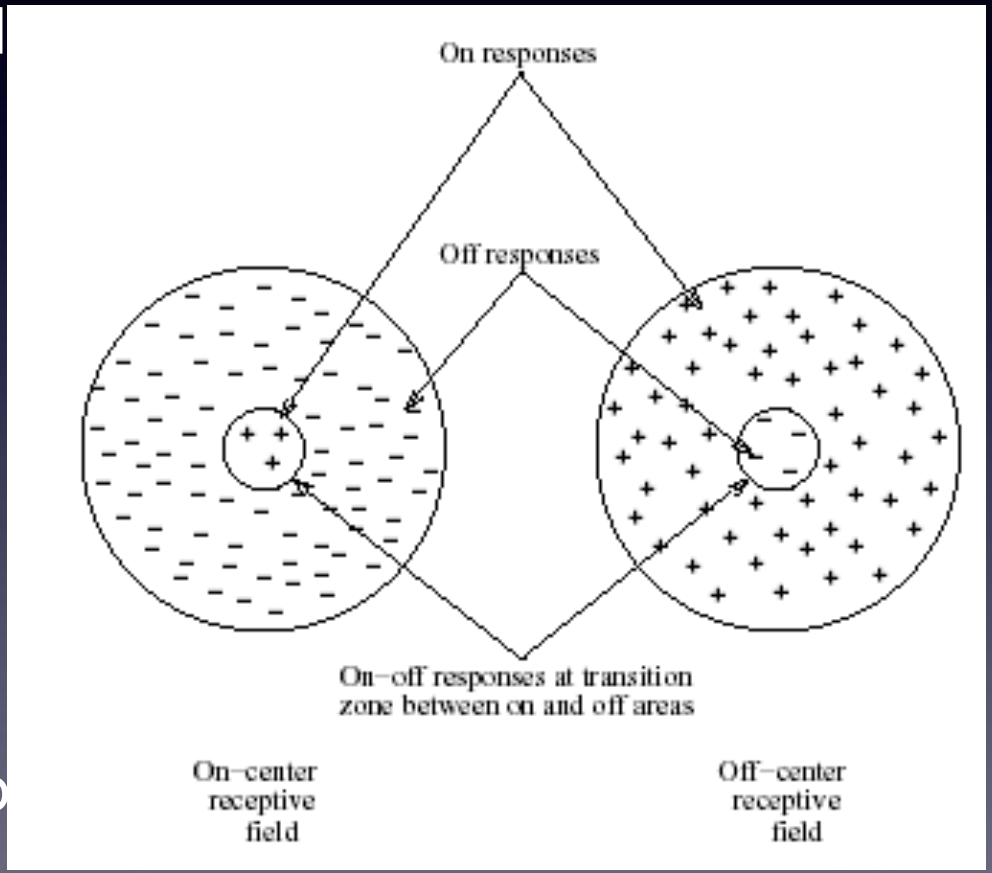


The visual pathway

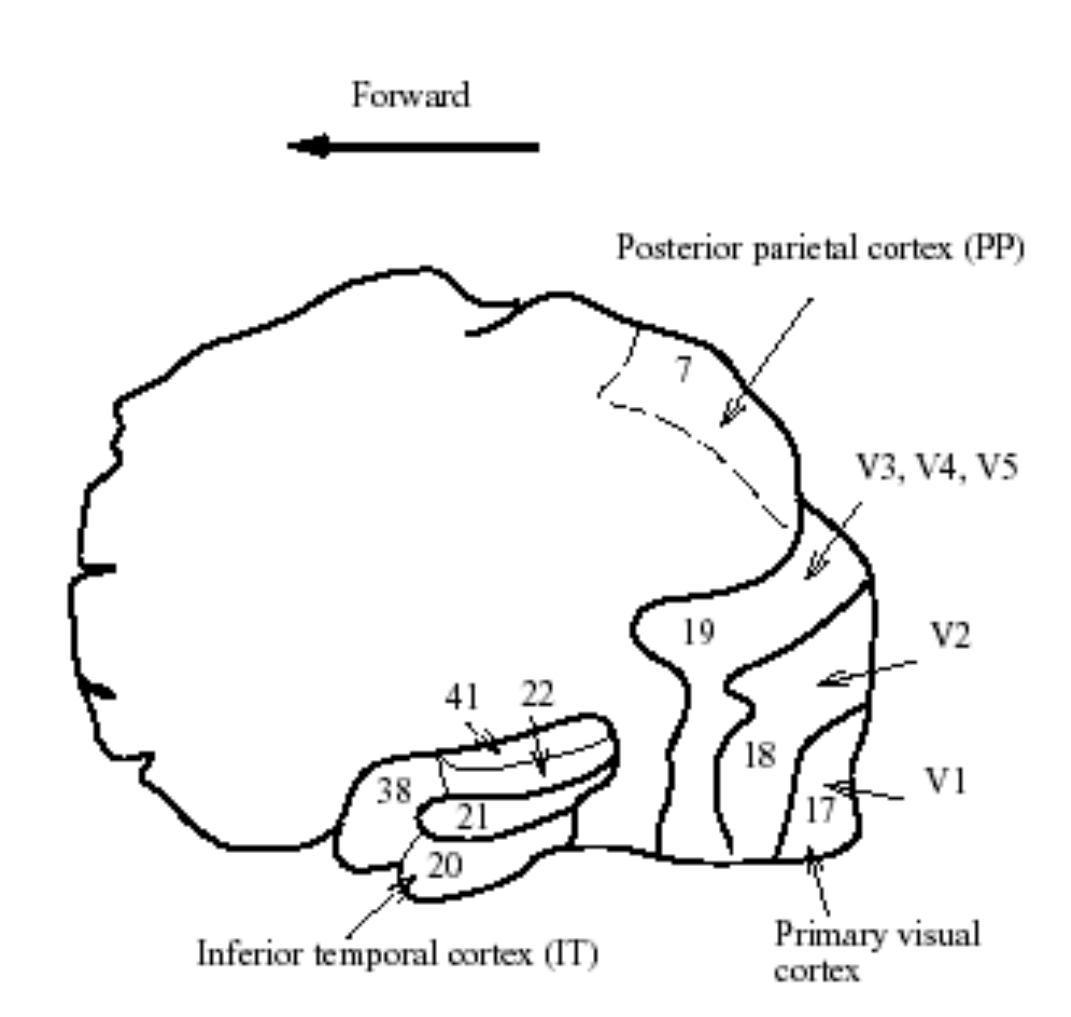


Colour-opponent model

- Centre surround
- L = C-S
- C1 = R-G
- C2 = Y-B
- in retinal ganglio cells and in LGN

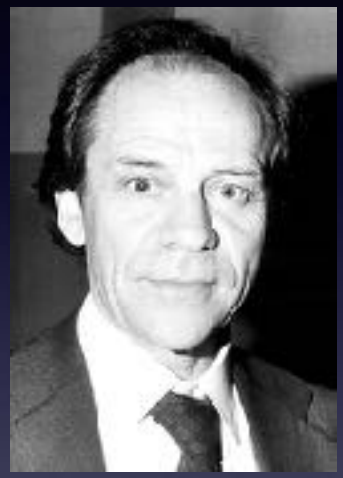


Cortical maps



1981 Nobel prize in Medicine

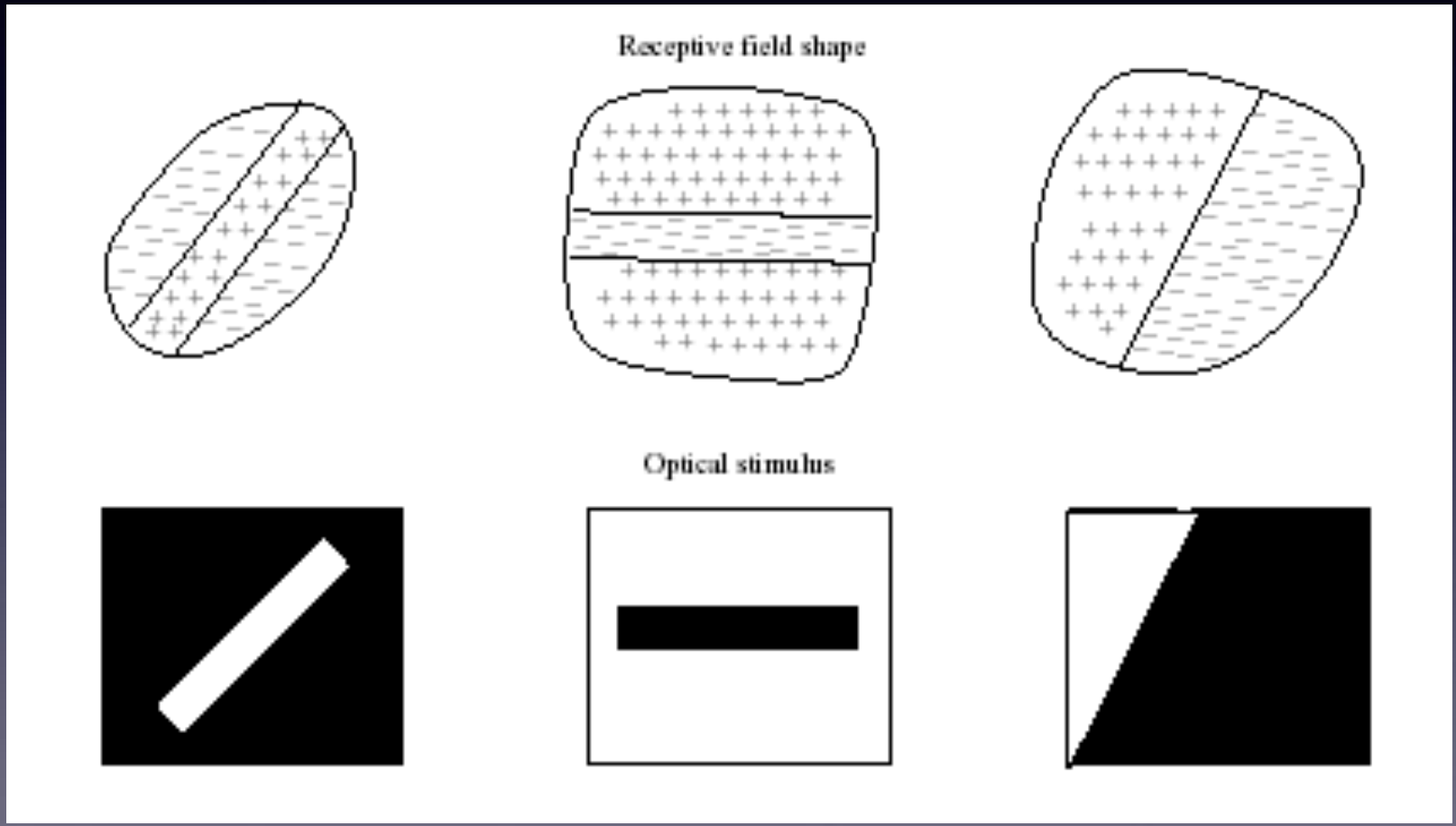
David Hubel, Harvard



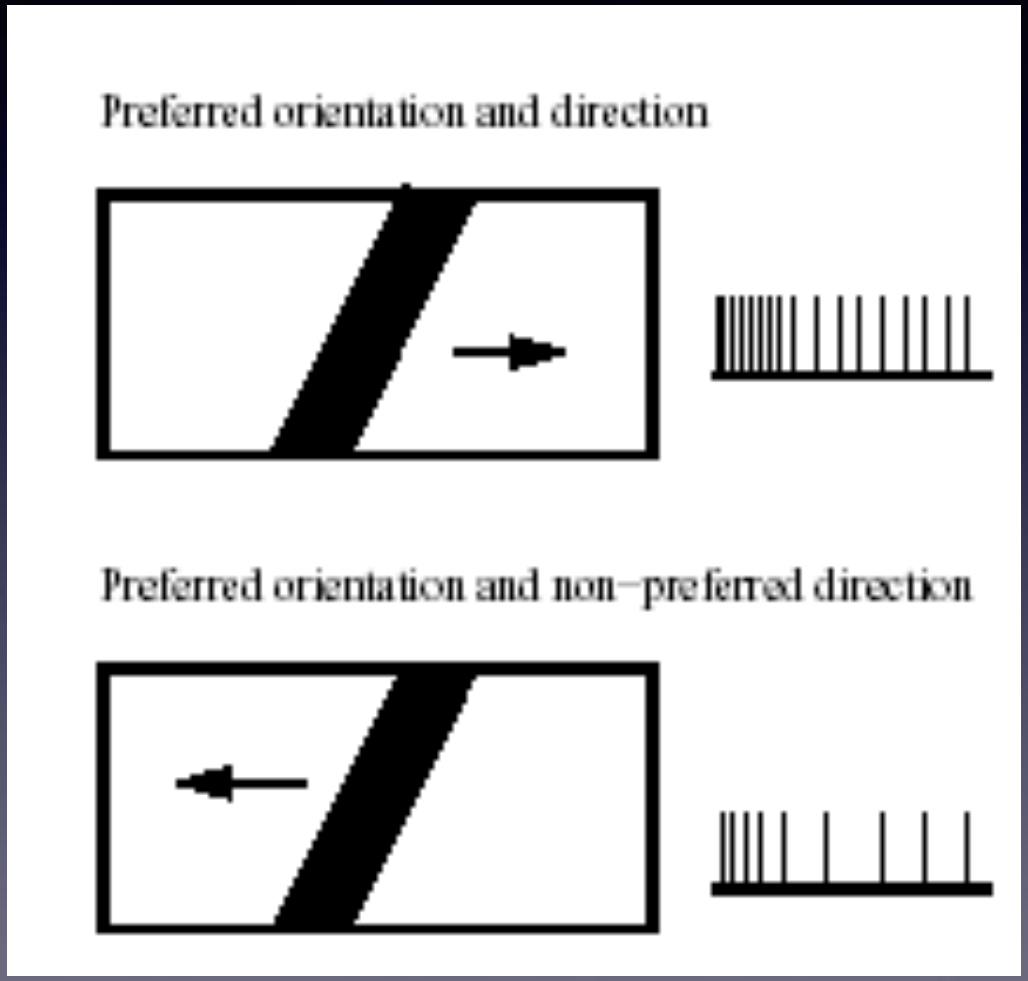
Torsten Wiesel, Harvard (initially KI)

