# Structure and Measurement of the brain lecture notes

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Based on slides from Flavia Filimon, 2008

# Motor and Limbic system

Lecture 5

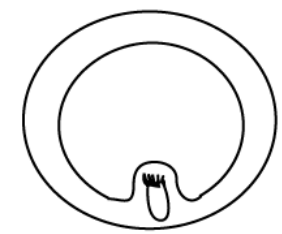
# topics

- Gaze stabilization
- Superior colliculus and VIP retinal and motor maps
- Motor control
- Basal ganglia
- Hippocampus and medio-temporal cortex:
  - Place cells/ head direction cells/ grid cells/ theta rythms

# Types of eye movement

I) Stabilizing eye movements:

1) VOR - vestibuo-ocular reflex



2) OKN - opto-kinetic nystagmus

3) smooth pursuit

II) Orienting eye movements:

4) saccades

# Goals for different eye movements

Stabilizing eye movements attempt to keep the world (or an object) stable on the retina, so the image is not blurry

- VOR: cancel head rotation by counter-rotating the eyes in the eye sockets
- OKN: cancel average world movement on the retina (retinal slip) via nystagmus (to-and-fro) eye movements
- smooth pursuit: track a small moving object and ignore background motion on the retina (cancels out OKN)
- saccades: look at something new, bring fovea onto new thing

# Examples

- VOR: rotating head while fixating something
- OKN: watching train cars go by at the train station: eyes oscillate back and forth; driving in a car, watching landscape go by
- smooth pursuit: track the tip of a pencil as you move it around
- saccades: rapid eye movement from point A to point B

# Pigeon OKN

- since pigeon eyes are lateral, rather than forward-facing, the word moves past its eyes as the pigeon is walking.
- This means the world would be blurry due to constant retinal slip
- To compensate for this, pigeon bobs the head (makes "head saccades"), head and eyes are held stationary relative to world as the body catches up, then head makes another saccade
- pigeon on a treadmill example: no OKN necessary

# Neural Circuitry: VOR & OKN

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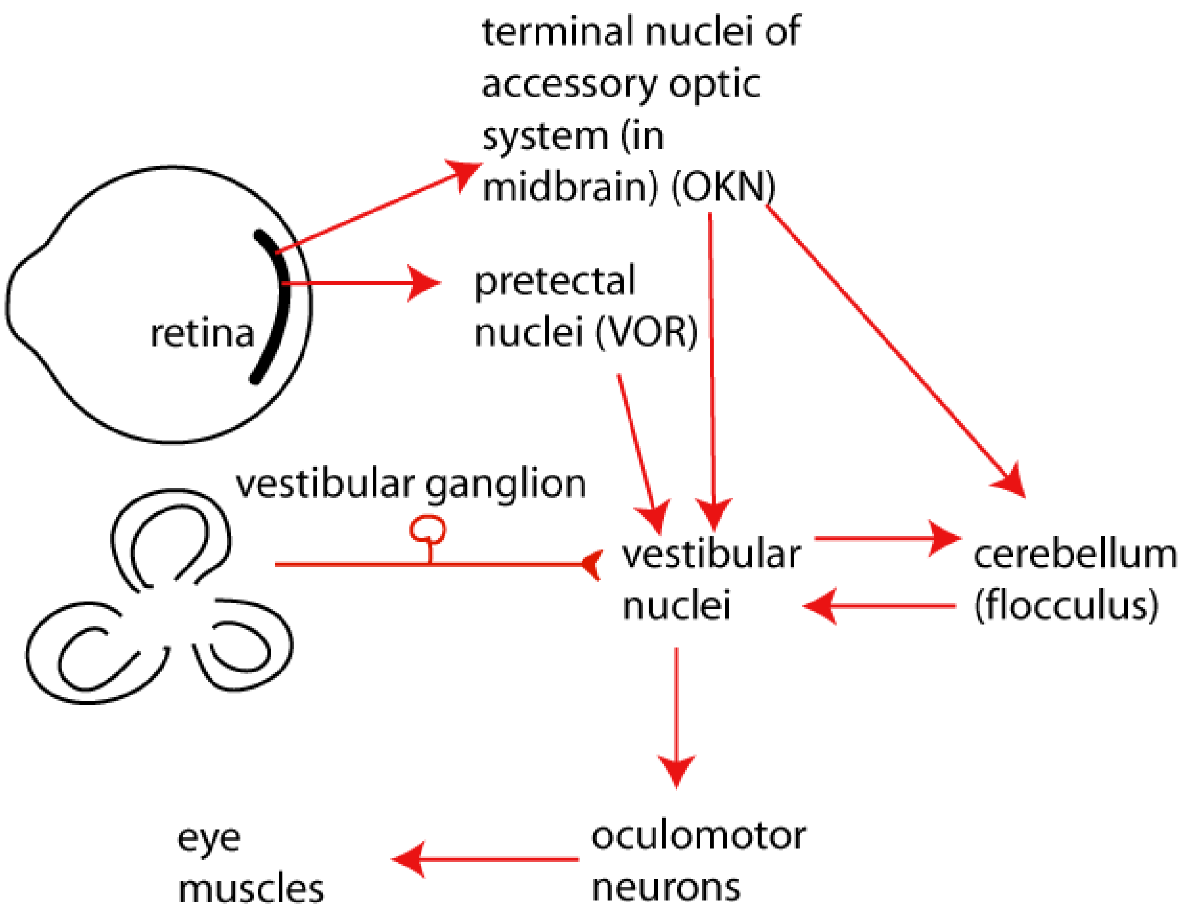
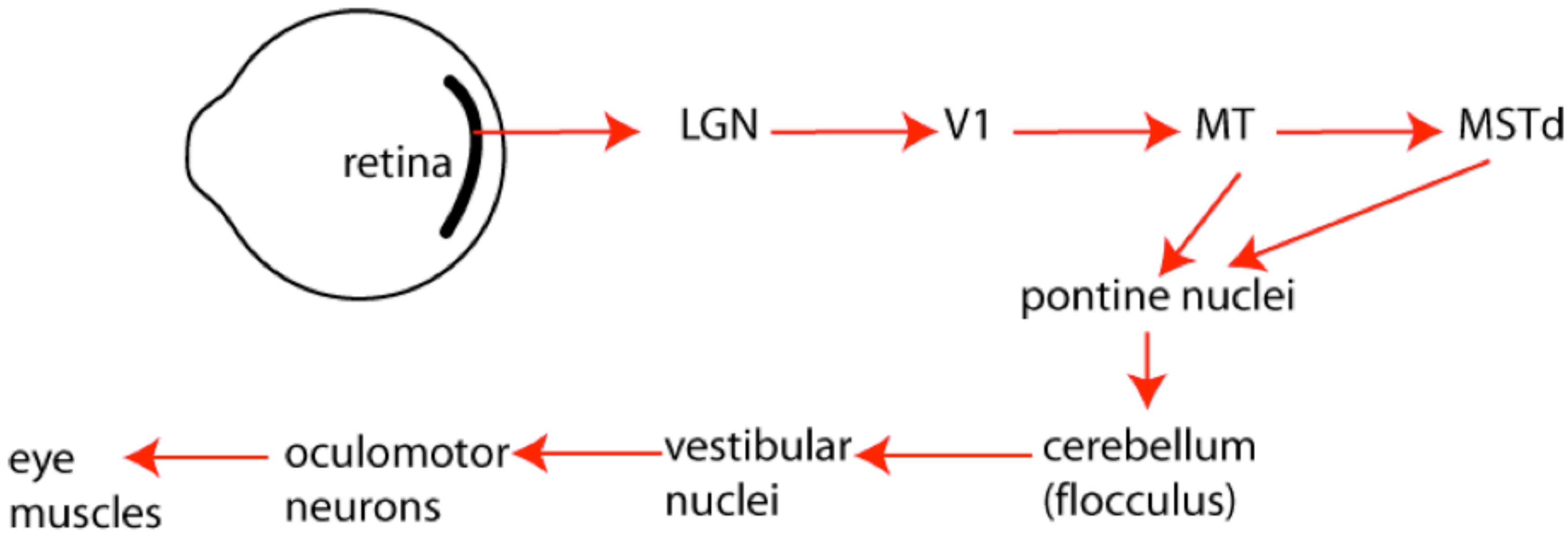
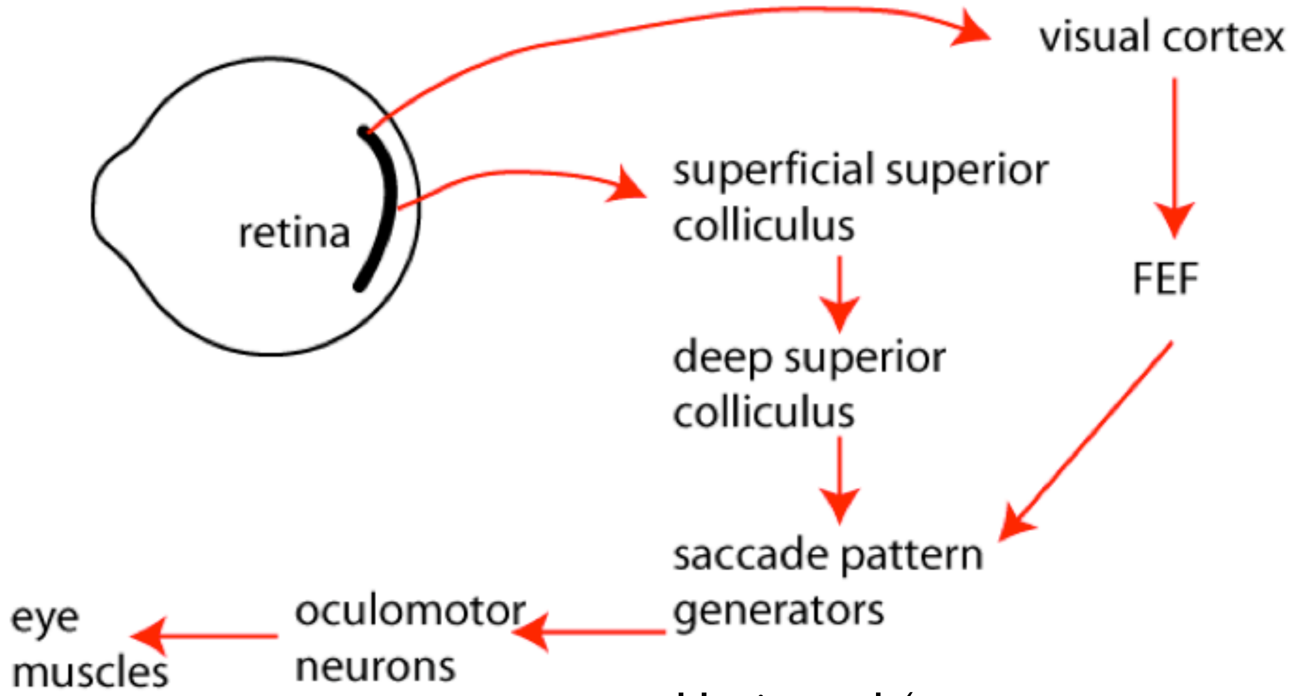


# Neural Circuitry: Smooth Persuit




- During smooth pursuit, cancel OKN
- Cerebellum shuts vestibular nucleus down

# Neural Circuitry: Saccades




Horizontal (paramedian pontine reticular formation)
Vertical (rostral interstitial nucleus of medial longitudinal falsiculus)

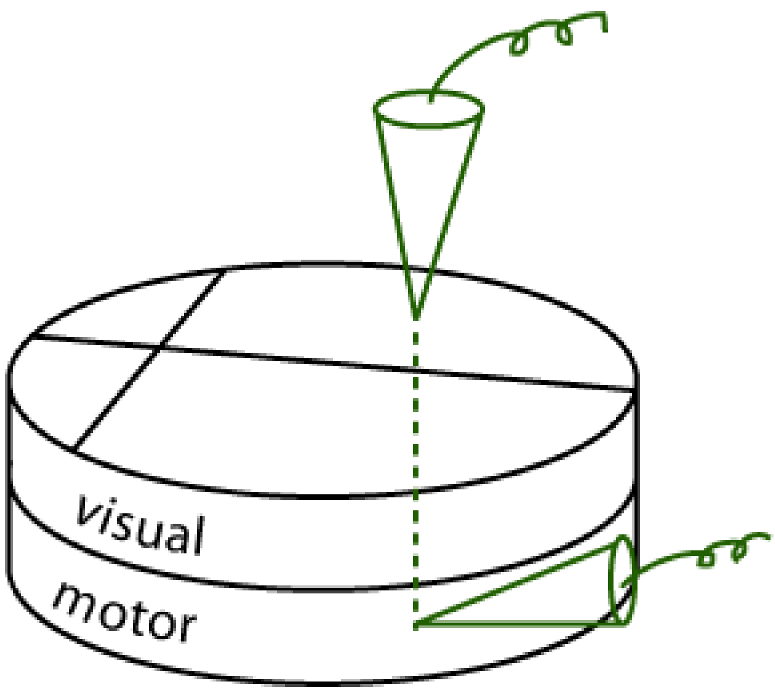
# Superior Colliculus & saccades

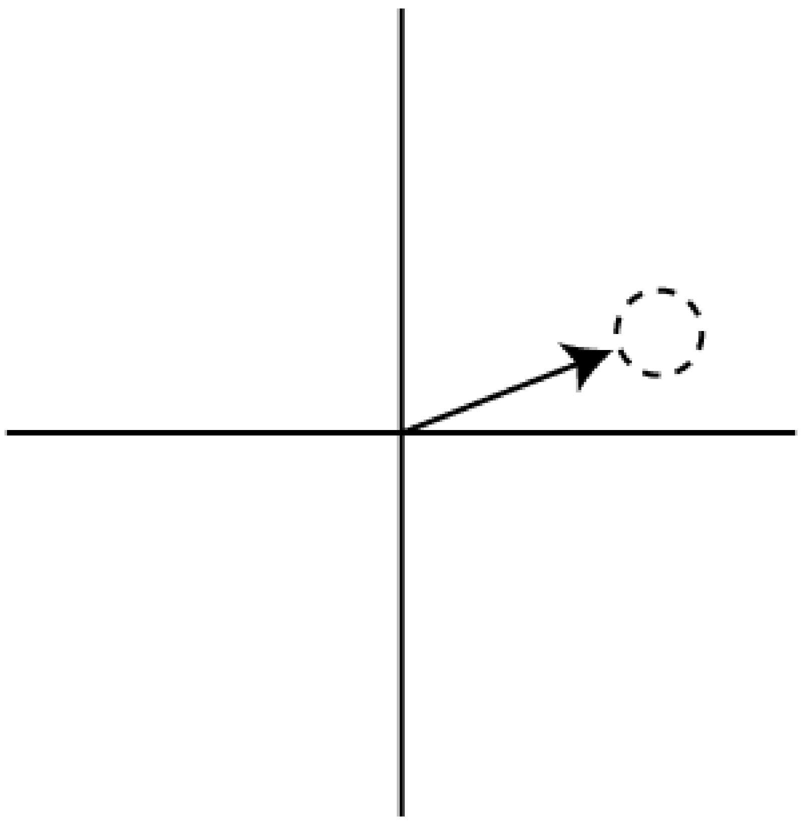
- SC: has superficial, intermediate, and deep layers
- superficial layers: visual (retinotopic map)
- deep layers: motor (motor map of visual field)
- intermediate layers: mixed sensory (e.g. auditory, etc.)

