Q355 / Q590: Neural networks and the Brain

Prof. Brown

Spring 2022

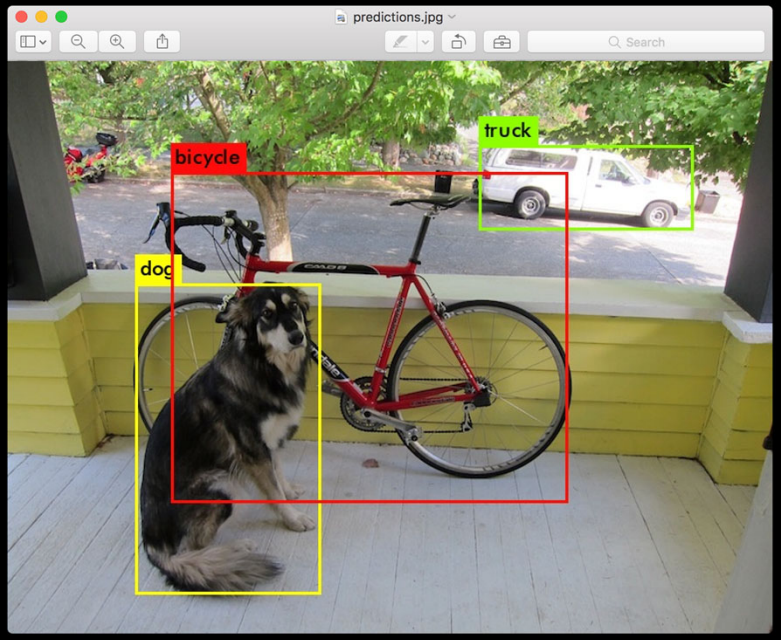
For discussion

- Is AI going to take over the world? Should we be afraid?
- What are neural networks?
- Are artificial neural networks similar to the human brain?
- What are neural networks better at the humans?
- What are neural networks worse at than humans?
- What are the most interesting questions about AI and neural networks?

Demos

- Google translate
- https://pjreddie.com/darknet/yolo/

- How do these work?
- How can you implement them?
- Are they like the brain?



What this course is about

- The neural network spectrum

<u>Machine Learning</u>

- How do we classify data and make $?
- Data science
- Classifier accuracy!
- Don't care about the brain *per se*

<u>Neuroscience/ Modeling</u>

- How does the brain work?
- Simulate neuroscience data
- Classifier accuracy less important

Syllabus

- **Professor: Brown**
- Meetings: M/W 1:45-3:00, Psychology 115
- Office hours: Wed 3:00pm and by appointment, Psychology Bldg. 336
- Telephone: (812) 855-9282
- Email: jwmbrown@indiana.edu

Syllabus

- **Course description:** The last few years have witnessed renewed interest in neural networks and deep learning as powerful tools for understanding and simulating cognitive processes. Neural networks are inspired by brain structure and function but vary in how well they perform cognitive tasks and how faithfully they simulate biological processes of the brain. This course provides an overview of common neural networks including deep learning, reinforcement learning, and self-organizing maps. Some practical computer programming exercises, mainly in Python, will provide training in how to implement neural networks to solve real-world problems. For each neural network, the course will critically analyze how well the networks solve real-world problems, how well they simulate neural systems in the brain, and where they fall short of biological plausibility. By the end of the course students will be able to implement practical neural network solutions and evaluate their suitability as models of the brain and cognition.
- **Prerequisites:** CSCI-C211 or COGS Q260, with a grade of B or better. Also COGS Q350 or COGS Q351/CSCI B351 or consent of instructor.

Syllabus – Q355

- Course requirements (500 total points possible):
- Attendance/Participation 60 points
- Homework Assignments 165 points
- Midterm exam: 75 points
- Final project: 100 points
- Final exam (cumulative): 100 points

- Grading: The course will involve lectures and regular assignments, which most commonly will involve running existing code provided by the instructor and modifying existing code in specific ways. Students may also be asked to write new simulation code. Other writing assignments may involve critical evaluation of neural network approaches and relevant findings from neuroscience. Grades will be based on participation in class, completing the programming and written assignments, and a midterm and final exam.

Syllabus – Q590

- Course requirements (500 total points possible):

• Attendance/Participation	80 points
• Python refresher exercise	20 points
• Final project proposal	50 points
• Final project:	350 points

Note that the final project for this class is of utmost importance for your grade. I will expect the final project to include (1) an extensive, critical review and analysis of the reading you have done this semester, and (2) a simulation project implementing a novel computational neural model, which may be an extension of an existing model, along with an analysis and discussion of the model results with respect to the literature. As a guide, your final project should include 10-15 pages of text, single spaced, plus simulation figures and references.

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- Course text: There is no official course text, but selected readings will be assigned. Note that for neural networks and deep learning, there is a lot of new material and demonstrations on internet blogs and youtube especially, as well as a lot of code on Github. You are encouraged to make use of this material as aids to learning. The two rules regarding this are: (1) Remember that the fact something appears on the internet does not mean it is necessarily true/accurate/correct, so you must evaluate everything critically, and (2) As is standard for academic honesty, you must acknowledge and cite any material you use from the internet, even if you have reworded and/or refactored it. Include reference URLs in any computer code you derive from another source.

- Course policies: Students are expected to be familiar with Canvas and to know how to download materials from and submit assignments to Canvas (http://canvas.iu.edu). Readings and materials that are not contained in the required texts will be placed online with Canvas. All readings should be completed before the first class session of the week in which they are to be discussed.

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- Active participation and respect by all enrolled students is expected. Prompt and regular attendance is expected barring extraordinary circumstances. Attendance will also be taken at each class session. Bring blank paper and a writing instrument (pen or pencil) to each class so that you can complete and submit in-class work.

