Lecture 1: Introduction

Cognitive Neuroscience (PSY493)

Paul Whissell, Ph.D.

Overview

- Part 1: What is Cognitive Neuroscience?
- Part 2: Syllabus Information
- Part 3: History of Cognitive Neuroscience
- Part 4: Neuroanatomy – A Quick Review

Let’s start with some big questions…

When you're at a party…

- …you're in a rich auditory environment (e.g. conversations, loud music, ambient noises + more)

- Yet somehow, auditory stimuli meaningful to you – such as your **name** – instantly grab your attention

How is this possible?

When it comes to emotions…

…is it better to **suppress** or **reassess**?

Which strategy works best?
How is either strategy even possible?

Can a computer read your mind?

- Answer: kinda, yeah!* (**above chance**)

How accurate is the computer?
How do we train a computer to do this?
Why would I ever want anyone to read my mind?

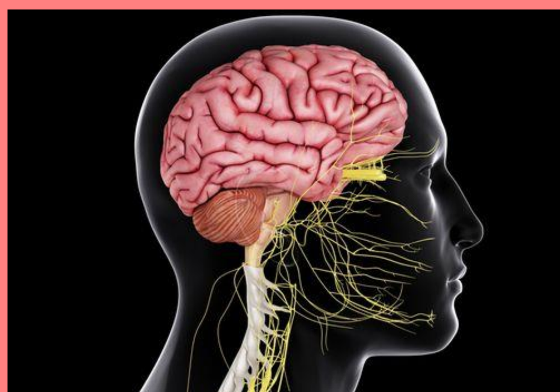
What is **consciousness?**

Are there varying states of consciousness?
If states exist, how does the brain create them?
What functional purpose would different states serve?

If these types of things pique your curiosity, then **cognitive neuroscience** is for you.

What is **Cognitive Neuroscience?**

Cognitive Neuroscience
The neural basis of cognition



Neuroscience
Study of the nervous system

Cognition
process of knowing, reasoning and understanding

How is this course different from…

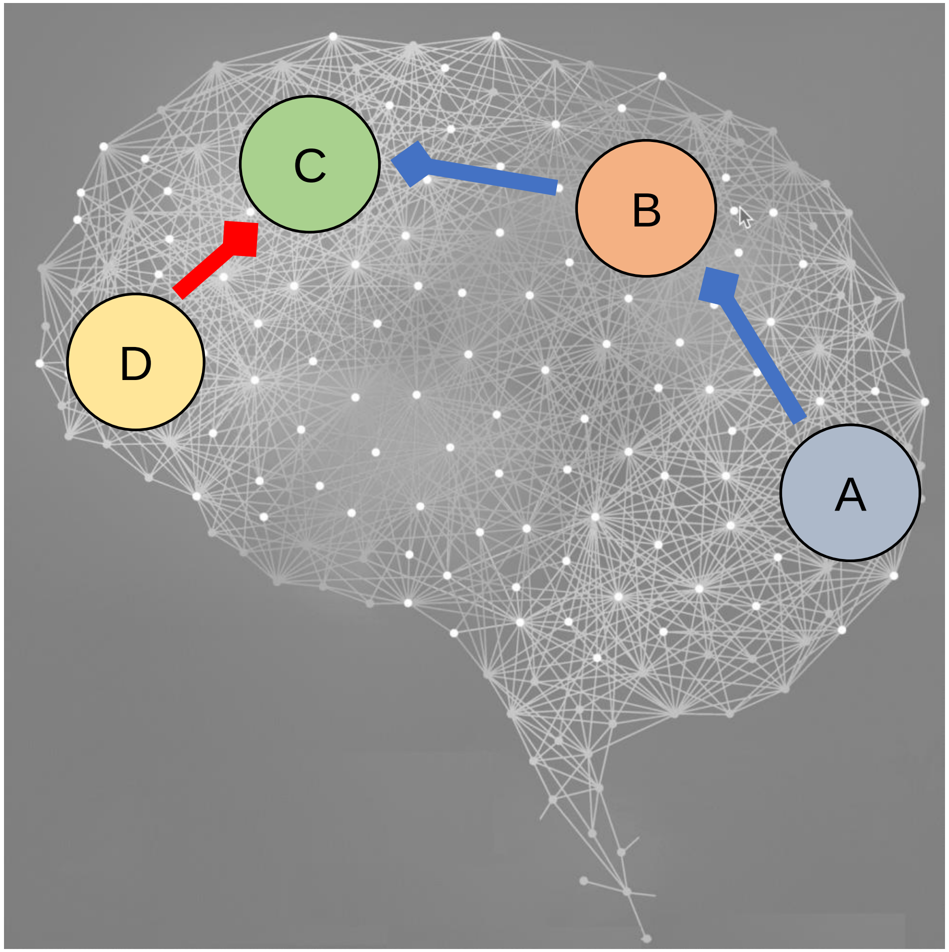
- *….Cognitive Science* (COG250)?
  - *Our course is less theoretical and* ***more experimental***

- *…Cognitive Psychology* (PSY270)?
  - *Our course focuses less on the properties of behaviors and more on* ***how behaviors are generated***

- …*Physiological Psychology* (PSY290) or *Introduction to Neuroscience* (HMB200)?
  - *Our courses focuses less on specific biological processes* (e.g. synaptic transmission, action potentials…)
  - *Our course focuses more on* ***experimental methods (e.g. neuroimaging) and experimental structure***

The ‘network-based approach’

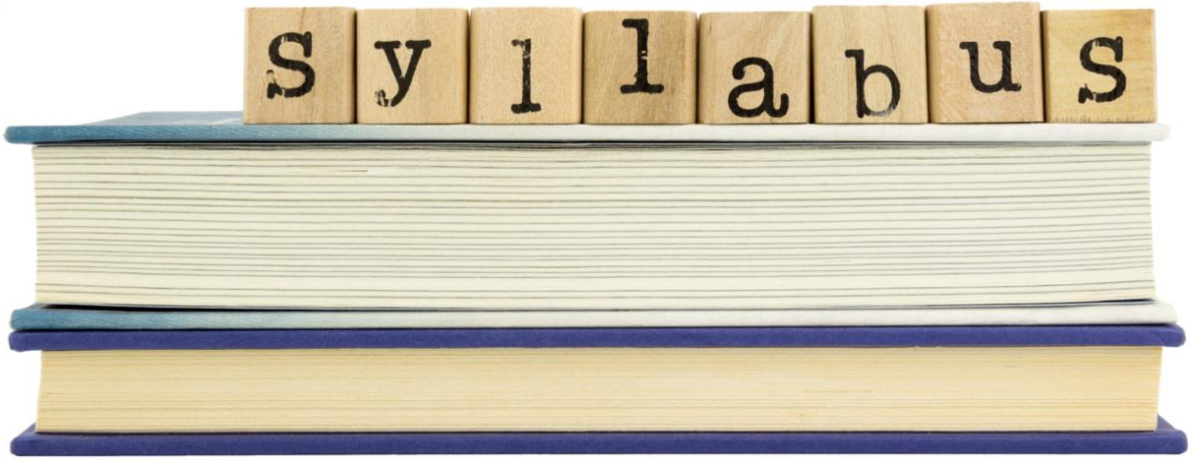
- How brain areas ‘work together’ to generate a behavior



In a given network, you might ask…

- Which brain areas are involved?
- What is the nature of processing?
- How do the brain areas influence each other?
- Does **experience** matter? If so, when and why?
- What types of changes in brain activity have consequences? Are all changes equally meaningful?

Part 2: Syllabus Information



Contact Hours

- **Instructor email:** paul.whissell@utoronto.ca
- **Virtual office hours** will be held every Friday, from 2 – 4 pm on BB Collaborate
- Outside of virtual office hours, I will be available via email (but will take ~48 hours to respond)*
- In the interest of getting a response as fast as possible, virtual office hours >>> email

Course Delivery

- **Asynchronous delivery**
  - Lectures do not occur at specific times
  - You are not required to attend any specific live events

- By Friday @ 11:59 pm every week, **lecture slides** (.pdf format) and **lecture recordings** (.mov format) will be posted according to the course schedule

- **Lecture slides** are available on Quercus

- **Links to lecture recordings** will be provided on Quercus in the announcements, and in a separate file

The recordings and the slides are very similar. Do I **have** to listen to the recordings?

You should.

The majority of questions are based on material straight from the slides (~90-95%).

A small amount of questions (~5-10%) are based on material only in the recording.

Marks Distribution + Major Dates

- **25% Test 1**, on **Oct 9 for 24 hours** based on L1 – 4
  - 2 hours; 30 MC + 5 WA questions worth 6 marks (60 marks)
- **25% Test 2** on **Nov 20 for 24 hours** based on L5 – 8
  - 2 hours; 30 MC + 5 WA questions worth 6 marks (60 marks)
- **35% Final Assessment between Dec 11 – 22** based on L1 – 10 (cumulative)
  - 3 hours; Format TBA

Tests

- **15% Research Assignment on Dec 4**
  - Format TBA

Specific Topics

- Introduction
- Methods
- Attention
- Sensation/Perception
- Memory
- Language
- Emotion
- Cognitive Control
- Social Cognition
- Consciousness

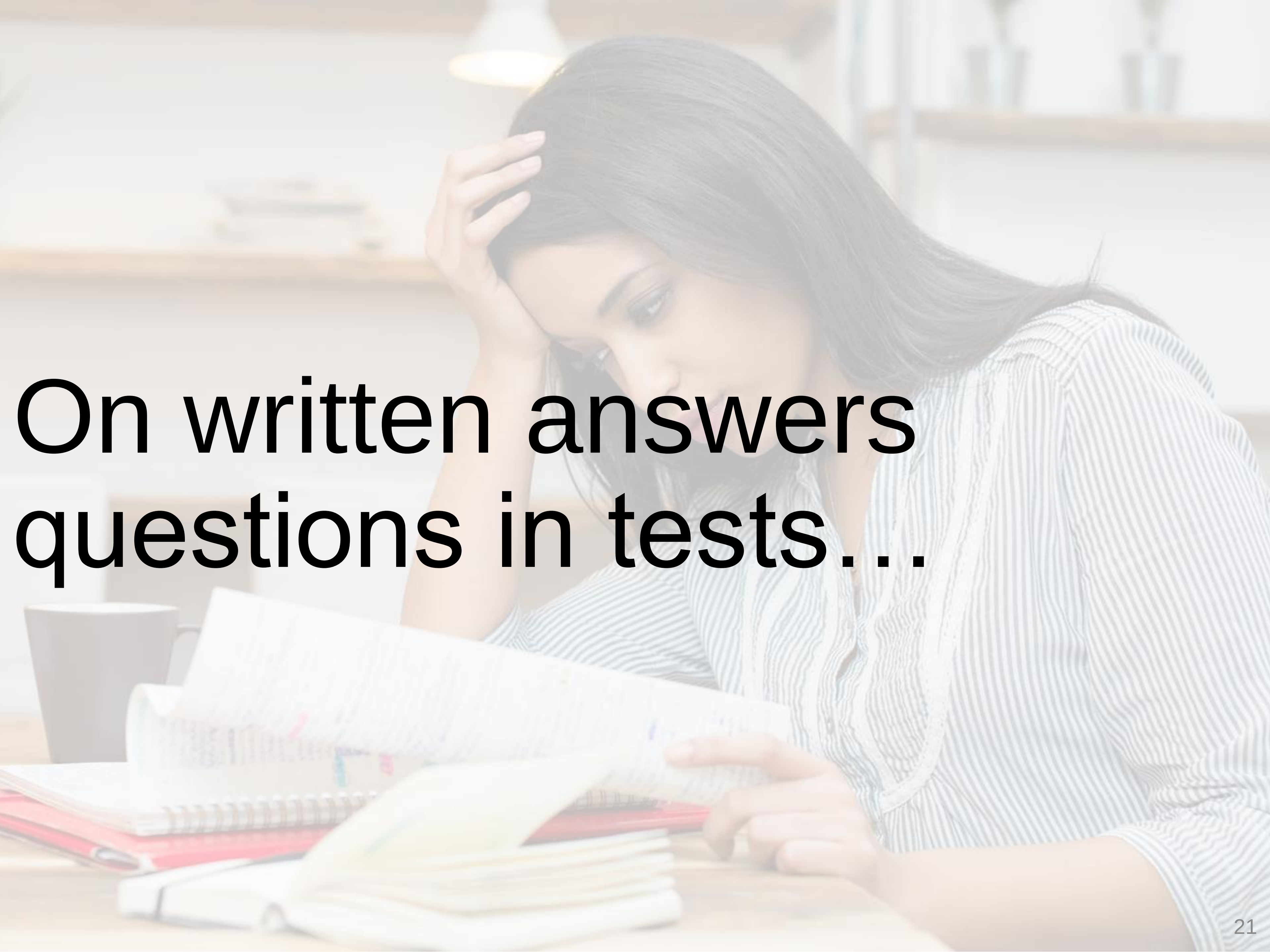
Test 1

Test 2

FA

About testing format …

- **Tests will be available for 24 hours** (i.e. from 12:01 am to 11:59 pm)
- You can start the test any time, but you **MUST** submit it before 11:59 pm
- Once you start the test, **you only have 2 hours to complete it (3 hours for final)**
- Make sure to start the test prepared (come with notes, lectures + back-up options in case of computer/connection trouble)



On written answers questions in tests…

Importantly…

- **All work should be your own thoughts, in your own words**

- You will be asked to sign an honor pledge as part of each assessment

- For certain assessments (e.g. research assignment), you will be asked to submit to **TurnItIn**

- These policies are in the interest of fairness to all students

The next part of your grade…

- 25% Test 1, on Oct 9 for 24 hours based on L1 – 4
  - 2 hours; 30 MC + 5 WA questions worth 6 marks (60 marks)

- 25% Test 2 on Nov 20 for 24 hours based on L5 – 8
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- 35% Final Assessment between Dec 11 – 22 based on L1 – 10 (cumulative)
  - 3 hours; Format TBA

Assignment

- **15% Research Assignment on Dec 4**
  - Format TBA

On the research assignment…

- Will require you to delve into original research papers in the area of cognitive neuroscience
- Similar to an independent research project
- There will be some choice in topic (from an approved list) and some training in presentation
- Comes later in the term, when your knowledge base/skills are better developed

Performance in the course

- The Psychology program is awesome, but competitive
- Consistent with this high standard, PSY493 will require you to learn a lot of content and use that content to solve challenging, conceptual problems
- Our average ranges from **70 – 75% every year**
  - **B+ grades or higher are common with hard work**
- Throughout the year, I'll be available to you and do whatever I can to help you achieve the best performance possible

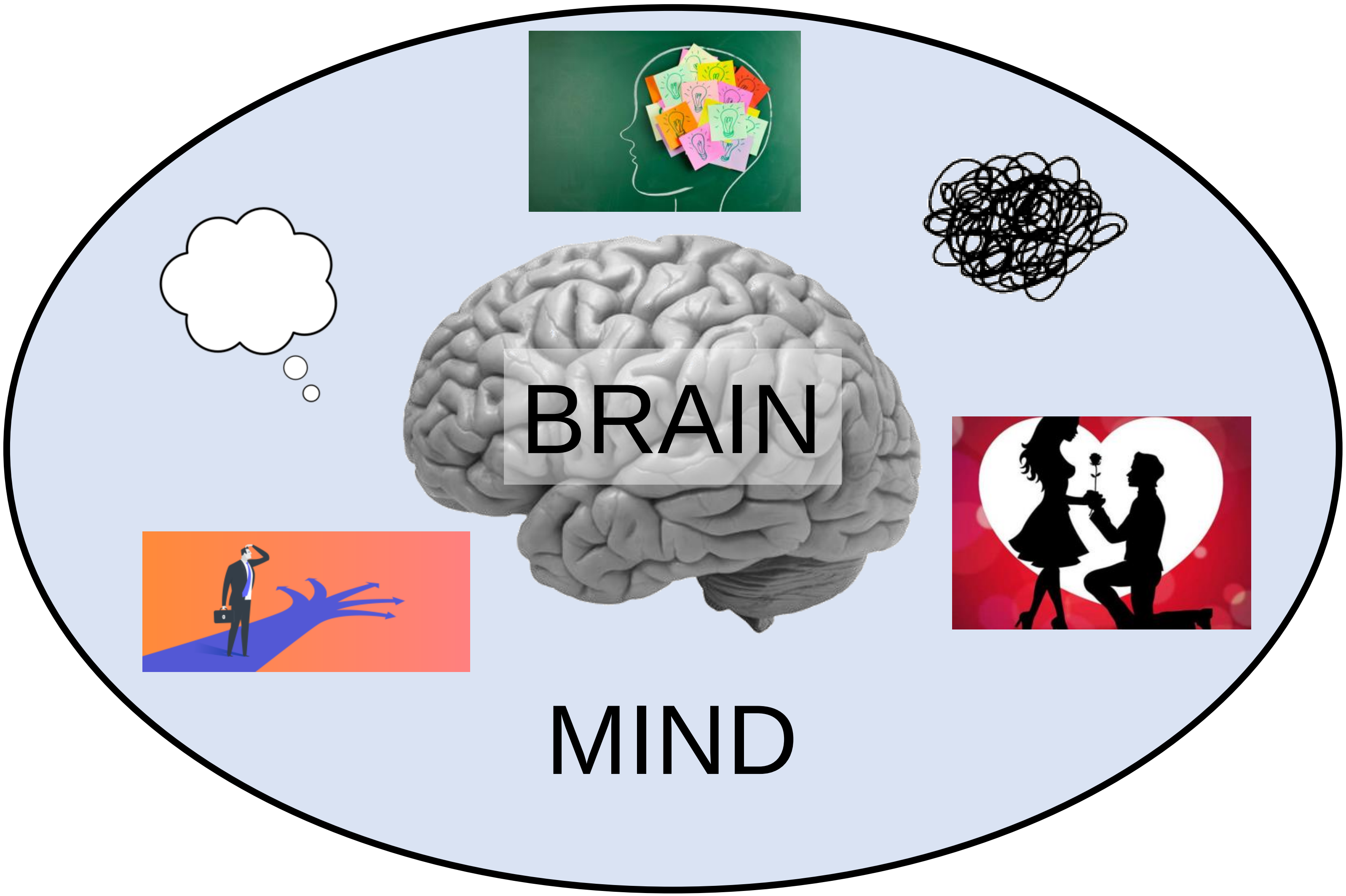
Part 3: History of Cognitive Neuroscience

How did we get to the point where we are studying the ‘neural basis of cognition’?