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

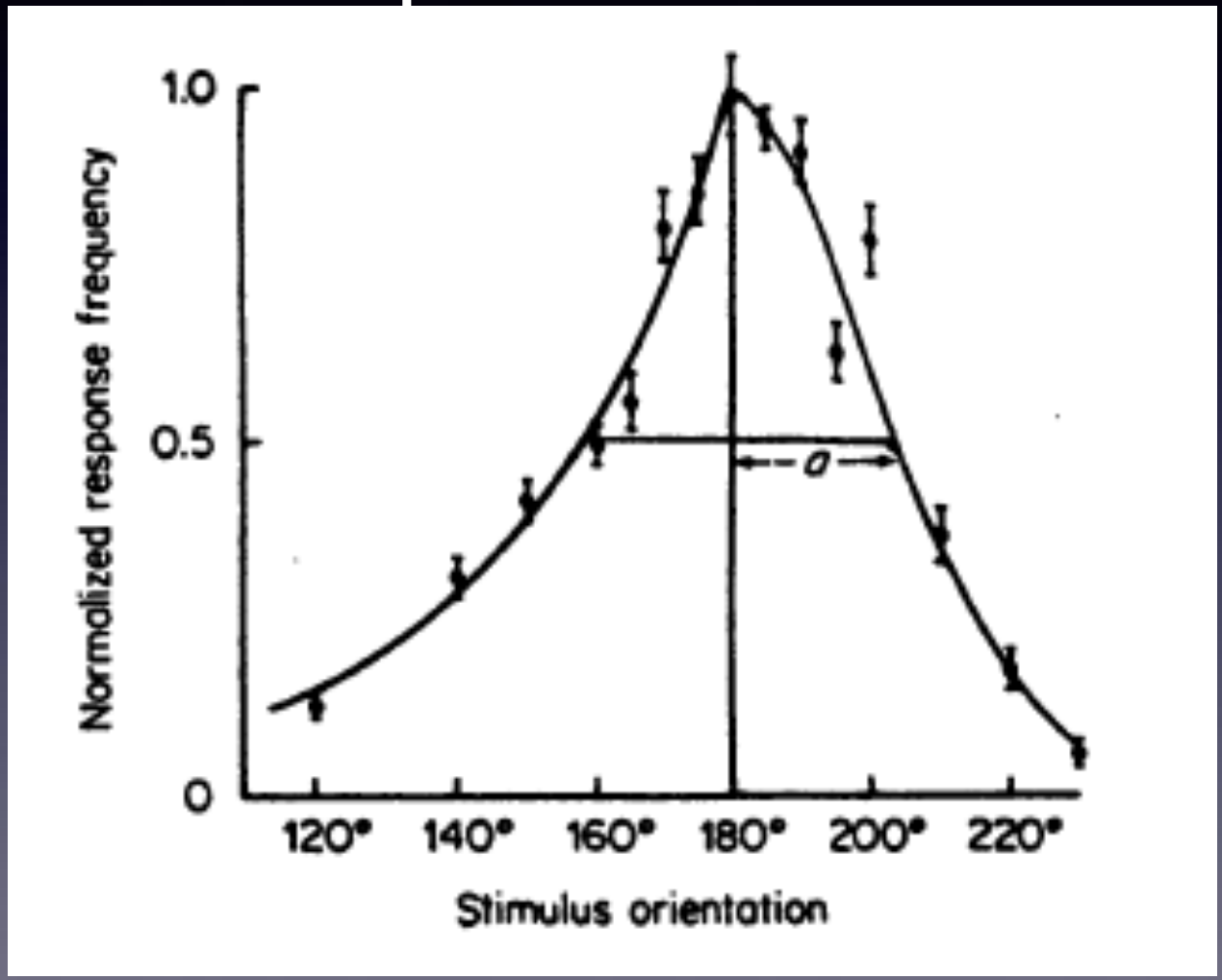
Receptive fields of simple cells



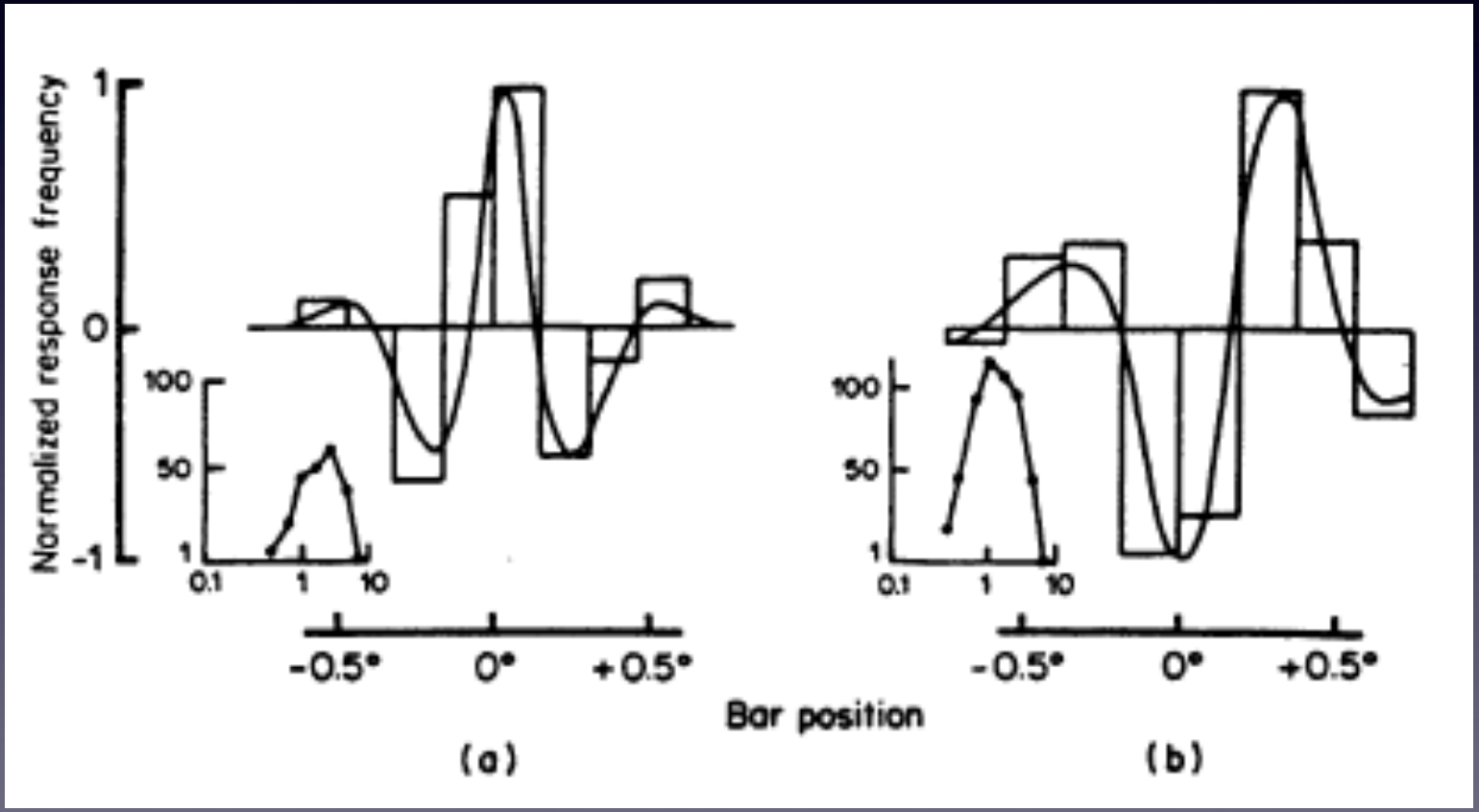
Preference of orientation and direction



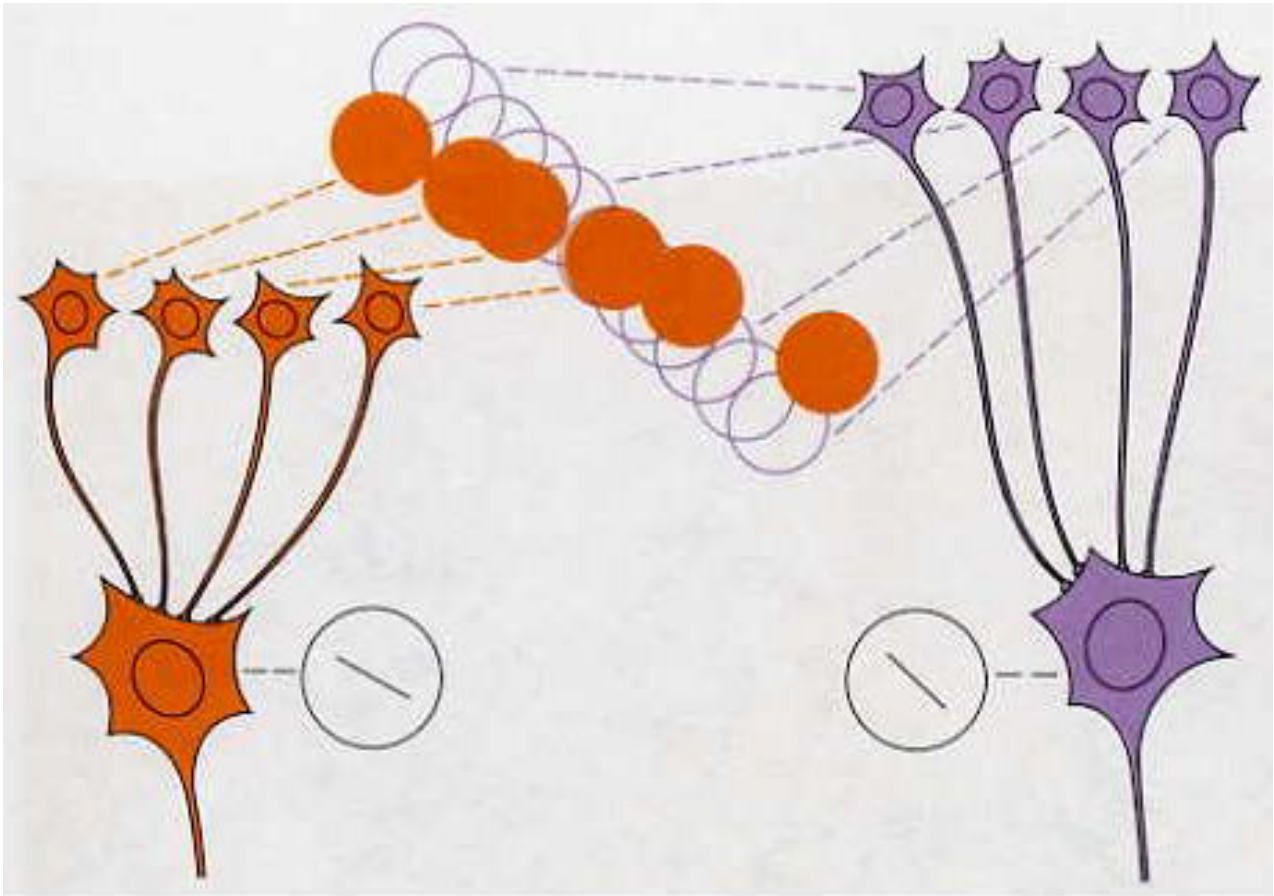
Orientation tuning
Simple cell of cat