- If you are not feeling well, DO NOT COME TO CLASS. The instructional mode of this class is "in person", so students are generally expected to attend class in-person, and attendance will be taken. Students should wear masks as prescribed by campus policy (https://www.iu.edu/covid/faq/index.html), currently with recommended KN95 masks or equivalent. Nevertheless, if you are unable to attend class for any reason (including covid, flu or other illness, family emergency, travel for IU athletic participation, hung over, over-slept, etc.), I do not need to know the reason. You can still earn full credit for attendance and participation. Lectures will be recorded via zoom and posted to canvas/Kaltura, and zoom will be running during the class sessions, so that you may connect to the course and participate via zoom at https://iu.zoom.us/j/81813075698?pwd=TmFHVDVIeGw3ZmJBUWlmb041U2ZxZz09 . The zoom link is provided for those who cannot attend in person but would still like to participate, but note that because this is an "in person" class, CONNECTING VIA ZOOM DOES NOT AUTOMATICALLY PROVIDE COURSE POINTS FOR ATTENDANCE. If you are unable to attend class in person, and even if you connected via zoom, to obtain credit for attendance you must do the following WITHIN TWO WEEKS for EACH missed class session.
  - (1) Review the lecture slides/notes from Canvas from the missed class.
  - (2) Write a summary of the material covered during the missed class session (minimum of 300 words). This summary should provide written definitions of concepts discussed in the course notes and provide examples of how the concepts are applied as appropriate.
  - (3) Students must complete any in-class assignments that were given during the missed session, providing written responses to the assignment questions.
  - (4) The written summary and responses to any in-class assignments must be emailed to Prof. Brown as soon as possible but not later than 14 calendar days of the missed class session, with the subject line: "Q355/Q590: Attendance makeup [date]", where [date] is the date of the missed class session.

There is no limit to the number of class sessions that can be missed and made up for full credit in this manner, except that the midterm and final exams must be taken.

Syllabus

- Turn off cell phone ringers during class. You are responsible for checking your official IU email account regularly for course communications. Prepare for all assignments in advance so that last-minute glitches do not catch you off guard, e.g. an internet connection fails right when an assignment is due or your computer crashes; none of these constitute acceptable excuses. Due dates are final deadlines. Late written work will be penalized at the rate of one grade deduction per day (i.e. a "B+" becomes a "B"). Extensions for written work will be granted only in exceptional circumstances, e.g. documented (bring me a paper copy that I can keep) medical or family emergency; if you know that you will need an extension, talk to me as far in advance as possible—do not wait until the day the paper is due.

- There is no make-up midterm examination; unexcused absence will result in a failing exam grade. In the rare case of an excused absence from the midterm examination (e.g. documented medical or family emergency), the midterm grade reported will be based upon other grades received up to that point, and the final examination will count for 175 points. The final examination must be taken as scheduled. A student who fails to attend the final examination and who has a passing grade up to that point will receive an Incomplete only if the professor has reason to believe that the absence was beyond the student's control. If not, the grade of "F" must be awarded, in accordance with University policies. In particular, purchasing airfare to leave town before the final exam or otherwise leaving town voluntarily before the final exam are NOT acceptable excuses that merit special arrangements for an early final exam. Students who anticipate absence from the final examination, or who are absent from the final examination for reasons they did not anticipate, should discuss their absence with the professor as soon as possible to make arrangements for the satisfaction of course requirements. At the professor's discretion, any student absent from the final examination must file a written explanation of the absence with the Dean of Students Office in Franklin Hall 108.

Syllabus

- Studying together is encouraged, but all written work (including assignments, quizzes, and exams) must be original and completed individually, except for assignments explicitly given as group assignments. No notes, outlines, readings, cell phones, laptops, or other programmable electronic devices are permitted during examinations. Any personal item with an on-off switch must be turned off during examinations. No assistance from other students or anyone else is allowed during examinations. The University reserves the right to penalize any student whose academic conduct at any time is, in its judgment, detrimental to the University. Such Conduct shall include cases of plagiarism, collusion, cheating, giving or receiving or offering or soliciting information in examinations, or the use of previously prepared material in examinations or quizzes. Violations should be reported to the professor, who will investigate and adjudicate allegations. In accordance with University policies, all incidents of academic misconduct will be reported to the Dean of Students. Cases of plagiarism or other dishonesty will most likely result in a failing course grade. Plagiarism includes failing to properly cite and acknowledge outside sources used in your written paper assignments, such as websites, books, other people, and custom paper-writing “services” on the internet. You must acknowledge the source of any other material you use, even if you paraphrase it, and quoted material must be enclosed by quotation marks. Be warned: many students have recently been caught plagiarizing from sources that supposedly passed automated plagiarism checks. The safest and right thing to do is to write your own papers and cite your sources properly. For further clarification, see the “Code of Student Rights, Responsibilities, and Conduct,” http://studentcode.iu.edu/.

Syllabus

- If any student will require assistance or appropriate academic accommodations for a disability, please contact the professor after class, during office hours, or by appointment as early as possible in the semester. Eligibility for disability support services must first be established through the Office of Disabled Student Services in Franklin Hall 096, (812) 855-7578, https://studentaffairs.indiana.edu/disability-services-students/. Confidentiality will be observed in all inquiries.

- If any student anticipates absences due to religious conflicts or religious holidays, satisfactory arrangements must be made with the professor during the first two weeks of the semester.

- This syllabus provides the precise formula for calculating a final letter grade in the course. Final course grade calculations displayed in Canvas may not be accurate for various reasons. Students should not rely on Canvas's grade summaries to display accurate information about course standing.

- This syllabus is subject to change as needed at the professor's discretion. If changes are made, notice will be given in class in advance.

Syllabus

- **Week 1. (Jan 10, 12)** Introduction. Syllabus overview. Introduction to Python. Overview of the brain, overview of neurons, point model of neurons. Assignment: Review of python and run simple program. Colaboratory. Pyzo.
- **Week 2. (Jan. 17, 19)** Neurophysiology. Assignment: Hodgkin-Huxley simulation of nerve cell.
- No class 1/17 - MLK
- (guest lecture 1/19 on neurophysiology)
- Assignment 1 due 1/19 (20 pts)
- Supplementary Reading: Book of Genesis, chap 4.
- **Week 3. (Jan. 24, 26)** HH models, continued. Linear algebra basics (focus on matrix multiplication) (guest lecture 1/24 HH models, 1/26 Linear algebra). Assignment: linear algebra review problems
- Reading: deeplearningbook.org Chapter 2
- **Week 4. (Jan. 31, Feb 2)** The perceptron, the delta rule. Unsupervised learning. Mike Merzenich empirical data on cortex reorganization, Kohonen self-organizing feature maps. Abstract clustering example.
- Reading: Levine, chapter 2 on Perceptrons
- Reading: Kohonen, 1982; Jenkins and Merzenich, 1990
- Assignment 2 due 1/31 (15 pts) – HH simulation
- Assignment 3 due 2/2 (15 pts) – Linear algebra
- **Week 5. (Feb. 7, 9)** Supervised learning XOR problem. Multi-layer perceptrons, Backprop, algorithm. Assignment: using multi-layer perceptrons to solve the XOR problem.
- Note: No in-person class meeting Feb. 7 (will be online asynchronous)
- Reading: https://www.deeplearningbook.org, chapter 6
- Supplementary reading: http://neuralnetworksanddeeplearning.com/chap3.html
- Assignment 4 due 2/9 (25 pts) – Kohonen map
- **Week 6. (Feb. 14, 16)** Error backpropagation and the brain. Leabra. Biological plausibility issues.
- Reading: http://neuralnetworksanddeeplearning.com/chap5.html
- Lillicrap et al., 2016
- Beniaguev et al. 2021 -- https://doi.org/10.1016/j.neuron.2021.07.002
- Supplementary reading: https://compcogneuro.org/ - chapter 4
- Assignment 5 due 2/16 (15 pts) - Backpropagation