Emergence of the sciences

- The idea that the natural world could be studied as an object (i.e. scientifically) has been around since the time of the ancient Greeks
- However, the idea of studying the brain, behavior or thoughts is relatively new
- In fact, such sciences are among the youngest sciences we have
- Psychology is roughly 140 years old whereas *Cognitive Neuroscience is only about 40 years old*

Consider the following…



Are the two separate? Are the two related?
How do we know?

From philosophy to medicine – 1

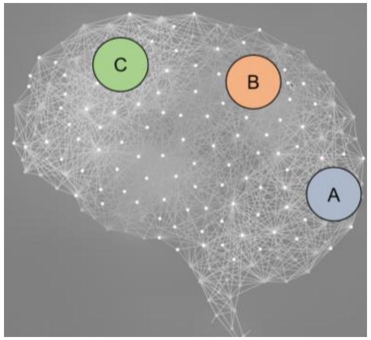
- Physicians of the ancient world argued for a role of the brain in behavior, from **Hippocrates** (~400 BCE) to **Galen** (2nd century AD)
  - Biology (i.e. the brain) affecting psychology (i.e. behavior)
  - How the brain accomplished this was not understood

- Many physicians noticed the correlation between brain injury and behavior over the years, but rarely was detailed anatomical data collected

- **Willis (mid 17th century)** was one of the first researchers to study the anatomy of the brain in detail
  - Willis and his colleague **Wren** produced a number of high-quality drawings of the brain (good for 200 years!)

From philosophy to medicine – 2

- **Gall** (18th century) further argued that **different brain regions had different functions**
  - This idea (**localized brain function)** is still being debated

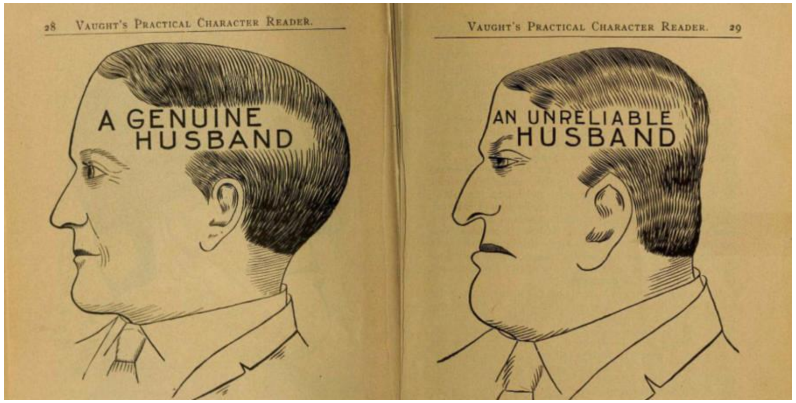


A, B + C are different parts of the brain
A, B + C have different functions

- Gall, w/others such as Spurzheim, also suggested **that brain areas developed with use**
  - This idea (**experience-dependent neuroplasticity**) is now widely accepted. But the form first proposed will surprise you.

Phrenology

- Brain areas were related to mental traits and would change in size with use of those traits
- Changes in the brain would cause changes in the cranium (e.g. brain area expands, deforms cranium)
- By measuring the cranium, you would understand the brain underneath + the mental traits it governs



Phrenology

- To everyone today and many people of the time, phrenology was considered a pseudoscience
- However, it included a few concepts which would later be shown to be well-supported by data
- Much data suggests the brain changes w/experience, *but changes are subtle + never visible externally*
- In fact, *meaningful changes in the brain (i.e. those changes which affect behavior) are so subtle they are often undetectable even by our best tools*

At this point, you might ask ‘how do we measure changes in the brain’? This is a great question – hold on to it for now.

From correlations to experiments

- So far, we've focused on physicians noticing **correlational relationships** between brain damage and behavior

- Correlations are informative, but limited in their usefulness. They cannot be used to infer causation.

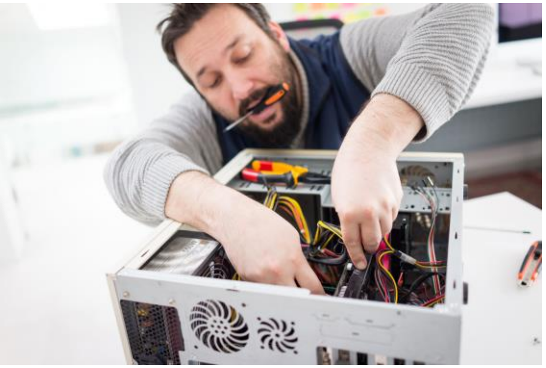
- To accumulate evidence for **causal relationships between brain and behavior**, we must do a controlled **experiment** in which we manipulate the brain and measure behavior

The experimental approach

- Allows for us to infer **causal** relationships between variables (i.e. brain and behavior)
- An **experiment** is a controlled environment wherein we study the relationship between a defined set of variables by controlling all the rest
- Simplest case: The researcher manipulates one variable (**independent variable/IV**) while measuring another (**dependent variable/DV**)
- **All other variables** are kept constant if possible

Analogy

Studying the brain using an experiment is somewhat like fixing a broken computer



- You change ONE PART, keeping OTHER PARTS the same. After making the change, you check to see if the computer FUNCTIONS properly
- If you change ONE PART and the system FUNCTIONS properly, the one part that you changed was likely the **cause** of your problem

The experimental approach

Cause		Effect
Manipulated		Measured
Independent variable	→	Dependent variable
Brain manipulation	→	Behavioral result

Because all variables are kept constant but the IV, any change in the DV must be due to the IV

How do we ‘manipulate’ the brain?

- Many available techniques, which we will cover extensively in Lecture 2
- To simplify for now, we can consider methods which deactivate brain areas (e.g. lesions) and methods which activate brain areas (e.g. stimulation)
- **Fluorens’** work (19^{th} century) studied the effects of lesions to the nervous system on behavior in birds
- **Fristch and Hitzig** (19^{th} century) also showed how stimulation of a dog’s brain elicited specific movements

As experimental evidence built up…

…correlational evidence from medical experts continued to accumulate and increase in quality

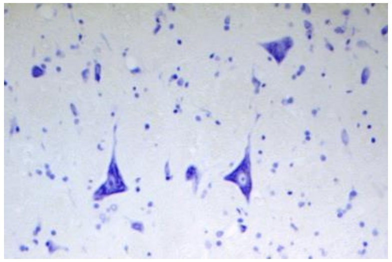
- **Dax** noted relationships between left hemisphere damage and language impairment (**aphasia**)
- **Wernicke** + **Broca** noted a relationship between damage to specific brain regions + specific aphasias
- **Jackson** hypothesized that the stereotyped sequence of behaviors during a seizure was due to a sequence of brain areas (w/different functions) being activated

In parallel with these discoveries, new biological techniques began to develop.

These techniques greatly enhanced our understanding of the brain.

The Brodmann Map (1909)

- Cell staining methods made it possible for us to observe the organization of neurons in the brain



Nissl stain revealing neuronal structure + organization

- Using these methods, Brodmann studied the histological structure/organization of neurons (**cytoarchitecture**)

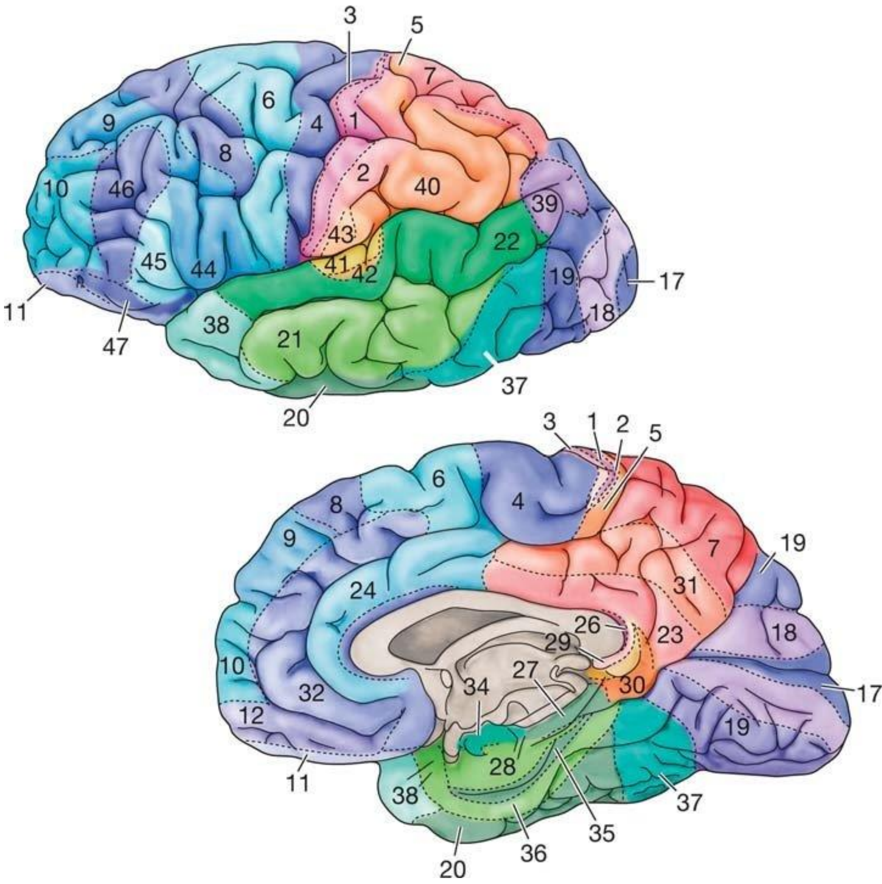
- Logic: Differences in properties likely had functional consequences. *If you map out cell properties, you map out functions.*

The Brodmann Map

- **52 Brodmann Areas (BA)** which each might serve a different function*

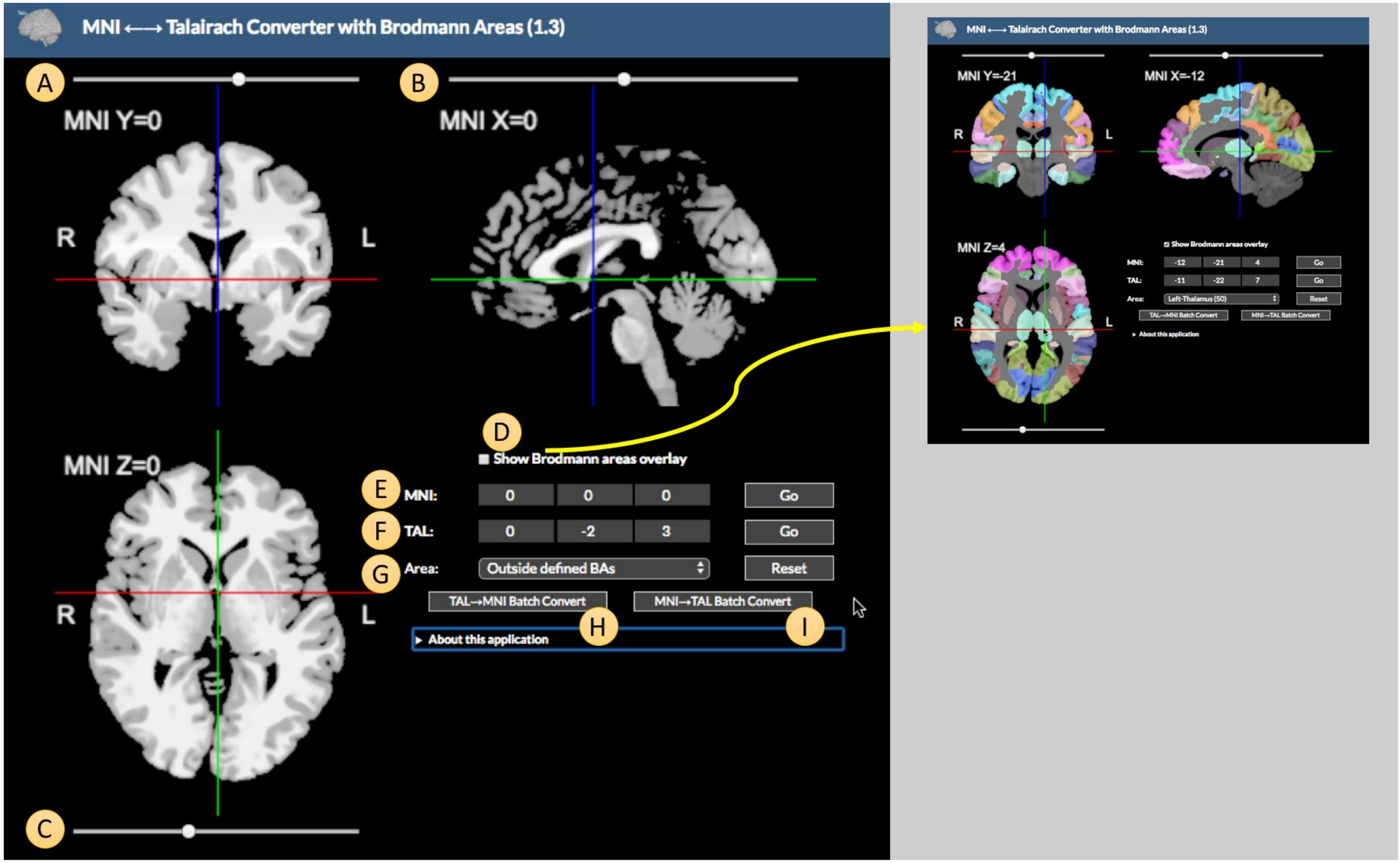
- Though imperfect, this map was very influential and is still in use today
  - Neuroimaging techniques (common in Cog Neuro) often refer to BAs

- In this course, we will frequently refer to BAs



Today…

- BA maps have influenced the development of Talairach/MNI coordinate systems, which we now use in stereotaxic surgery and experimental approaches



However…

- The BA map seems consistent w/the **localization of function idea** (one brain area, one function)

- Gradually, we've moved from an extreme localization of function position to a more moderate view

- Today, we understand that a single brain area can serve multiple functions and any one behavior is the result of multiple brain areas working together

- We also appreciate that reorganization of the brain can occur w/experience + injury

