580.422

System Bioengineering II: Neurosciences

Introduction: From Neuron to Behavior

Prof. Xiaoqin Wang

Syllabus

Week	Lecture	Date	Instructor	Title	Content	HW	
1	1	Mon, Jan 26	Wang	Course Introduction, Policy	From neuron to behavior		
	2	Wed, Jan 28	Wang	Methods in Psychophysics	Psychometric function, signal detection theory		
	3	Fri, Jan 30	Wang	Essentials of neural coding (1)	Quantitative analysis of neural firing	1	Wang
2	4	Mon, Feb 02	Wang	Essentials of neural coding (2)	Poisson model of spike train, simulation		
	5	Wed, Feb 04	Young	Neural excitability 1	Neural excitability, excitation, inhibition, review of Hodgkin Huxley		
	6	Fri, Feb 06	Young	Neural excitability 2	calcium, bursting, complex neurons	2	Wang
3	7	Mon, Feb 09	Young	Synaptic transmission and neuromodulation	synaptic transmission, pre and postsynaptic mechanisms		
	8	Wed, Feb 11	Young	Synaptic integration 1	dendrites, cable theory, electrotonic propagation		
	9	Fri, Feb 13	Young	Synaptic integration 2	propagation of action potentials, synaptic integration, spines	3	Young
4	10	Mon, Feb 16	Young	Neural integration	How is information presented to dendrites?		
	11	Wed, Feb 18	Kirkwood	Cellular mechanisms of learning (1)	Hippocampal LTP		
	12	Fri, Feb 20	Kirkwood	Cellular mechanisms of learning (2)	Spike timing and the mechanism of LTP and LTD	4	Young
5	13	Mon, Feb 23	Connor	Visual system (1)	Early visual system: From Retina to V1		
	14	Wed, Feb 25	Connor	Visual system (2)	Central visual processing		
	15	Fri, Feb 27	Chib	Brain stimulation			
6		Mon, Mar 02	Exam #1	(include Lectures 1-15)	Note: Exam will take place in the evening		
	16	Mon, Mar 02	Wang	Periphery Auditory system	Cochlea, hair cells, auditory nerve		
	17	Wed, Mar 04	Wang	Central Auditory system (1)	Brainstem processing, sound localization		
	18	Fri, Mar 06	Wang	Central Auditory system (2)	Cortical processing, speech processing	5	Wang
7	19	Mon, Mar 09	Young	Hearing losss and cochlear implant	Cochlear implant and its underlying neural mechanisms		
	20	Wed, Mar 11	Wang	Somatosensory system (1)	Tactile receptors		
	21	Fri, Mar 13	Wang	Somatosensory system (2)	Central somatosensory system	6	Wang
8		Mon, Mar 16	Spring Break				
		Wed, Mar 18	Spring Break				
		Fri, Mar 20	Spring Break				
9	22	Mon, Mar 23	Shadmehr	Introduction to neural basis of motor control			
	23	Wed, Mar 25	Shadmehr	The motor system of the spinal cord			
	24	Fri, Mar 27	Shadmehr	Muscles, proprioception, and reflexes		7	Shadmehr
10	25	Mon, Mar 30	Shadmehr	From visual goals to motor commands			
	26	Wed, Apr 01	Shadmehr	Posterior parietal cortex			
	27	Fri, Apr 03	Shadmehr	Motor areas of the frontal lobe		8	Shadmehr
11		Mon, Apr 06	Exam #2	(include Lectures 16-27)	Note: Exam will take place in the evening		
	28	Mon, Apr 06	Bastian	Cerebellum			
	29	Wed, Apr 08	Bastian	Basal ganglia			
	30	Fri, Apr 10	Zhang	Perceptrons and feedforward networks		9	Zhang
12	31	Mon, Apr 13	Zhang	Recurrent networks, attractors networks			
	32	Wed, Apr 15	Zhang	Hippocampal place cells and models			
	33	Fri, Apr 17	Zhang	Models of learning and plasticity		10	Zhang
13	34	Mon, Apr 20	Zhang	Map formation and Kohonen nets			
	35	Wed, Apr 22	Zhang	Population coding and decoding			
	36	Fri, Apr 24	Guest lecturer	Human brain recording			
14	37	Mon, Apr 27	Sarma	Deep brain stimulation			
	38	Wed, Apr 29	Guest lecturer	Brain-machine interface			
	39	Fri, May 01	Wang	Course summary			
		TBD	Exam #3 (final)	(include Lectures 28-39, plus general questions)			

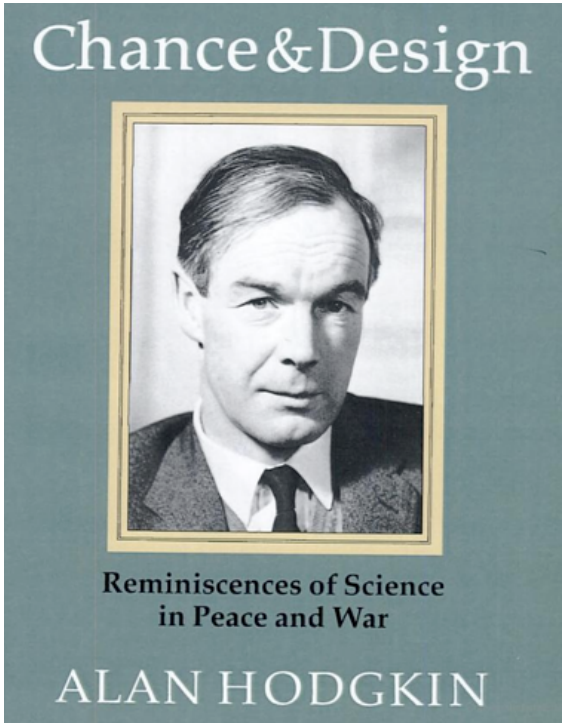
The objectives of this course

- Understand the general structure and functions of the nervous system and the brain
- Understand the basic principles of sensory and motor processing
- Understand the basic principles of neural computations

What is the difference between a typical neuroscience course and a neuroscience course for BME students?

