Brain & Space

(1) Introduction – Brain, space, spatial boundaries
computational neuroscientist
Making Space – Jennifer M. Groh

(2) Vision: What do we see?
vision – spatial sense.
Democritus – intromission (object emanates something to the eye) dirn ✓ nature ✗
Plato – extromission
Extromission seems plausible
- Vision is active (something you do to the world)
- If intromission was true you'd be able to see everything.

ibn al-Haytham – said the extromission part was bs. light (Alhazen)

(3) Vision: How light is sensed by neurons
light: energy not matter EM wave
Why do we see some freq and not others?
Biological Detection of light:
Vision involves light sensing neurons – photo-receptors achieve light sensing properties with spl. molecules called photo-pigments.
They reflect some wavelength absorb others
400 - 700 nm

Danny Kahneman

Endings matter.

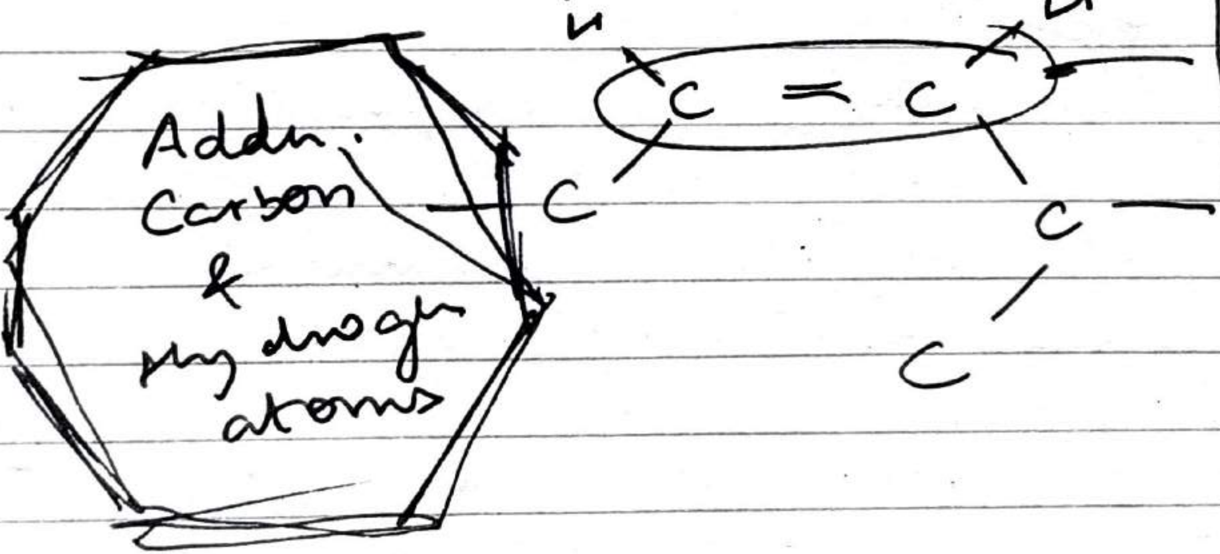
5 Humility Optimism

Brain & Space

How do photopigments work

~~Photo~~pigment molecule – Rhodopsin

Found in rod photoreceptors of the eye



Double bond not free to rotate

More atoms and the protein opsin

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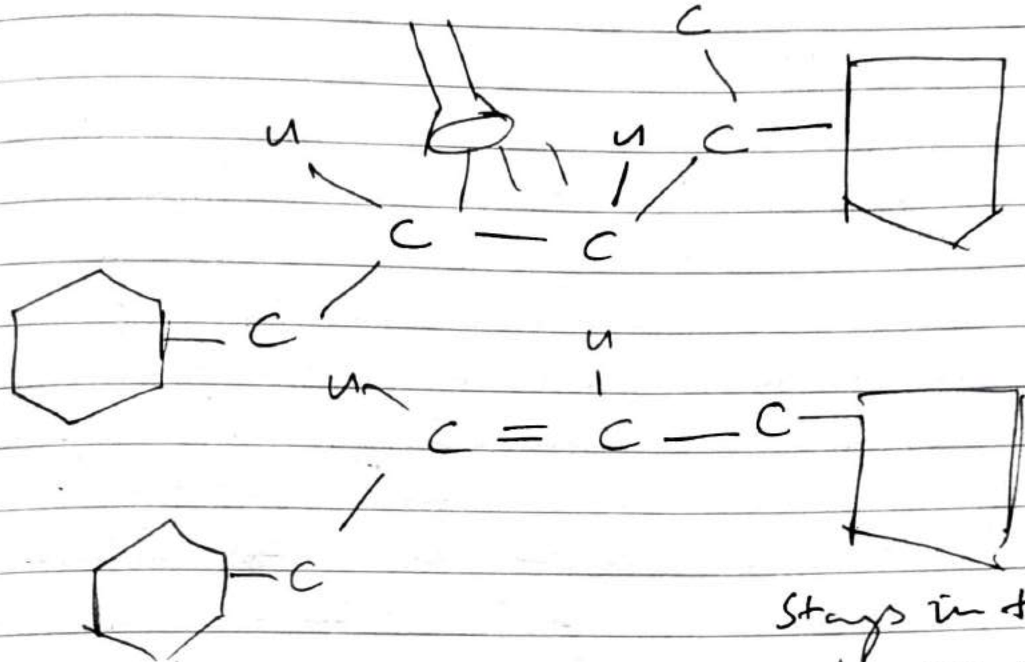
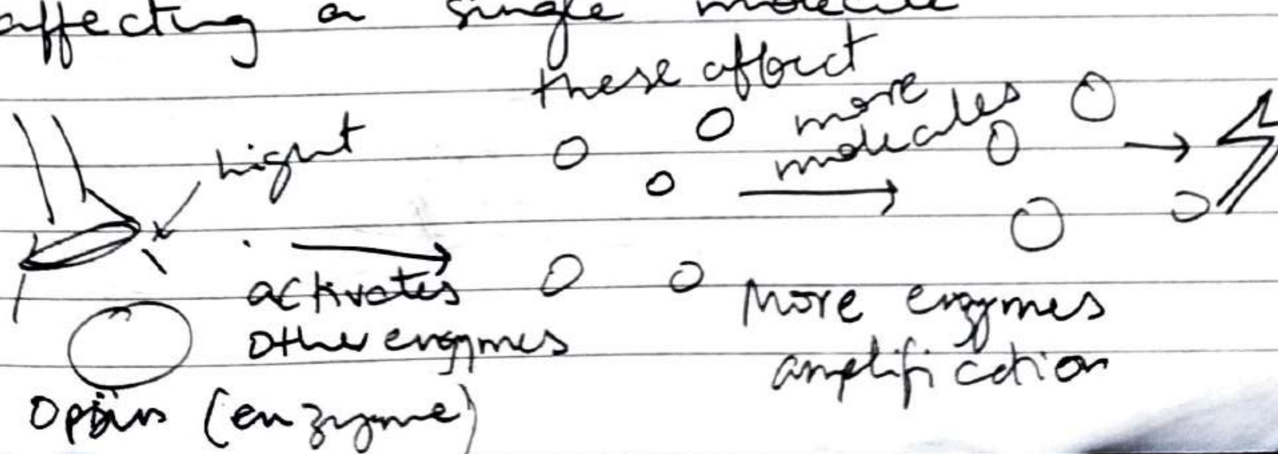
Double bond becomes a single bond temporarily when light comes on. and allows rotation..



Stays in this form.

Light triggers a chain rxn.
Light hits rhodopsin → causes flipping in the portion of the molecule called opsin → opsin break free from rhodopsin → opsin is an enzyme ∴ it catalyze and facilitate chemical rxn. and facilitate the same rxn over and over again. this allows an amplification of an initial event of a photon affecting a single molecule



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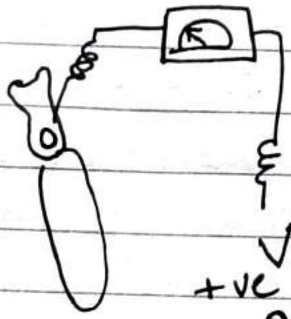
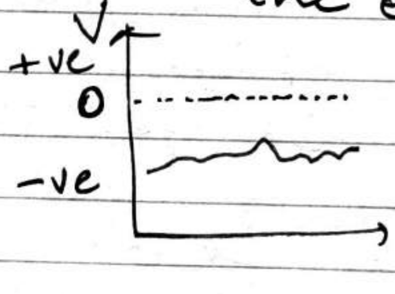
Find stage of the cascade is when the enzymes affect the electrical activity of the eyes. How a biochemical rxn. leads to a neural response.

1.4 **How light is sensed by neurons?**

Then they change the electrical signals in photoreceptor neurons.
Neurons are brain's "infor. process. unit" by encoding signals through electrical activity. Neurons are encased in membranes that provide electrical boundaries. If you place an electrode inside a photoreceptor

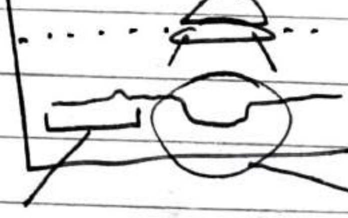


and compare the voltage
Voltage inside is more negative than the outside



inside —
outside ....

What happens when we shine light?



Slight dip

Resting membrane potential

Deviation from "rest" = neural response

Bastille
clog warm bodies

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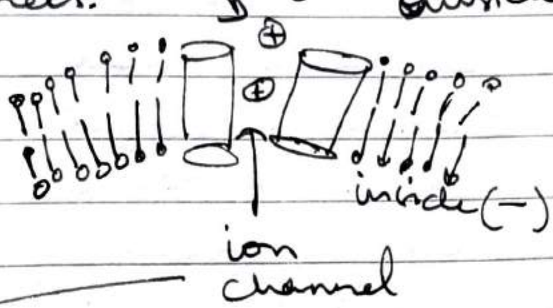
Other neurons respond to their inp. in diff. ways. Light changes electr electric potential here.

How does this happen?
Electrical milieu inside a neuron is regulated by the membrane. Membrane serve as barriers (btw inside & outside). It has small openings in the membrane called ion channels.



allow ions to move through, when they move electric potential changes. Regulate the electrical potential inside photoreceptor neurons. When light trigger the biochemical rxn, it causes the sodium ion channels in the photoreceptor neuron to close.

prevents + ions from entering

causes a -ve diffn.
That without this the + ions would flow becomes ~~more~~ more negative on the inside than it normally is

1.3 <u>How the Eye forms the image.</u>

Not all light sensing involves image formation. Key diff. are where sensors

are located. Plants & simple animals like tapeworms / flat worms / planaria have light receptors on the surface of their body. Can Tell night from day, give dirn of light ∴ Trees grow upwards. Don't see patterns of light
— on the surface of body.

Light sensing with image formation occurs in animals that have receptors inside the eye. Light sensing cells are at the back.

→ How the eye forms an image?
How does light travel?
- Spreads outward from every point in the visual scene.
- Light at every ~~other~~ point arrives from every other point.
- Travels in straight lines.

Auguste Renoir
Luncheon of the Boating Party.

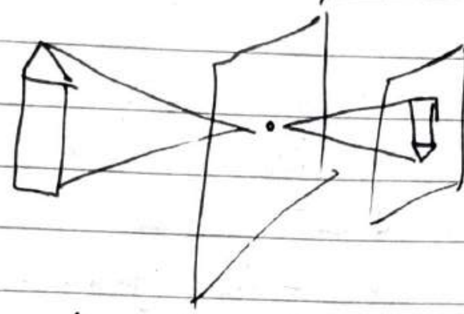
How does the eye keep the light organized to form an image.
TO form an image
- Sort the light Keep it organized
- Keep light from diff obj/locations Separate.
- Create a 1-to-1 correspondence

btw location of origin & location on the set of light sensors.

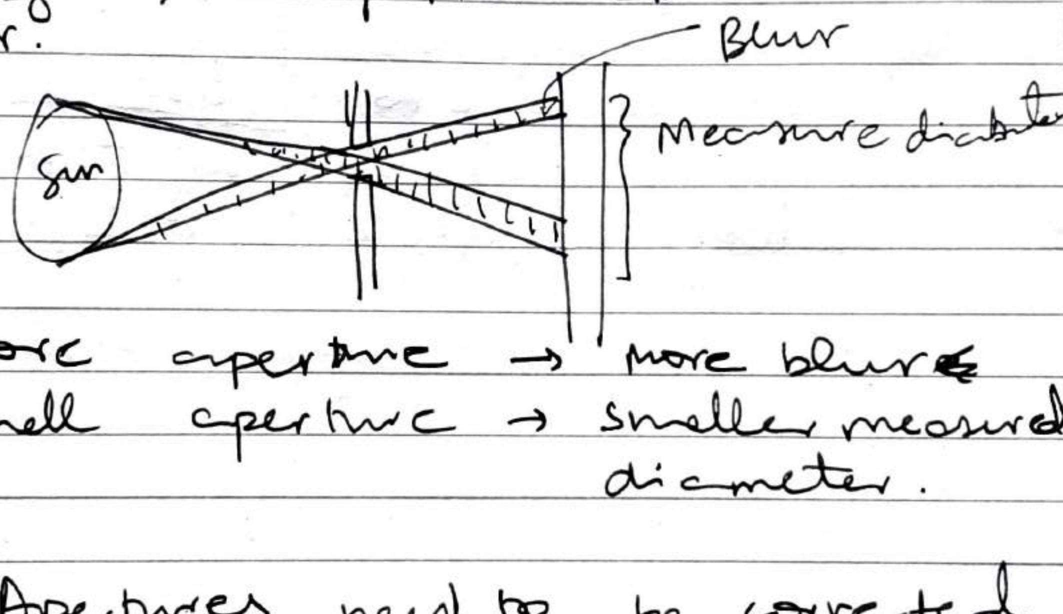
How do you form an image?

Pinhole.

- Image formation by pinhole (4-5th Century)
- Camera Obscura. / Pinhole Camera.



Eye has a pinhole: Pupil.
Size of the aperture creates a blur.

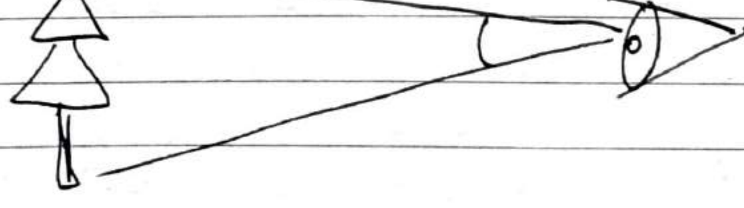


more aperture → more blur
small aperture → smaller measured diameter.