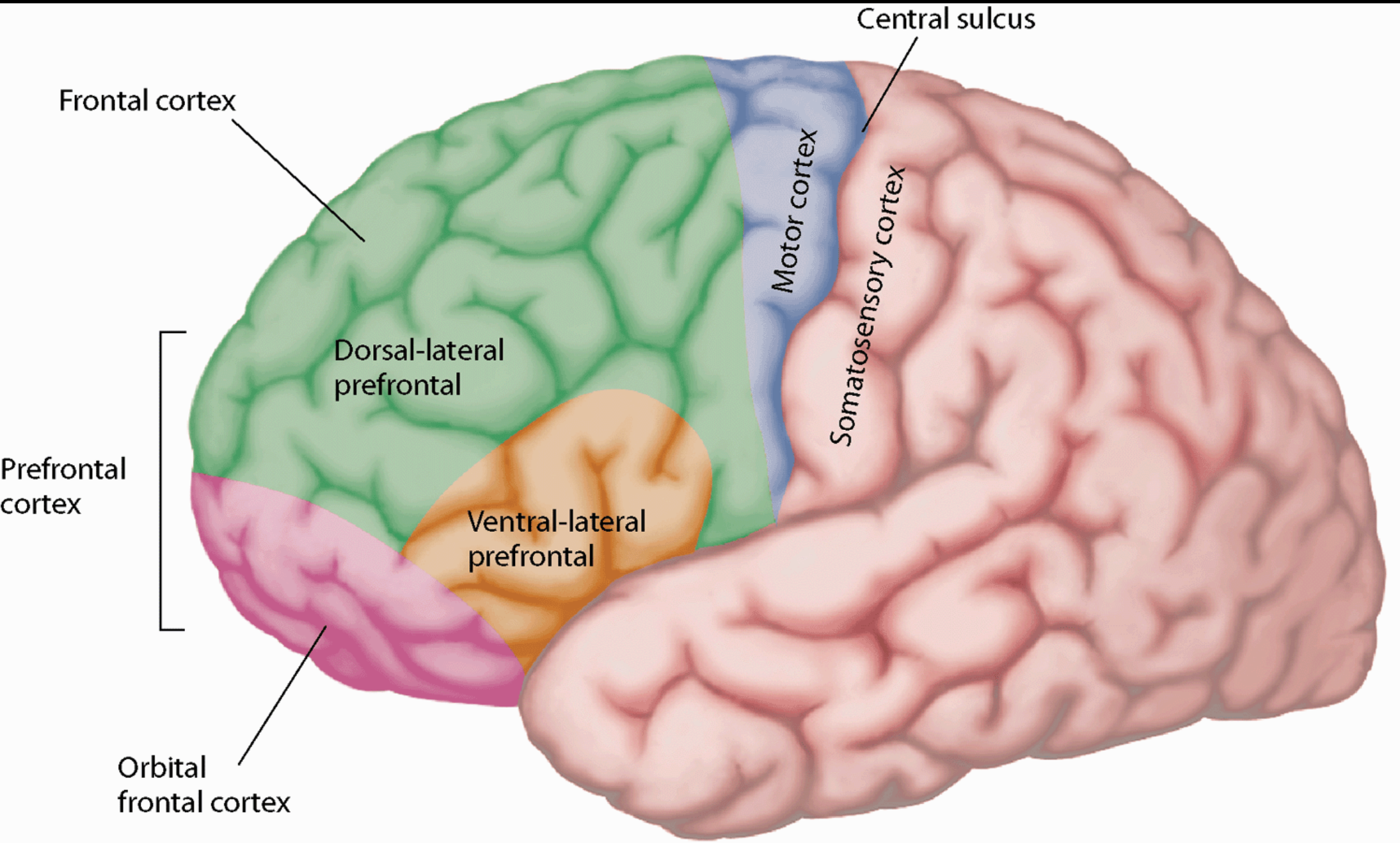
Syllabus

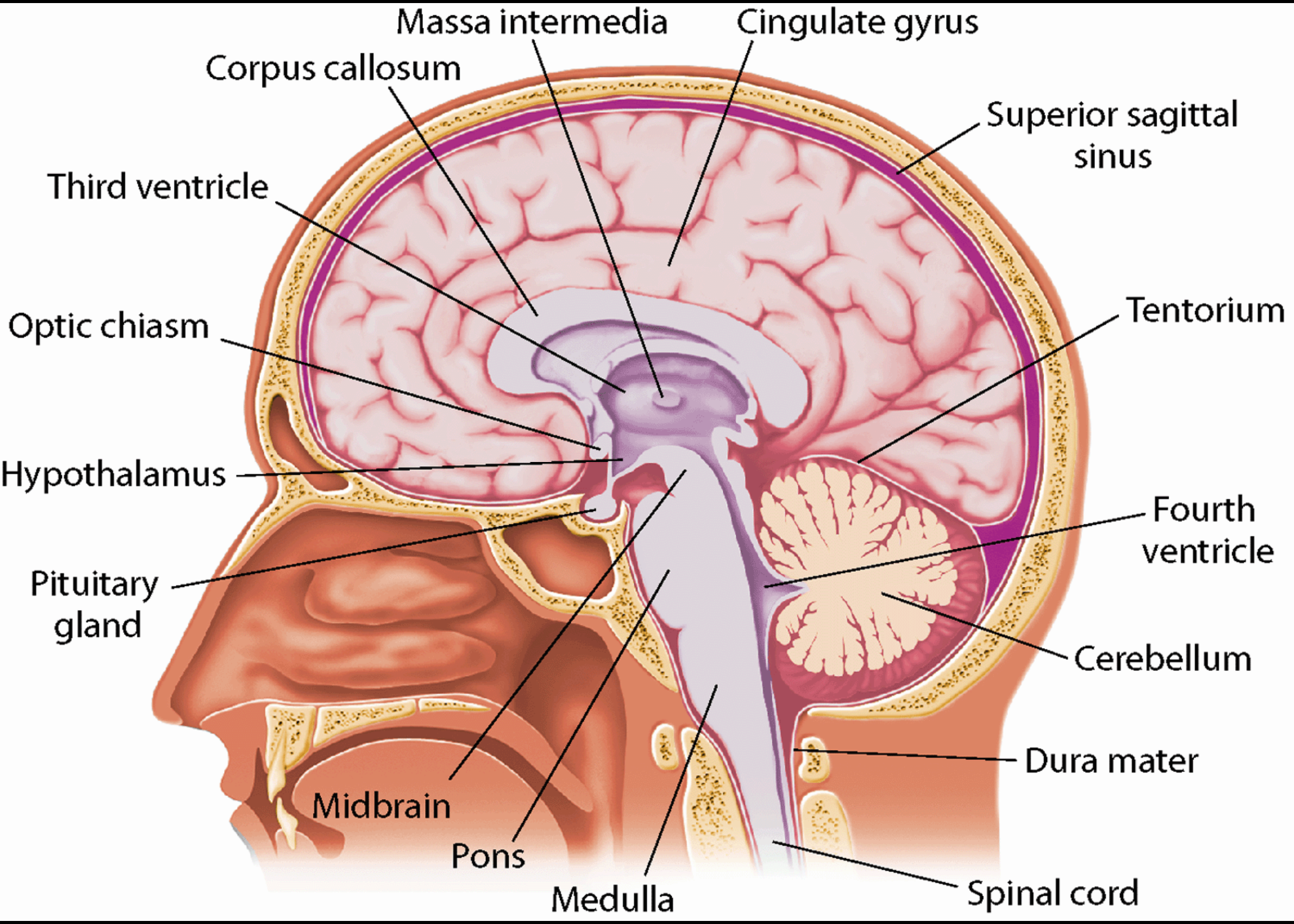
- **Week 7. (Feb. 21, 23)** Intro to deep learning. Deep learning, vanishing gradient problem, rectified linear units. Recent examples from Google DeepMind and others. Tensorflow introduction
  - Reading: http://neuralnetworksanddeeplearning.com/chap6.html
  - Assignment 6 due 2/23 (15 pts) – Feedback alignment
- **Week 8. (Feb. 28, Mar 2)** Vision – brains and machines. Principal component analysis. Fusiform face area, anterior IT. Paper on anterior IT by Kriegeskorte et al, 2015. Assignment: MNIST digit recognition using existing code.
  - Reading: Kriegeskorte, 2015
  - Midterm Exam – Feb. 28
- **Week 9. (Mar. 7, 9)** Recurrent neural nets. Basic overview of RNNs and LSTM.
  - Assignment 7 due 3/9 (20 points) - Tensorflow
  - Reading: Deeplearningbook.org, chap 10
- Spring break (Mar 14, 16) – no class
- **Week 10. (Mar 21, 23)** Recurrent neural nets, continued. Example of stock market prediction and pitfalls. New feedback alignment RNN. Dropout and hexagonal representation. Assignment: RNN time series prediction
  - Reading: Murray, 2019, https://elifesciences.org/articles/43299; paper by Cheng, Newman & Brown