On the study of behavior…

- So far, we’ve talked about linking brain to behavior in general, but have not been especially specific
- The term ‘behavior’ is broad and includes many things, namely thoughts (mental processes)
  - Mental processes are the focus of cognitive scientists
- For a long time, *the experimental study of mental processes was considered impractical + unnecessary*
- *It’s worth discussing why this was the case, and why things changed*

History of Psychology

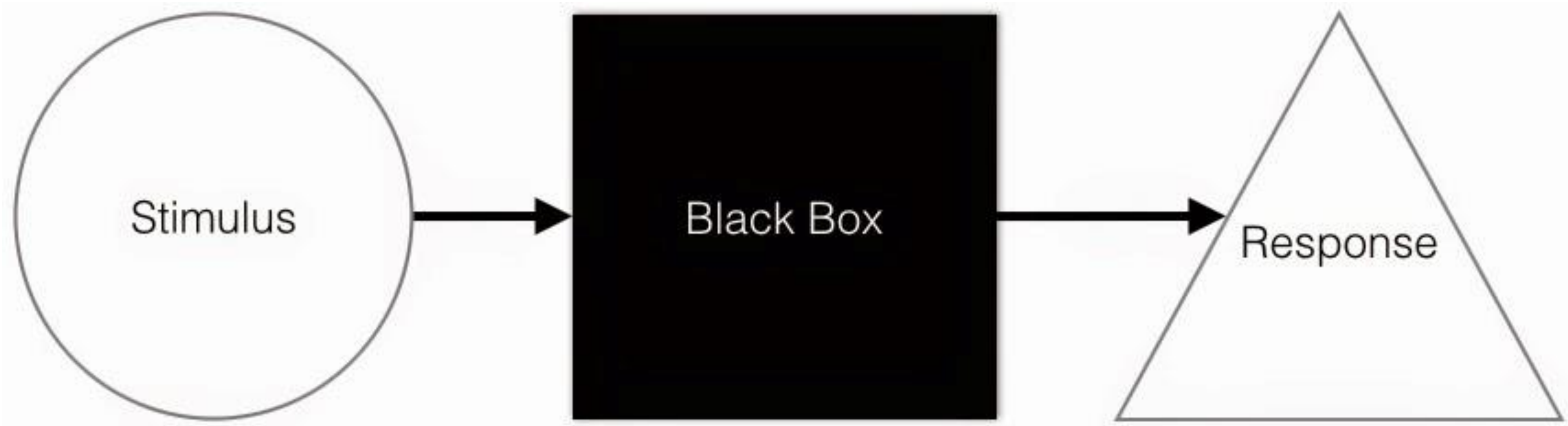
- **Structuralism:** Strived to identify the contents of mental processes through analytic introspection (not successful)

- **Functionalism:** Focused on the purpose (i.e. adaptive function) of mental processes, but not their contents

- **Psychodynamics:** Focused on mental processes but was not experimental

- **Behaviorism:** Ignored mental processes, focused on circumstances that modify behavior

Behaviorism



Any change in the internal or external environment

Mental thought processes (not practical to measure)

Activity

Behaviorism focuses on 1) the relationship between stimuli and 2) the relationship between stimuli and responses, which is moderated by reinforcement + punishment.

Behaviorism - Reinforcement

- In both humans and animals, **behavior can be shaped by its consequences**

	Reinforcement (Increase / maintain behavior)	**Punishment** (Decrease behavior)
Positive (add stimulus)	**Add** pleasant stimulus *to* **Increase / maintain** behavior	**Add** aversive stimulus *to* **Decrease** behavior
Negative (remove stimulus)	**Remove** aversive stimulus *to* **Increase / maintain** behavior	**Remove** pleasant stimulus *to* **Decrease** behavior

Watson + the Rise of Behaviorism

Introspection forms no essential part of its methods, nor is the scientific value of its data dependent upon the readiness with which they lend themselves to interpretation in terms of consciousness. . . . What we need to do is start work upon psychology *making **behavior**, not consciousness, the objective point of our attack*. (Watson, 1913)

“psychology . . . need no longer delude itself into thinking that it is making mental states the object of observation” (Watson, 1913).

Rise of Behaviorism

- Appealing concept, consistent w/the **Blank Slate** idea
- ‘Anyone can be anything’, depending upon the experiences that they have
- However, evidence gradually accumulated that mental processes were essential to understanding behavior
- Behaviorist perspectives could not predict every outcome

Limitations of Behaviorism

- Does not explain the development of **language** (as pointed out by **Chomsky** and other critics)
  - Children develop original, grammatically incorrect and socially inappropriate phrases never reinforced before
  - Not all behavior is learned; some might be innate

- Conflicts with **infant attachment theory**
  - Children who spend lots of time with their parents tend to rely less on their parents with time

- These issues highlighted the need to think differently about behavior, starting with a re-examination of the role of mental processes

Examining mental processes requires creative designs

Studying Decision-Making

Task 1

Press J key when you see a light.

Task 2

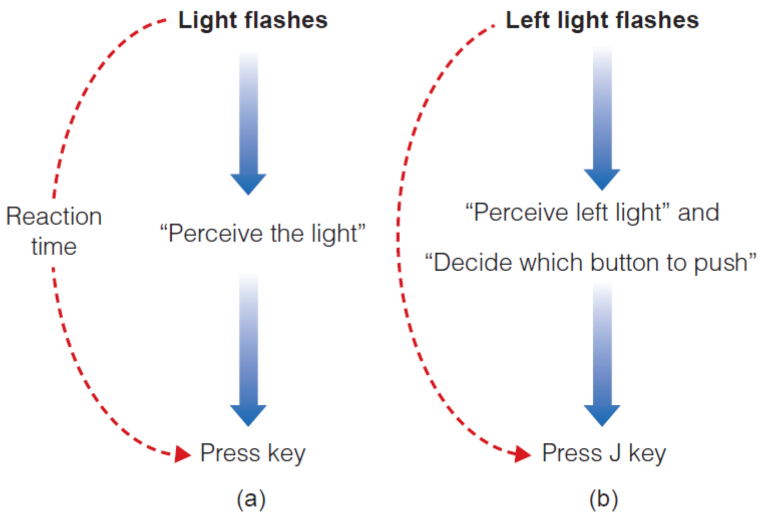
Press J key when you see a light on the left.
Press K key when you see a light on the right.

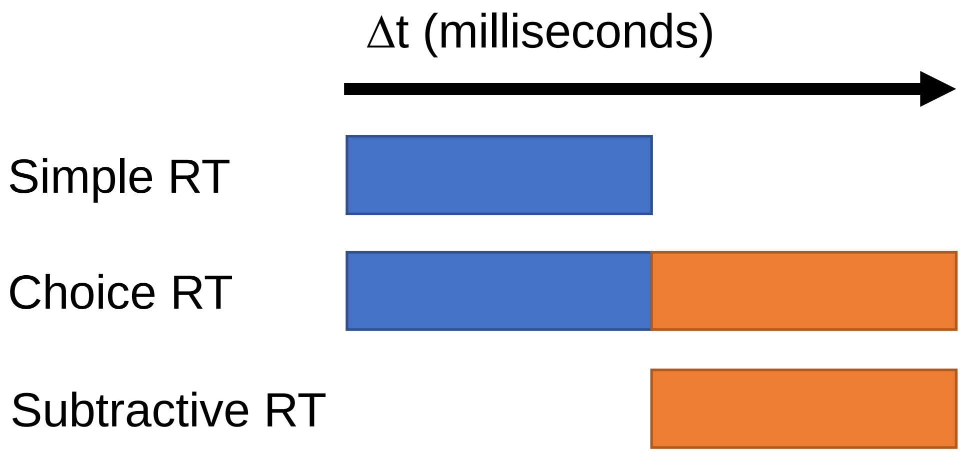
(a) Press J when light goes on. (b) Press J for left light, K for right.

Which task takes longer (has higher reaction time)?
Why did you answer the way you did?

Studying Decision-Making

- The additional step of decision-making requires time





- We can estimate the amount of time required to make the decision using **subtractive RT**:

Choice RT – Simple RT = Subtractive RT

Significance

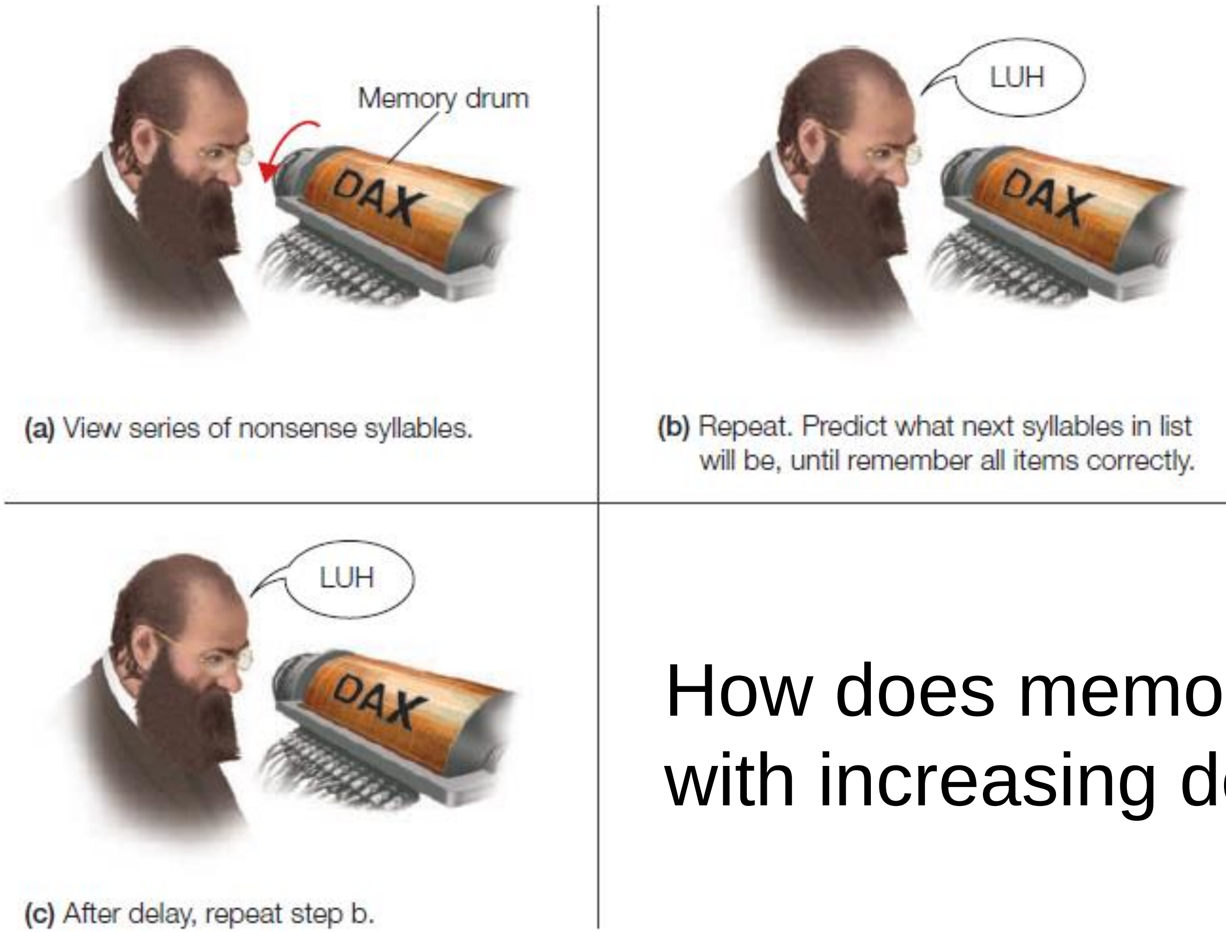
- This experiment, originally done by Donders in 1868, was remarkable in that it showed how we could *make inferences about mental processing from the observation of behavior*

- Specifically, Donders' study allowed us to estimate the time required for certain mental processes (**Mental Chronometry**)

- Variations on this approach are still used in cognitive experiments today

Ebbinghaus' Experiment

- Memorize a string of non-sense syllables (e.g. DAX, LUH, ZIF) in order and test memory after delays



(a) View series of nonsense syllables.

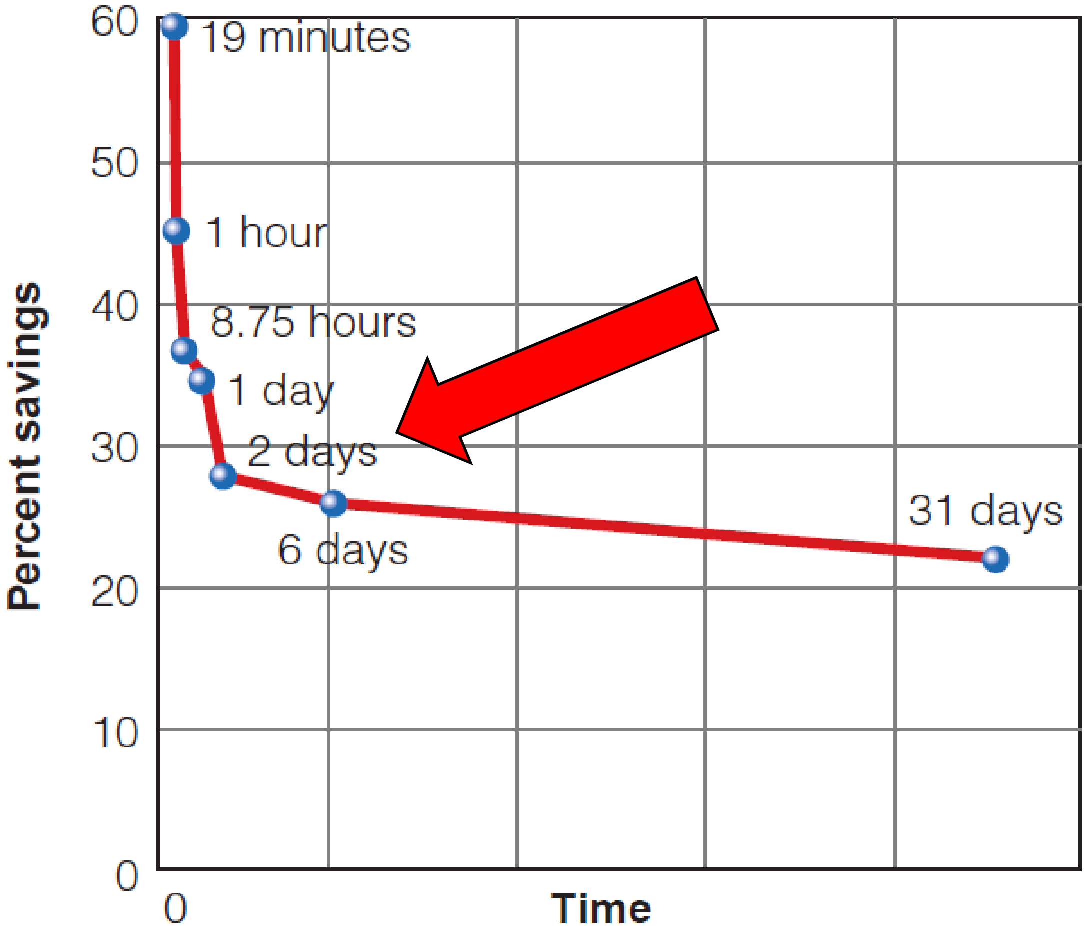
(b) Repeat. Predict what next syllables in list will be, until remember all items correctly.

(c) After delay, repeat step b.

How does memory change with increasing delays?

Ebbinghaus' experiment

- *Recall decreases over time* (due to **forgetting**). The rate + pattern of this decline can be quantified!



Note that most decline occurs quickly (~2 days).

