

Cognitive Neuroscience for AI Developers

Brain Structure and Functional Systems, Lateralization

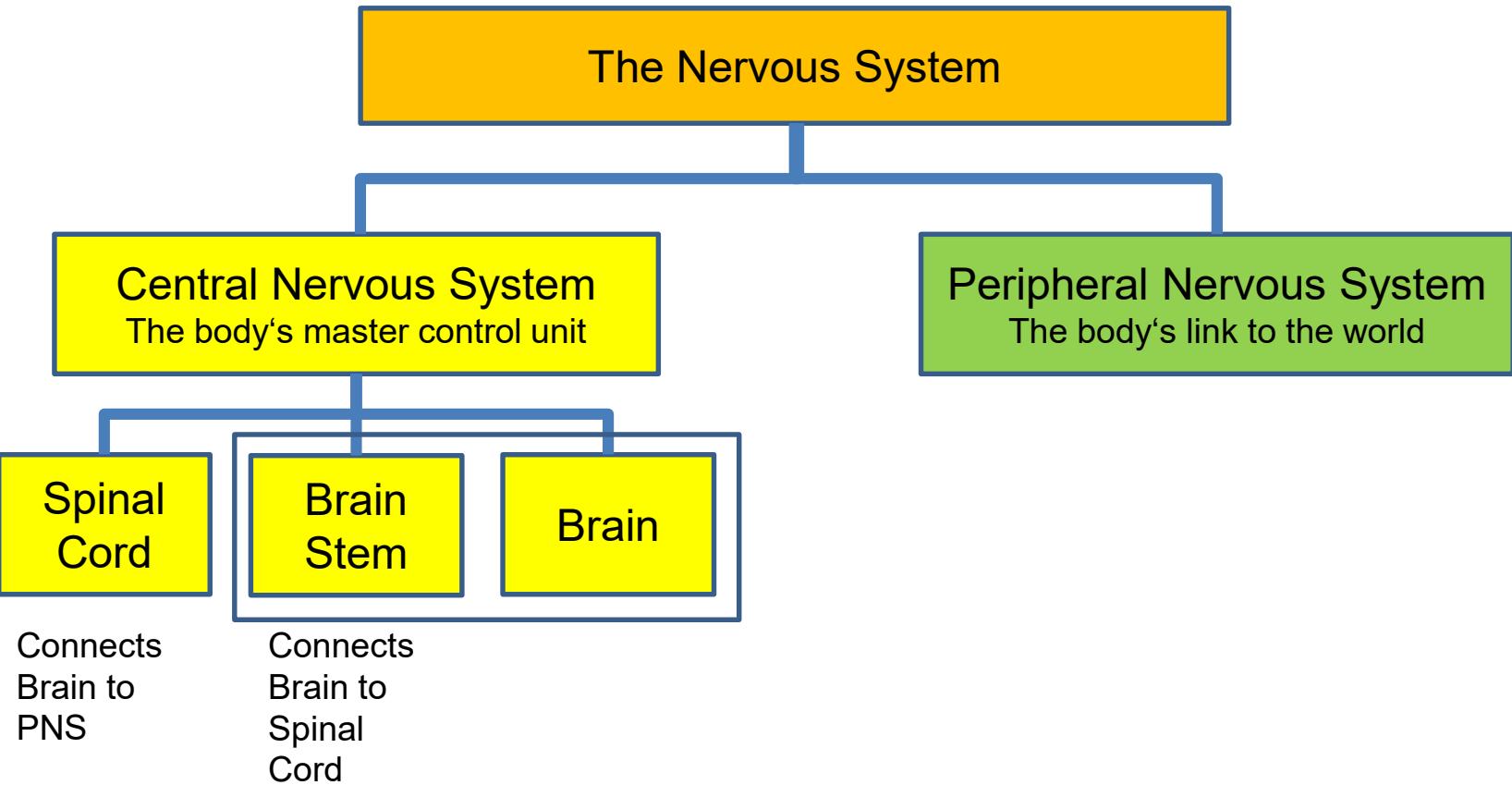


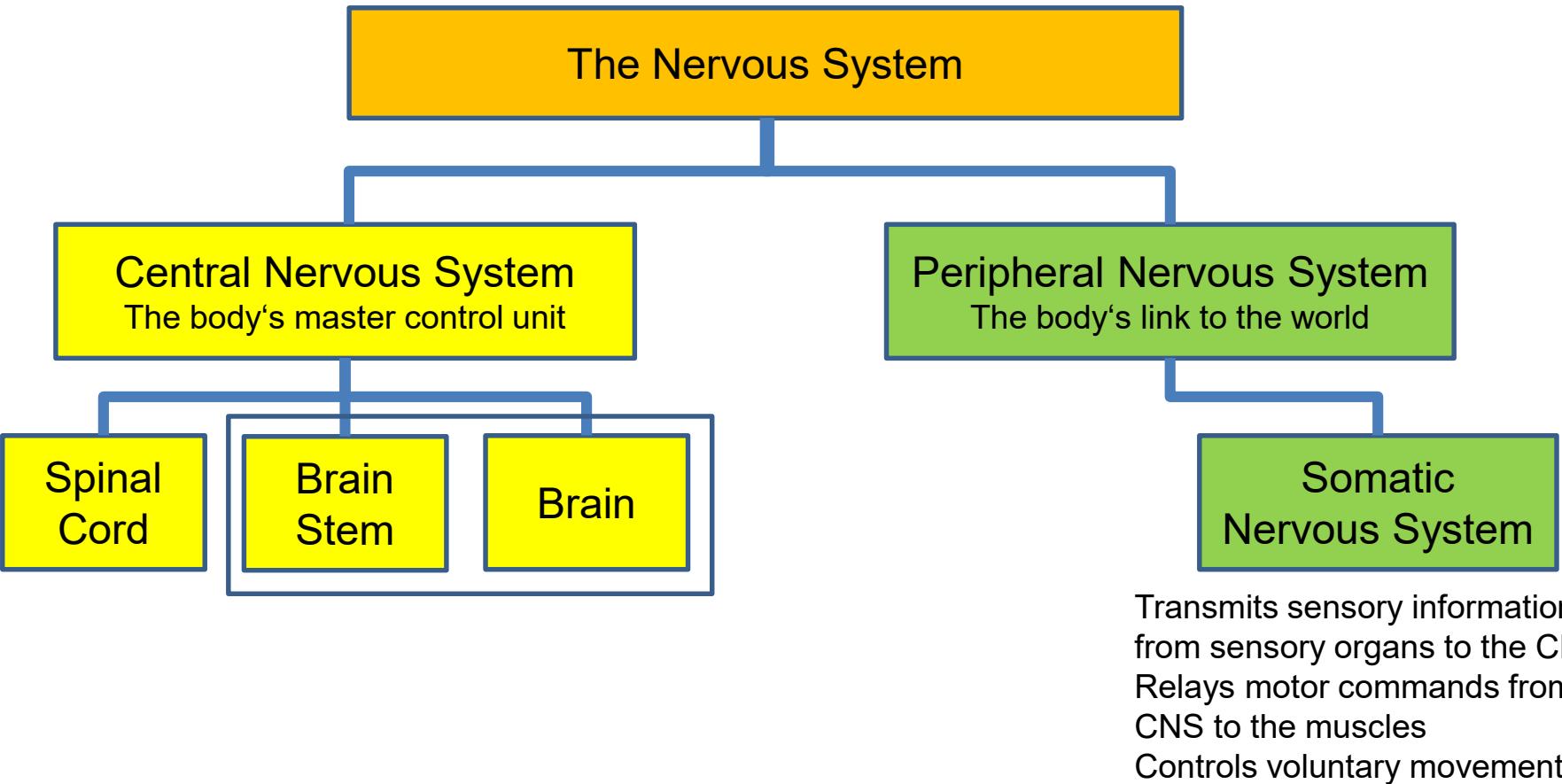
The human nervous system (coarse grained)

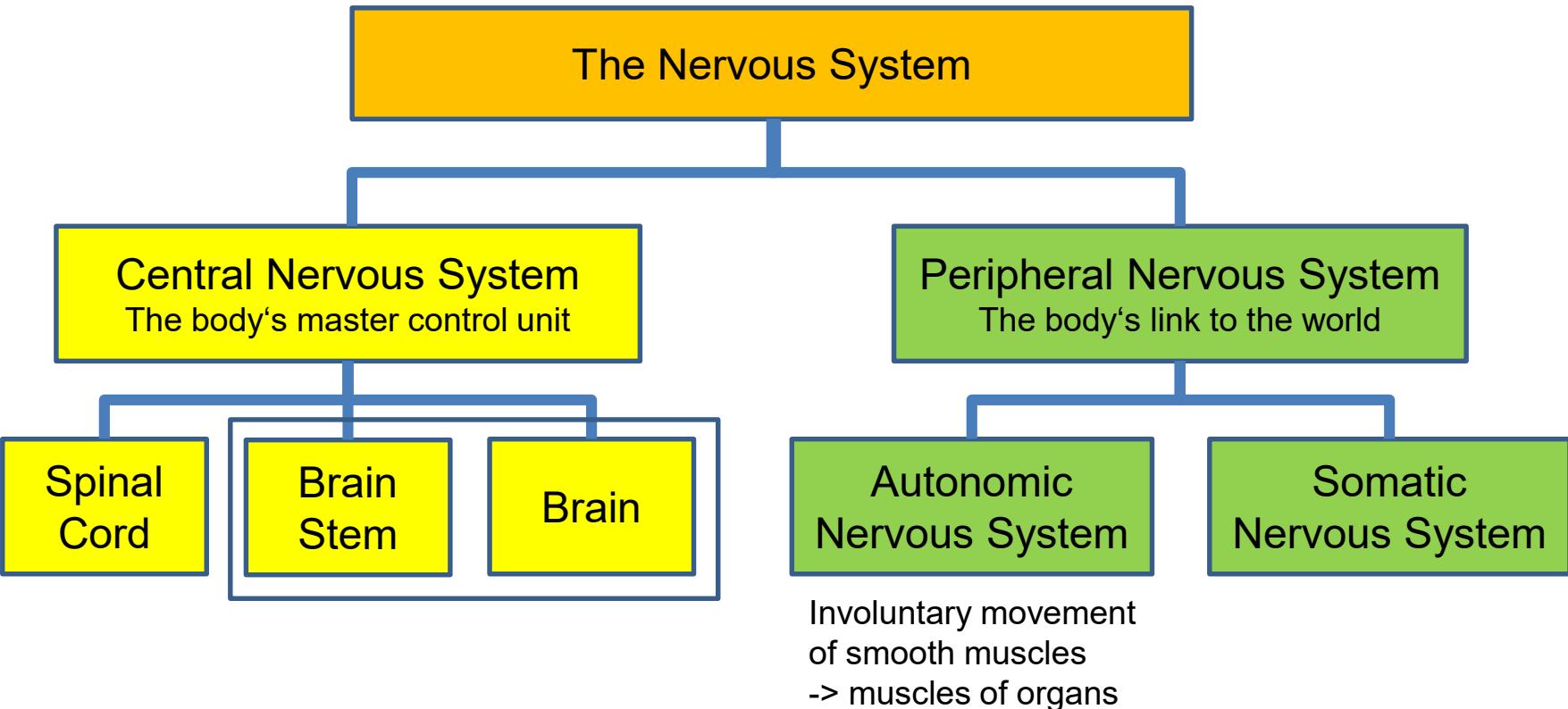
The Nervous System

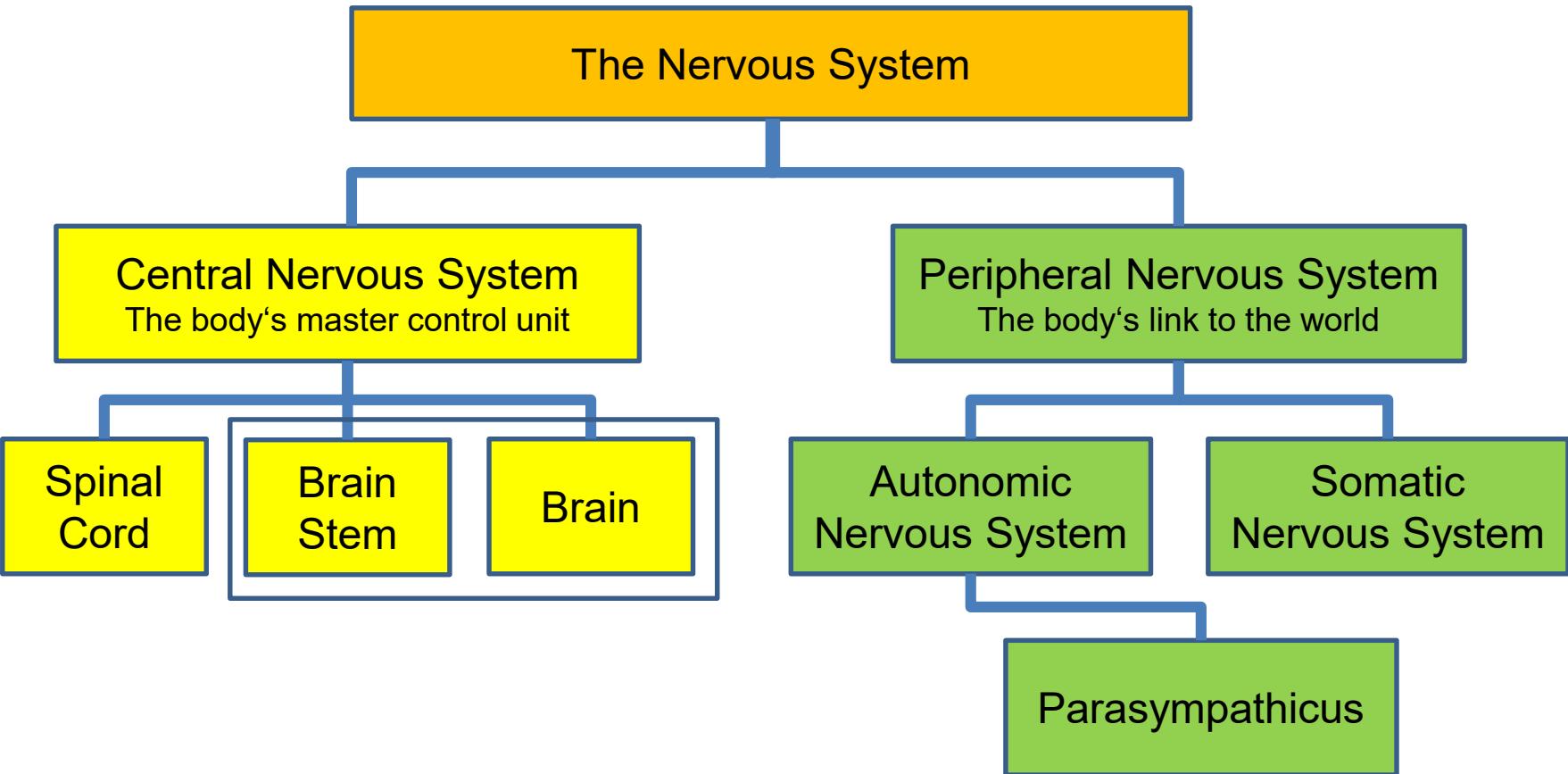
Central Nervous System
The body's master control unit