~~Also~~ Apertures need to be corrected.
Kepler showed how light passes in str. lines.

Visual Angle.

units of visual size on retina are degrees



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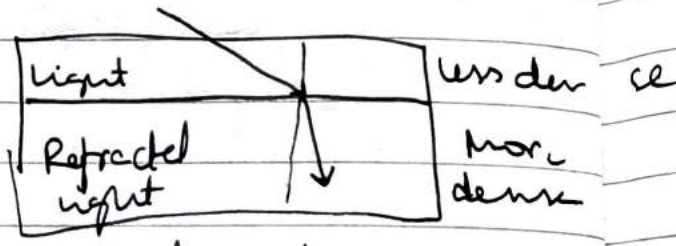
Pinhole : Vision should be blurrier.
2.5 mm pupil diameter
25 mm dist from pupil to retina.
6° of blur.
(width of your head when arms extend).
- We see 300x better than that.

1.6 How the Eye forms the image
What did Kepler find.
Kepler : What else is involved in image formation?
Pinhole
Refraction
This happens in the eye to focus rays of light onto the rear surface of the eye.



Get a eye diagram & summary.

acuity
Rene Descarte + Kepler.

Image is upside down & backward
Inversion prism goggles
George Stratton , 1890s
Ivo Kohler , 1950s

Vision guides the body
Visual body interactions are learned
We perform better when the retinal image is what we're used to

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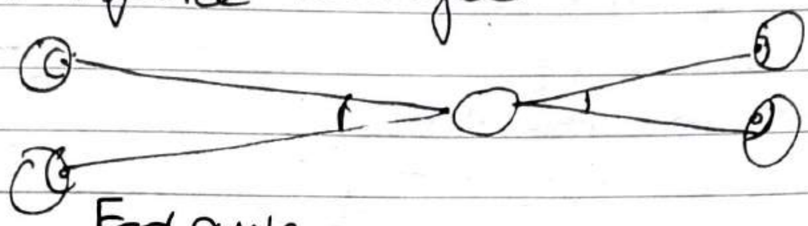
Week 2

Light & Image forming eye

① How we create a 3D. Retinal img is 2D flat projection, we can tell depth

convergence angle

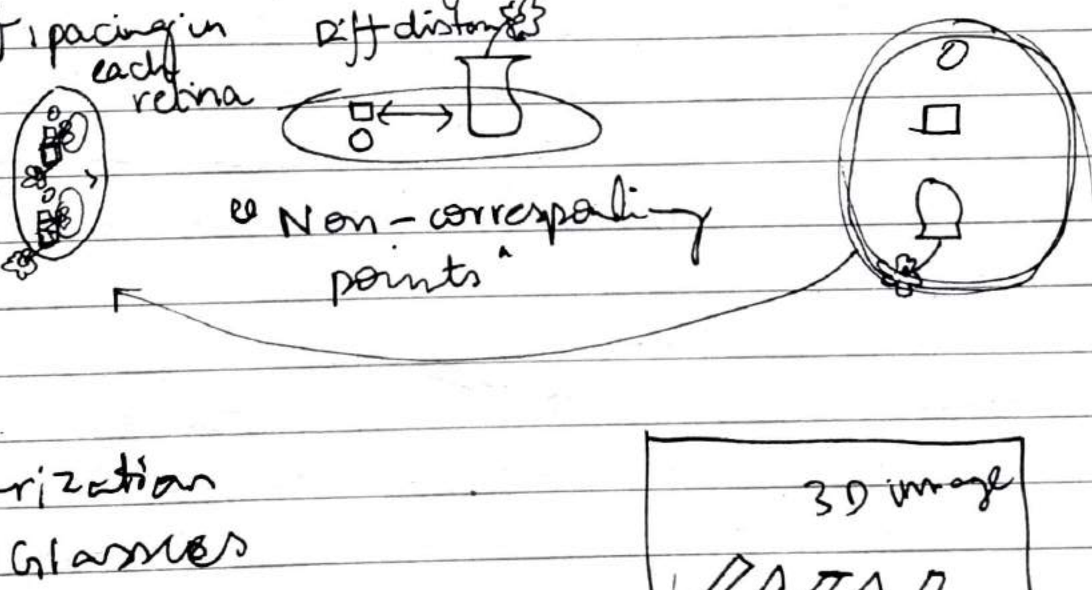


Far away
nearly parallel

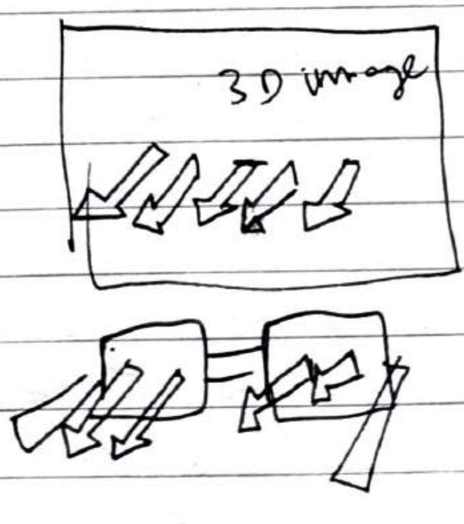
Stereovision

ce Same spacing in each retina. Same distance away

"corresponding points



polarization
3D Glasses



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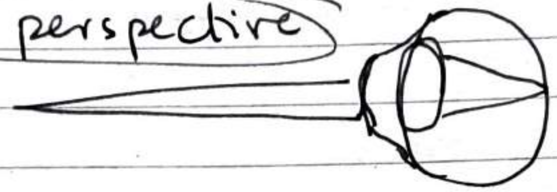
The Blank Check - Rene Magritte

MC Escher → Waterfall

Focus accomodation, Relative size
perspective, occlusion, cues
source of illumination, Shape from shading

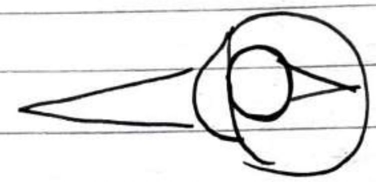
linear perspective

Far



Binocular distance cue

Near



lens is rounder

Blur/Haze vs. Focus/Accomodation
- Both involve image clarity
- Blur involves color
- Focus/acc. involve knowing the lens setting to focus the image
- Blur info of scale in km
- Focus info of scale in meters

Motion Parallax
- Our own movements cause image motion on the retina.
- closer obj move more than farther ones.

convergence angle - angle btw 2 eyes looking at obj at different distances.

Shape from shading (convex concave)

stereovision - location of the images of those obj on 2 eyes and the comparison the brain makes b/w those 2 eyes.

Body Position Sensing

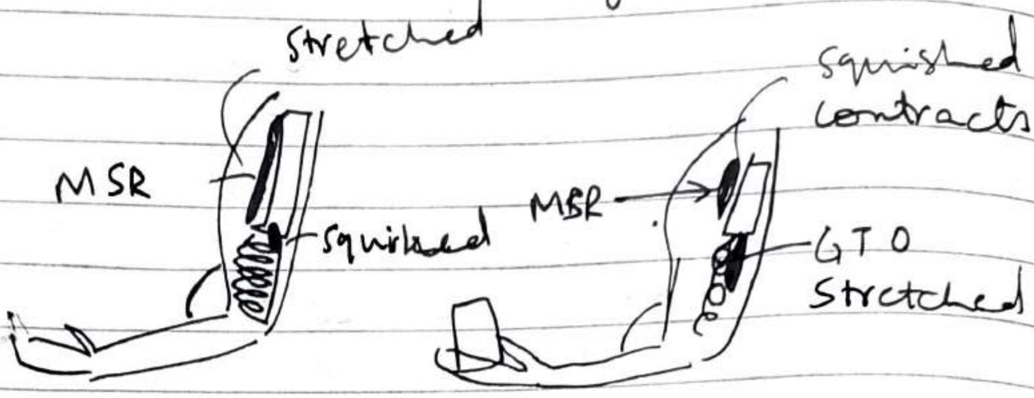
Sistine Chapel - Michelangelo
Vladimir Horowitz - Pianist
sensors we use to give us info on our body config in space.

Sensors that measure body's position
Golgi Tendon Organs, Muscle spindle Receptors.

GTO	MSR
• Stretch-sensing neurons	• Same
• located at tendon muscle junction	• Located within muscle.
• In series with muscle.	• In parallel with muscle.
• By being in series they are sensitive to the force applied	• By being in parallel aren't directly connected to the load the muscle is carrying but are sensitive to the length of the muscle. as this changes with diff body positions.

agent fluent direct unless out of Dr

Same Angle diff load



Neural signals

Neurons have an electric potential

4 principles

① · 2 of chem / physics

② · 2 "design features" of neurons

① 1) Like charges repel, unlike charges attract.

These are imp. for electrical signalling in neurons.

2) Molecules descend their concentration gradient. move from high conc to low. descent in conc. gradient.

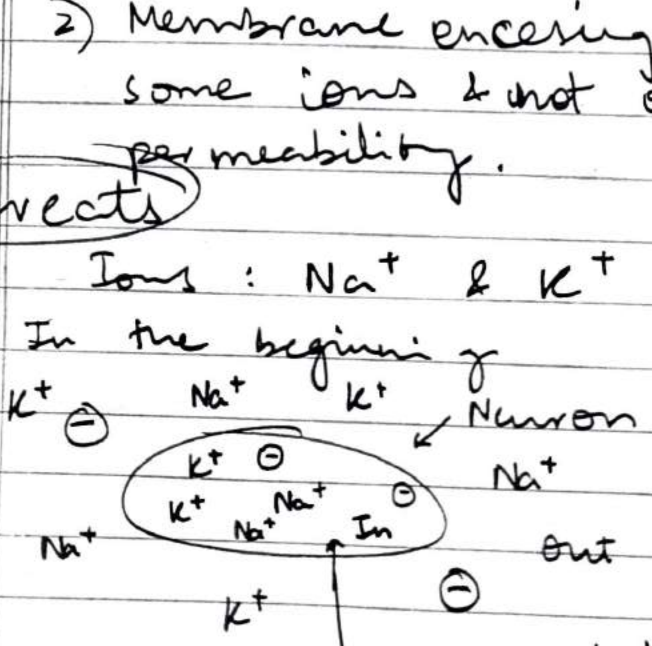
② 1) Diff conc. of various ions inside and outside the neuron

2) Membrane encasing the neuron leaks some ions & not others. selective permeability.

Caveats

Ions : Na^+ & K^+

In the beginning



Equal conc.

+ve & -ve balance inside

No net electrical signal.

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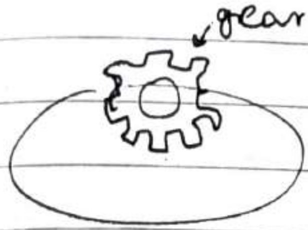
Neurons have a device in their membrane move Na^+ & K^+ around : Na & K pump.

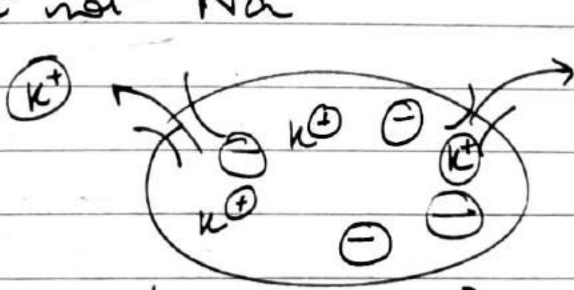
2. Sodium Potassium pumps.



creates high conc of Na^+ outside and K inside.

Eventhough ions have been moved around no net electric singnal as charges moved in both dirn. We need the membrane to now leak but leak selectively.

(3) Membrane contains openings called ion channels. The relevant ion channel here is a selectively permeable ion channel that allows K^+ to pass through it but not Na^+



Why would K^+ leak?

1) Its conc. gradient favours it
More K^+ inside than outside ∴ flows out.
This K^+ leakage creates an electrical signal by leaving the -ve ions behind and electric gradient is created.

2) K^+ reaches an equilibrium
Conc. gradient & electrical gradient balance at -70 mV

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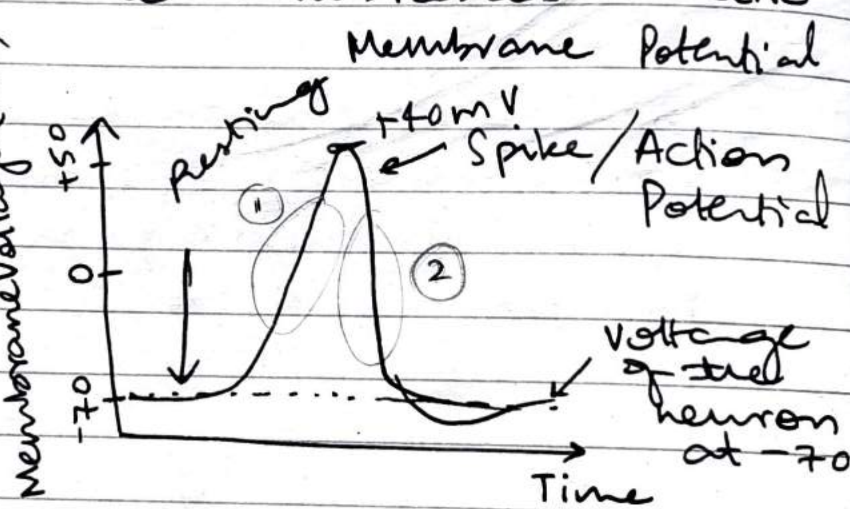
And that's the resting ~~voltage~~ membrane potential in most neurons.
Resting membrane potential reflects that balance btw electrical & chemical factors that governs how ions move.

Accomodation lens curvature on

The Action Potential / Spike

Resting Membrane Potential
created by combination of conc. gradient and leaking of K^+ across neuron's
Anything that alters this process will change the membrane's electric potential.



What makes it go down? / and go up
1 Rise is caused by the opening of Na channels

What happens when the sodium channels open?

→ Sodium flows into the neuron ~~due~~ to conc. gradient and electric gradient across the membrane on

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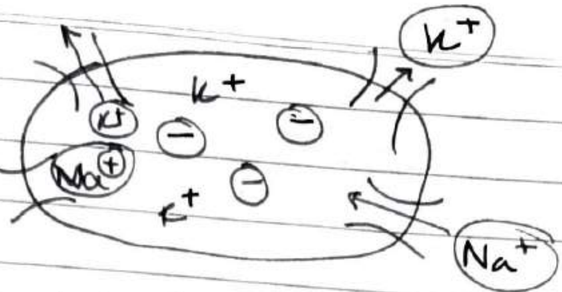
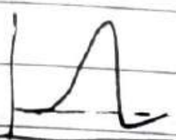


what effect does the Na influx have on the neuron's electric potential?

