Cognitive Computing

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Our unique brain capabilities: Motion

- Precision throwing: no other animal can do that even they have visual motion detection capabilities.
- Avoid/catch animal by looking their motion
- Facial expressions are incredibly subtle and we can detect fleeting expressions.
- Direction of motion

(Why) Do We Need to be Able to See Motion?

1. How do we use visual motion information?

2. Might this ability be important enough that our brains would allocate special machinery to seeing motion?

3. If you had to write an algorithm to take video input and figure out if an object is moving or in what direction, what would that code look like?

Some Bare Basics about the Brain

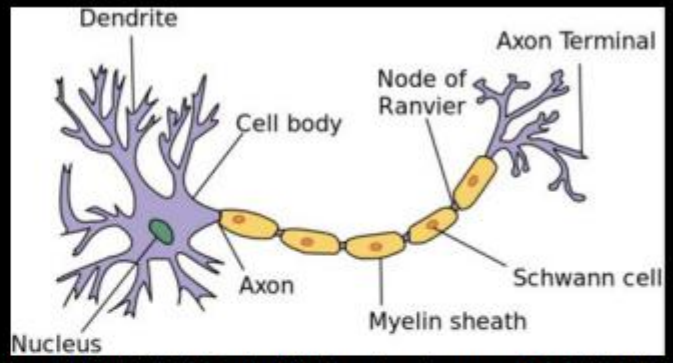
- human brain contains ~ 100 billion (10^{11}) neurons*

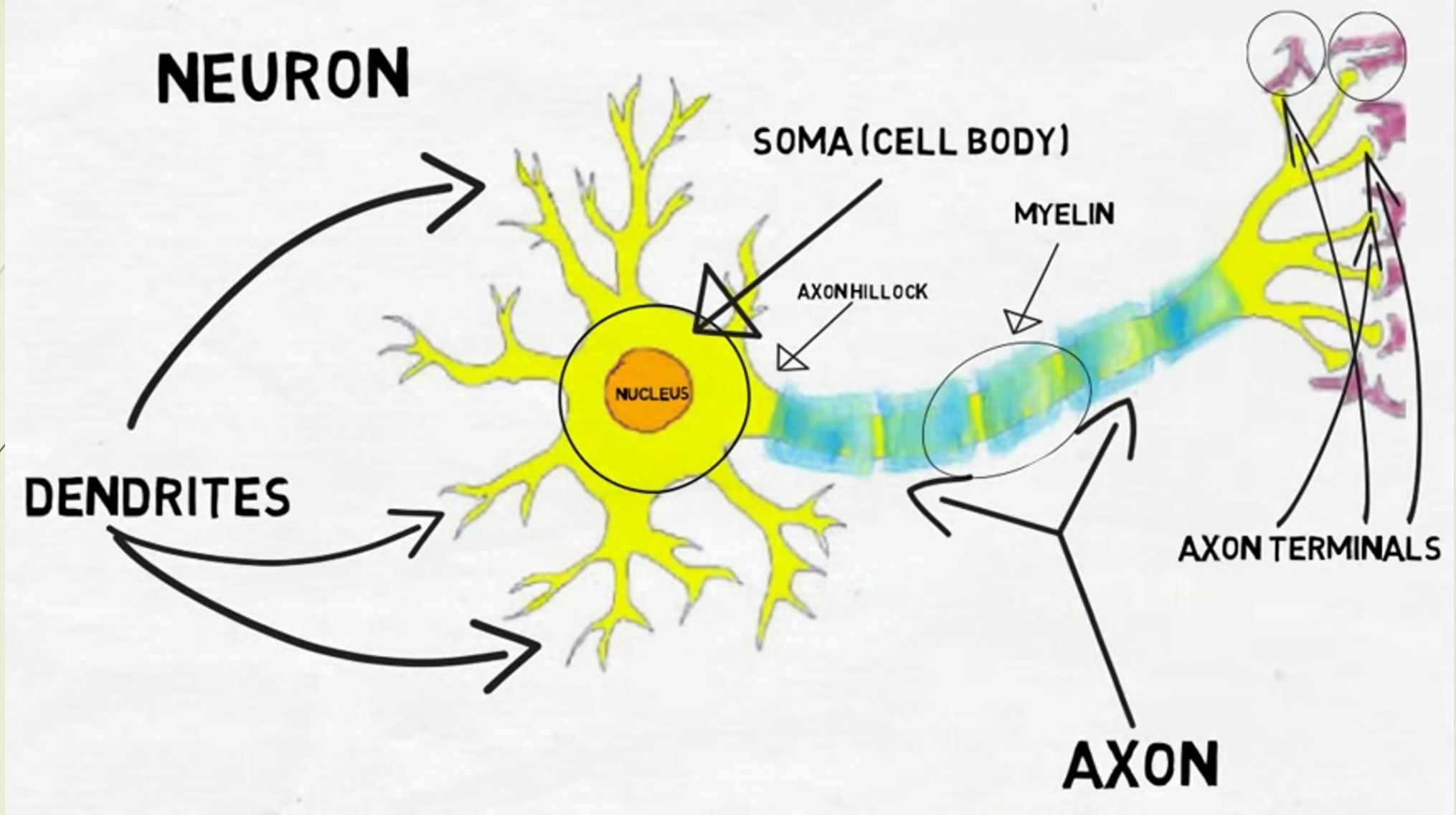
  ~~ thousand of synapses per neuron

- human brain runs on 20 watts

  vs: IBM's Watson: 20,000 watts

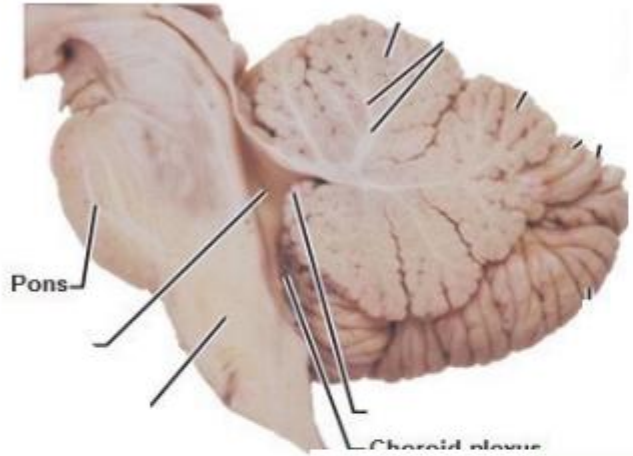
Brain is incredibly energetically efficiently



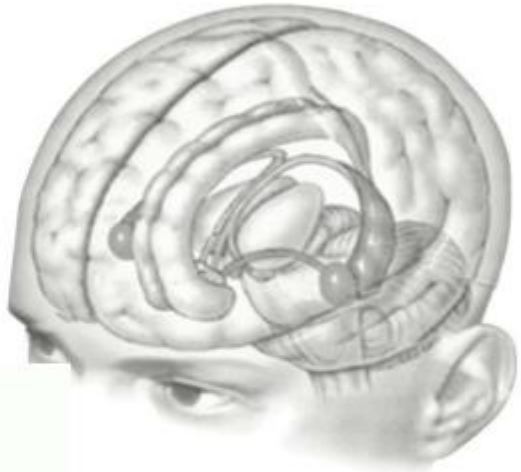

NEURON
SOMA (CELL BODY)
MYELIN
AXON HILLOCK
NUCLEUS
DENDRITES
AXON TERMINALS
AXON

Four Major Components of the Brain

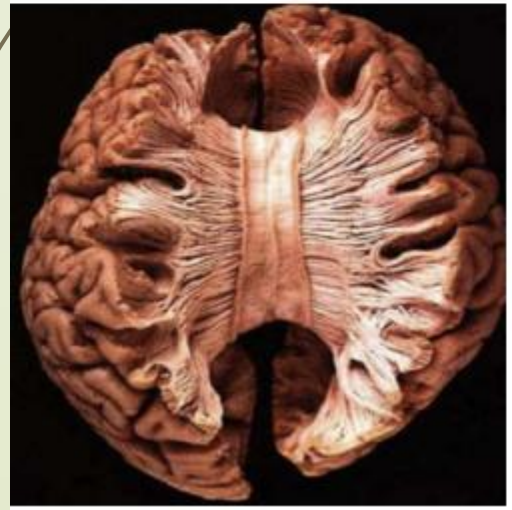
1. Brain stem & cerebellum



2. Limbic system
(subcortical regions)

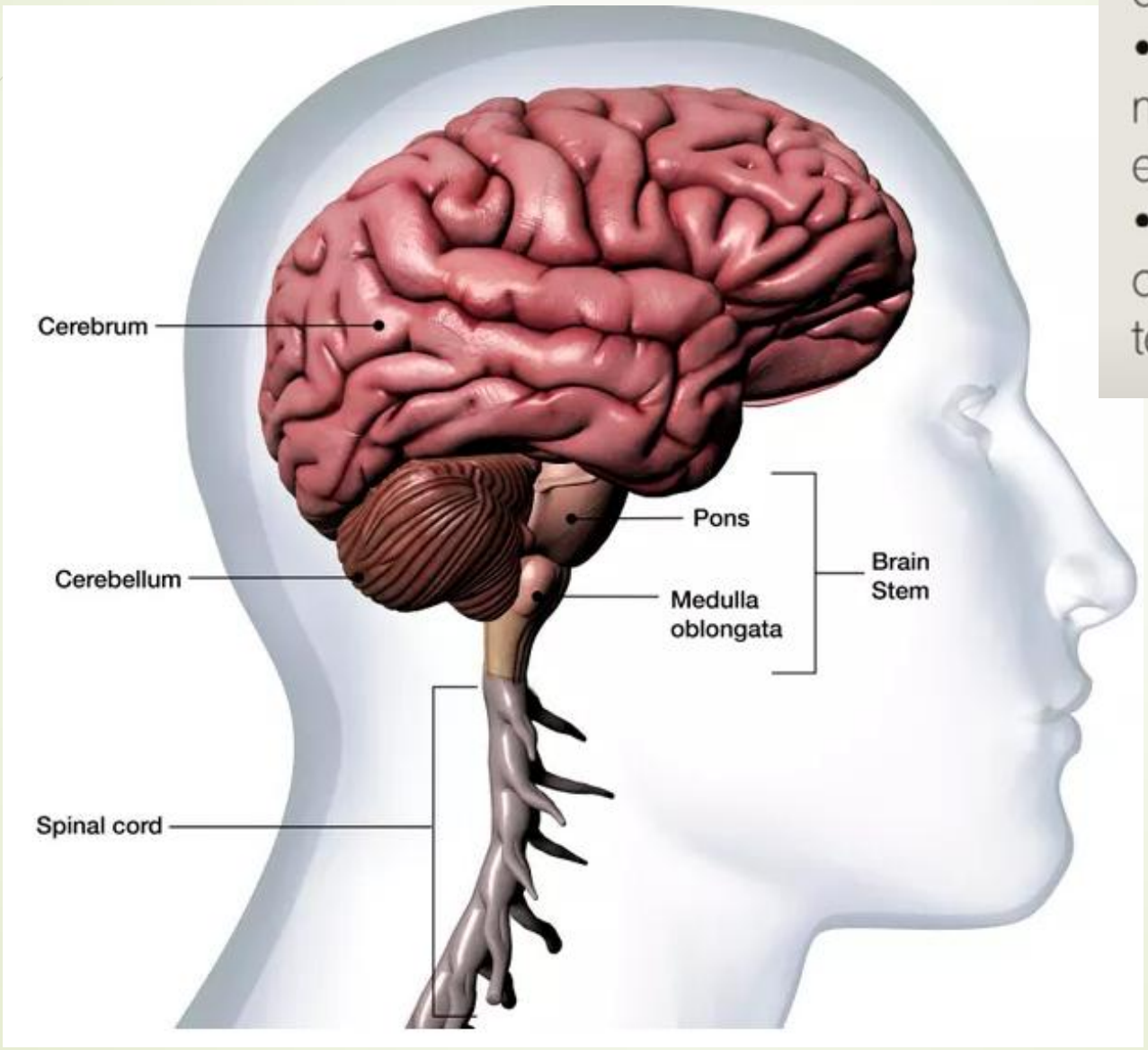


3. White Matter



4. Cerebral cortex (outer sheet)

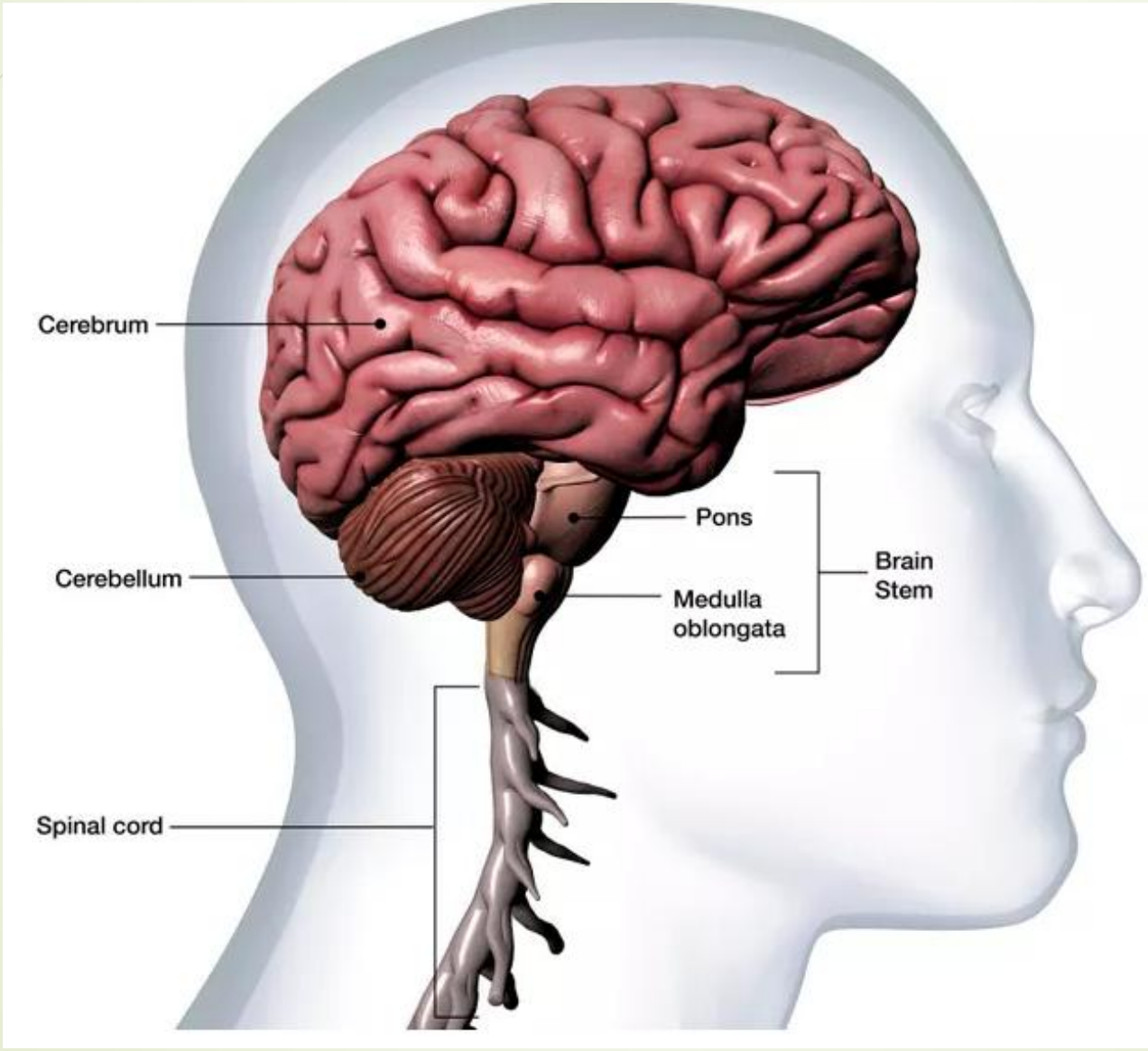
Brain stem & cerebellum



- brain stem = set of relays between spinal cord and cerebellum
- most "primitive" part of mammalian brain, but also most essential to life.
- centers regulating breathing, consciousness, body temperature.