Sensitivity profiles of simple cells a)Bisymmetrical b)Antisymmetrical

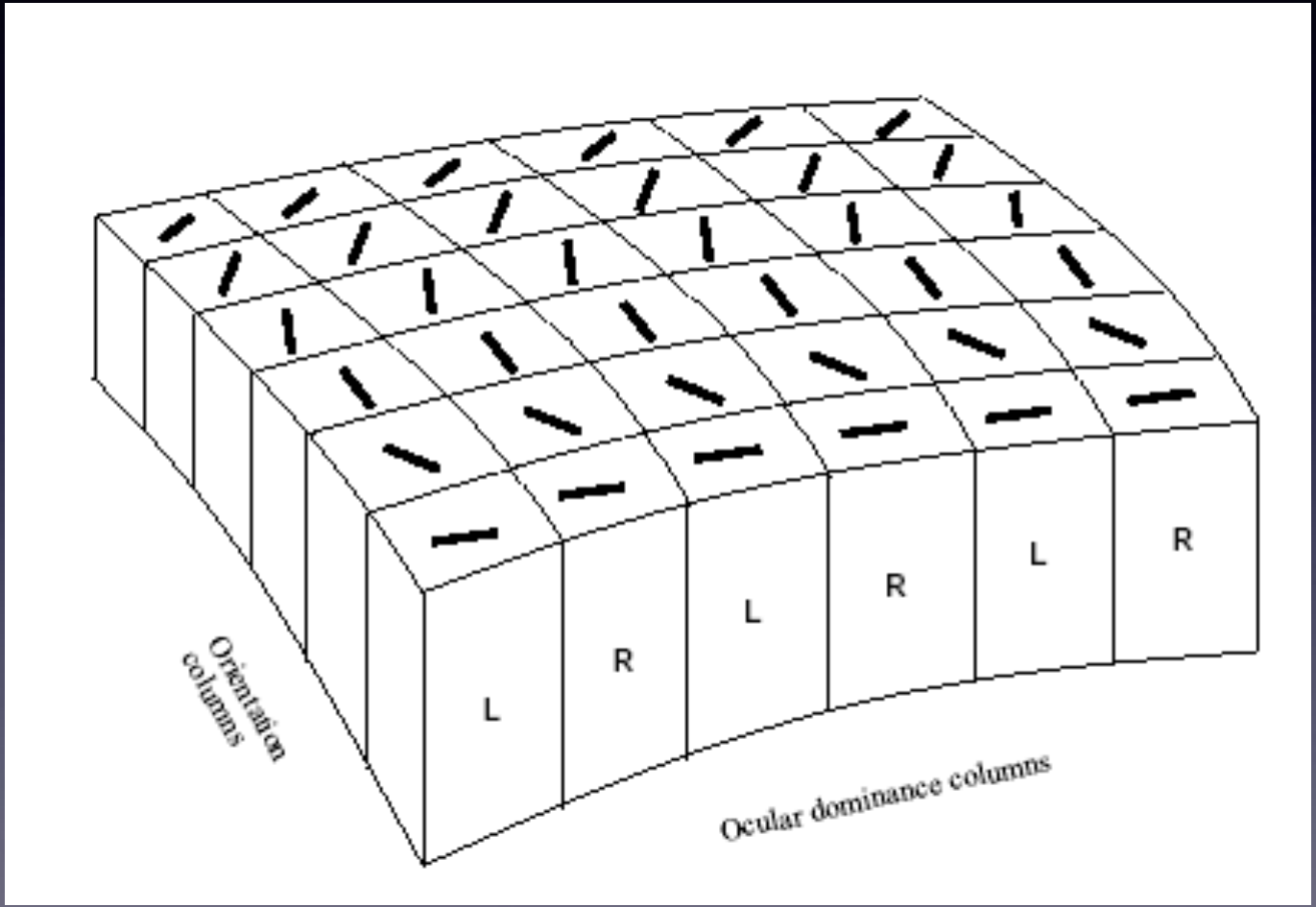


Implementation of simple cell receptive fields

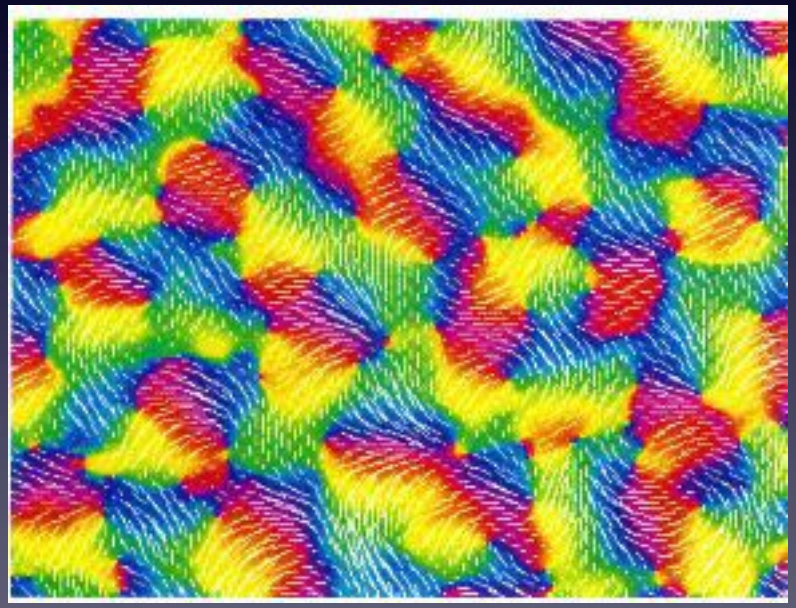


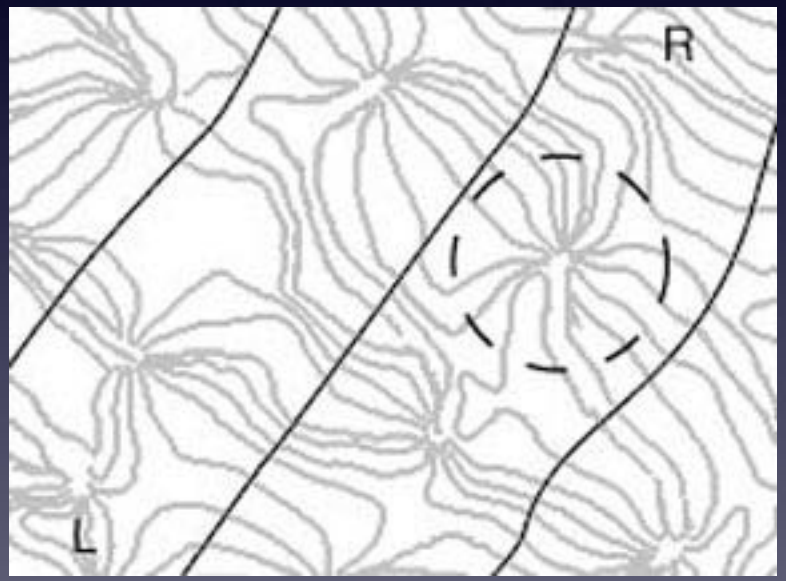
David Hubel, Eye, Brain and Vision

