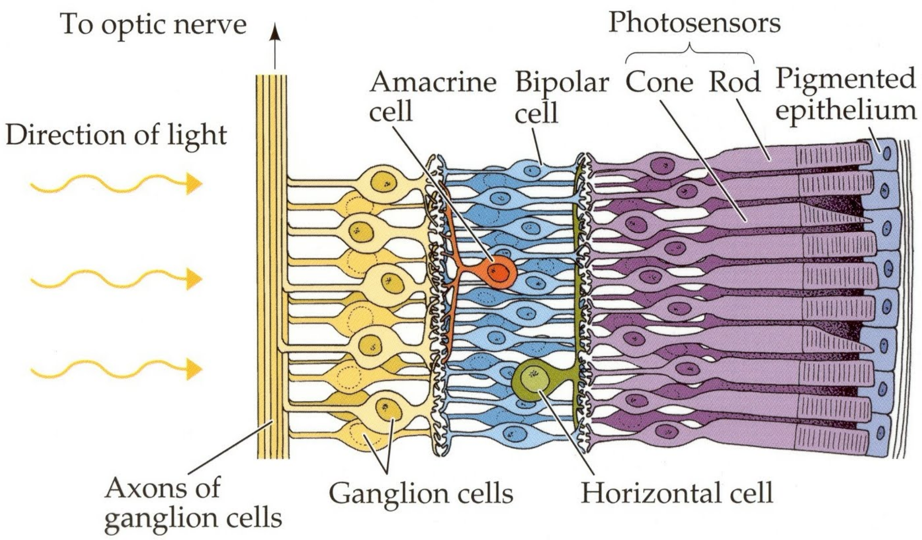
Neuroscience for Psychologists

// The visual system

- about half the brain is dedicated to processing visual information in one way or another
- **transduction**: when a biological cell converts one kind of signal or stimulus into another
  - in the eye: the transformation of electromagnetic radiation into neural impulses
  - cornea: the site at which most of the focusing occurs
    - when light passes from a medium of low density to a medium of higher density, it changes its direction
  - the lens is a fine-tuning mechanism, doing the remaining 30-40% of the focusing
  - the **visual axis** is an imagined feature of the eye; a straight line that passes through both the centre of the pupil and the centre of the fovea
  - the **optic disk** is the raised disk on the retina at the point of entry of the optic nerve
    - lacks visual receptors, and so creates a blind spot

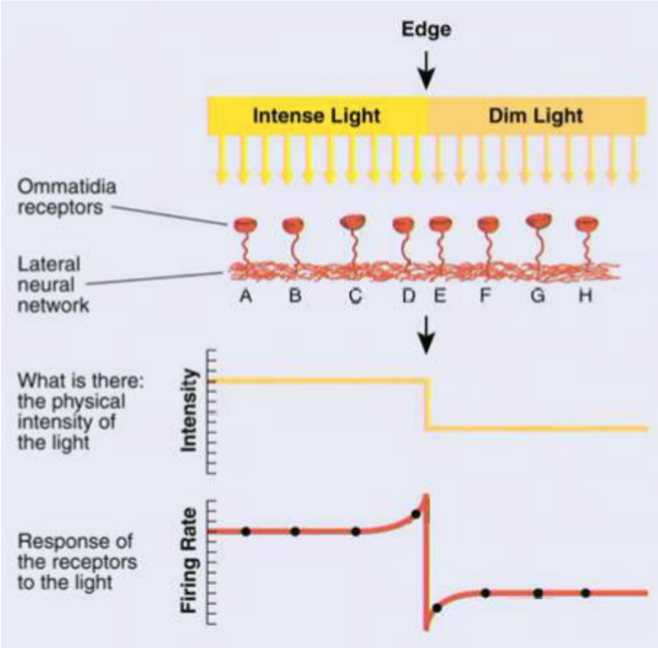


  - the **fovea** is a solution to the “inside out” design of the retina
    - the layers of cell bodies and axons thin out around this area
- cones have a low **degree of convergence**
  - in the fovea, the ratio of cone to ganglion cell is 1 to 1
- rods have a high degree of convergence, allowing higher sensitivity to light
  - the circuit is summing the signals received by many rods to one ganglion cell
  - but this also causes low positional acuity, since we don’t know which of the rods the light is falling on