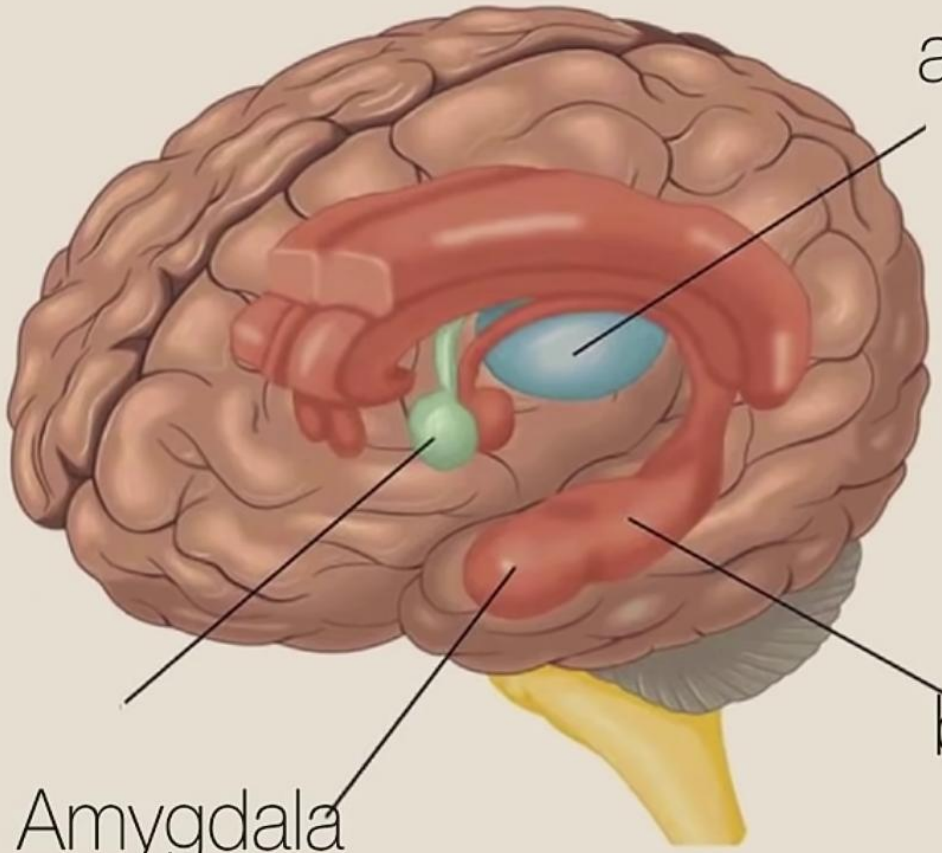
Brain stem relays for the information coming from spinal cord.
And send to Cerebellum.

Brain stem & cerebellum



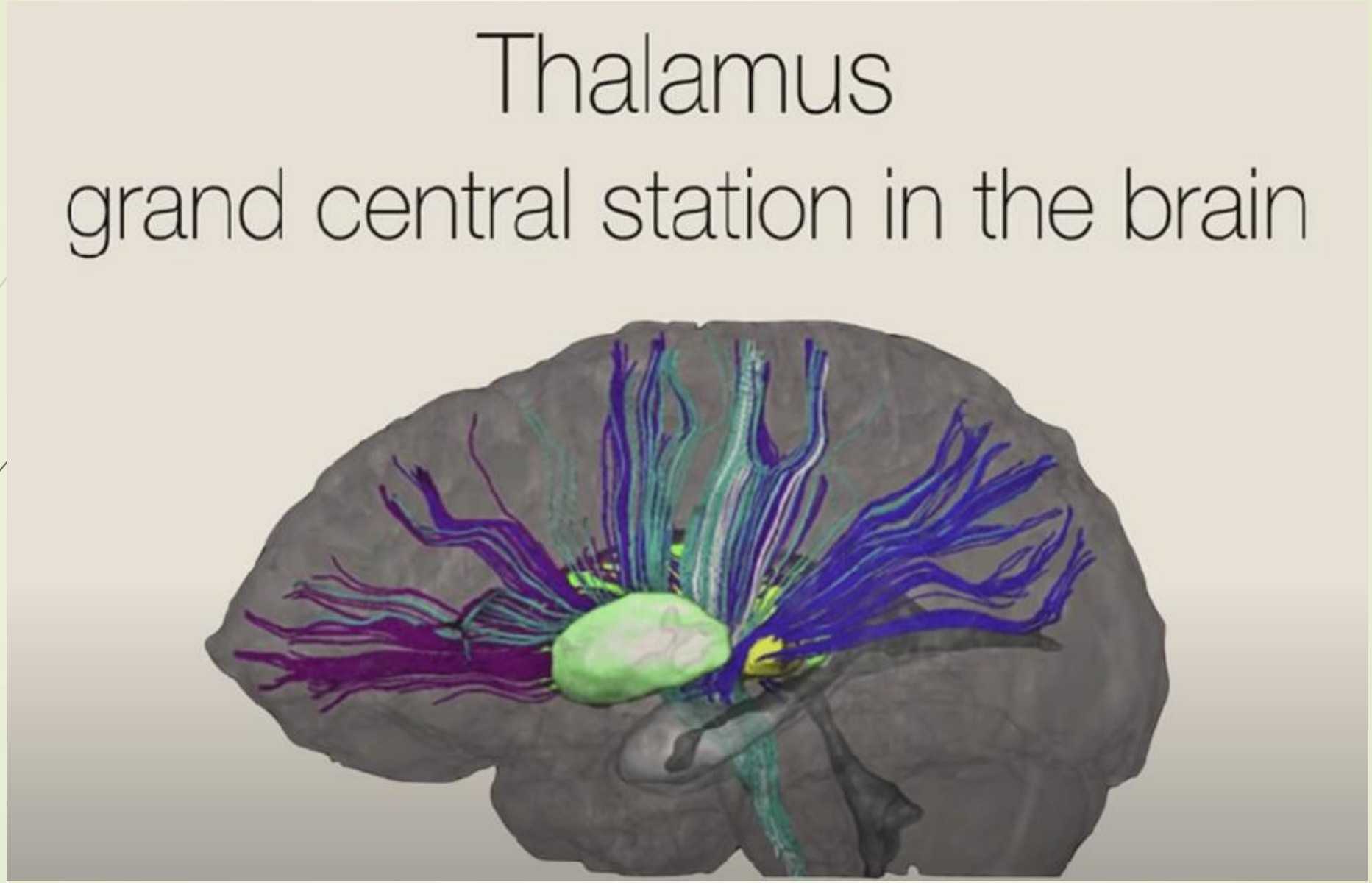
- Cerebellum involves in motor coordination
- Role in cognition is unclear

2. Important Subcortical Bits

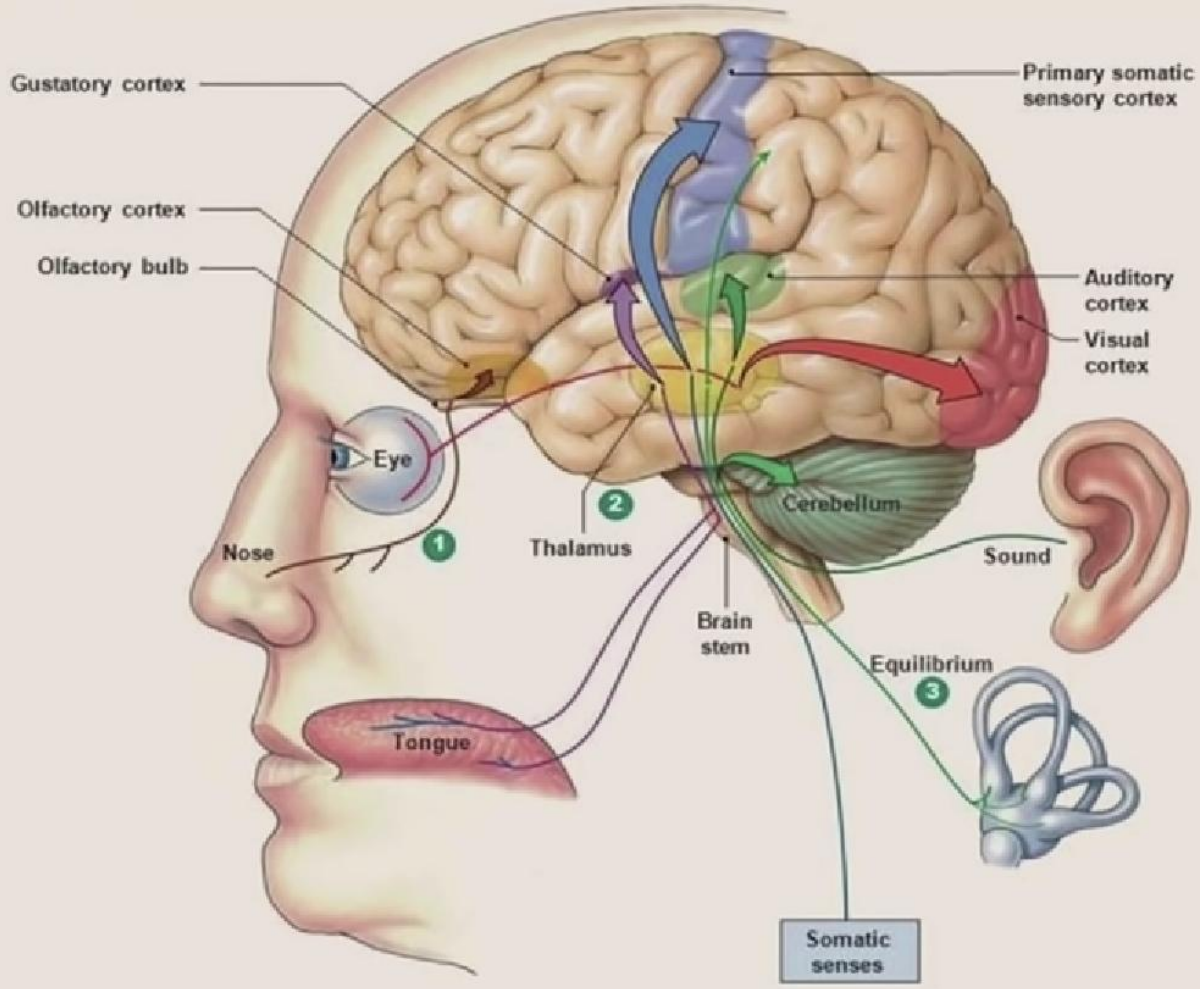


Thalamus

grand central station in the brain



Thalamus

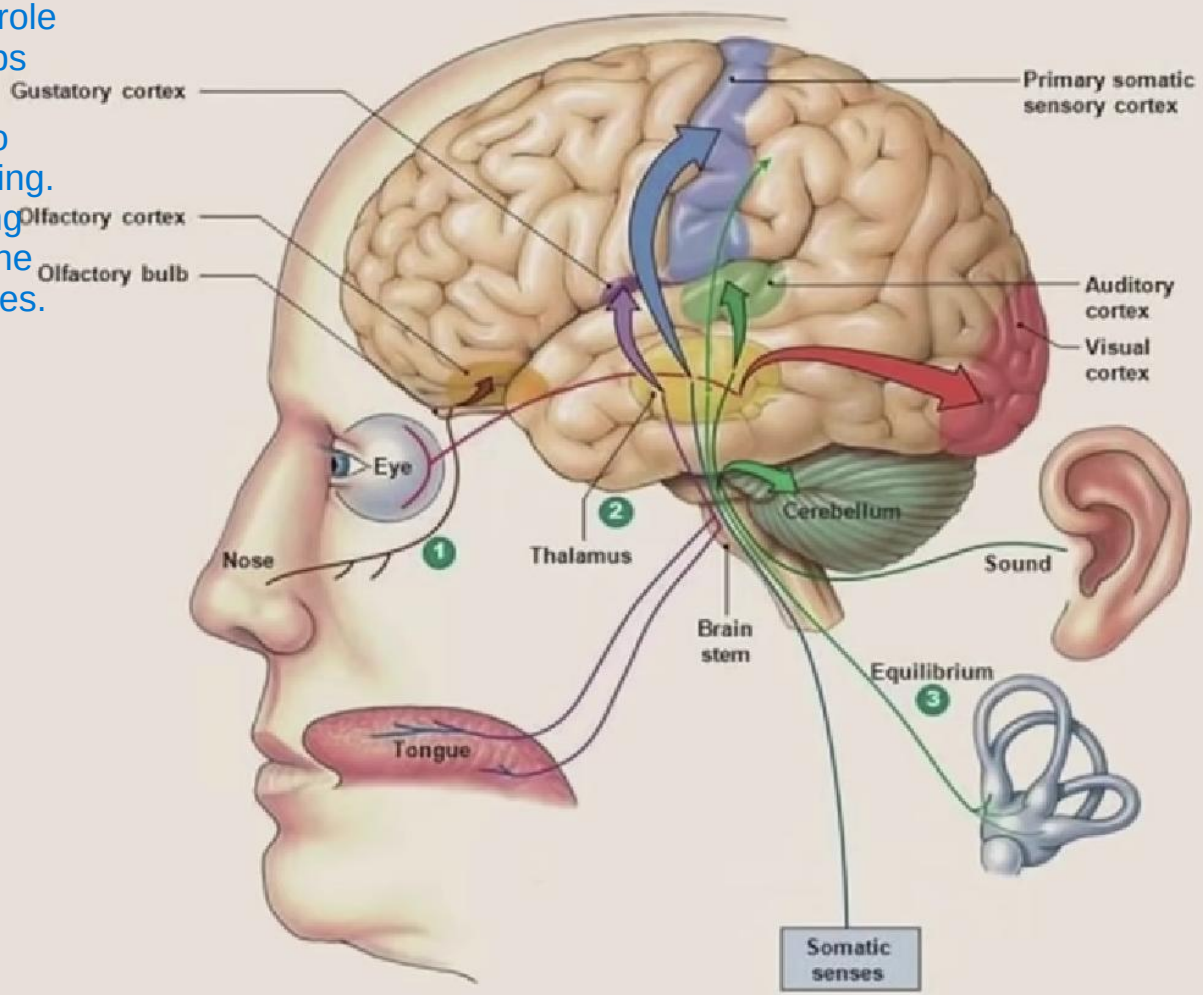


- Most incoming sensory information makes a stop in thalamus en route to cortex.

lateral geniculate nucleus, LGN, The LGN plays an important role in visual perception, as it helps to filter and organize visual information before it is sent to the cortex for further processing. It is also involved in controlling the size of the pupils and in the regulation of sleep-wake cycles.