An important goal for BME students:

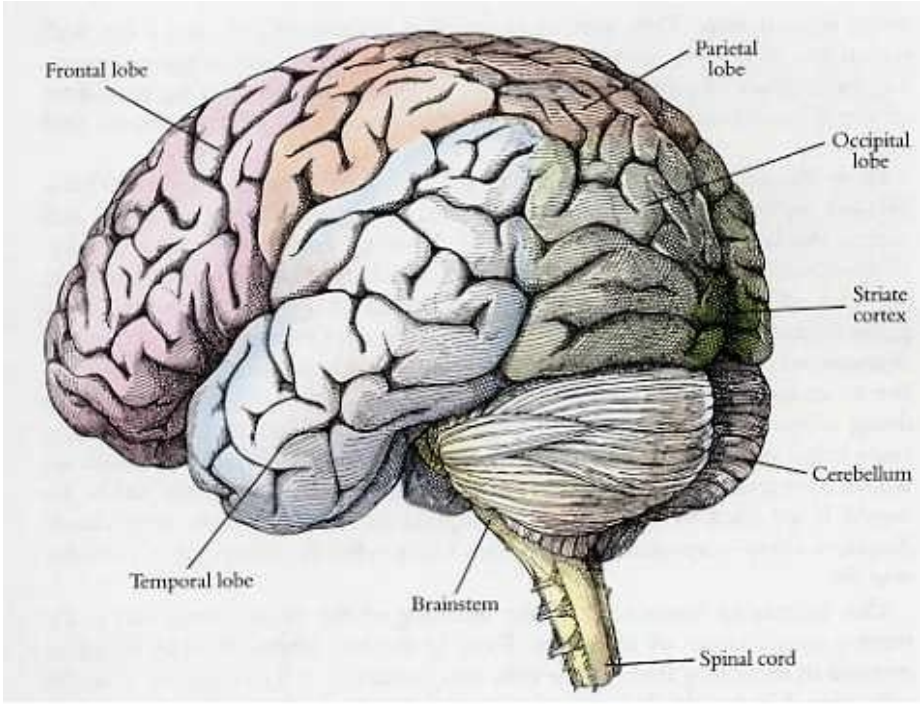
Applying quantitative approaches to study the brain



Dr. Alan Hodgkin is a British physiologist and biophysicist, who shared the 1963 Nobel Prize in Physiology or Medicine with Andrew Huxley and John Eccles for their work on the basis of nerve "action potentials".

During the World War II, he worked on the development of centimetric radar, including the design of the Village Inn AGLT airborne gun-laying system. He returned to Cambridge University after the war ended and completed the Nobel winning research.

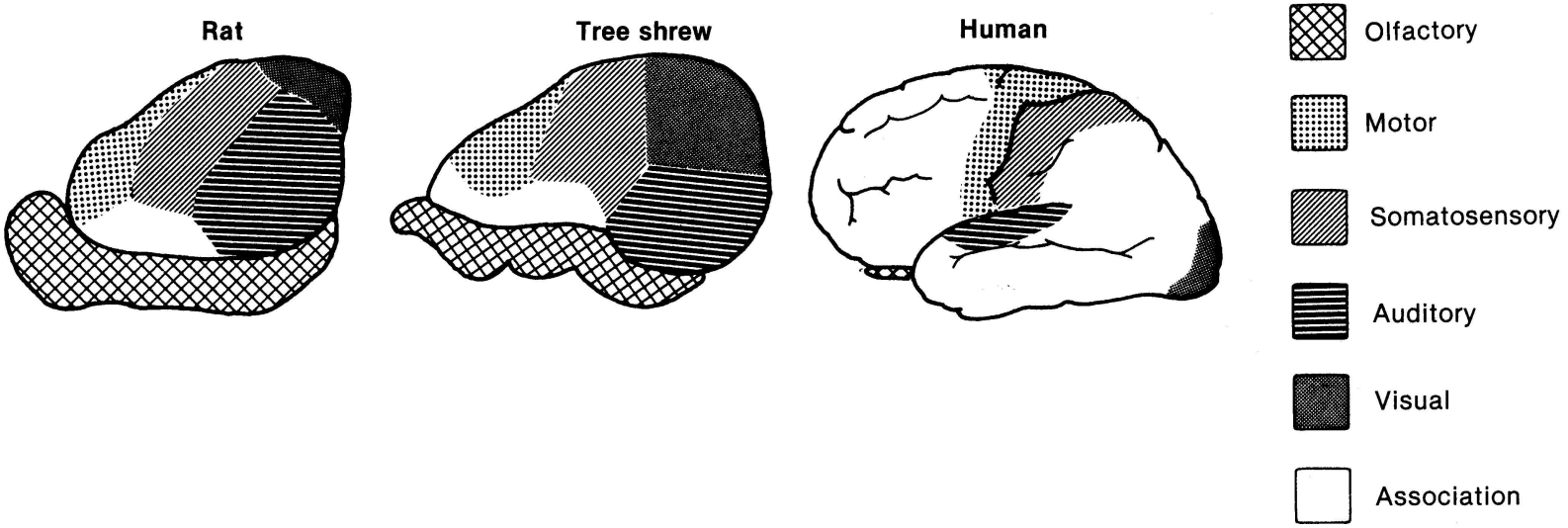
Brain: The last frontier of biological sciences