- **Week 11. (Mar 28, 30)** Recurrent neural nets, continued. Generative models. Example DeepDrumpf. Start on reinforcement learning
- **Week 12. (Apr. 4, 6)** Reinforcement Learning. Wolfram Schultz and dopamine, neuroscience data.
  - Guest lecture by Prof. Eduardo Izquierdo April 4, on genetic algorithms to train dynamical recurrent networks.
  - Assignment 8 due 4/6 (20 points) – recurrent neural networks
  - Reading: Montague et al., 1996
  - Assignment 9 due 4/11 (20 points) - plan for final project
- **Week 13. (Apr 11, 13)** Sutton and Barto, 1983, pole cart problem. Regions of state space ("boxes"). Deep Q learning.
  - Reading: Barto et al., 1983, Silver et al. 2017, Mnih et al., 2015
- **Week 14. (Apr. 18, 20)** Neuroscience and biological plausibility – Guest & Love, 2016; Yamins & DiCarlo 2016.
- **Week 15 – (Apr. 25, 27)** course review and final project presentations. No assignments.
  - Final project in-class presentation Apr. 25
  - Final project due April 29 by 5pm (100 points): build your own neural network applied to a problem of your choice. Explain how it works, how it performs as a machine learning method, and how it is or is not a model of neural function.
- **Final exam: 12:40-2:40 p.m., Wed., May 4**