→ Make it more +ve on the inside than it was. Triggering +ve feedback



• Na channels are <u>voltage-sensitive</u> as membrane potential become more positive more channels open up, so more Na^+ flows in and membrane potential become still more +ve. Peaks at +40mV approx.

Then it comes back down?

• Voltage-sensitive K^+ channels open to counter the effects of Na^+.

• Na^+ channels inactive when the membrane potential is +ve staunching the flow of sodium and allowing the membrane potential to return to the resting membrane potential. These channels don't quite close, they can't actually open again until voltage returns to baseline. This prevents them from reopening prematurely as the voltage begins to drop.

→ and can't be predicted

Action potential can happen by event

• Sensory receptor : physical stimulus
• Input from another neuron via a synapse.

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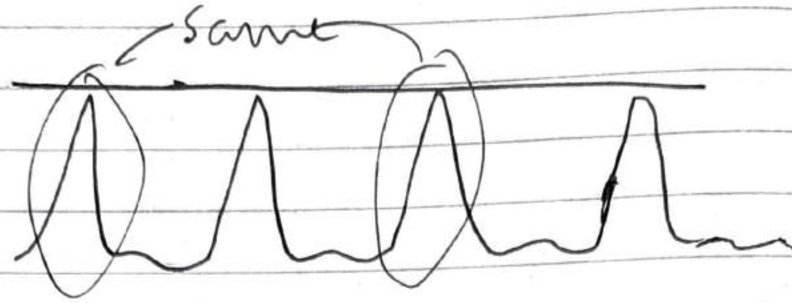
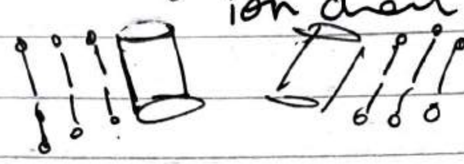
Once triggered they are all alike.
Action potential is stereotyped. :)



2.7 Mechanical force somehow also alters ion channel opening



like it directly might affect
(mechanotransduction mechanism #1
#2)

or perhaps some types of protein molecule → biochemical cascade
└ changing its shape
Like the case for vision

Volta

More stretch
Less stretch] — Same size just spacing changes.

If we move a pen ½ mm away we can still feel it due to hair follicle receptors, receptors in the skin. Cats whiskers
They work like GTO, MSR
Muscle Spindle Receptor
Golgi Tendon Organs.

neuromorphic

2.8 Illusions in body position

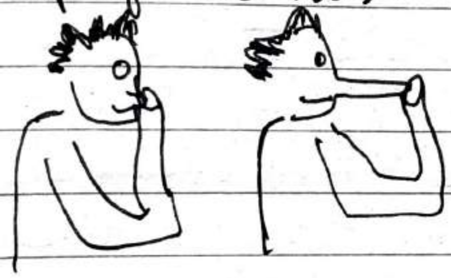
combine signals from
- touch
- body position
- Vision.

1. Vibratory Myesthetic Illusion (Lackner)
2. Crossed-Hands experimentit (Groh & sparks)
3. Prism Adaptation

(1) Apply vibration here hand moves away

Tricep hand moves towards.

Perform experiment with finger touching tip of the nose



pinocchio illusion

saccades
(didn't really get what she did in the cross-hands exp).

Relation of body/movement to visual space is a learned limb-by-limb.

Baseline phase	Adaptation Phase	After effect
• Before exp. know relation btw. visual scene and body	• Goggles forced to learn a new reln. • Learning was specific to hand practiced with	• Didn't immediate shift to original accuracy instead behave like goggles still on.

Jigsaw - Daniel Sloss

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Week 3

3.1 Figures & Backgrounds

Organization of info to perform comp. tasks in brain.
Visual percept: where obj are located in space?
→ identify boundaries and assign them to different obj. Where one obj bonds and the other ends:
Overall process: Figure-Ground segregation
Distinct parts of visual scenes correspond to physical entities.
Rubins Face Vase Illusion
MC Escher - Mosaic II

How? • Find where light changes
• local circuitry in the retina
• center-surround organization.

Local circuitry in the retina begins the process of finding where lt visual scenes are changing.

2n [redacted] paper matters

Neurons are more sensitive to than

3.2 Synapses & Center-Surround Organization

Receptive fields, present in many areas of the visual pathway serve to enhance contrast detection.

(insecure condescending)

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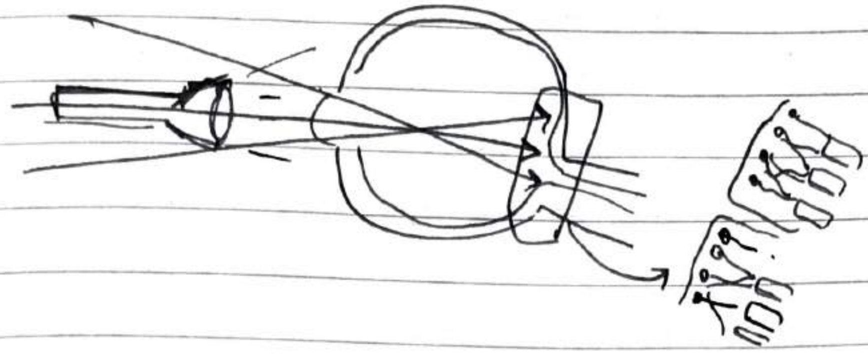
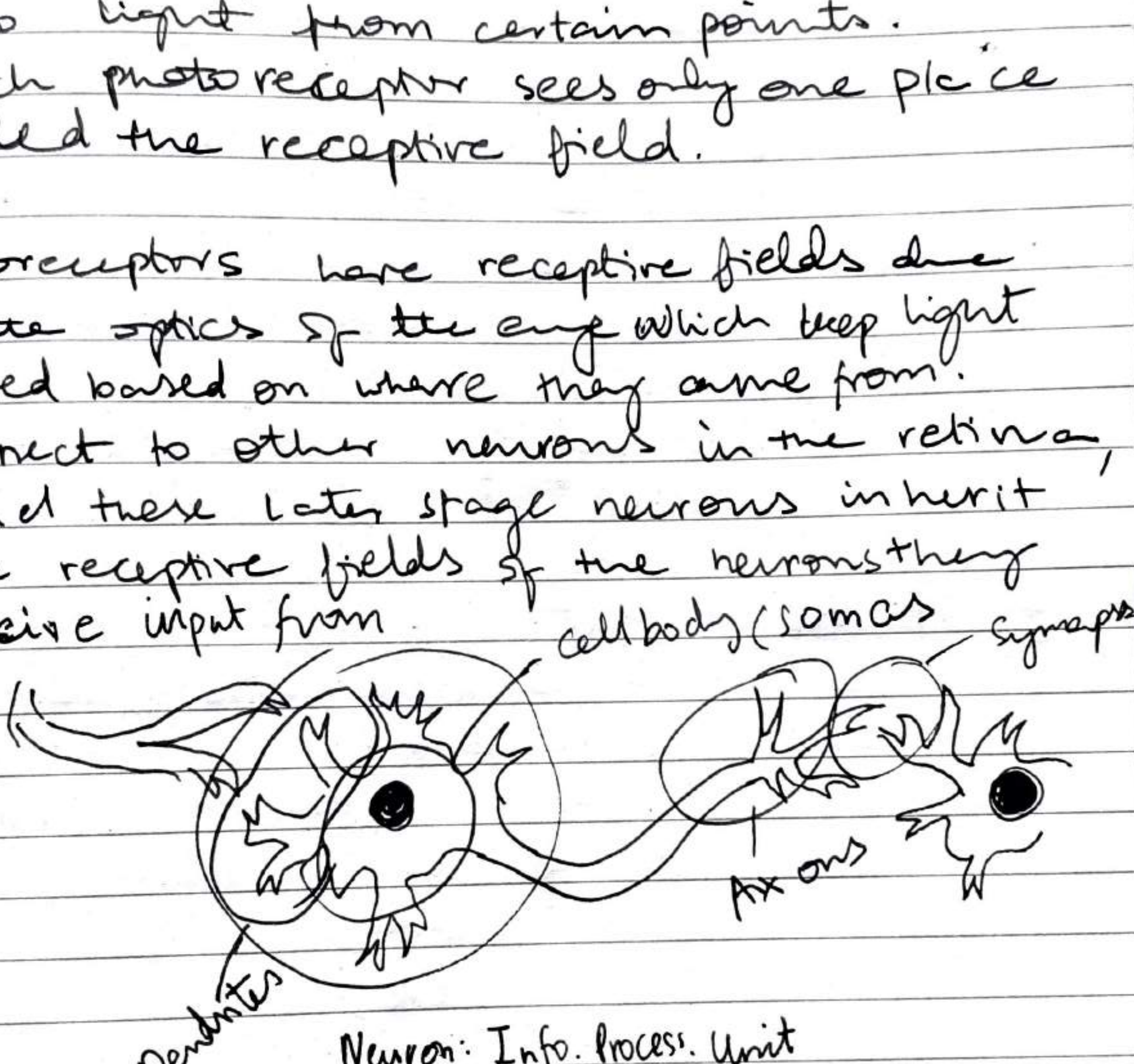
(delusional self-righteous)



Certain photoreceptors are sensitive to light from certain points.
Each photoreceptor sees only one place called the receptive field.

Photoreceptors have receptive fields due to the optics of the eye which keep light sorted based on where they came from. connect to other neurons in the retina, and these later stage neurons inherit the receptive fields of the neurons they receive input from.



Neuron: Info. Process. Unit

Dirn. of Info flow:
Dendrite → Soma → Axon
synapses can be from dendrite to dendrite
axon to axon
axon to dendrites

When one neuron fires an action potential it travels down the axon
(outspoken repressed)

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① Neurotransmitter released
② Binds to receptors.
③ Open/close ion channels

to reach the presynaptic side of the synapses that the neuron forms with other neuron. The action potential sits in a biochem chain rxn that culminates in the release of small molecules called neurotransmitters.
The travel btw the small space btw axon of 1st and dendrite of 2nd. These neuro transmitter molecules than bind to the receptors on the postsynaptic side the dendrite of the synapse.

③ Receptor molecules cause ion channels in the receiving neuron to open/close. Depending on: kind of ion channel what it permits passage of, what electrical effect it produces.

④ Electrical effect.
The effect on the postsynaptic neuron may be to make it more +ve or −ve
Generally speaking

Change in membrane potential	Synapse
+ve	excitatory
−ve	inhibitory

Inhibitory synapse flipping the sign of a signal and can be used to make neurons respond in the opp. way from their inputs.

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Some famous Neurotransmitters
- Serotonin • Adrenaline • Endorphins
- Dopamine • Glutamate • GABA

Medication affects these.

If activity happens simultaneously in excitory synapses in enough of the dendrites then the soma of the neuron is depolarized enough to trigger an action potential. The action potential doesn't occur in the dendrites, rather a decision is made in the soma whether to fire it or not and then it travels down the axon

Retinal Ganglion Cell
- RGC are the last stage of processing in the retina
- From there signals go into the brain
- Synthesize net input

Center Surround Organization
ON center off surround
OFF center on surround.

That some cat Hubel Wiesel thing

3.3 Where light lands on retina via orderly connection patterns btw. retina & cortex and how brain connects the dots demarcates contours in the visual scene.

Retina → Optic Nerve → Brain

contains axon
retinal ganglion cells.

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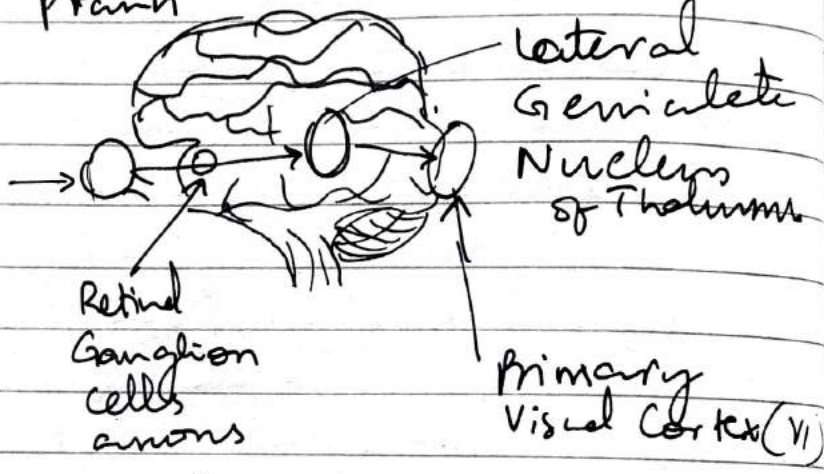
Each axon travels from the back of the eye to the Thalamus (located in the middle of the brain).
The particular region of thalamus we deal with is the Lateral Geniculate Nucleus.
on the sides — bent curved shape

2:00 Then axons are sent to the Primary Visual cortex (V1) located in the back of the brain



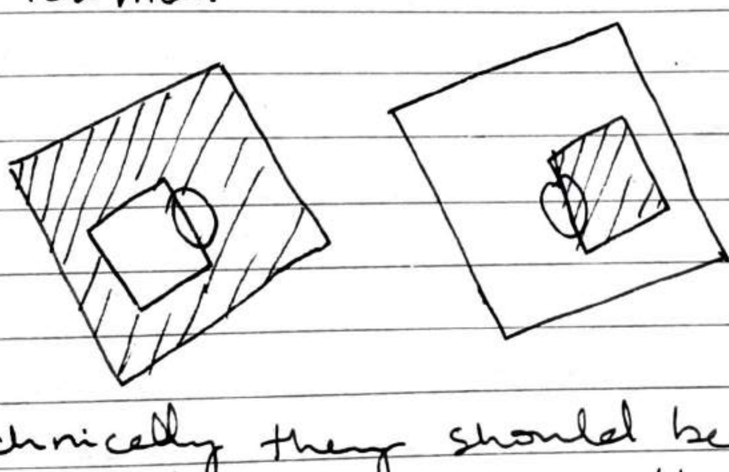
Neurons are sending axons to very long distances compared to their size
They maintain "nearest-neighbour" relationships. form connections within a common region of the Primary visual cortex
By maintaining this local order, physical location in the brain preserves info about the physical location of stimuli in the world. It's preserving the map built by eye using pupil & lens. Neurons in similar location in the cortex recieve ~~info~~ input one originated with a common population of photoreceptors

Retinotopic Maps (in visual cortex)
reflects topography of the retina.
Color depicts the eccentricity of the location in the visual scene ↑ how far away the obj is straight ahead pink/purple. Around the periphery green/blue.