- identification of edges is one of the most important tasks of the visual system
- **lateral inhibition** is the capacity of an excited neuron to reduce the activity of its neighbours
  - it disables the spreading of action potentials in the lateral direction
  - in vision, it enhances edges by producing overshoot and undershoot

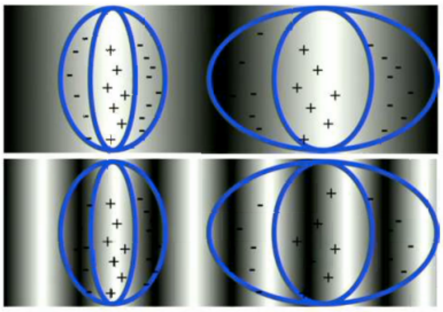
- the horseshoe crab offers insight into this effect
  - it has a very primitive visual system, but the way that it’s wired up is similar to humans

- networks of individual photoreceptors called ommatidia
- when B fires, it inhibits A and C, but A and C are also being inhibited on both sides, so they all produce the same response
- when D fires, it is not being inhibited very much by E because E is receiving less light
    - D therefore produces a stronger response
- E is inhibited extra much by the strong D, so its response is lower than F and G, even though all three of them are receiving the same amount of light
- **Mach bands** are created



- **hemidecussation**: the rearrangement of the fibres of the optic nerves in the **optic chiasma**
    - so that e.g., all information from the right field of vision is sent to the left hemisphere of the brain (each eye receives info from both fields of vision, so their fibres have to rearrange)
- retinotopic organisation
- **cortical magnification factor**: a disproportionate amount of the cortex is dedicated to processing info from the fovea

- **simple cells** are found in the primary visual cortex and respond primarily to oriented edges
    - called simple because:
        - they have distinct excitatory and inhibitory regions
        - these regions follow the summation property
        - these regions have **mutual antagonism**
            - excitatory and inhibitory regions balance themselves out in **diffuse** lighting
        - it is possible to predict responses of moving stimuli given the map of excitatory and inhibitory regions
    - each simple cell has a small, clearly delineated receptive field within which a small spot of light produces either on or off responses
    - the difference between these cells and cells at earlier levels is in the geometry of the maps of excitation and inhibition
        - cells at earlier stages have maps with circular symmetry
            - consisting of one region (on or off) surrounded by the opponent region (off or on)
        - cortical simple cells have excitatory and inhibitory domains separated by a straight line or by two parallel lines



- simple cells also code **spatial scale**
    - **low spatial frequency** activates simple cells with widely separated subfields
        - info about texture; blurred edges
    - **high spatial frequency** activates simple cells with less

separated subfields
    - tells us that fine detail is present; info about edges

- **complex cells** are found further on in the visual pathway, monitoring the activity of cells with simple cell receptive fields
  - aggregate information from many simple cells
    - don't have defined on or off regions
    - give you information about movement
  - many complex cells are **binocular**: they receive input from both eyes
    - the cell will increase firing if input arrives from either eye
      - there is a more vigorous response if input arrives from both eyes simultaneously
      - **ocular dominance**: some cells favour one eye over the other, responding more vigorously
        - this has a bimodal distribution: lots of cells driven by either ipsilateral or contralateral eye, and only a few driven equally by both eyes
    - they therefore underlie stereoscopic depth perception

Organisation of the visual cortex

- signals flow from simple to complex cells
- organisation is systematic and columnar
  - functionally similar cells are grouped in **columns** in V1
  - if you pick a spot on the surface of the visual cortex and go **vertically** down, you will encounter cells with the same eye dominance, corresponding to receptive fields in the same location on the retina, and maximally sensitive to the same orientation
  - if you insert an electrode and proceed horizontally along the cortex, you will encounter regions of neurons with different eye dominance, retina locations, and orientation sensitivity
    - **ocular dominance columns:** columns alternate in eye dominance