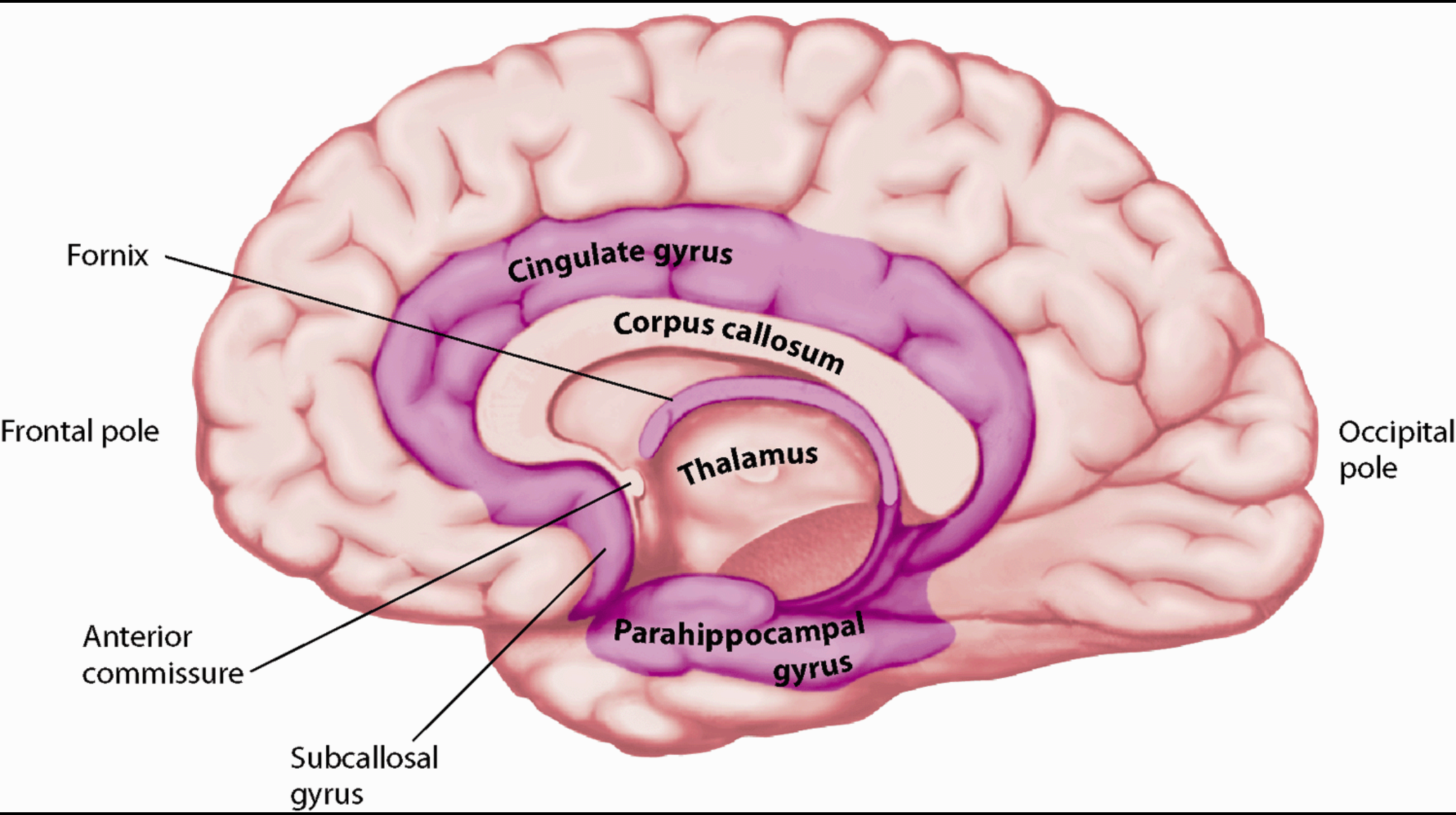
Python

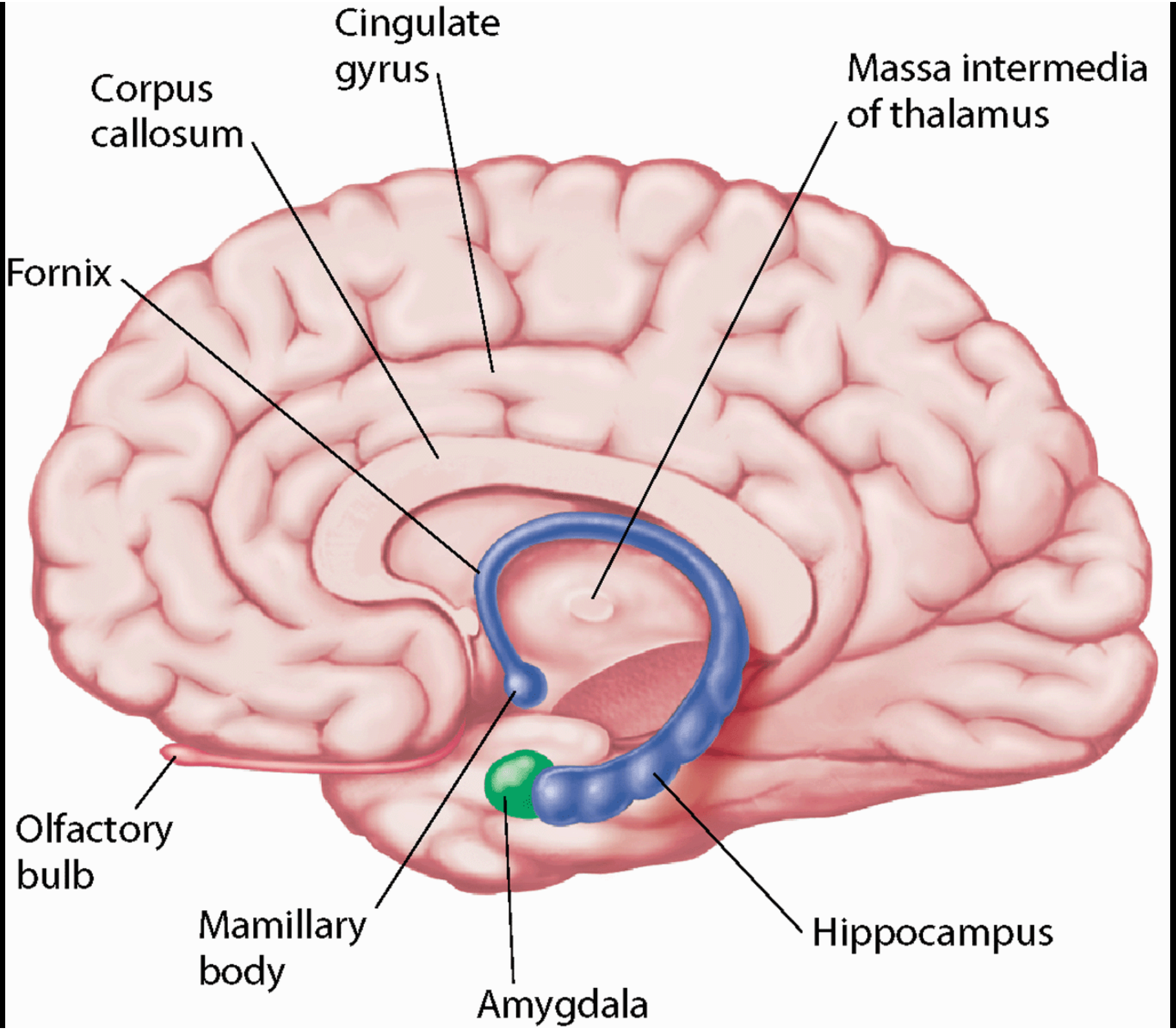
- We will use python for exercises this semester (mainly python 3)
- → You should already have a working knowledge of python and be able to write some basic python code
- Some assignments will ask you to modify existing code
- Others may ask you to write some code