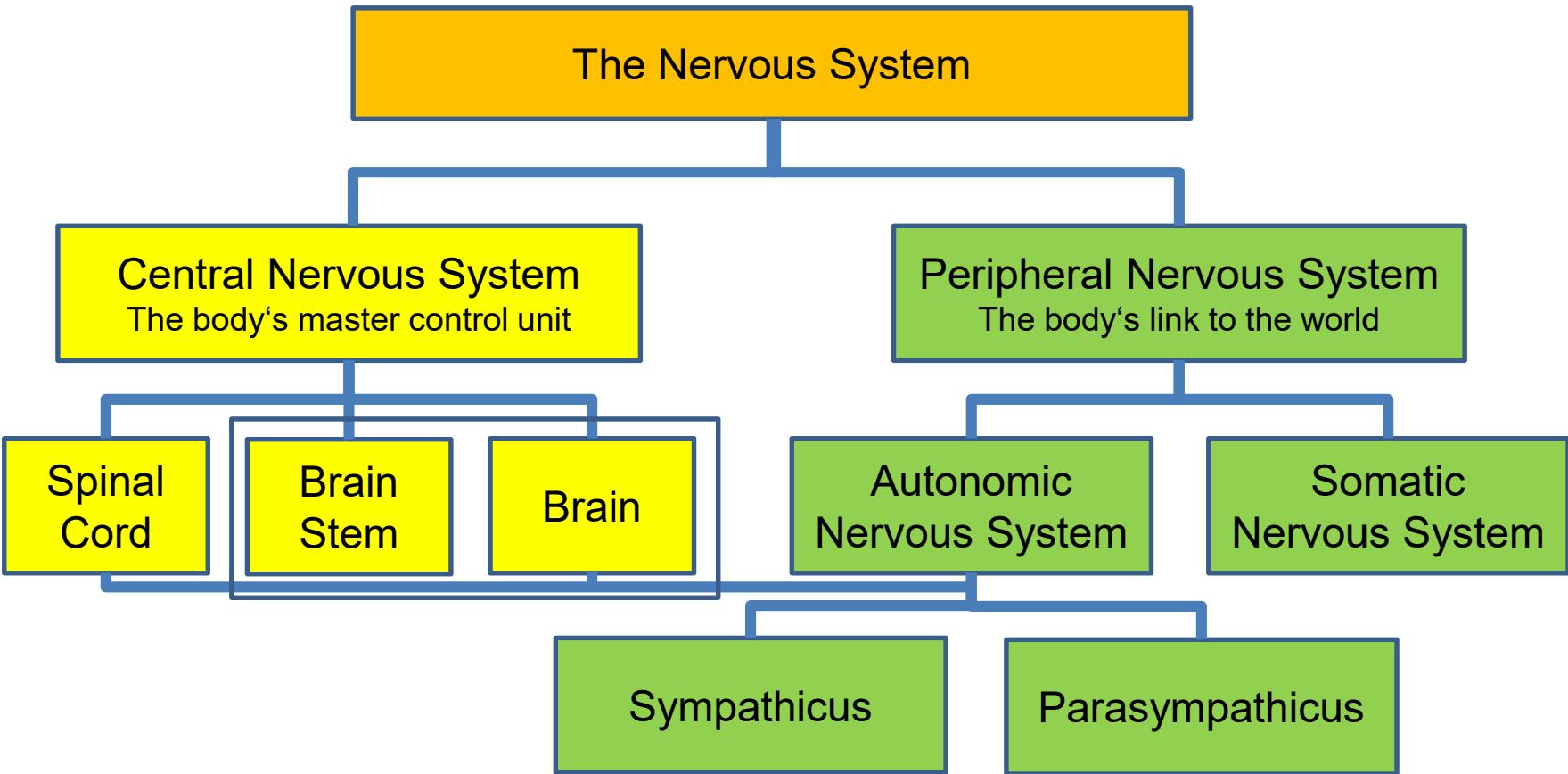
Peripheral Nervous System
The body's link to the world







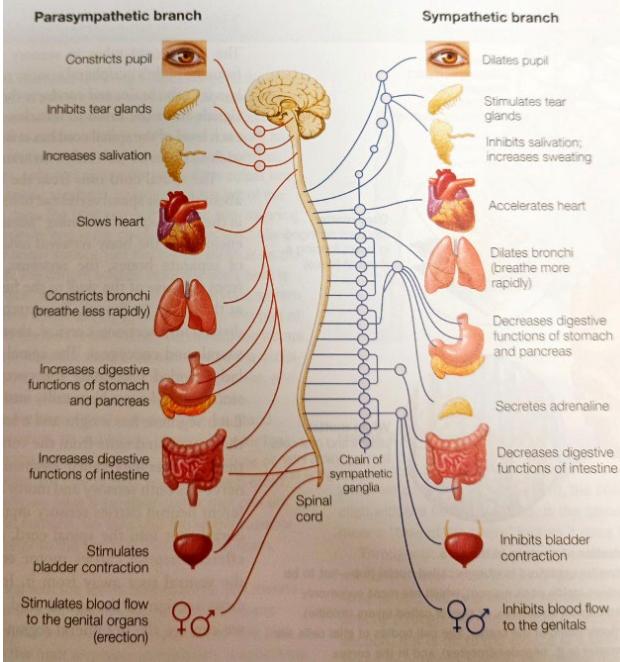




The autonomic nervous system

A quick description of the autonomic nervous system (also called visceral)

- Autonomic system controls involuntary action of smooth muscles, heart and glands
- Autonomic system has two subdivisions: Sympathicus and parasympathicus
- **Sympathicus:**
 - increases heart rate, prepares body for action (fight or flight)
- **Parasympathicus:**
 - slows heart rate stimulates digestion



Cognitive neuroscience, Gazzaniga, Ivry, Mangun, 2014

A quick description of the autonomic nervous system (also called visceral)

Not very interesting for cognitive neuroscience!

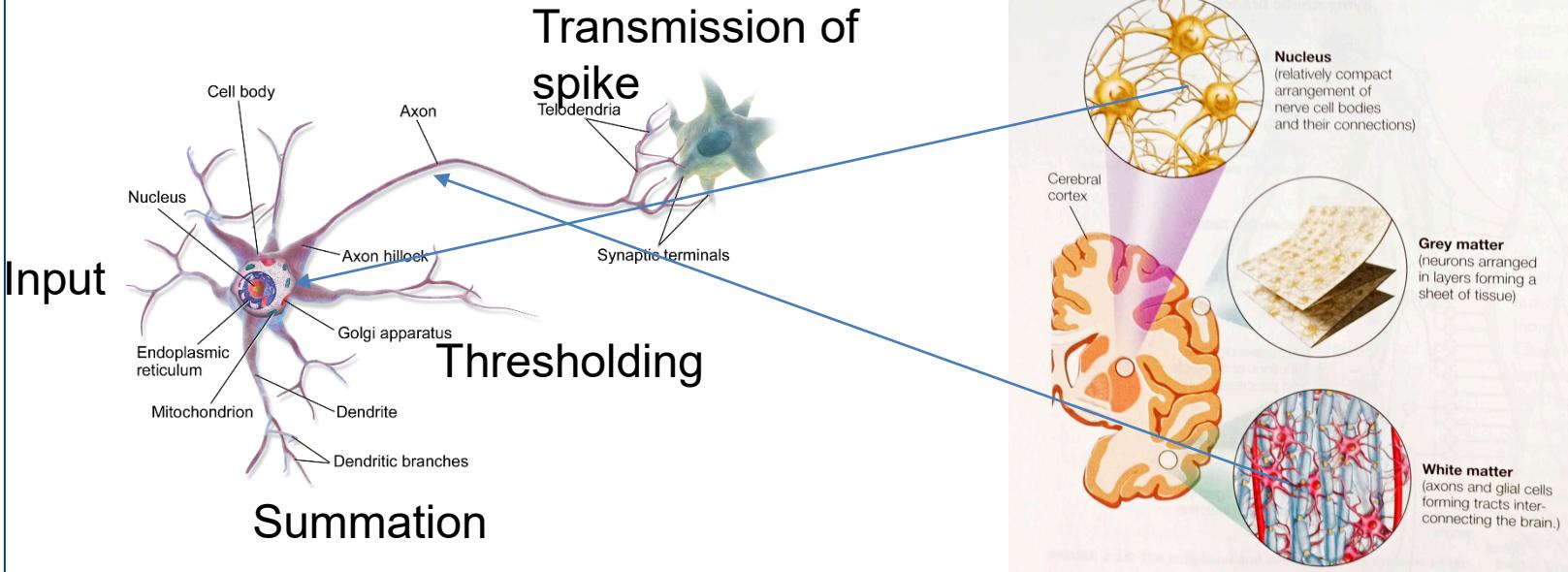
- For cognitive neuroscience the somatic nervous system and CNS is more important

The central nervous system (CNS)

Basic Terms (CNS)

Organization of neurons in the CNS

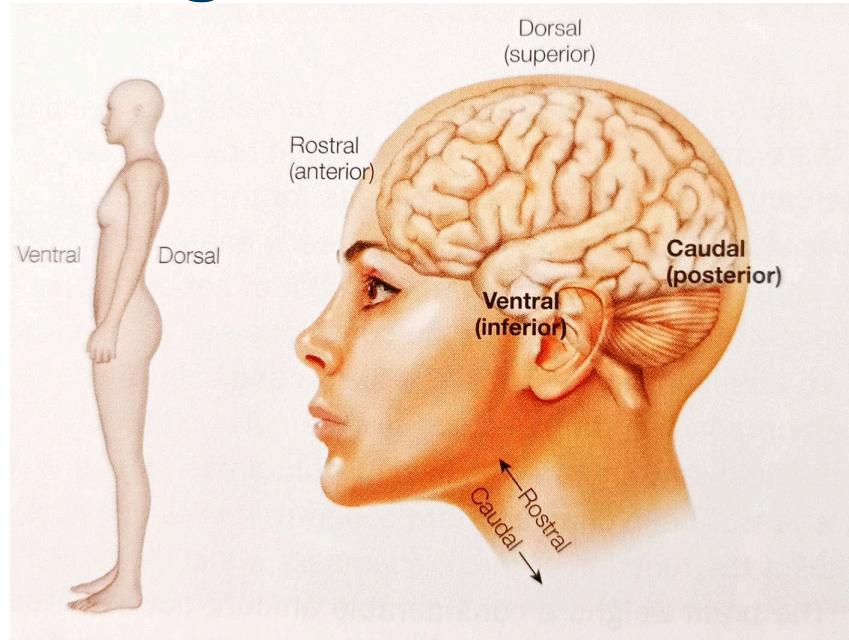
Neuron: processing unit of the brain (analog to transistor)



<https://en.wikipedia.org/wiki/Neuron>

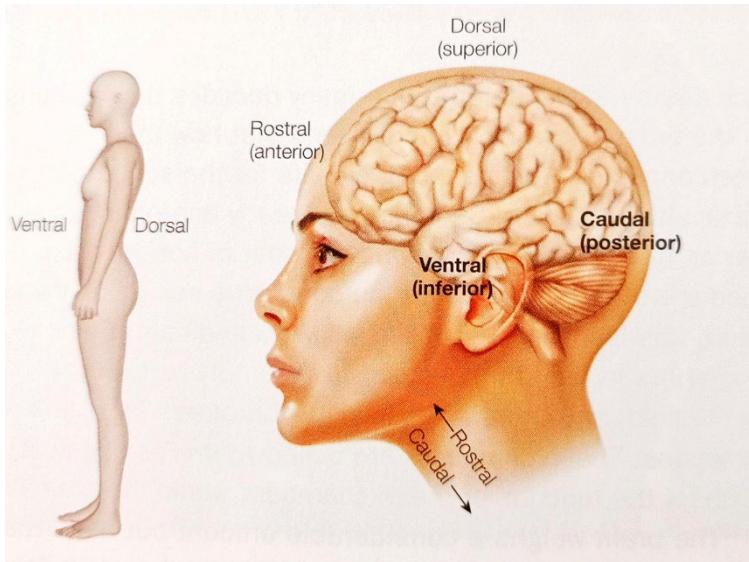
Cognitive neuroscience, Gazzaniga, Ivry, Mangun, 2014

Navigate through the CNS

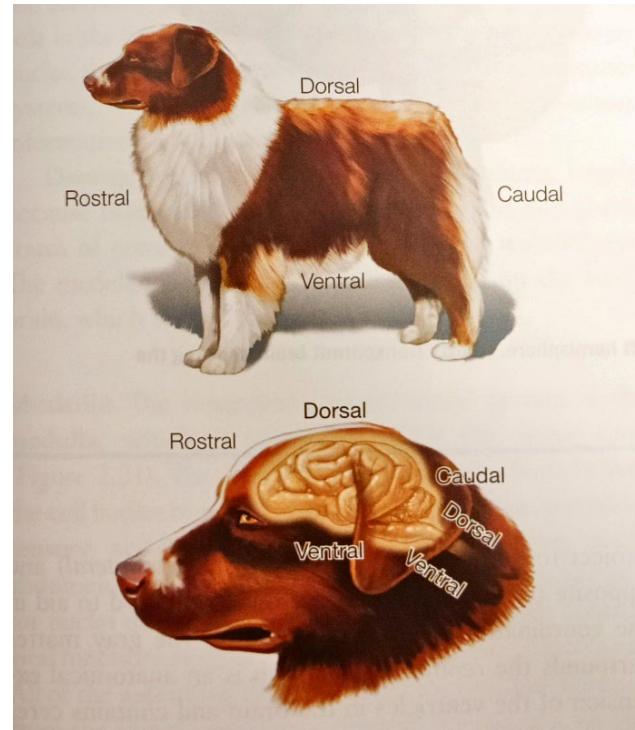


Cognitive neuroscience, Gazzaniga, Ivry, Mangun, 2014

Navigate through the CNS



Cognitive neuroscience, Gazzaniga, Ivry, Mangun, 2014

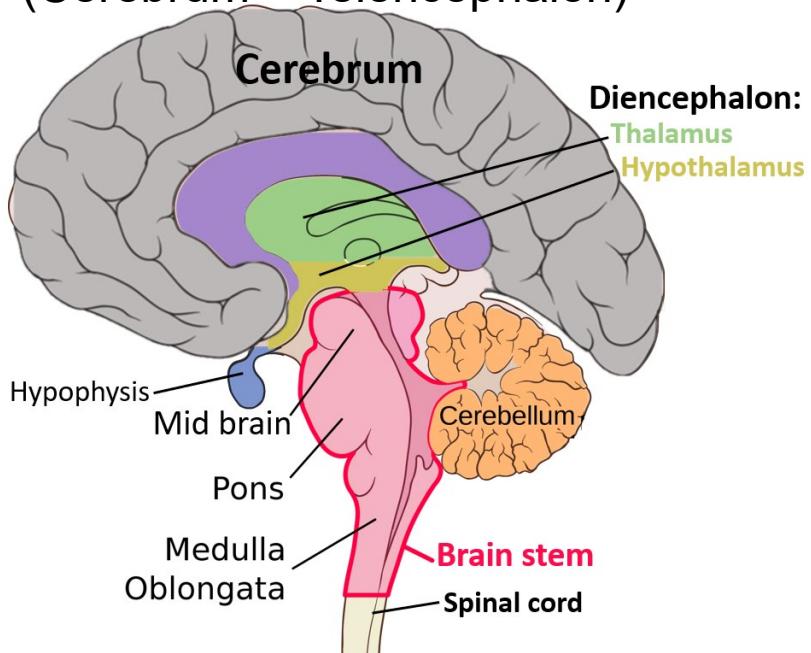


Cognitive neuroscience, Gazzaniga, Ivry, Mangun, 2014

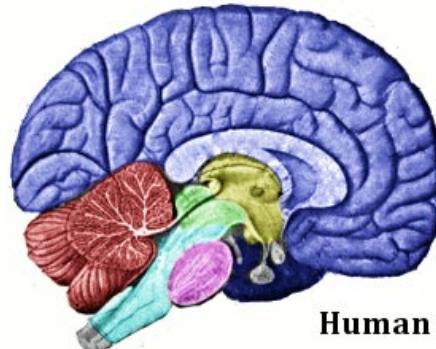
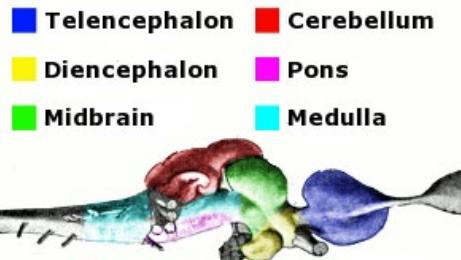
The parts of the central nervous system (CNS)