* **movement fields** for deep layer neurons line up with retinotopic visual **receptive fields**

- movement field = location in visual space toward which a saccade will be executed

# Movement fields in SC



# SC saccade vectors: if stimulate same neuron twice, get twice the vector

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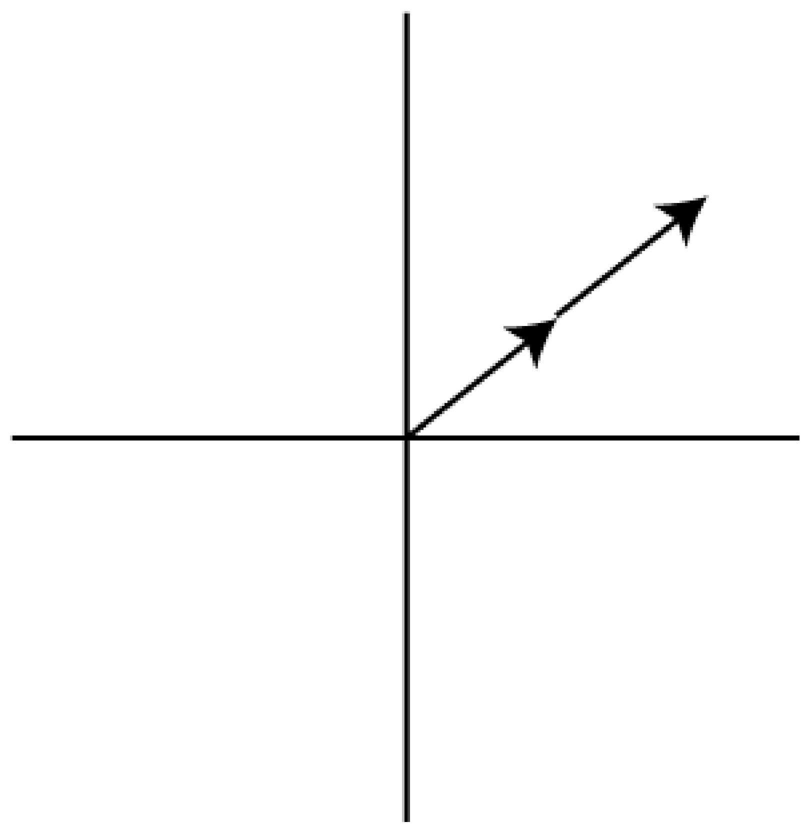


# FEF and SC work in parallel

Stimulate SC

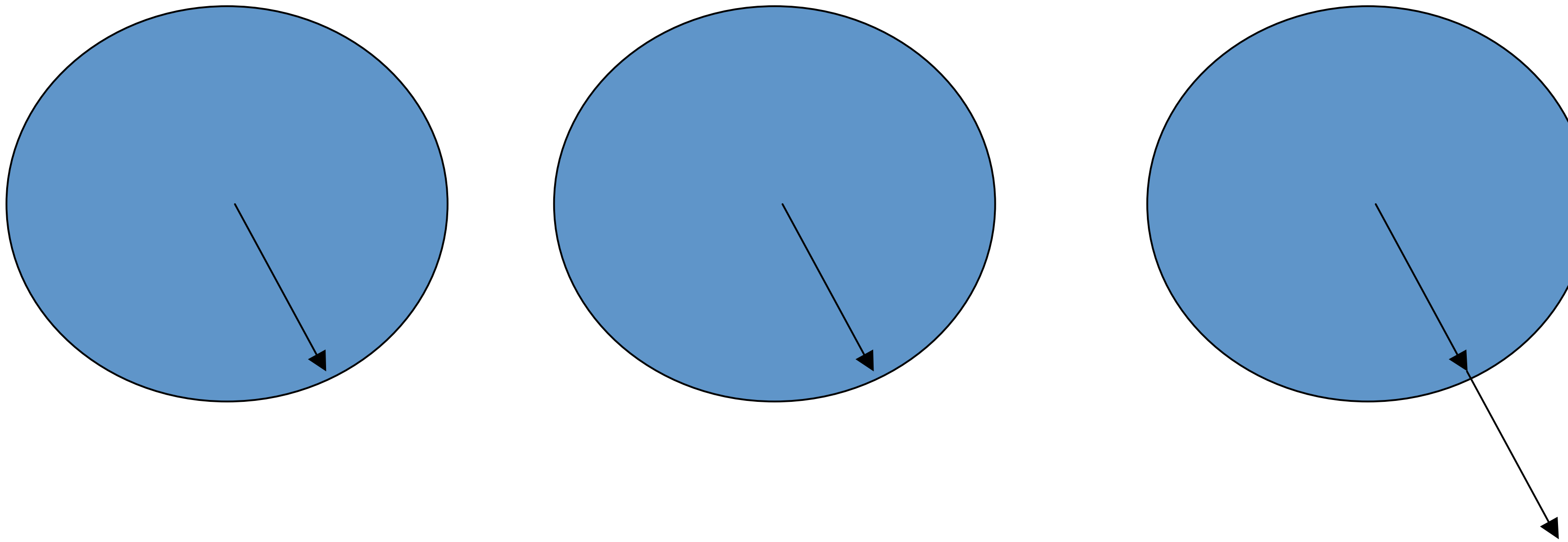
Stimulate Frontal Eye Fields (FEF)

Stimulate FEF and SC at same time

saccade

saccade

double saccade



In normal situation FEF (cortex) and SC (midbrain) must "communicate" to determine which structure controls saccade.

# Visual representation in superficial SC layers: the whole world moves in parallel on superficial SC

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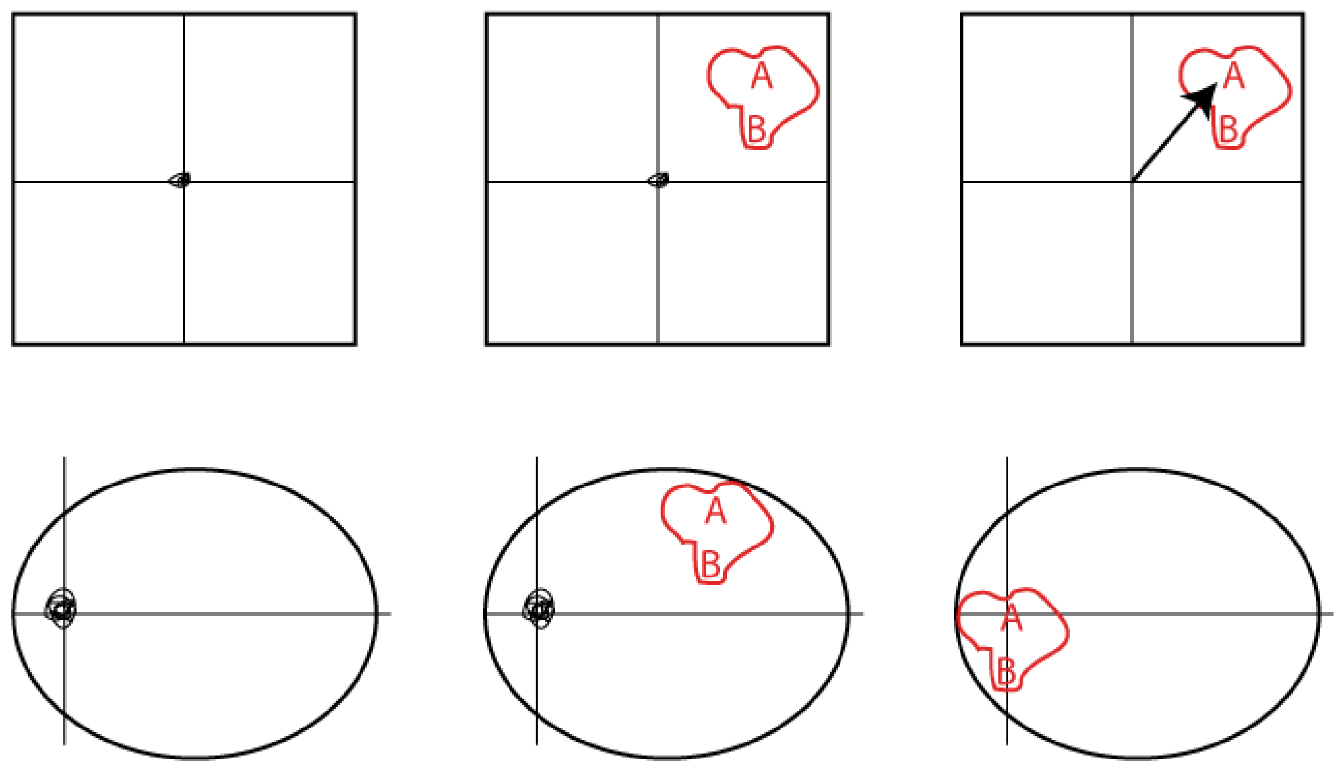
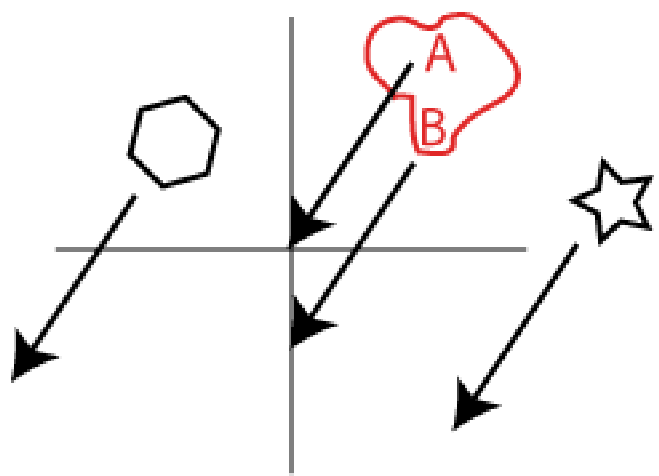
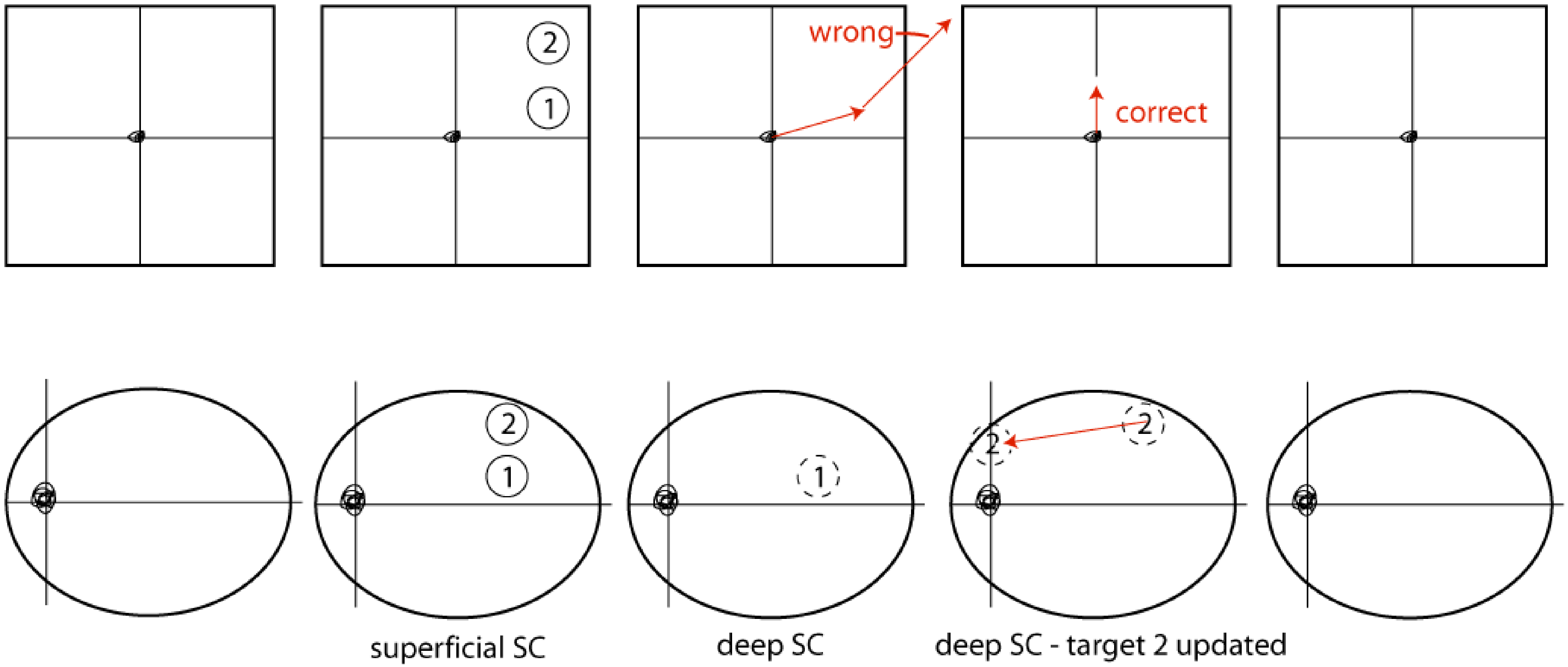


# Visual representation in superficial SC layers: the whole world moves in parallel on superficial SC

- 


visual world moves in opposite direction to saccade on SC

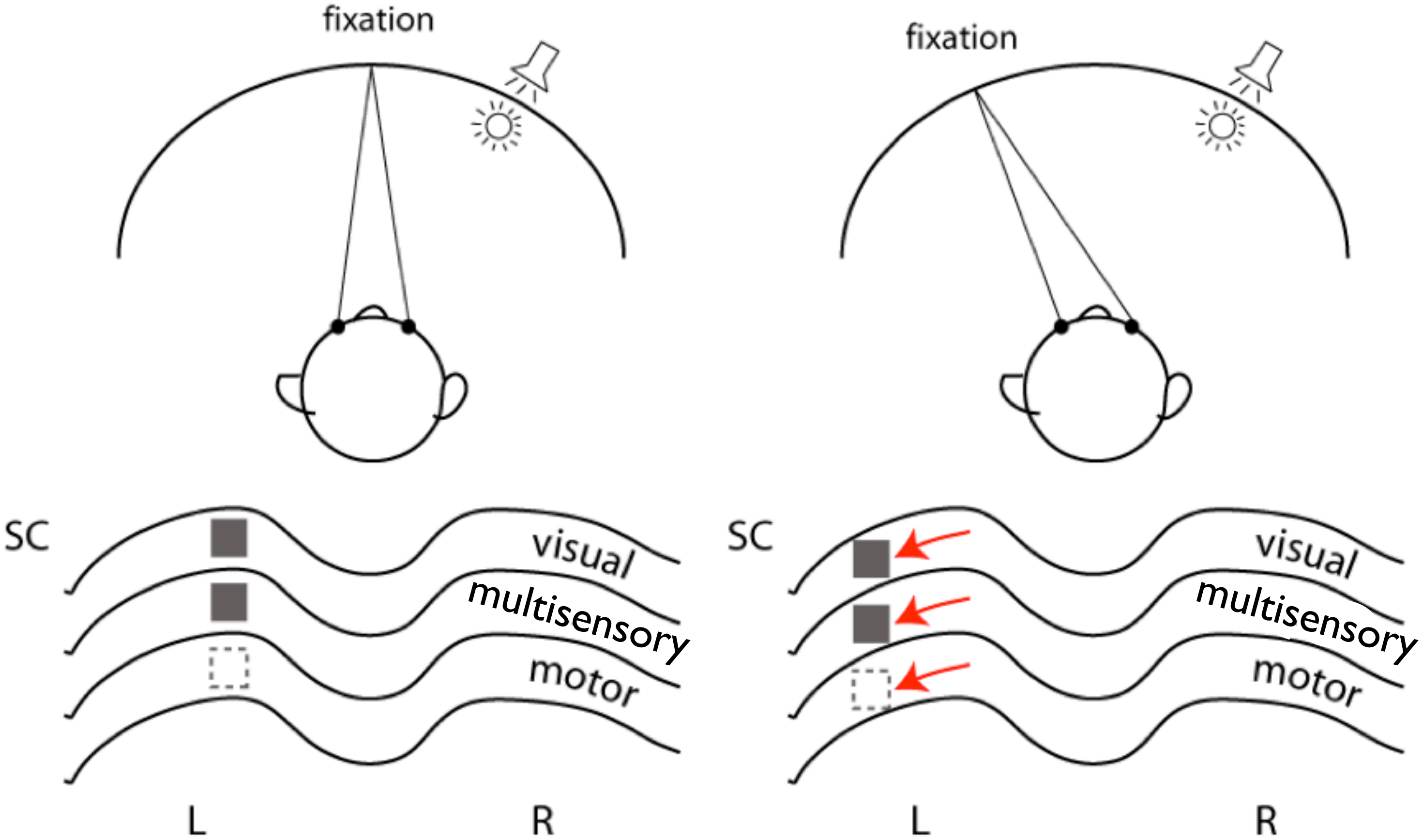
# Superior Colliculus **updates** saccade target locations even if no longer visible



# Updating in the SC

- sometimes several targets appear briefly and then disappear, even in real world.
- all saccades are planned before eye movement is executed
  - the SC ‘hallucinates’ where the 2nd target *would have gone* had it stayed on, after the 1st saccade.
  - 1st saccade is subtracted out from the planned saccade to target 2, before executing a saccade to target 2
  - this is called “updating” (also present in area LIP)

# (Sensorimotor) coordinate transformations in the SC



# Coordinate transformations in the SC

- the auditory representation is **remapped** to match the visual representation of the target (speaker/light), **even though the ears/head haven't moved**.
- this is b/c the SC cares about **eye movements** - i.e. how far to move the eyes to a target.
- → remapping of auditory coordinates in visual coordinates
- (Jay and Sparks, Science 1984)

# SC coordinate transformations

- the remapping of the auditory stimulus location allows for a correct saccade from the new eye position

