Eye structure:

- Muscles:
  - Ciliary muscle stretches the lens, changing the focus power of the eye
  - Muscle within the iris control the light intensity perceived by the eyes
  - 6 strands of extraocular muscle controls allows movement of the eye in three dimensions.
- Optic disc is where RGCs exit the retina and where blood vessel enter, no rods or cones, result in blind spot.

- Binocular vision:
  - Each eye have a 170° visual field
  - Two eyes have a 120° overlap, which provides stereo vision, allows depth perception (stereopsis)

- Different types of eye movements
  - Smooth persuit: synchronous voluntary eye rotation, keep eye remain fixed on a target
  - Vergence eye movement: voluntary eye rotation to opposite directions, allow changing of distance of focus.
  - Saccadic movement: rapid involuntary eye movement, allow capture of details, prevent image stabilisation (which will cause image fading due to desensitisation?)

Principles of vision

The eye detect visual features: 5 main features are

- Wavelength: colour
- Contrast: edges
- Spatial frequency: size of the object in the image
- Orientation: different direction of the lines
- Direction of movement

Parallel processing: different subset of cells extract different properties of the image (some cells perceive low spatial frequency version of the image, others perceive higher spatial frequency version of the image)

The retina: Structure originated from the neural tube

- Transparent layer, with the photoreceptor at the back of the retina,
- Nerve fibre layer is the first layer to contact the light.
- Arrangement of rod and cone cells defines physical limitation of the resolution, closer arrangement of cone cells + exclusive connection to RGC result in higher resolution but lower sensitivity in the fovea.
- Two types of photoreceptors present:
  - Rod cells are more light sensitive, higher in number (outnumber cone 20 to 1), converge to RGC
  - 3 types of cone cells are sensitive to colour, concentrated in the fovea.

Photoreceptor cell structure

- Outer segment: lamella in cone cells, discs in rod cells, contain pigments.
  - Membrane contains 7TM Rhosopsin/Opsin GPCR containing vitamin-A derived cofactors covalently bound to one of the domains.
  - Retinal is a chromophore, which absorbs light to undergo photoisomerisation, from cis-configuration to all trans configuration
  - The photoisomerisation leads to conformational change in rhodopsin and opsin, reveal G-protein transducin binding site on the C-terminus

    - Differential spectual tuning: Rhodopsin have highest sensitivity at 500 nm, three opsins (S, M, L) have different corresponding wavelengths with highest absorbance. Relative stimulation of different GPCRs allow colour perception.
- Inner segment: cell body containing mitchondria and synaptic terminal capable of glutamate release.

Phototransduction

- Photoisomerisation of retinal cofactor leads to the conformational change of the rhodopsin/opsin GPCR, exposing C terminal binding site.
- Transducin G-protein bind to C-terminal binding site, GDP exchanged by GTP, become activated
- Activated transducin activates phosphodiesterase
- Phohphodiesterase catalyse the conversion of cGMP to GMP, sequestrate cGMP binding to cationic channel
- Closing of constitutively active Na+ channel, stop dark current depolarisation —> hyperpolarisation.
- Reduction in depolarisation leads to decrease in glutamate release.
- Micropipette allow measuring membrane potential of individual rod/cone cells.
- Light stimulation leads to a graded hyperpolarisation, higher light intensity = greater hyperpolarisation.

- When returned to dark condition, rhodopsin/opsin phosphorylated by rhodopsin/opsin kinase, prevent activation of transducin, binding of arrestin quench signalling, retinal recycled in pigment epithelium.

Differences between rods and cones:

Rod: High quantity of photopigments, hence sensitive to light (scotopic). High amplification of light signals, less time sensitive (latency to hyperpolarise), easy to saturate. Achromatic.

Cones: Low quantity of photopigments, lower sensitivity to light, active during the day (photopic), quicker response to light. Less amplification, chromatic (colour), higher acuity

ON/OFF pathway:

Mediated via bipolar cells, interneurons in the retina, On pathway RGC spiking increase with increasing light intensity, OFF pathway spiking decrease with increasing light intensity.