Orientation and ocular dominance columns

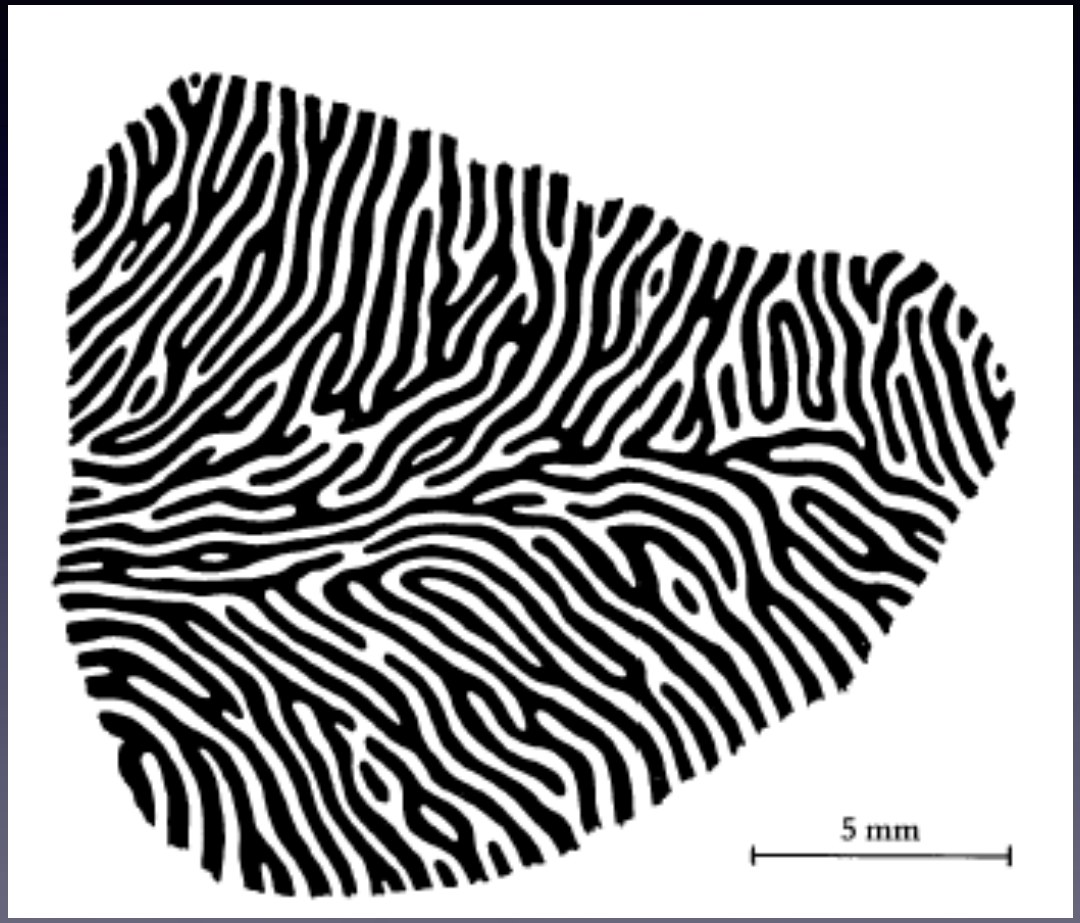


Orientation dominance

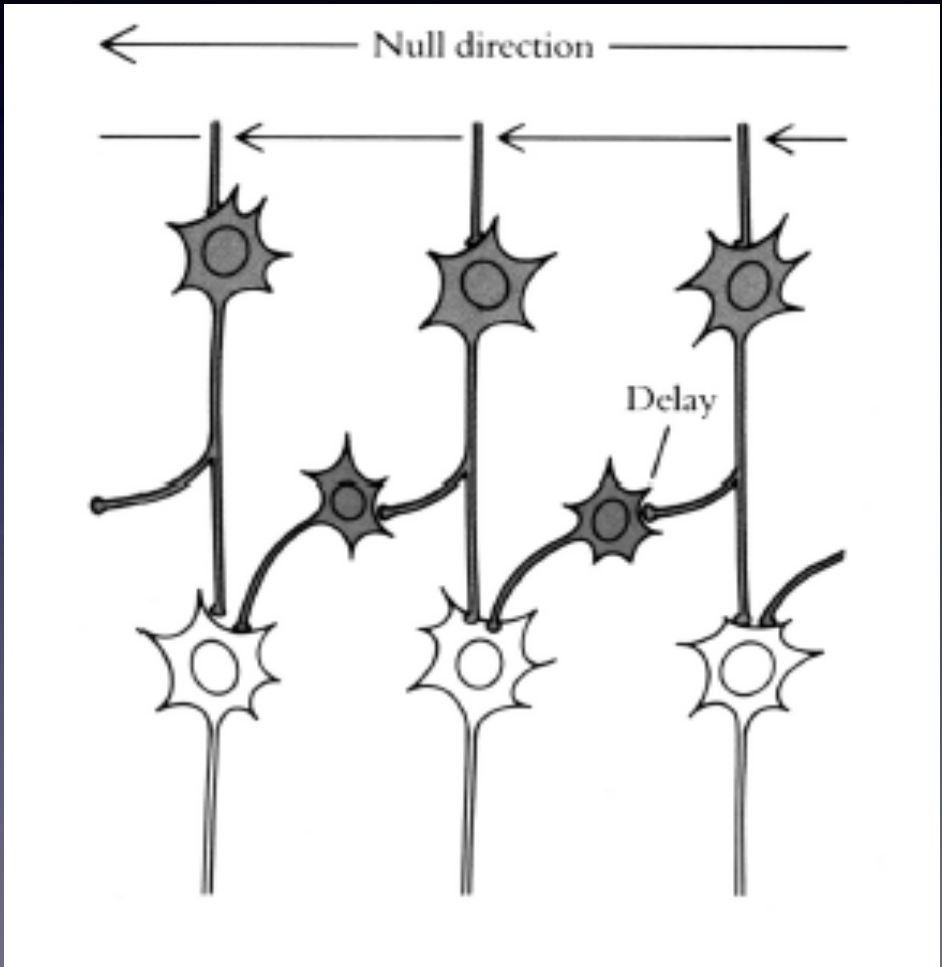




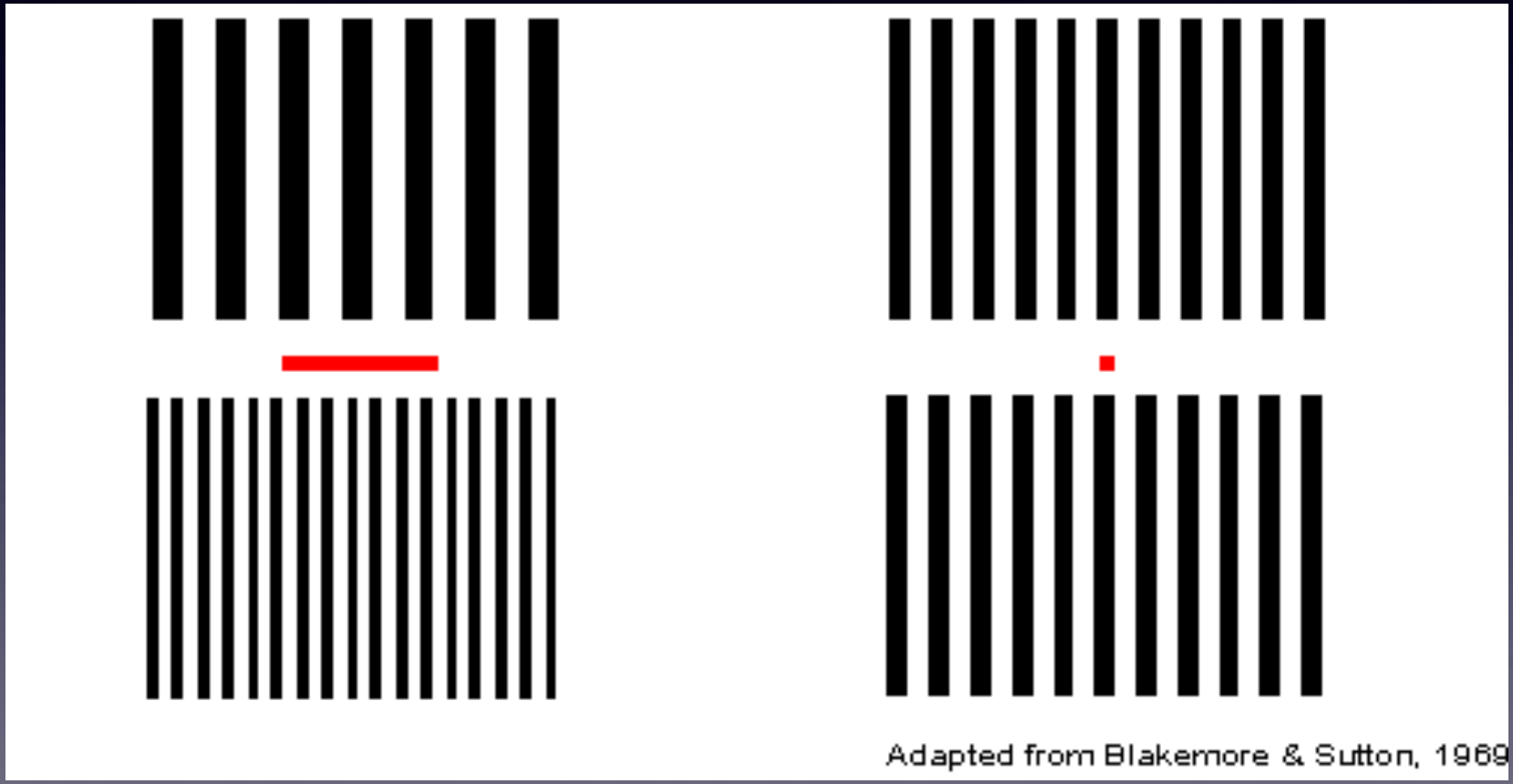
Ocular dominance map



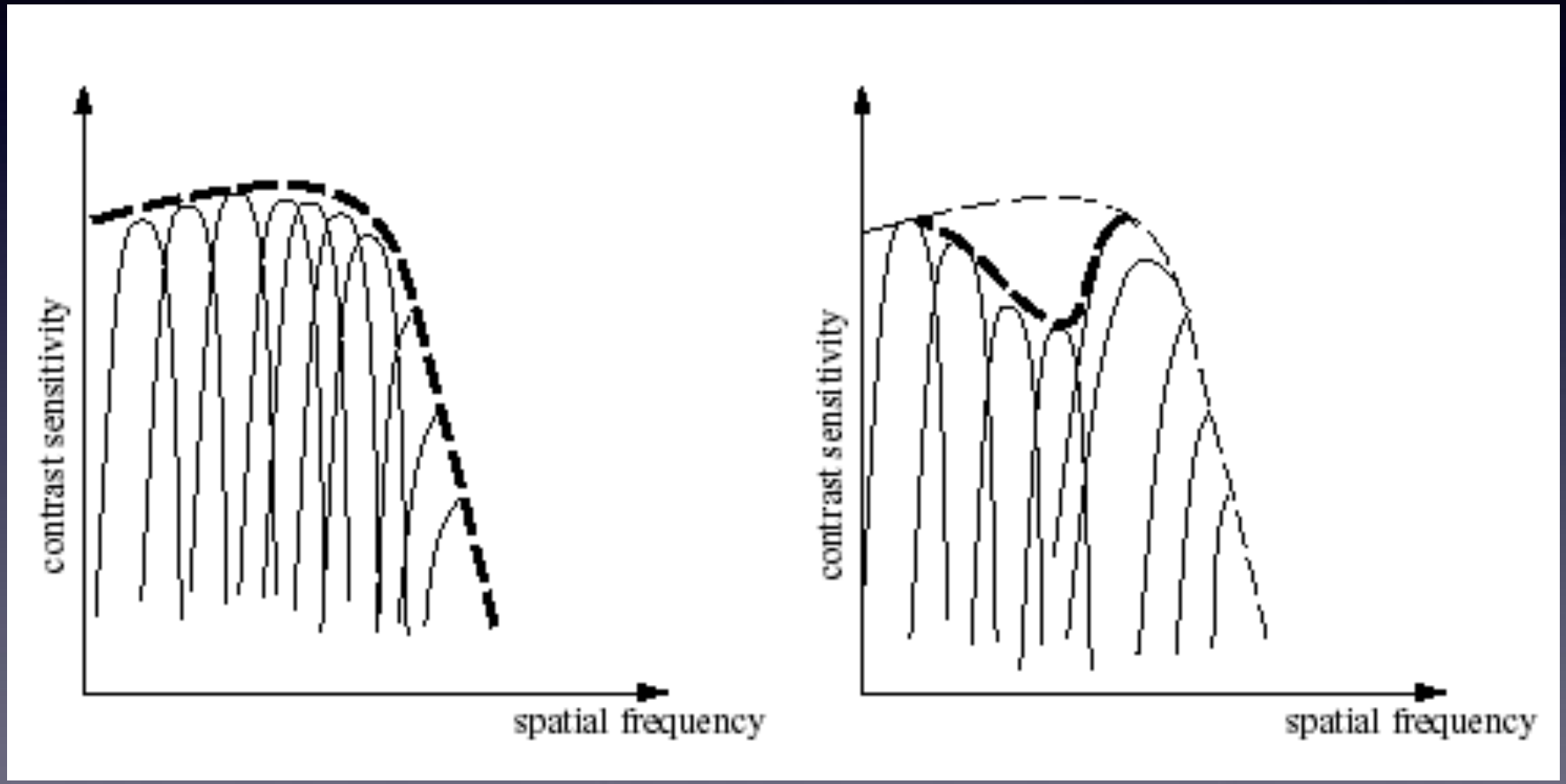
Implementation of direction-sensitive cell