Early experiments, in summary

- Insight into mental processes could be gained through studying behavior

- Though these early experiments were promising, it would be a long time (decades) before the study of mental processes was seriously pursued

- During the behaviorist era, interest died down

- Later developments in the mid-20th century – including Tolman's work, Cherry's work + the advent of computer technology – re-ignited an interest in mental processes

Influence of Computer Technology

- Once we created a way for computers to process information, *we started re-evaluating how humans processed information*

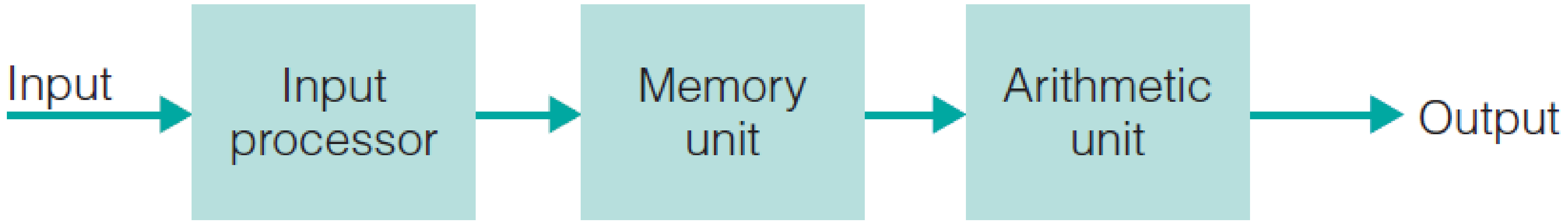
- Two conferences on computer technology were pivotal

- One was the Summer Research Project on AI (Dartmouth conference)
  - Simon + Newell present the first AI program (Logic Theorist)

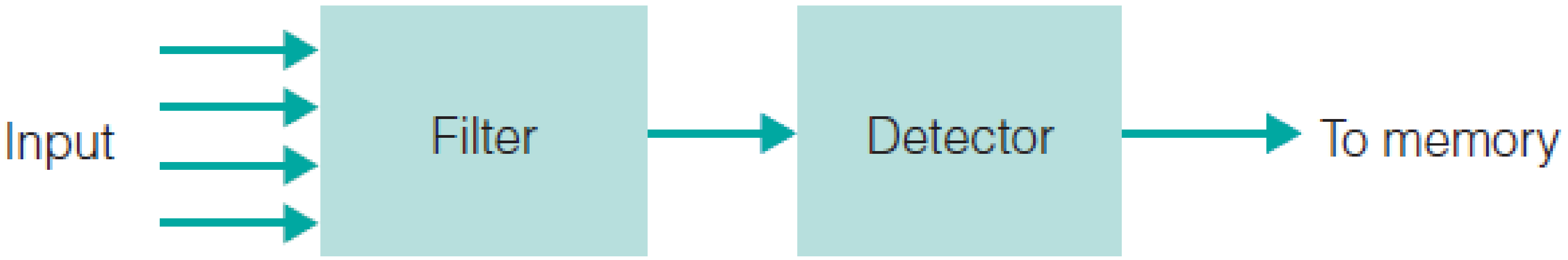
- Another was the MIT Symposium on Information Processing
  - Miller presents the ‘magical number 7’ studies

Influence of Computer Technology

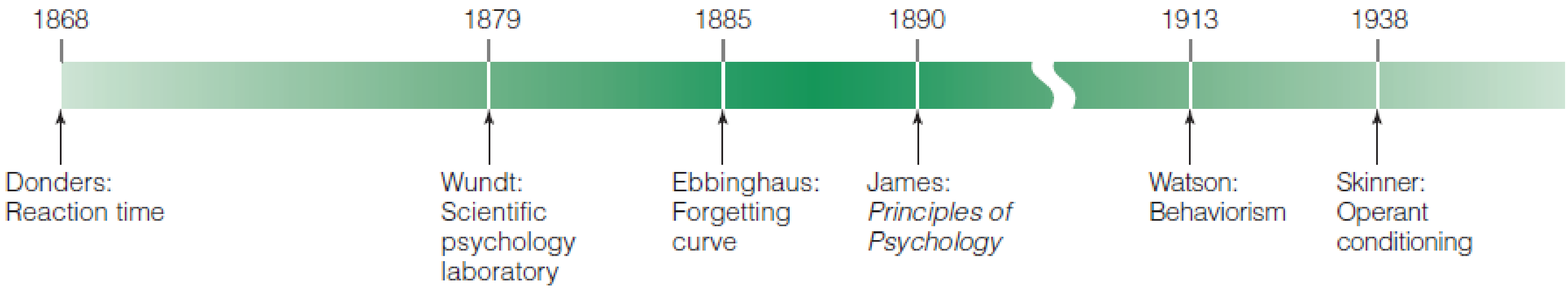
- The design of computers led us to reconsider the design of the human mind

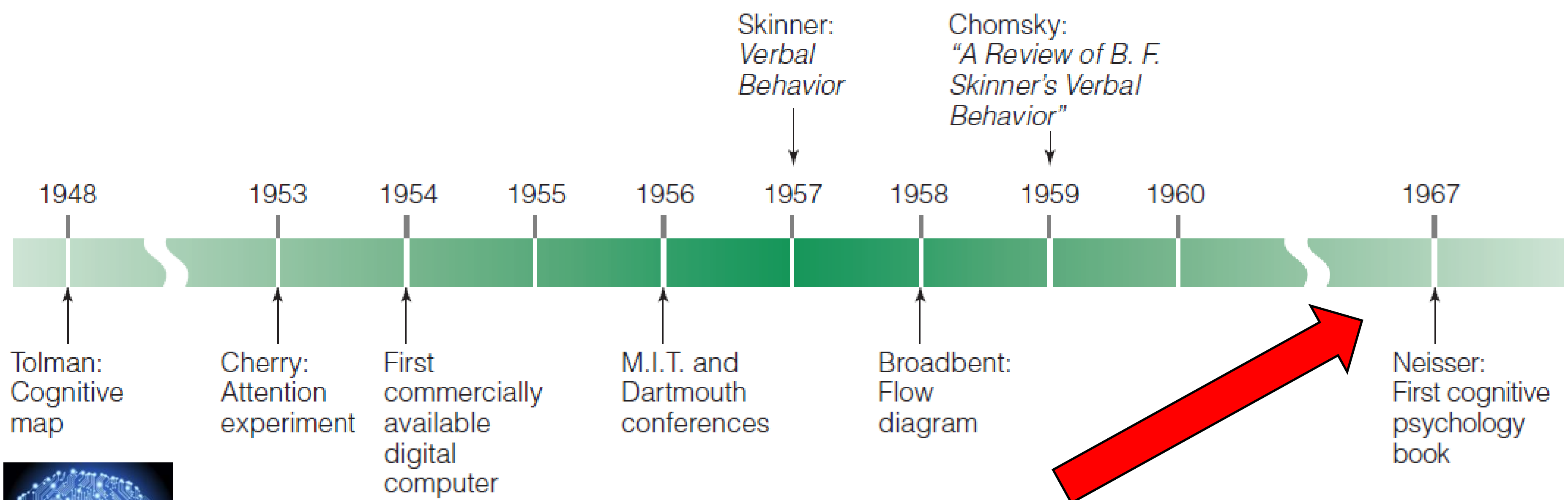


- **Broadbent's model of cognition** (which considers filtration and limits on processing) was as follows:



Towards the Cognitive Revolution





Beginning of the 'Cognitive Revolution'

At this point…

1. Based on correlational data, we've established a relationship between brain damage and behavior

2. Using biological methods, we've developed the ability to study brain structure post-mortem*

3. Using experimental studies, we've shown how manipulating the brain in live animals* can affect behavior

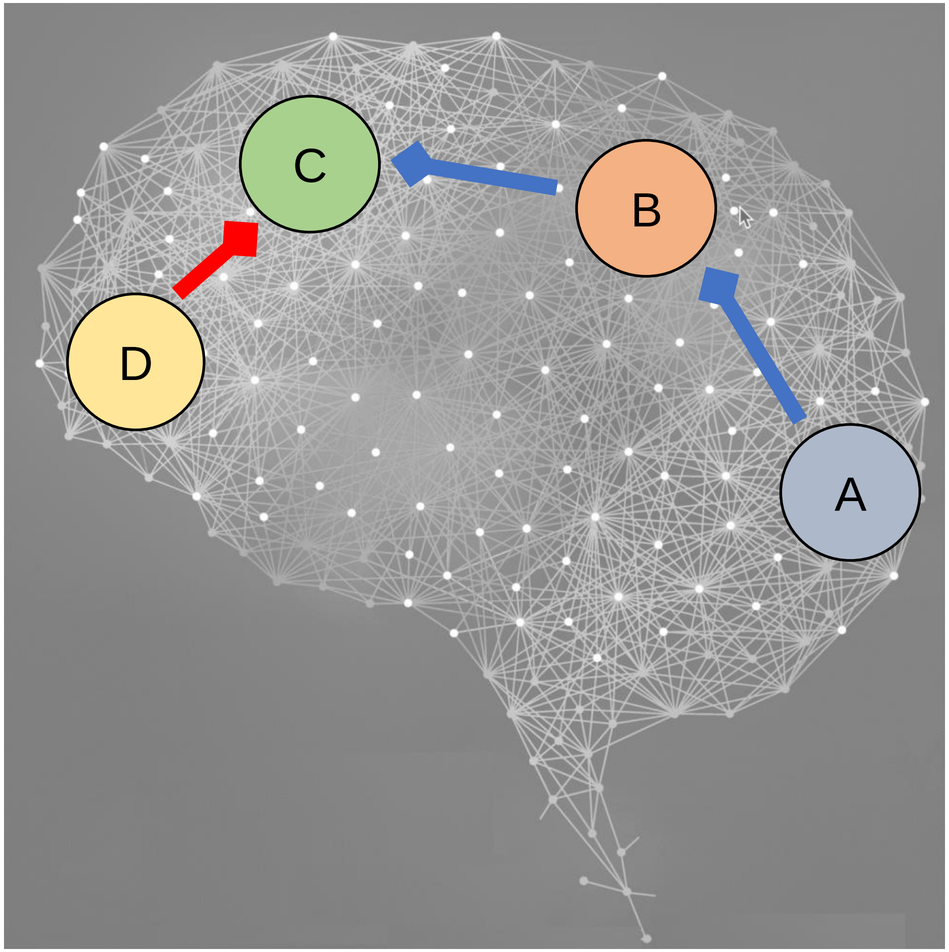
4. We've shown that studying mental processes is not only vital, but achievable, with the right approach

There is one final piece to the puzzle.

To really get insight into neural mechanism, we *must measure neural structure + activity in the live human brain*.

The ‘network-based approach’

- We need to measure **brain activity + structure in humans during cognitive tasks**



Measuring the brain

- Effective tools for measuring brain activity are quite new, some are less than 40 years old
- **Electroencephalography (EEG)** ~1920, with **Event-related Potential (ERP)** in ~1960
  - Measuring electrical activity
- **Positron Emission Tomography (PET)** ~ 1970
  - Measuring metabolism (glucose), structure
- **Functional Magnetic Resonance Imaging ~** 1990
  - Measuring blood oxygenation, structure

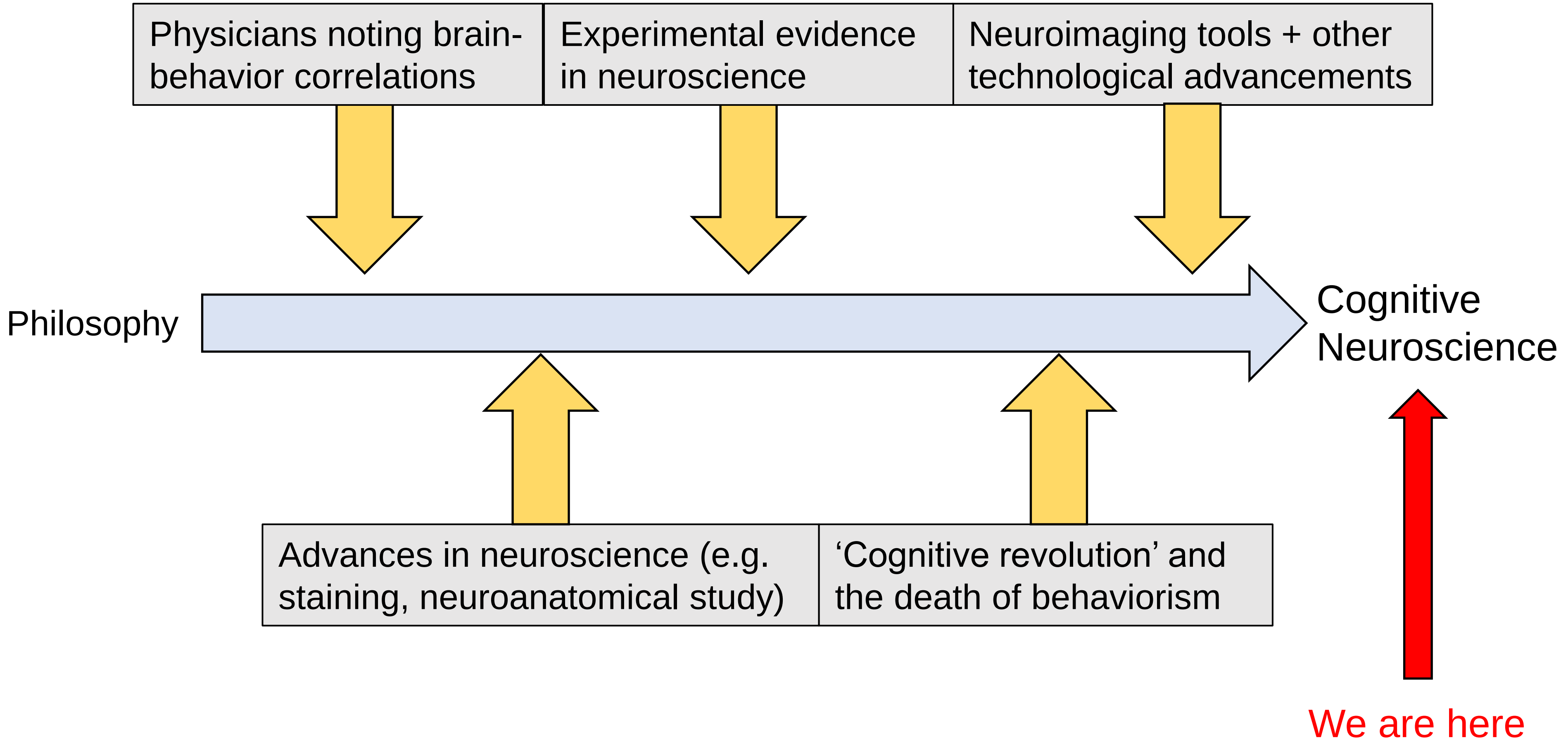
Measuring the brain

- With these tools, we can now study the **neural basis** of cognition

- Neuroimaging techniques in particular are a cornerstone of Cognitive Neuroscience, and will be a major focus of this course

- We'll be covering these techniques in Lecture 2 extensively

Timeline



Physicians noting brain-behavior correlations
Experimental evidence in neuroscience
Neuroimaging tools + other technological advancements
Philosophy
Cognitive Neuroscience
Advances in neuroscience (e.g. staining, neuroanatomical study)
'Cognitive revolution' and the death of behaviorism
We are here

Part 4: Neuroanatomy – A Quick Review

Back to basics

- *If we're going to study the neural basis of cognition, we need to be familiar with the nervous system*