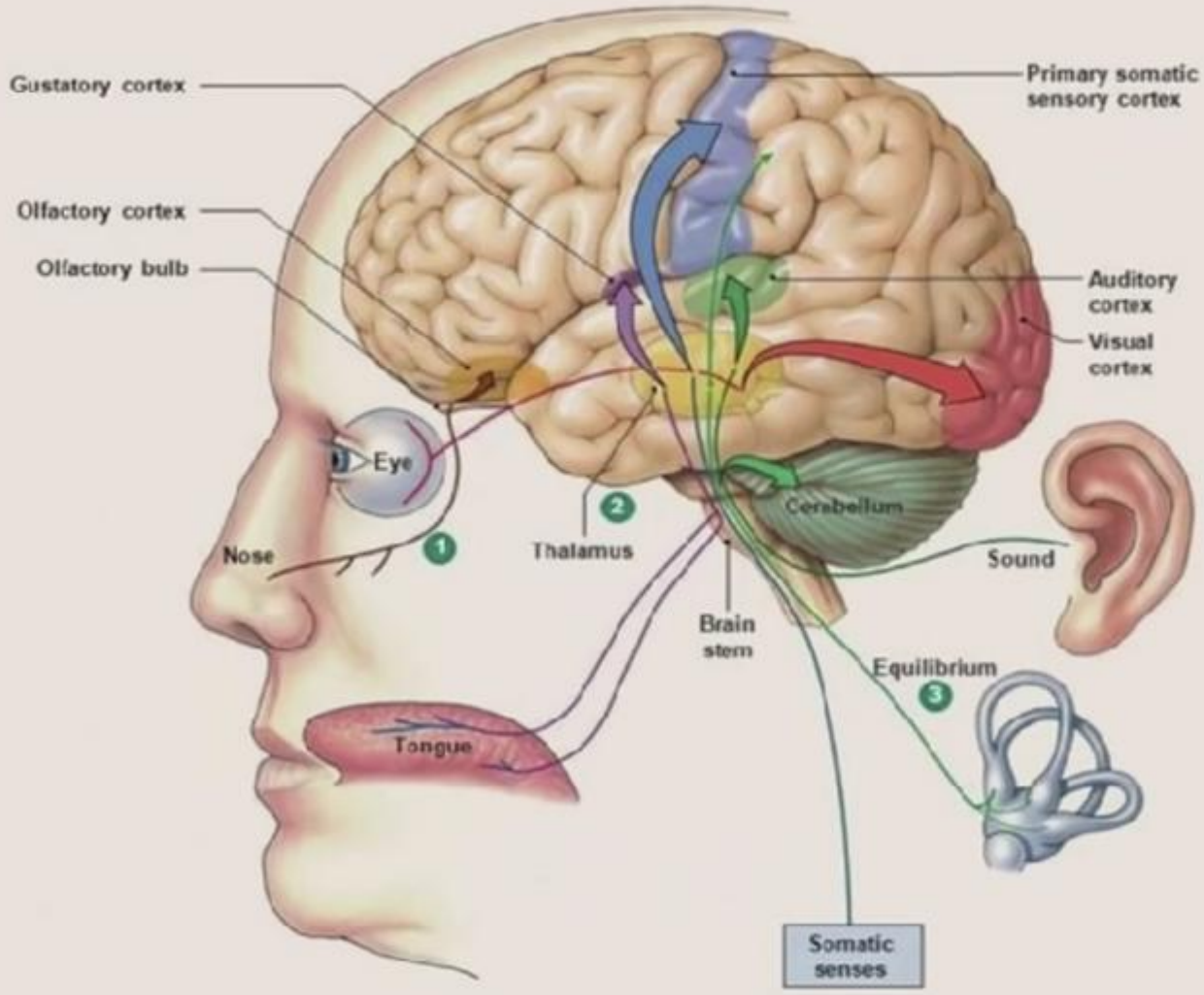
Smell

Thalamus



- Most incoming sensory information makes a stop in thalamus en route to cortex.
- What is the visual part of the thalamus that relays info. from retina to cortex?
- Which sense does not go through thalamus?

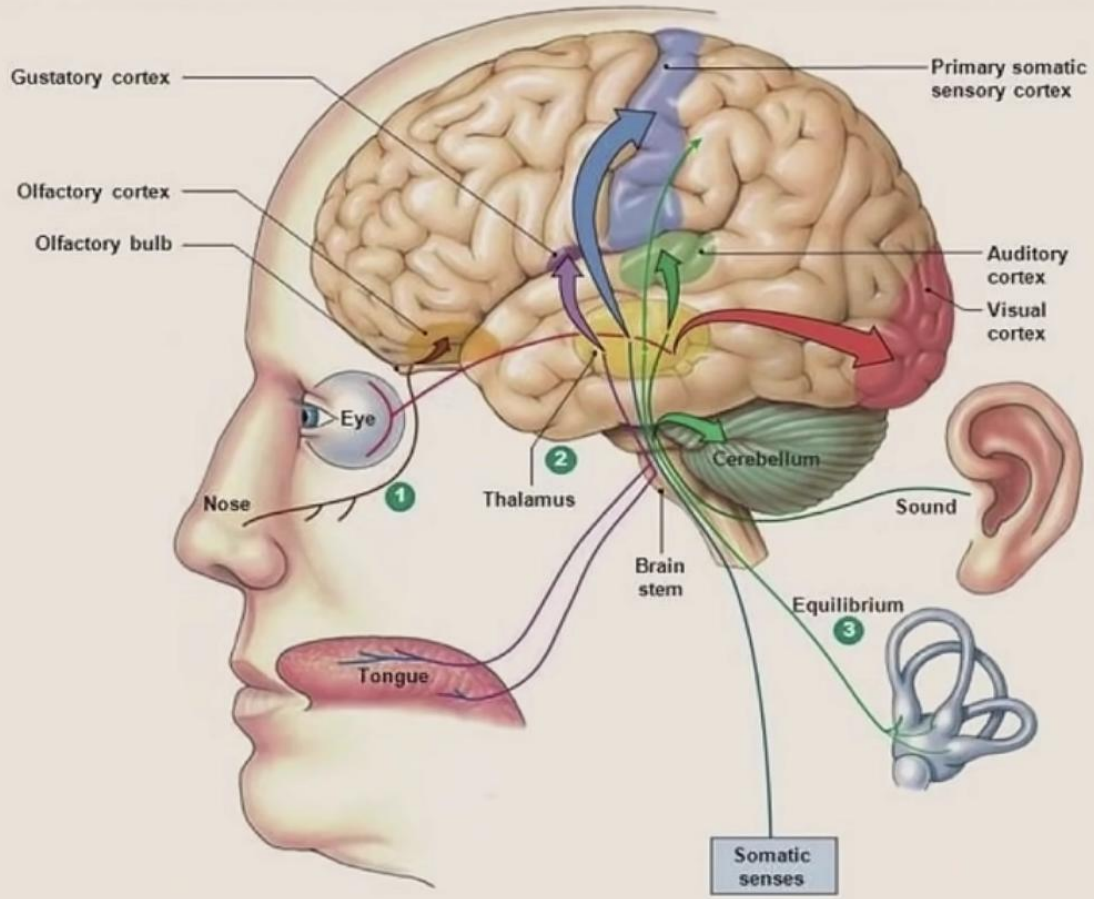
Thalamus



Thalamus is not just a relay up to cortex!

1. Many connections go back down to thalamus. e.g. 10x as many connections from V1 to LGN as from LGN to V1!

Thalamus



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2. Mike Halassa

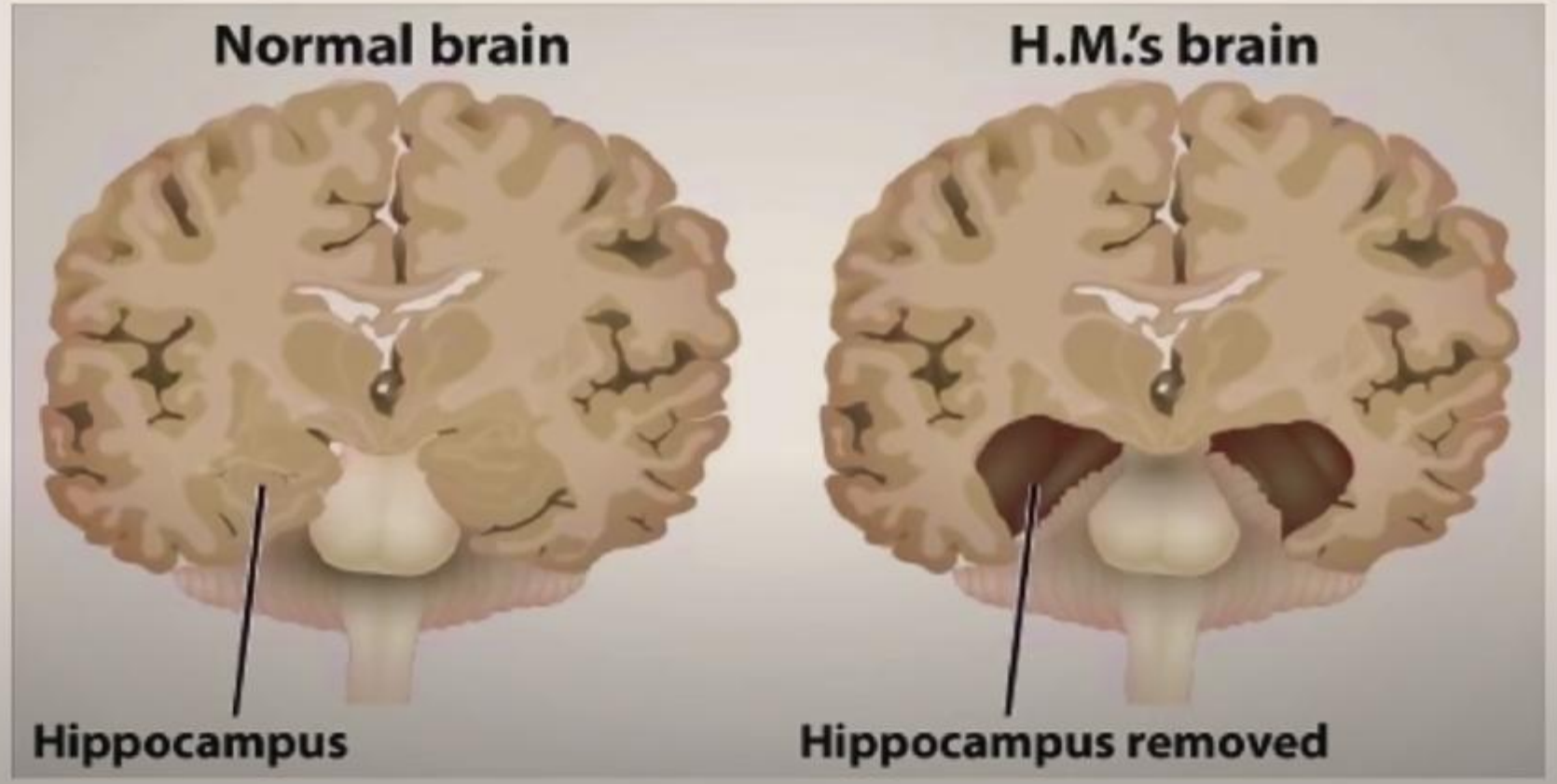
Possible role in complex computations.
Task switching.
Stunning work in mice.

Thalamus involved in high-level cognitive computation in mice.

When mice needs to switch from one task to another, Thalamus plays a key role.

Hippocampus

long-term memory; spatial navigation



The curious case of HM Brain

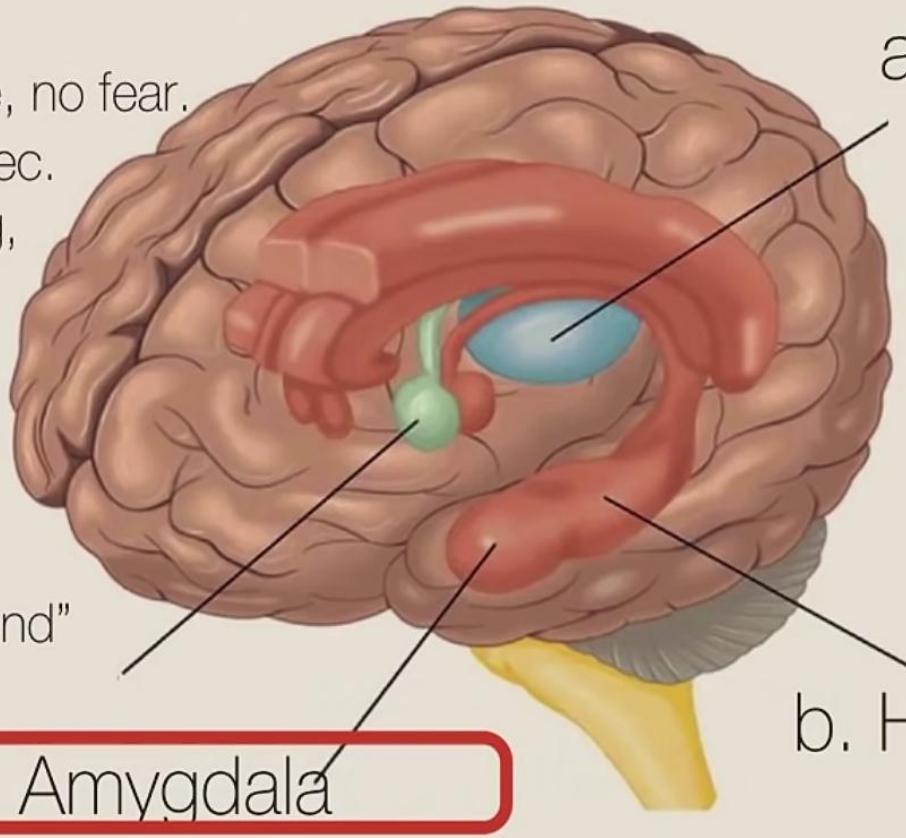
- **Henry Gustav Molaison** (February 26, 1926 – December 2, 2008), known widely as **H.M.**, was an American.
- Surgically resect his hippocampi in an attempt to cure his epilepsy.
- Although the surgery was partially successful in controlling his epilepsy, a severe side effect was that he became unable to form new memories.
- Another case of **Lonni sue Johnson**: Multitalented lady,
- Does not remember any events of previous life, after viral infection.