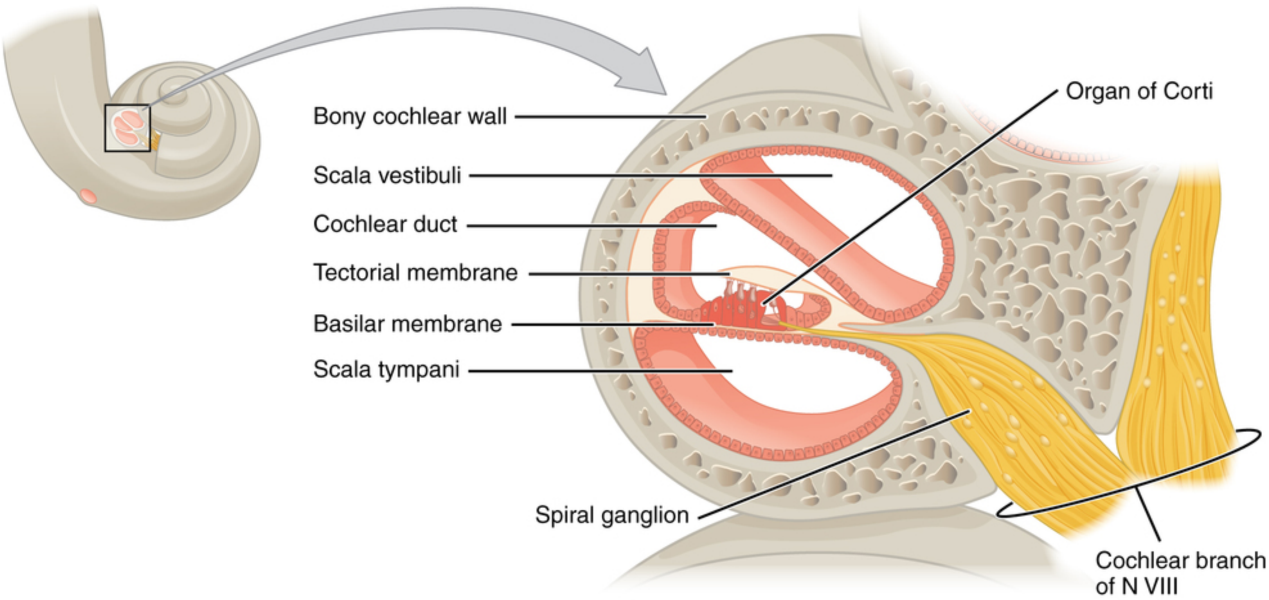
- **cortical scotoma:** a partial loss of vision or a blind spot in an otherwise normal visual field
  - you might not even notice you have one
    - your conscious visual experience may seem normal even if you have significant cortical scotomas
      - behavioural indicators: you would notice things like bumping into doorways very often
  - a person with a scotoma has a healthy eye and intact pathways, but might have damage to a part of the V1 corresponding to that spot in space

- after the V1, higher order processing occurs in the dorsal and ventral streams
  - **dorsal stream** specialises in visually guided behaviour
  - **ventral stream** specialises in conscious visual perception
- two areas of the secondary visual cortex
  - fusiform face area (in ventral stream): damage leads to prosopagnosia
  - **middle temporal area** (MT/V5) (dorsal stream): damage leads to **akinetopsia** (motion blindness; can see stationary objects but not perceive motion)
    - 95% of neurons in the MT/V5 respond to specific directions of motion

// Non-visual systems

- **pinnae** collect sound waves and channel them into the auditory canal: the tube that offers protection to the middle and inner ear
  - they also play an important role in **localising sounds**
    - the folds of the pinnae selectively reflect sounds of various frequencies around the ear and into the auditory canal
    - as a sound source changes its location relative to the head, the frequency profile of these reflections changes
      - offers a clue to the location of the source
- the **ossicles** concentrate the vibrations of the tympanic membrane on a very small area on the oval window
  - similar to how pressure is increased by concentrating a given mass on a small area
  - the lever action of the ossicles amplifies the vibrations by approximately 1.3 times
    - combined, this accounts for a 22-fold increase in the strength of vibrations hitting the tympanic membrane