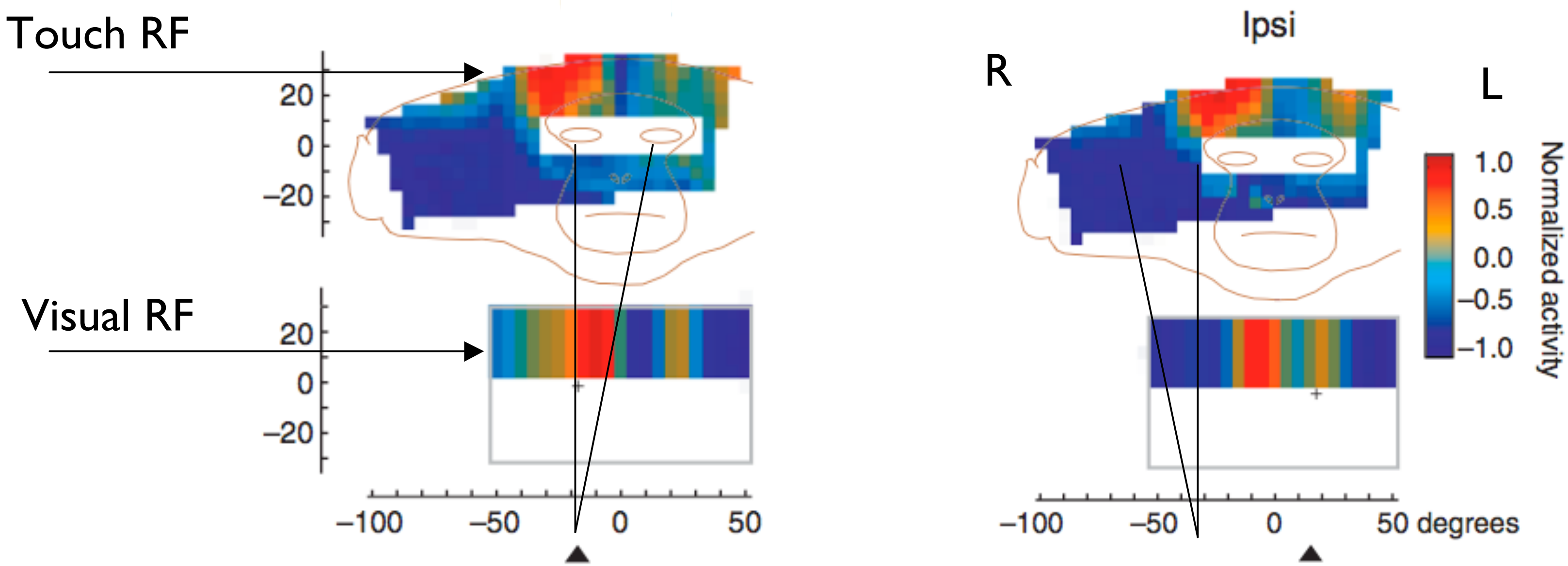
# Multimodal VIP: remaps visual to somatosensory coordinates

- VIP has neurons that have visual and auditory and visual and somatosensory receptive fields
- Multimodal RFs of a neuron are aligned in space (response preference for same location)
- Contrary to superior colliculus, RFs response can be independent of direction of eye-gaze (head centered)

Example 1

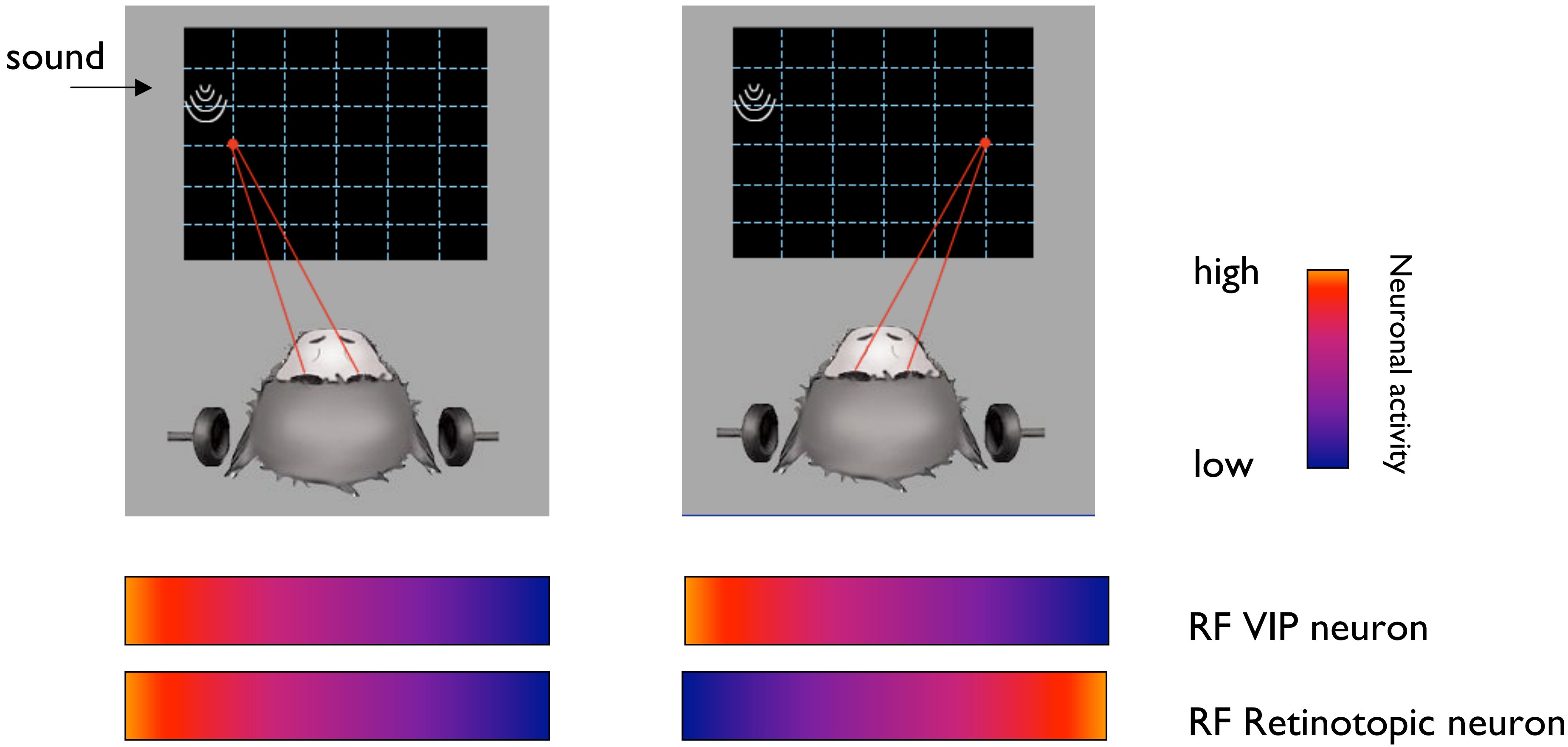
# Multimodal VIP: remaps visual to somatosensory coordinates

- Monkey moves eyes to the left, so stimulus appears further to the right with respect to eye.
- Visual receptive field stays right, in line with upper right forehead rather than shifting left with eye



Example 2

# Multimodal VIP: remaps visual to auditory coordinates



# Multimodal VIP: remaps visual to somatosensory coordinates

- Visual RF is remapped (here: stays in the same place, namely lined up with (1) somatosensory or (2) auditory RF) even though the eyes have moved

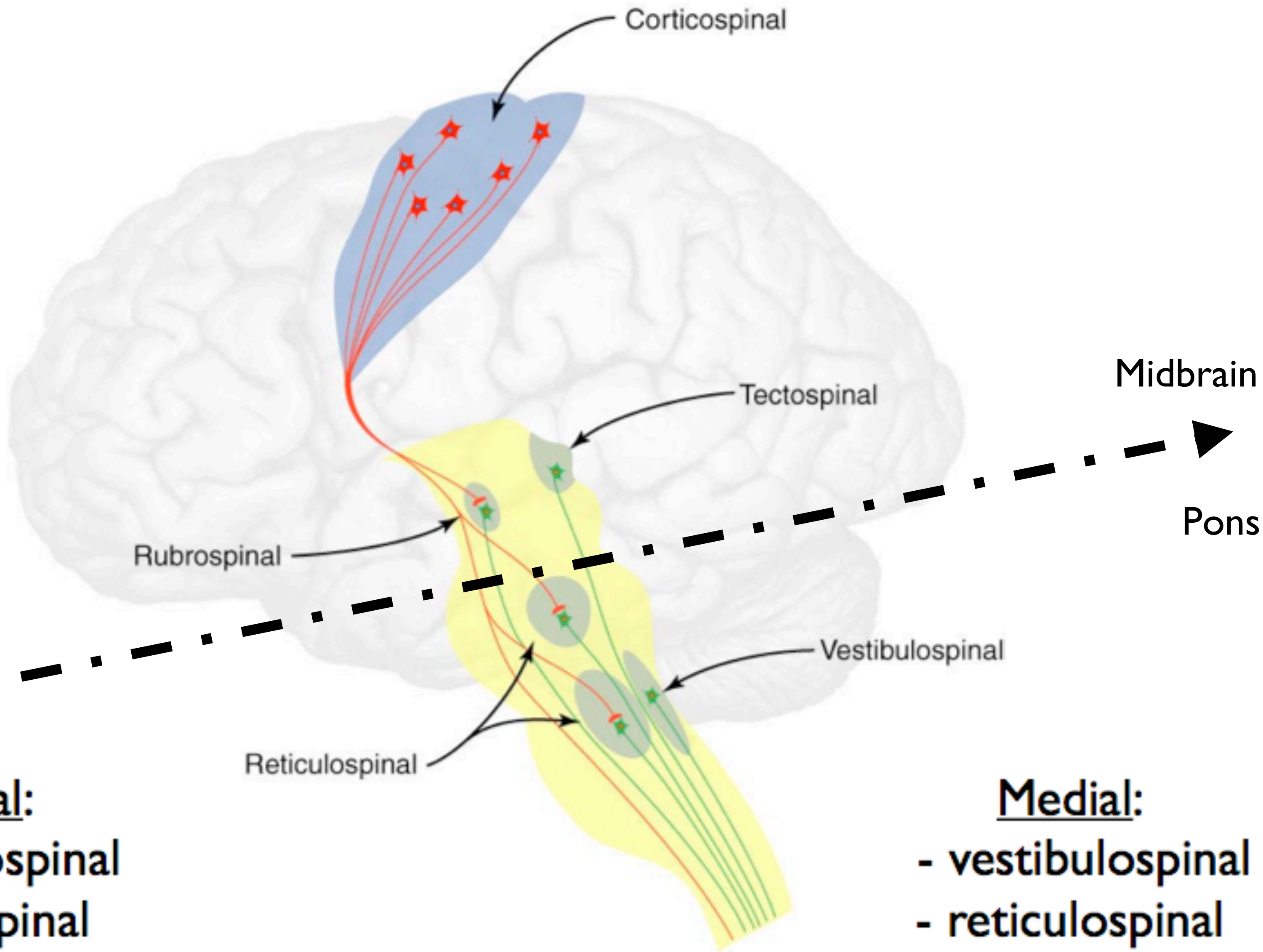
- Possibly VIP cares about protecting or guiding the head, regardless of current gaze direction

- Hence need to be able to respond to stimuli approaching the face (e.g., branch hitting face) regardless of where eyes are looking

# Conclusions

- several types of eye movements
- SC updates eye movement targets and visual representations following saccades, even if targets are no longer visible (updating)
- The SC and VIP convert sensory coordinates into the coordinates that are of interest to each -- e.g. eye coordinates for purpose of eye movements in SC; skin coordinates for purpose of head movements in VIP (coordinate transformations)

- · - · - · -   Rule of Sereno






**Lateral**:
- corticospinal
- rubrospinal

**Medial**:
- vestibulospinal
- reticulospinal

# 4 major pathways for motor control

Descending from brain to spinal cord to control muscles

1) vestibulospinal: vestibular nuclei → spinal cord

2) reticulospinal: reticular nuclei → spinal cord

3) rubrospinal: red nucleus → spinal cord

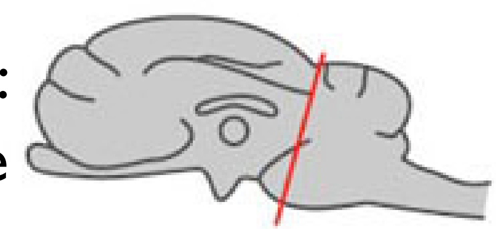
4) corticospinal: cortex → spinal cord

# Pathways from brain to spinal cord

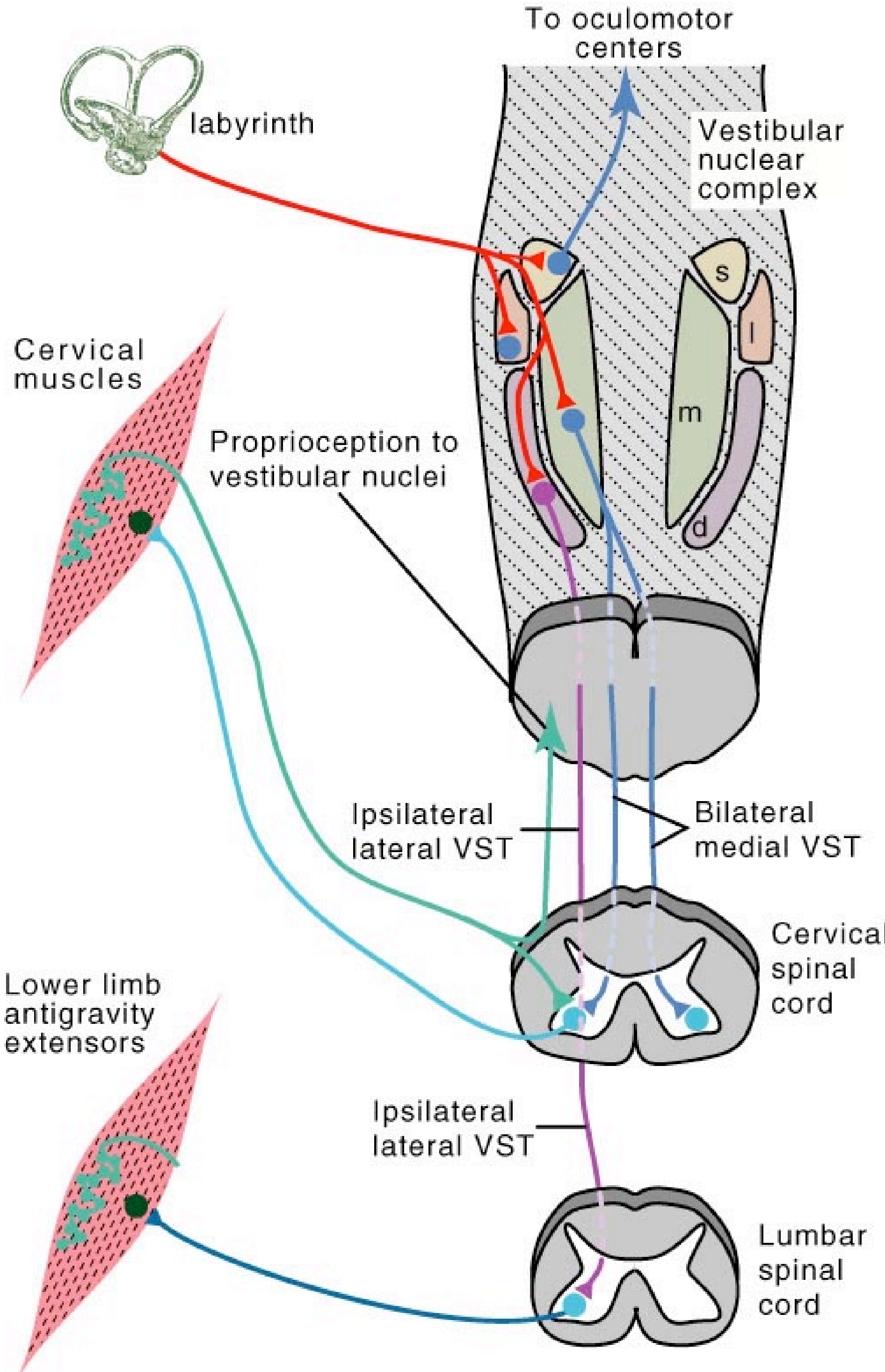
- Medial system: posture control; locomotion
- Lateral system: fine, distal limb motor control
  - e.g. lizard - has no motor cortex, hence no fine motor control of limbs

# Flexors and Extensors

- Lateral system (corticospinal + rubrospinal) controls <u>flexors</u>
- The vestibular + reticular nuclei control <u>anti-gravity extensors</u>
- → decerebrating an animal at the level of the pons: antigravity extensors: exaggerated standing posture