2. Important Subcortical Bits

Experiencing and recognizing emotions, esp fear

- patient SM:

no amygdalae, no fear.
normal face rec.
overly trusting,
normal IQ



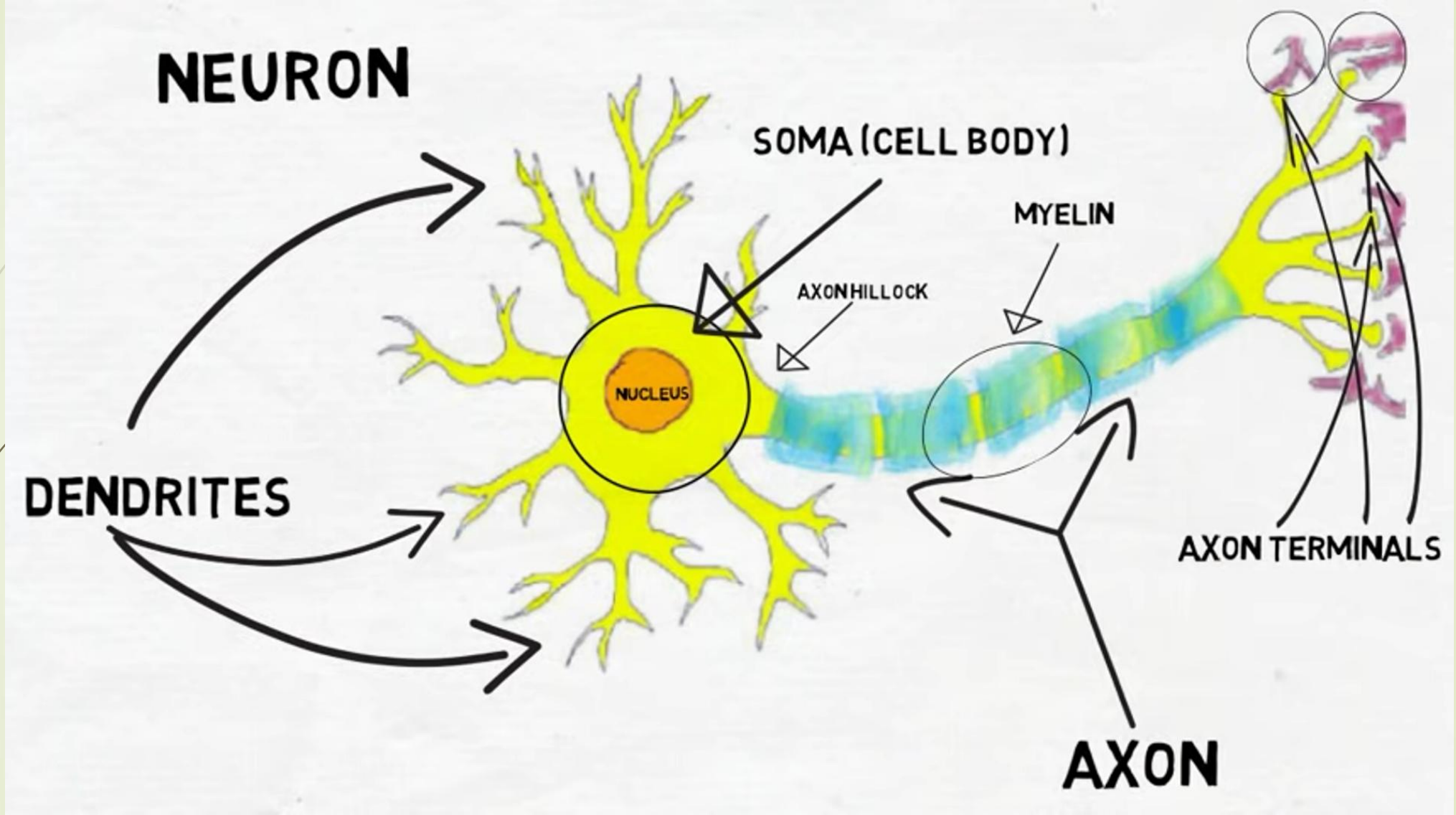
a. Thalamus

b. Hippocampus

means "almond"
in Greek

c. Amygdala

S.M., also sometimes referred to as **SM**-046, is an American woman with a peculiar type of brain damage that may affect her ability to feel fear.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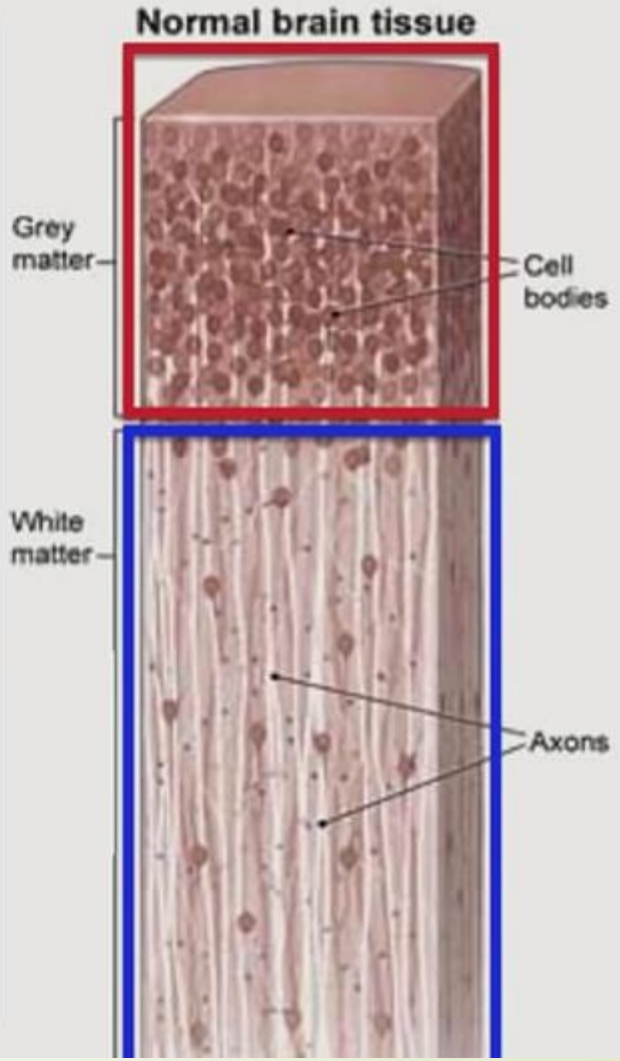
Grey and white matter

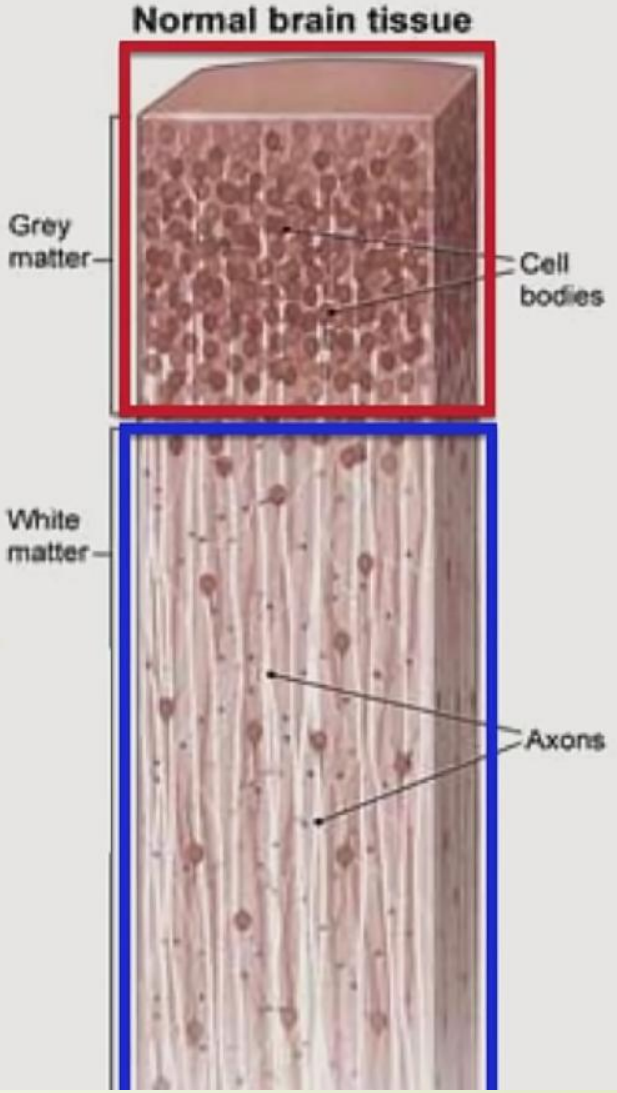


Grey and white matter

Cross section of Cortex

Grey Matter: = cell bodies

White Matter:
= myelinated axons
think: long-distance wires connecting different regions



Axons travel in bundles in white matter
You will see this in the dissection.

Here is an actual cross section of the brain…

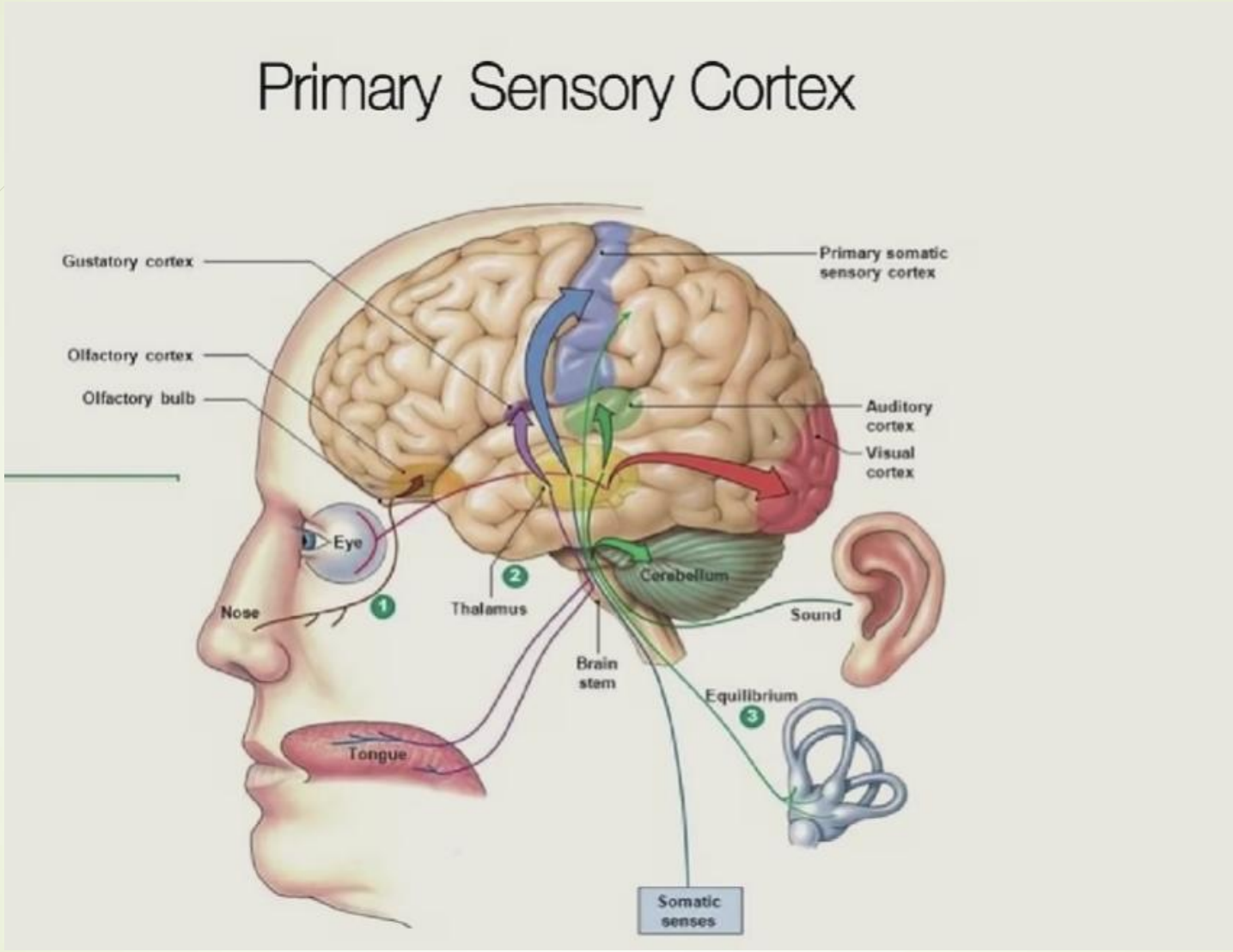
Just bunch of wires, but they are very interesting.

Who Cares about White Matter?