3.4 <u>Orientation selectivity</u> / Border Ownership

point in visual cortex
Boundary btw obj problem. Not just sensitive to the orientation of obj in space but to orientation of contours in space.

Another property imp for figure ground segregation — Rudiger Von Der Heydt & Friedman

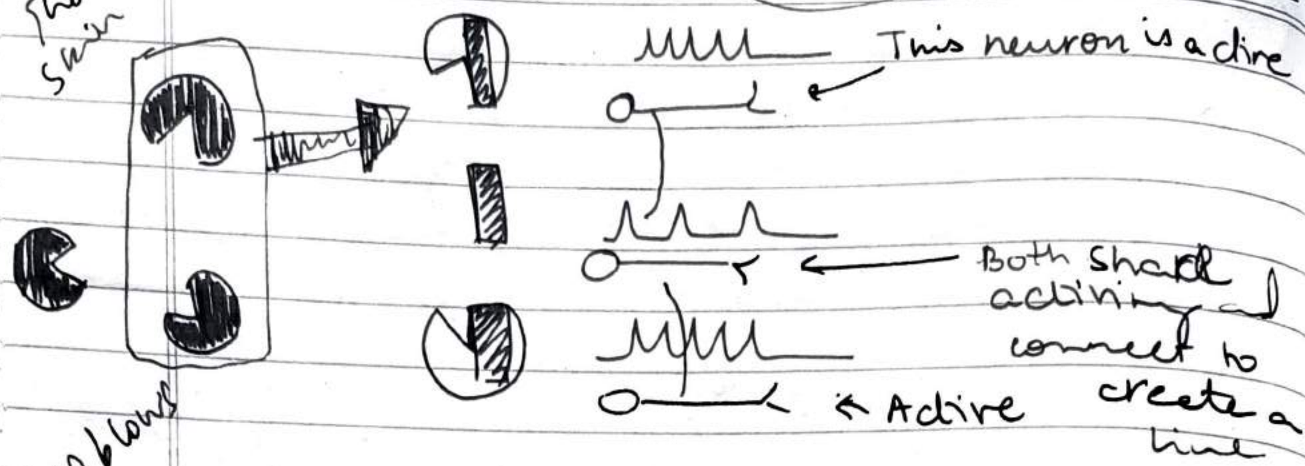


Technically they should be the same but they aren't.
Some neurons in the visual cortex even though their receptive fields recieve the same pattern of light
MC Escher Mosaic 2
Kanisza Triangle (Illusory contours)

Don't Look Back Rashomon devastation

Agnes Varda La Pointe Courte

The Soft Skin



The 400 blows

Chuck Close. (Not so great)

maps of body — visual maps

$8\frac{1}{2}$ 3.5

Phantom limb & Blind spot

Motion vision: perceive velocity

Le Mepris

Body (somatotopic) maps

· Wilder Penfield

electrical stimulation on patients of epilepsy to activate neurons. Where he stimulated in cortex determined the body surface: all parts of body were represented on the somatosensory cortex. Areas of ~~somatosensory~~ particularly sensitive to tactile stimuli were disproportionately: cortical magnification.

Kameraa Stolen kisses

Jules et Jim

Breathless

Fovea of eye is enlarged high density of photoreceptors, highest spacial acuity hands, mouth.

Pierrot le Fou

Odd boy

Phantom Limb Syndrome

Le Beau Serge

Occurs in amputees, who feel their

Shoot the Pianist Vivre Sa Vie Weekend (1967)

City of God   Antoine & Collette   Cleo 5 to 7   Date: / /
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missing limb is still present.

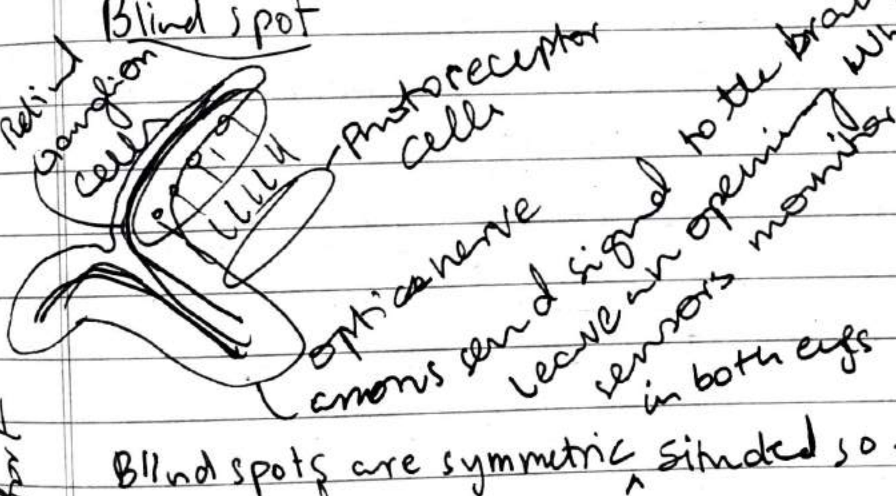
[V.S. Ramachandran
\ Phantoms in the Brain
Future of Mind – Michio Kaku.

Perhaps due to brain activity persisting in such maps in the absense of the amputated body part.
Touching on ~~brain~~ ⇒ missing body part
part adjacent in ⟶ to
cortical map on body

Shaving face but feels in the arm

"Secrets of the ~~Brain~~ Mind" Nova PBS

Blind spot



Blind spots are symmetric, situated so they look at diff. visual scenes ; dirn. in

Glaucoma – Vision loss due to damage to retina, not noticeable as the brain fills in the details

The girls of Rochefort

Une Femme Est une Femme   Mommy (2013)

Stanford -

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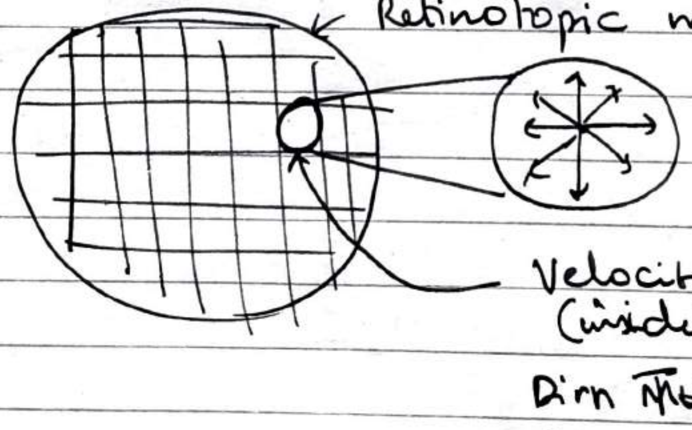
3.6 Motion Vision
- Motion Perception
- Motion signals in Brain
- Motion-guided behaviour

Perceptual quality of motion constructed by our own brain.
"Cinema is truth 24 frames per second".
Images spun about.
Stimuli varying in position across time
But a lot of things change pos over time
Not stimuli is perceived as motion.
Too fast or too slow to be perceived.

Brain area for sense of motion : MT
(middle temporal region of cortex).
Neurons of MT
- Receptive fields in space called retinotopic maps. More responsive to moving stimuli than stationary
- Sensitive to dirn. & speed. Topographically organized to velocity preferences.



Motion Induced Behaviour: Smooth Pursuit Eye movements
You can't make smooth pursuit eyemovements unless you see a moving target.

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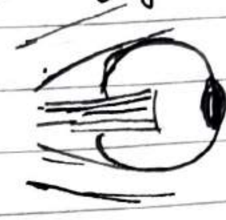
How does MT guide smooth pursuit?

Many neurons voting for diff. velocities

One eye movement

MT → Evaluation of MT's signals →



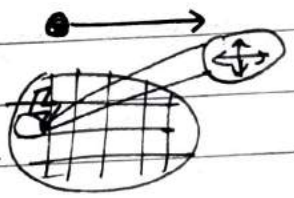
How are these votes counted: Eye

Possibilities
1. Winner-takes-all: use votes of most active neurons
2. Averaging
3. Summation

Only one visual stimulus at a particular location fool the brain to encode more than one velocity

(a) • Real visual stimulus

(b) • Artificial stimulus by electrical stimulation

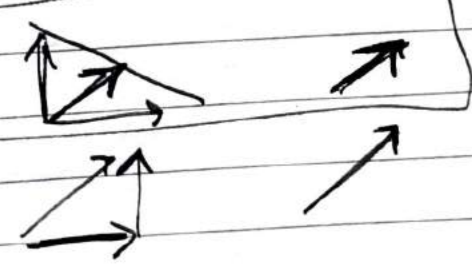


↑

(1) → + ↑ } → & ↑ which ever wins Ig.

(2)

(3)



— True visual stimulus.

But how does the brain compute the average?

~~That we~~

Some possibilities: Groh, J. M. (2001) Biol. Cybern. 85: 159–165

Computation models to show how the brain does this calculation.

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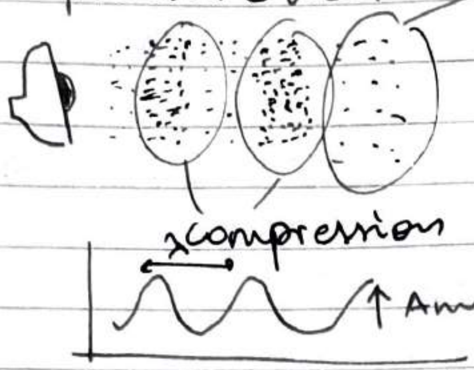
Week 4

4.1 What's sound & how is it sensed?

sound pressure wave. — Rarefactions



Enter ear canal cause vibration of tympanic membrane

vibration of ear drum → through bones of the middle ear: Malleus, Incus, Stapes → located within the inner called Oval window → behind this is a fluid filled

4.2 cavity (snail shaped) cochlea

Bones of middle ear serve to provide mechanical advantage taking pressure wave and air and create a pressure wave in cochlea's fluid.

Then they convert into a neural signal

(1) Ear drum vibrates

(2) Oval window

(3) Basilar membrane vibrates

free flowing at one end vibrates first (3)

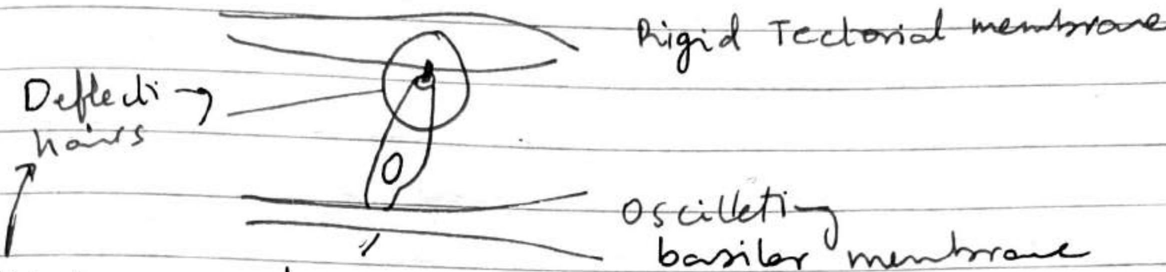
(4) Then Tectorial membrane more rigid. Spl cell on Basilar membrane bump onto Tect. Membrane.

Basilar membrane goes up and down

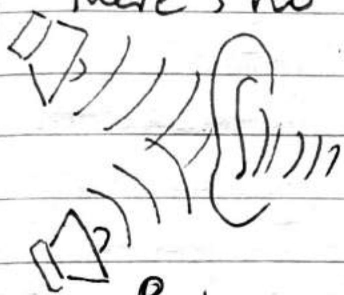
Hair cell on top move back and forth

Cilia embedded on Tectorial membrane gets scraped.

Auditory Transduction

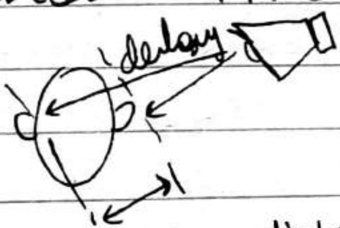


Mechanical forces affecting the hair cause ion channels to open & close
There's no spatial info of the sound.

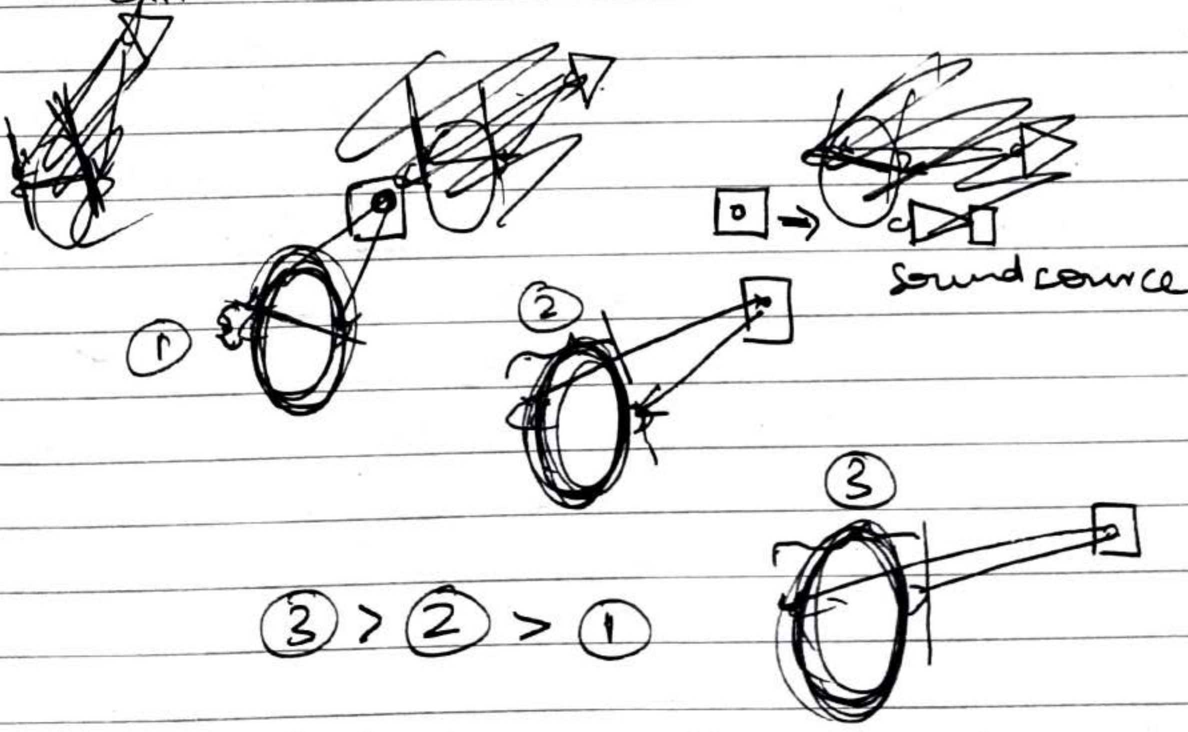


How do we localize sounds if we don't have image forming ears?