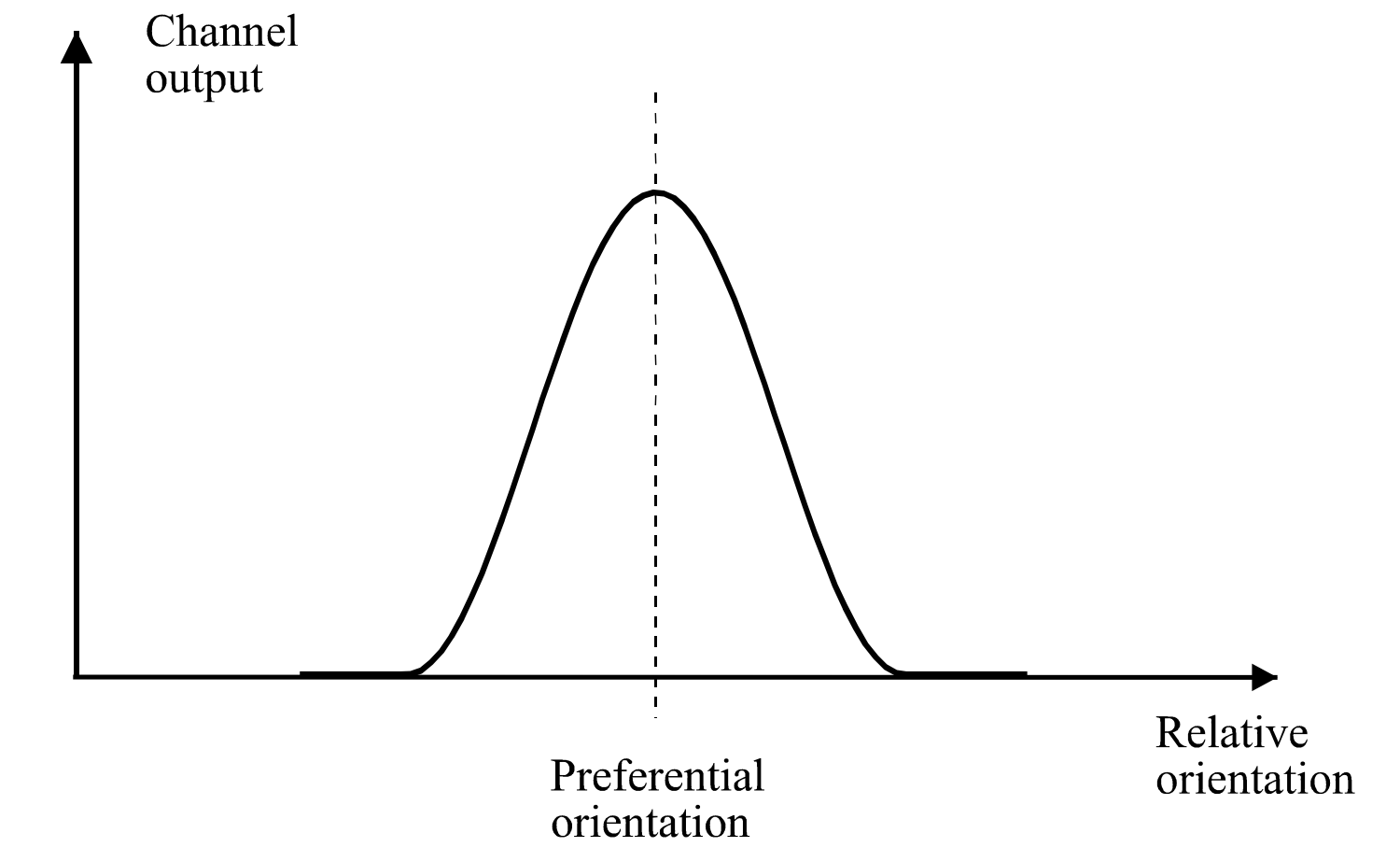
Spatial frequency adaptation



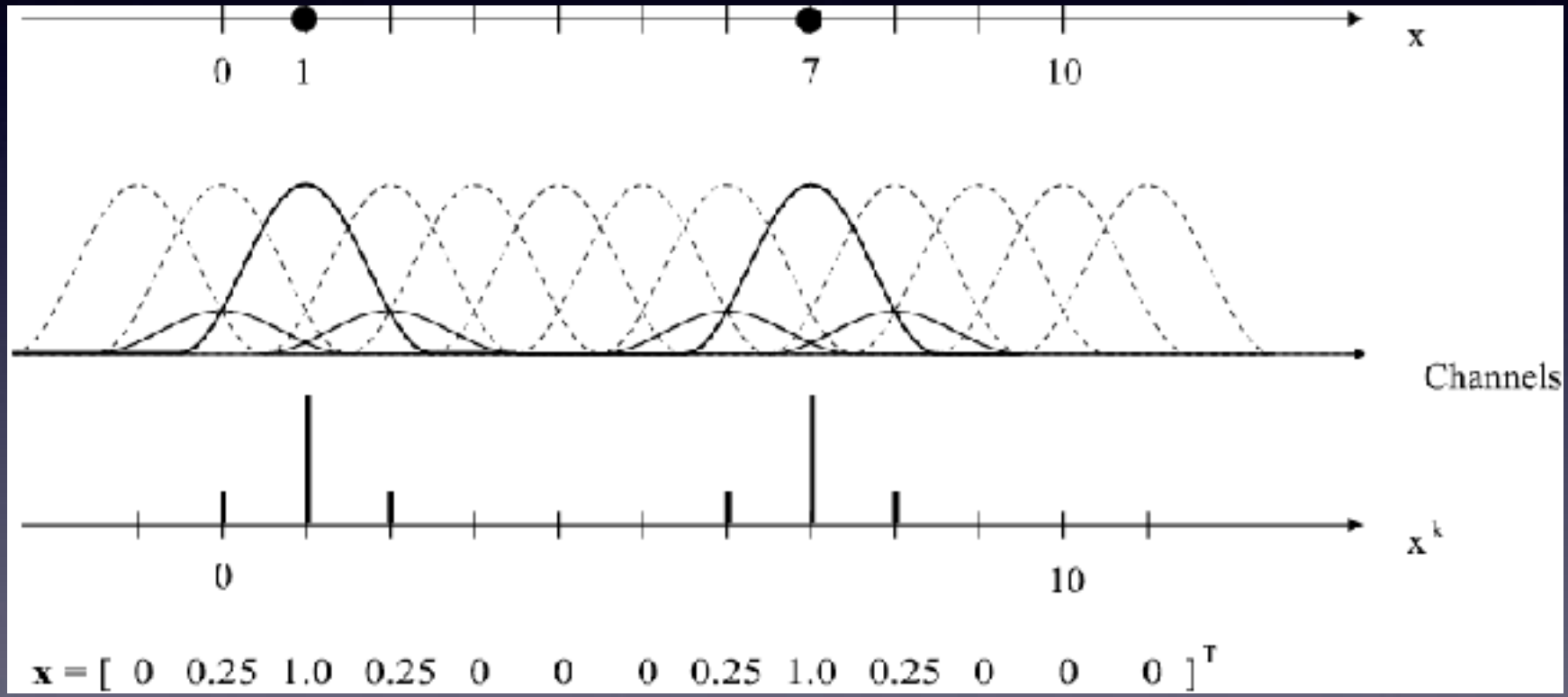
Build-up from separate channels
Effect on sensitivity of channels



Channel representation



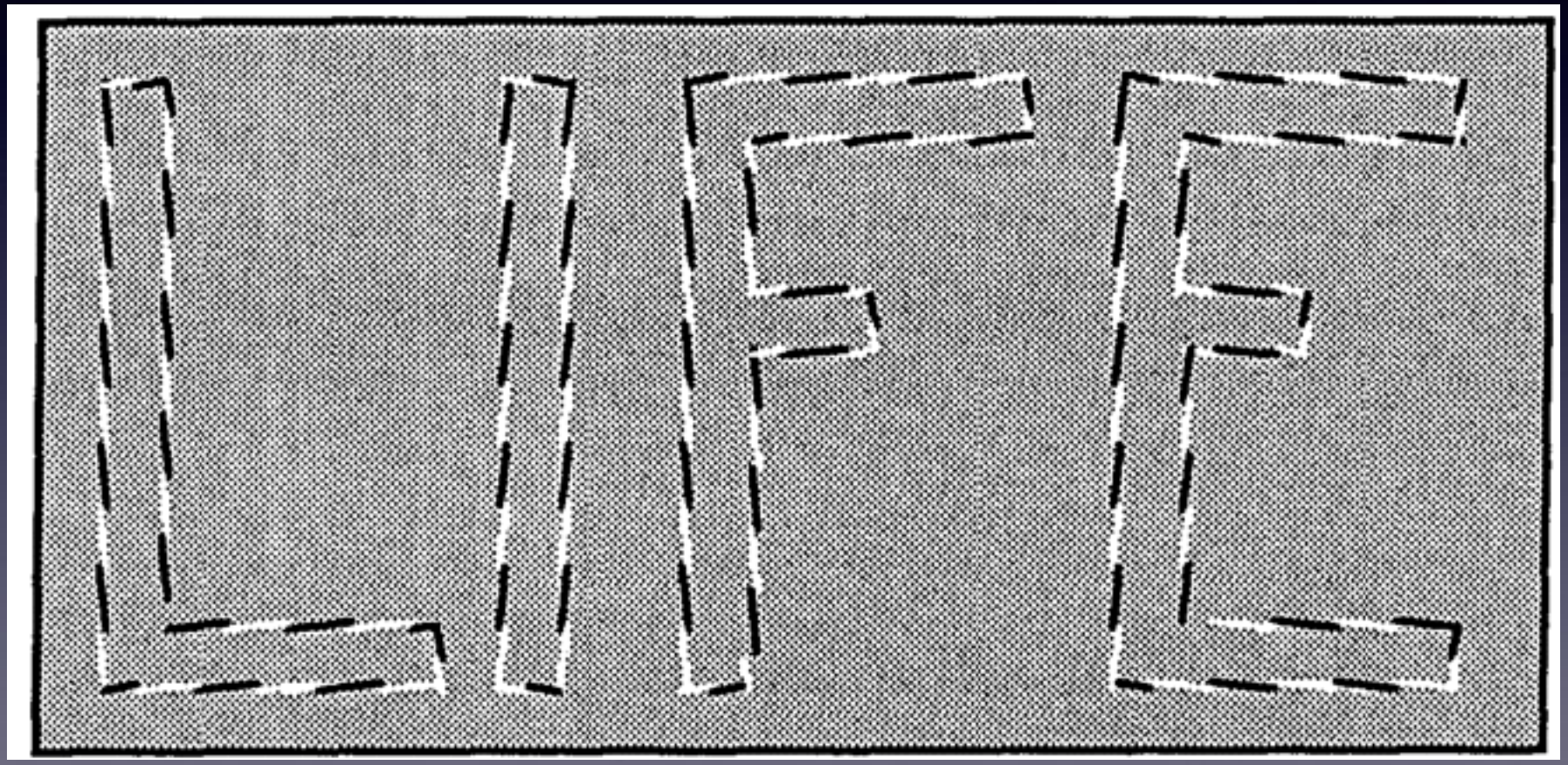
Channel Information Representation



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*** leading to a sparse representation