1. White matter makes up 45% of the human brain.

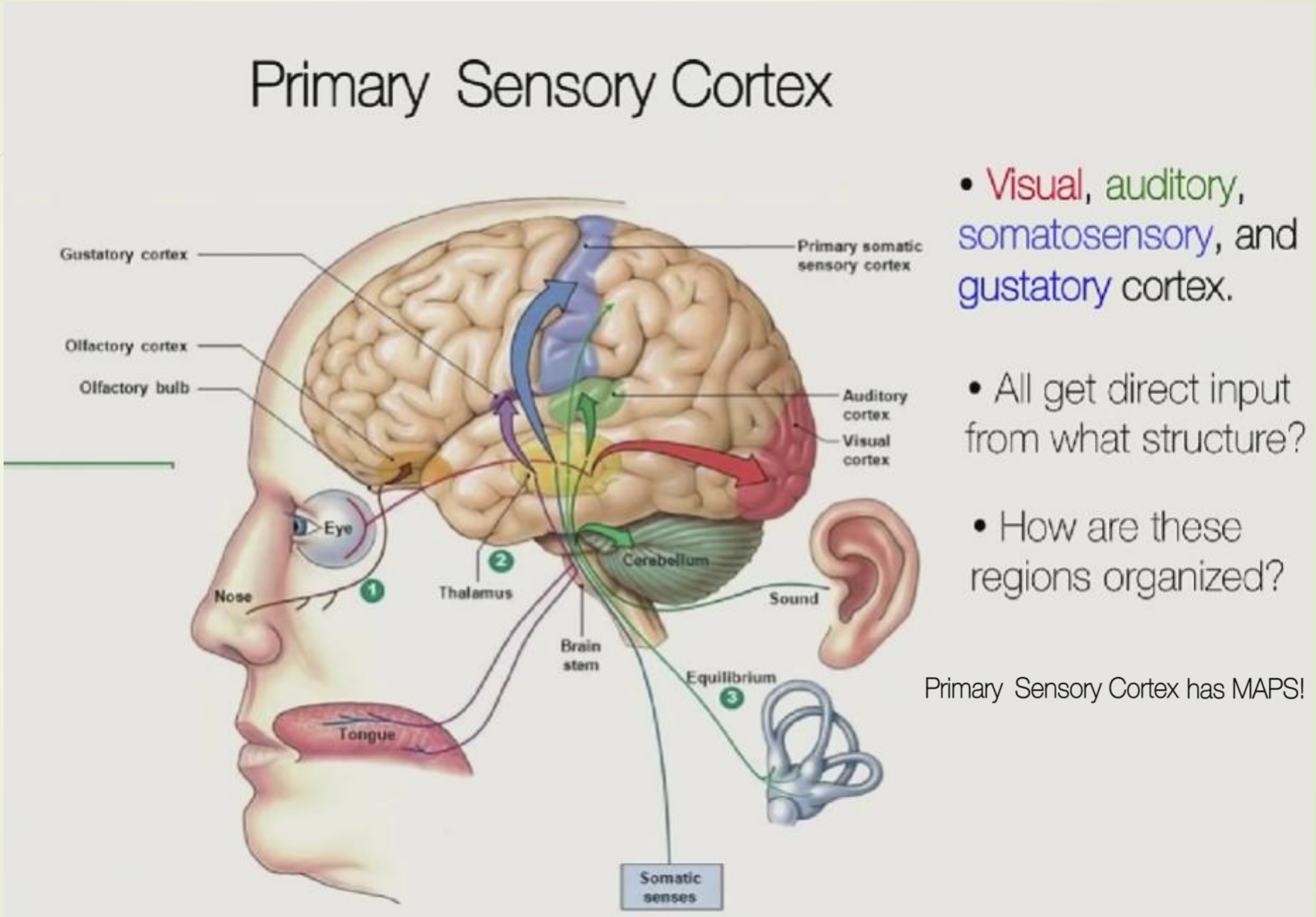
2. We cannot understand cortex w/out knowing the connections between regions.

3. The specific connections of each region may serve as a "fingerprint" of that region across species, enabling us to discover interspecies homologies.



They are primary in the sense, this is the first place there sensory information lands up at the cortex coming from the senses.

Primary Sensory Cortex



- Visual, auditory, somatosensory, and gustatory cortex.
- All get direct input from what structure?
- How are these regions organized?

Primary Sensory Cortex has MAPS!

Primary Sensory Cortex has MAPS!

To understand map, first we need to understand Receptive Field.

RF is the property of individual cell in the brain.

Refresher: What is a Receptive Field?

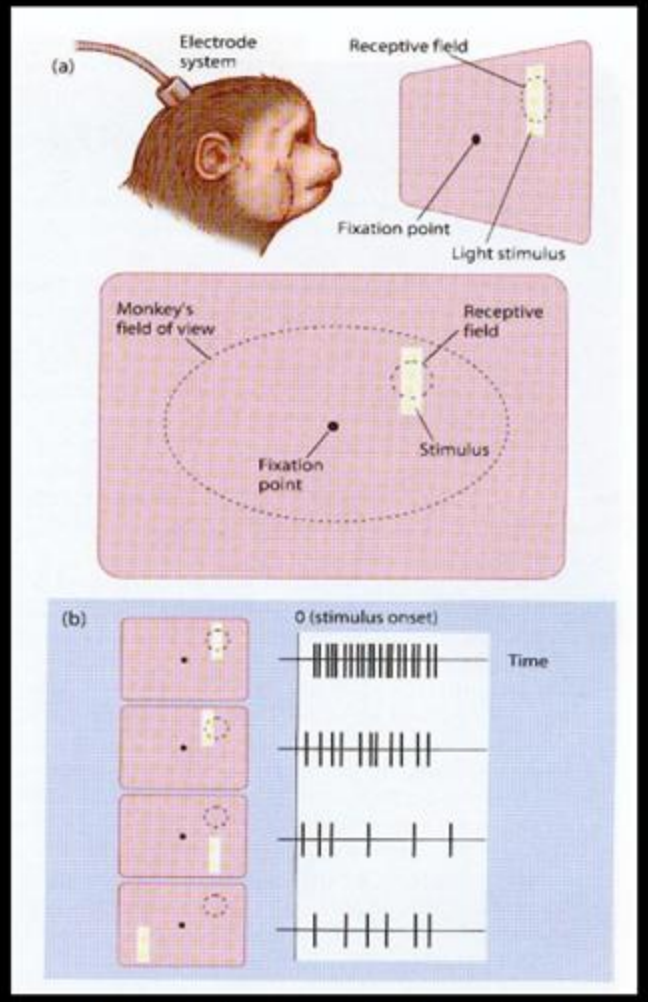
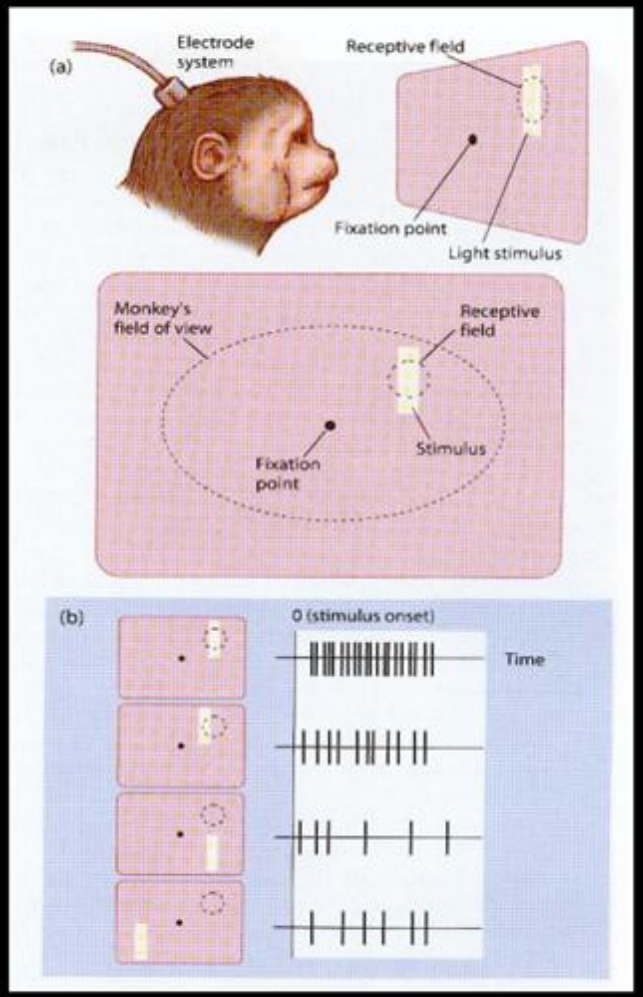


Figure from Gazzaniga, M., Ivry, R. & Mangun, G. (2002). *Cognitive Neuroscience: The Biology of Mind*. All rights reserved. This content is excluded from our Creative Commons license. See https://ocw.mit.edu/fairuse for more information.

Place an electrode next to a cell in monkey visual cortex

Sources: Gazzaniga, Ivry & Mangun, 2002

Refresher: What is a Receptive Field?



Place an electrode next to a cell in monkey visual cortex

Train the monkey to stare at a fixation spot w/out moving its eyes

And then while recording neuron,
You put flash different locations.

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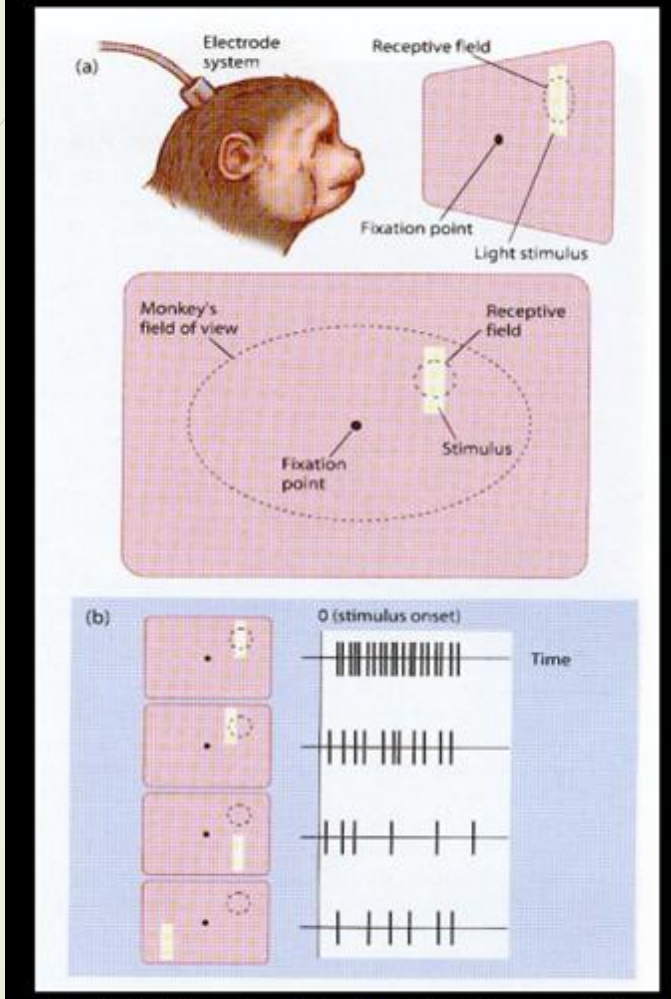

Place an electrode next to a cell in monkey visual cortex

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RF is the place in the visual world that makes a particular neuron fire.

Responds to a particular flash location not others flashes.

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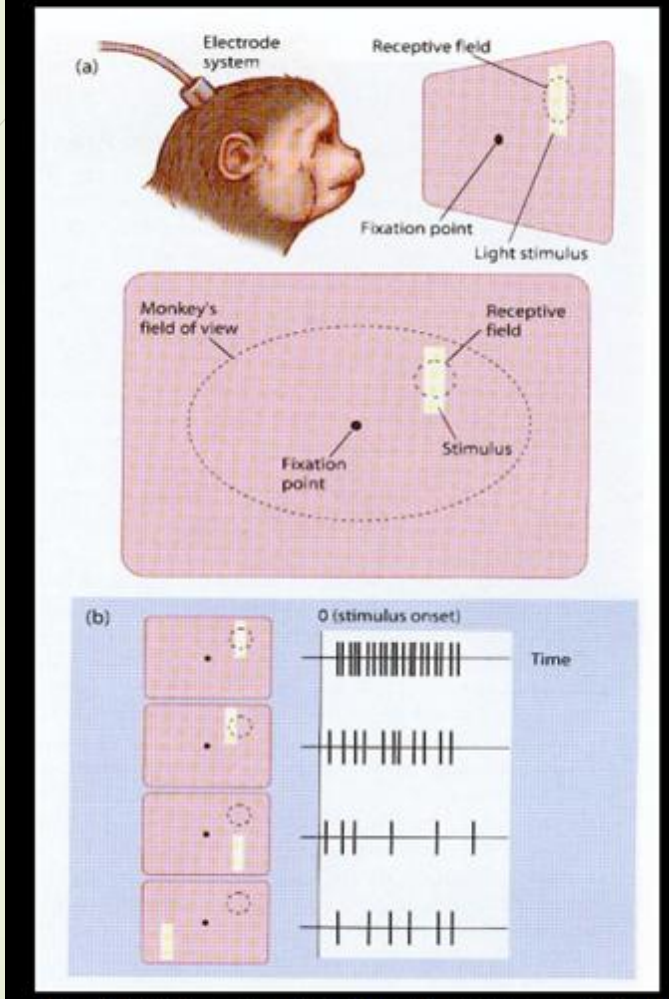


Place an electrode next to a cell in monkey visual cortex

Train the monkey to stare at a fixation spot w/out moving its eyes

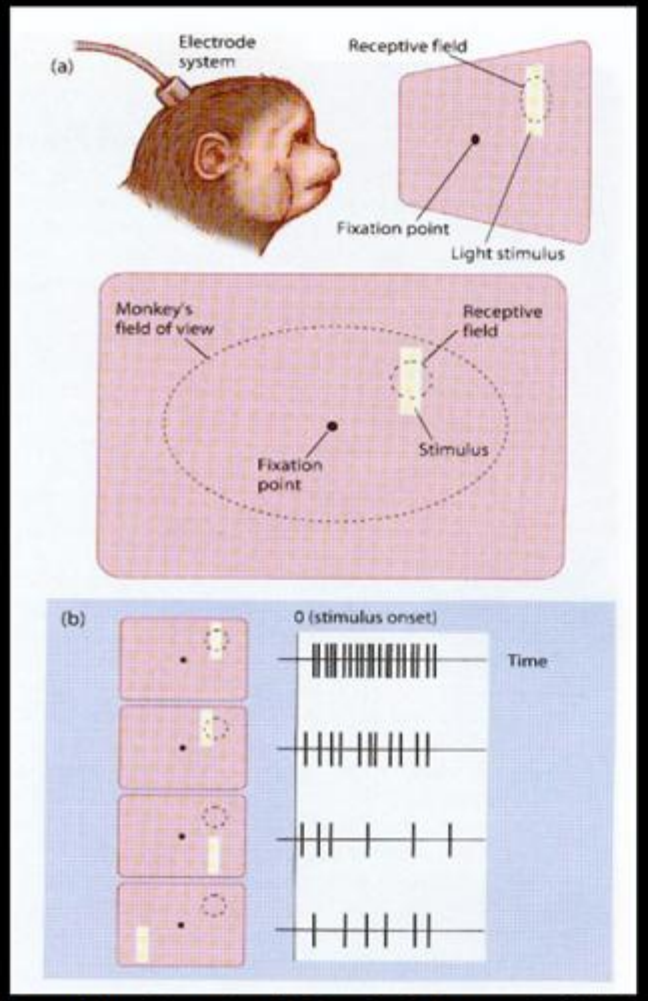
In visual cortex, neurons have restricted RF.