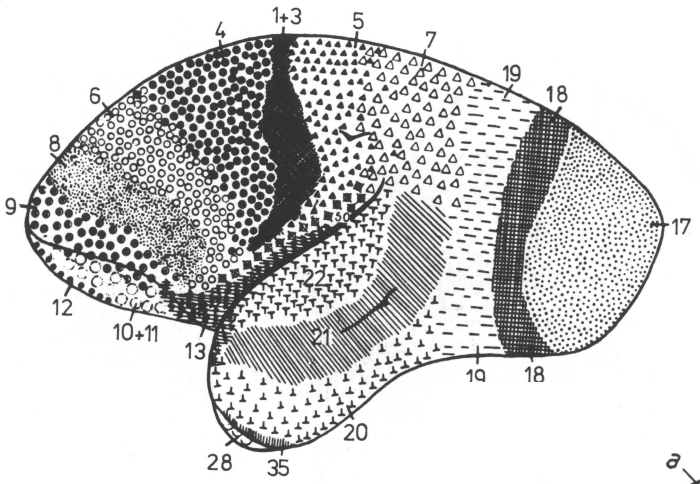


The most complex system ever studied by scientists

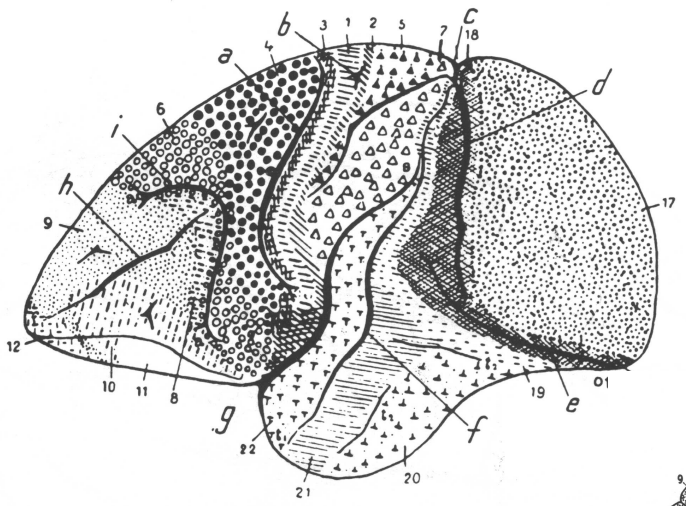
Understand the brain through the evolution

Cortical areas in different species



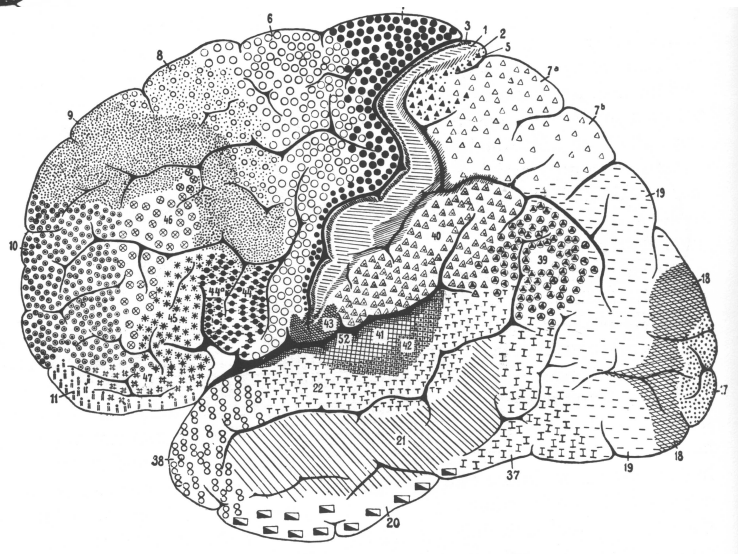


New World Monkey
(*Callithrix jacchus* –
common marmoset)



Old World Monkey
(*Cercopithecus)*

Human



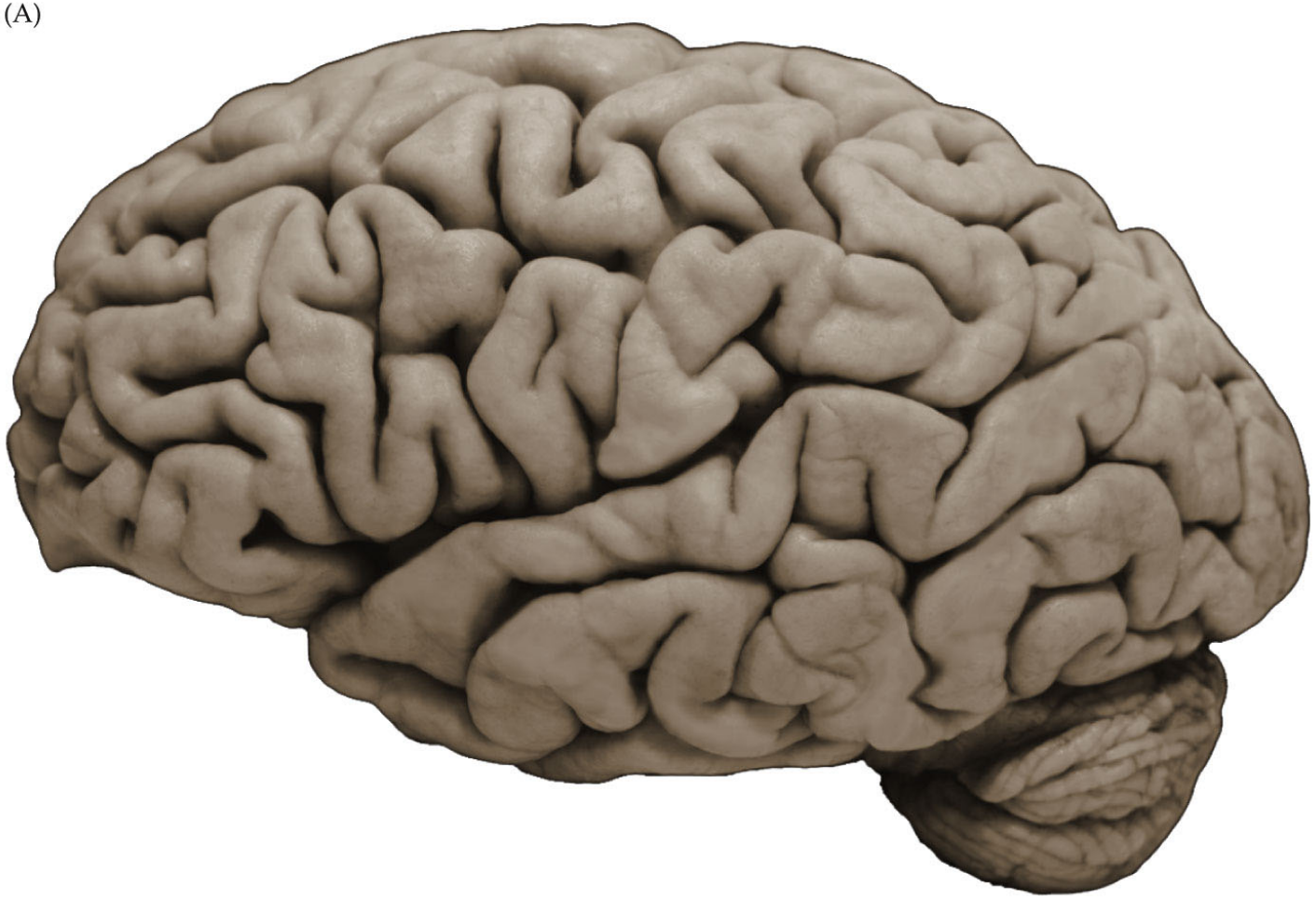
Comparison between the brains
of primate species