But we can compute the location of sounds. by comparing the soundwaves that arrive at each ear.



extra distance is short but it makes a diff



A sound located farther ~~to~~ one side

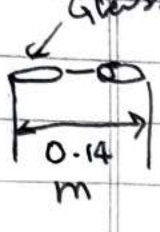
Shockwave - Gallahager

involves a bigger diff btw near ear & far ear. These diffs. are Interaural Time Delays = ITD

To figure out delay we know:

→ Separation btw 2 ears

→ speed of sound.

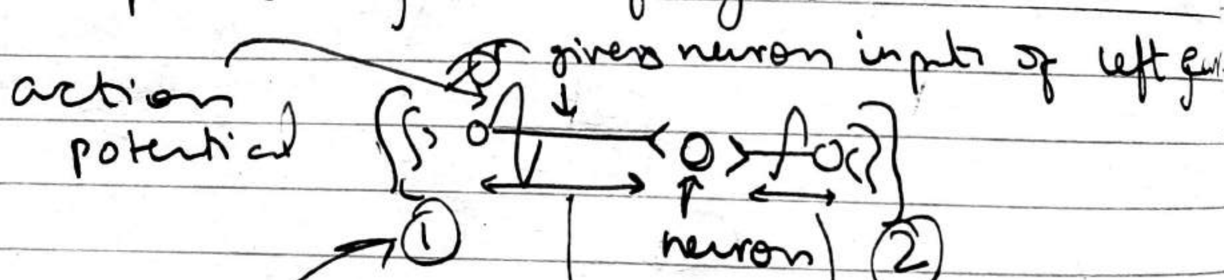


speed of sound 340 m/s

$$\frac{0.14\,m}{340\,m/s} = 0.00041\,s = 0.41\,ms$$

small amt of time, less than the time of an action potential (1 ms) and cant occur more rapidly than about every 2 ms. This 0.4 about a 1/5 of the spacing btw 2 action potentials And we can detect it.

Delay signals from one ear in comparison to other and having those signals converge on a particular neuron that responds sllectively to coincident inputs as opposed to inputs coming in out of sync.

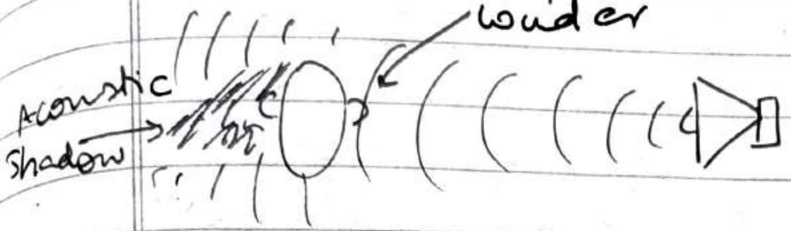


time it took for the action potential to come from either ear. More sensitive

Neuron with shorter "delay line" is more responsive to sounds from the left.

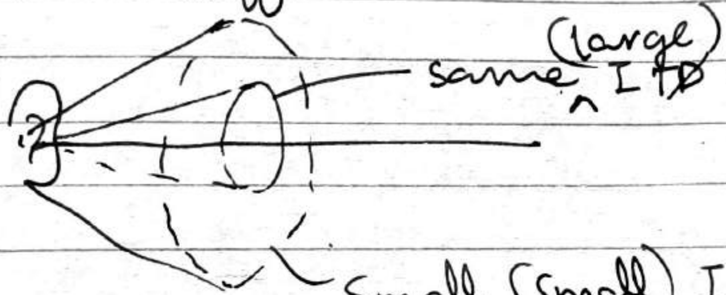
That neuron shell respond better when ① hears the sound first & ② hears it 2nd.

We also compare sound loudness



brain can infer dirn.

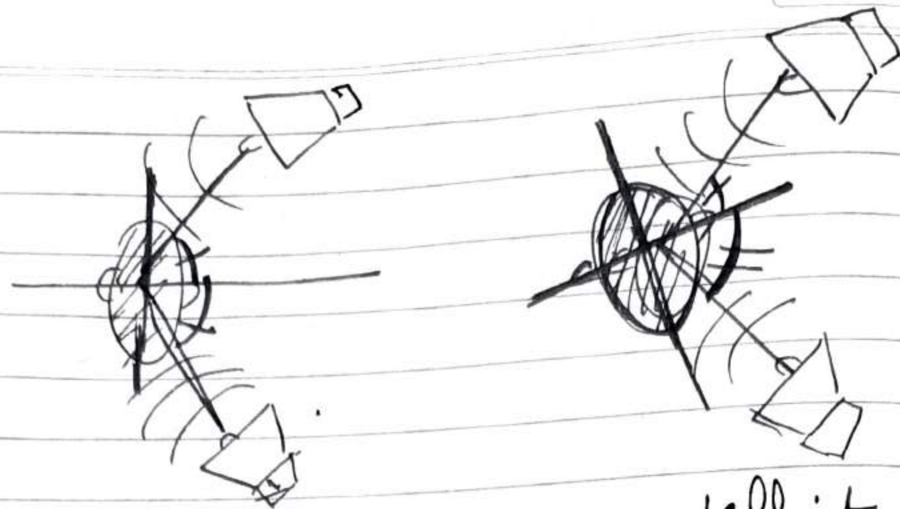
Cone of Confusion
Many locations produce same timings & level diff



Sound All the way right or left produce max level diff signal.

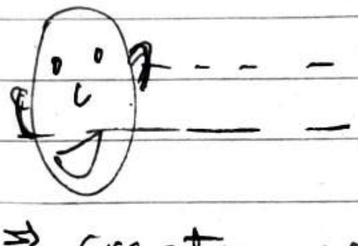
4.3 ITD & Level Diff told info about horizontal location of sound. But we perceive vertical & front/back dirns, but we're not that accurate as we are in horizontal. This is by
→ movements we make
→ using sound freq.

Movements
Head movements can disambiguate.



by Turning heads we can tell if the sound is in front or behind. For brief sounds head movements don't help. but even 1/2 a second is enough.

Head tilt gives info about vertical dimension.

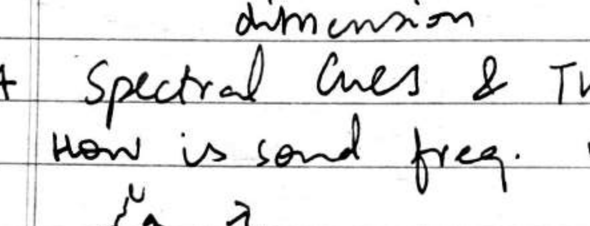


} vertical Interaural difference.

Tilt ⇒ create assymetry gives small time diff that corresponds to vertical dimension

4.4 Spectral Cues & The cone of Confusion.

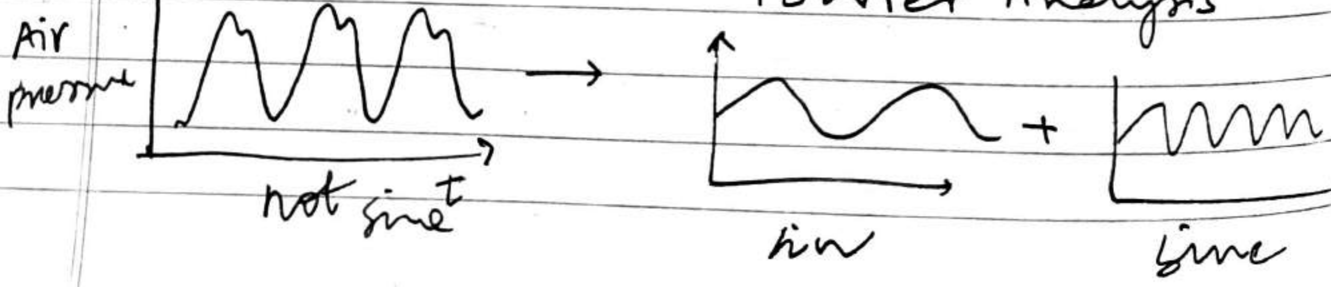
How is sound freq. used.



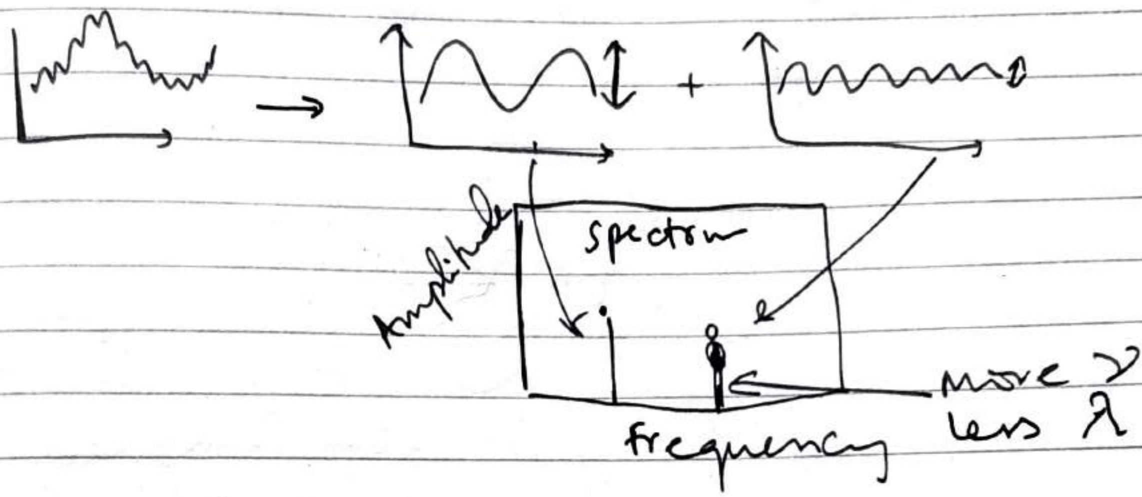
$$\nu = \frac{1}{\lambda}$$

Waves need to be decomposed into sine

Fourier Analysis

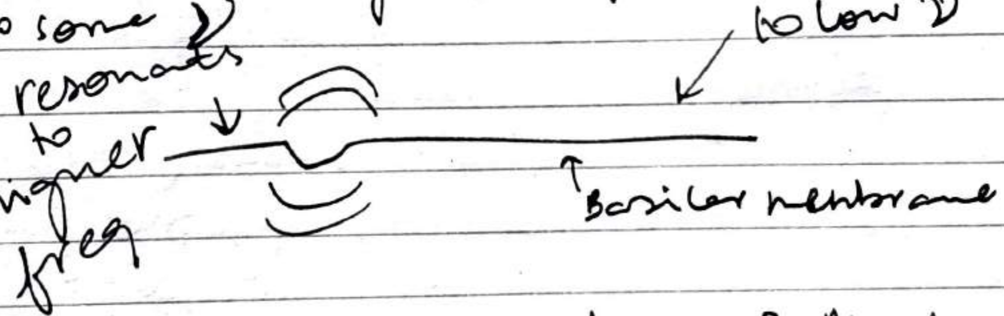


most sounds have multiple ν
~~diff~~ instrument, same note, because same fundamental freq.



Two ways of encoding sound frequency

① Location of hair cells in cochlea
Basilar membrane has a resonance membrane along its length. Resonates better to some ν



Resonance varies along B. Membrane. Diff ν cause max displacement in diff. places.

② Timing of action potential

hair scraps back & forth causing ions channels to open & close

Opening of ion channels is synchronized to hair → to sound. This synchrony is called phase locking.

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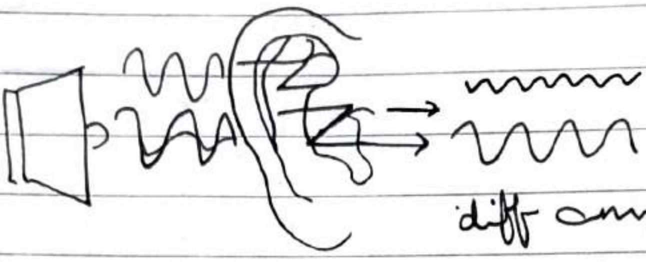
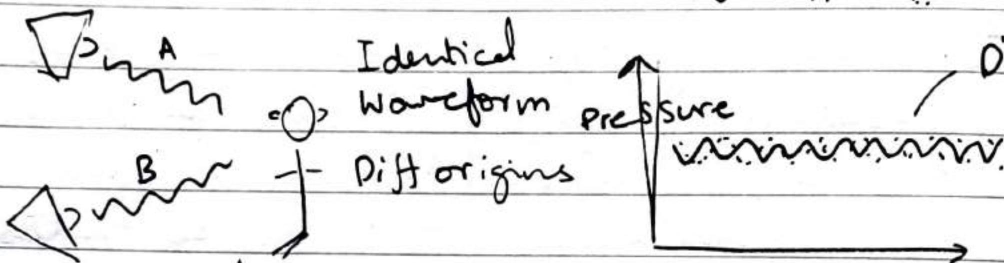
Sounds are filtered by external ear (pinna).
Filtering alters the energy at diff ν and is direction-dependent. ν are attenuated to diff degrees. ν info. about sound location is called spectral cue.



diff path diff attenuation

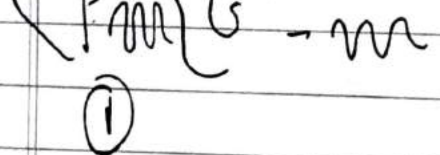


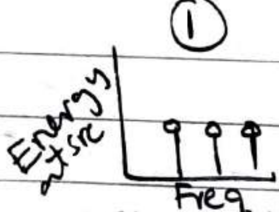
Spectral cues vary in all dirn horizontal, vertical, front/back

4.5 Learning to find sounds.

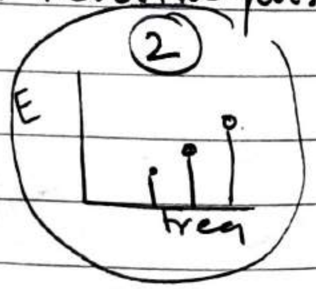
We learn: spectral cues ITD, lvl diff

Using:
- Movements
- Vision Eg: Ventriloquism



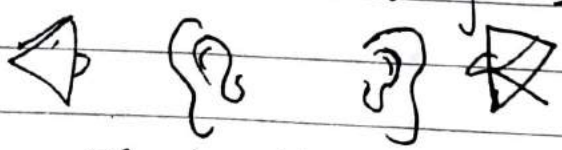


Start with all same Energy



Brain needs to compare 1 & 2 and it knows only 2

∴ comparisons happen btw the 2 ears.



or to the memory of same sound

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Everyone has diff. ears ∴ you learn your own ears filtering habit. You can learn to hear with new ears.

