CDL PS2011/16

Lecture 2
The physiology of low level vision

Reading

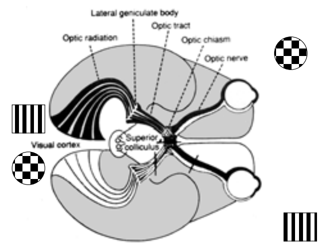
Essential
- Bruce, Green & Georgeson (2003).
Chapter 2; Chapter 3. Pp. 43-50.

Recommended
- Gordon (2004), Chapter 4 or Gordon (1997), Chapter 5.
- Rosenzweig, Breedlove & Leiman (2002).
Biological Psychology. Sunderland (Mass), Sinauer (3rd ed).
Chapter 10, with CD ROM.

Additional
- Eysenck & Keane (2000). Chapter 2, pp. 43-45;
Chapter 3, pp. 53-58.
- Wade & Swanston (2001). Chapter 3.

Primary Visual pathways

- from the retina to the visual cortex
- stimuli from each hemi field are processed in ipsilateral hemisphere



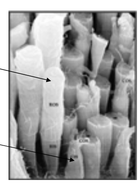
- Perception requires the detection of energy
- For visual perception this energy is light

Retina

layer of photoreceptors (light sensitive cells) with an outer (pointing externally from the retina) segment containing light-sensitive pigment

rods – long cylindrical outer segment
sensitive to low intensity light

cones – short conical outer segment
important for colour processing



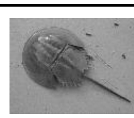
Cones densely packed in the fovea

Function of photoreceptors
transduce light energy into electric energy

In vertebrate retina
Outer segment
absorption of light
chain of chemical reactions

Inner segment
release of neurotransmitter
trigger electric signal in postsynaptic cell

Retinal functions in the horseshoe crab
(Hartline and Graham, 1932)



Simple retina
- axons of photoreceptors form the optic nerve

Recordings of electric activity of optic nerve following stimulation by light
- rate of electric impulses proportional to light intensity

Adaptation
- transformation of activity in time
- high rate of electric activity at light onset
- rate decreases with time but still proportional to light intensity

Dark adaptation
receptor adapted to light then left in the dark
sensitivity to light increases

General function of adaptation
- emphasises sudden light changes
- prevents the visual system to be fooled by gradual light changes (e.g. time of the day; weather; shade)

Lateral inhibition (Hartline, Wagner & Ratcliff, 1956)
- transformation of activity in space
- stimulation of adjacent receptors produces reciprocal inhibition
- caused by collateral branches of receptors

General function of lateral inhibition
- emphasises rapid changes of light in space
- important for edge detection (see computer vision)

The vertebrate retina

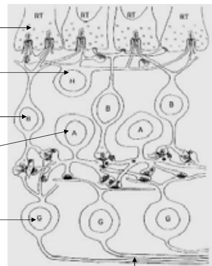
Receptors (terminals)

Horizontal cells

Bipolar cells

Amacrine cells

Ganglion cells



Optic nerve

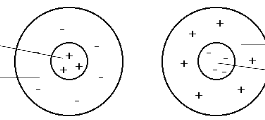
Receptive fields in ganglion cells (Kuffler, 1953)

Receptive field
- portion of the retina that if stimulated by light causes activity in a ganglion cell

Different types of receptive fields
- e.g. concentric receptive fields

Excitation

Inhibition



Excitation

Inhibition

On-centre cell

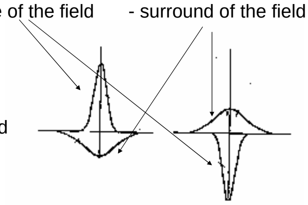
Off-centre cell

Gaussian curves of activation (Enroth-Cugell & Robson, 1966)

Rate of response described as bell-shaped curves for the:

- centre of the field
- surround of the field

Antagonistic organisation of the field



On-centre cell

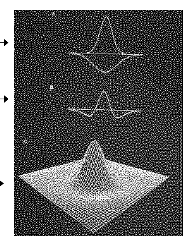
Off-centre cell

The algebraic sum of the centre and the surround describes the response of the ganglion cell to light falling on the receptive field

Centre and surround components →

Positive centre component + negative surround component →

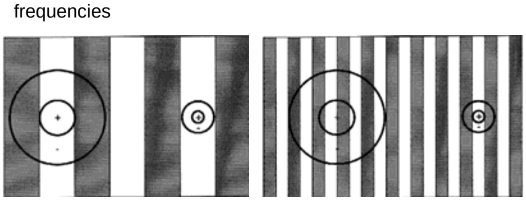
Three dimensional representation of the algebraic sum of centre and surround components →



On-centre cell

Gratings of light and dark stripes can be used to determine the relationship between input patterns and cell activity