Brodmann (1909)

Plate 1 Surface features of a human brain specimen (Part 1)

The Human Brain

(A)



***NEUROSCIENCE, Fourth Edition,* Atlas, Plate 1 (Part 1)**

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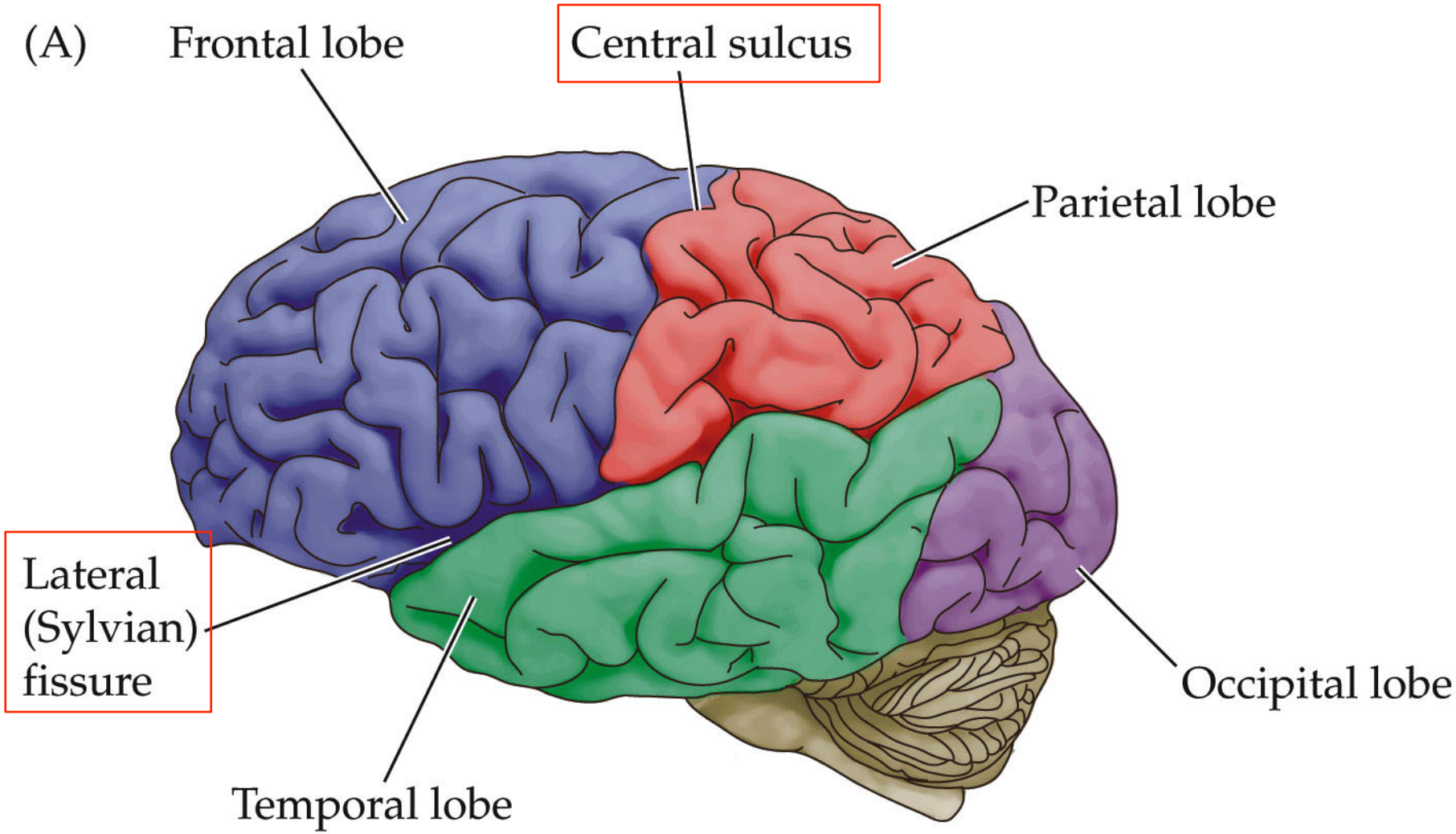
Figure A3 Surface anatomy of the cerebral hemisphere (Part 1)