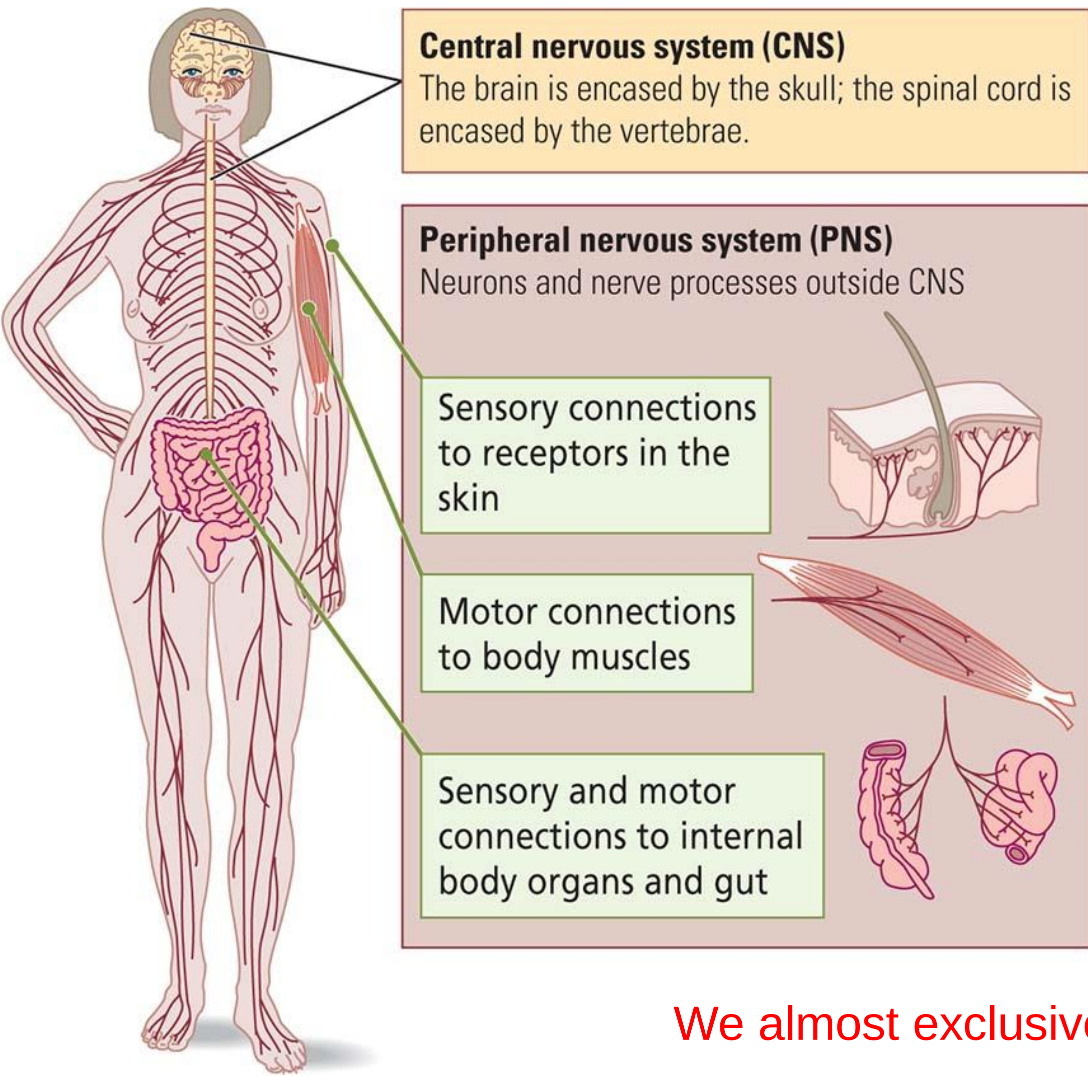
- Today, we'll do a review the main parts of the nervous system

- In each lecture, we'll revisit this overall plan and cover a specific group of brain areas in greater detail

- You'll gradually be building your knowledge of the brain throughout the term, a piece at a time

The Nervous System

- Divided into **central (CNS)** and **peripheral (PNS)**

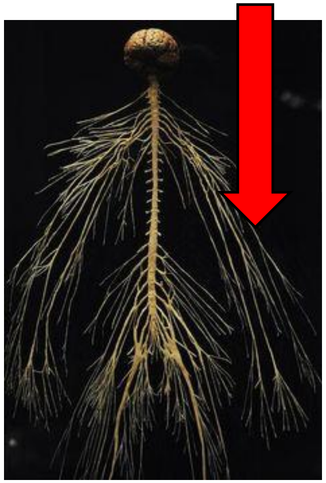


CNS = brain + spinal cord, encased in bone (skull and vertebrae, respectively)

PNS = everything else outside the CNS

CNS

PNS

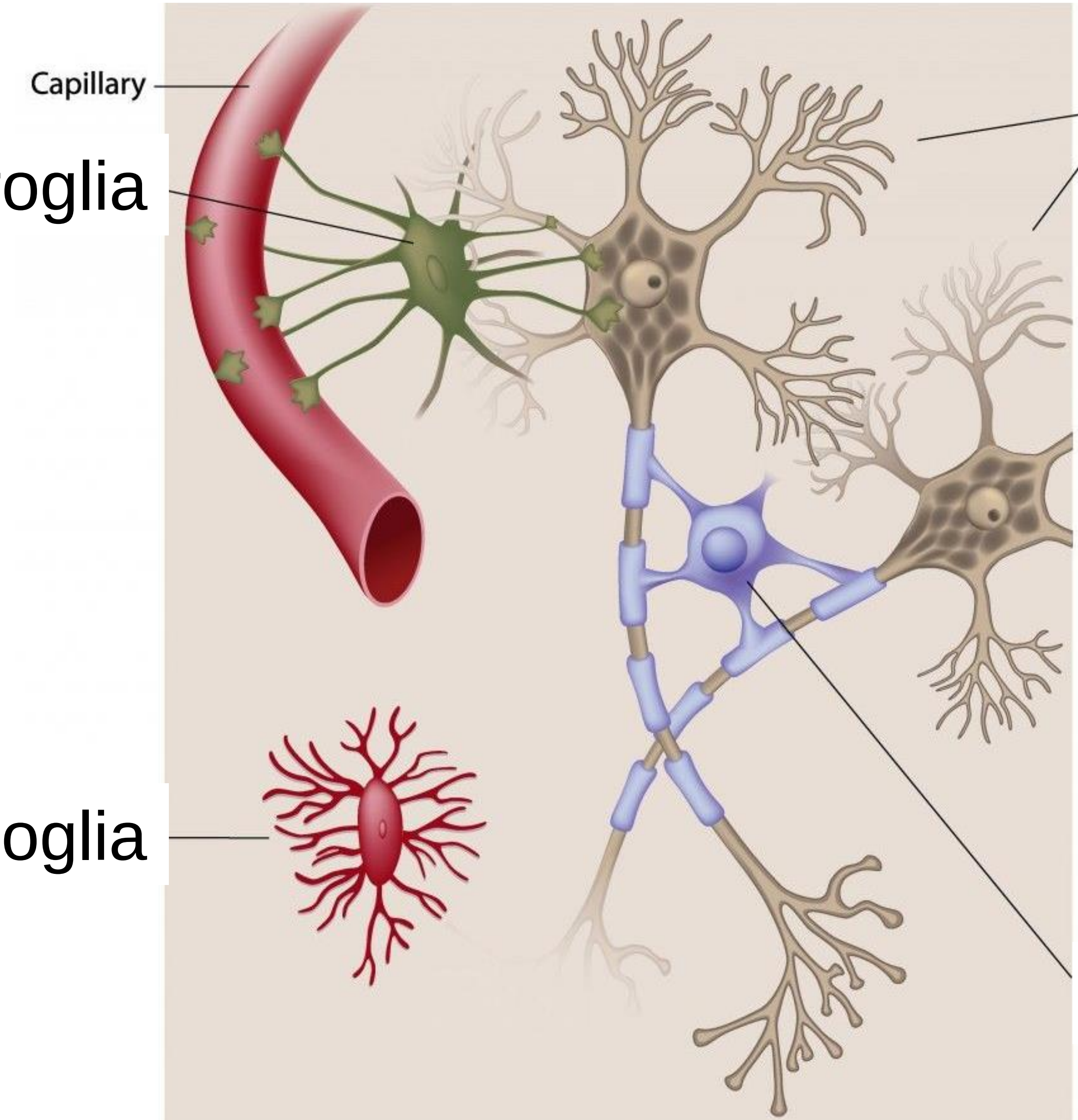


We almost exclusively focus on the CNS

Cells of the CNS

Astroglia

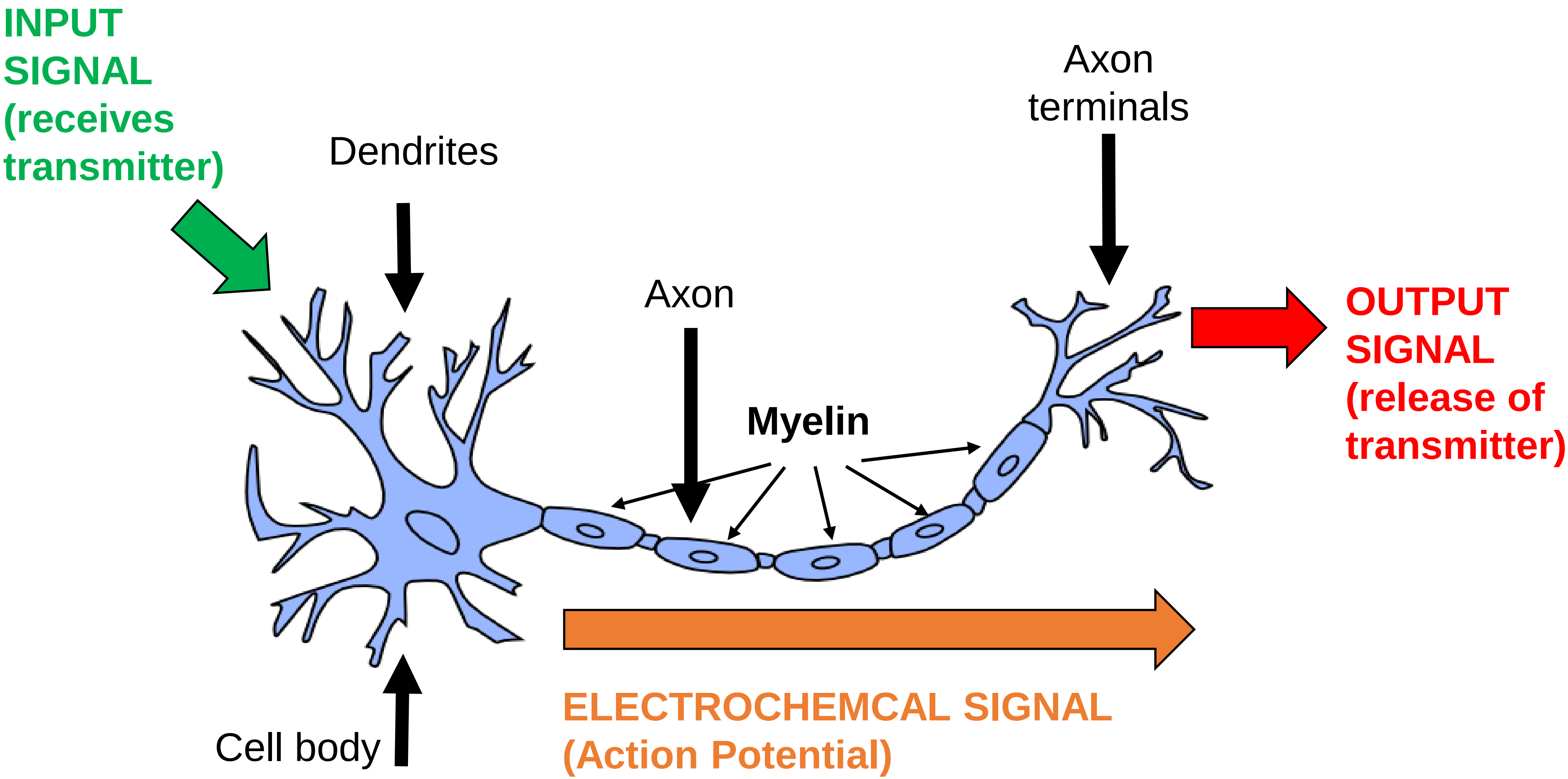
Microglia



Neurons

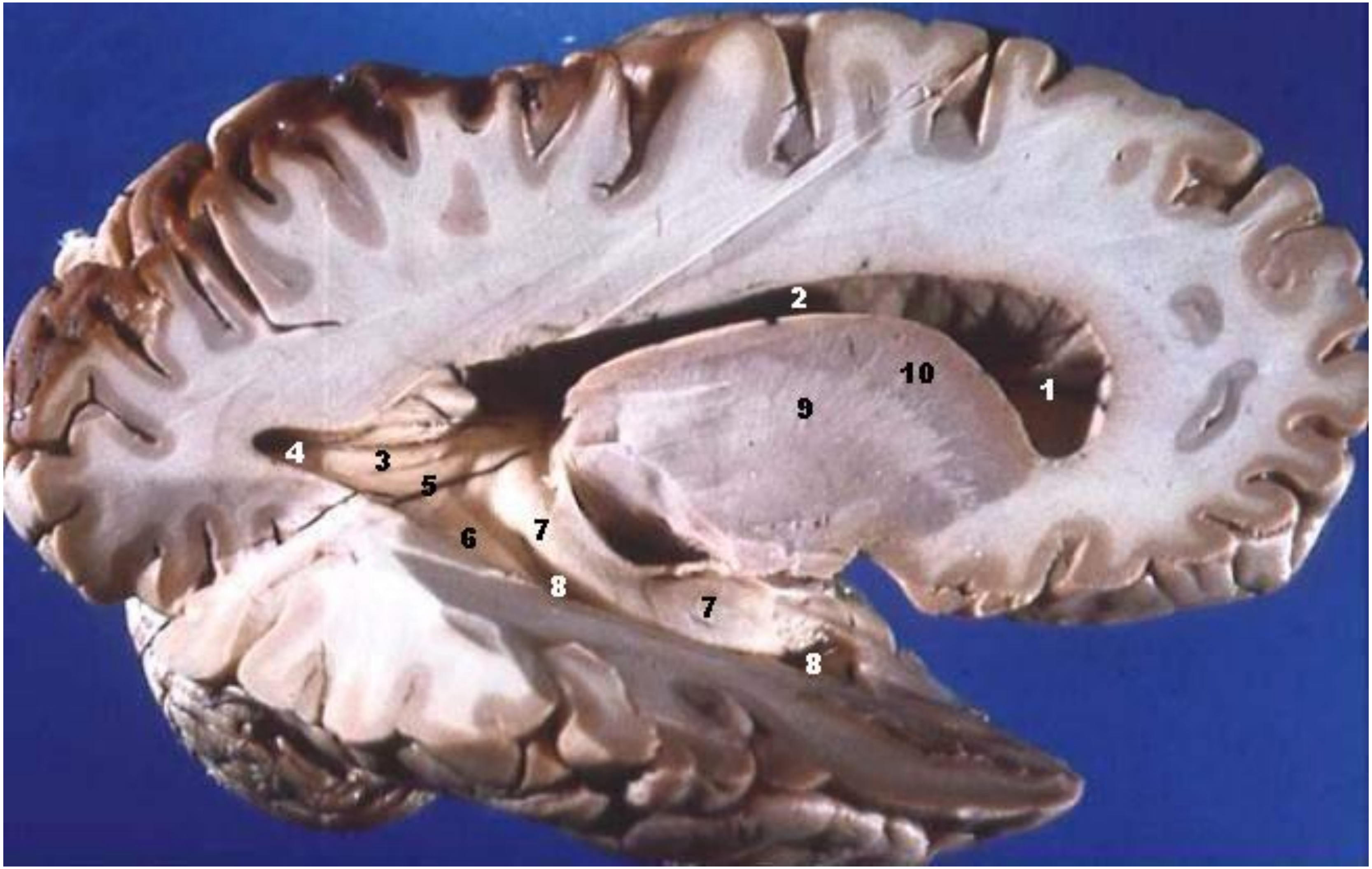
Oligodendroglia*

Neurons are our focus



Excitable cells that generate and conduct electrochemical signals. Later, we'll discuss in more detail why changes in firing rate as so important.

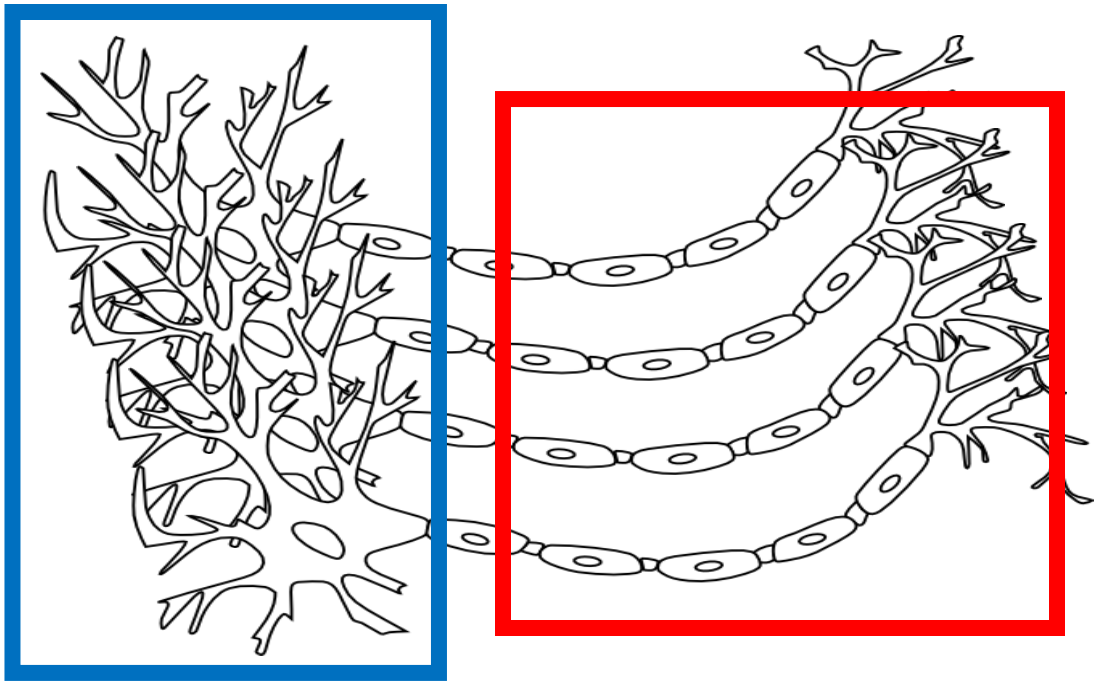
How are neurons organized?