4.6 Ventriloquism & Finding sounds

Social cues are uncertain: Intrinsic ambiguities and sound cues change as we grow. We need evidence from movement & vision.

Vision

Visual stimuli can capture the perceived sounds location – ventriloquism effect. We perceive that sound is coming out of the mouth of someone on the screen when its the speaker. Effect can persist after the visual stimulus disappears (ventriloquism aftereffect). Vision helps calibrate localization.

How do you know which visual stimulus made the sound if you can't use loc. as guide?
- Visual - auditory synchrony
- Guess and location making a guess of the loc and making eye movement to that and see whether that's plausible. We look for this visual stimulus.
Movement of eyes for visual feedback is imp.

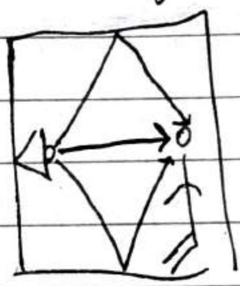
4.7 Determining Distance of sounds: loudness & Echoes.

- loudness diminishes with dist.

How do we compare when the only sample is in your ears. Therefore we could compare how loud it was when it started in the ear to the inside (doesn't happen)

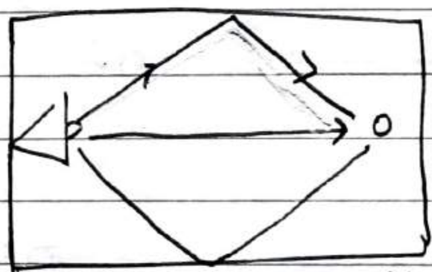
Inferring distance from loudness requires a comparison to prior knowledge. (we know how loud cars usually are, or people). Works better for familiar sounds.

A cue to infer dist that doesn't require prior knowledge: Delay of echoes as it bounces of nearby surfaces before reaching our eyes.

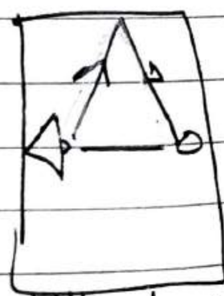


Environment is a hall of mirrors

Comparison of far & near



diff small



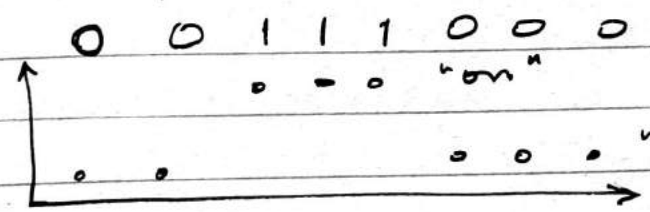
diff large

Echolocation : generating sound yourself and listening for the echoes of that sound. (bats)
• Make sound • Remember when you made it
- listen for echoes. • All happens very fast

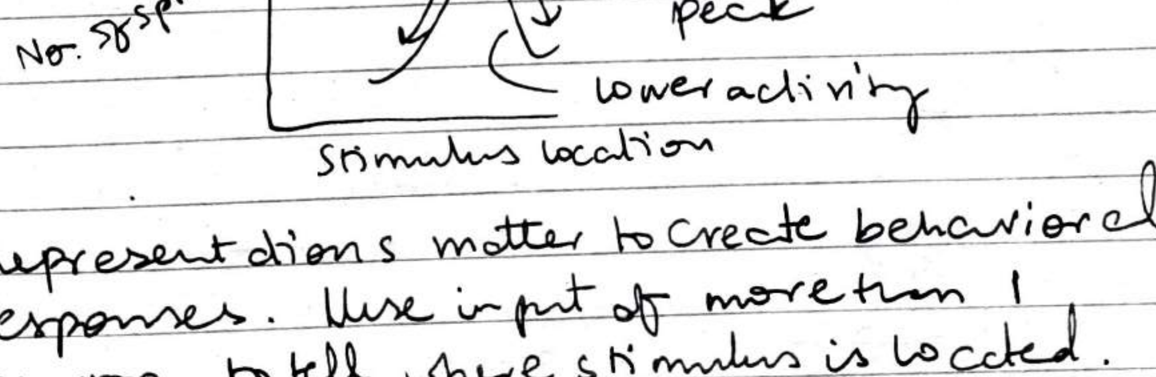
4.8 Brain Maps and Representations

Computer
Number → Binary

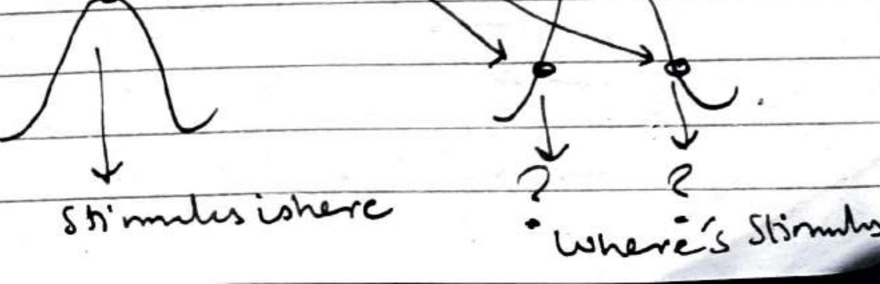
Neural Rep: symbol — Meaning
Neural activity pattern — Sensory stimulus, Desired movement



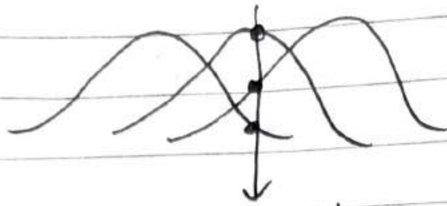
Neurons are diff from logic gates (no 'on' and 'off' but rather graded firing).



Representations matter to create behavioral responses. Use input of more than 1 neuron to tell where stimulus is located.

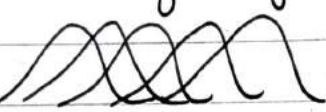


These maps need to be read and activity needs to be evaluated in combination.



Requirements of Map:

- Individual neurons should be tuned, show peaked tuning functions and there are many of ~~these~~ neurons.



- Population of neurons, diff neurons tuned differently, all locations represented point-to-point

4.9 Brain Representation

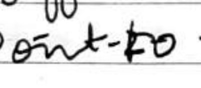
Maps aren't the only repr. Brain Meter is important

Brain Map → which neurons are active

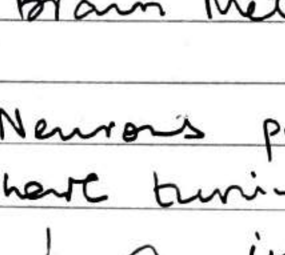
Brain Meter → Amt of neural activity

Maps / Tuning

Neurons participating in a Brain map have tuning functions, activity of individual ~~function~~ neuron is ambiguous



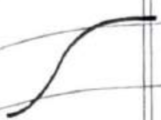
Meters Proportional



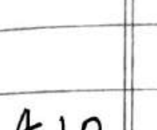
Their activity scales proportionally with stimulus parameter. Given activity level uniquely related to a

particular value of that stimuli.
Brain structures that read meters evaluate spikes fired. No. of spikes tell location of stimulus. Level of neural activity is what signals the variable that is being encoded

Requirements of Meter:



- Individual Neurons should exhibit monotonic patterns rather than tuning. Monotonicity allows for unambiguous relationship btw firing rate and particular stimulus parameter (location).



- Population of neurons may be involved in particular to include neurons, preferring one direction vs. neurons in another dirn. to disambiguate
- Must be some sensible axis for organizing this information

Alternative coding format when brain controls movements

4.10 Brain Meters & Movements

Movements: connection btw neurons & muscles they control muscles with spl. synapses called neuromuscular junction and cause the muscle fibres to contract

Force in muscle prop. α # of spikes

dependent → Force

#spikes – independent variable

Visually-guided movement
Visual location → encoded via maps (of neurons that have receptive fields that derive from the image forming property of the eye)
Movement → meter
∴ V-g move. requires translation btw map to meter

Eye movements – by extraocular muscles (outside the eye)
6 of them muscles.

rotate the eye horizontally
vertically

saccadic
~~Scaddic~~ eye movements / saccades
Rapid eye movements (~500 degrees per second)
3 saccades per second.
involuntary.
Reason: one area of retina is densely packed with photo receptors – fovea and we have better visual acuity when we aim our fovea on the stimulus of interest (visual, auditory, tactile) onto high-res fovea

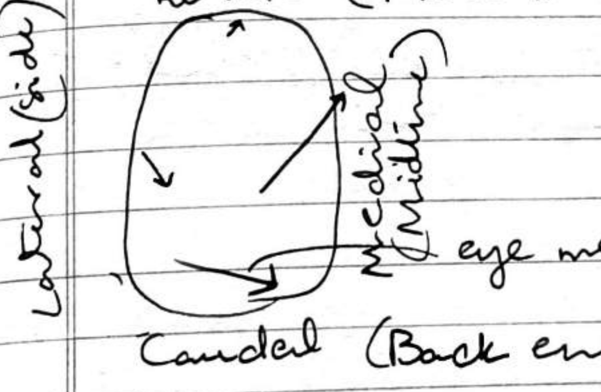
4.11 Translating Maps ~~to~~ Meters
Maps : visual spacial info
Meters : encode amt of force needed to move the body

Brain Region: Superior Colliculus

Where info from diff sensory sys combine prepare for interacting with muscles.

Loc: Middle of brain, top of brain stem, underneath the overlying cortex

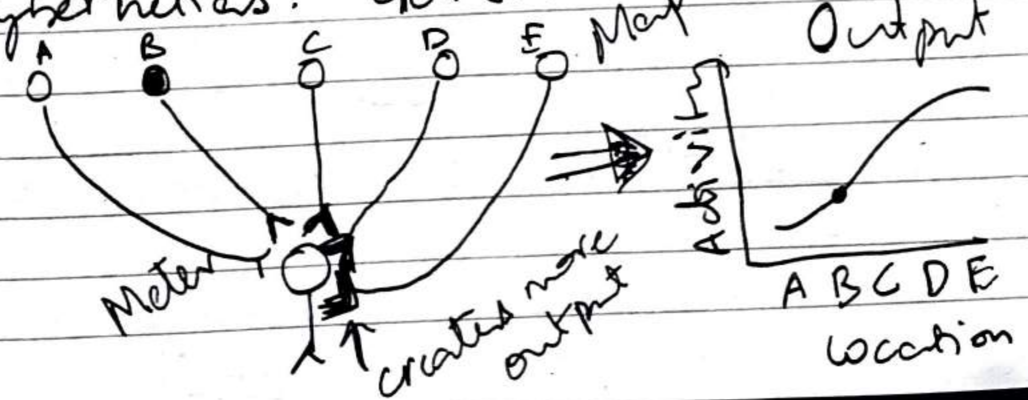
Involved in: controlling saccades (and attention), Recieves visual, auditory and tactile inputs. contains "motor map" If you artificially simulate the colliculus you can trigger an eye movement. Where the eye moves depends on where you ~~...~~ deliver the electric current. (David Robinson 1972)



SC on left controls both eyes ~~...~~ rightward dirn (via versa)

All muscles are used to see in all dirn. amt of force is gen by no. of spikes. Mapped signals get conv. to meter to make eye movement.

Conv. place codes to rate codes Biological Cybernetics. Groh JM



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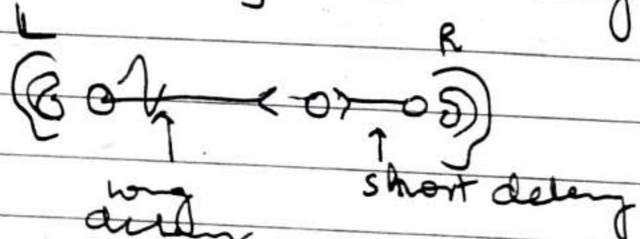
Synapses have different weights (weighted functions in ML) one neuron could have more neurotransmitter released at some synapses than others or more receptors for a specific neurotransmitter on the post synaptic neuron.

How does normalization happen in this model where there's diff no. of stimuli or stimuli vary in factors like brightness or when electrical stimulation is being used to manipulate the activity in the map.
(Eye movement wala Visual MT wala problem bhi same).
Read the paper by her.

4.12 Brain Representations for sound
What kind of representation does the brain create by synthesis of these cues.
Jeffress Model (1948): brain constructs a (co-ords) representation of sound by ITD using diff delay lines



· Neuron responds best when inputs are coincident
∴ Neuron is more responsive to sounds located to the left.

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Sond located in left, Action potential Reaches left first and travel down the longer path. Right takes shorter path which compensates for delay for sound located at the left

mitter ∴ This neuron (in pic) responds better to sounds in the left.

Brain forms "map of auditory space".

Barn owls (have maps for auditory space)
Primates (monkeys) use meters for auditory space.

3:00

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Week 5

5.1 Defining Spatial Locations

Refrence frame, Sensors move (head, ear, eyes, body)

5.2 Visual space is synthesized Across Eyemovements.

We can tell whether our sensory receptors are moving or the obj in world are

Ability to tell. Object is unchanged despite changes in sensory receptors: location constancy. Same obj can be sensed by diff. receptors, yet we perceive it as being the same.

Synthesize a mental visual img
- At any moment we only see a portion of the scene with clarity
- We move our eyes to see other areas
- Brain combines these snap shots into a percept

(Arjun)

we never actually experience.

Synthesis requires accurate knowledge of eye position.

5.3 Sensing eye position via Motor commands

MSR & GTO lift weights and we can tell their pos.

Eyeballs don't lift weight

Brain can know where the eye moved by monitoring motor command.