The gross organization of the brain

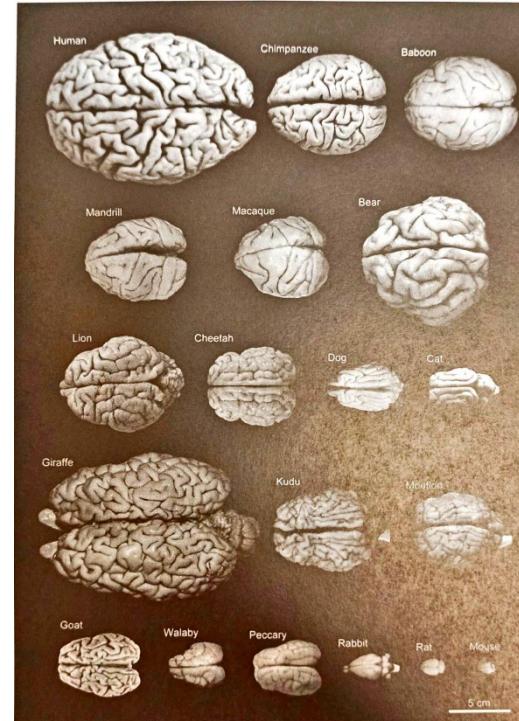
(Cerebrum = Telencephalon)



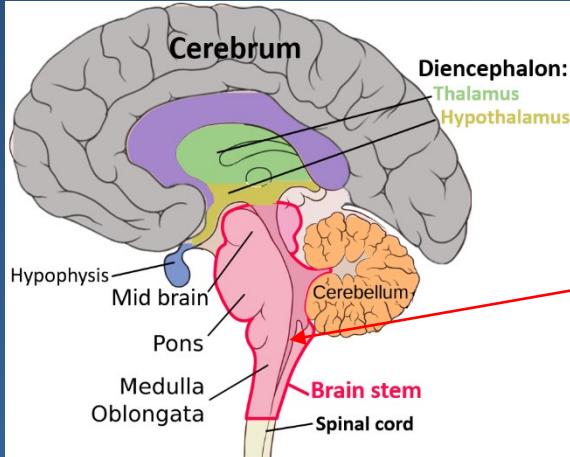
https://en.wikipedia.org/wiki/List_of_regions_in_the_human_brain#/media/File:Basic_structures_of_the_brain_highlighted.png



<https://en.wikipedia.org/wiki/Brain>



Cognitive neuroscience, Gazzaniga, Ivry, Mangun, 2014

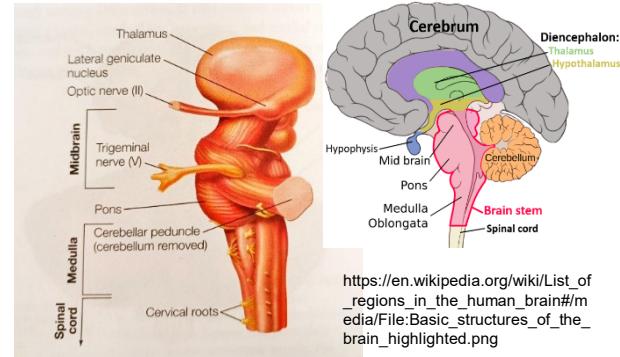


The brainstem

https://en.wikipedia.org/wiki/List_of_regions_in_the_human_brain#/media/File:Basic_structures_of_the_brain_highlighted.png

The brainstem (Medulla, Pons, and Midbrain)

- Contains basic function: Damage is life threatening
- **Medulla (oblongata)**: motor nuclei that innervate the heart, controls respiration, heart rate etc., relay station for sensory and motor information
- **Pons**: connection between brain and cerebellum, important for eye movement (saccades), responsible for generating rapid eye movement (REM) sleep
- **Midbrain (mesencephalon)**: large fiber tracts from the telencephalon/diencephalon run through the midbrain to spinal cord or cerebellum, midbrain contains:
 - **inferior colliculus**: important to locate auditory stimuli
 - **superior colliculus**: important to locate visual stimuli
 - **red nucleus**: motor coordination (arm swing while walking)

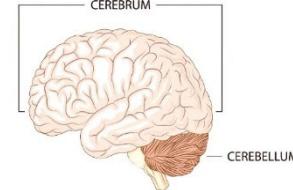
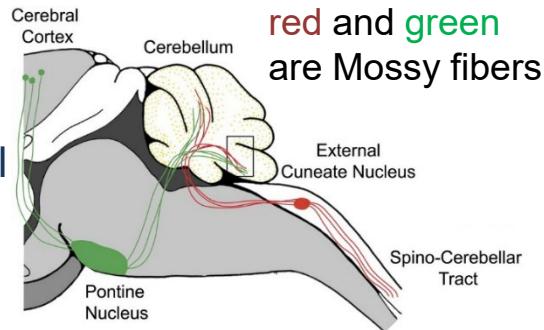


Cognitive neuroscience, Gazzaniga, Ivry, Mangun, 2014

https://en.wikipedia.org/wiki/List_of_regions_in_the_human_brain#/media/File:Basic_structures_of_the_brain_highlighted.png

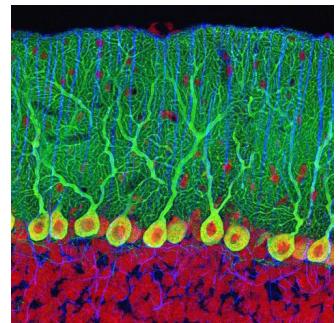
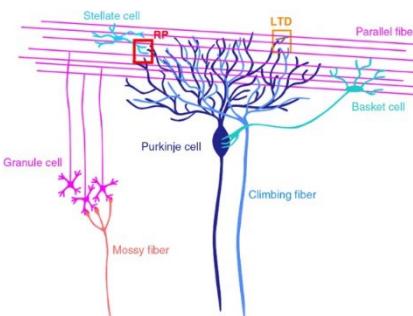
Cerebellum

- Contains most neurons of the brain!
69 billion neurons from 86 billion neurons in total
- Temporal coordination of movements (and cognition) and error correction of movements -> smooth execution of movements and learning new motor skills
- Extremely regular structure
- Climbing fibers: error signal (from sensory and motor cortices), Mossy fibers: motor and sensory signals
- Purkinje cells only output from cerebellum (inhibition) -> to vestibular nuclei in medulla (balance)



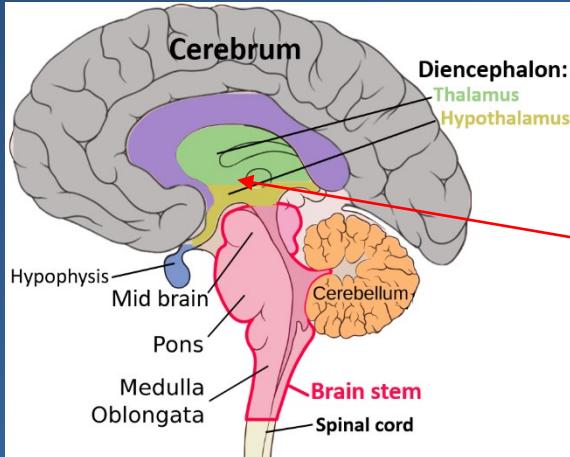
Source:
www.psychologytoday.com

<https://elifesciences.org/articles/00641>



<https://www.frontiersin.org/articles/10.3389/fncel.2014.00042/full>

<https://www.psychologytoday.com/intl/blog/the-athletes-way/201411/autism-purkinje-cells-and-the-cerebellum-are-intertwined>

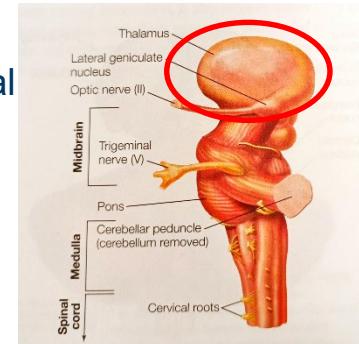


The diencephalon

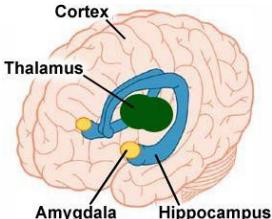
https://en.wikipedia.org/wiki/List_of_regions_in_the_human_brain#/media/File:Basic_structures_of_the_brain_highlighted.png

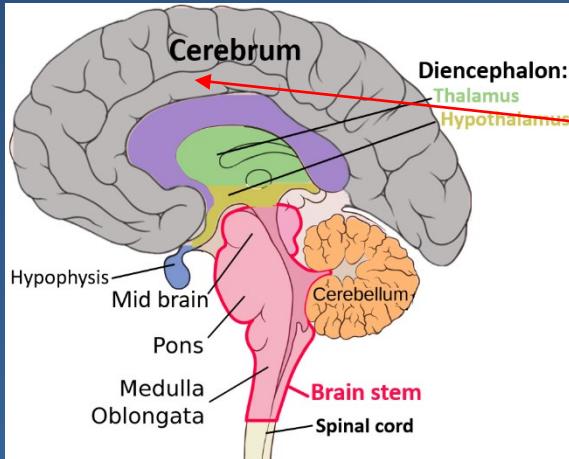
The diencephalon (thalamus and hypothalamus)

- Thalamus:** „gateway to cortex“ („gateway to consciousness“)
 - All sensory input has to pass the thalamus (except olfactory input)
 - Builds neuronal circuits with basal ganglia, cerebellum, neocortex, and medial temporal lobe
“Grand Central Station of the Brain”
 - Several nuclei: lateral geniculate nucleus, medial geniculate nucleus, ventral posterior nuclei, pulvinar nucleus (attention)
- Hypothalamus:** Connection of the brain and the endocrine system
 - Mammillary bodies: circadian rhythm (light dark cycles)
 - Hypothalamus controls functions of maintaining normal state of body
 - Sends signals out that drive behavior to alleviate hunger and thirst
 - Controls body temperature
 - Controls pituitary gland which releases hormones into the blood stream



Cognitive neuroscience, Gazzaniga, Ivry, Mangun, 2014





The telencephalon

https://en.wikipedia.org/wiki/List_of_regions_in_the_human_brain#/media/File:Basic_structures_of_the_brain_highlighted.png

The telencephalon (limbic system, hippocampus, amygdala, basal ganglia, cerebral cortex)

- Evolutionary newer
- Limbic system (functional structure):
 - Consists of cingulate cortex (band of cerebral cortex), parts of **hypothalamus, hippocampus, amygdala (emotional responses, control of fear, anxiety, aggression)**
 - Limbic system as system of emotional behavior,
-> Criticism: Limbic system is nebulous -> **could be discarded**

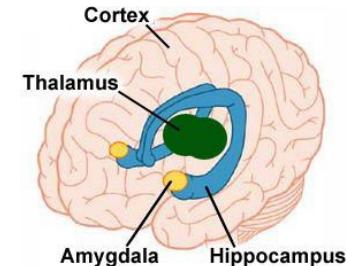
- **Hippocampus:**

- Spatial Navigation
- Episodic Memory
- Memory formation
- Organization of thoughts

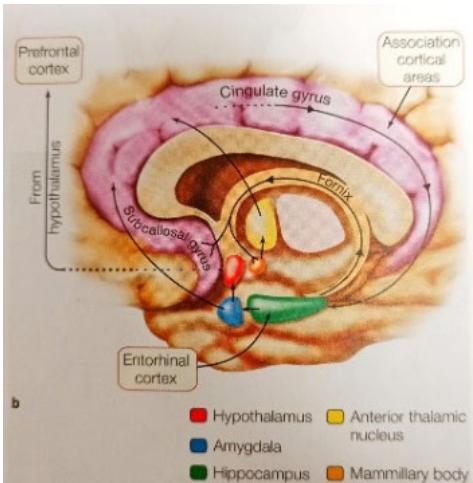


Source: wikipedia.org

Cognitive neuroscience,
Gazzaniga, Ivry,
Mangun, 2014

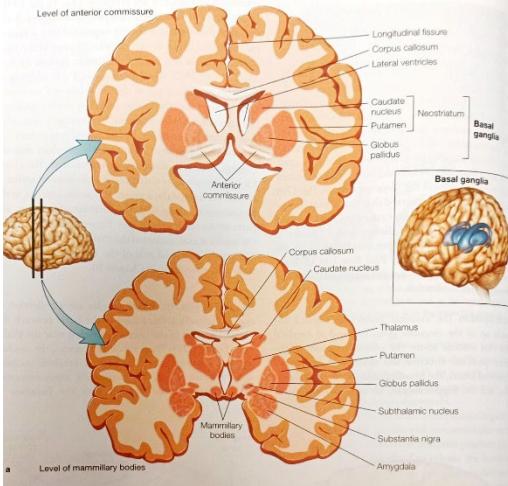


Source: <https://www.pinterest.de/pin/384494886932859162/>

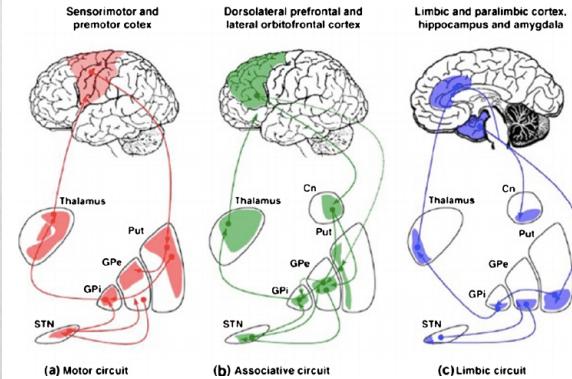


Basal ganglia

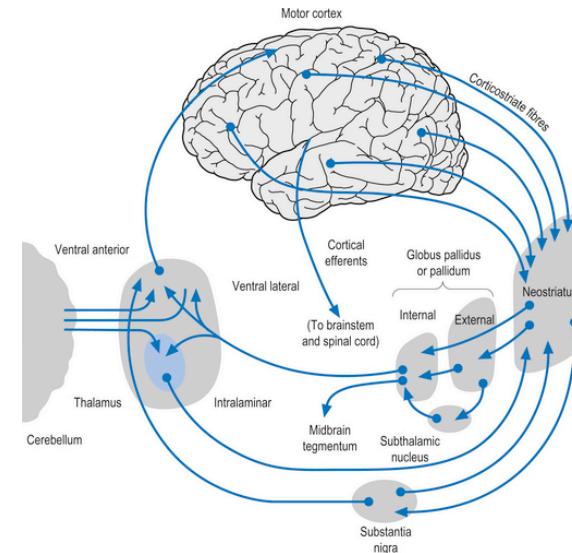
- Collection of nuclei near the thalamus (Caudate nucleus, globus pallidus, subthalamic nucleus, substantia nigra)
- Tasks: action selection, motor preparation, motor learning, reward-based learning
- Feedback loops with cortex areas and thalamus etc.