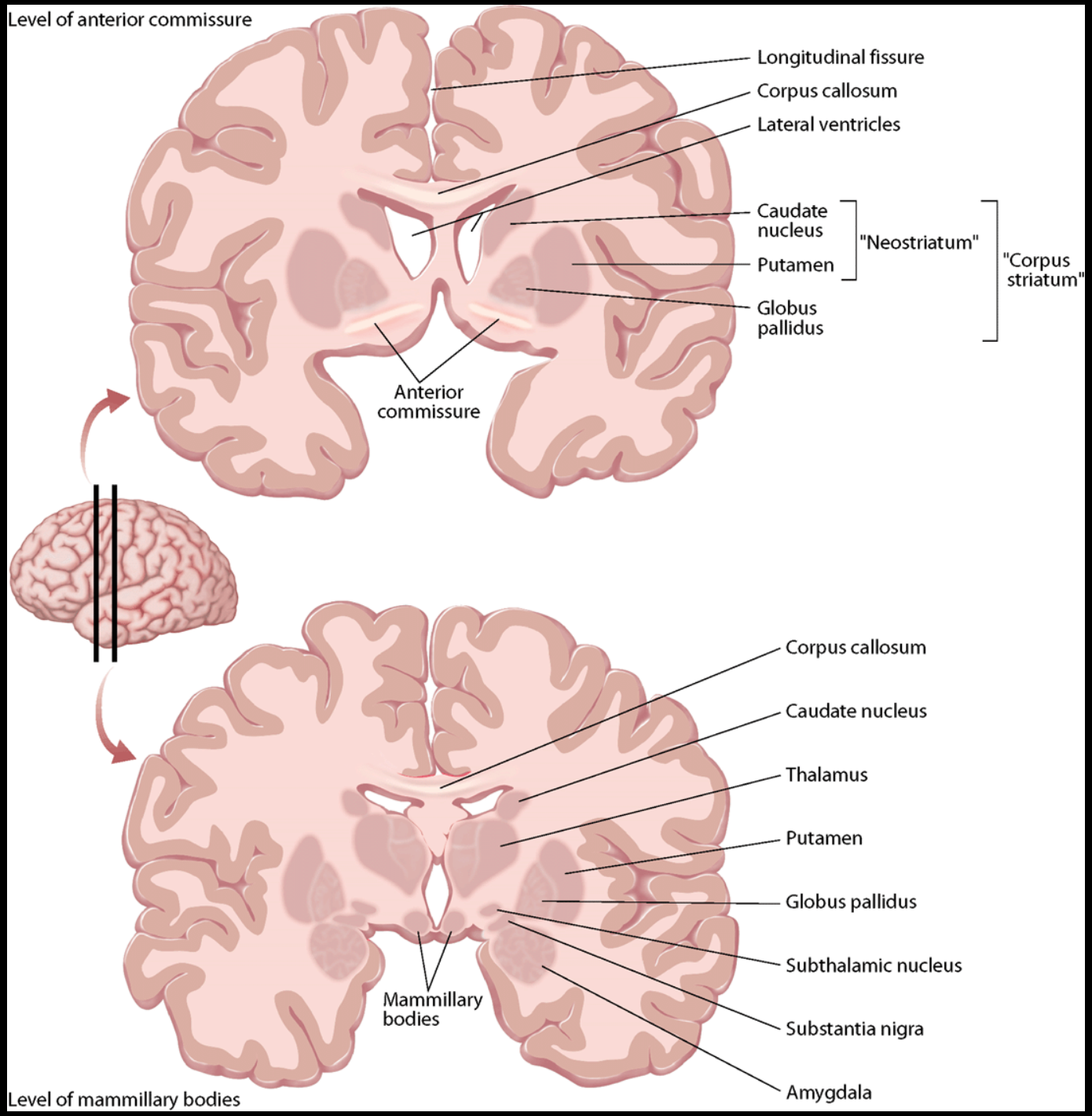
- Recommended resources:
  - https://wiki.python.org/moin/BeginnersGuide/Programmers
  - Pyzo.org, for built in python coding
  - Colab.research.google.com – browser based, has GPUs!
  - Lots of other python distributions
  - Tensorflow.org
  - github


Central sulcus
Frontal cortex
Motor cortex
Somatosensory cortex
Dorsal-lateral prefrontal
Prefrontal cortex
Ventral-lateral prefrontal
Orbital frontal cortex