***NEUROSCIENCE, Fourth Edition,* Appendix, Figure A3 (Part 1)**

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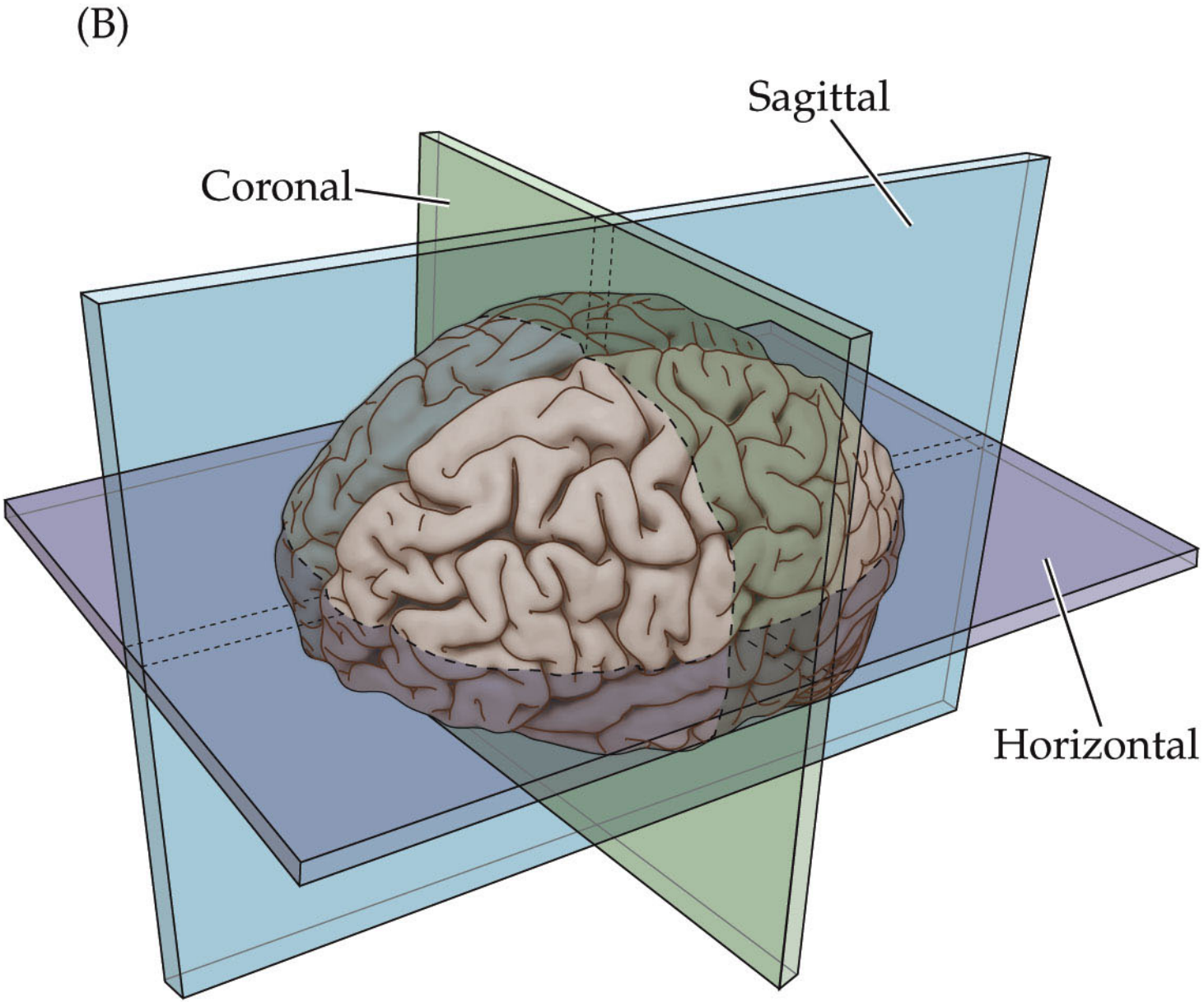
Figure A1 (B) Major planes of section of the brain (Part 2)



***NEUROSCIENCE, Fourth Edition,* Appendix, Figure A1 (Part 2)**

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Plate 2 Coronal section demonstrating internal forebrain structures, MRI (Part 2)

(B)

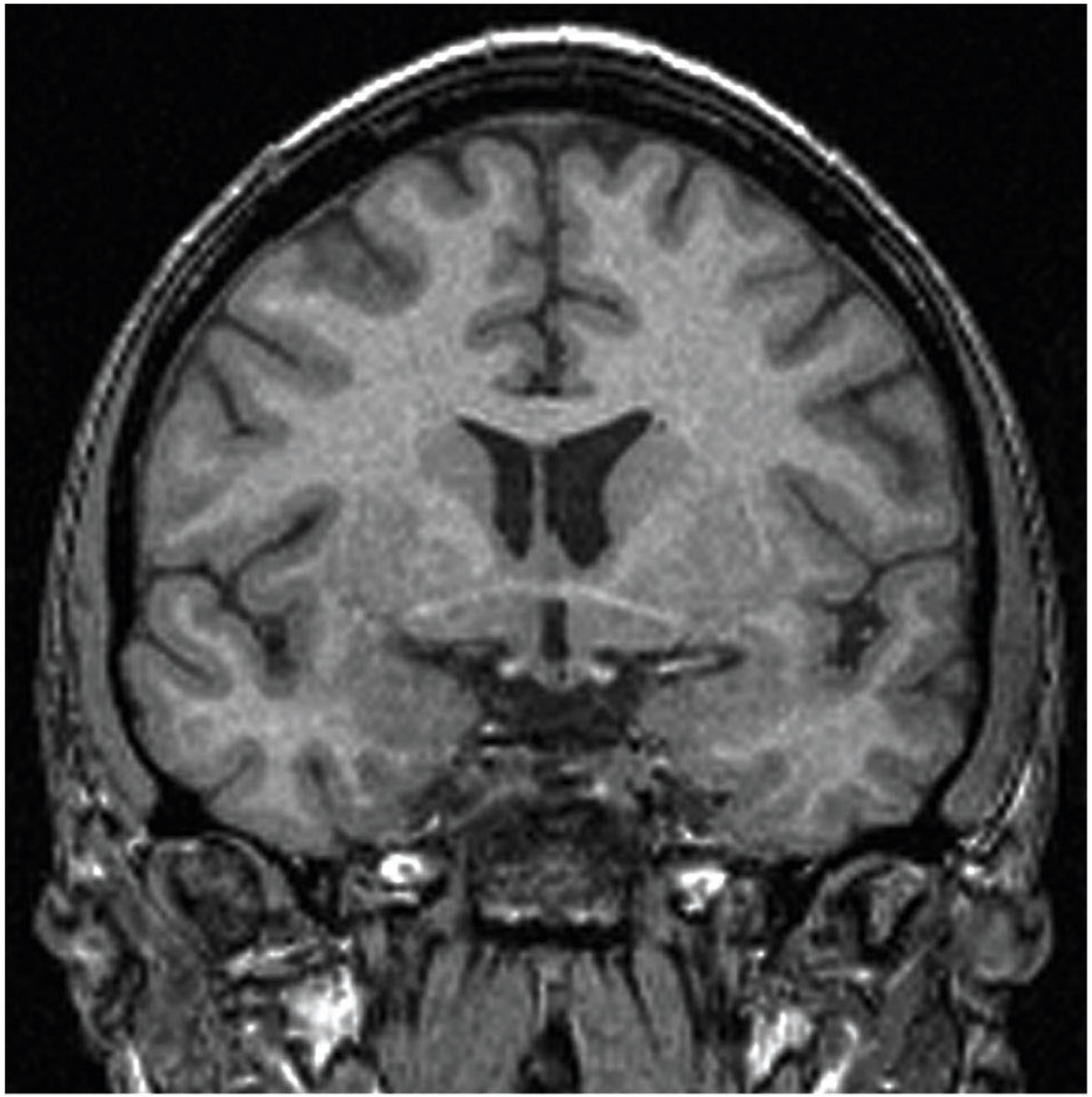

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Plate 3 Horizontal section demonstrating internal forebrain structures, T1-weighted MRI (Part 3)