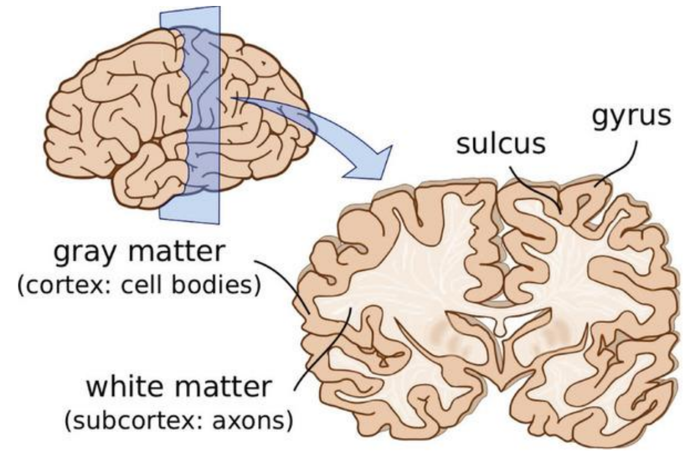


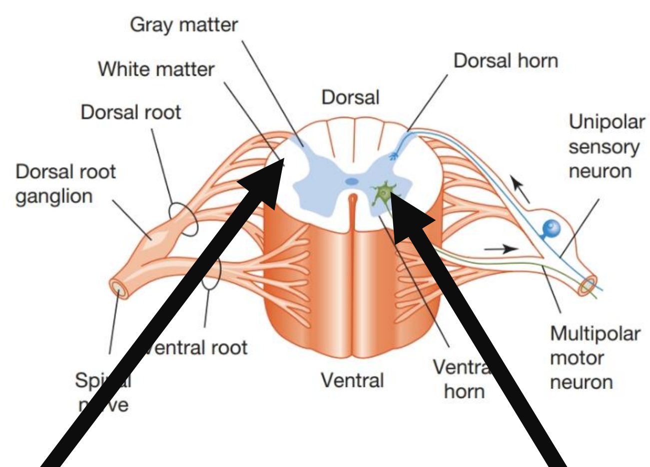
Organization of Cells in the CNS

Cell bodies
Nuclei
Gray matter

Axons
Tracts
White matter



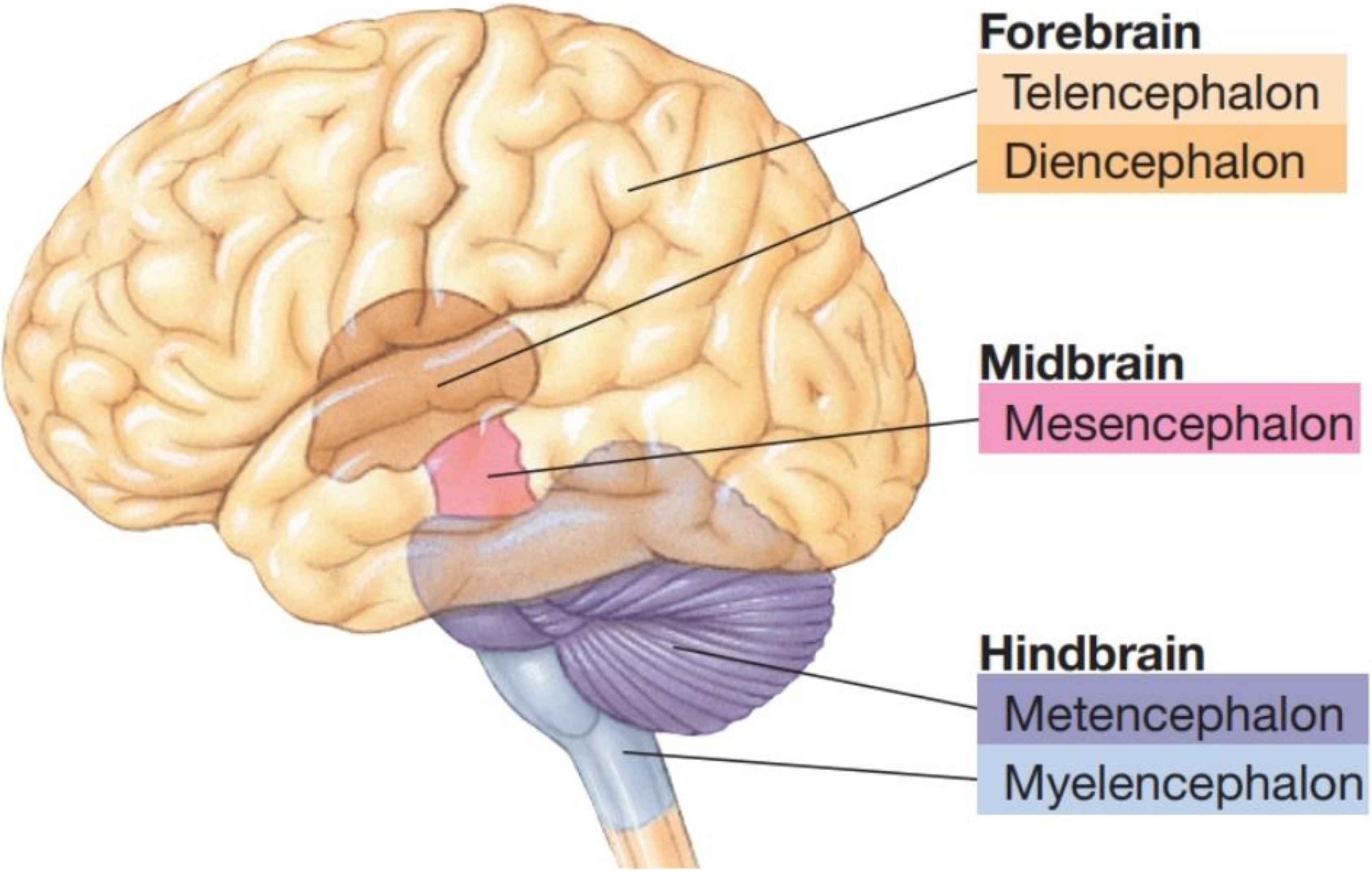




White
matter

Gray
matter

The Brain

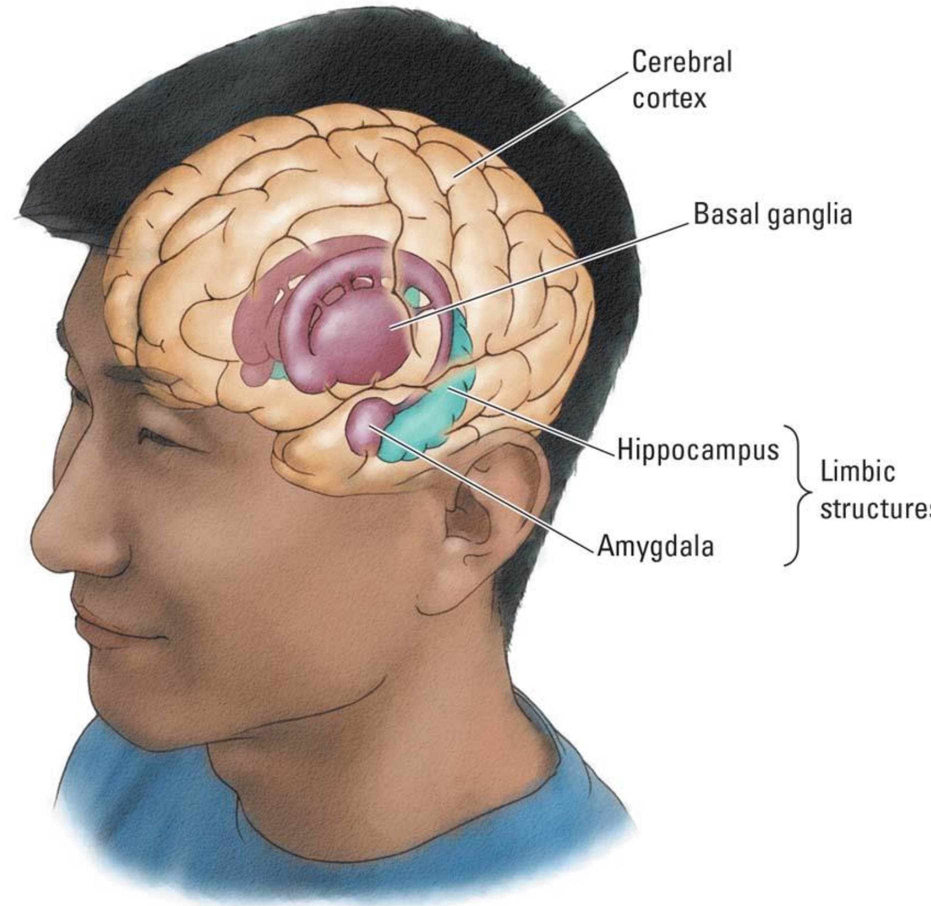


In this course we focus extensively on the telencephalon, occasionally discussing the mesencephalon, diencephalon and hindbrain.

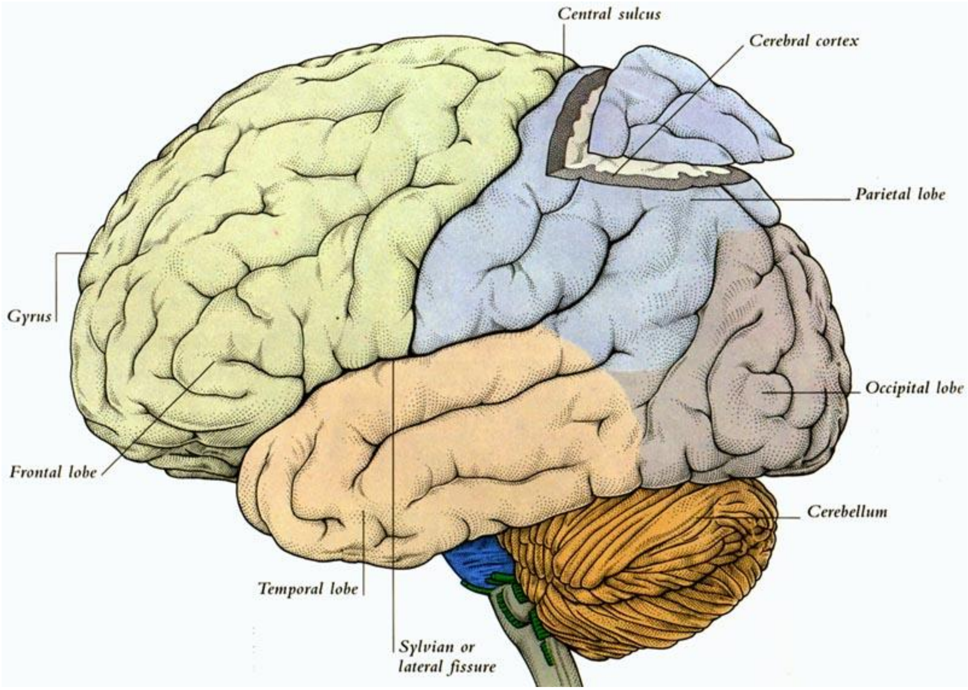
1 – Telencephalon

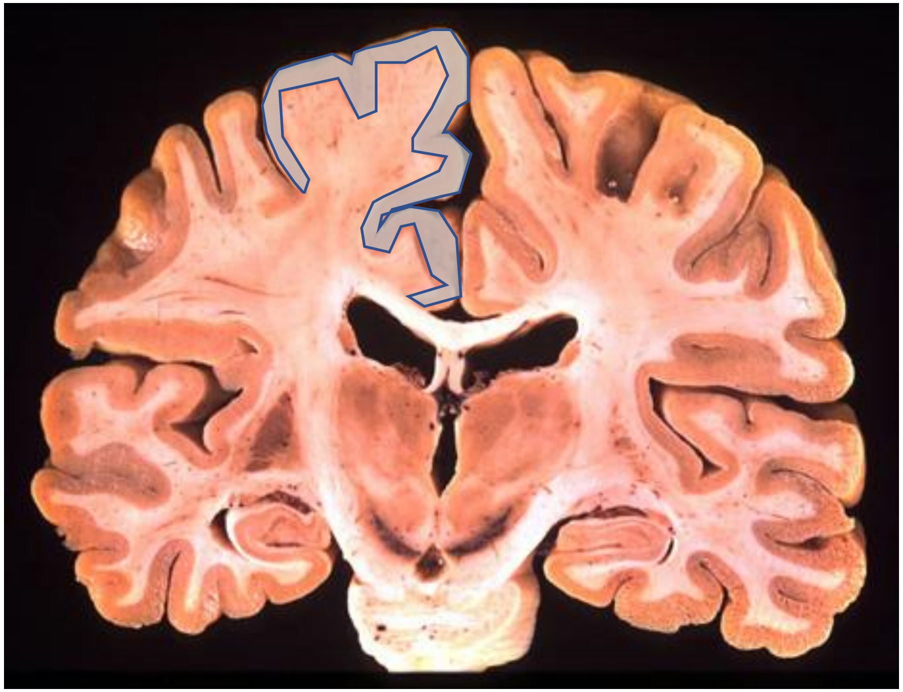
- The forebrain includes the **cortex (outer layer)** of the brain

- Also included are the **basal ganglia** and **limbic system structures** (e.g. hippocampus, amygdala and parts of the **olfactory system)**