They don't respond anything and anywhere in the visual field.

They respond to a particular place in the space.

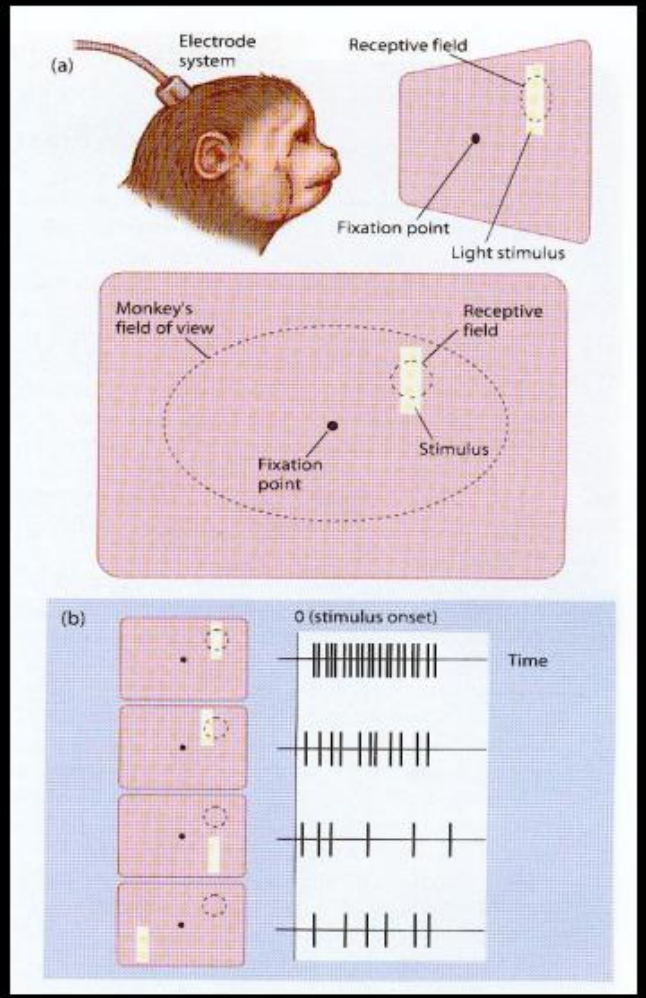
Sources: Gazzaniga, Ivry & Mangun, 2002
Jody Culham

Refresher: What is a Receptive Field?



- Place an electrode next to a cell in monkey visual cortex
- Train the monkey to stare at a fixation spot w/out moving its eyes
- Stimulate various regions of visual space
- A cell will respond to stimulation in one part of space more than any others
- The region of visual space that drives a particular cell forms its receptive field (RF)

Refresher: What is a Receptive Field?



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Place an electrode next to a cell in monkey visual cortex

Train the monkey to stare at a fixation spot w/out moving its eyes

Stimulate various regions of visual space

A cell will respond to stimulation in one part of space more than any others

The region of visual space that drives a particular cell forms its receptive field (RF)

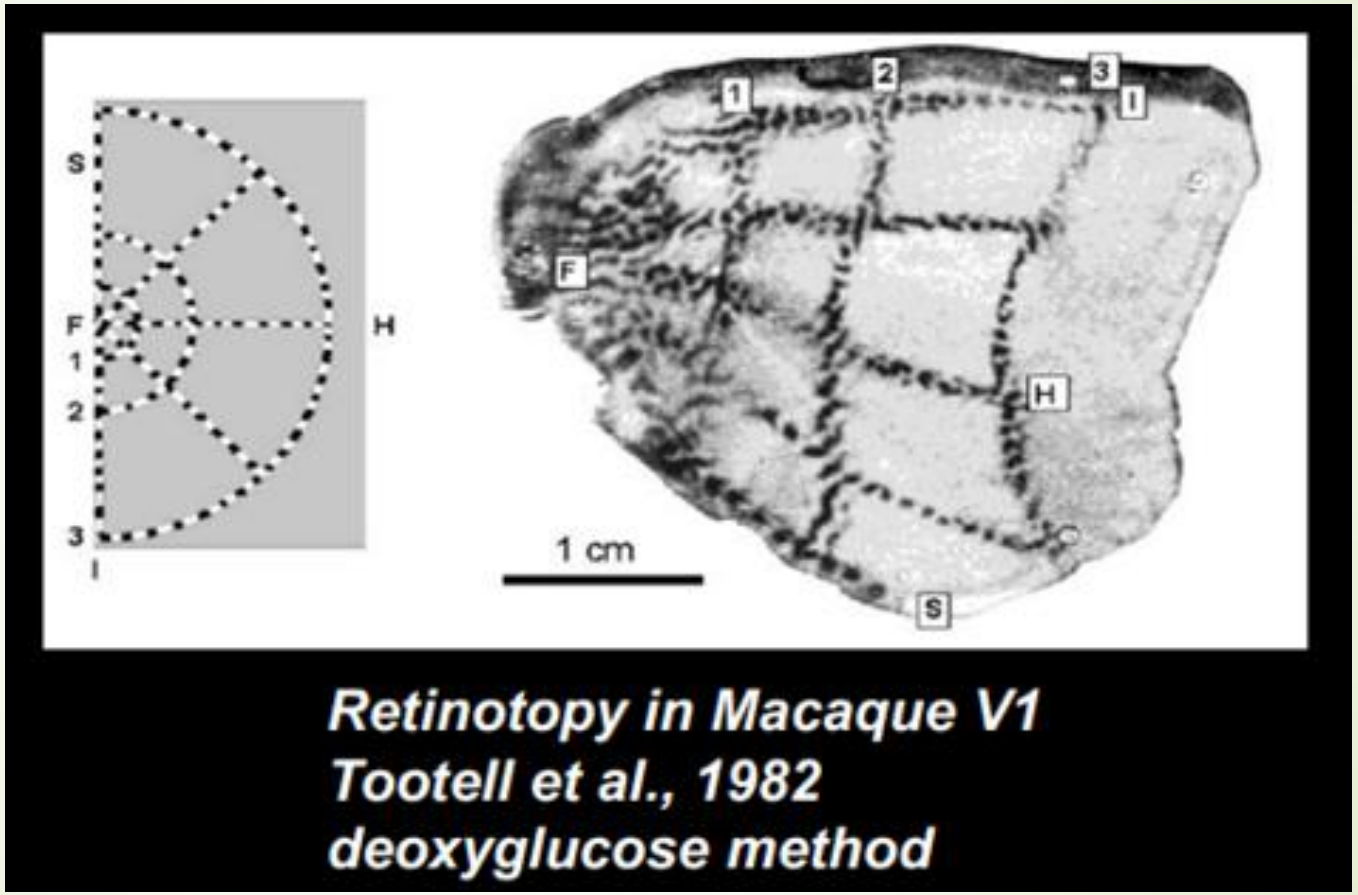
Different cells have different RFs

Some cells' responses are tuned not only to the location of the stimulus but also other properties (shape, color, direction of motion)

Nearby cells in the cortex have nearby receptive fields, producing *retinotopic maps* in visual cortex…..

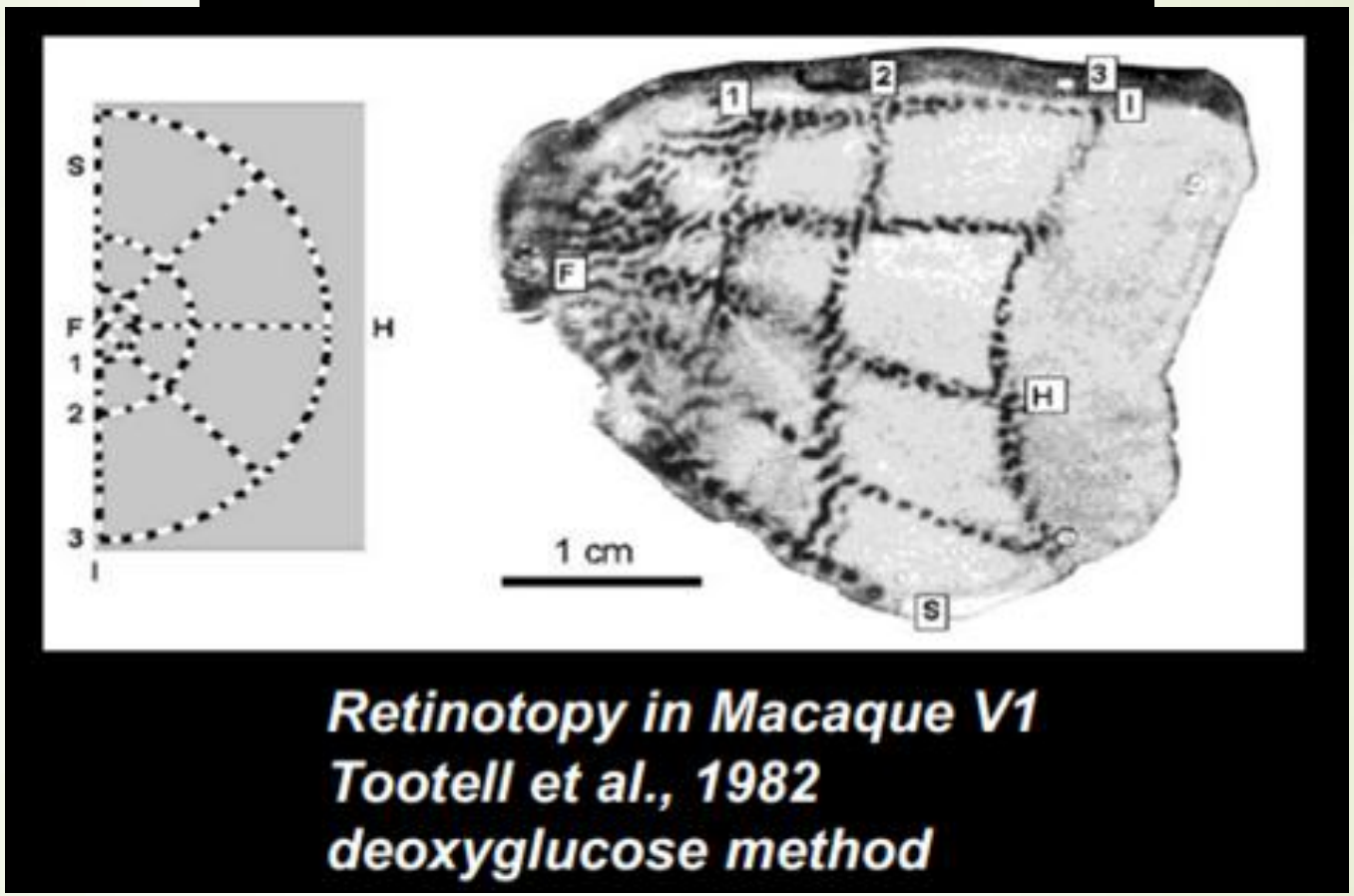
Sources: Gazzaniga, Ivry & Mangun, 2002
Jody Culham

Retinotopic Maps



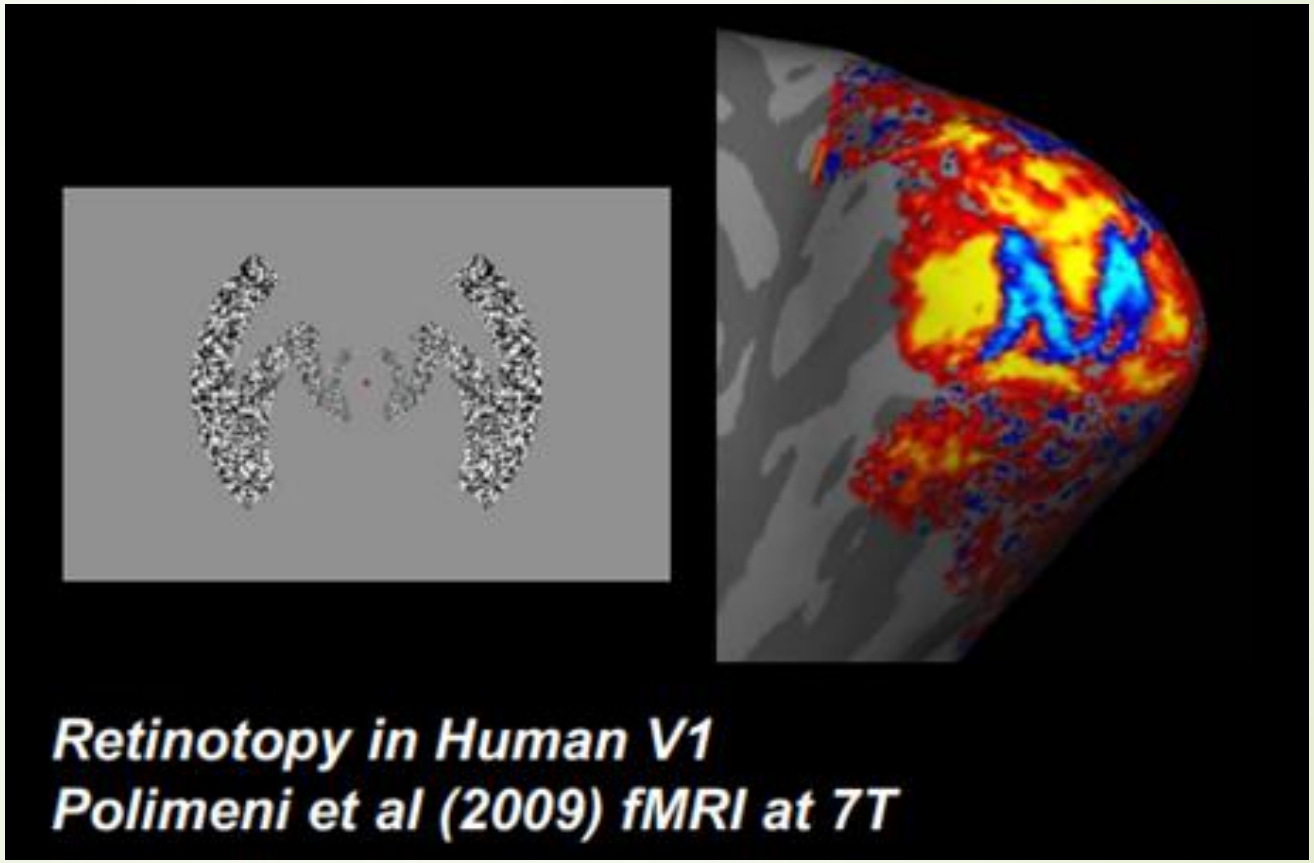
Totell injects radioactive deoxyglucose when monkey looking at one point

Retinotopic Maps

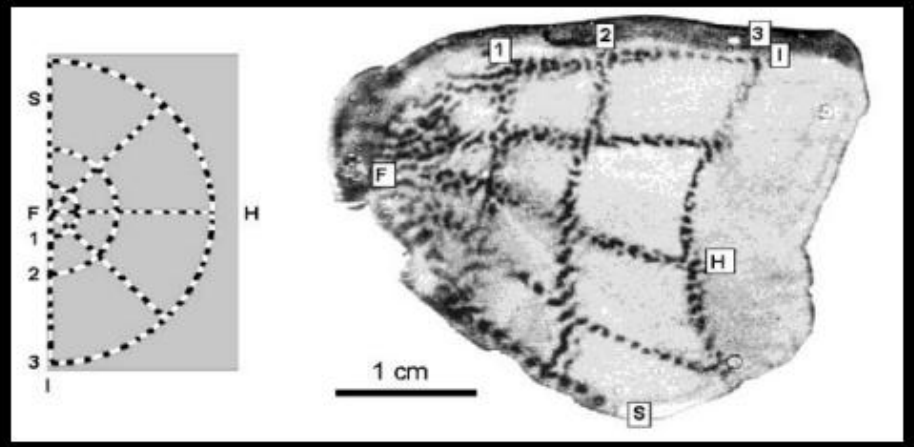


Totell injects radioactive deoxyglucose when monkey looking at one point.
Radioactive chemical emits radiation and it is detected by radioactive detector.