(C)

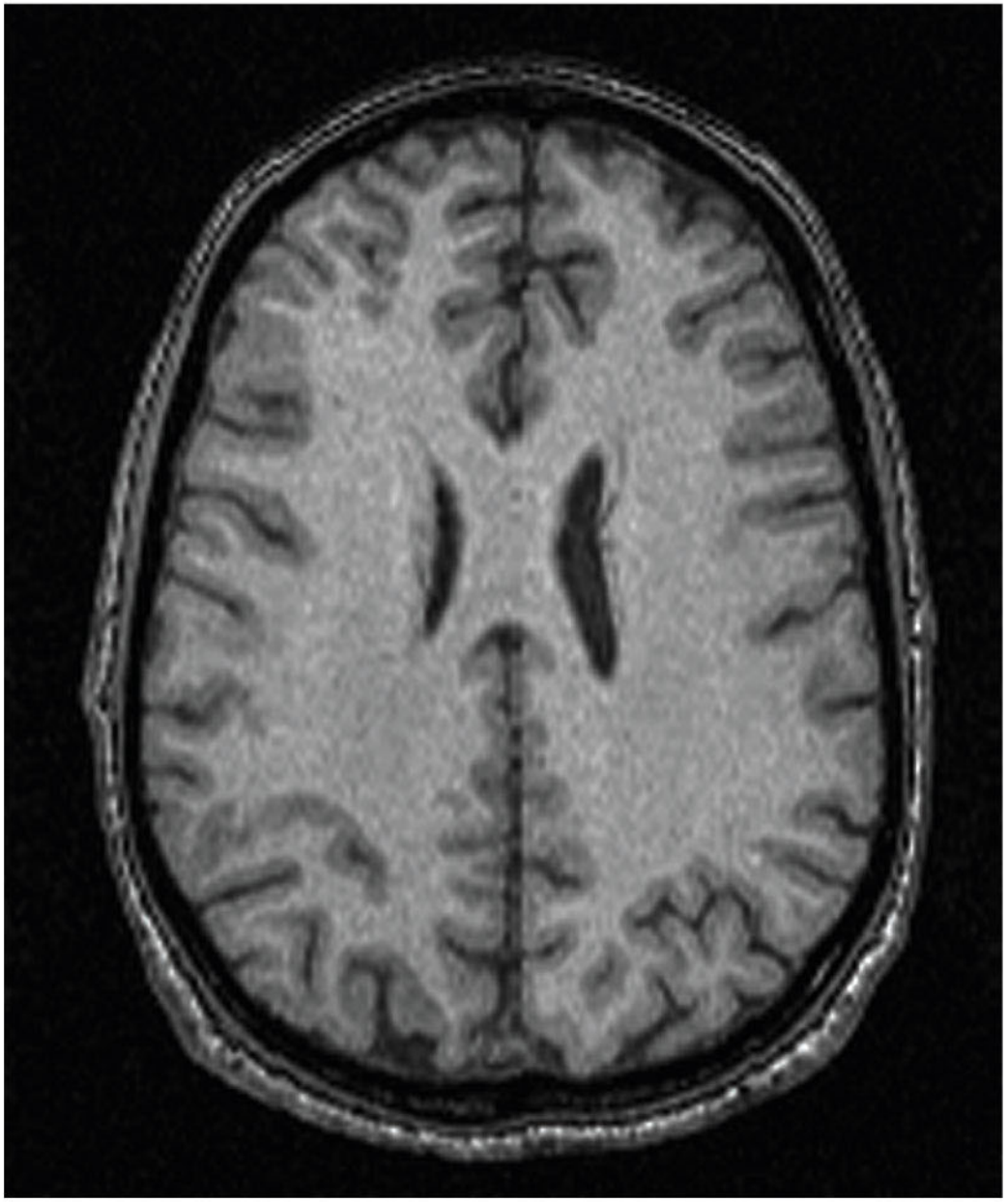

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Plate 4 Sagittal section demonstrating internal forebrain structures, T1-weighted MRI (Part 2)

(B)