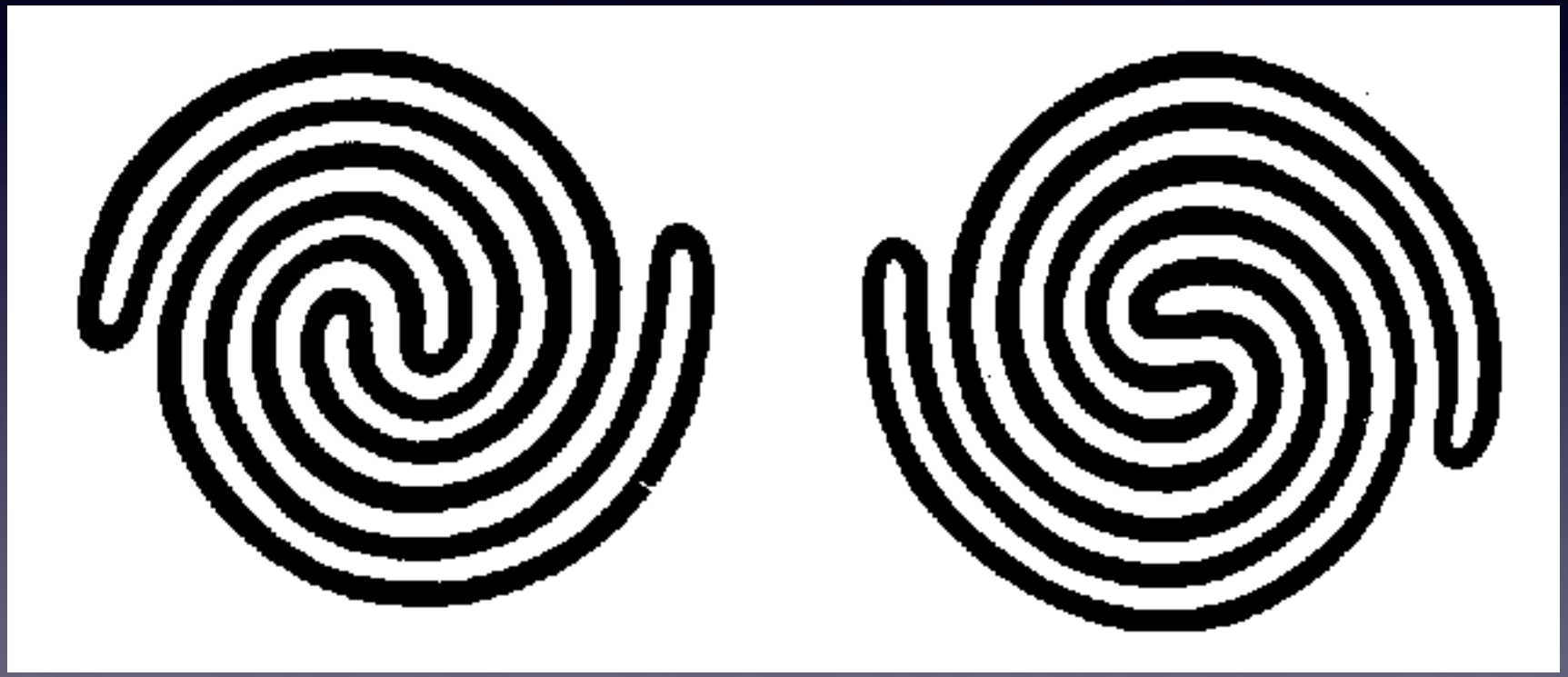
Local versus global properties



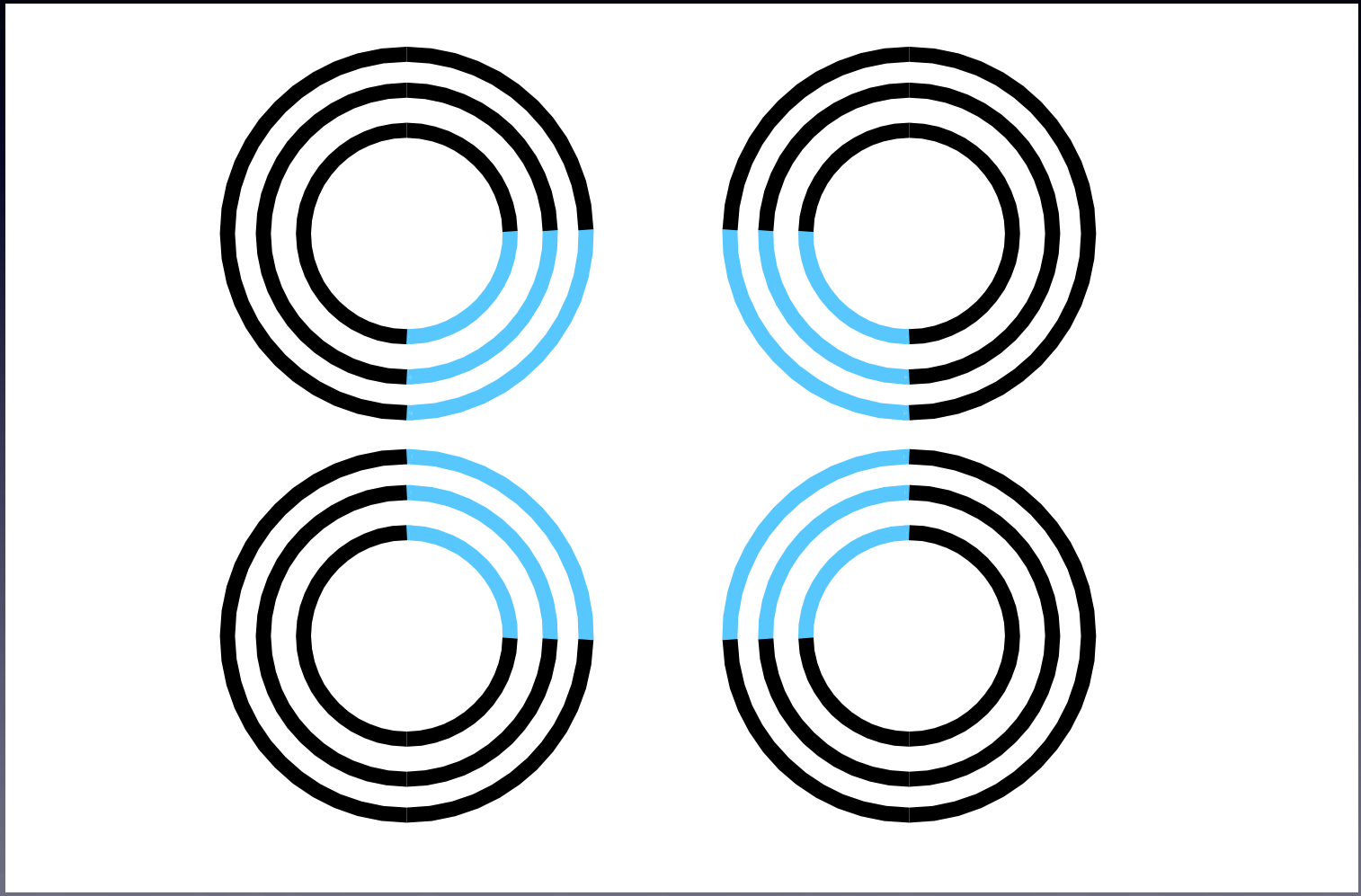
Conflicting interpretations

Parallel interpretation

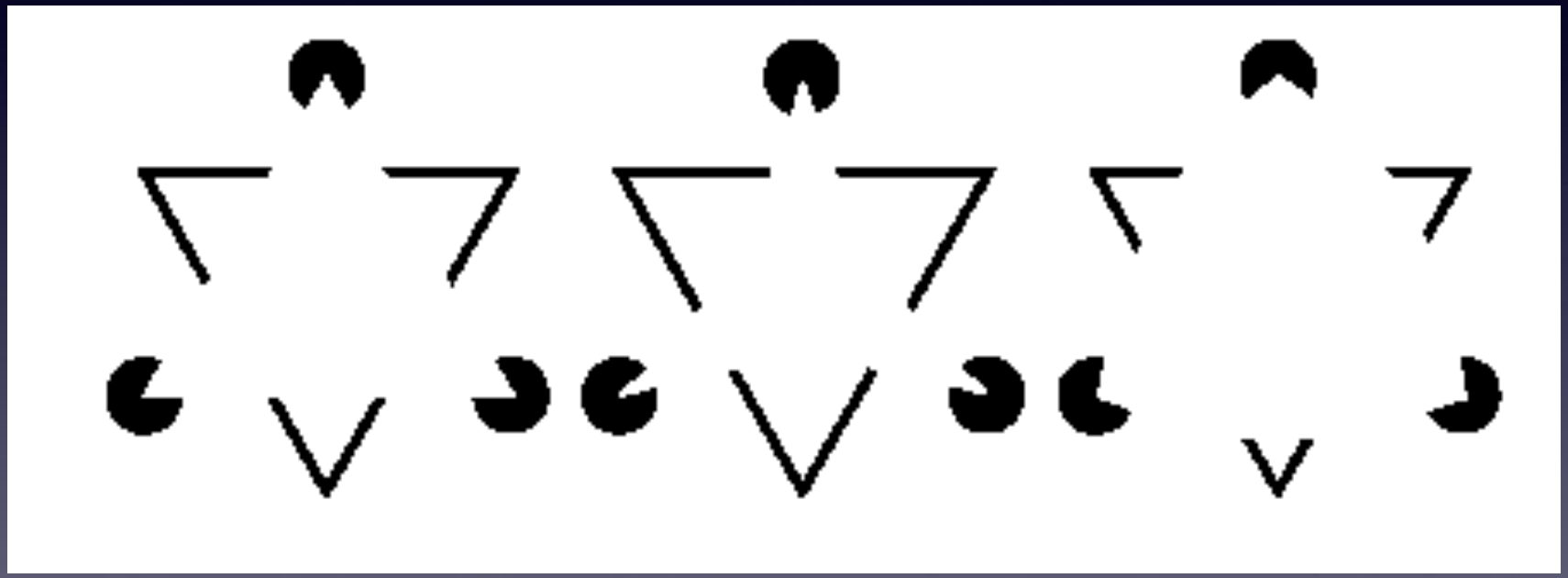
Sequential interpretation



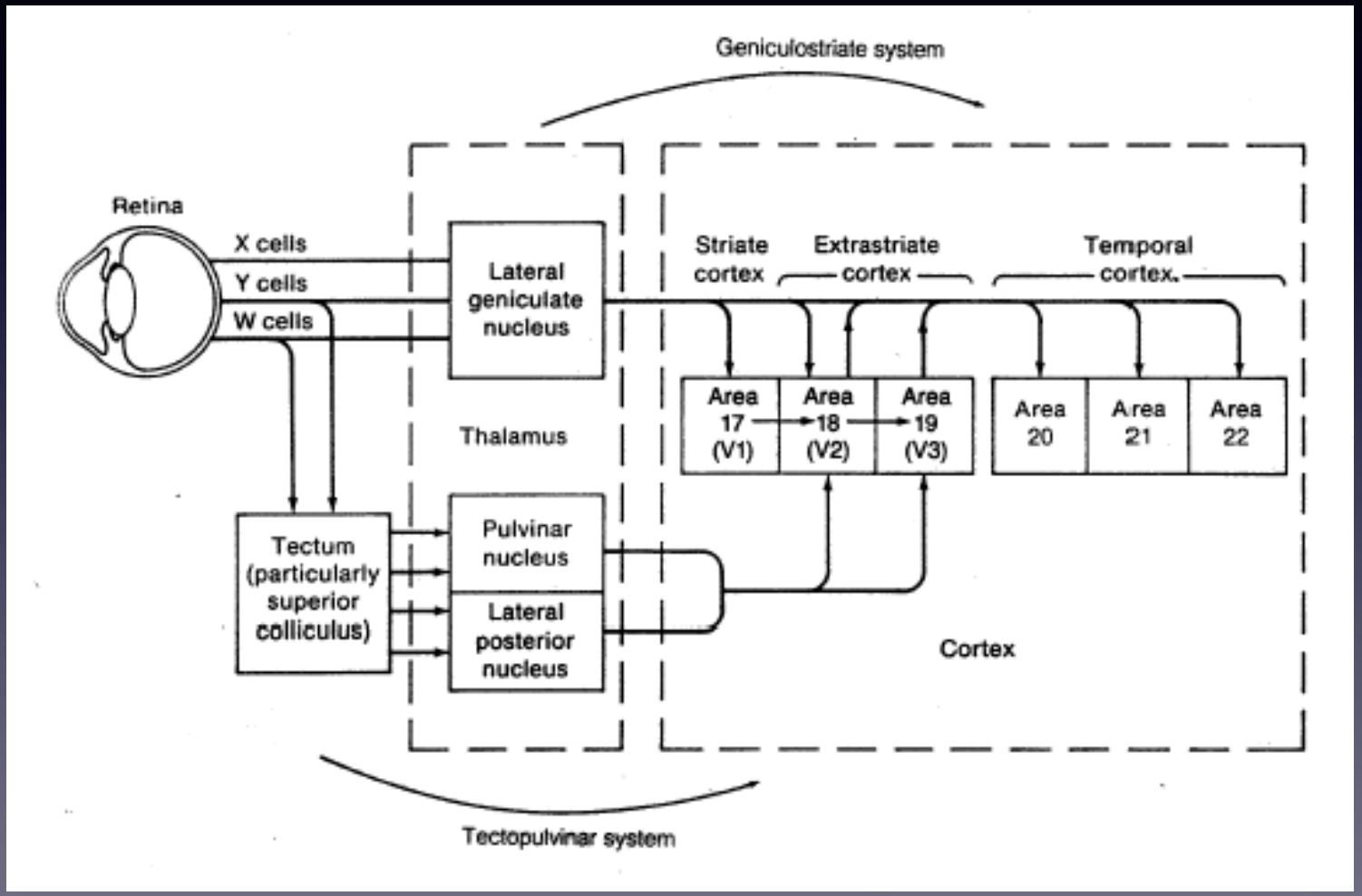
Extrapolations forming illusions



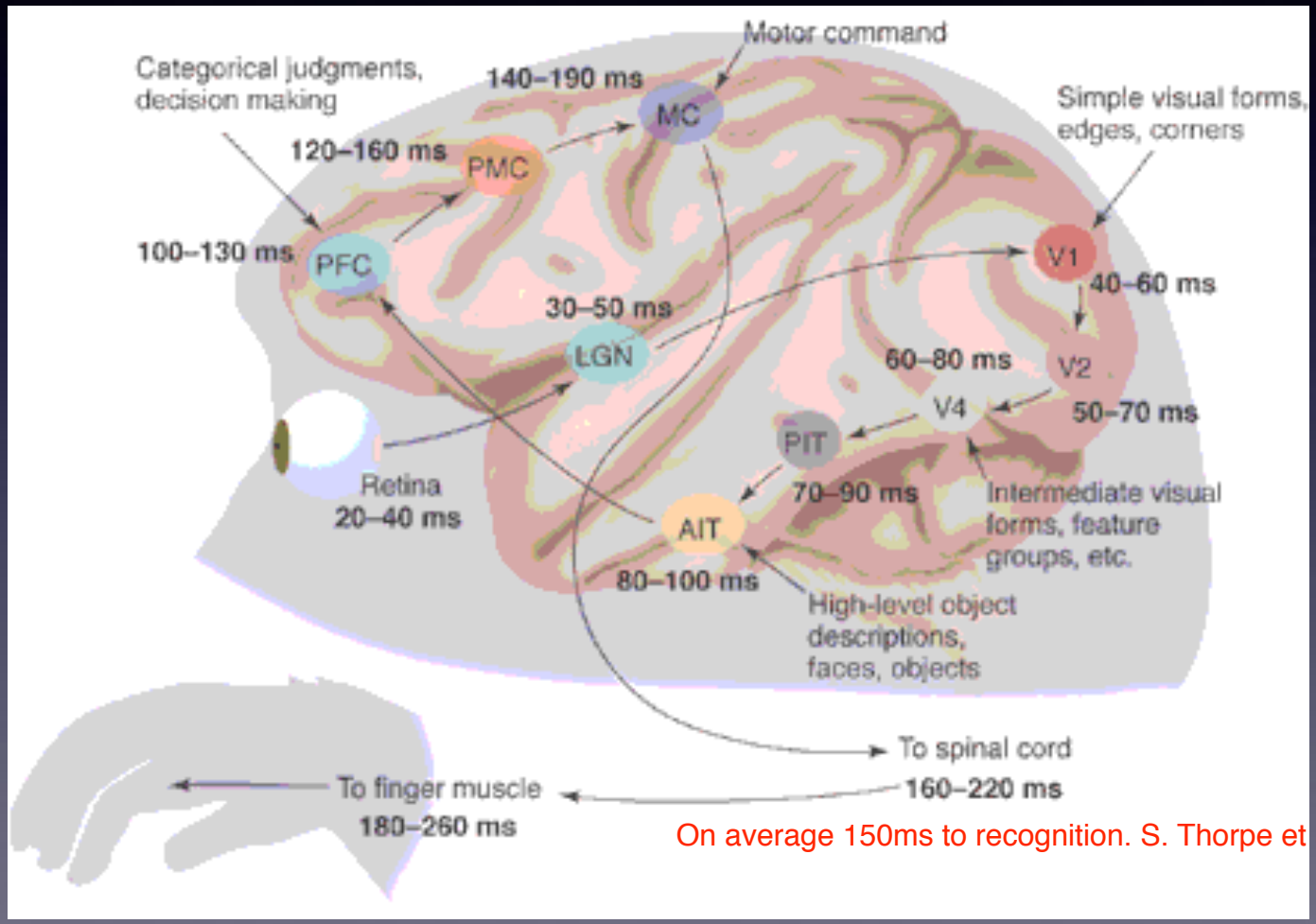
The Kanitza triangle



Part of processing pathway

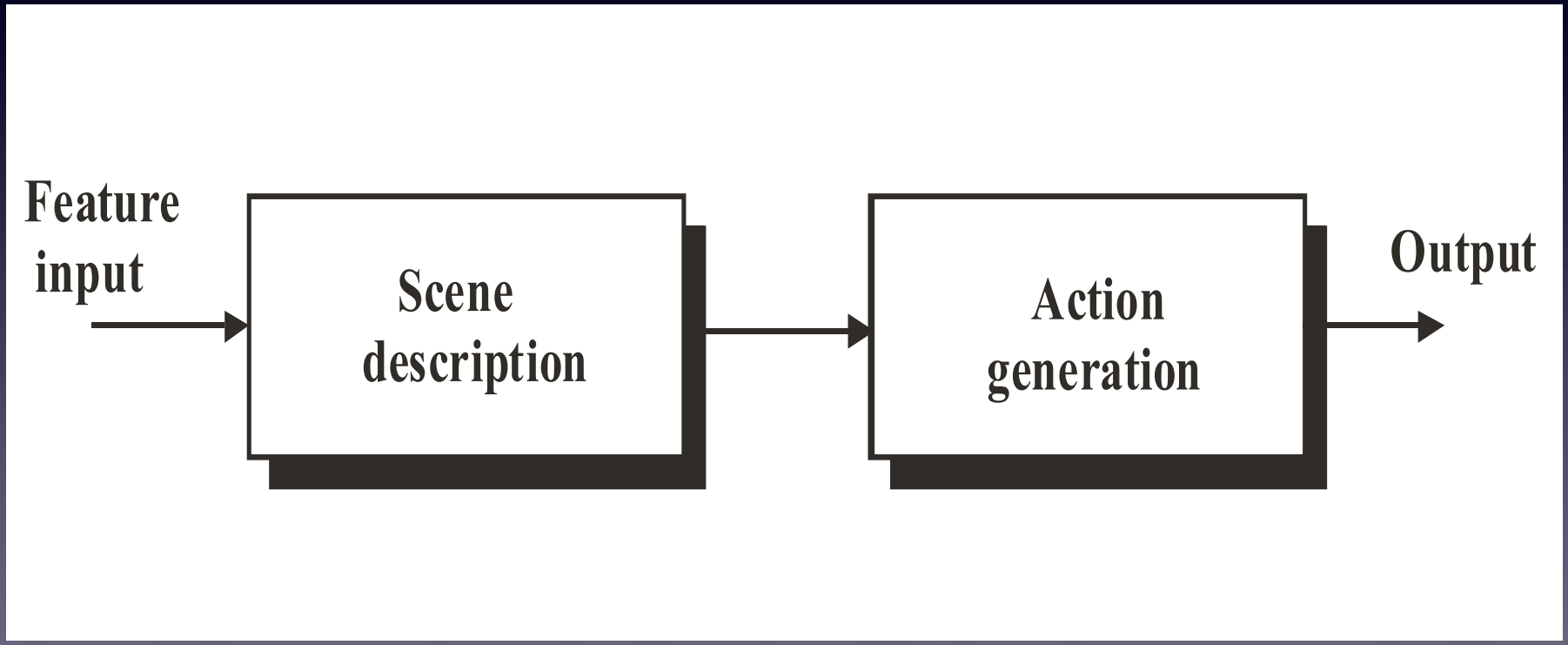


Computation times

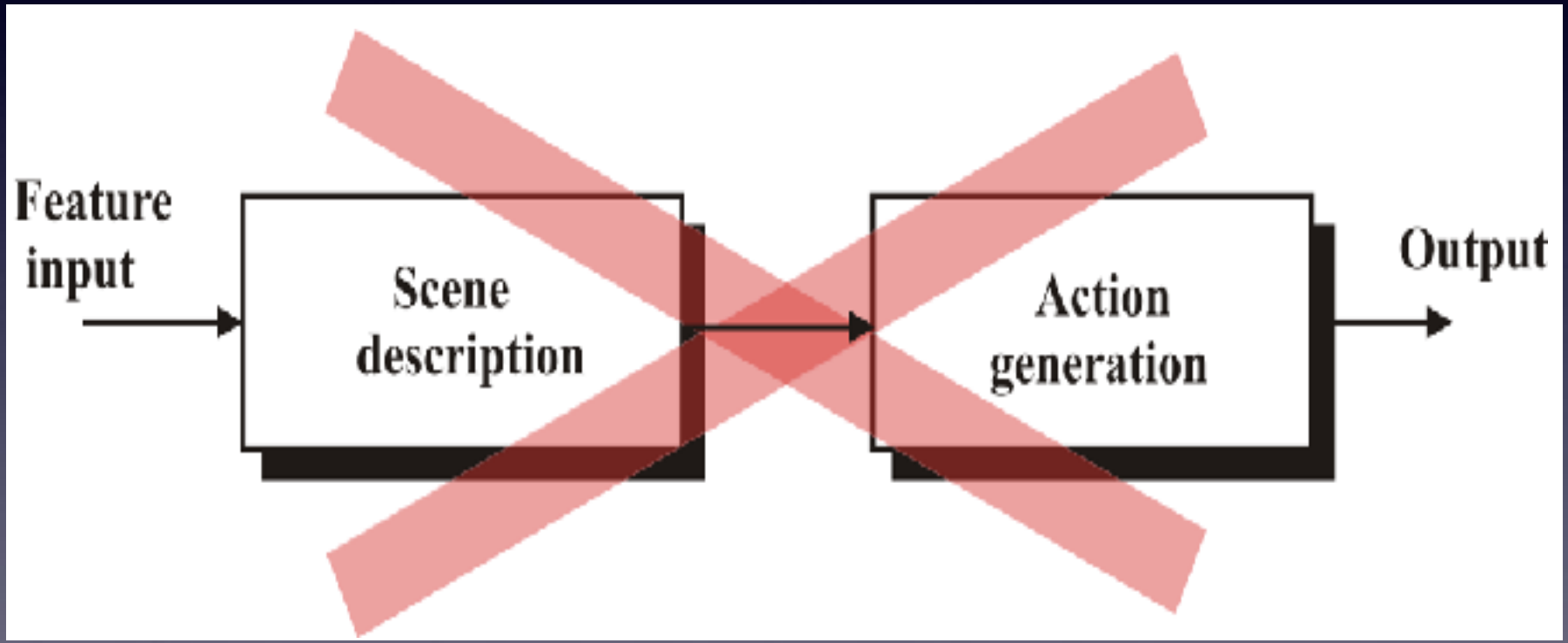