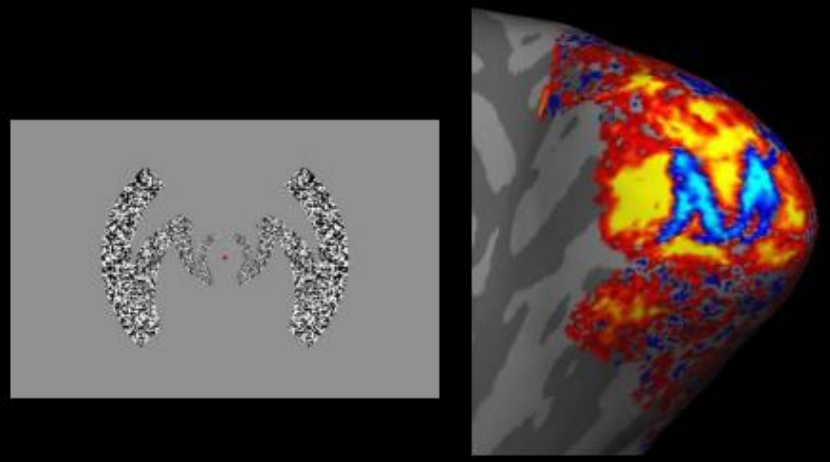
Retinotopic Maps



Retinotopic Maps

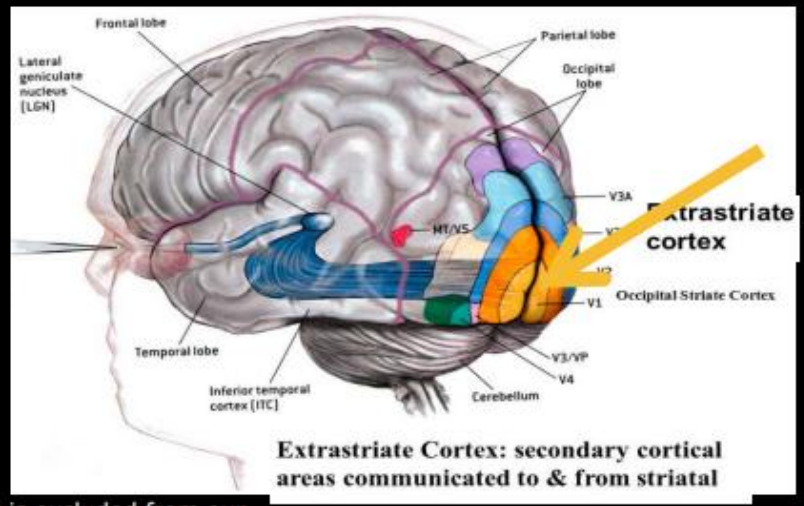


Retinotopy in Macaque V1
Tootell et al., 1982
deoxyglucose method



Retinotopy in Human V1
Polimeni et al (2009) fMRI at 7T

- Retinotopy: Adjacent parts of the visual scene are mapped to adjacent parts of the cortex
- Terminology: V1 = primary visual cortex = striate cortex



What exactly is a cortical area?

Criteria: A region of cortex distinct from its neighbors in

- Function
- Connectivity to other areas
- Distinctive layer structure/cell types

- Physically different

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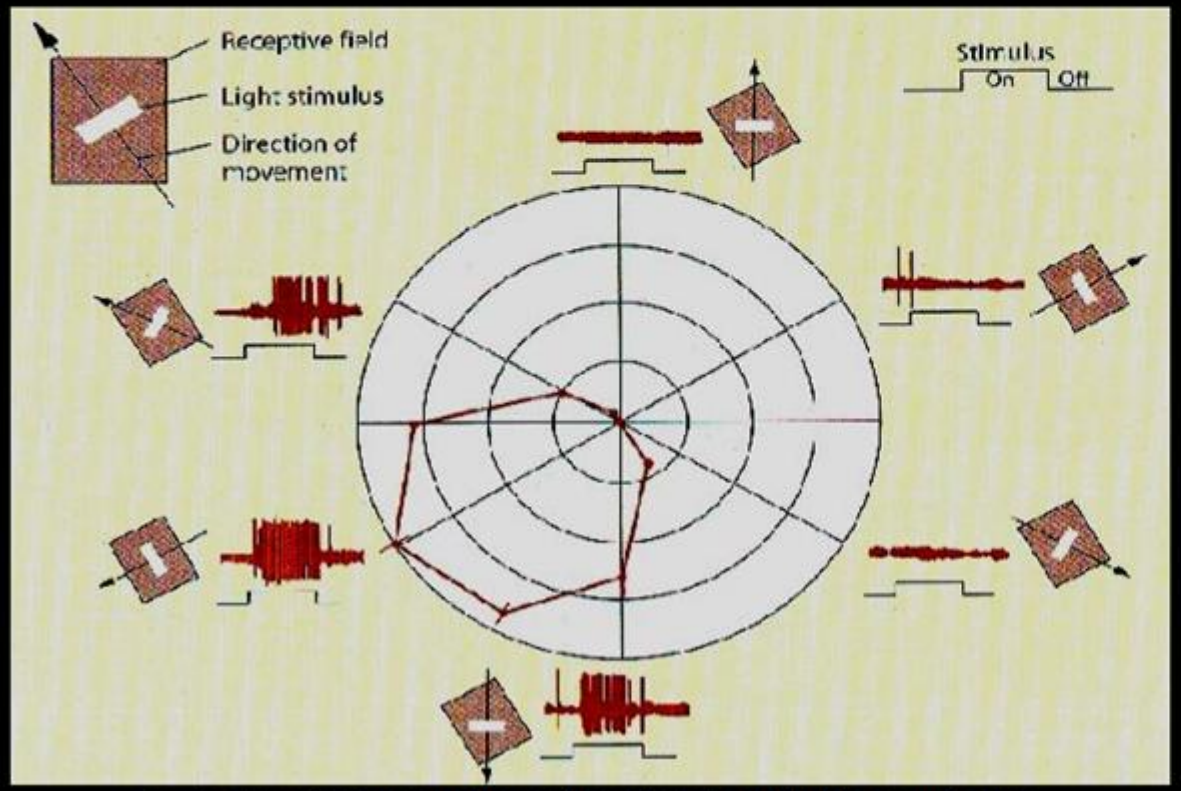
Let's look at a classic example: Visual Motion area MT
Meets all the criteria for a visual area.

MT: Function

Single unit recording

- Single neurons in MT are tuned to the direction of motion
- Nearby neurons within MT have similar directional selectivity
  (sound familiar?)



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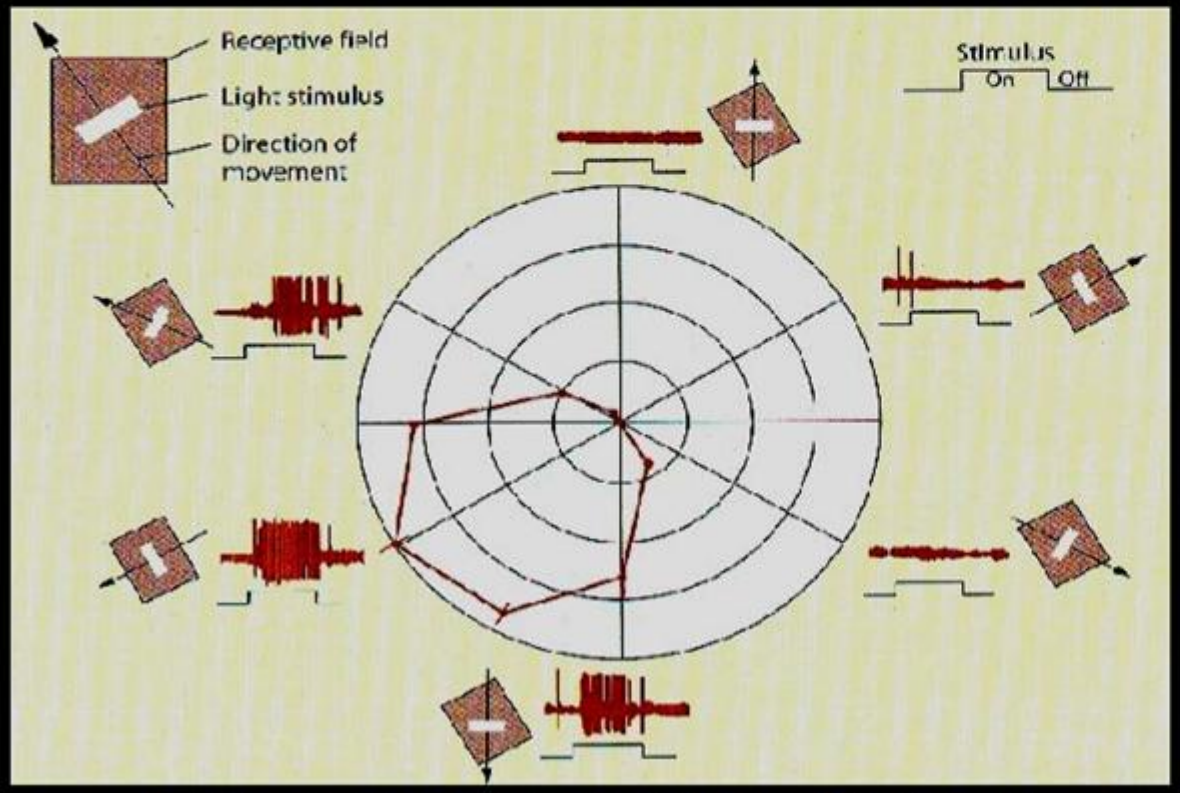
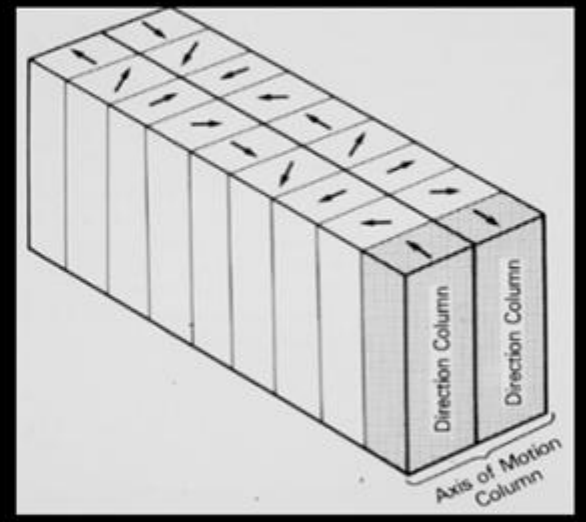


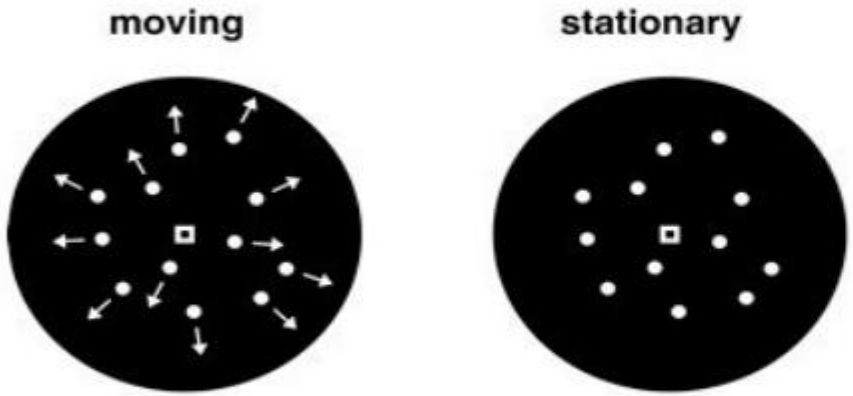


As you move across the cortex, you see a systematic change in the direction selectivity of neurons.