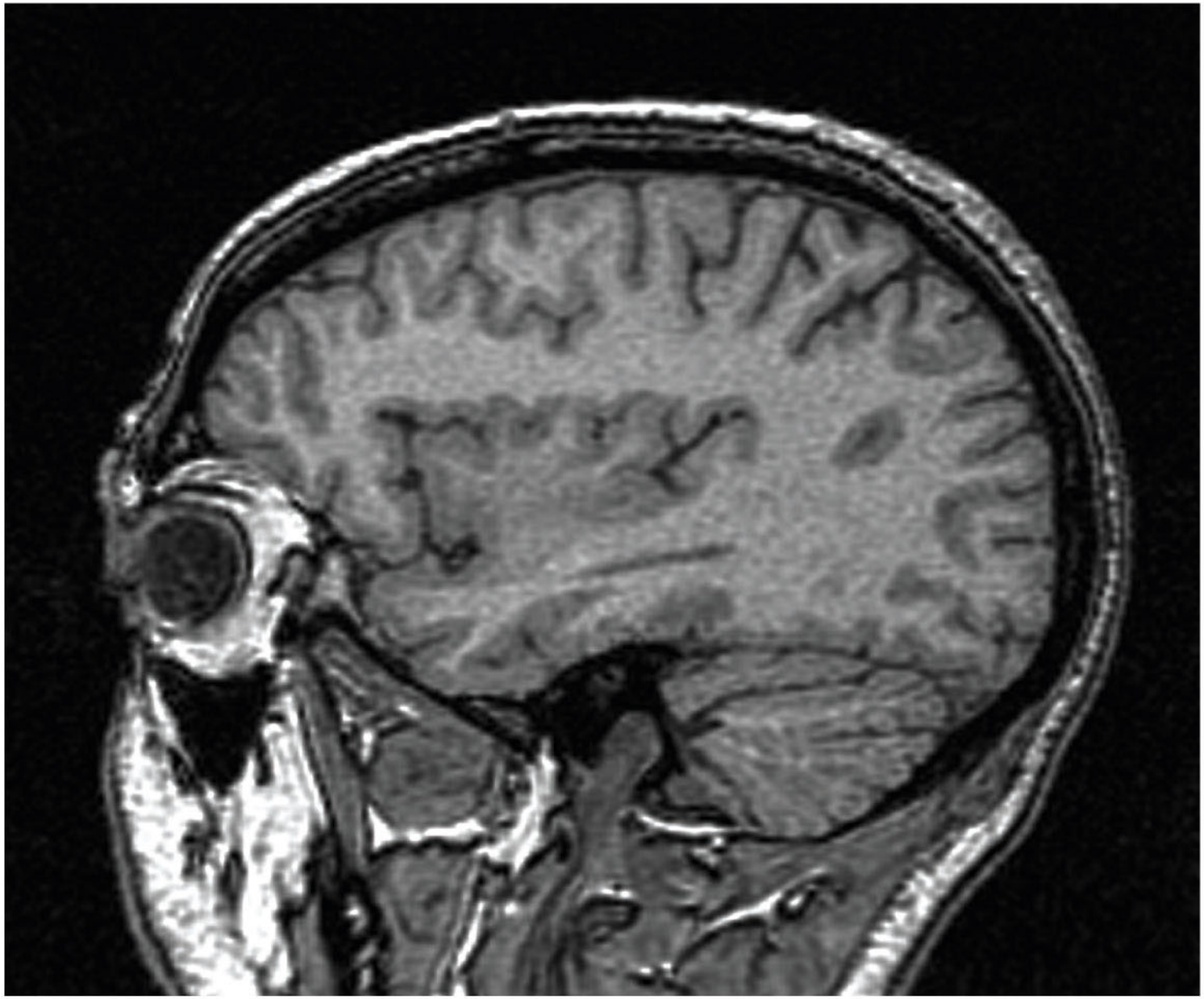

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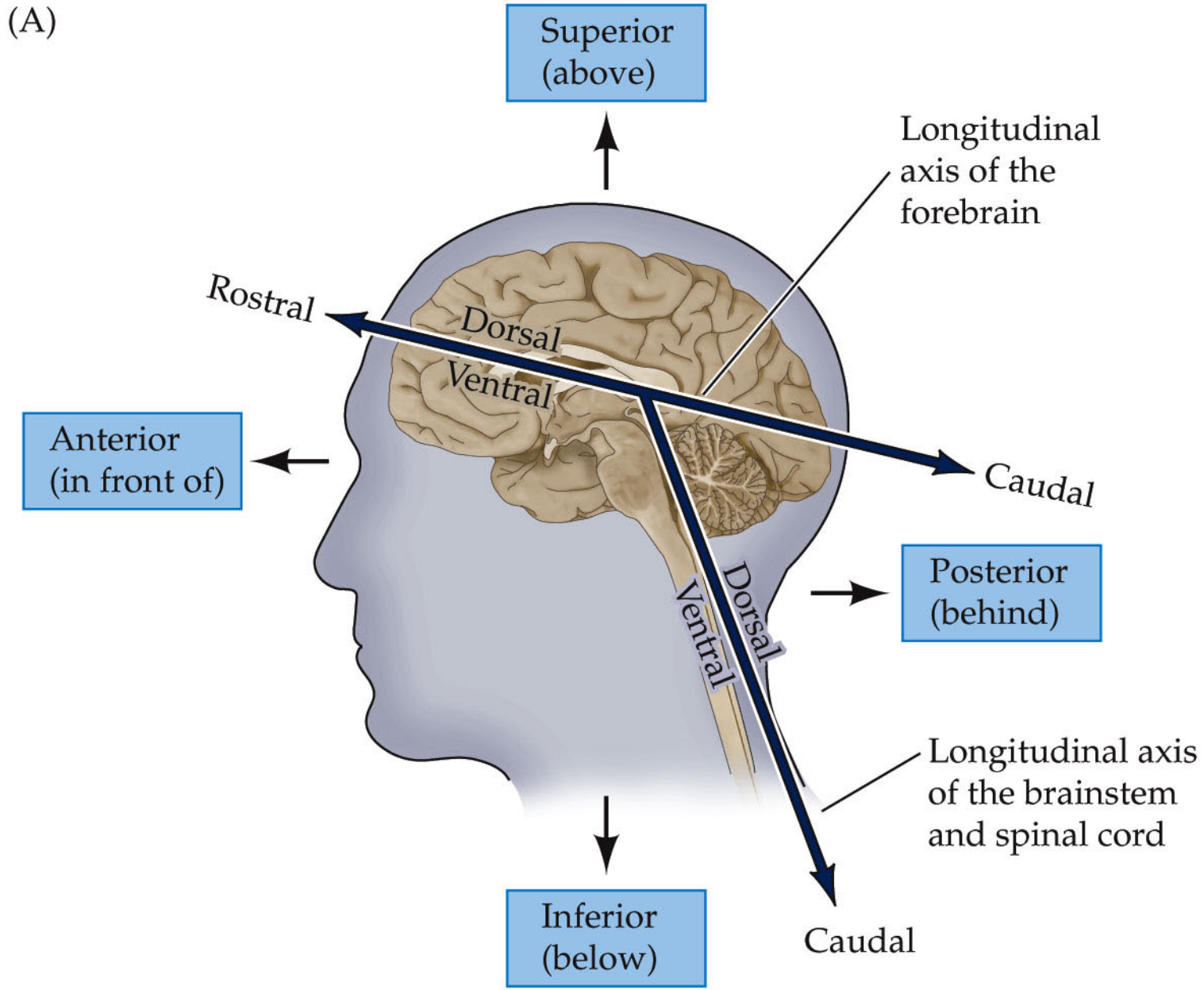
Figure A1 (A) Anatomical terminology of the brain and brainstem (Part 1)