Cognitive neuroscience, Gazzaniga, Ivry, Mangun, 2014



Source: www.researchgate.net/publication/263584956_Neuromodulation_for_Obsessive-Compulsive_Disorder/figures?lo=1



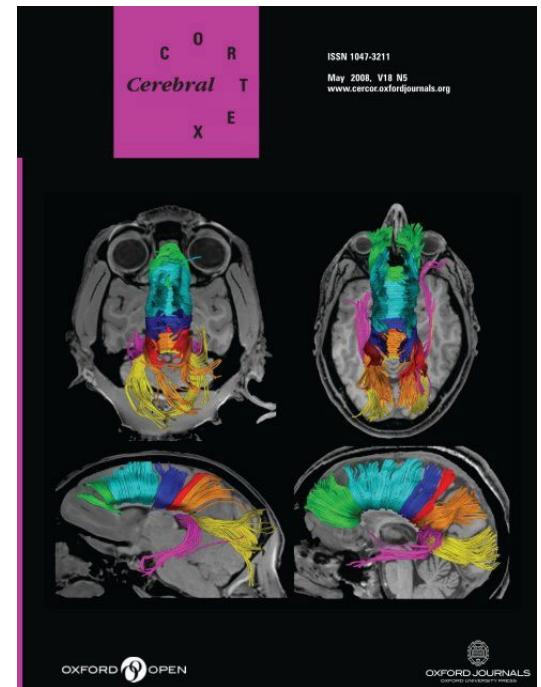
Source: <https://clinicalgate.com/the-basal-ganglia/>

The cerebral cortex (part of telencephalon)

The Cerebral Cortex

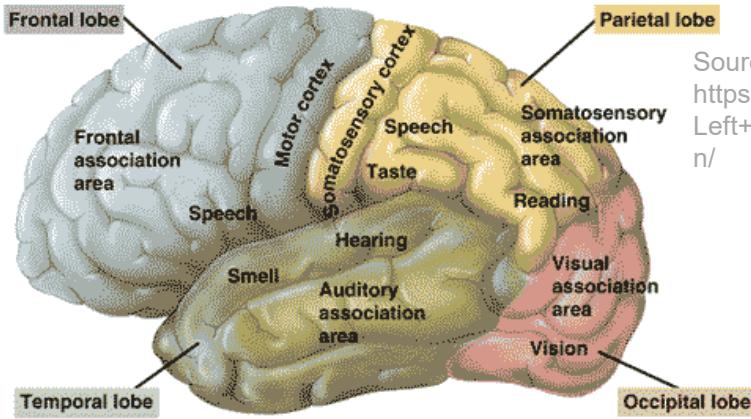


Source: Brainline.org

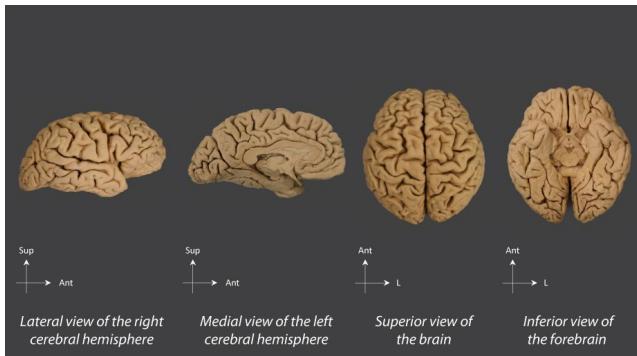


Source: <https://academic.oup.com/cercor>

Cerebral Cortex



Source:
<https://dronefest.cc/search/Left+Frontal+Lobe+Function/>



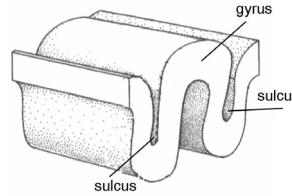
Source: sites.uclouvain.be

- Approx. **16 billion** neurons
- Highest level of control
- Voluntary movements
- Conscious perception
- Highest cognitive functions
 - Language
 - Math
 - Reading
- Semantic memory
- Auto-biographic memory

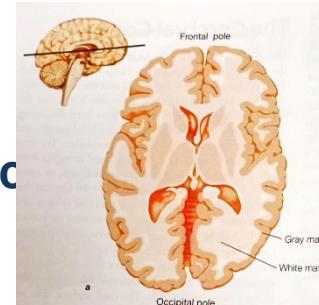
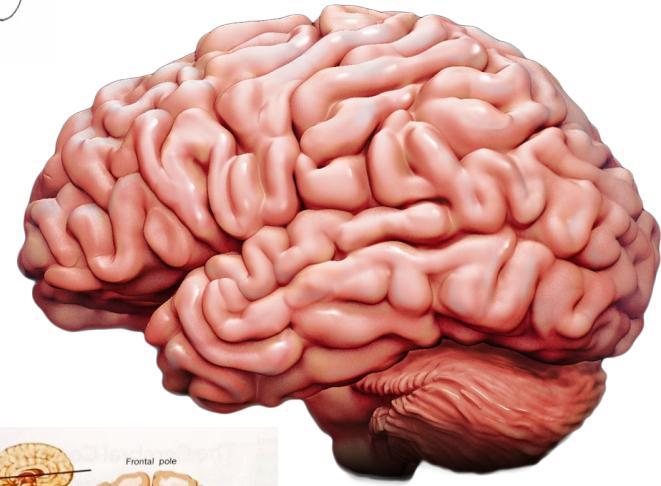
→ Lecture 11 (Memory)

The Cerebral Cortex

- Made of large sheets of layered neurons (contains cell bodies and dendrites, input axons)
- Draped and folded over two **nearly symmetrical** hemispheres
 - Folding for **larger surface**
 - **Shorter axonal connections** (3D structure)
- Cortex can divided **anatomically, cytoarchitectonic** and **functional**



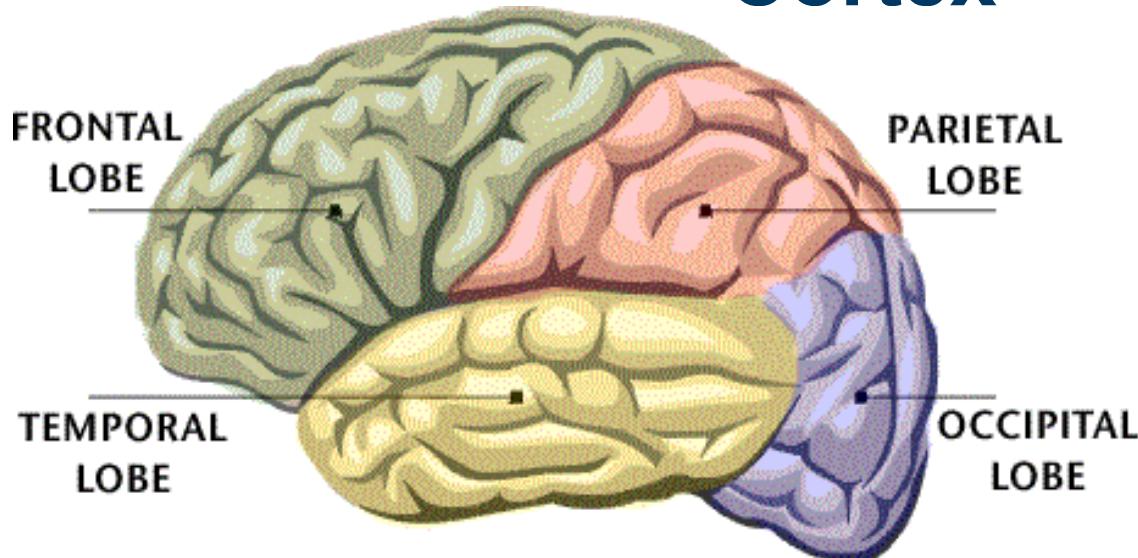
Source: wikipedia.org



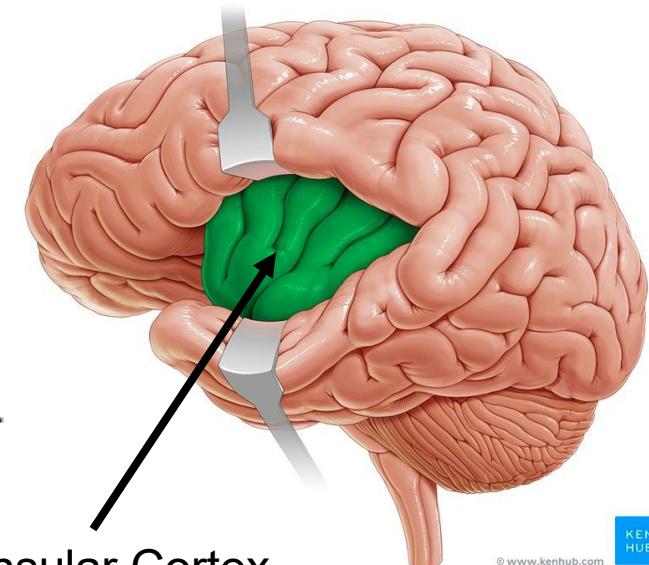
Source: Brainline.org

Anatomical organization of the cerebral cortex

Anatomical Organization of the Cerebral Cortex



Source: http://michellejl.github.io/education_digest/brain.html



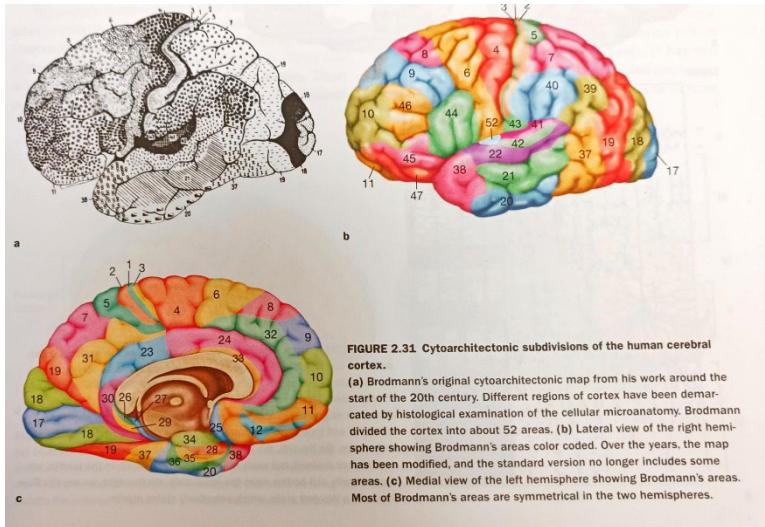
© www.kenhub.com

KEN HUB

Source: kenhub.com

Cytoarchitectonic organization of the cerebral cortex

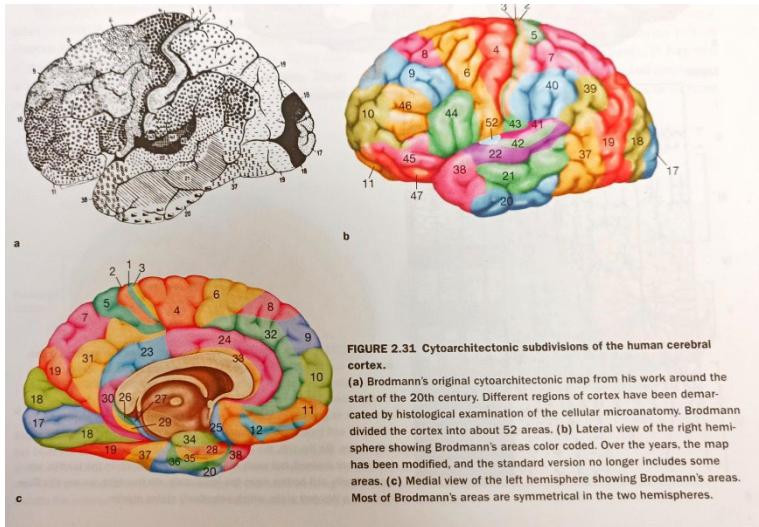
Cyto-architectonical Organization of the Cerebral Cortex



Cognitive neuroscience, Gazzaniga, Ivry, Mangun, 2014

- **Cytoarchitectonics uses microanatomy of cells**
- started with Korbinian Brodmann at beginning of 20th century
- Brodmann found 52 regions
- Later more than 200 regions were defined based on cytoarchitectonics
- However: Brodmanns numbering scheme is still used
- **Problem:** nomenclature not fully standardized!