There are many cone bipolar cells with only one rod bipolar cell

- In OFF cone bipolar cells, less glutamate bind with AMPA receptor on post-synaptic terminal, decreasing spiking
- In ON cone bipolar cells, less glutamate bind with mGluR6 metabotropic receptor decrease inhibition, increase spiking

Rod bipolar cells similar to cone bipolar, express mGluR6, depolarise in increasing light condition, however it signal to the RGC through amacrine cells

- ON rod pathway amacrine cells have gap junction to transmit electric signal
- OFF rod pathway amacrine cells have glycine synapse, decrease spiking in cone bipolar cells

Visual processing

Receptive field: A region in space where presence of a stimulus trigger changes in neuronal activity

Center-surround cell antagonistic receptive fields (CSARF) is discovered in 1953, by Stephen Kuffler

Two types of cells are found in a concentric manner.

- ON receptive fields have ON-ganglion cells in the middle with OFF-cells surrounding it
    - Highest spiking activity observed when light shine on ON center, and dark for OFF-surround.
    - Two types of cells act in an antagonistic manner.

Horizontal cells are responsible for the characterstic response of the CSARF.

- Horizontal cells is activated by glutamate release from surrounding cells, and release GABA to the PRE-synaptic terminal of central photoreceptor cells. Producing angatonistic effects.

Two major types of ganglion cell populations

- Parvocellular (ON/OFF)
    - Constitute for 90% of ganglion cell population in primates
    - Smaller receptive fields, as small as 1 cone cell as center
    - Show sustained response to contrast
    - Concentrated around the fovea
    - Able to detect colour contrast (M-center, L-surround / L-center, M-surround / S-center, (L+M)-surround)
- Magnocellular (ON/OFF)
    - Large receptive field, can receive information from many photoreceptors
    - Transient response to light/dark contrast
    - Distributed all over the retina
- Each type of retina ganglion cells have their own mosaic arrangement with minimal overlap in receptive fields.

From the retina to the visual cortex

Projection from the retina:

- Superior colliculi (in the midbrain): guidance of movement, saccadic eye movements
- Pretectum: Pupillary reflex. (Respond to changes in light intensity levels)
- Lateral Geniculate Nucleus (Thalamus): 90% of primate axon project through the nucleus to the visual cortex
    - Retinal ganglion neurons form synapse with LGN neurons within the nucleus, project to the visual cortex
    - RGCs form synapse in a layered fashion: separated by side of origin, cell type and position in the retina

Optic chiasm: approximately half of the retinal ganglion axons in mammal cross to the contralateral LGN.
All RGCs receiving visual input from the right visual field end up synapsing in the Left LGN. In general, nasal RGCs will cross to the contralateral side

Visual cortex

From the visual cortex V1, visual information received from the LGN is transmitted to dorsal or ventral pathways

- Magnocellular visual input provides spatial information travel via the dorsal pathway (PMAd)
- Parvocellular visual input providing property recognition travel via the ventral pathway (PMAv)

- The visual cortex contains 6 layers, neurons in the LGN from the thalamus enters the visual cortex via layer 4.
- From layer 4, visual information can be transmitted via intracortical pathways:
    - Radial pathway to other layer within the V1
    - Horizontal pathway from V1 to other cortical regions
- Three functional patterns found in the visual cortex: Ocular dominance column (Layer 4), Retinotopic map, Orientation selection column (Layer 4).

1. Ocular dominance column: (Hubel and Wiesel, 1978, radiolabelled dye injection into one eye) within V1 layer 4, LGN neuron innervate in an alternating monocular fashion. Neurons in the layer 4 can only be innervated by LGN neuron from either the left or right eye, in contrast to mixing of signals in other layers.
2. Retinotopic map: Adjacent areas on the visual fields are represented by adjacent neurons in the retina and visual cortex
3. Orientation selection columns: Elongated receptive fields with parallel ON/OFF subpopulations allow detection of edge with a particular orientation angle. Uniform down the vertical column except in layer 4. Cells clustered into the same orientation is known as iso-orientation domains
4. Directional selectivity:
    - Movement of edges across the simple cell show detection of perferred direction and null direction

Receptive fields —> Simple cells —> Complex cells

Proposed in Hubel & Wiesel's model:

- Superimposed ON centers and OFF surround regions of the receptive fields allow formation of simple cortical cells, sensitive to edges, selectivity for orientation, but position of the edge is importants.
    - Two sets of receptive fields can also be used to generate simple cells, where their ON center overlap with counteracting group's OFF surround, producing synergistic effect towards a stimuli. e.g. M/L+L/M
- Complex cells are sensitive to edge, orientation, but is not sensitive to position of the edge, might be generated by superimposing simple cells
- HOWEVER, the propsed model of contructing complex cells is not proven experimentally

Summarisation of the maps: functional module

- Each function module is proposed to analyse different properties of edges within the visual space