Ste
ex

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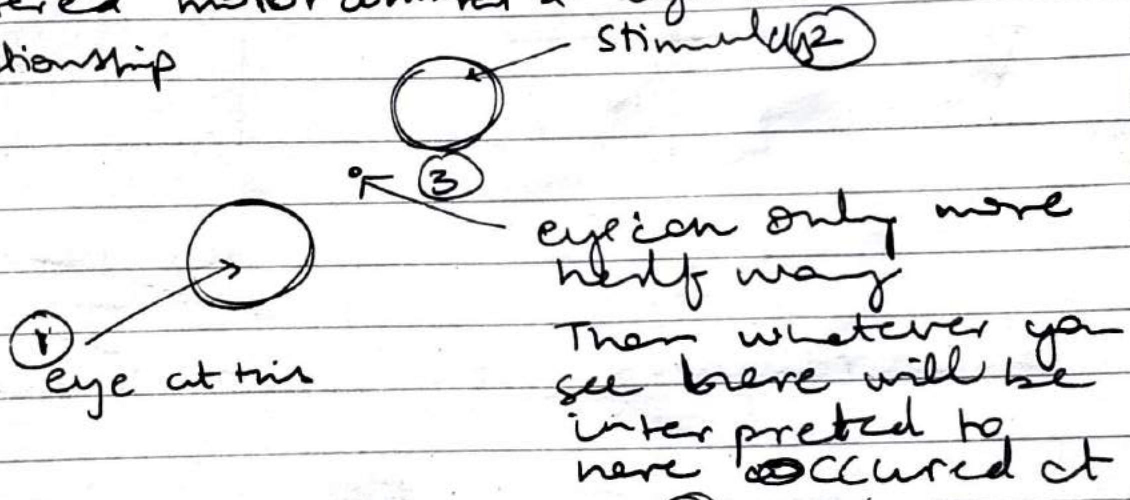
Brain keeps track of what it asked the eye to do. Assume that the eyes implemented that command. This method of knowing where they eyes are is efference copy or corollary discharge.

Experiment: if u alter the effectiveness of the motor command by manipulating the transmission of information at the neural-muscular junction & alter the visual perception

Curare (poisonous drug) that impairs communication btw neurons & muscles by impeding respiration. Took the drug

Stevens exp. altered motor command & eyes movement relationship



This mismatch makes it seem that the visual scene is jumping around.

Perceived stability of visual scene

- Req. accurate knowledge of eye movements
- Because eye doesn't carry load we do this by monitoring our own motor commands.

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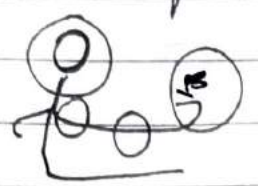
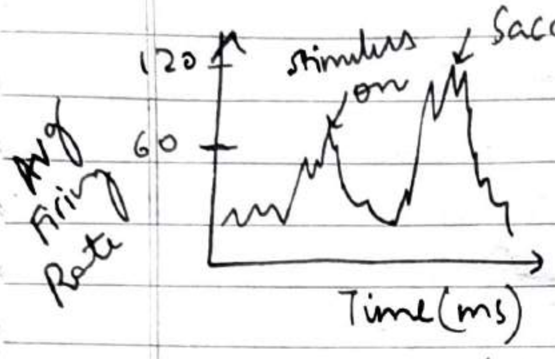
Super colliculus: Vision, Hearing & Touch

look at mosquito

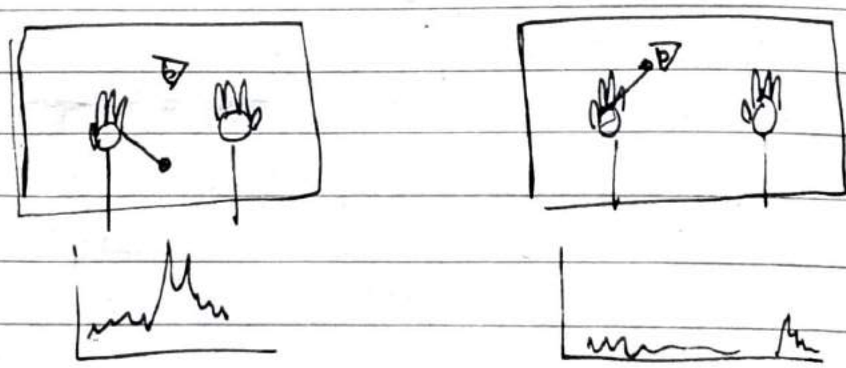


~~Know~~ position ~~of~~ angle of hand, elbow, shoulder, head to look at mosquito.



neurons SC respond to to touch & eye movement

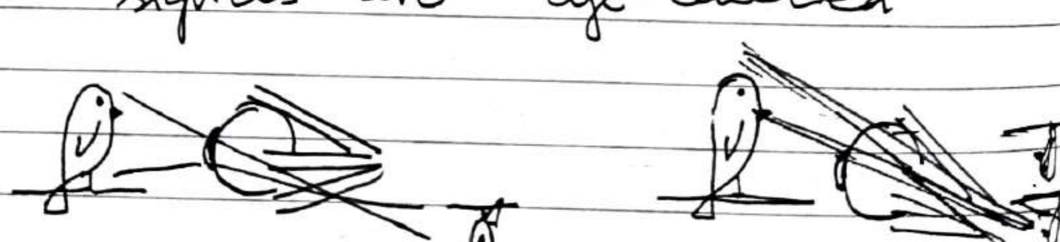
SC responses depend on eye position | Not all rxn to stimulus produce the same response.



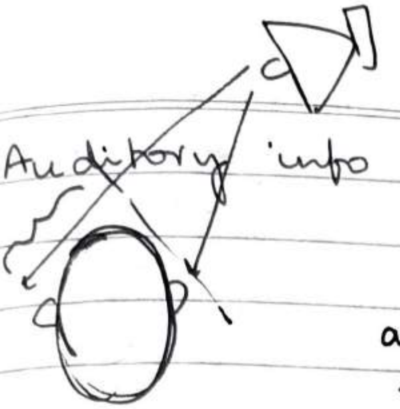
5.5 Coordinating btw. Vision & Hearing

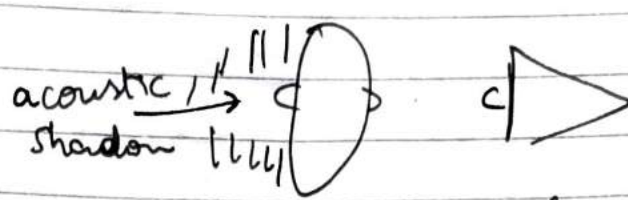
McGurk Effect, like the Pinocchio effect compromise interpretation.

Visual signals are "eye-centred"



Auditory info about sound locations





Interaural timing diff

Interaural level diff

spectral cues are "ear-centred" / or "head-centred" as ears are immobile.

4:20

5:05

tricky to reconcile what we see and what we hear.

communication btw visual & auditory systems

- Req. info about eye pos

- Eye position modulates activity at multiple levels of auditory pathway ~~all that~~

This suggests that there are widespread interactions btw visual & auditory pathways.

Information flows both ways in the ear.

Info flow ↑

etc.

* Auditory cortex

Medial Geniculate Nucleus of Thalamus

* Inferior Colliculus

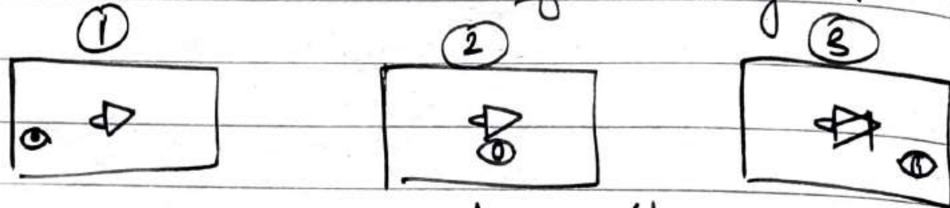
Super Olivary complex

Cochlear Nucleus (brain)

cochlear (ear)

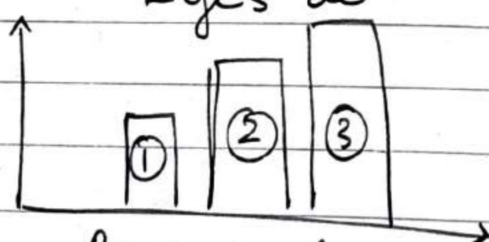
Info flow ↓

* Here ~~sounds~~ neurons were found to be sensitive to sounds & orientation of the eyes.



sound doesn't move
Eyes do

No. of spikes.



Response to a given sound in a neuron in the Inferior Colliculus/Auditory cortex

Since sound doesn't move ∴ the eye orientation makes a diff.

Ventriloquism aftereffect depends on eye position.

Thinking that a visual stimuli is the source of sound.

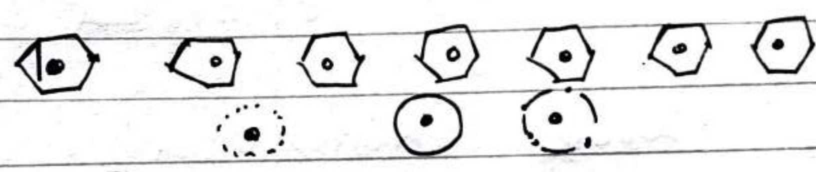
Ventriloquism aftereffect is biggest when sound location and eye position match the orignal exposure

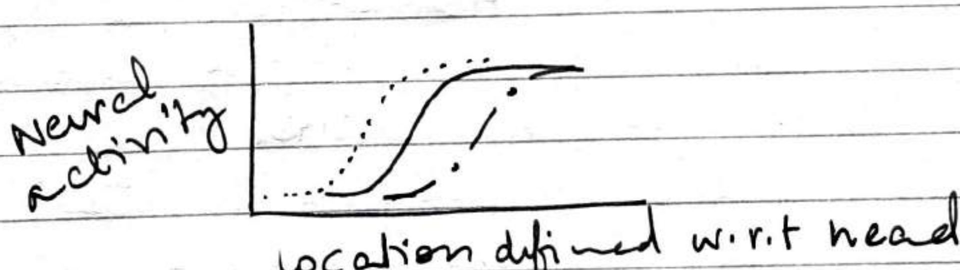
10:20

5.6 Translating Auditory Information into Visual coordinates.

Sounds

Eye Fixations

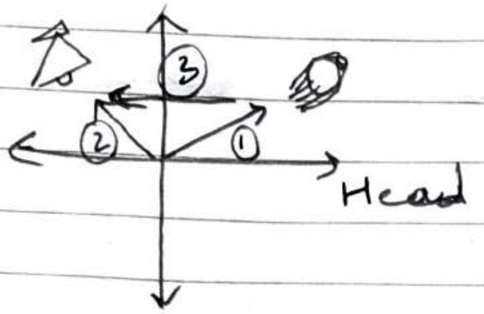




Neurons exhibit response pattern in which neural ~~pattern~~ activity is a function of sound location w.r.t head (eye loc).

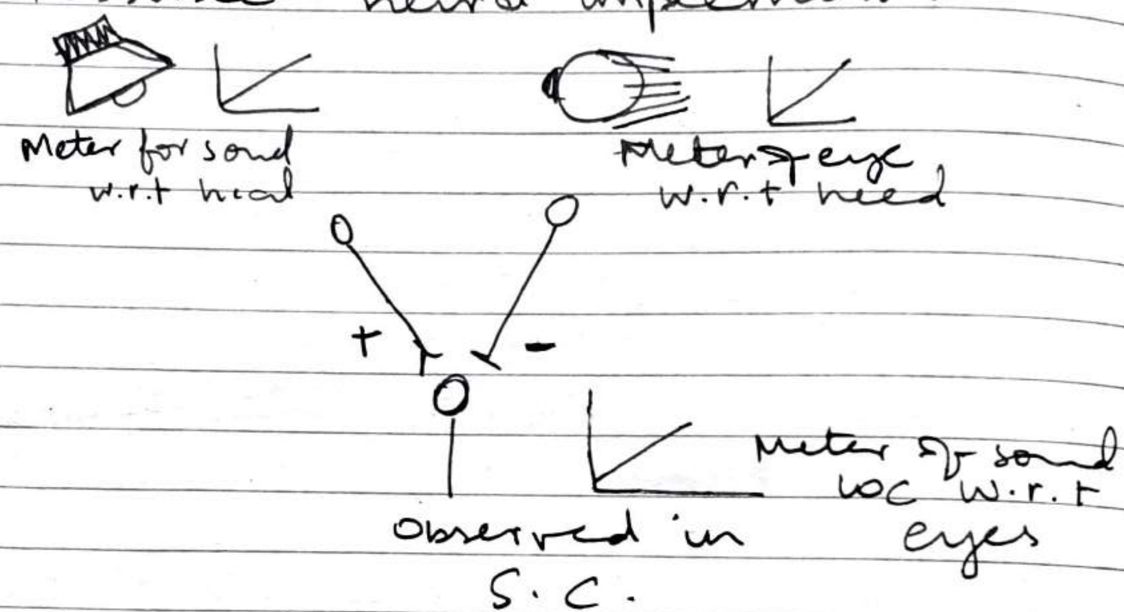
Underlying math is easy!
Figure where sound is w.r.t eyes
If you know sound loc w.r.t head
& pos of eyes w.r.t head it involves
vector subtraction operation

Persona
Wild strawberries
Autumn Sonata



subtract 1 from 2
gives 3 = loc of sound
w.r.t eyes

Possible neural implementation



- Senses communication
- Reference frames are a challenge when communicating across different sensory modalities
- The brain translates info btw ref-frames. brings auditory info into a frame of ref more appropriate for communicating with the visual system.
- We know less about how this happens for the sense of touch but it has similar mechanism.
- "Early" brain areas are involved suggesting widespread interactions btw senses

Ex: areas part of the main ascending pathway of auditory sys are influenced by visual info

5.7 Going Places Vesticular System

The "View from your window" contest
Vestibular System (balance) in the inner
ear near the cochlea: semicircular canals
and utricle & saccule

	Semicircular canals	Utricle & saccule
	• Rotation of head	• Translation of head
Similar to hair cells in cochlea →	• Hair cells	• Hair cells
	• The hairs of hair cells are dragged by cupula	• hairs of hair cells are tickled by "rocks" or otoconia

2:46 - 6:17

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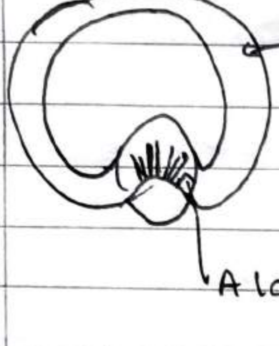
Vestibular illusions : Dizziness
Spin long enough fluid in semicircular canals move. When you stop it lags behind ⇒ dizziness or drink too much Alcohol – The Bouyancy Hypothesis
Alcohol diffuses in the cupula



Doesn't diffuse here
∴ creates a diff in density

Alcohol diffuses here

• Diff diffusion rates alter relative density
– Change mechanics
– Alter neural signals
– Creates dizziness

5.8 Vision Movement
Knowing where we are involves:
• Vestibular sys • Vision • Motor Control
• Memory

Optic flow
Characteristic pattern of visual motion throughout visual scene – due to motion in the world.