Cyto-architectonical Organization of the Cerebral Cortex



- Example for bad nomenclature:
 - First cortex are to perceive visual input
 - Brodmann area 17 (cytoarchitectonic)
 - Striate cortex (highly visible stripe of myelin, cytoarchitectonic)
 - Calcarine cortex (surrounding calcarine fissure, anatomical)
 - Primary visual cortex (functional)

Cognitive neuroscience, Gazzaniga, Ivry, Mangun, 2014

Cortical Layers

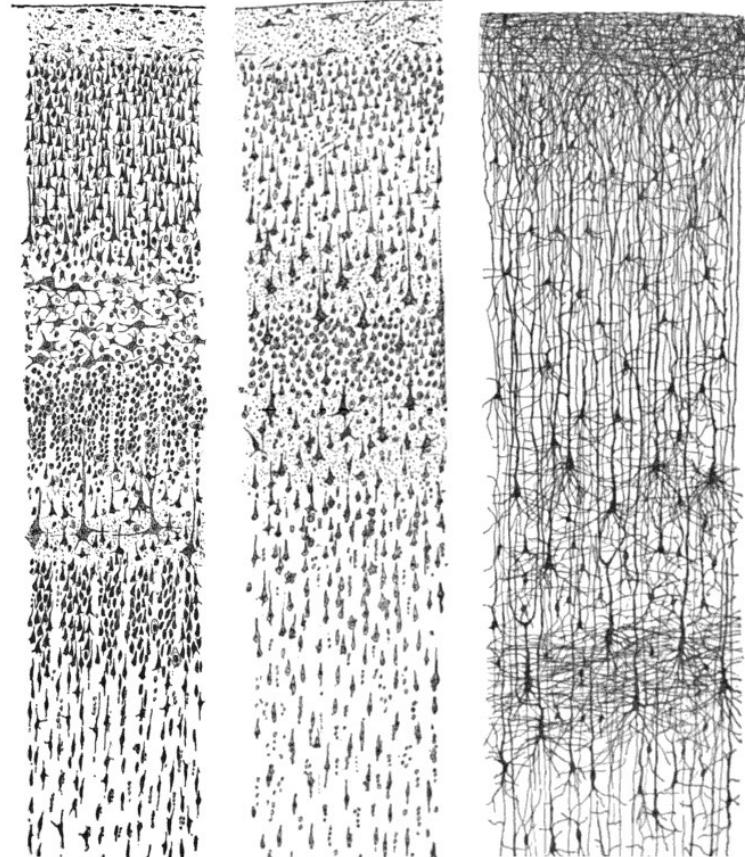
1. **Nissl stain:** cell bodies of neurons

2. **Golgi stain:** dendrites and axons of a random subset of neurons

Left: Nissl-stained visual cortex, adult

Middle: Nissl-stained motor cortex, adult

Right: Golgi-stained cortex of an infant



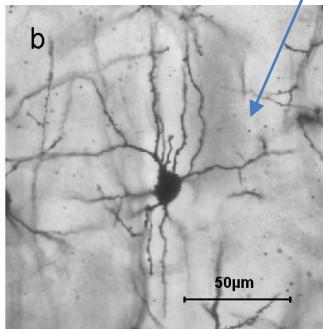
Source: Wikipedia.org

Cortical Layers

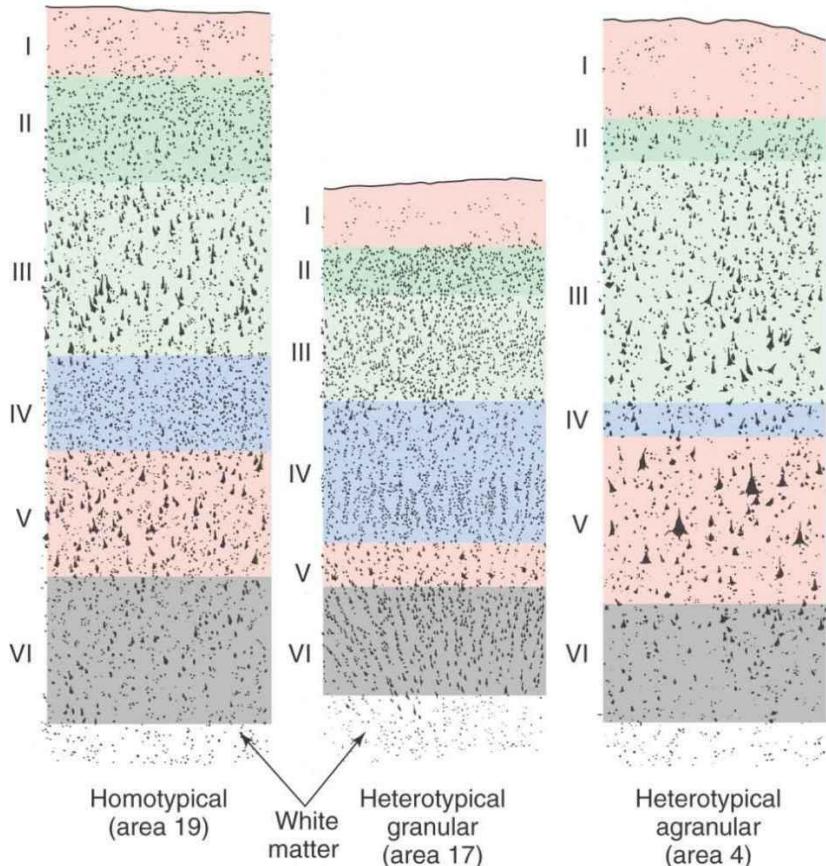
- Six layers with characteristic cell types in each layer
 - Layer 4: input layer (stellate neurons)
 - Layer 5: sends signal from cortex back to thalamus (pyramidal neurons)
- > Later more



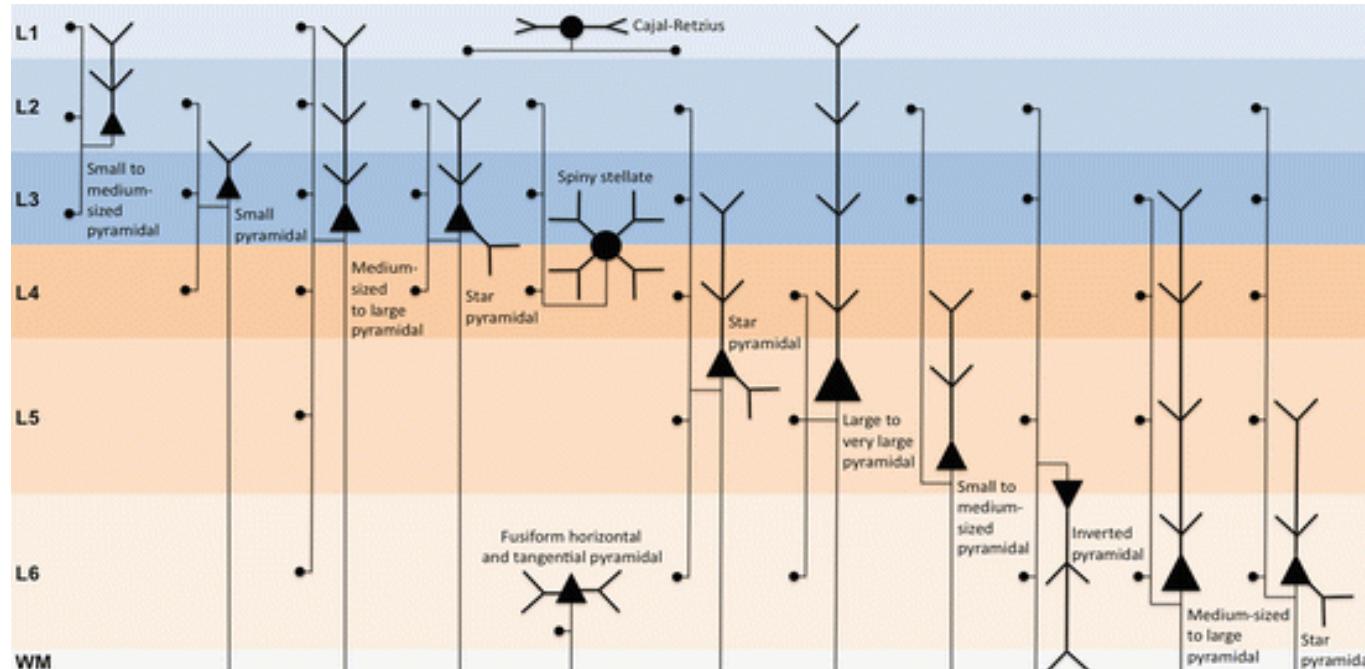
https://en.wikipedia.org/wiki/Pyramidal_cell



https://en.wikipedia.org/wiki/Stellate_cell

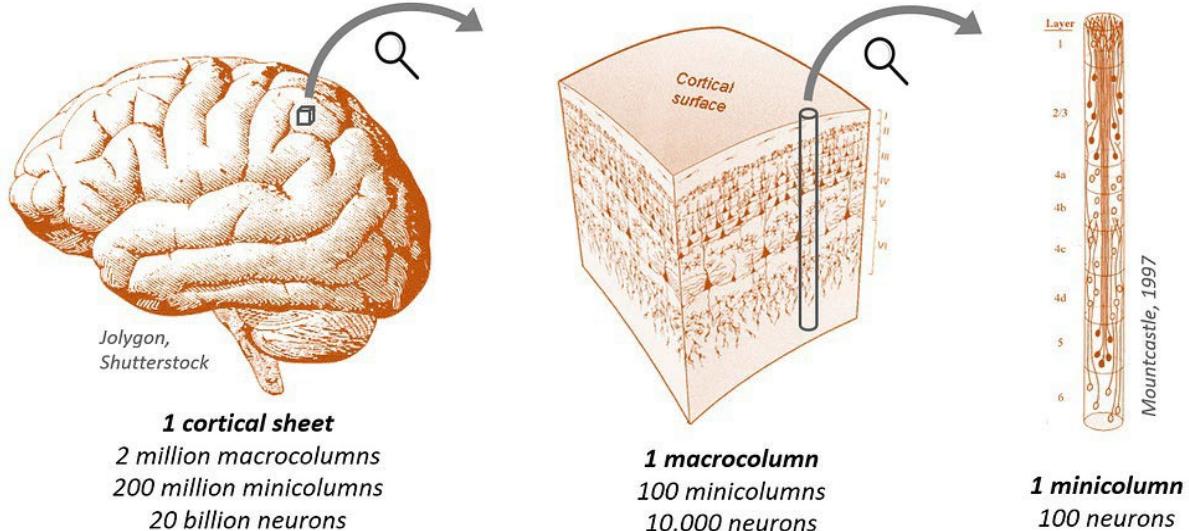


Cortical cell types



Source: SpringerLink

Cortical Columns



Source: <https://www.insightsfromthebrain.com/>

- Minicolumns fundamental processing unit in the cortex
- E.g. neurons in one minicolumn of somatosensory cortex have the same receptive field

Jones, E. G. (2000). Microcolumns in the cerebral cortex. *Proceedings of the National Academy of Sciences*, 97(10), 5019-5021.

Favorov, O. V., Diamond, M. E., & Whitsel, B. L. (1987). Evidence for a mosaic representation of the body surface in area 3b of the somatic cortex of cat. *Proceedings of the National Academy of Sciences*, 84(18), 6606-6610.

Concept is also criticized:
"However, it is unclear what advantage, if any, is conveyed by this form of columnar segregation. Although the column is an attractive concept, it has failed as a unifying principle for understanding cortical function." (Horton and Adams 2005)

Horton, J. C., & Adams, D. L. (2005). The cortical column: a structure without a function. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 360(1456), 837-862.

New publication in Science

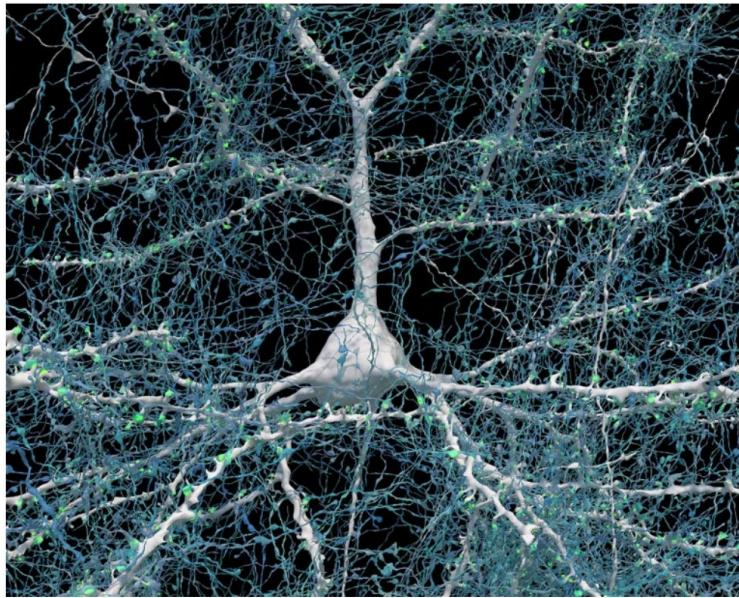
RESEARCH ARTICLE

NEUROSCIENCE

A petavoxel fragment of human cerebral cortex reconstructed at nanoscale resolution

Alexander Shapson-Coe^{1,2†}, Michał Januszewski^{3†}, Daniel R. Berger^{1†}, Art Pope⁴, Yuelong Wu¹, Tim Blakely⁵, Richard L. Schalek¹, Peter H. Li⁴, Shuhong Wang¹, Jeremy Maitin-Shepard⁴, Neha Karlupia¹, Sven Dorkenwald^{4,6,7}, Evelina Sjöstedt¹, Laramie Leavitt⁴, Dongil Lee^{1,8}, Jakob Troidl⁹, Forrest Collman¹⁰, Luke Bailey¹, Angerica Fitzmaurice^{1,11}, Rohin Kar^{1,11}, Benjamin Field^{1,11}, Hank Wu^{1,11}, Julian Wagner-Carena¹, David Aley¹, Joanna Lau¹, Zudi Lin⁹, Donglai Wei¹², Hanspeter Pfister⁹, Adi Peleg^{1,13}, Viren Jain^{4*}, Jeff W. Lichtman^{1*}

Shapson-Coe, A., Januszewski, M., Berger, D. R., Pope, A., Wu, Y., Blakely, T., ... & Lichtman, J. W. (2024). A petavoxel fragment of human cerebral cortex reconstructed at nanoscale resolution. *Science*, 384(6696), eadk4858.

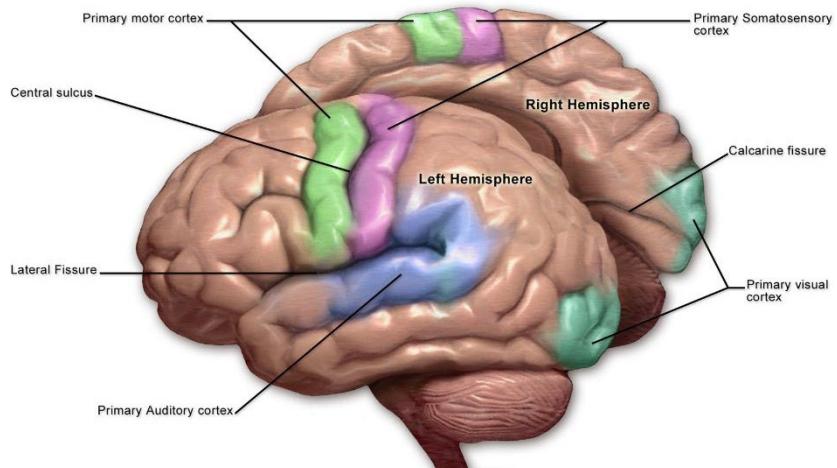


Wong, C. (2024). Cubic millimetre of brain mapped in spectacular detail. *Nature*.