- decorticate cat vs. decorticate primate: in cat, all limbs extended fully; in primate, front limbs are brought in (b/c anti-gravity in primates means lifting yourself up a tree)

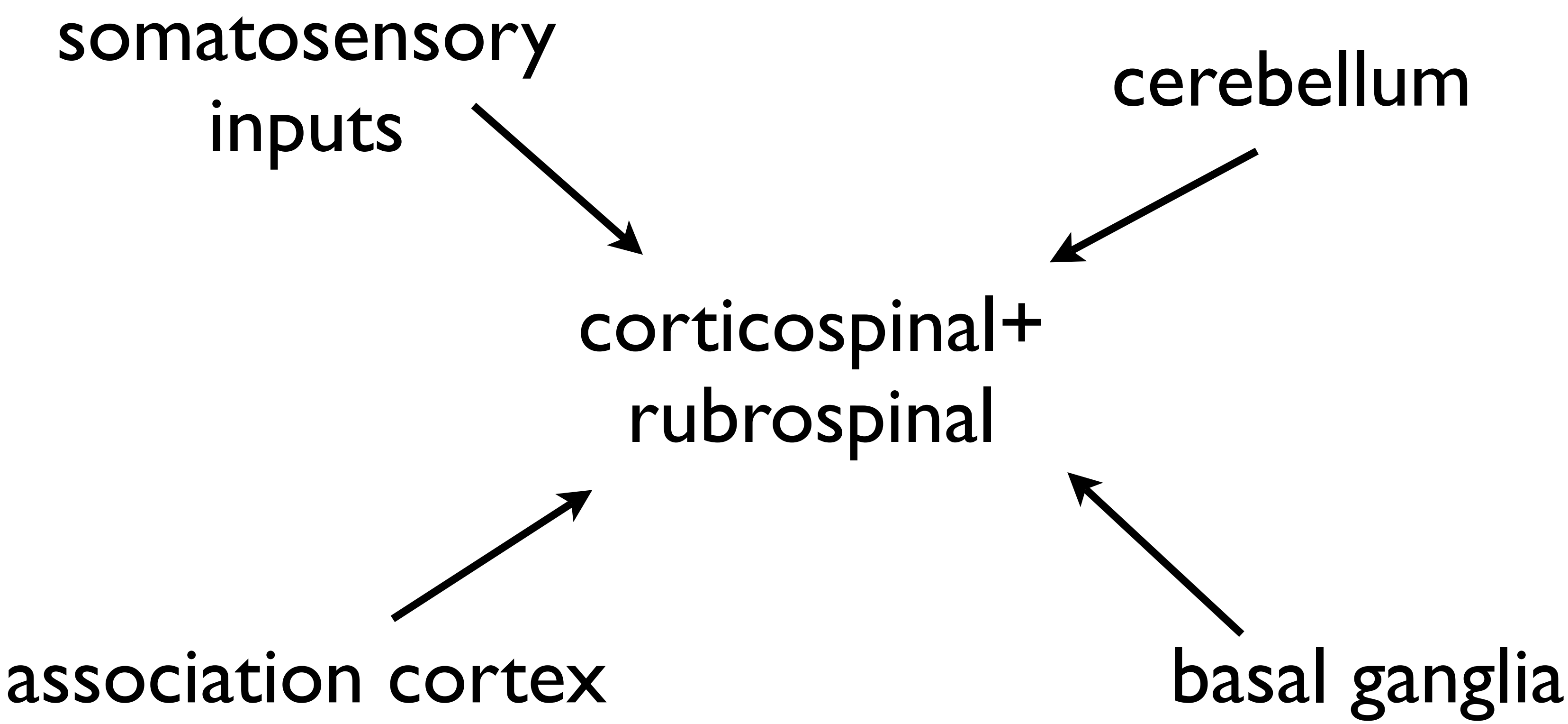





# Medial system

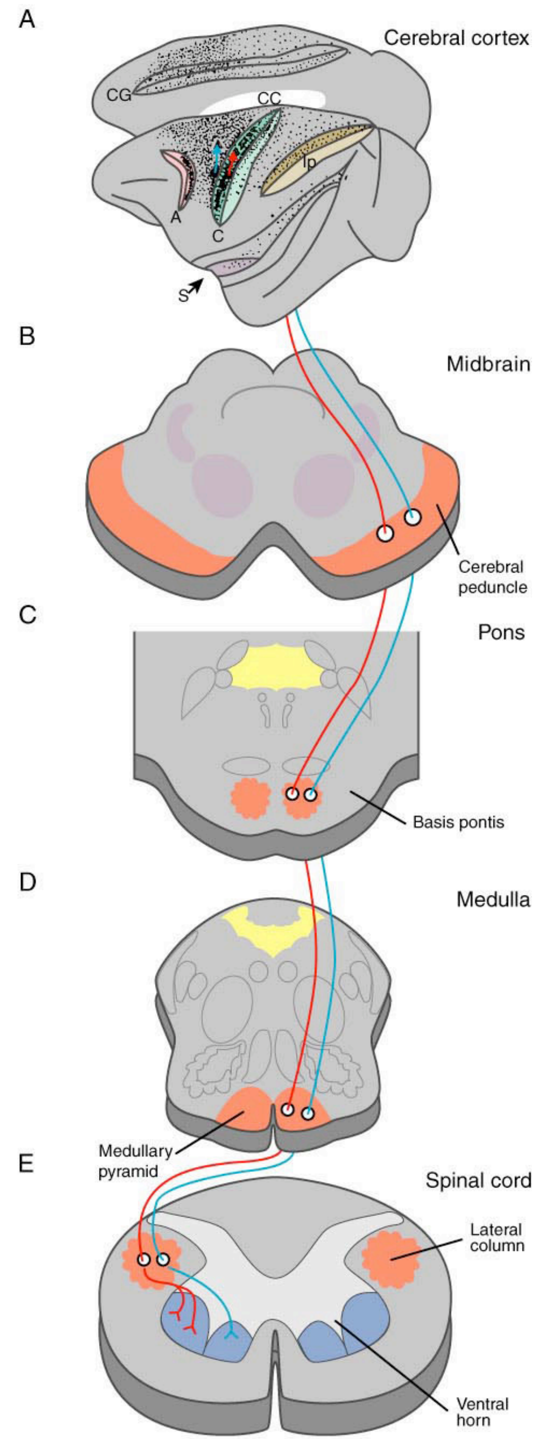
(Vestibulospinal & reticulospinal)

# 2) Lateral system

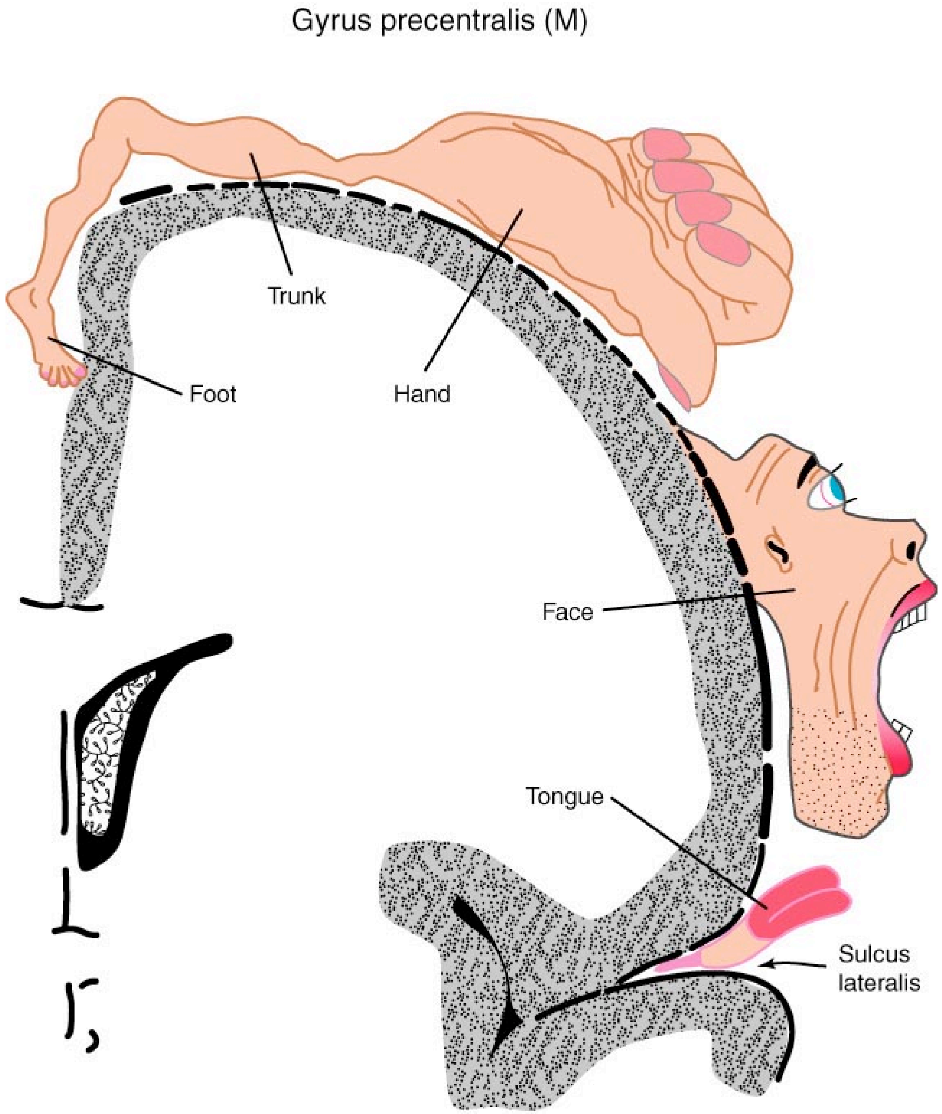


# Corticospinal projection

- projections cross to the **contralateral** side below the medulla, such that the right primary motor cortex controls the left side of the body



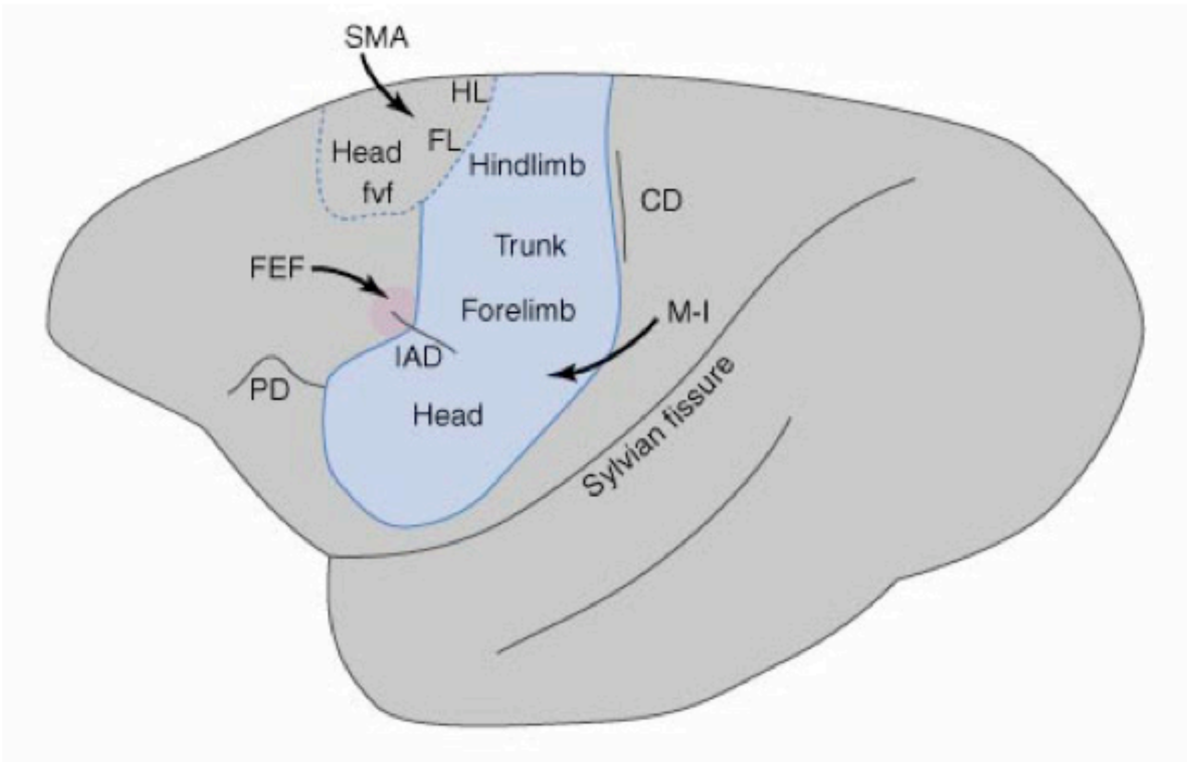
# Somatotopic representation in primary motor cortex (M1)





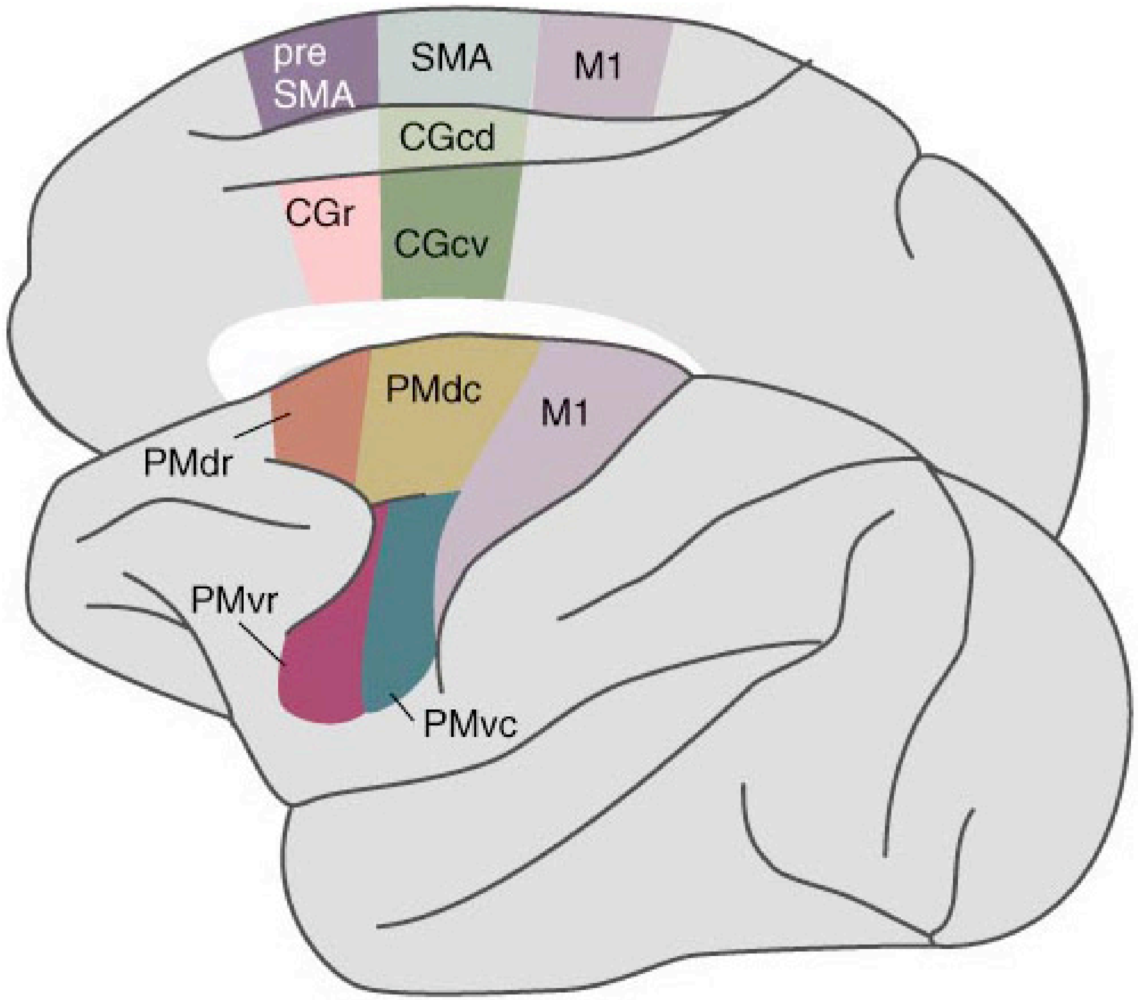

- M1, just like S1, has a somatotopic representations, but of *movement*
- areas devoted to body parts that use fine motor control (speech, manipulation of objects w/ fingers) are larger