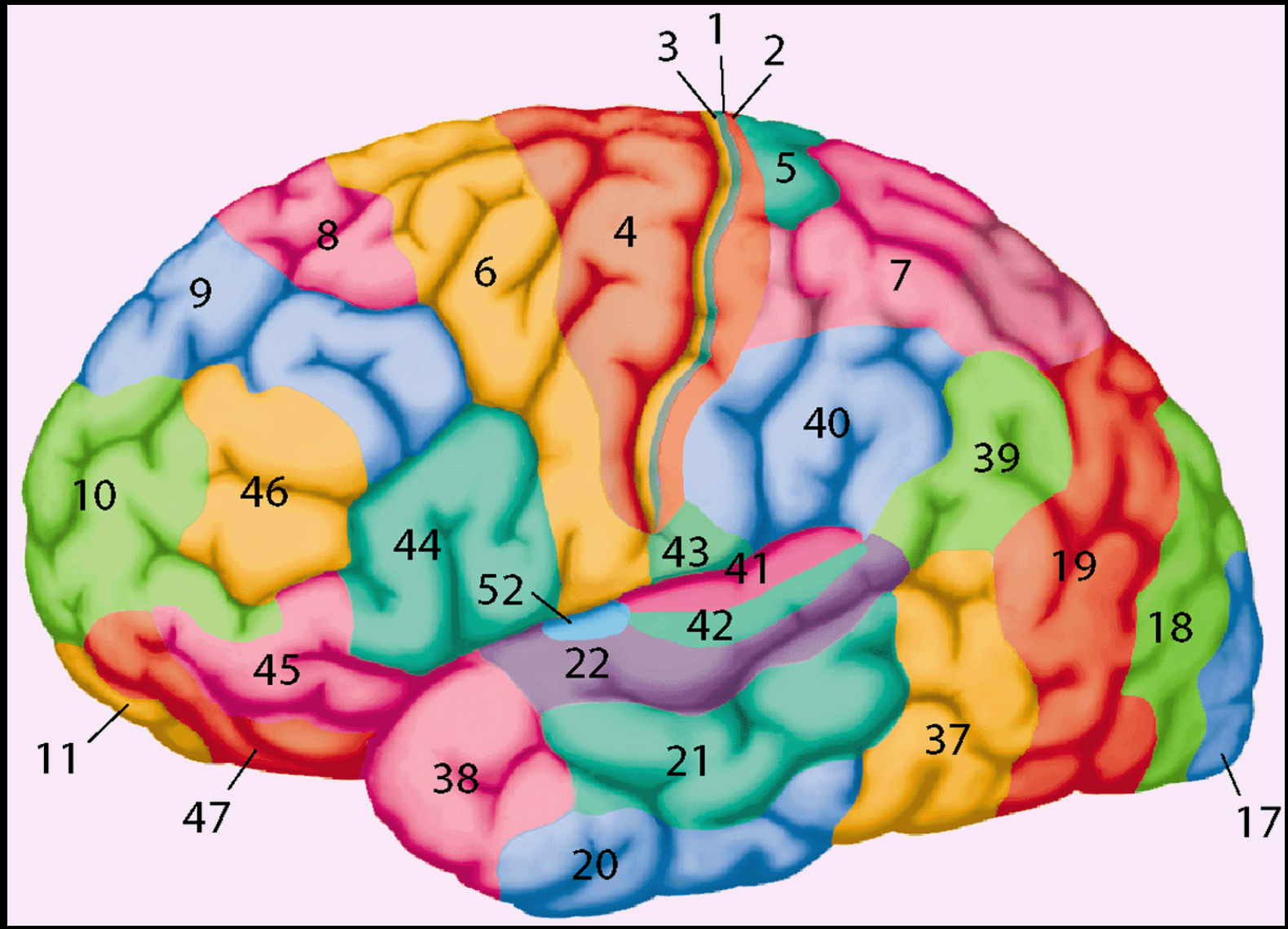

Massa intermedia
Cingulate gyrus
Corpus callosum
Superior sagittal sinus
Third ventricle
Optic chiasm
Tentorium
Hypothalamus
Fourth ventricle
Pituitary gland
Cerebellum
Dura mater
Midbrain
Pons
Medulla
Spinal cord


Fornix
Cingulate gyrus
Corpus callosum
Frontal pole
Thalamus
Occipital pole
Anterior commissure
Parahippocampal gyrus
Subcallosal gyrus


Cingulate gyrus
Corpus callosum
Massa intermedia of thalamus
Fornix
Olfactory bulb
Mamillary body
Amygdala
Hippocampus


Level of anterior commissure
Longitudinal fissure
Corpus callosum
Lateral ventricles
Caudate nucleus
Putamen
Globus pallidus
"Neostriatum"
"Corpus striatum"
Anterior commissure
Corpus callosum
Caudate nucleus
Thalamus
Putamen
Globus pallidus
Subthalamic nucleus
Substantia nigra
Amygdala
Mammillary bodies
Level of mammillary bodies