- Cubic millimeter of human brain temporal cortex
- 57.000 cells, 230mm of blood vessels, 150 million synapses, 1.4 petabytes
- Many weak synapses and around 50 strong connections to single neurons
- 5,000 slices of 34nm each

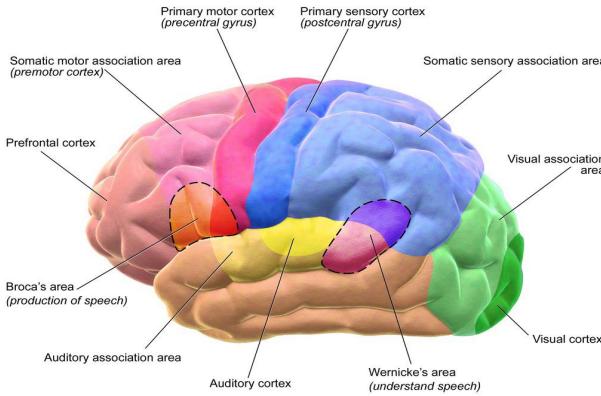
Functional organization of the cerebral cortex

Functional Organization of the Cerebral Cortex



Source: Blausen.com staff (2014)

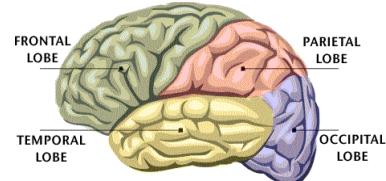
Motor and Sensory Regions of the Cerebral Cortex



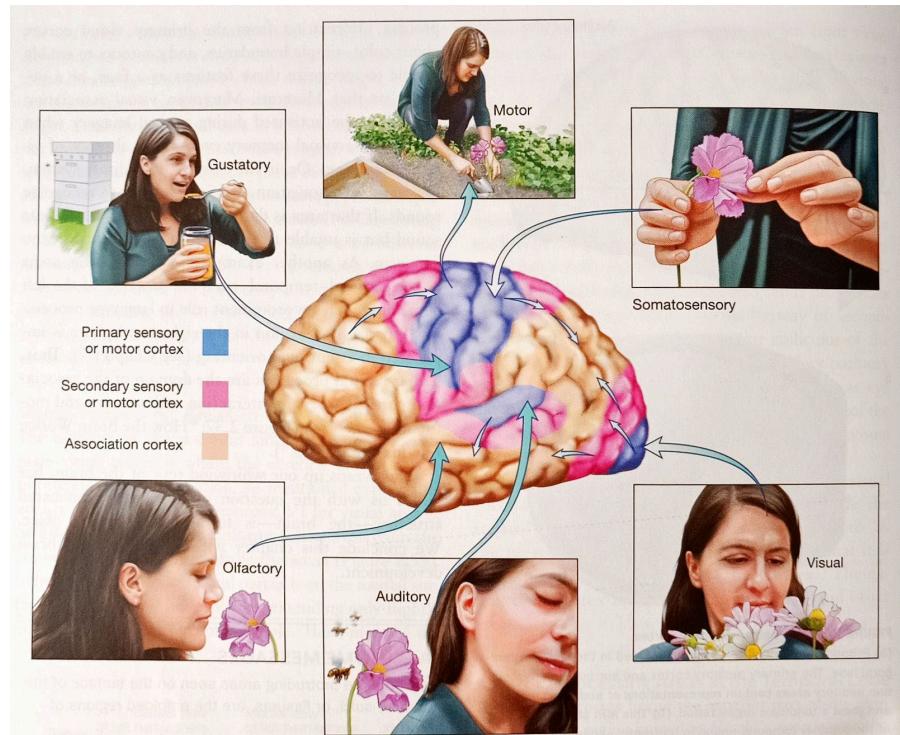
Source: Blausen.com staff (2014)

Source:
http://michellej.github.io/education_digest/brain.html

- Motor areas at frontal lobe: planning and execution of motions
- Somatosensory areas of the parietal lobe
- Visual processing in the occipital lobes
- Auditory processing at temporal lobe
- Association cortex: not sensory not motor cortex (integrate information)



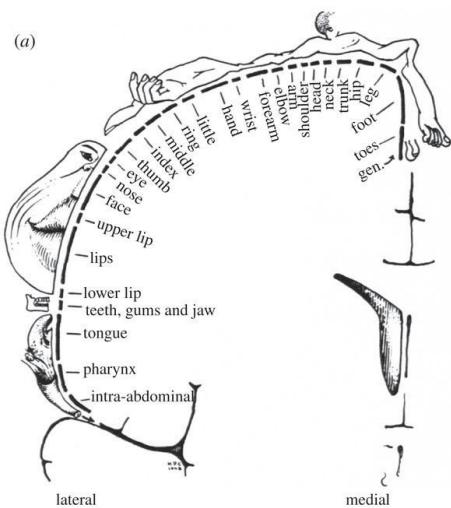
Functional Organization of the Cerebral Cortex



Cognitive neuroscience, Gazzaniga, Ivry, Mangun, 2014

Map-like organization (topographic) of cortical areas

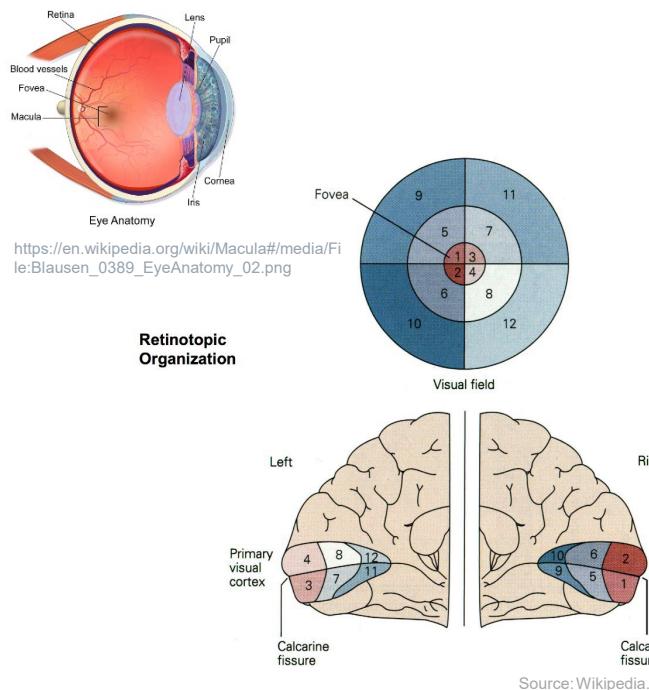
Somatosensory Cortex/ Motor Cortex



Hashimoto, T. et al., (2013). *Philosophical Transactions of the Royal Society B: Biological Sciences*, 368(1630), 20120417.

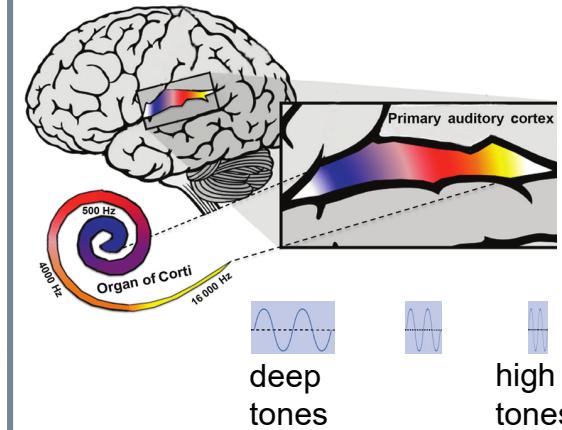
Somatotopy

Visual Cortex



Retinotopy

Auditory Cortex



Source: ResearchGate.net

Tonotopy

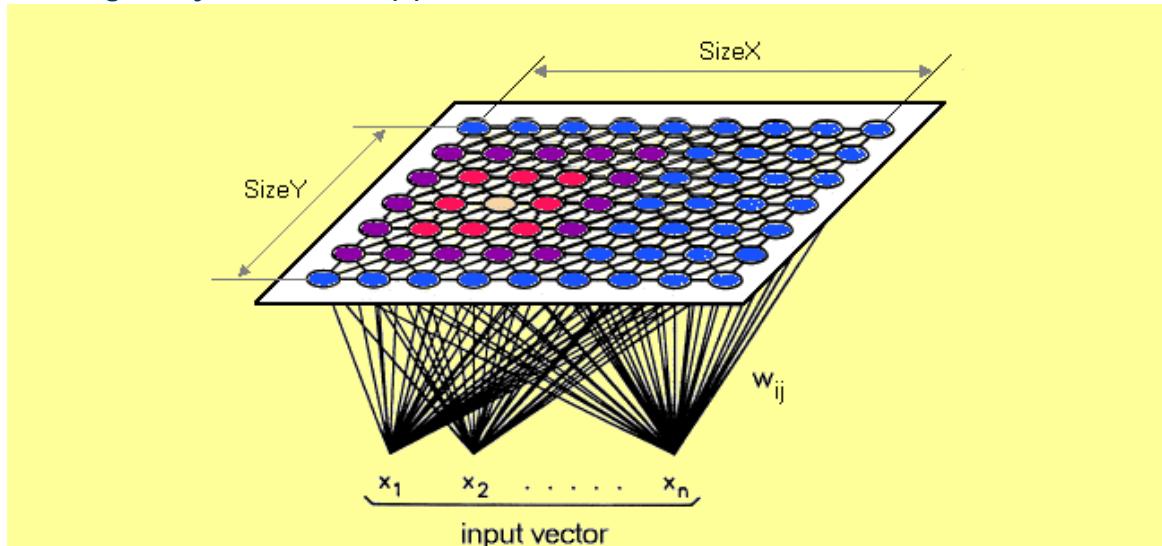
**Side note: Artificial creation of
topological correct feature maps
(as we have it in the cortex)**

Self-organizing feature maps

Introduced by Teuvo Kohonen, 1982

Kohonen, T. (1982). Self-organized formation of topologically correct feature maps. *Biological cybernetics*, 43(1), 59-69.

- Unsupervised learning
- Topological correct feature maps
- Not very often used to cluster in modern AI

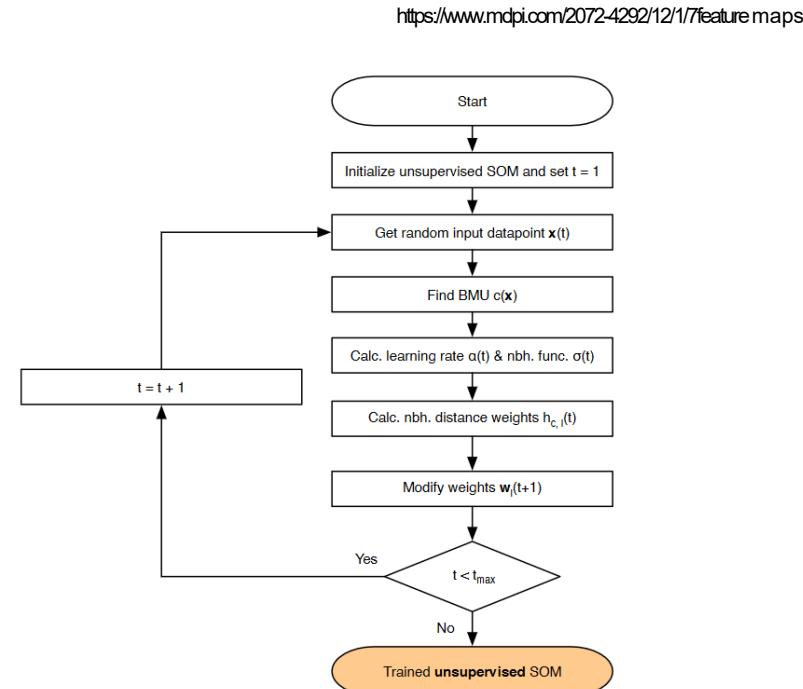


Source: <https://medium.com/@abhinavr8/self-organizing-maps-ff5853a118d4>

Self-organizing feature maps

Algorithm

- neurons are arranged in a grid -> **neurons have a physical position** (contrast to normal machine learning)
- Each neuron has a weight vector of the same size as the input data (n-dimensional)
- **Training:**
 - 1) Calculate Euclidean distance between input and weight vector
 - 2) Find neuron with the lowest distance of weight vector and input vector -> called BMU
 - 3) Update the weight vectors of all neurons however higher learning rates in neurons with lower distances to BMU
 - 4) Similar input is at similar position after training

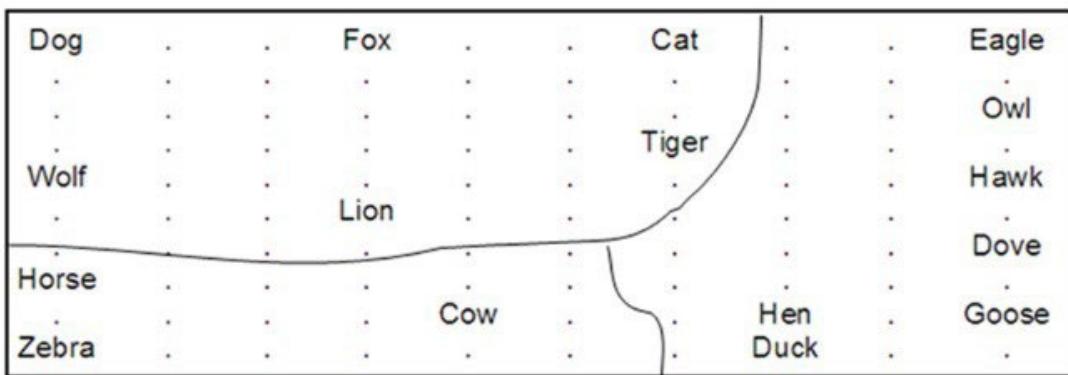


$$w_i(t+1) = w_i(t) + \alpha(t) \cdot h_{c,i}(t) \cdot (x(t) - w_i(t)), \quad (5)$$

with neighborhood function $h_{c,i}(t)$, learning rate $\alpha(t)$, and weight vector $w_i(t)$ of node i at iteration t .