# Somatotopic representation in primary motor cortex (M1) and premotor cortex (PM)



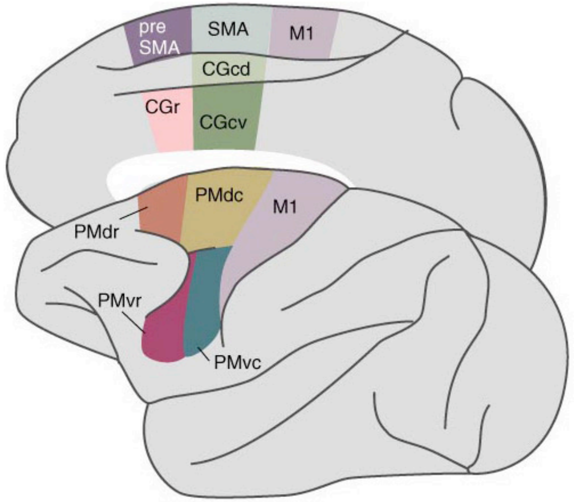

Note that M1 and S1 do **NOT** have the same somatotopic maps

# Cortical motor areas



# M1 plasticity

- similar to S1, if you denervate a body part, the cortical territory of a neighboring muscle in **M1** will expand
- repetitive use of a muscle: larger cortical motor representation
- practicing finger movement sequence: enlarged cortical representation of those muscles
- changes can happen within minutes → synaptic mechanism (LTP and LTD at existing synapses)




# What are the different motor areas doing?

- **M1** responses correlate with direction, force, position, velocity
- **SMA**, **PMd**: planning, but also execution of a movement in a particular direction; SMA = motor memory (internal cues for movement)
- some **PMv** neurons: movement force; visual target (external cue for movement)
- **parietal** areas: movement planning & online guidance?
- →distributed, overlapping motor representations

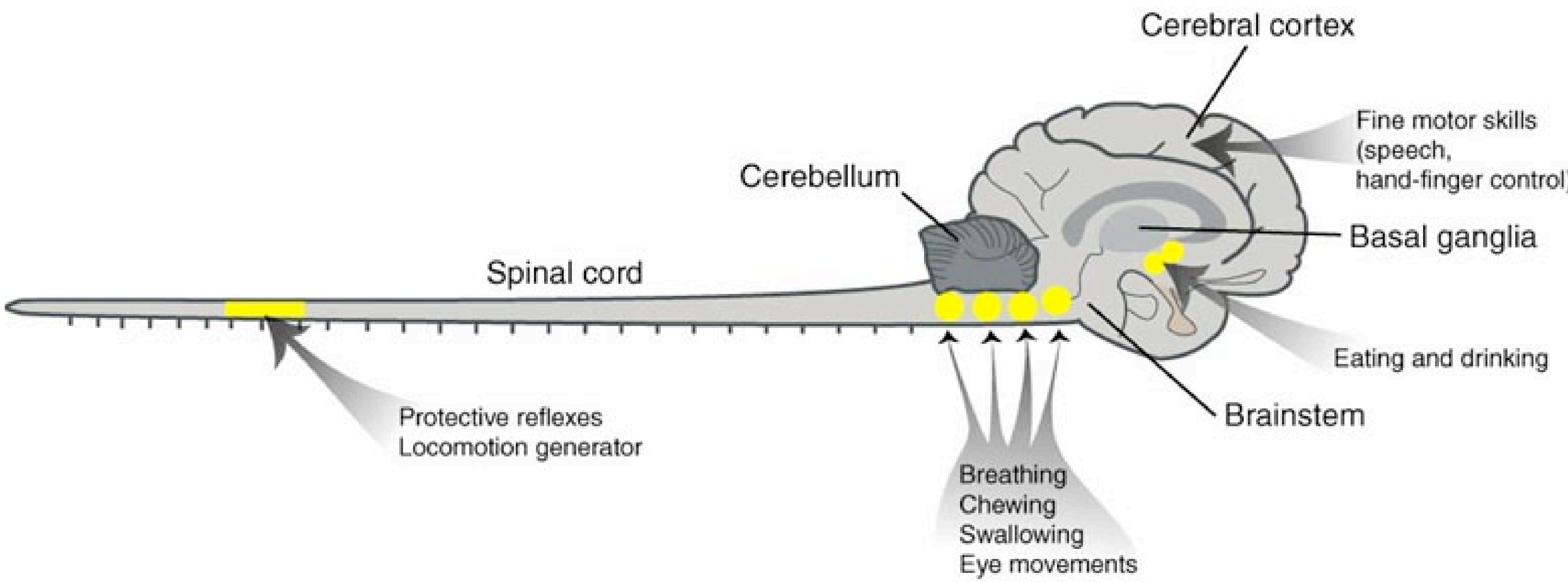
# Summary

- There are 4 main descending pathways for motor control, from the brain to the spinal cord
- they group into medial (posture; proximal control) and lateral (fine control of voluntary movement) systems
- there are several cortical motor areas with overlapping functions
- M1 has a somatotopic map of the body, although convergent and divergent corticospinal projections lead to highly distributed activation during movement
- precise movements are coded by population vectors

# Central Pattern Generators

- preformed motor programs (microcircuits)
- Interneurons which oscillate / fire rhythmically to activate motor neurons in the spinal cord, which then activate groups of muscles
- at brain stem/ spinal cord level
- in vertebrates and invertebrates
- Examples: walking, chewing, breathing, protective reflexes

# Central Pattern Generators



# Decerebrate vs. Decorticate behaviors

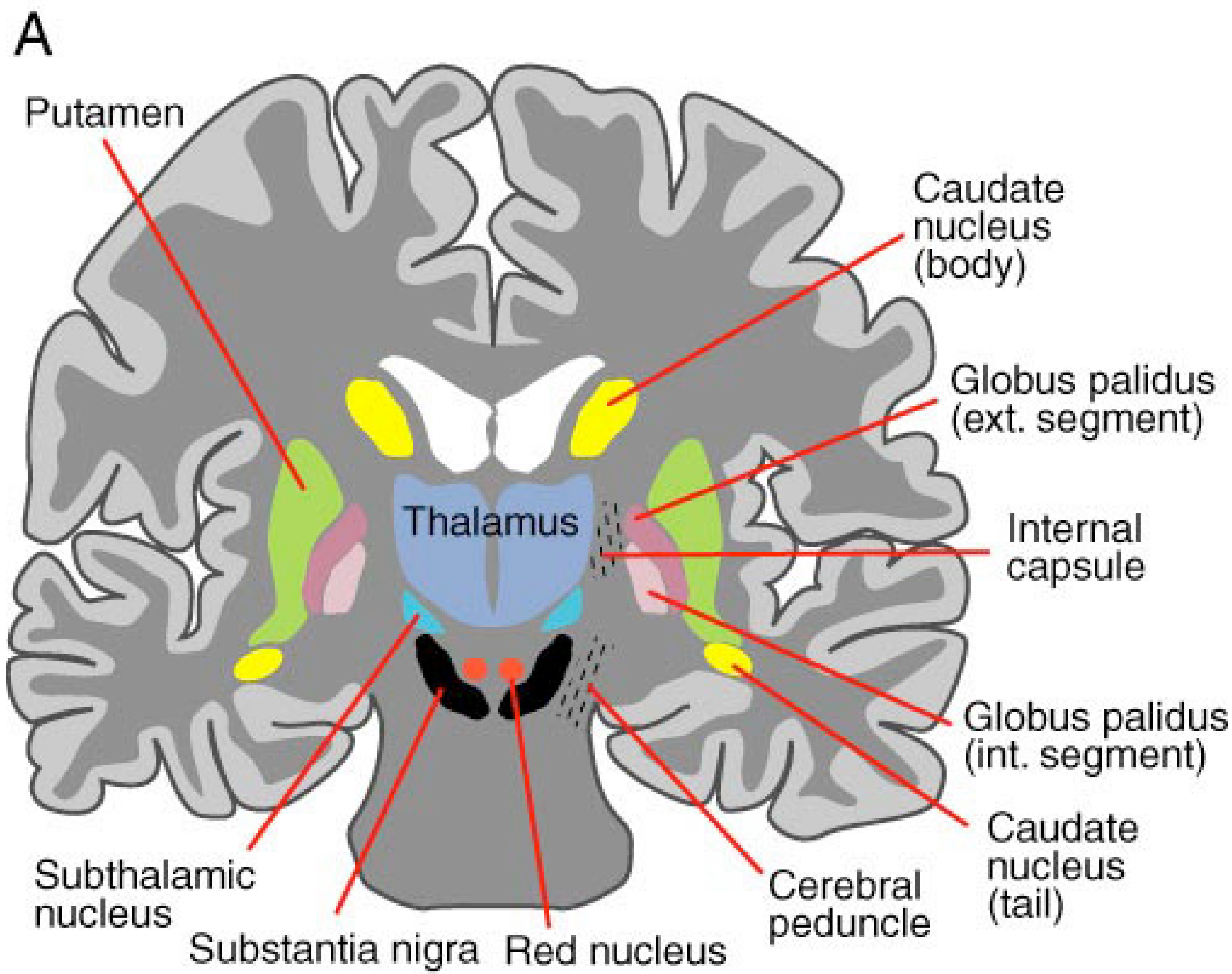
- decerebrate: if you cut forebrain off, while leaving spinal cord and brain stem intact: animals can still walk, trot, breath.

  → but: robot-like

- decorticate: removing cerebral cortex but leaving subcortical areas (diencephalon; basal ganglia and hypothalamus) intact: animals can eat, drink, search for food, move around

  → but: not interacting normally with environment

# Subcortical structures involved in motor control: basal ganglia




Squire et al., 2003

# Basal Ganglia

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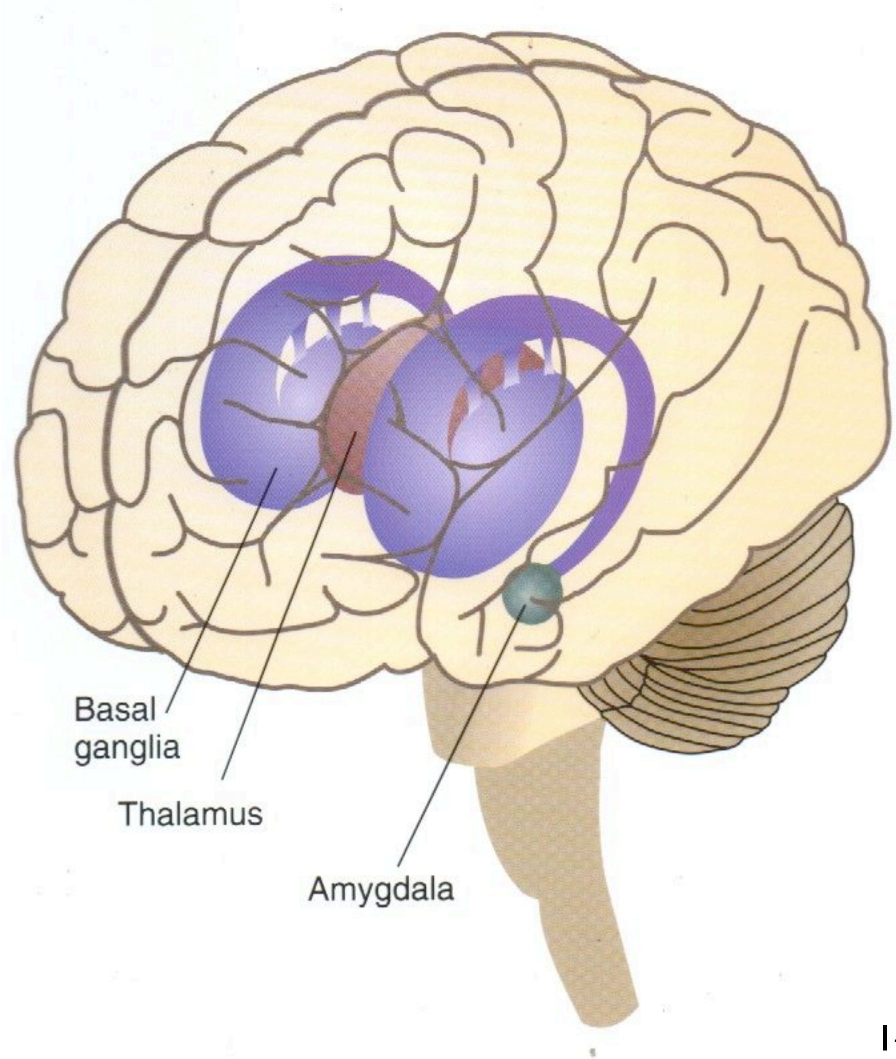
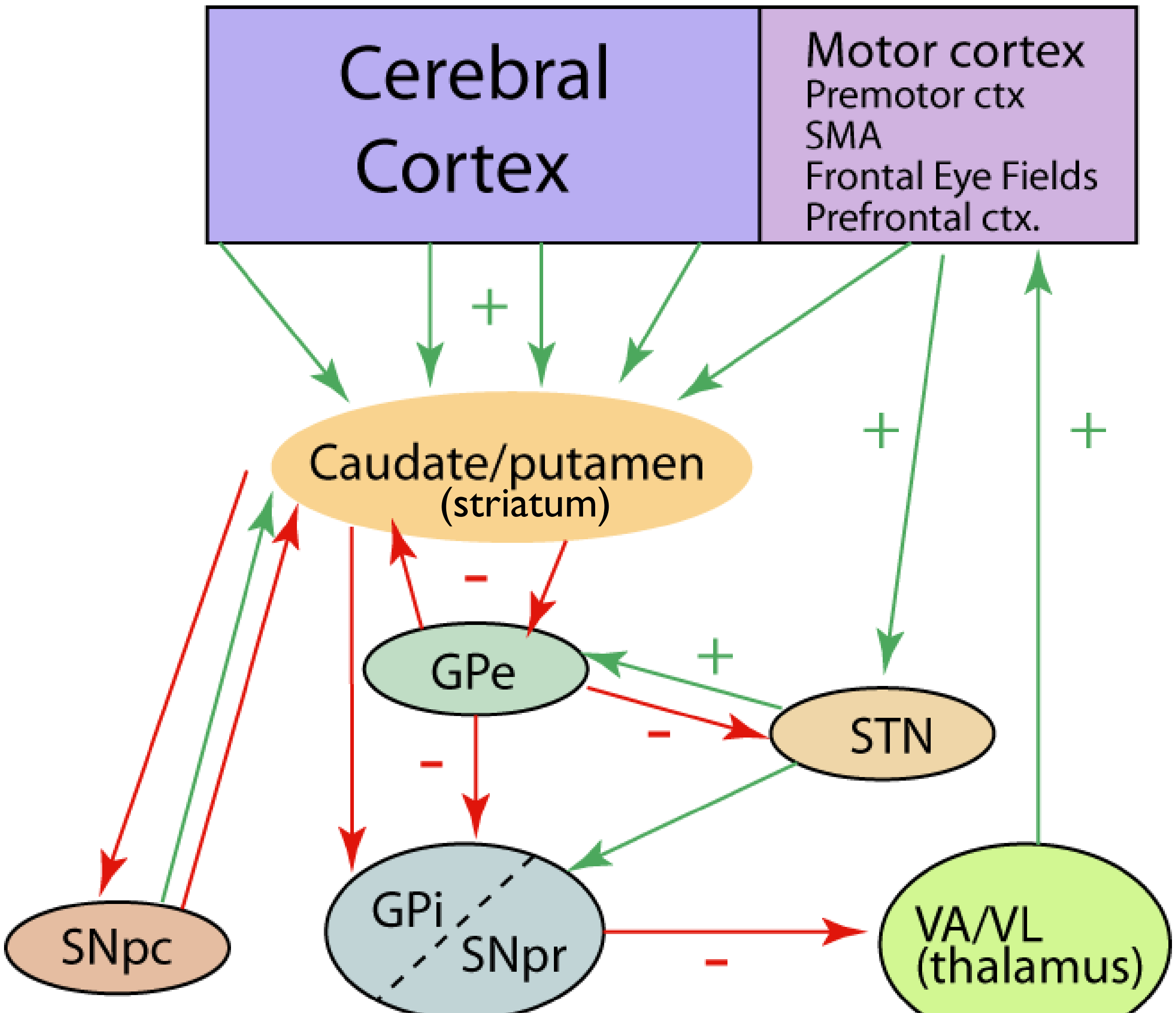
The Location of the Basal Ganglia in the Human Brain




- striatum (= caudate + putamen)
- STN = subthalamic nucleus
- GP = globus pallidus (internal or external segment -- GPi vs GPe)
- SN = substantia nigra (SNpc -- pars compacta or SNpr -- pars reticulata)

# Excitatory and Inhibitory connections




Gpe = globus pallidus, external part
GPi = globus pallidus, interna part
STN = subthalamic nucleus
SNpc = substantia nigra pars compacta (source of dopamine)
SNpr = substantia nigra pars reticulata
VA = ventro-anterior
VL = ventro-lateral