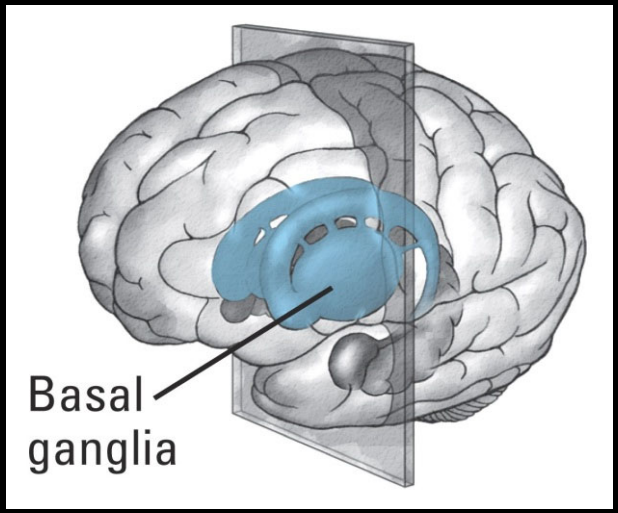
Brodmann's Areas

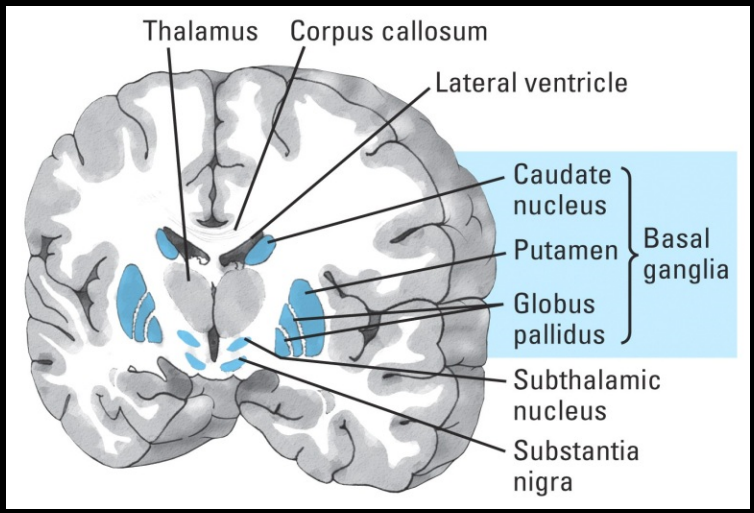


The Basal Ganglia

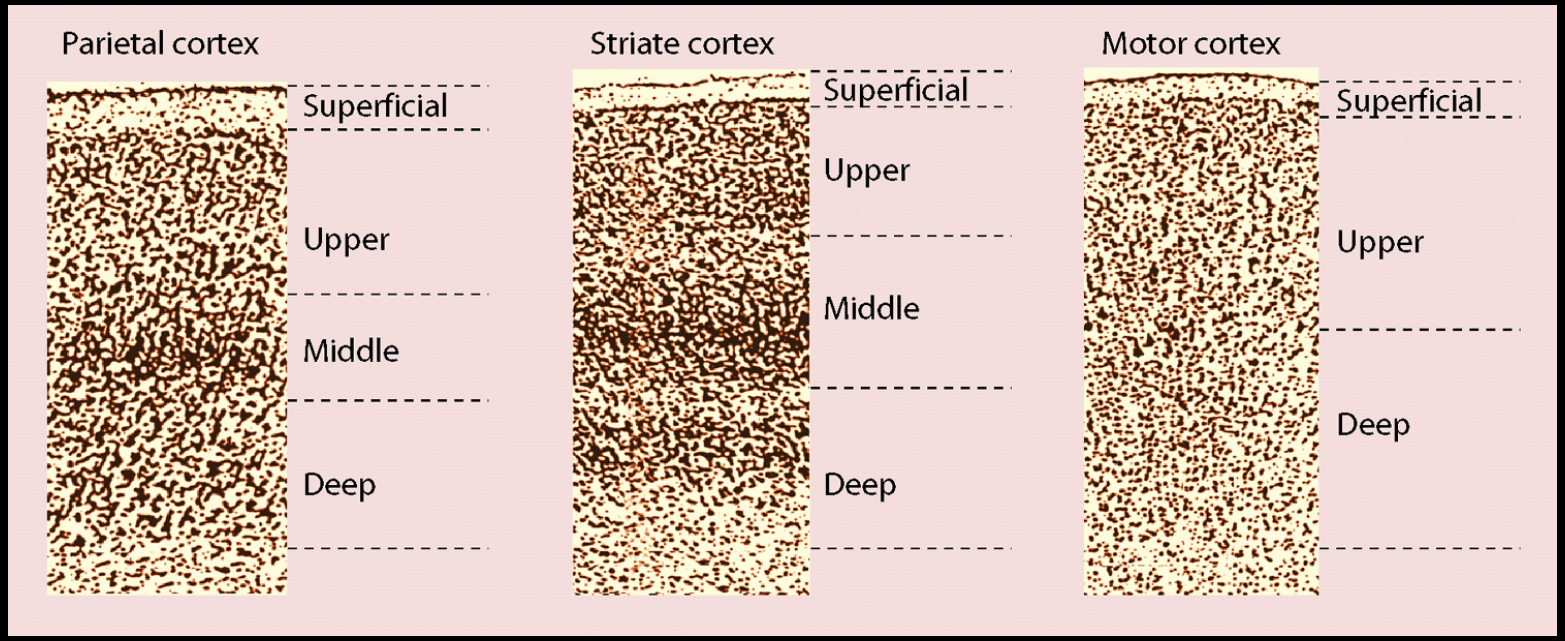
- Collection of nuclei that include putamen, globus pallidus, caudate nucleus: receives projections form all areas of neocortex and sends to thalamus, amygdala
- Role is muscle tone, posture, and habit learning. Damage results in tremors, twitches, jerks etc.

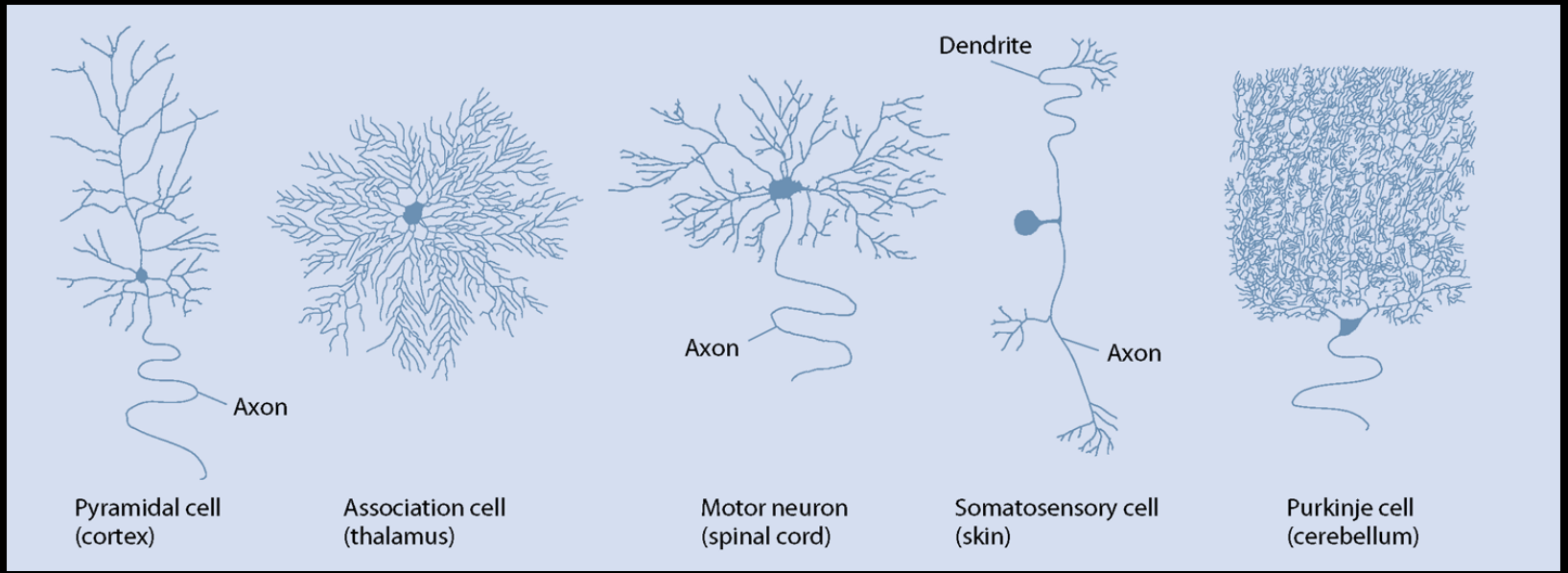
- Reciprocal connections with substantia nigra, role in Parkinson's disease.





6 layers of cortex





The Cortex

Gyri & sulci