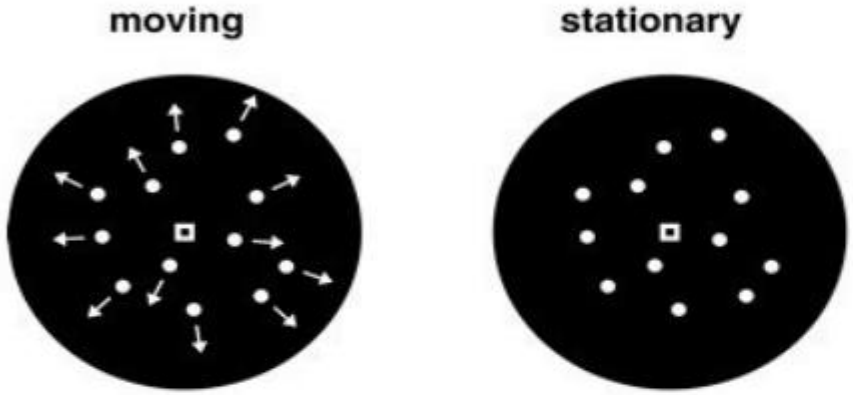
MT (middle temporal)

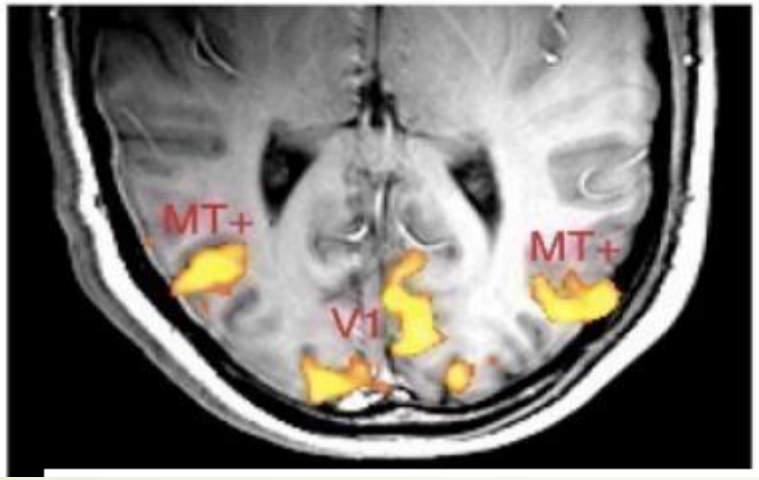
- In MT, we have map of direction preference.
- Like we have map of spatial location in V1.

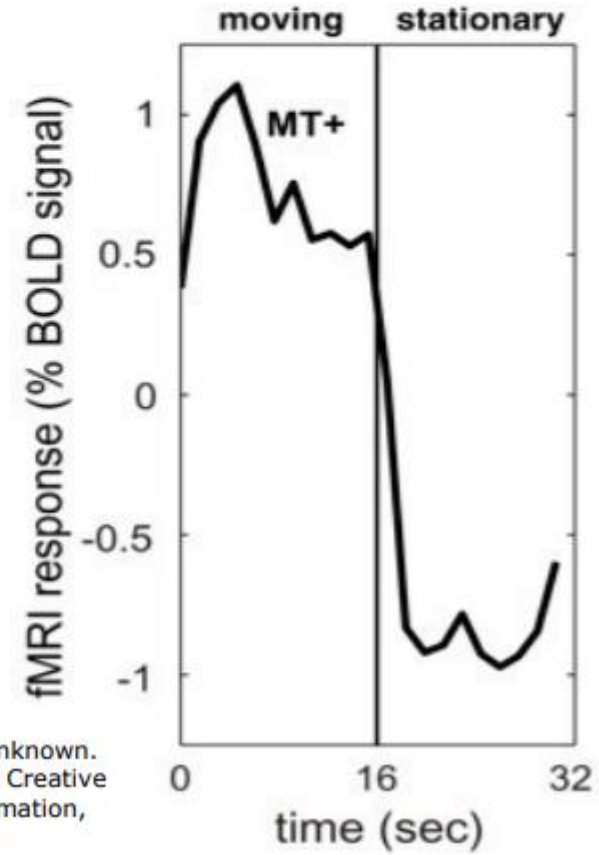
Visual motion area MT



Visual motion area MT

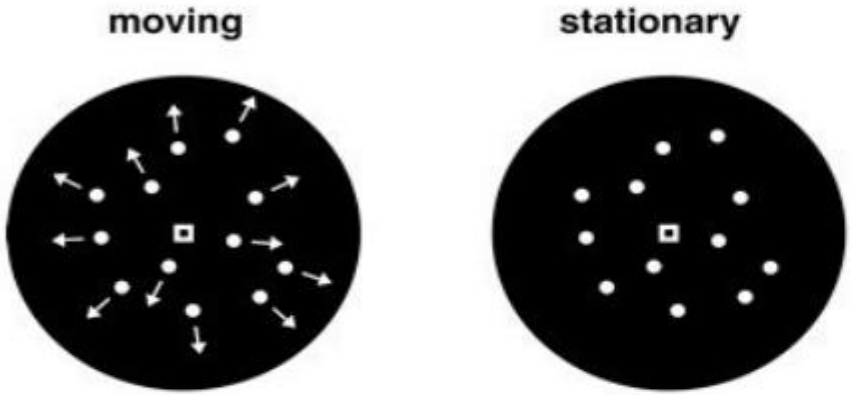


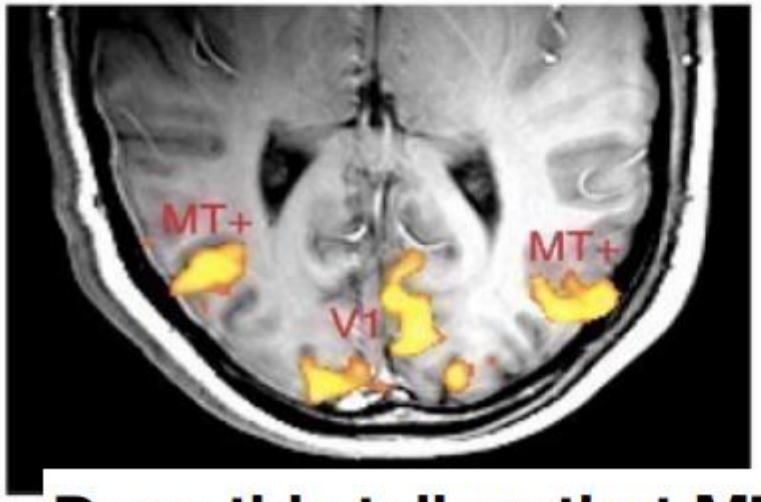


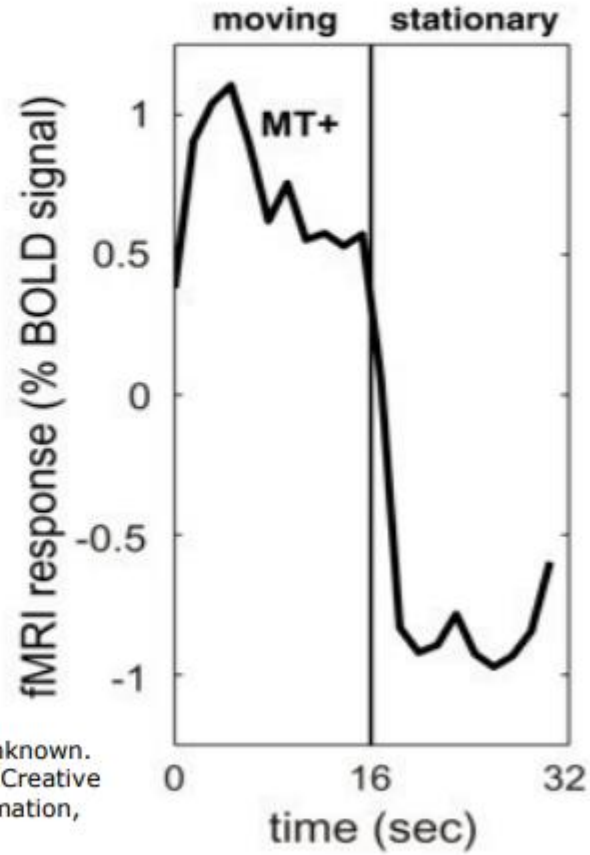


blood-oxygen-level-dependent (BOLD)

Visual motion area MT







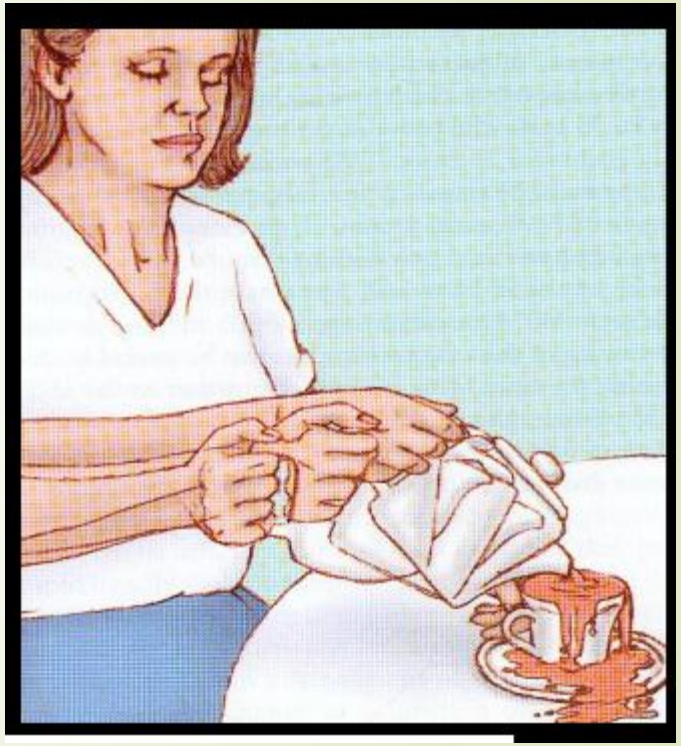
Does this tell us that MT represents the *direction* of motion, or just the *presence* of motion?

MT Function

- Lesions
  - lesions to MT lead to deficits in perceiving motion

    A patient with bilateral lesions to MT can no longer perceive motion
    (Zihl et al., 1983)

    "Akinetopsia"



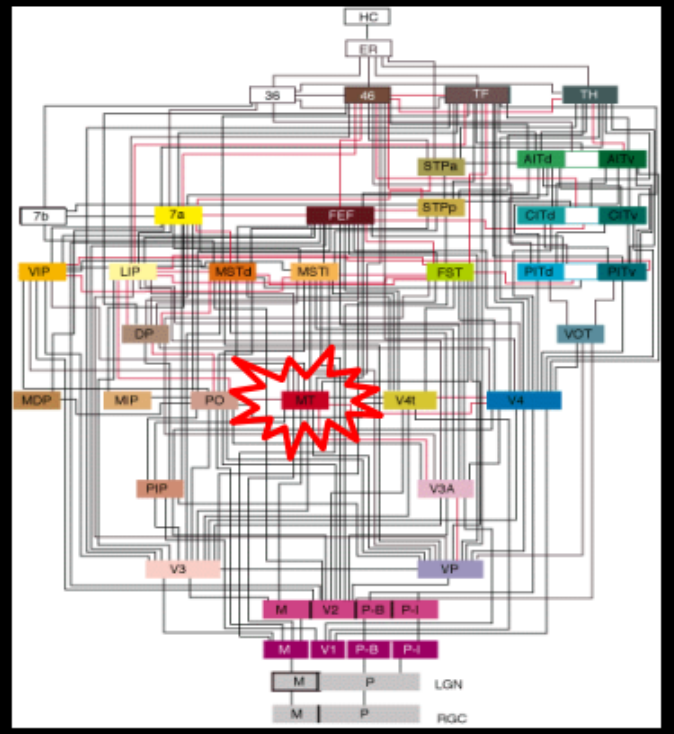
What exactly is a cortical area?
Example: Visual Motion Area MT

Criteria: A region of cortex distinct from its neighbors in

- Function, e.g. selectivity/processing a specific dimension, e.g.
  - MT selectively engaged in processing motion
    - single neurons in monkeys
    - fMRI in humans
    - psychophysics (aftereffects)
    - microstimulation in monkeys
    - lesions in humans

- Specific Connectivity
  - To other areas
    a distinct "connectivity fingerprint"
    a signature of that region

- What about physical/cellular diffs?
  = "cytoarchitecture"
  an old idea….



Cytoarchitecture, also known as cytoarchitectonics, is the study of the cellular composition of the central nervous system's tissues under the microscope.

Brodmann Areas

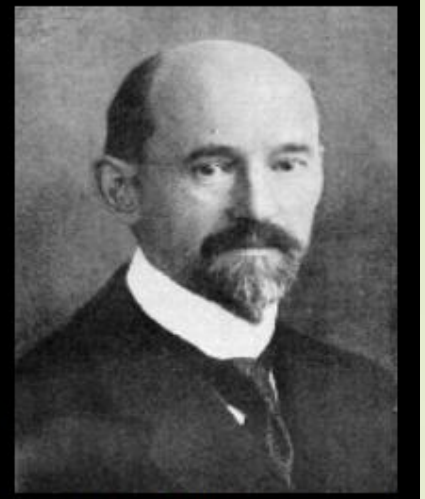
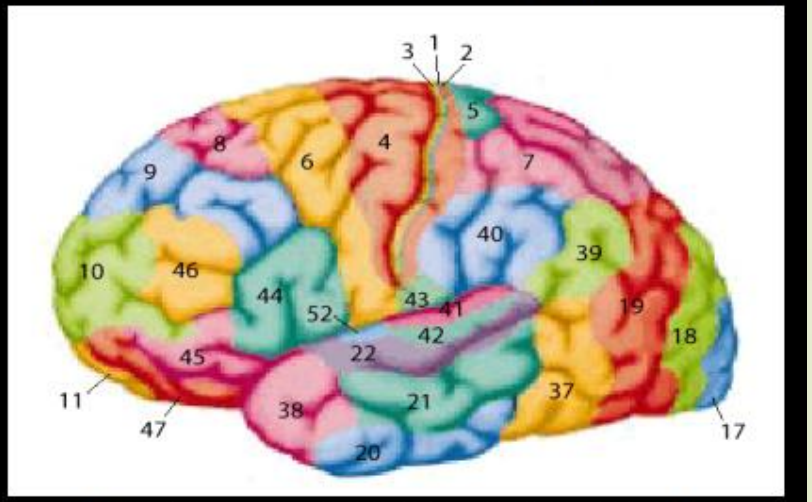


Photo of K. Brodmann is in the public domain. Source: Wikimedia Commons.

- Korbinian Brodmann (1868 –1918)

  Identified 52 distinct "areas' based on cytoarchitecture
  Thought of them as like "organs"

  "The specific histological differentiation of the cortical areas proves irrefutably their specific functional differentiation--for it rests as we have seen on the division of labor."



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Very clear for primary cortical regions (visual, auditory, ss, motor).
Less clear for most others, except...

Summary on Cortical Area MT

MT fulfills all the criteria for a cortical area:

- Distinctive function: motion processing
  - lots of lines of evidence (remember these)
- Distinctive connectivity (best data from monkeys)
- Distinctive cytoarchitecture (best data from monkeys)