# Functions of the Basal Ganglia

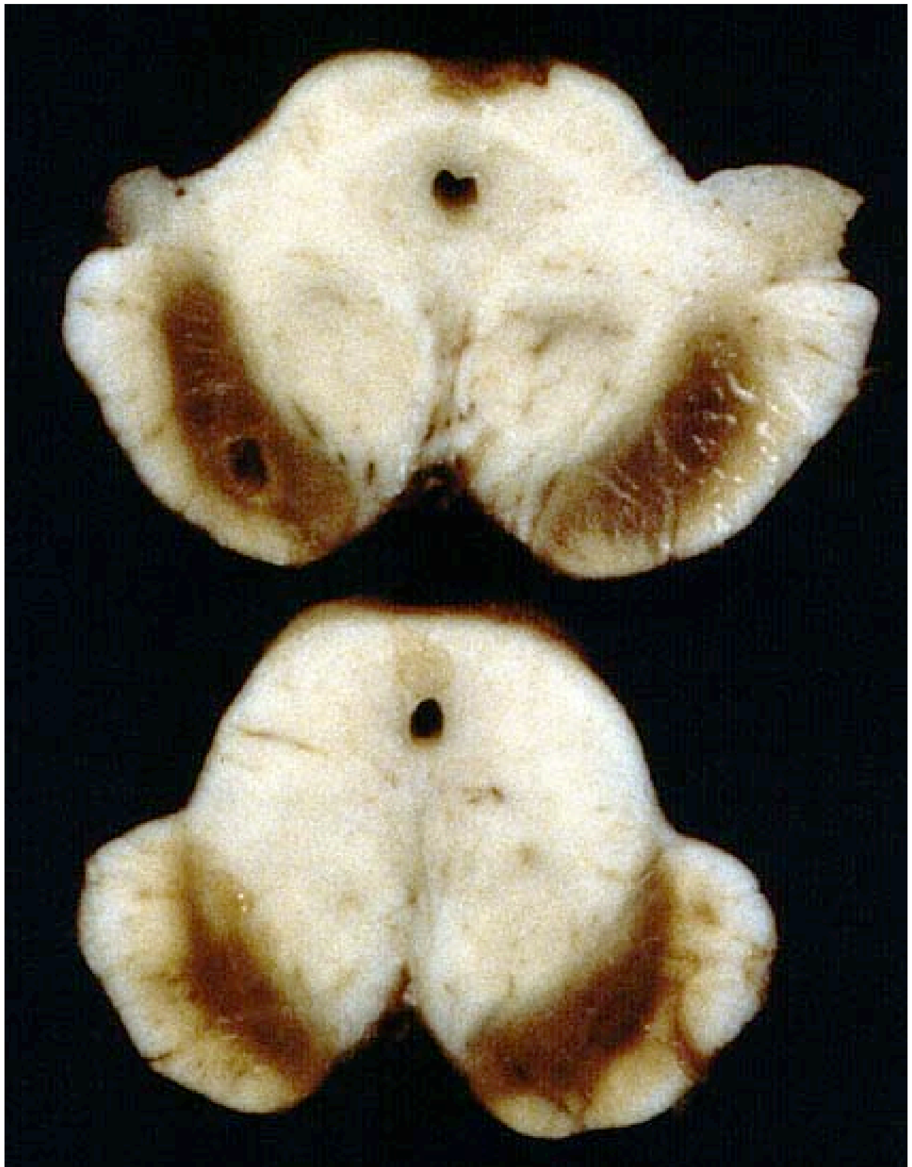
- output is inhibitory → reduce activity in targets

1) Basal ganglia do not initiate movement (-- prefrontal, premotor, motor cortex, do) - but basal ganglia may contribute to automatic execution of movement sequences

2) Basal ganglia may use two parallel pathways (inhibitory and excitatory) to excite or inhibit motor cortical targets

3) Basal ganglia may act like a "brake" (modulating inhibitory Gpi activity) to produce or prevent movement

# Parkinson's Disease



- due to progressive degeneration of dopaminergic neurons in Substantia Nigra, pars compacta

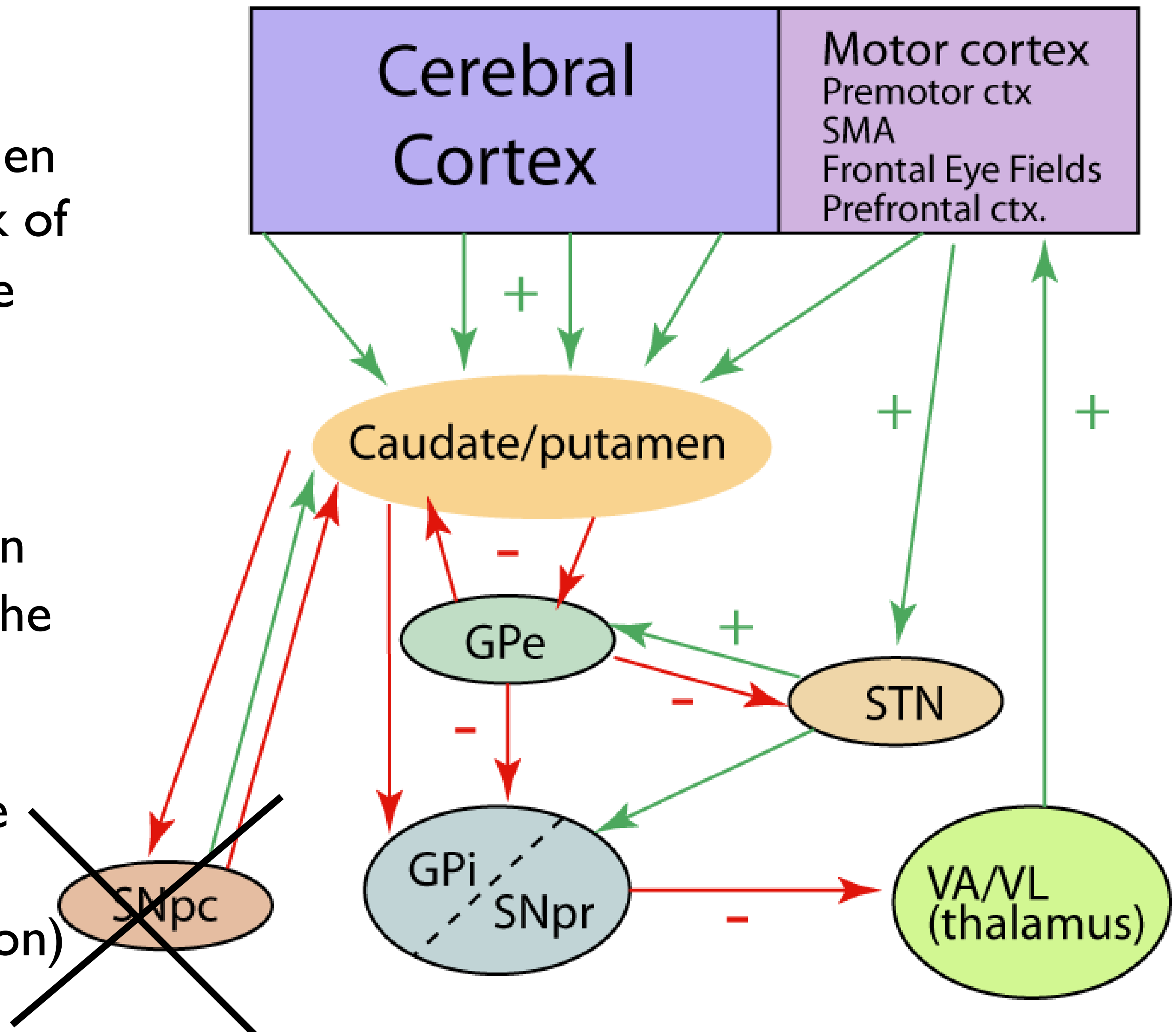
# Parkinson’s Disease

- damage to SNpc (substantia nigra, pars compacta)
- tremor at rest (decreases during movement)
- slowness of movements (bradykinesia)
- akinesia (lack of movement); hypokinesia
- muscular rigidity
- unstable posture

- example Parkinson’s patient

# Parkinson's Disease

- lack of dopaminergic excitation of Caudate/Putamen
→ leads to lack of inhibition of the Globus Pallidus (increased GPi activity)
→ which is then free to inhibit the thalamus
→ which then does not excite motor cortex (excess inhibition)

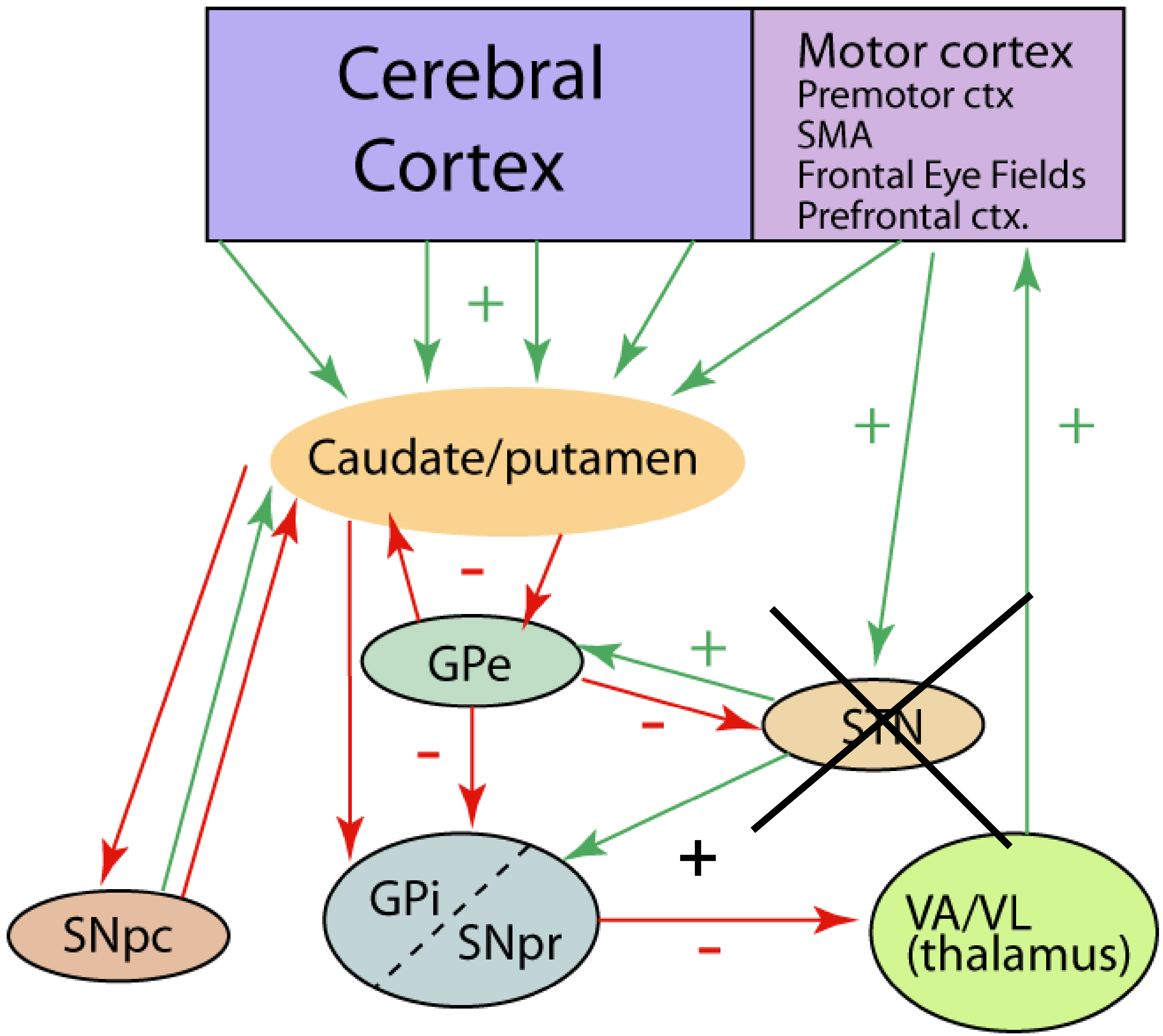


- Reason for tremor not well understood - perhaps abnormal bursting of thalamic neurons

# Hemiballismus

- damage to STN (subthalamic nucleus)
- large, involuntary, flinging movements of the contralateral arm and leg
- loss of excitatory input to GPi → decreased Gpi activity → disinhibition of motor cortex and brain stem motor networks

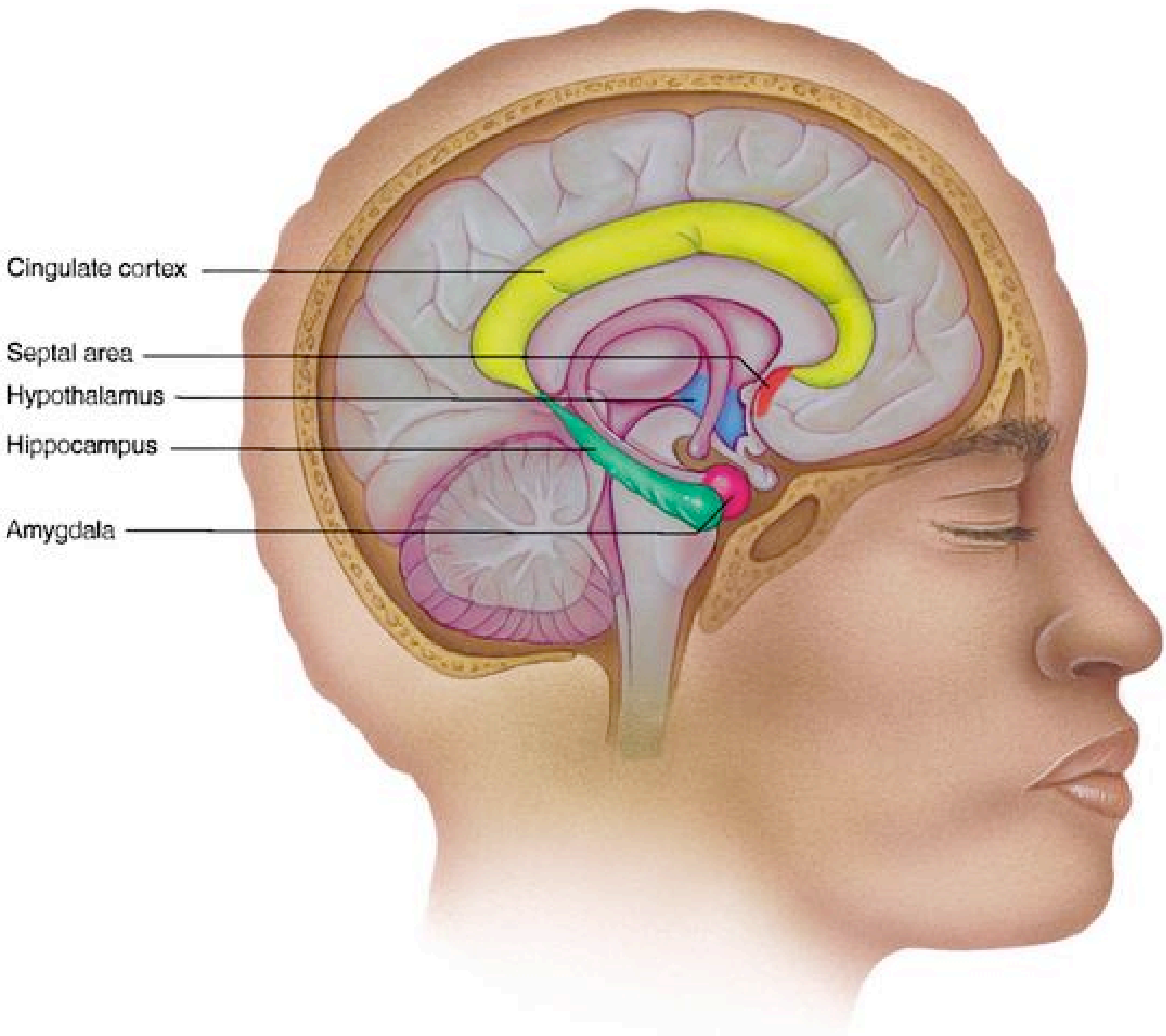
# Hemiballismus



# Summary

- brain stem and spinal cord interneurons (central pattern generators) control certain kinds of movements (rhythmic, reflexive, saccadic)
- basal ganglia are involved in motor control: damage results in various motor deficits.