On average 150ms to recognition. S. Thorpe et al. 1996

A conventional robotics structure



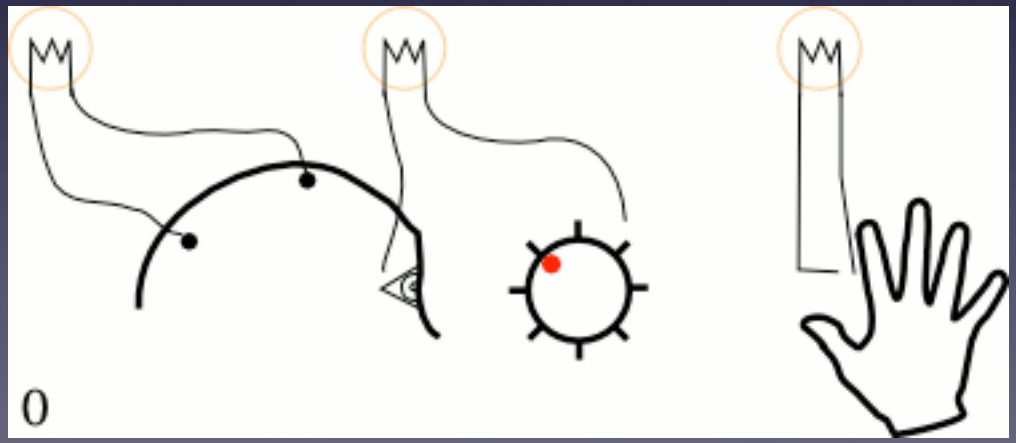
Not done in biological vision



Consciousness - an afterthought

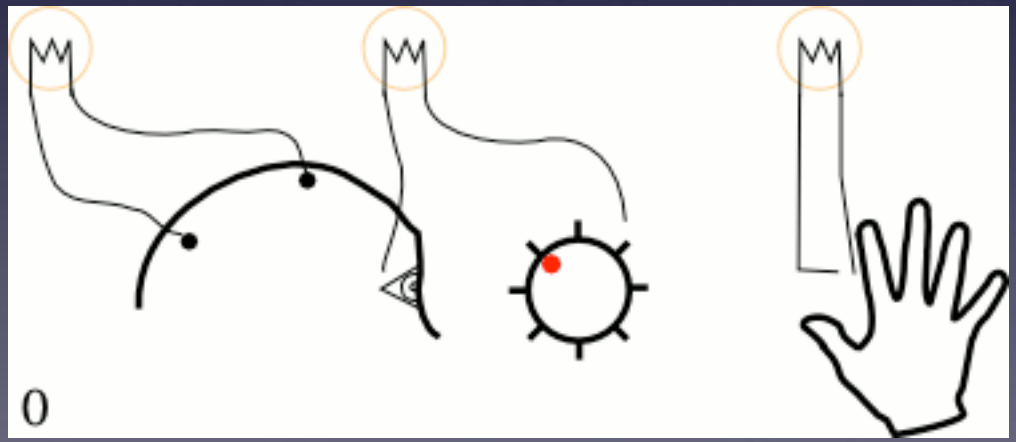
Experiments by Benjamin Libet show that:

Action is initiated before it reaches consciousness



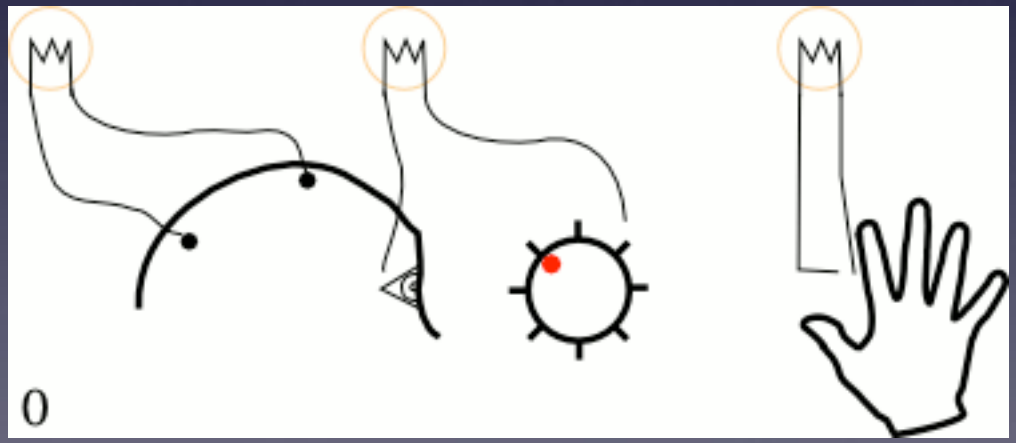
Consciousness - an afterthought

Synchronized EEG and rotating clock, subject notes position on timer when ”he/she was first aware of the wish or urge to act”