Self-organizing maps

	dove	hen	duck	goose	owl	hawk	eagle	fox	dog	wolf	cat	tiger	lion	horse	zebra	cow
is small	1	1	1	1	1	1	0	0	0	0	1	0	0	0	0	0
is medium	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0
is big	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
has 2 legs	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
has 4 legs	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
has hair	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
has hooves	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
has mane	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0
has feathers	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
likes hunt	0	0	0	0	1	1	1	1	0	1	1	1	1	0	0	0
likes run	0	0	0	0	0	0	0	1	1	0	1	1	1	1	0	0
likes to fly	1	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0
likes to swim	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0



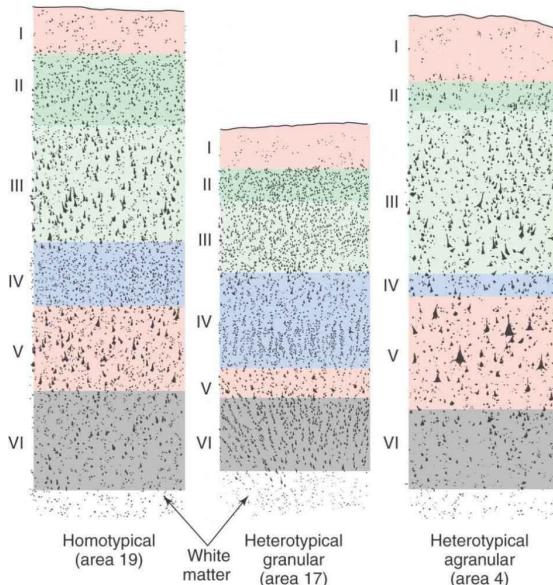
Source: <https://doi.org/10.3389/fpsyg.2013.00828>

Fig 1 Animal names and their attributes

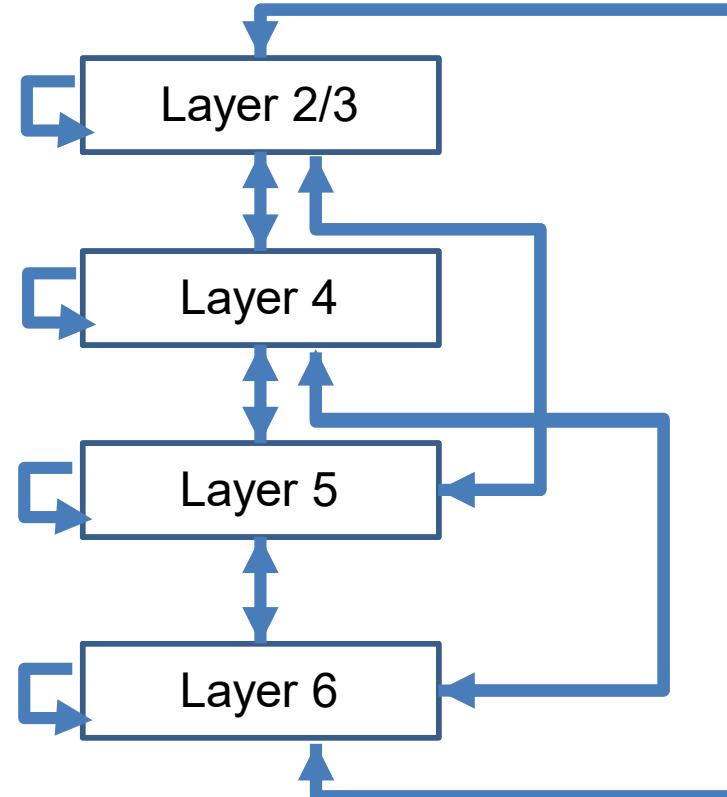
Source: semanticscholar.org

Canonical cortical connectivity (function of the 6 layers)

Cortical connectivity

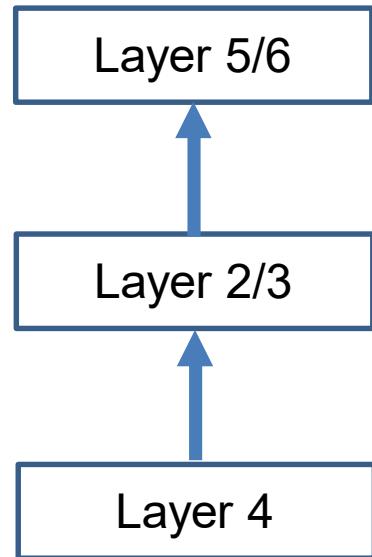


Source:
neupsykey.com



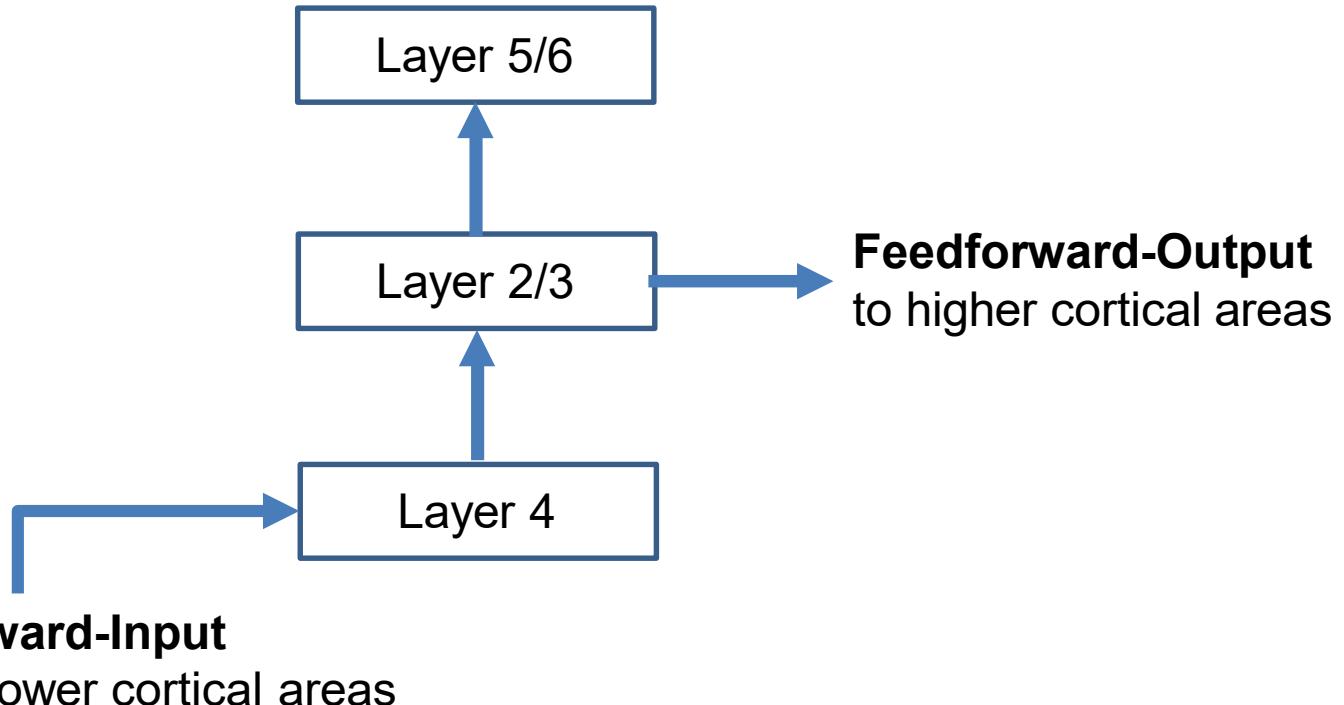
The Canonical Cortical Circuit

main information flow



The Canonical Cortical Circuit

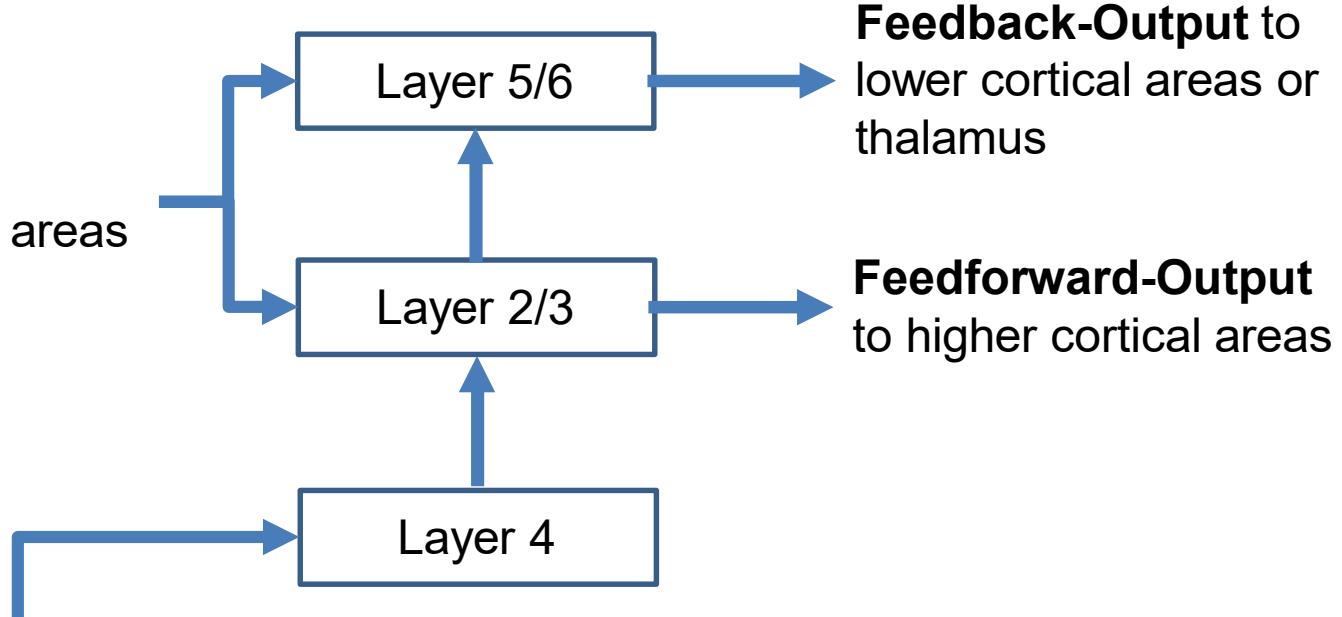
main information flow



The Canonical Cortical Circuit

main information flow

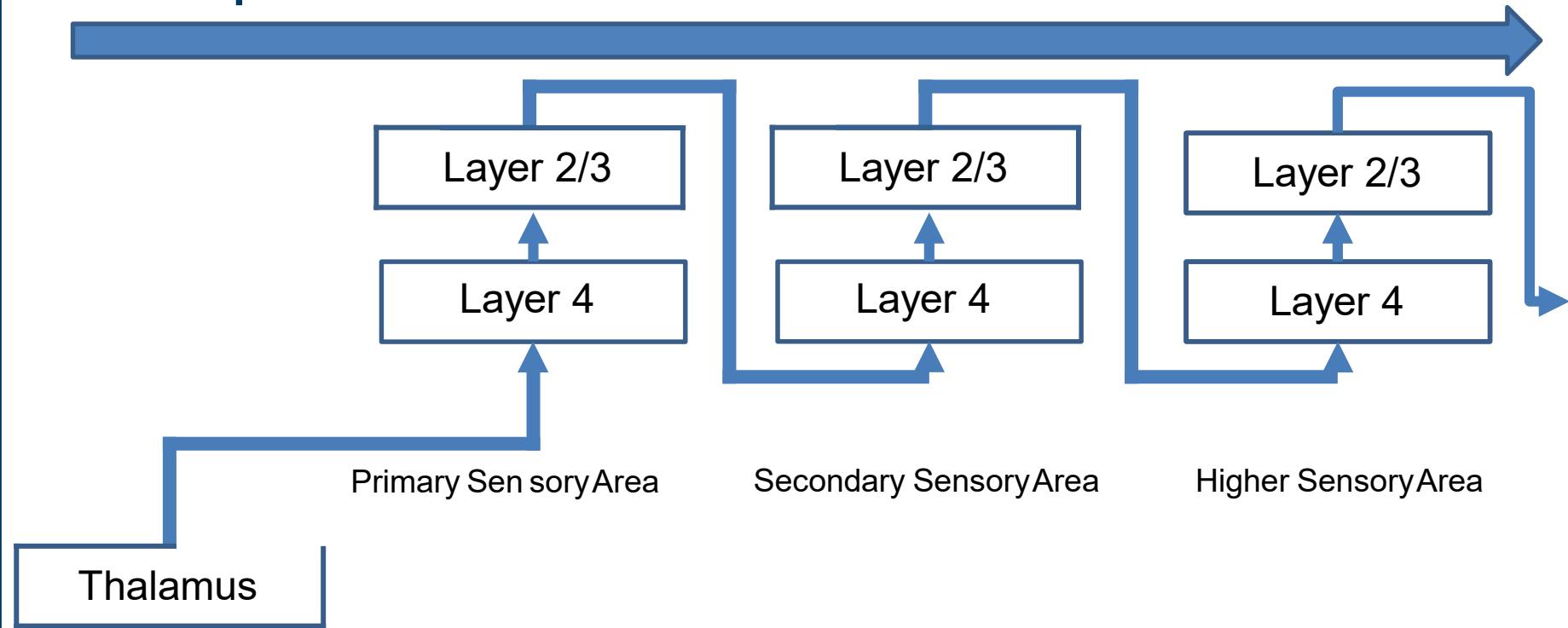
Feedback-Input
from higher cortical areas