# Limbic System




- Structures included in the Limbic System:

  - hippocampus
  - amygdala
  - hypothalamus
  - cingulate cortex
  - mammillary body
  - fornix
  - pituitary
  - orbitofrontal cortex

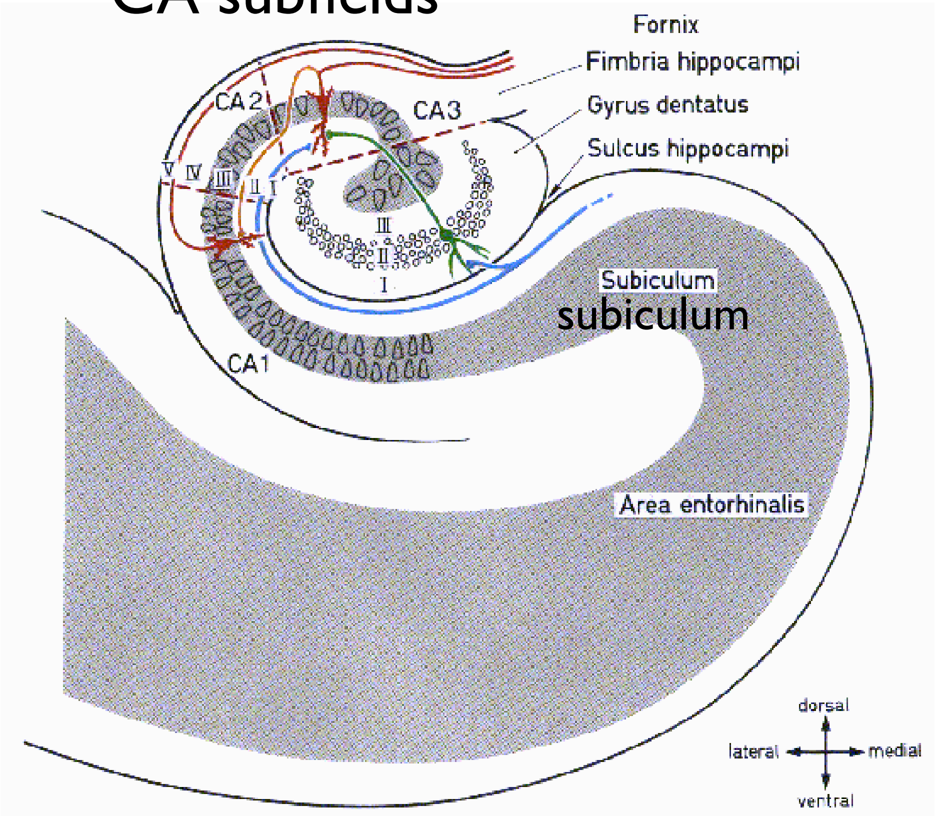
- Function:

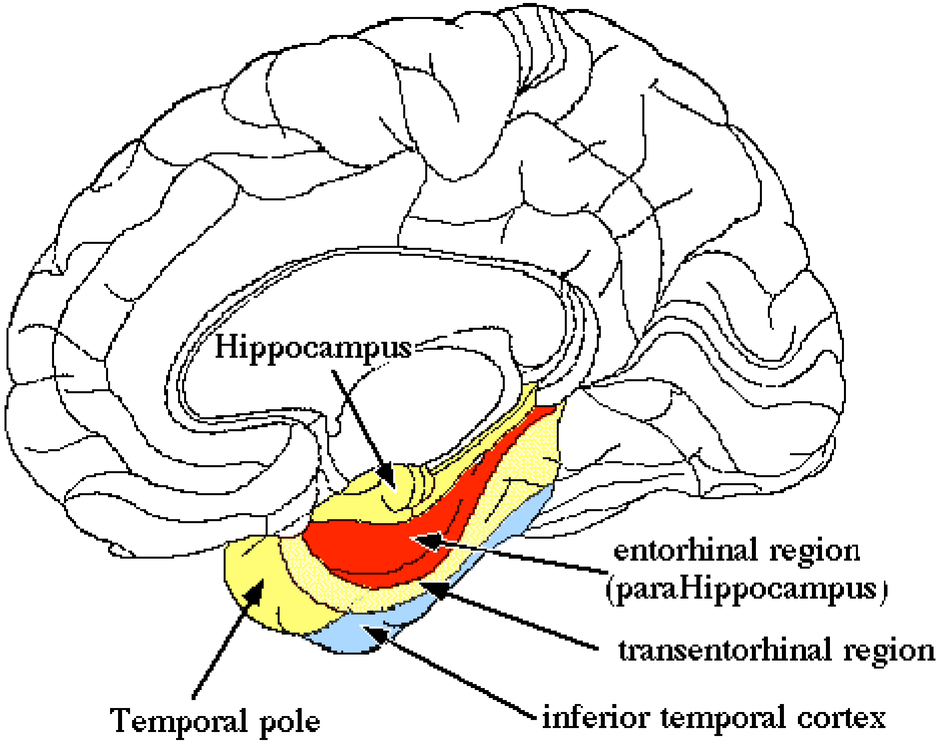
  - fear, fighting, food, sex

  - monitoring internal state of the body (e.g. hunger, but also location in environment)

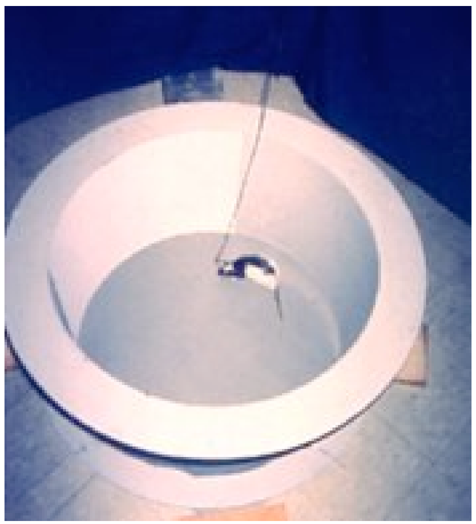
# Hippocampus

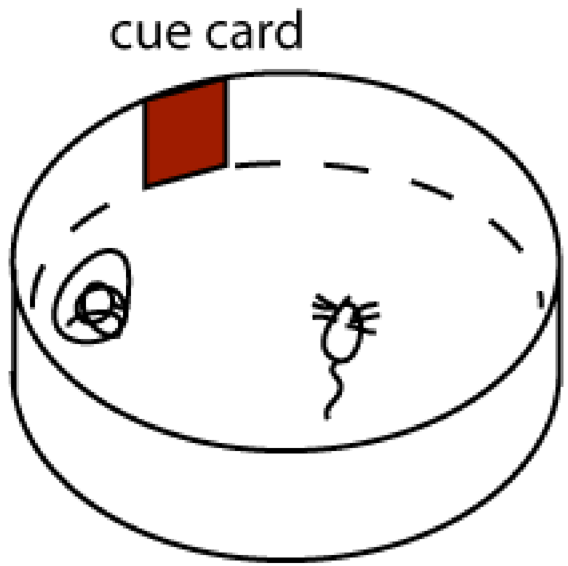
CA subfields

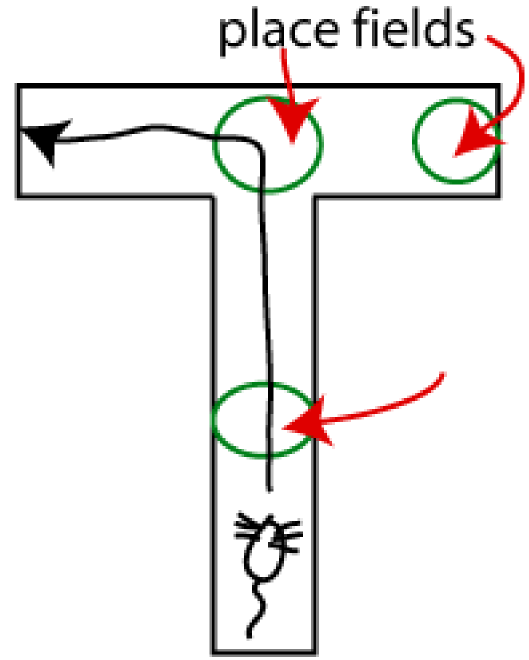


# Studying place cells in rat hippocampus



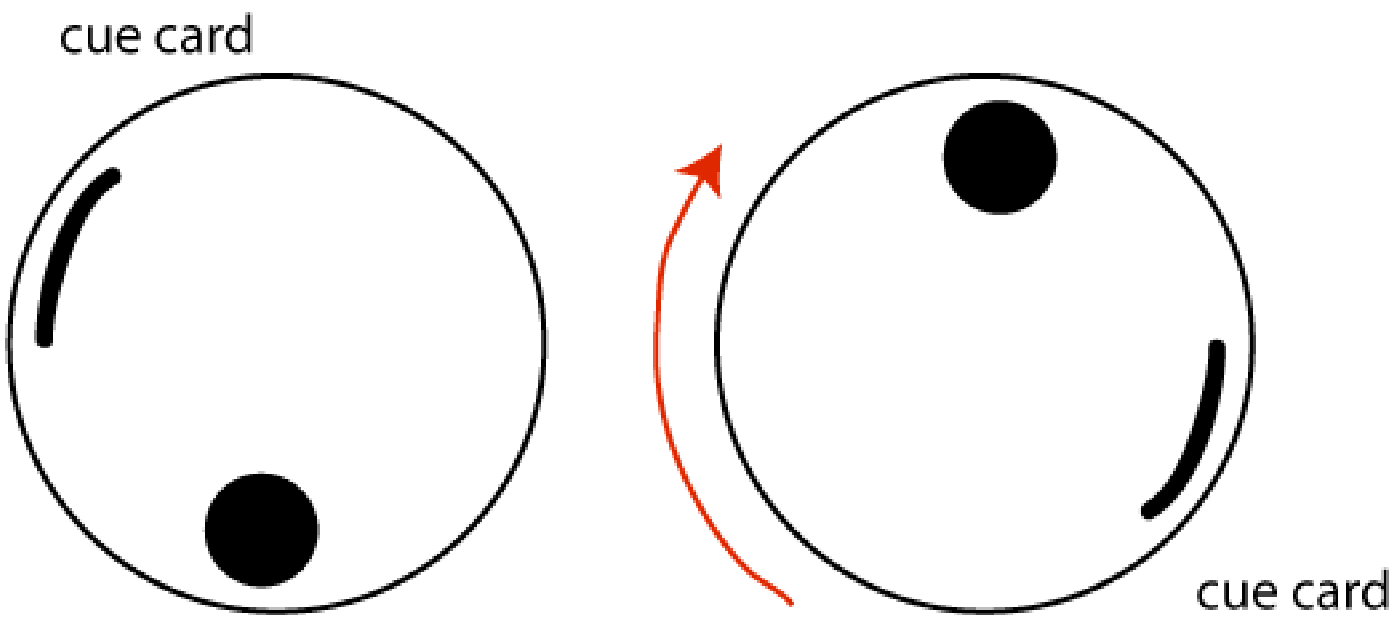



- A place cell is a hippocampal cell, located in the CA fields, which fires when the animal is in a particular location in the environment

- the spot where that cell fires is called a **place field**

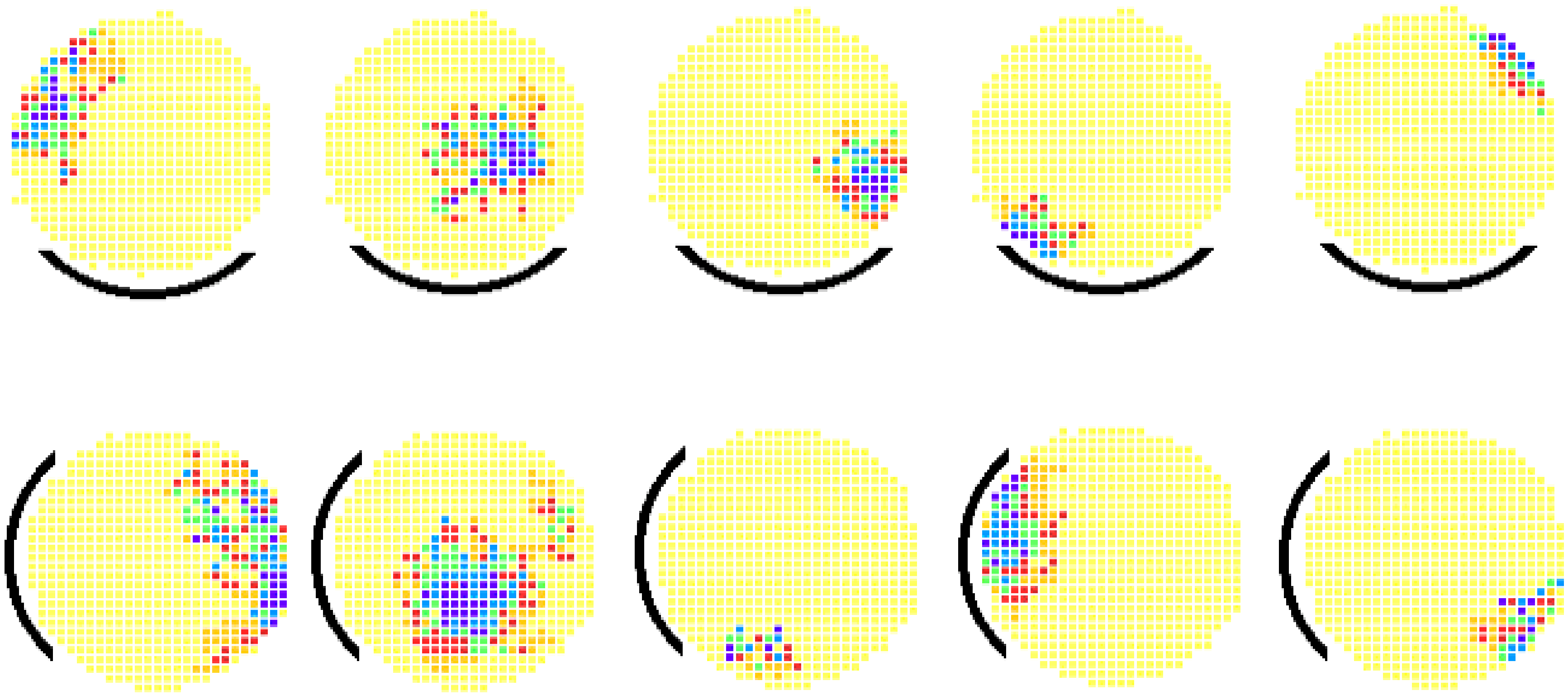
# Place fields rotate when visual cue card is rotated




- take rat out of cylinder, move cue card without rat seeing; place field rotates with new cue card position

# Place fields rotate when visual cue card is rotated

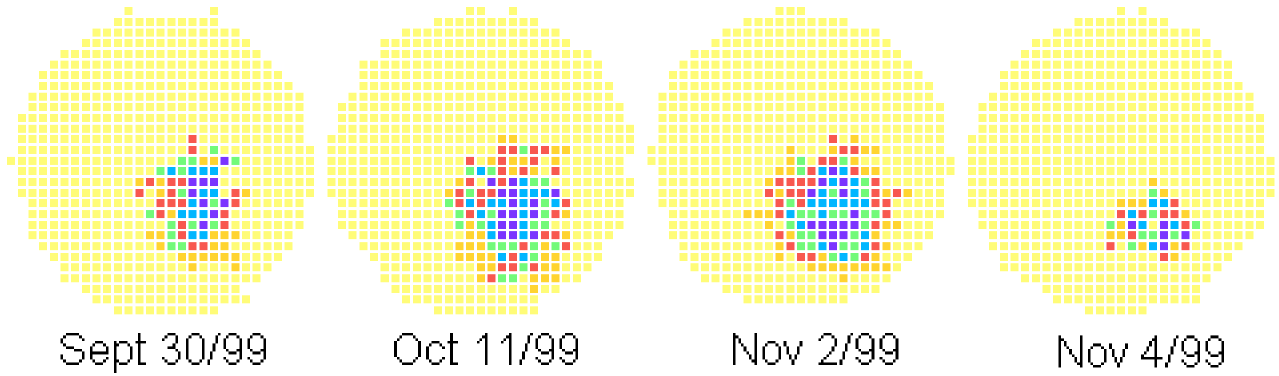
different place cells' place fields



rotation of those place cells' place fields with cue card rotation

http://homepages.nyu.edu/~eh597/place.htm

# Place field is stable



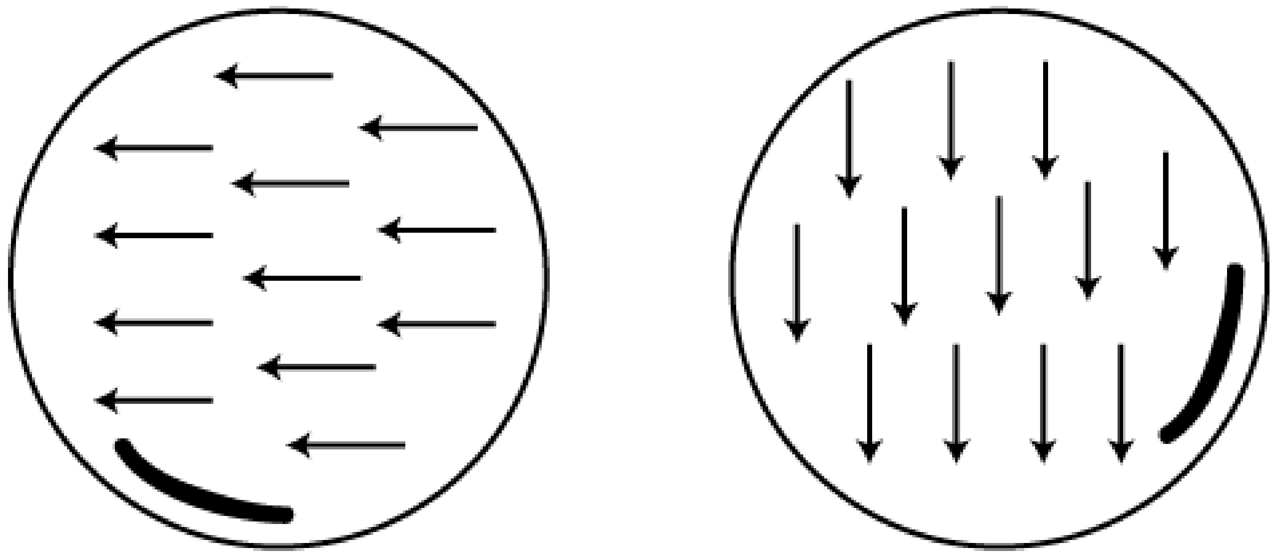

http://homepages.nyu.edu/~eh597/place.htm

# Experiments

- If you bundle up rat so it can't move and move it around passively: place cells don't fire (similar to being in passenger seat)
- if you slowly move cue card while rat is watching: place field does not rotate, remains anchored to lab/environment.
- Turn off lights: place fields remain -- path integration, proprioceptive cues in addition to vision
- shake cylinder, confuse rat: place fields reset.
- **Distal** cues (window, objects in room) override local cues (pee).
- cells not topographically arranged