The **Cortex** of the Brain

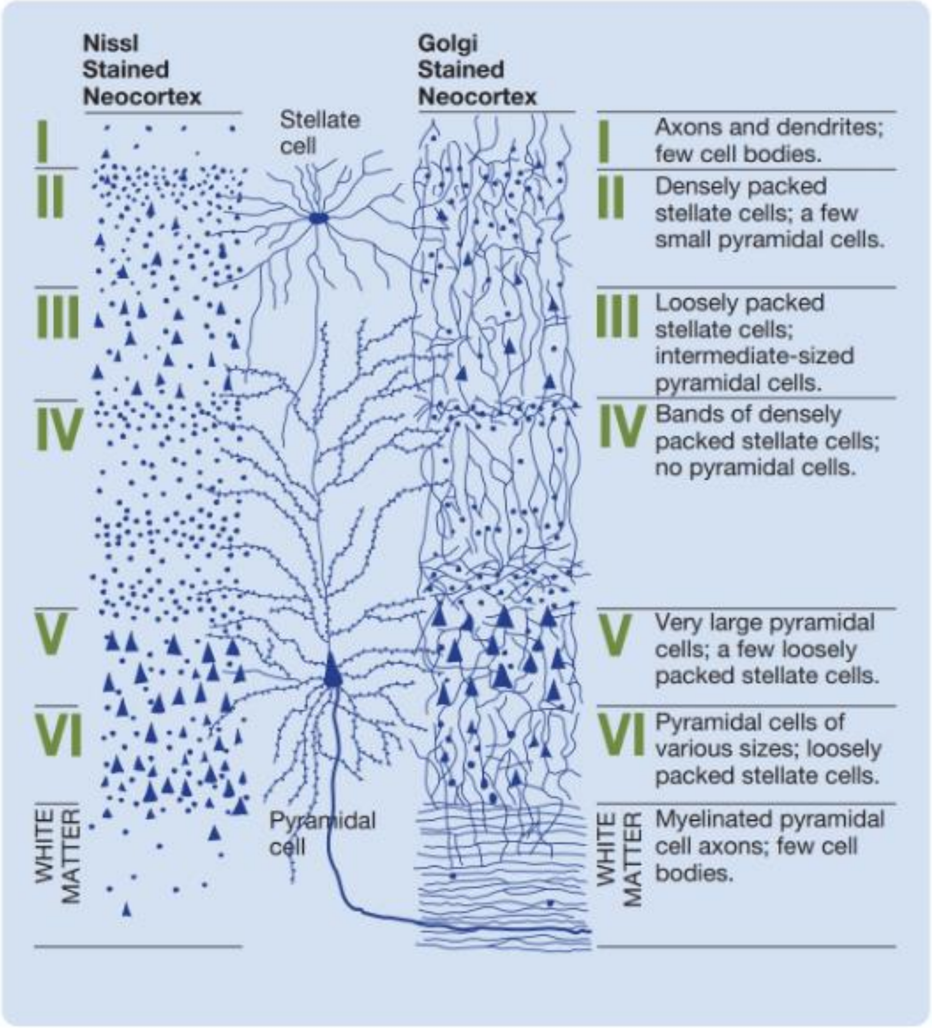




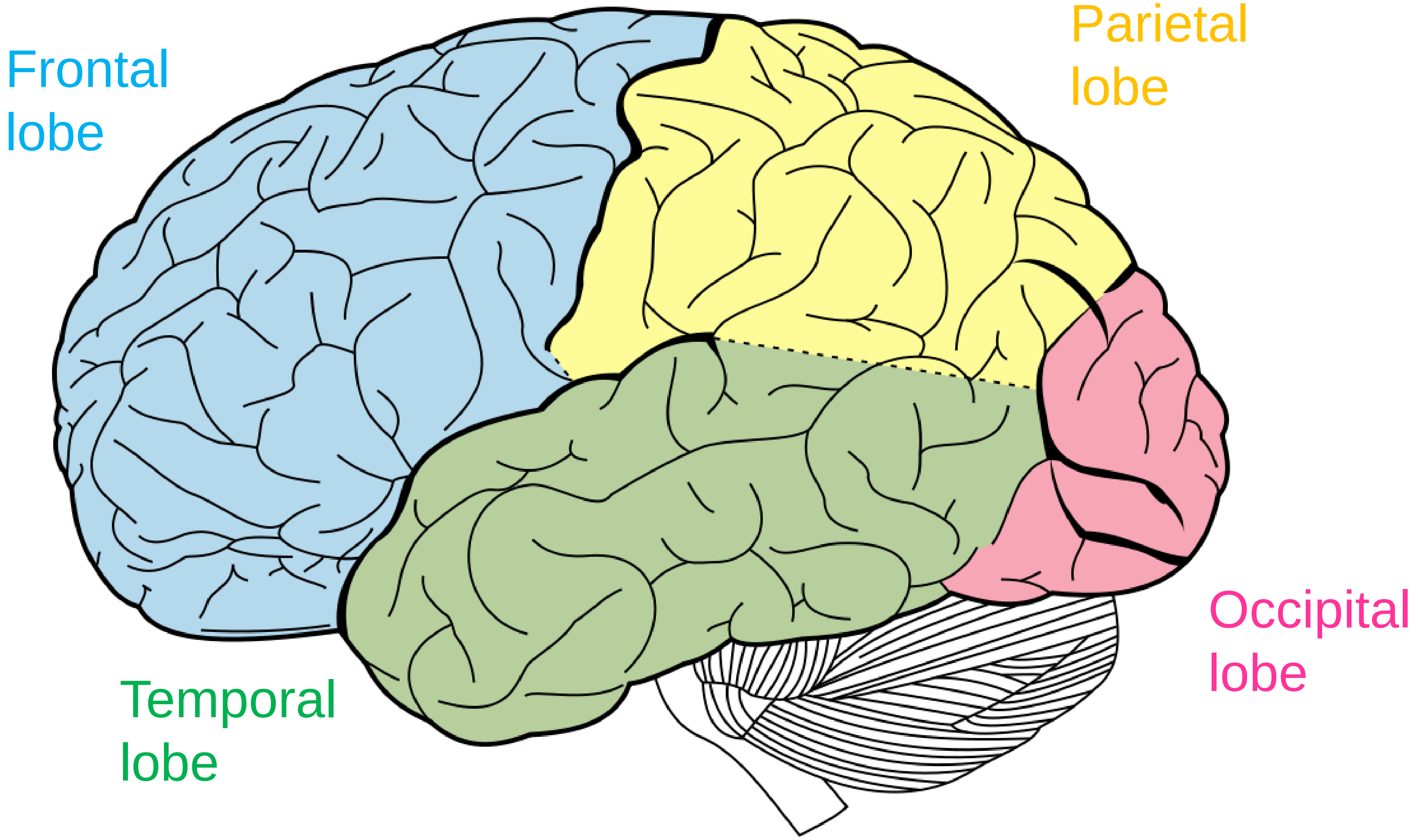
- **Outer layer** of cells (cortex means 'bark')
- Gray matter (mostly cell bodies of neurons)
- Thin (~2-4 mm in humans)

Breaking down the cortex

- Subdivided into two parts: **neocortex** (6 layers) + allocortex (3 layers)*
- In humans, *90% of cortex is neocortex*
- The neocortex is thought to be phylogenetically newer and explain the majority of our higher order behaviors



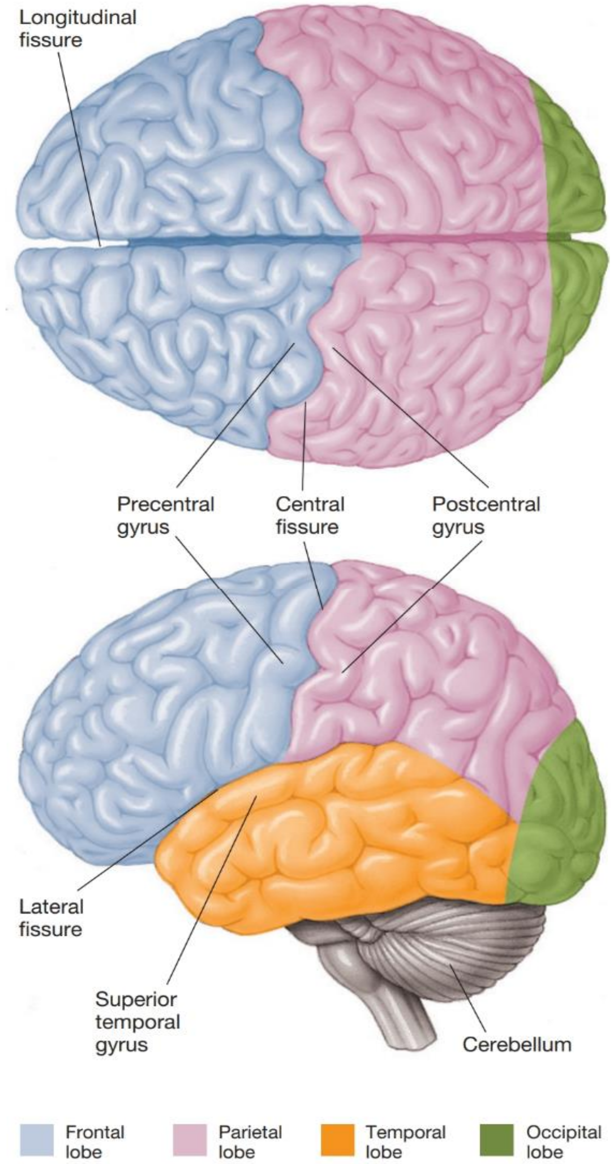
The four lobes of the brain



Bumps = **Gyri** (s. Gyrus)
Folds = **Sulci** (s. Sulcus) or Fissures

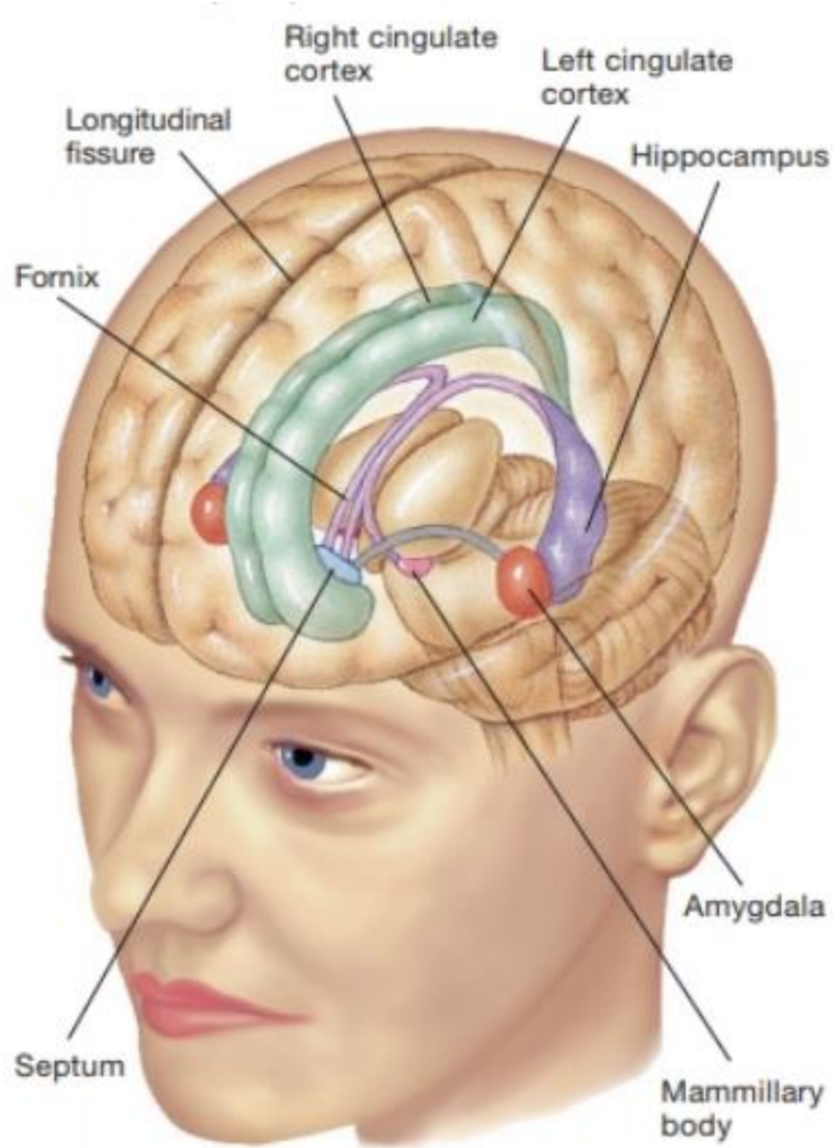
Surface of the brain

- **Longitudinal fissure** = divides the hemispheres
- **Central fissure** = frontal and parietal lobes
  - Pre-central gyrus before the fissure (frontal)
  - Post-central gyrus after the fissure (parietal)
- **Lateral fissure =** top half (frontal + parietal) from bottom half (temporal)



Limbic System

- Cingulate cortex
- Hippocampus
- Amygdala
- Mamillary body
- Septum

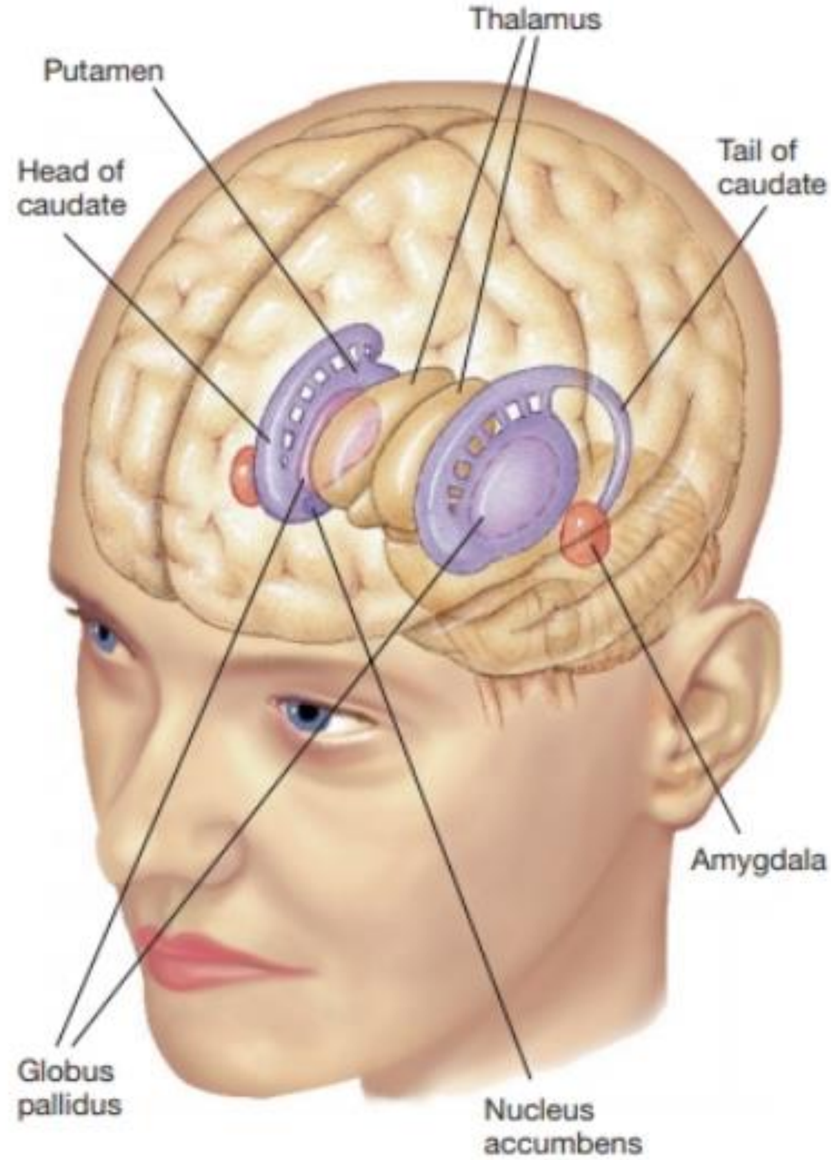


Many functions (though everyone only highlights memory + emotion)

Basal ganglia

- **Caudate + Putamen** (together = dorsal striatum) as well as **Globus Pallidus**
  - Important for Movement

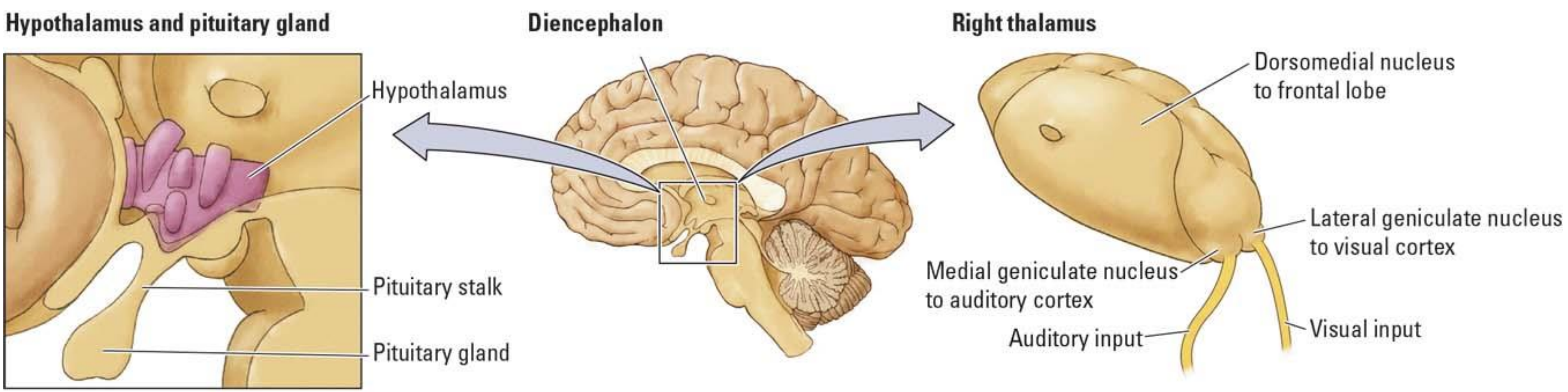
- **Nucleus Accumbens** and other structures (= ventral striatum)
  - Role in reinforcement learning + habit formation (relevant to addiction)