Expansion of visual scene.
Optical Flow Illusions –
Imax Movies, Trains/cars
Desert ants navigation

6.1 Memory & Space
Synthesizing all inputs req memory.
And memory uses brain's spatial sys.s.

What we remember is connected to location, had an idea forgot it go back to the place you had the idea and remember it. Space provides content for recall. We memorize location

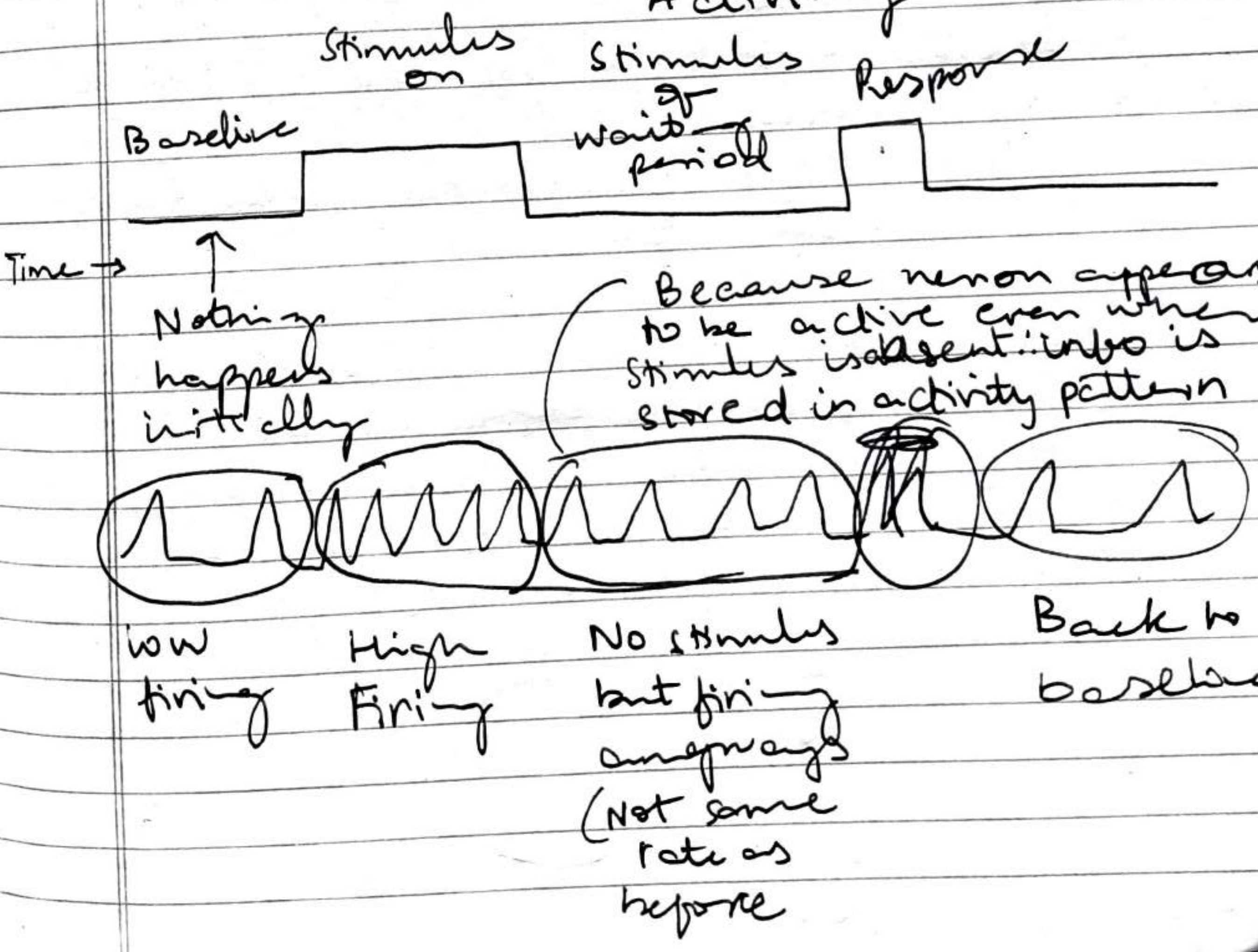
Method of loci : Memorize arbitrary items by associating them with locations that ~~you~~ are familiar with.

6.2 Memory in Neural Activity

~~Ext~~ : Memory in spikes

- A response to a sensory stimulus that outlasts the stimulus itself. Occurs in awake animals performing tasks req. memory (eg. delayed -response task).

Memory in Neural Activity



Memory in Neural activity is found in many brain areas S.C., Parietal cortex, pres frontal cortex (also have sensory & ~~motor~~ motor activity).
Infrastruct. for memory & space Overlap.

6.3 Memory in synapses Ex #2

Info can be stored via changes in Synaptic efficacy and these often occur in (spatial) sensory/memory pathways.

Evidence that supports this idea comes from a Model System : Vestibulo - ocular reflex

Interaction btw balance sense and ability to move our eyes.

- Counter-rotation of eyes when the head turns
- serves to keep visual image stable on retina
- Must be calibrated

Humans/other animals mobile eyes img. stabilization through eyes
Otherwise mobile legs and not eyes img. stabilized through keeping the head still as the body moves - chicken.

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Gain of VOR

$$\text{Gain} = \frac{\text{Eye turn}}{\text{Head turn}}$$

desired gain = 1

if look at something faraway

head & eye rotate about diff axes

Not wearing axes.

Glasses change the size of the visual scene.

VOR gain must be adjusted when you get new glasses. Where do these changes occur? In the pathway that senses the head turn & moves the eye which is Vestibular nuclei and Cerebellum

Synapses change in strength by inc/dec amt of neurotransmitter released or no. of receptors on the post-synaptic side.

Changes in the gain of VOR are thought to be accomplished by changes in the strength of synapses and these synapses are in the vestibular - oculomotor pathway. No specific part of the brain stores this memory but instead it is interdigitated with sensory and motor pathway.

64 Parietal Cortex

Spatial processing & role in memory retrieval.

Parietal cortex, subset of parietal lobe along the banks of the sulcus called the intraparietal sulcus.

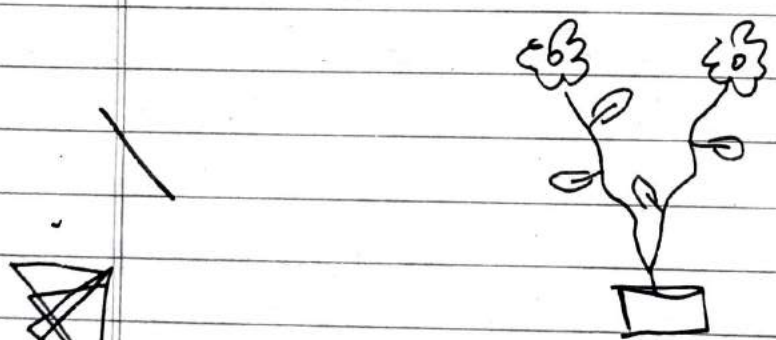
Parietal cortex shows:

Visual Activity
Auditory Activity
Responsive to tactile stimuli → Somatosensory Activity
→ Movement-related activity
Eye or reaching out movements

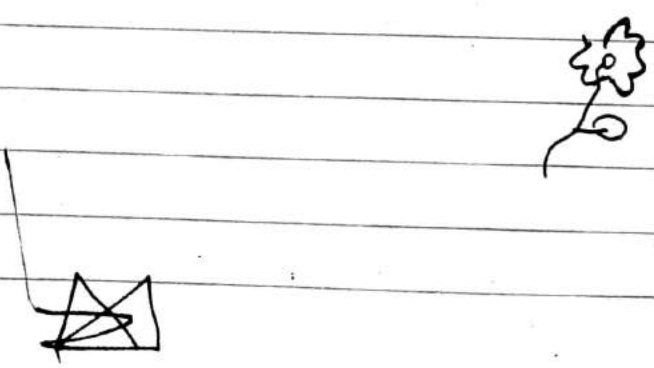
} all spatial

PC doesn't simply involve seeing, hearing or feeling. but some higher order function lesions of PC produce hemineglect syndrome in which patients fail to attend to or process at partial locations in space. Eg: drawing task

A patient with a lesion to the right parietal lobe may fail to process stimuli in the left



Patient copies



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Parietal cortex exhibits Delay period activity (info of stimuli is preserved in firing patterns). P.C. has been implicated in reference frames and in transformation from one ref. to another. They exhibit a mix of raw untransformed & transformed ref. frames (info). For visual frames some of them are eye-centered ref. frame and some are head centered frames, similarly for auditory ref. frame, and some are mix of head & eye. P.C. helps link info across time (as sense organs move).

Bisiach & Luzzatti
Piazza del Duomo Milan
4:13 Patients with lesions in the right of P.C can remembers stuff in left and then told them to turn around 180° then they remembered landmarks on the opp. side.

6.5 Mem. Navigation and Hippocampus

~~Ex#4~~.

Henry Molaison, bicycle crash, removed hippocampus & surrounding tissue to control epilepsy, but then he suffered anterograde amnesia (no new episodic memories can be formed) His own face wasn't recognizable to him. Hippocampus Memento

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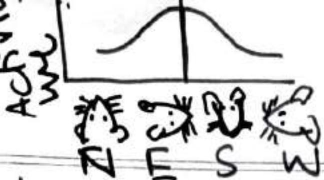
for new long term memories. Broadly confirm a role for hippocampus in memory particularly when connected to space.
Morris water maze task, rats swim around to find location of hidden platform to stop swimming. Rats with an intact hippocampus can remember previously learned location but not the ones with lesions.
Hippocampus encodes position in the environment – Cognitive Map
It involves a particular response pattern called a "place field"
Hippocampal "place cells" have place fields and their neurons are sensitive to location.

3.22 diagram.

Activity of hippocampal place cells vary with location. of placefields
Hippocampus representation is different from the topographical rep. in primary visual cortex. A neuron with a place field at one end of the enclosure could be located right next to a neuron with a place field at the complete opp. end of a particular environmental space. Each neurons place field isn't unique, individual neurons can exibit placefields in more than one environment.
Neurons in the visinity of the hippocampus participate in other

Head Dirn. cells



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activities that are helpful in cognitive mapping
Entorhinal Cortex show a property related to heading (What dirn are you facing).
Head dirn cells. 1 Best dirn SE.
a compass in your head. Also, there are signals for distance travelled in E.C. and they're called grid cells. 7:58 pic related. keep track of pattern of activity in the grid cells other ckts in brain can tell the dist. travelled.

6.6 Space & Thinking

Neurons barely do just one thing
Some maybe sensory + Motor, Tactile + Auditory Vision memory. Responses vary with attention familiarity, pay off for task performance Neurons do double duty. 3:20 pic related
Overlap btw cognitive & sensor/motor func
lesions produce deficits. Attention deficit in P.C. or memory deficit (in Hippocamp, P.C).
But the neurons in these structs respond in conjunction with sensory & motor events. Embodied & Grounded Cognition: cognitive abilities are grounded in sensory & motor processing.
What happens when we think?
We stimulate sensory and motor features related to the concept. Think of cat visual cortex - Image of Cat, Auditory cortex - sound, sensory: ~~Cora~~ feels

6.7 Behavioural ties btw Space & Thought

How we respond depend on irrelevant features of sensory stimulus that often involve space

(Jung)
Expt #1: Tucker & Ellis 0:50
Expt #2: Mental Rotation 2:21 ~~Rl~~ Related Rotation
Rxn. time depends on angle of rotation as if you were physically rotating the obj. Surprising the rxn time is how much time it would take you to accomplish to a real motor task.

6.8 Brain evidence connecting Space & Thought

Human Imaging Studies
fMRI - functional Magnetic Resonance Imaging
non-invasive technique for measuring brain activity in humans
fMRI suggests when we engage in Mental Imagery
Visual mental imagery evokes activity in visual cortical areas.

Extent of activity varies with the size of the object being imagined - tying into the visual cortex map of space.

Expt. Body Action words
somatosensory cortex - Ramachandran
2:00 expt. related. even the somatosensory cortex reacts to visualising the action word. kick → relates to foot region
But what happens when we think of more abstract concepts?

6.9 Space & Abstract Thought

Conceptual Metaphor Theory and how to ground your cognition.
Embodied / Grounded cognition.
Thinking involves simulating the sensory & motor aspects of a concept
What about abstract concepts — democracy?
Book — Metaphors we live by
Author - Lakoff & Johnson
Abstract is connected to the concrete thru of metaphor. These metaphors permeate our everyday language and they have consistent patterns.

Love is a journey through space
• We're at a crossroads • we've come to an end • going our separate ways
Emotion & temp. → she froze me up
Argument is war
Time & space → look at the week ahead
Evidendence : Lacey & Stilla R etc 2012
Brain & language : Tactile Metaphors
→ She had a rough day. affect activity in the somatosensory cortex.
→ Behavioural studies involving connection btw space & time : Boroditsky, Gaby A
Representation of space differ across cultures and languages and the impact

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that it has on representations of time
2:20 expt rejected.
Spatial language matters in anything that we connect to space via metaphor
How we think and reason depends on our neural toolkit. linguistic and cultural diff illustrate that there's more than one way to about abstract concepts and more than one way to tie them to something concrete. Flexibility is a hallmark in human cognition compared to our animal ancestors
Over the course of evolution our brains expanded in size : due to mutations that may have duplicated certain brain regions / duplication of "modules". Ancestors primitive had extra copies of these brain and used it for other cognitive purposes but footprints of the original purpose - sensory / motor processing is retained. Visual info, body pos. info., balance & movement info all necessary for our sense of space is repurposed at a grander cognitive scale / integrating info from diff. sources (imp. for processing spatial info) may in fact contribute to our ability to think flexibly

Making Space - How the Brain knows where things are.
Whisky Before Breakfast — Tasty Possum