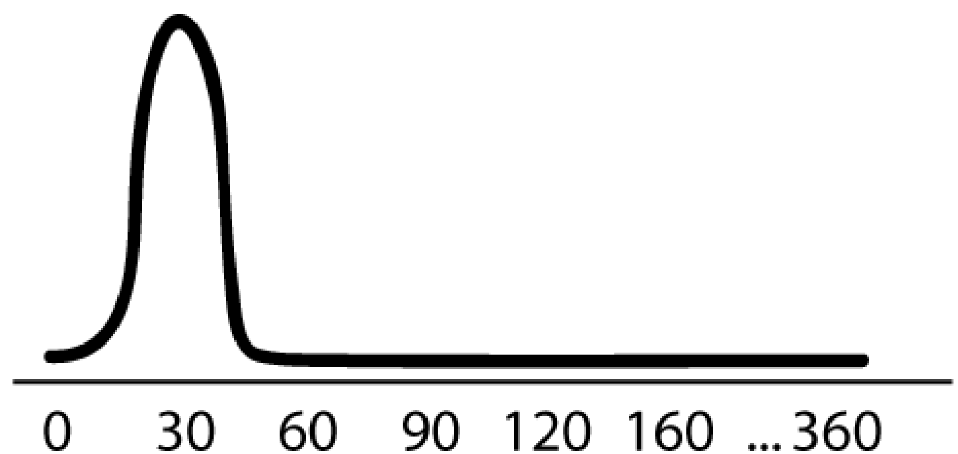
# Head direction cells

- in postsubiculum,  anterior dorsal thalamus, lateral dorsal thalamus, posterior parietal, retrosplenial cortices



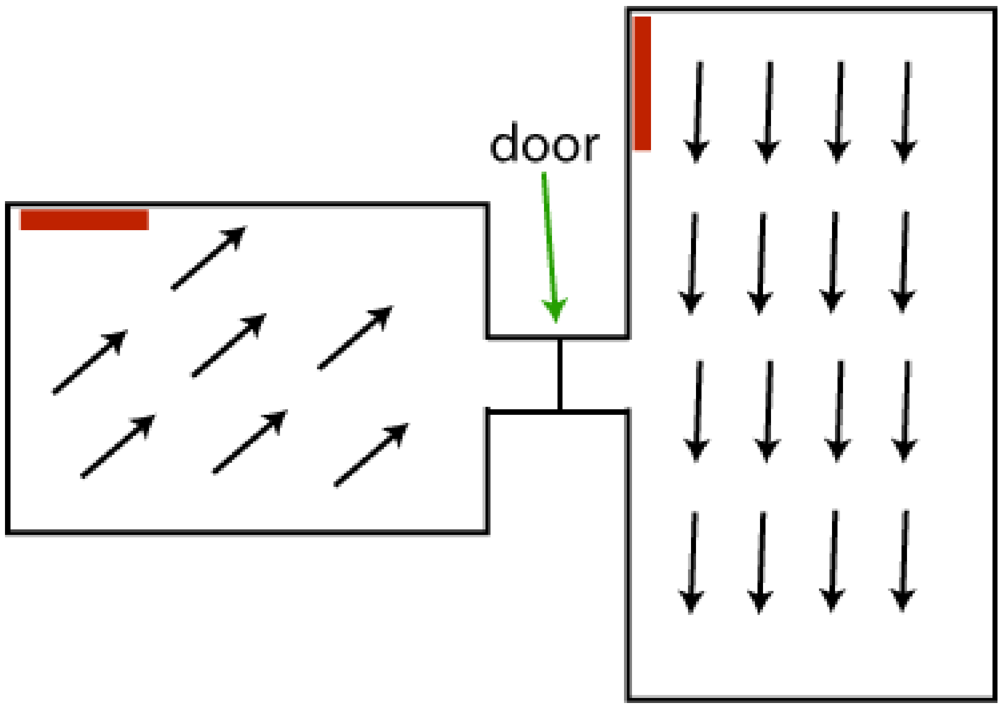
- take rat out of cylinder, move cue card without rat seeing; then put rat back in: head direction resets

# Head direction cells are sharply directionally tuned



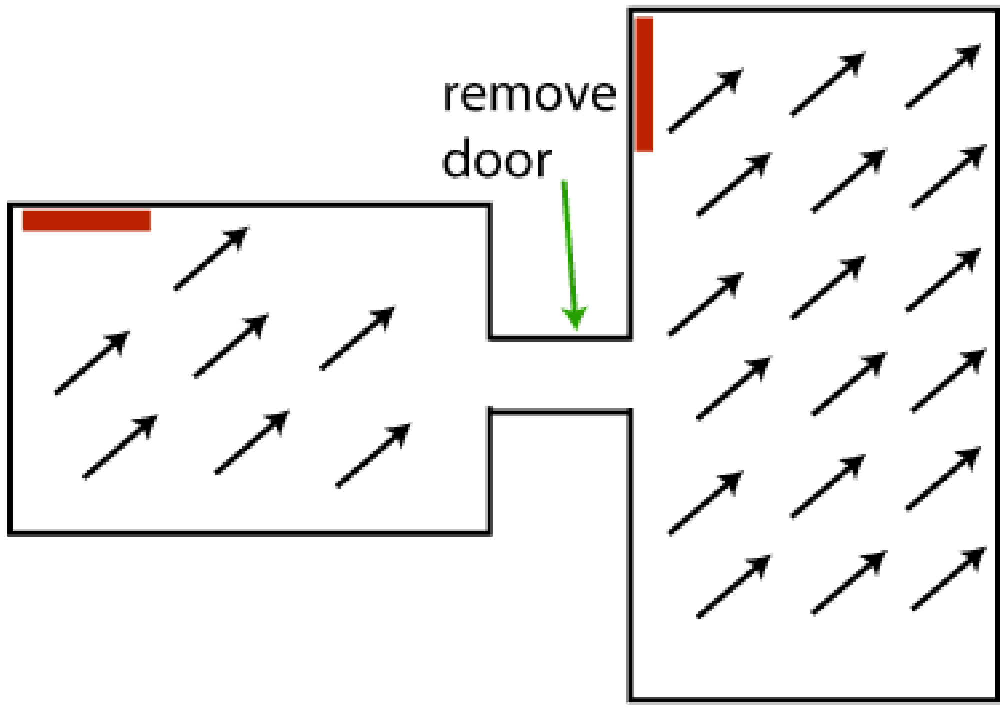

- head direction cell only fires when head is oriented in a particular angle relative to the environment -- not relative to the body
- like a "compass"

# Resetting of head direction




- 2 containers, separated by a door - rat's preferred head direction (one cell) is different in each container

# Resetting of head direction

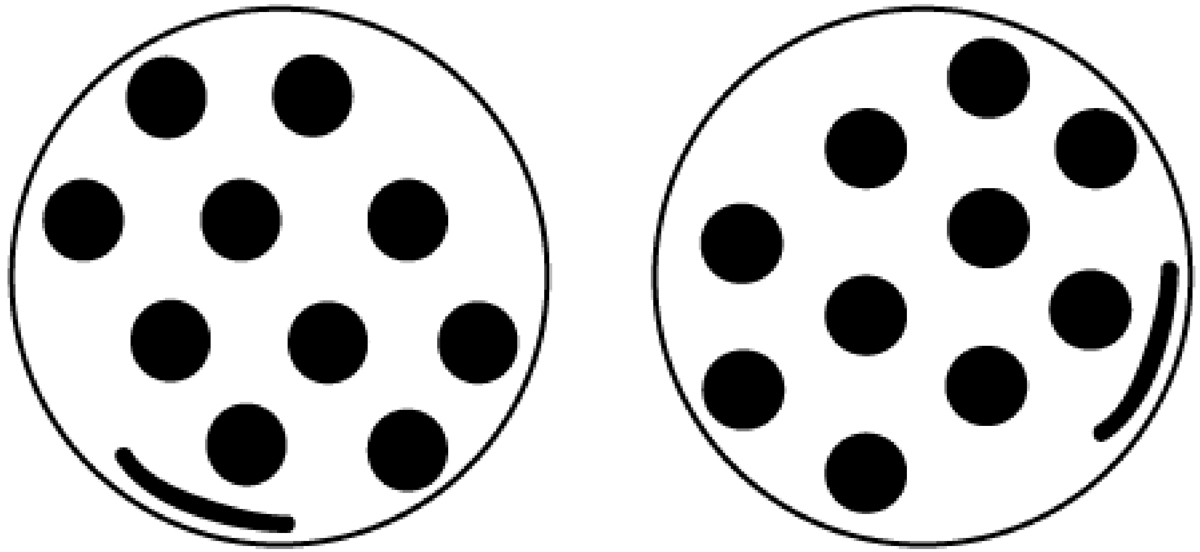



- when door is removed, rat's head direction resets to match one of the environments

# Experiments

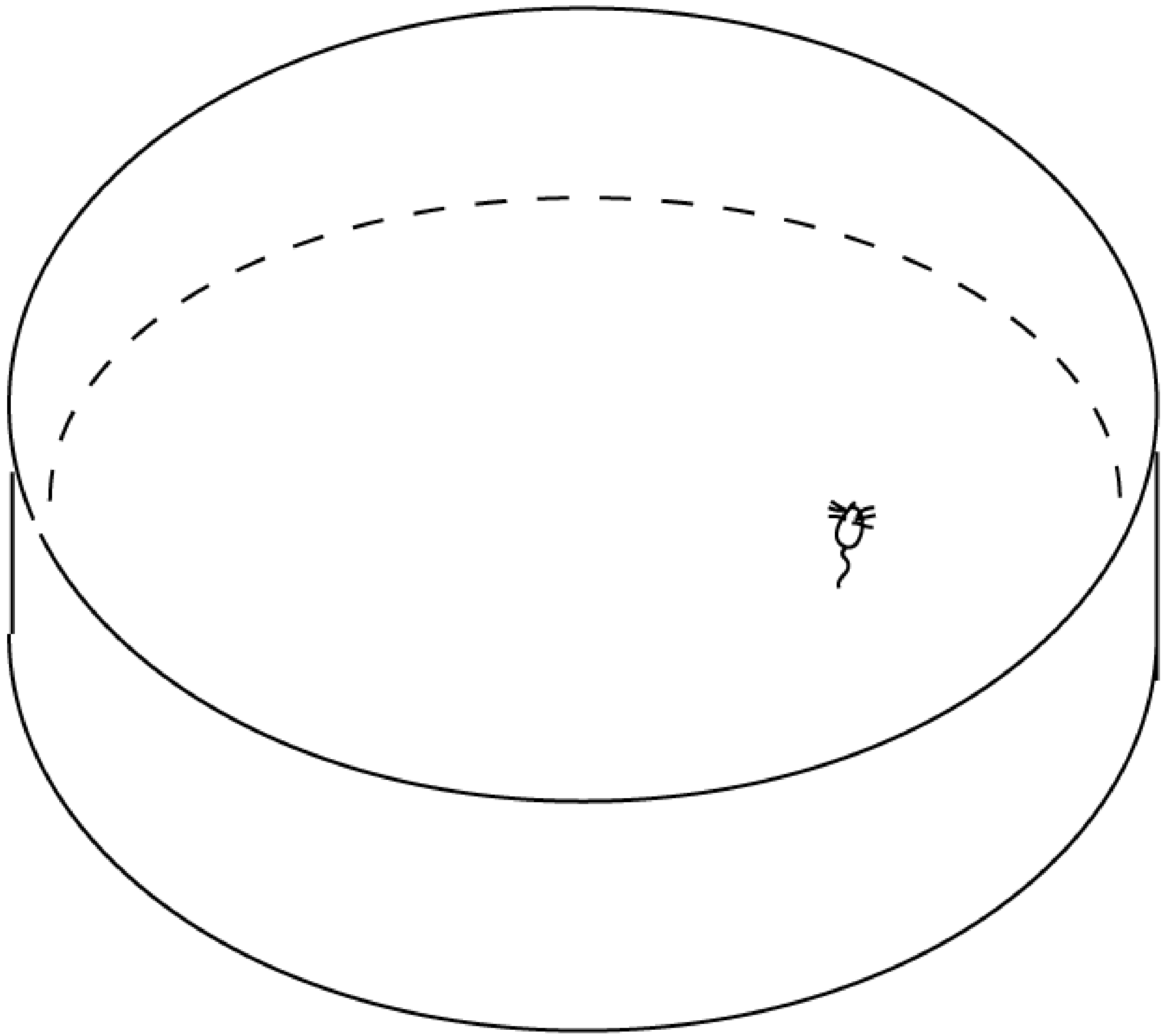
- turn off light: head direction cells still fire ( i.e. both visual and vestibular cues are used).
- like place cells, visual/distal cue dependent for initial setting
- head direction is relative to environment, not to neck angle
- direction in horizontal plane, not vertical
- cells not topographically arranged

# Grid cells



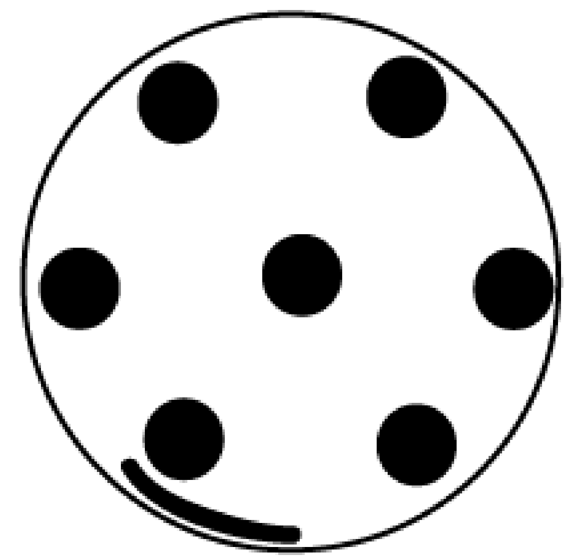
- in dorsocaudal medial **entorhinal** cortex
- cell fires at multiple location in environment: "grid-like" arrangement; equal spacing between firing fields
- grids are anchored to external cues

# Grid cells discovered when large environments were used



# More ventral cells are more spaced apart and have larger fields

- field size and spacing increase from dorsal to more ventral locations
- no systematic orientation change from dorsal to ventral locations



# Experiments

- turn off lights: grid fields remain (not just visual cues, but also path integration cues)
- topographical representation of environment across surface of medial entorhinal cortex
- grid is applied to novel environments too
- multiple entorhinal cells project to CA cells -- overlapping grid fields form individual place fields

# Summary

- Place, head direction, and grid cells contribute to spatial maps of the environment, allowing an animal to navigate though the environment.