Different receptive fields can be sensitive to different spatial frequencies

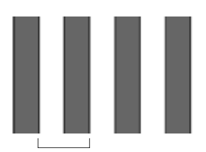


Surround component neutralises centre component

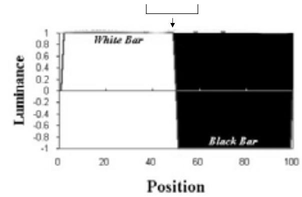
Centre component outweighs surround component

Waveforms can be used to describe the pattern of light intensity in gratings

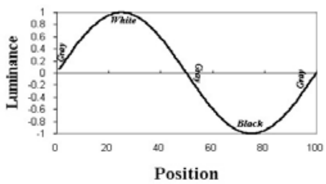
e.g. a grating of white and black bars



can be described by a square wave



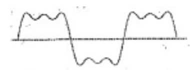
Gratings where luminance changes gradually
can be described by other sinusoidal waves



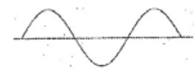
Fourier analysis

Mathematical procedure to describe a pattern in terms of sinusoidal components

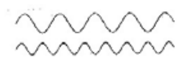
e.g.



Can be described as the sum of

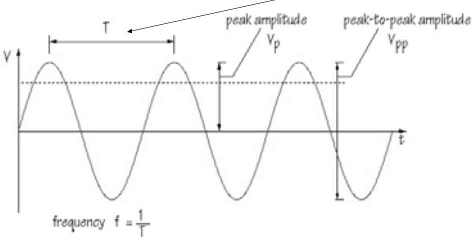


and



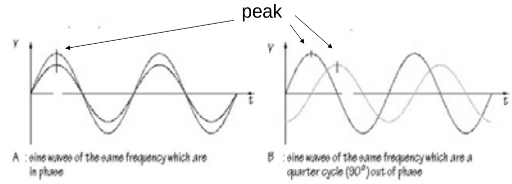
Different parameters characterise sine waves

- Amplitude
    - light intensity of peaks
-Frequency
    - length of distance between peaks



-Phase
how component waves are lined up

peak

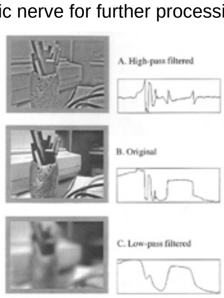


If orientation is specified as well, any image can be described in terms of Fourier transformations

The retina as a filter

An important function of retinal processing might be to filter out particular spatial frequencies and channel them through the optic nerve for further processing in the brain

e.g.



The majority of mammalian ganglion cells project to the Lateral Geniculate Nucleus (LGN) of the thalamus

The receptive fields of LGN cells are similar to those of the retinal ganglion cells (mainly concentric)

Relatively little more filtering takes place in the LGN

LGN cells project to the striate cortex

The striate cortex

- Striped appearance due to different density of cells in different layers
- Complex interaction between cells at different layers

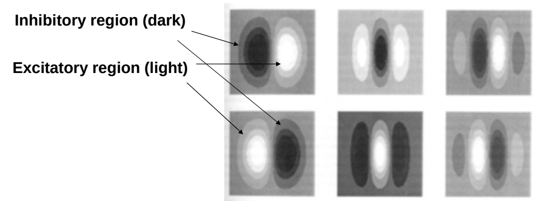
Single cell recordings in the striate cortex (Hubel and Wiesel, 1959; 1962)

- simple cells
- complex cells
- hypercomplex cells

Simple cells

- cells with concentric fields similar to ganglion and LGN cells
- cells with elongated adjacent fields

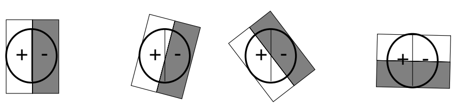
e.g.



Orientation of the field can be oblique, the fields can be symmetrical, anti-symmetrical or asymmetrical

Orientation selectivity of simple cells

- Due to their elongated fields simple cells respond most strongly to a particular orientation of bars, edges or gratings



maximum response | intermediate response | minimum response

- responses based on input from several ganglion cells
- can be the basis of feature detection in pattern and object recognition

Complex cells

Phase invariance

- suitably oriented stimuli elicit responses independently of location
- response determined by interactions within striate cortex

Hypercomplex cells

End inhibition

- respond more strongly to bar or edges terminating within the receptive field than to bar or edges that extend beyond the receptive field

Summary

RETINA
- adaptation
- lateral inhibition
- receptive fields in ganglion cells
- Fourier analysis and filtering

LGN
- mainly relay between retina and striate cortex

STRIATE CORTEX
- Hubel & Wiesel
- orientation sensitivity
  - simple cells
  - complex cells
  - hyper-complex cells