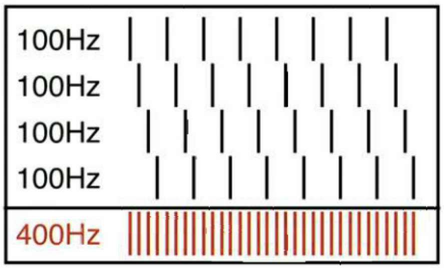
- mechanical energy is transduced into neural impulses in the cochlea
  - fluid vibrations cause the **tectorial** and **basilar membranes** to shear against each other
    - hair cells sticking up through the basilar membrane (and covered by the tectorial membrane) rub back and forth as well
    - the bending of the hair cells initiates a neural response
  - hair cells are very sensitive
    - at auditory threshold (the quietest sound you can detect), the hair cell displacement is 100 picometres



Perceiving pitch

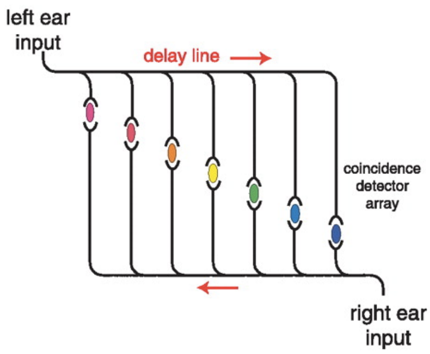
- a single neuron can only fire about 1,000 times per second (maximally)
  - but we can perceive sounds that are 23,000Hz
  - how does the auditory system do this?

- three systems come into play, facilitating our perception of different ranges of frequencies
  - 0 - 100Hz can be accounted for by the **direct firing rate** of a neuron
  - for 100 - 5,000Hz, neurons cooperate to signal frequencies that they couldn't accomplish on their own (**Volley theory**)
    - on the image to the right, each neuron can fire a maximum of 100Hz
      - each line represents a cycle / action potential
      - a single neuron can only catch every fourth cycle of the 400Hz tone
      - so it cooperates with nearby neurons, which catch every fourth cycle from different starting points



    - **Place theory** explains the perception of 5,000 - 23,000Hz
      - the basilar membrane is interesting because it changes in its width and elasticity as you travel from the base to the tip of the cochlea
        - for high frequencies, maximal deflection of the basilar membrane is very close to the base
        - lower tendencies travel further along the membrane such that the maximum point of deflection is closer to the tip
      - the membrane's connections to the auditory cortex are organised in such a way that signals from the base of the membrane are coded as high frequency
        - we're not depending on complex neural computations, just physical properties of the membrane

- one of the reasons we don't understand the auditory system as well as the visual system is that its pathways are much more complex (at least in the early stages)
  - there are many cross-connections before the signal even reaches the thalamus
- the processes in the hindbrain allow us to localise sounds in space
  - **interaural time differences:** sound travels slow enough for the brain to differentiate the time it takes for sound to reach your left ear and right ear
    - it is a simple and elegant system
      - **temporal summation**: a neuron is more likely to fire if it receives *simultaneous* inputs from other neurons
      - e.g. (on the right), if input from the left ear has to travel until the blue neuron before the right ear input reaches it at the same time (and results in an action potential), that means that the left ear is much closer to the sound source (since the delay from the right ear is so large)



  - **interaural intensity differences**: your head creates an **acoustic shadow**, meaning that the ear that's facing the source of a sound receives more acoustic energy than the shadowed ear
    - the acoustic shadow is also dependent on the frequency of the sound
      - low frequency sounds have long wavelengths that bend around your head and don't create a large shadow
      - higher frequencies bounce off your head more, resulting in pronounced shadows
    - the mechanism behind this is a bit more complicated
      - a stronger stimulus to the left ear would excite the left **lateral superior olive** (LSO)
      - the stimulus would also inhibit the right LSO via an MNTB interneuron