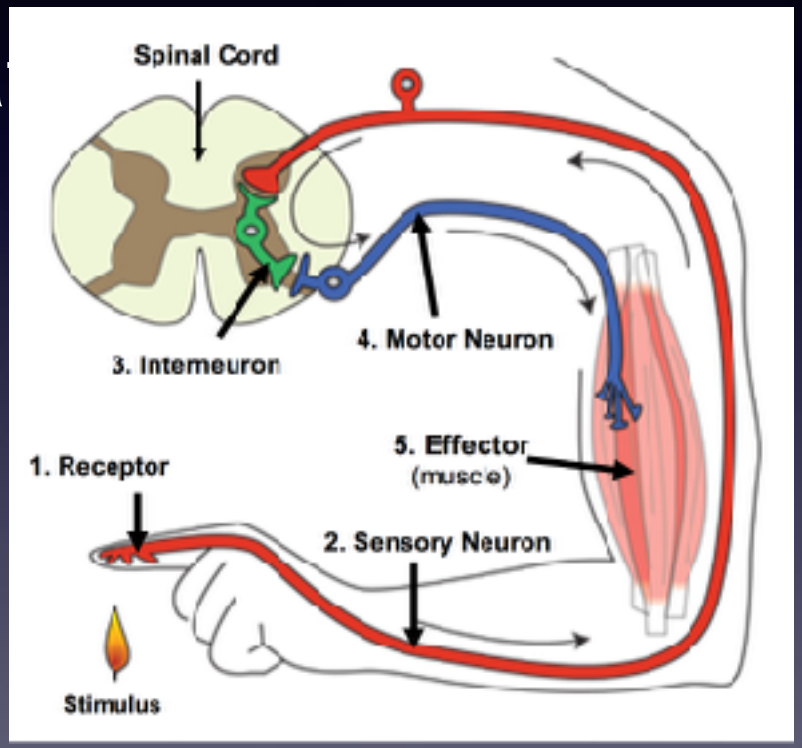
Consciousness-an afterthought

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

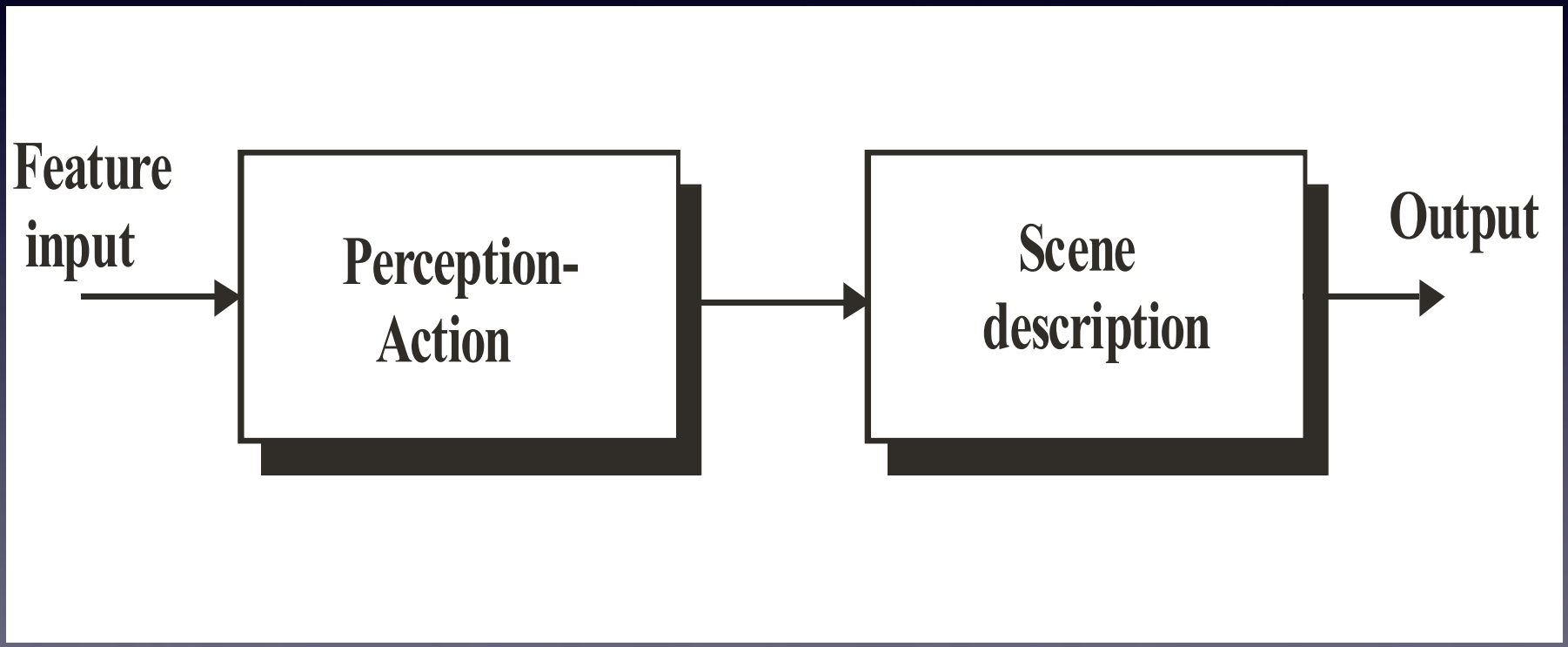


Other examples

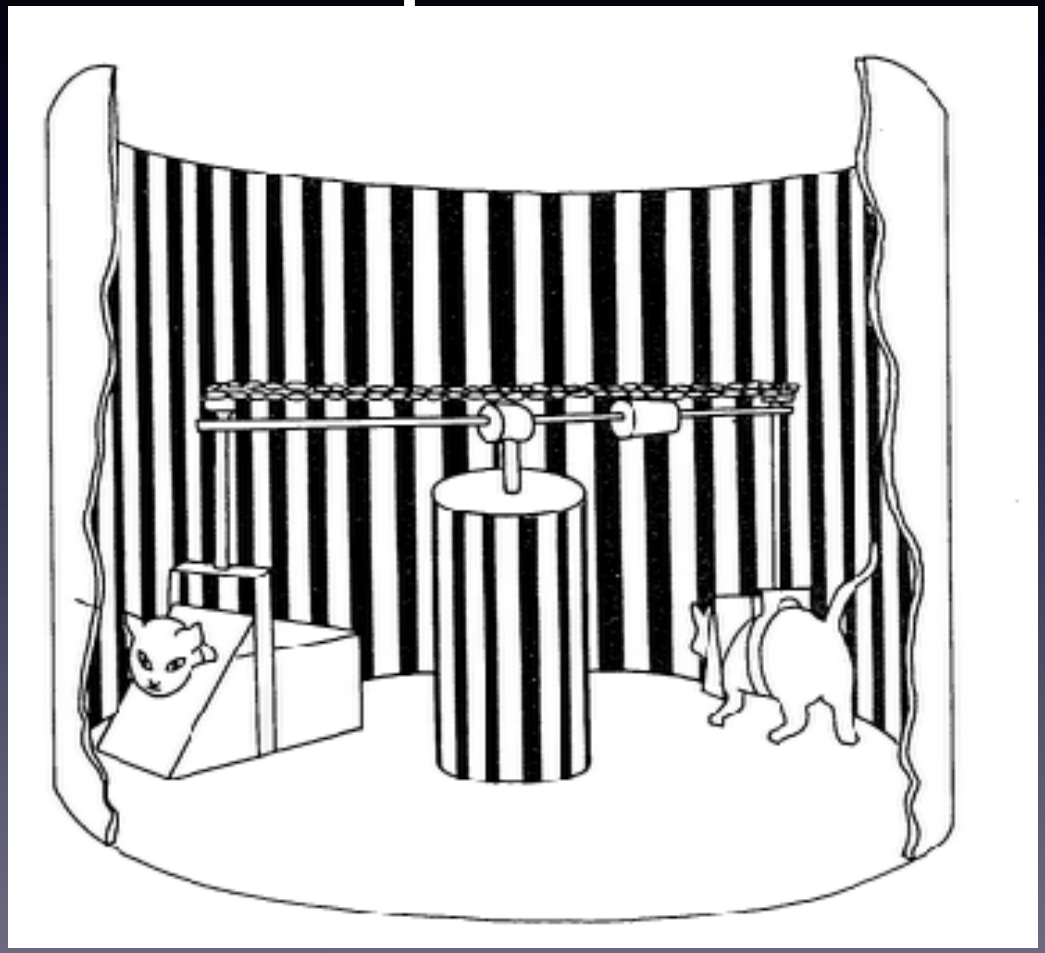
1. It is well known that reflex actions are pre-conscious
2. You do not consciously plan all details of e.g. walking pattern



Order is the opposite!



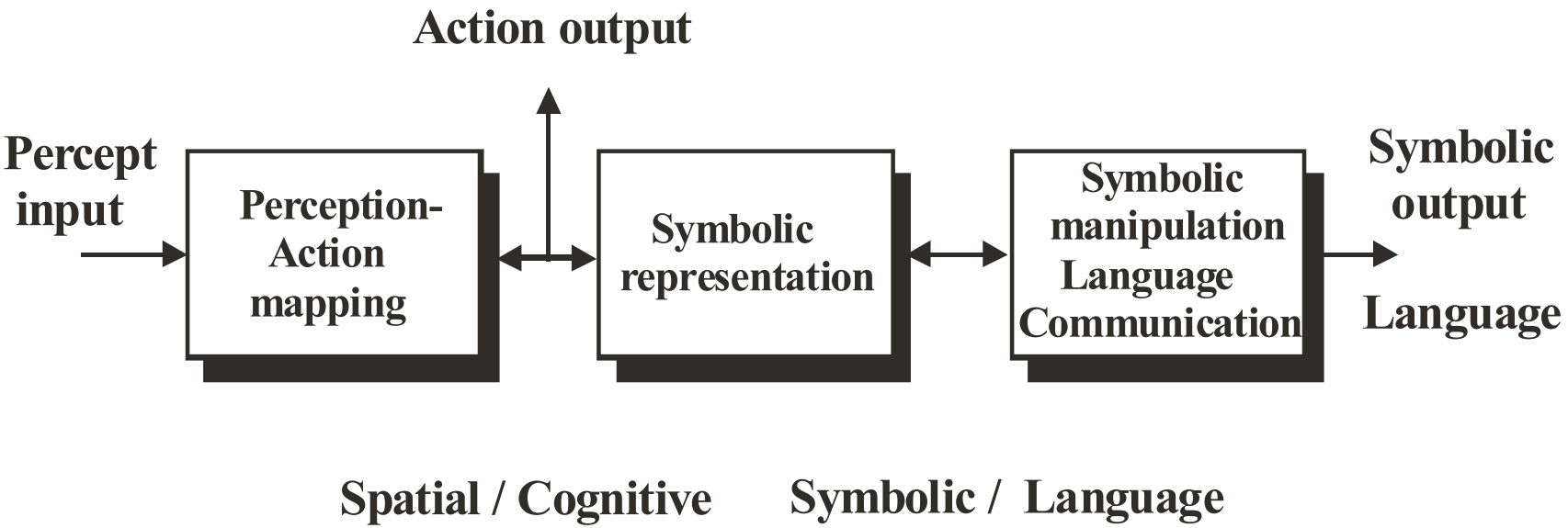
Active versus passive exposure



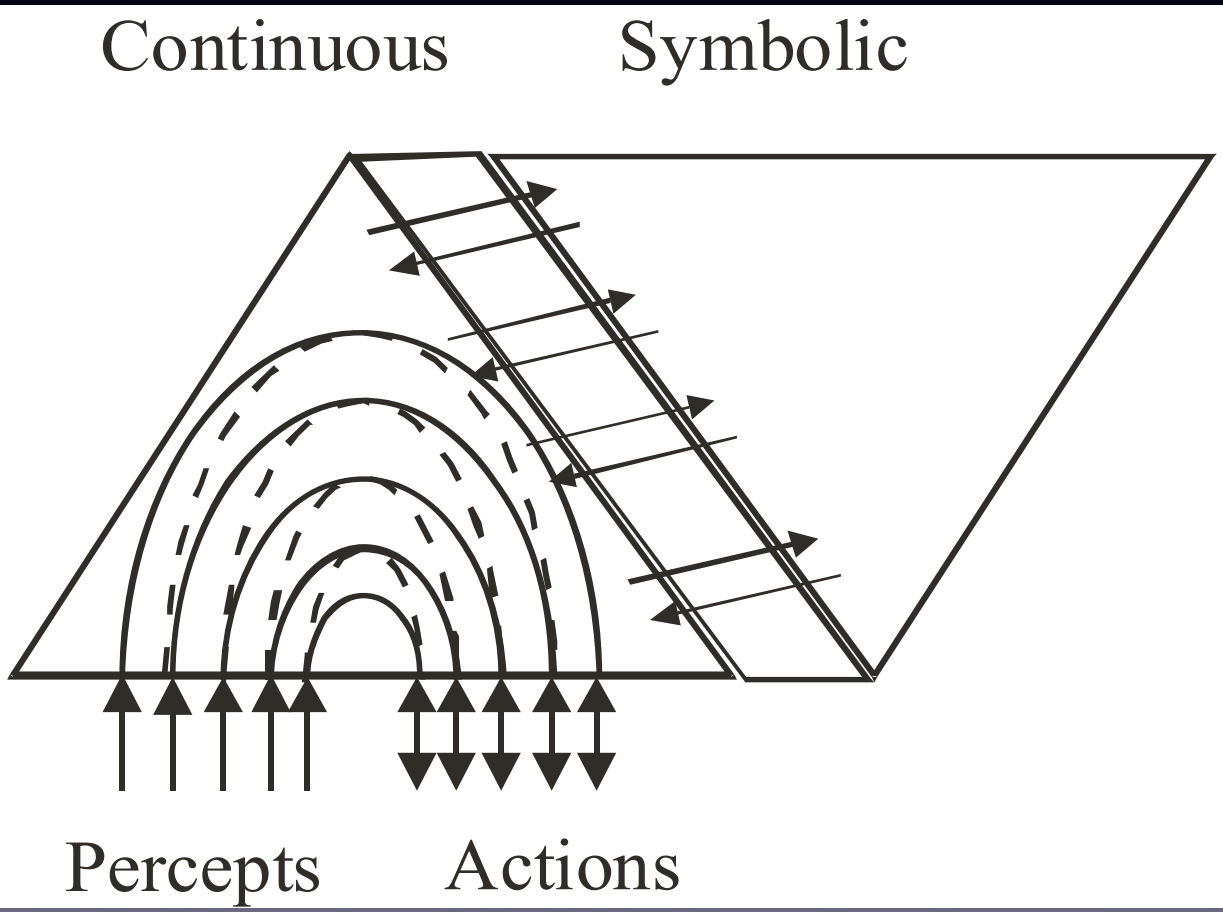
Why active learning?

- 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



Pyramid version



Summary

- Biological vision is 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

Course format

- The participants arrange the seminars
  - A **presenter** presents the chosen article
  - The **reviewer** does a critical discussion of the article. Approx. 10 topics. Encourage other participants to take part in the discussion.
  - Everyone else reads the article and participates in the discussion (at least 3 times).

Paper Assignment Table

	P1	P2	P3	P4	P5	P6	P7	P8	R1	R2	R3	R4	R5	R6	R7	R8
Amanda Berg					X						X					
Gustav Häger								X						X		
Karl Holmqvist	X												X			
Joakim Johnander		X							X							
Andreas Robinson							X			X						
Emil Brissman			X													X
Abdelrahman Eldesokey				X											X	
Felix Järemo Lawin						X						X				