Feedforward-Input
from thalamus or lower cortical areas

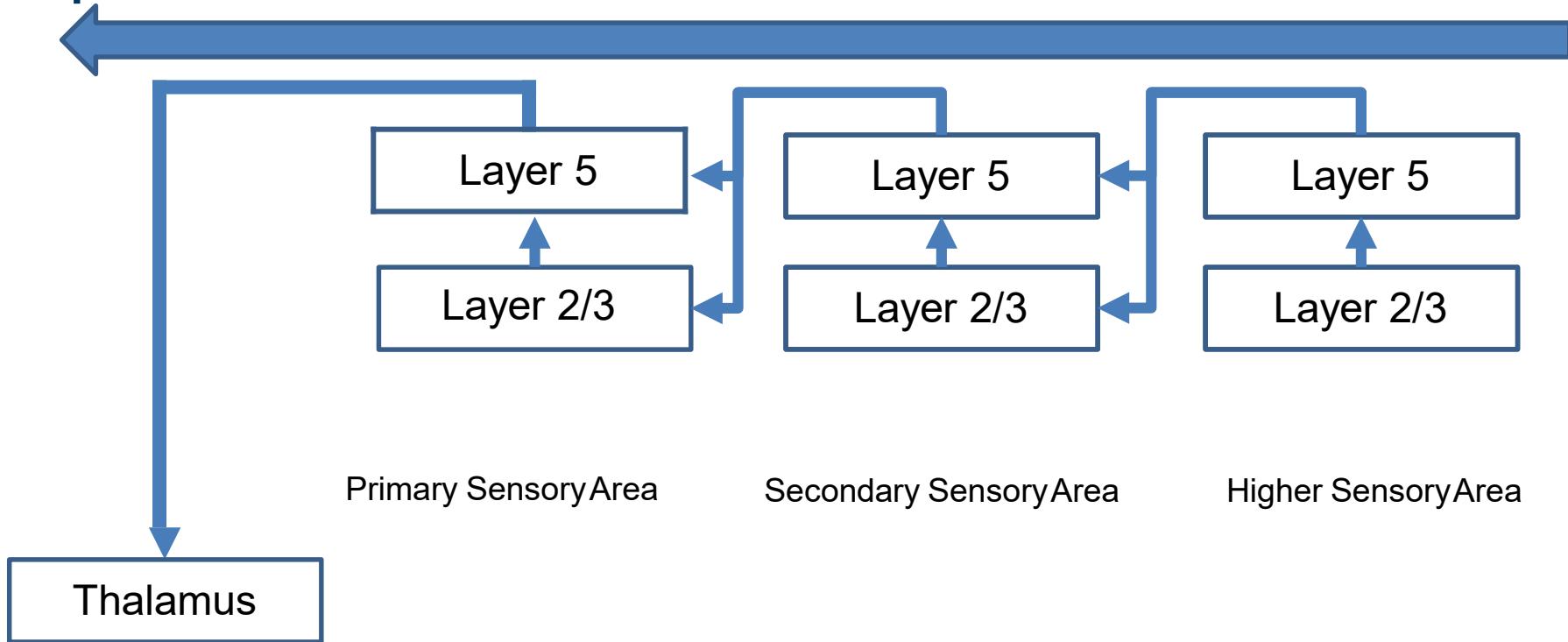
The Canonical Cortical Circuit

bottom up information flow / feedforward connections



The Canonical Cortical Circuit

top down information flow / feedback connections

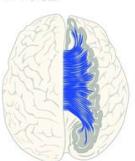


The Canonical Cortical Circuit

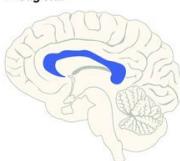
horizontal information flow / lateral connections, inter-hemispheric



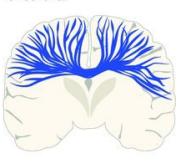
A Dorsal



B Sagittal



C Coronal



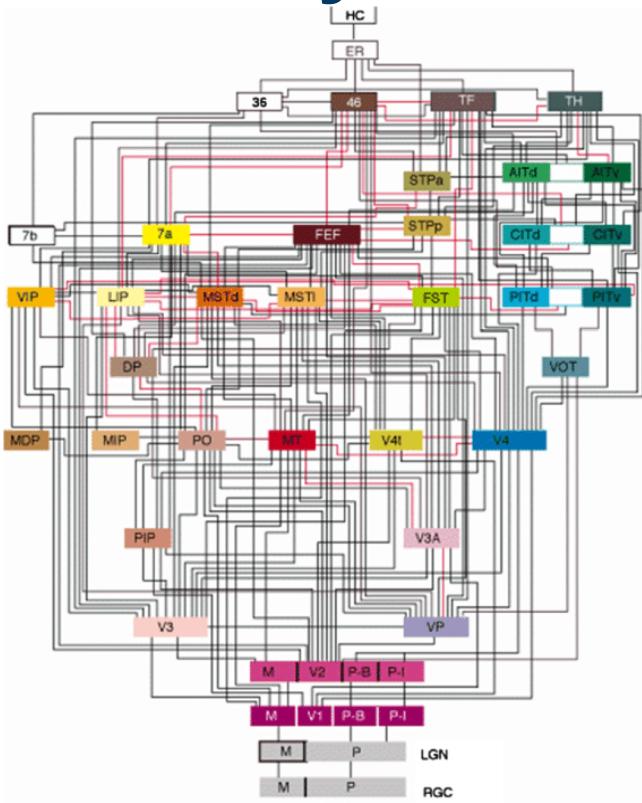
Area A

Area B

Area C

areas of same hierarchical level!

Hierarchy of cortical areas



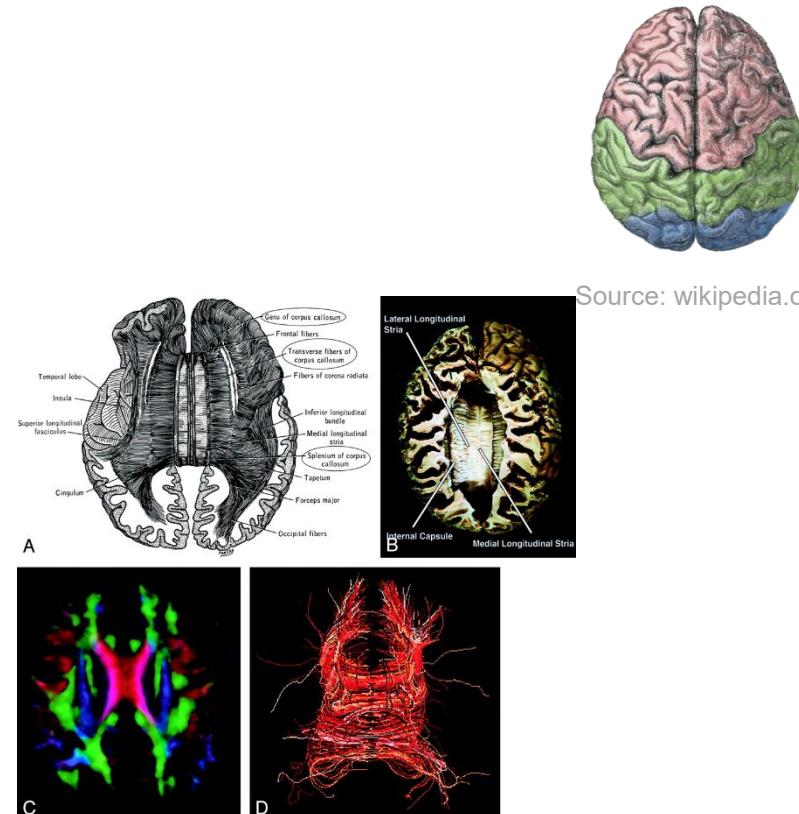
- Visual System of monkeys
- Lowest level: **Thalamus and Primary Visual cortex**
- Highest level: **Hippocampus!**

Lateralization of Brain (Structure) and Function

Lateralization

Reminder:

- Each part of the brain exists twice: left and right side (except glands and corpus callosum)
- Cerebral Cortex: left and right hemisphere
- Corpus Callosum connects both **cortical** hemispheres
- Left hemisphere represents right side of the body and vice versa

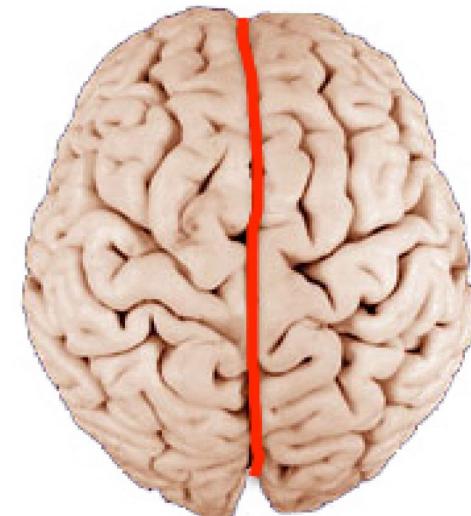


Jellison, B. J., Field, A. S., Medow, J., Lazar, M., Salamat, M. S., & Alexander, A. L. (2004). Diffusion tensor imaging of cerebral white matter: a pictorial review of physics, fiber tract anatomy, and tumor imaging patterns. *American Journal of Neuroradiology*, 25(3), 356-369.

Anatomical asymmetries

Left hemisphere shows:

- larger total specific gravity
- larger insular cortex
- larger gray matter (neurons' cell bodies) fraction
- larger inferior temporal lobe
- larger primary sensory areas
- smaller association areas



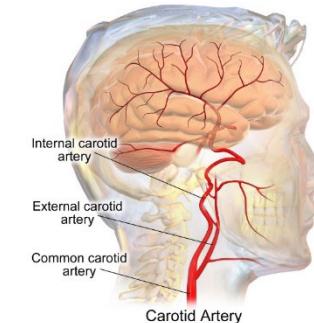
<https://www.mdpi.com/2227-7080/5/2/16>

Lateralization of Brain Function

- **Lateralization:**
 - tendency for neural functions or cognitive processes to be specialized to one side of the brain
 - homologue cortex areas at both sides have different functions

- **Best example is language:**

Broca's and Wernicke's area located exclusively in left hemisphere in 95% of right-handers and 70% of left-handers



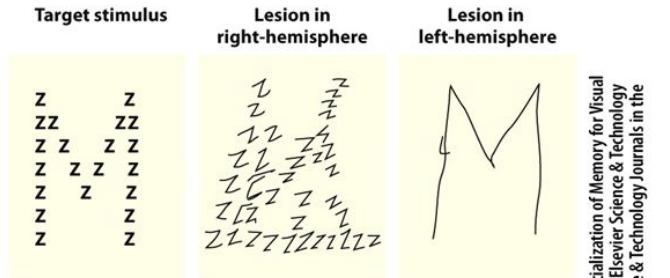
https://en.wikipedia.org/wiki/Internal_carotid_artery

- **Reminder: Lesion Studies as important tool to investigate brain lateralization**
- **Wada test:** hemispheres reversibly blocked:
 - Injection of amobarbital into carotid artery -> deep anesthesia of ipsilateral brain hemisphere
 - > investigation of lateralization of language processing

Lateralization of Brain function: Unilateral cortical lesion

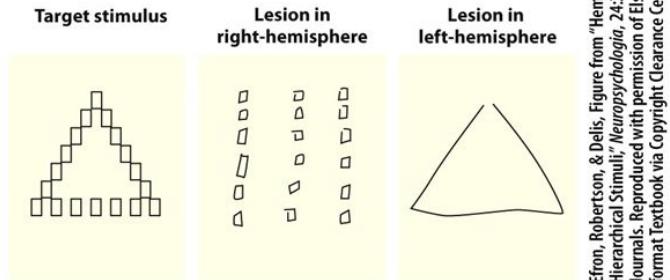
Extreme failures of hierarchical processing following brain damage

Linguistic stimulus



Efron, Robertson, & Delis, Figure from "Hemispheric Specialization of Memory for Visual Hierarchical Stimuli," *Neuropsychologia*, 24:2, © 1985 by Elsevier Science & Technology Journals. Reproduced with permission of Elsevier Science & Technology Journals in the format Textbook via Copyright Clearance Center.

Nonlinguistic stimulus



- Hierarchical stimulus: Letter or sign made of several letter or signs
- Lesion left: drawing only the big contours
- Lesion right: drawing only local elements
- **Right hemisphere:** extraction of big picture
- **Left hemisphere:** more detail oriented

Functional asymmetries

Left hemisphere:

- Language: Word detection/generation
- Verbal
- Reading
- Problem solving
- **Sequential processing** (math...)
- **Analytic**

Right hemisphere:

- Melody, Pitch, Intensity
- Non-verbal
- Drawing
- Visio-spatial tasks
- Face recognition
- **Parallel processing**

Theory of mind

- **Theory of mind refers to our ability to understand that other individuals have thoughts, beliefs and desires**
- When lateralized at all -> to the right side
- **Shocking finding:** if information of beliefs of others is in right hemisphere and in **split brain people** is not transferred to left hemisphere (speaking)
-> that would have an huge effect on **moral reasoning** -> **was not found**
- Also left hemisphere can do processing needed for belief attribution (but slow)

Reminder Lecture 2: Sally-Ann False Belief Test

GPT-4: Understanding beliefs

We will read about a scenario, and then have a question and answer session about it.

--

Scenario:

Alice and Bob have a shared Dropbox folder.

Alice puts a file called 'photo.png' inside /shared_folder/photos.

Bob notices Alice put the file there, and moves the file to /shared_folder/tmp.

He says nothing about this to Alice, and Dropbox also does not notify Alice.

--<|endofprompt|>

Q: After the call, Alice wants to open 'photo.png'. In which folder will she look for it?

Alice will most likely look for 'photo.png' in /shared_folder/photos, the folder where she originally put it. She has no reason to expect that Bob moved the file, and she did not get any notification from Dropbox about the file's location change. Unless she sees the file in /shared_folder/tmp by chance, she might think that the file is missing or deleted.

Bubeck, S., Chandrasekaran, V., Eldan, R., Gehrke, J., Horvitz, E., Kamar, E., ... & Zhang, Y. (2023). Sparks of artificial general intelligence: Early experiments with gpt-4. *arXiv preprint arXiv:2303.12712*.

Baron-Cohen, S., Leslie, A. M., & Frith, U. (1985). *Cognition*, 21(1), 37-46.

The interpreter

- We know: **Causal inferences are a specialized ability of left hemisphere**
-> left hemisphere is the interpreter
- **In split brain patients:** left hemisphere tries to find explanations for actions initiated by right hemisphere
- Example 1: „stand up“ presented to right hemisphere
 - > person stands up
 - > ask person „Why did you stand up?“
 - > left hemisphere creates plausible explanations „I wanted a coke“
- Example 2: "Why are you upset?" -> "The experimenter upsets me!"

Split brain patients and consciousness

- **Split-brain patients do not report differences in conscious experiences!**
 - Left brain hemisphere acts like there was never a right hemisphere
 - Perhaps consciousness is not a single generalized process
 - > emergent property out of thousands of modules
 - > modules compete for attention
 - „*This dynamic moment-to-moment cacophony of systems comprises our consciousness*“ (from Cognitive Neuroscience, Gazzaniga)
 - However: We do not hear the chattering -> the interpreter is crafting this narrative
 - Also explains **Anosognosia**: people with brain lesions are unaware of problems and deny that they have problems
- > *more on consciousness in later lecture*

Hemispheric specialization in Nonhumans

Chickens and pigeons:

Better discriminate food and non-food items presented to right eye

-> **left hemisphere**

Better respond to unique properties of objects (color, size, shape) and better learn exact localization of objects presented to left eye

-> **right hemisphere**

Birdsong: **left hemisphere**



Source: collinsdictionary.com



Source: collinsdictionary.com

Summary I

Left hemisphere

- Larger primary motor and sensory areas
 - > enables higher resolution, more fine-grained representation
- Smaller association areas
 - > enforces more compressed representation, focus on smaller patterns

Right hemisphere

- Smaller primary motor and sensory areas
 - > enforces smaller resolution, more compressed representation
 - > left hand can be controlled in a less fine-grained way
- Larger association areas
 - > enables to represent more, larger patterns

Summary II

- **Left hemisphere:** sequential-analytic processing
- Speech as a continuous stream: rapid segmentation into component parts
- **Right hemisphere:** holistic-parallel processing
- Visual-Spatial representations: coherent whole, not just component parts
- Hemispheric specialization may emerge because certain tasks benefit from one processing style or another

Asymmetry may:

- be a more efficient and flexible design principle
- reduce redundancy across hemispheres
- allow for no-cost extension: expands cortical capacity