2 – Diencephalon

- **Thalamus:** relay center for incoming sensory information (everything except olfactory input)

- **Hypothalamus:** key drive center (the four fs: fighting, fleeing, feeding and sweet love)

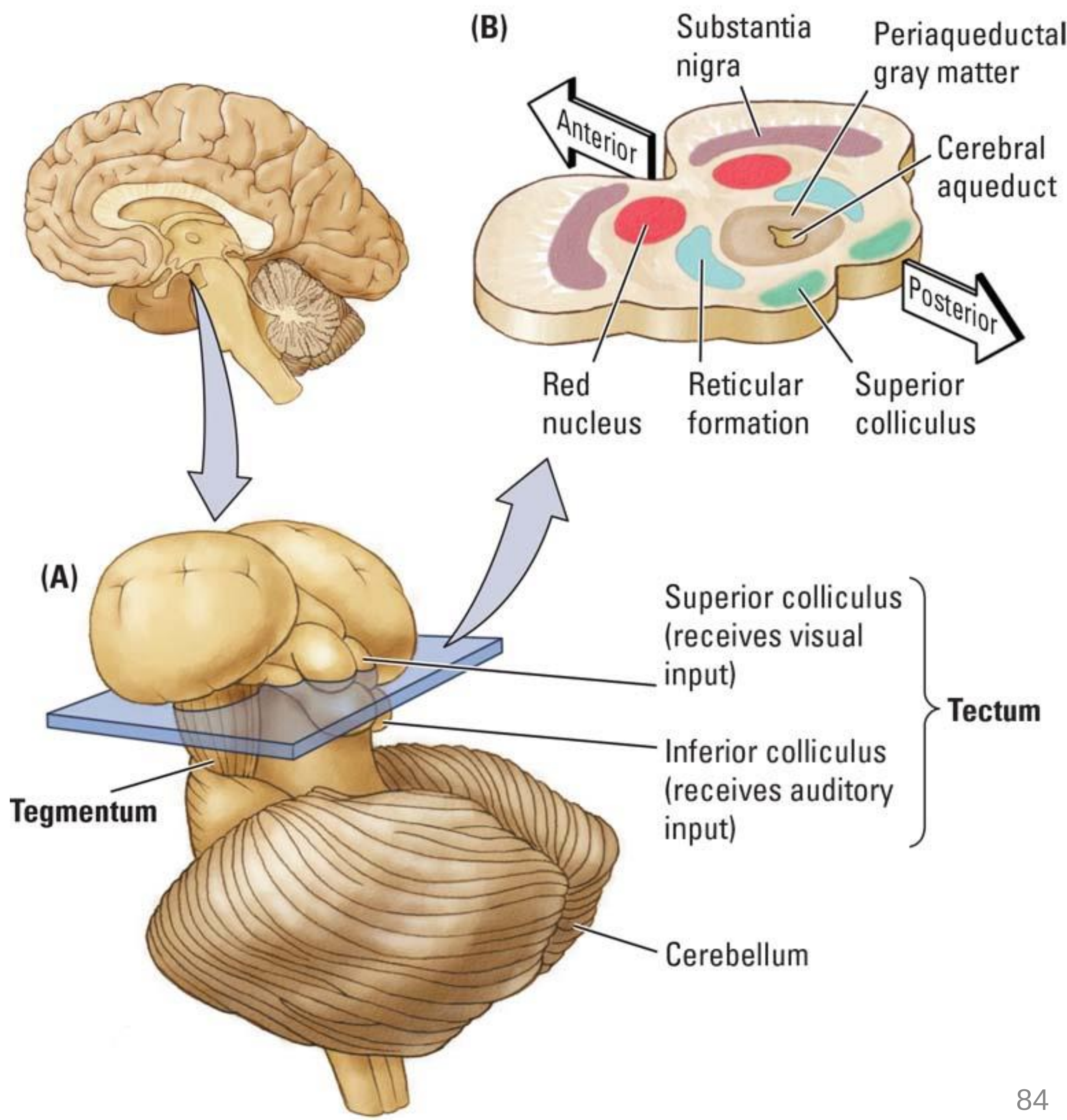


In this course, we'll focus on the thalamus mostly during our Sensation/Perception lecture. We'll (surprise) be avoiding the hypothalamus, for the most part.

3 – Mesencephalon

- **Superior colliculus** (vision-related)
- **Inferior colliculus** (auditory-related)
- **Substantia nigra** (motor coordination)
- **Reticular formation** (arousal)
- **Periaqueductal grey** (nociception/pain)

… and more

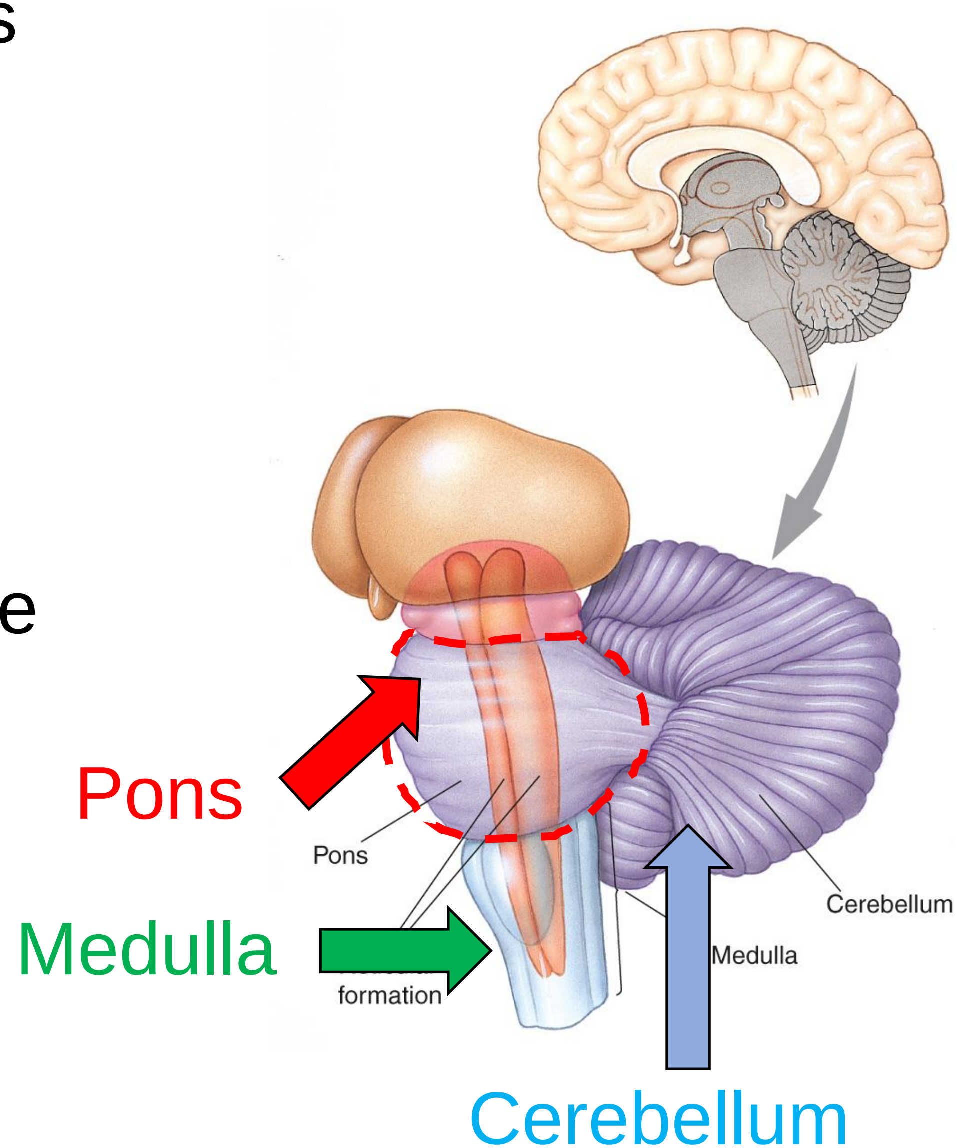


4 + 5: Met- and Myelencephalon

- **Metencephalon** includes **pons** + cerebellum

- **Myelencephalon** is just the **medulla**

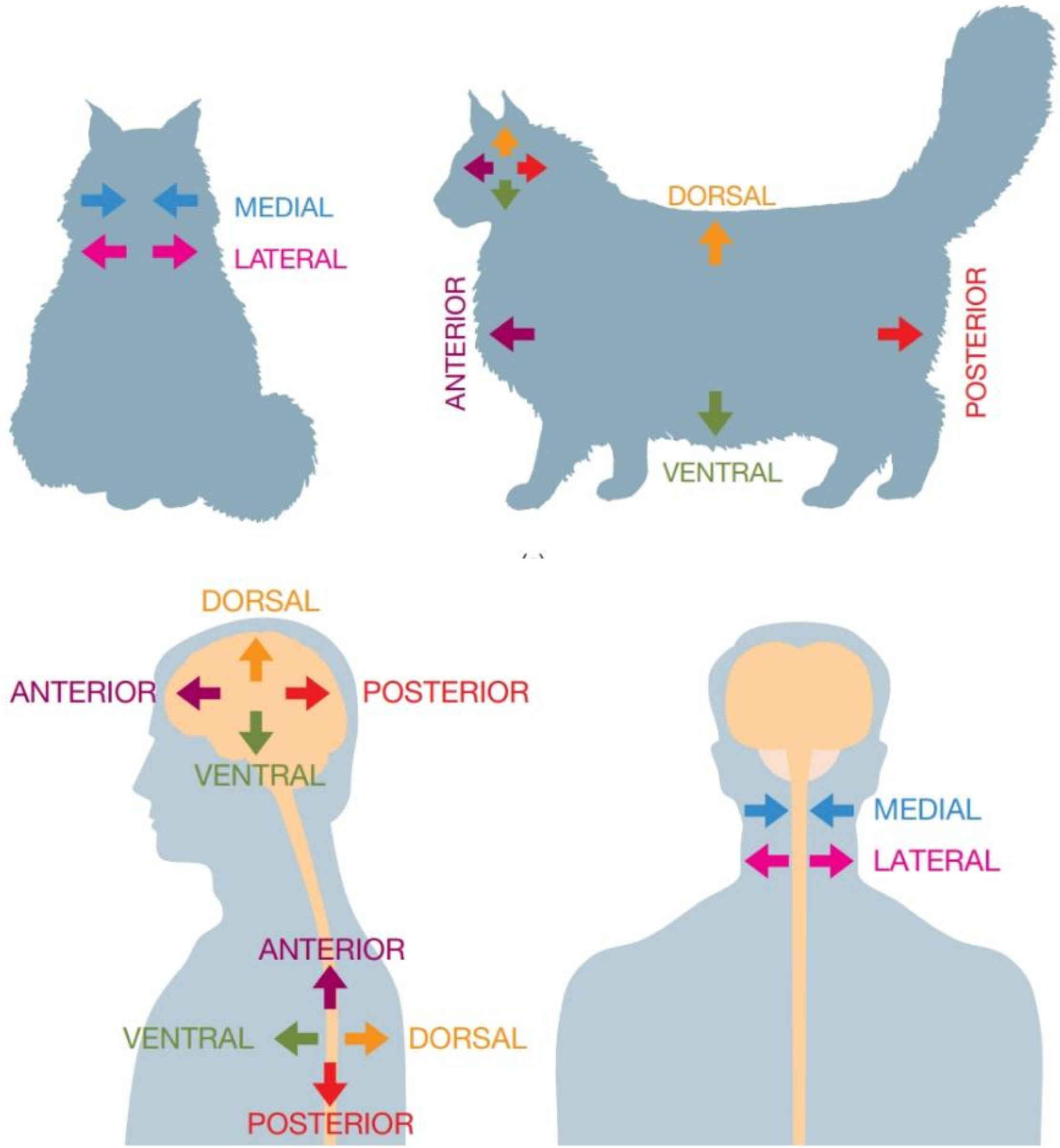
- Similar organization in the pons + medulla
  - Important incoming tracts (sensory information) + outgoing tracts (motor instructions and more)



Navigating the Nervous System

Three dimensional axis system, with:

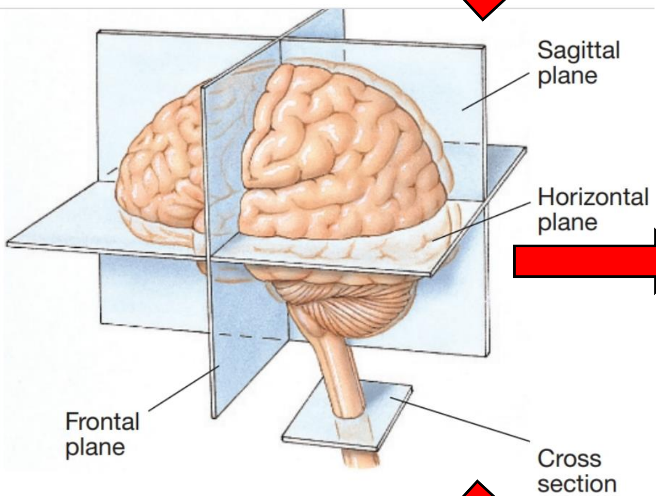
- Medial-Lateral axis
- Rostral-Caudal axis
- Dorsal-Ventral axis



Navigating the Nervous System

- Rostrolateral frontal cortex
  - Front, outer part of the frontal cortex
- Dorsolateral frontal cortex
  - Top, outer part of the frontal cortex
- Ventromedial hypothalamus
  - Bottom, middle part of the hypothalamus
- Posteromedial hypothalamus
  - You get the idea

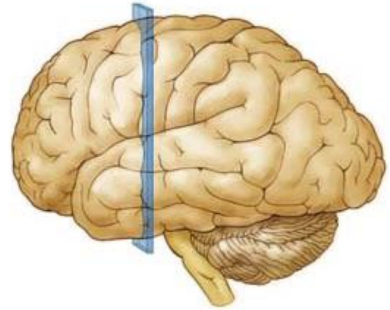
Visualizing the Brain along the axes



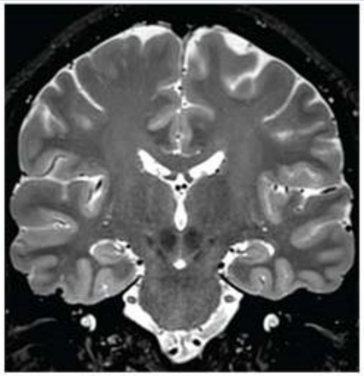
Coronal

Horizontal

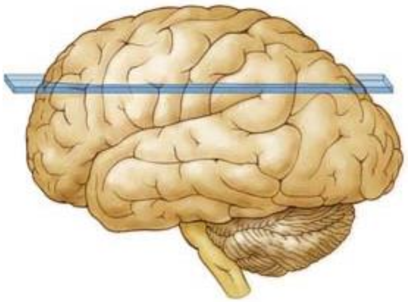
Sagittal



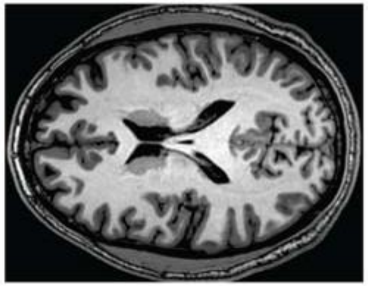
Coronal section



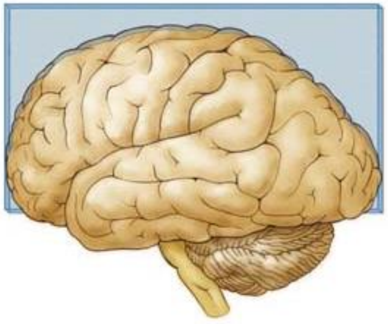
Frontal view



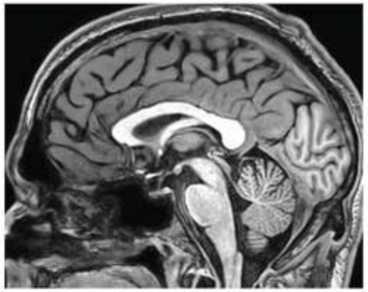
Horizontal section



Dorsal view



Sagittal section



Medial view