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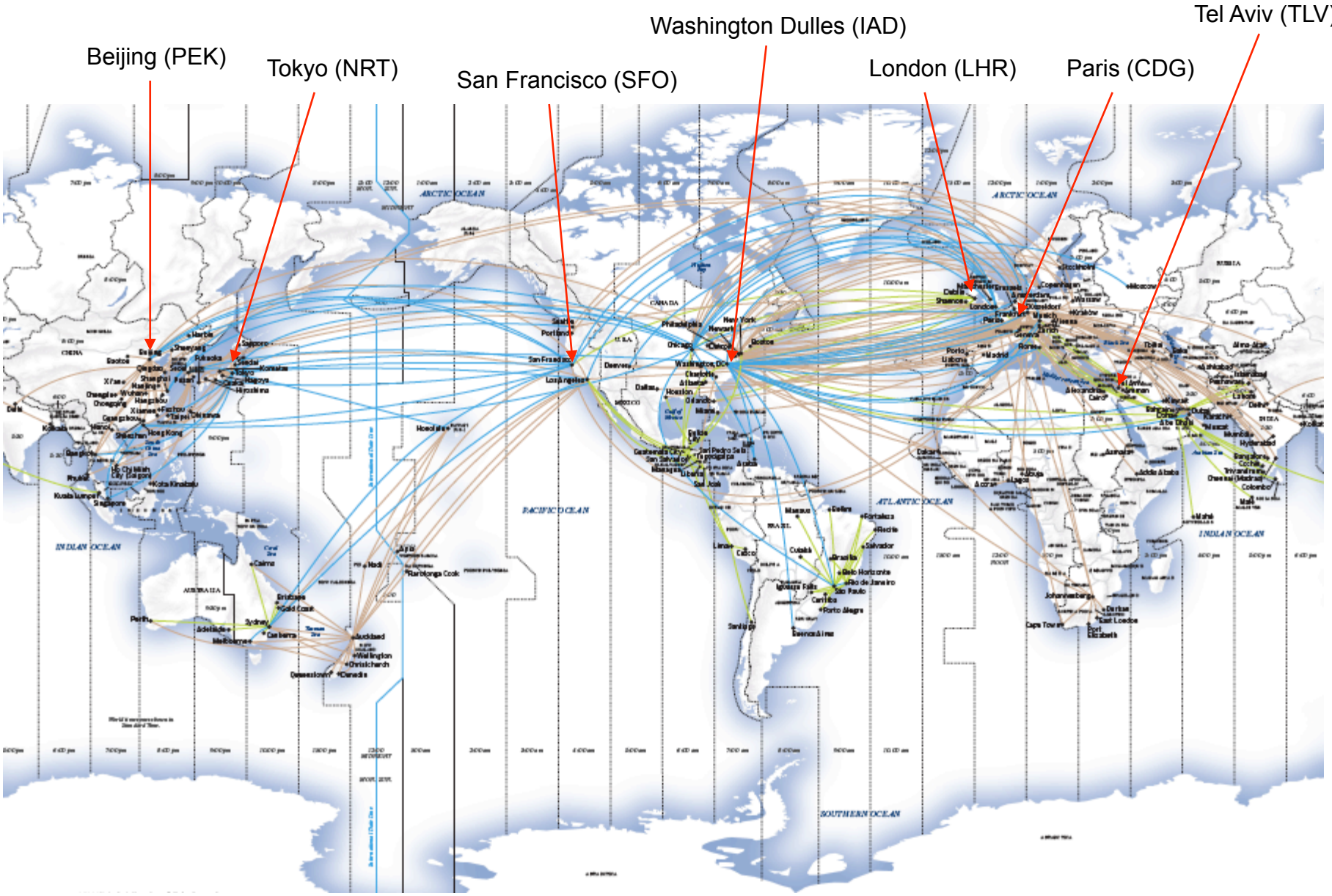
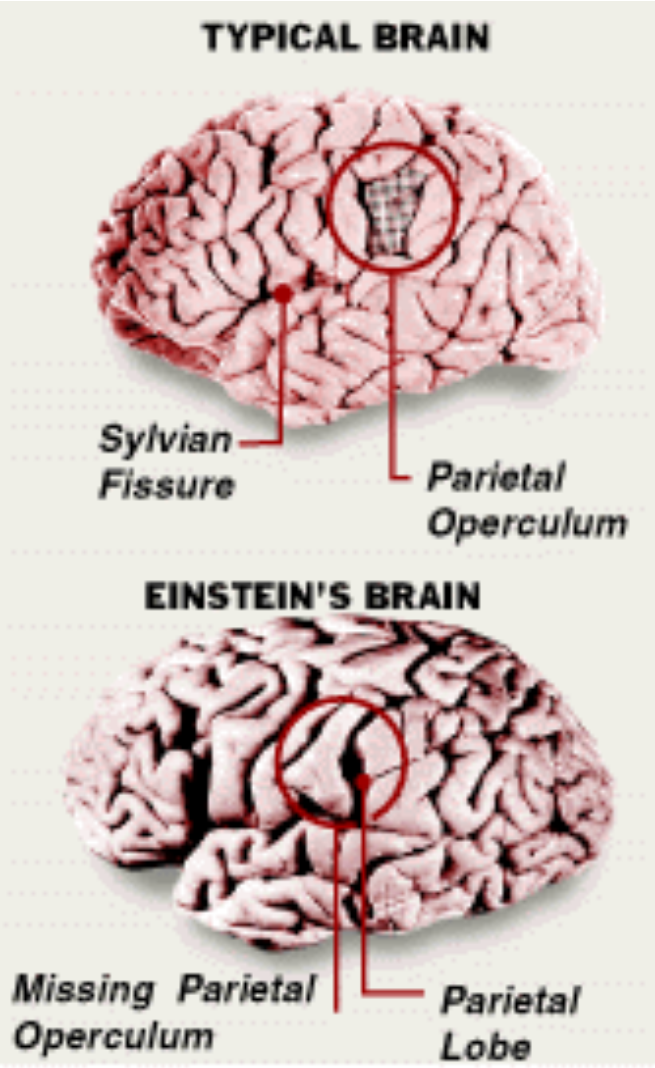
United Airlines Route Map



What is special about Einstein's brain?



"For nearly half a century the pickled brain of Albert Einstein has roamed the world in Tupperware containers, courier packages, and, most famously, car trunks. The story begins with in April 1955, when Thomas Harvey, chief pathologist at Princeton Hospital, found himself in charge of dissecting the cadaver of the greatest scientist of his age, perhaps of any age. He seized the opportunity to do something "noble." Using an electric saw Harvey sliced through the skull and gingerly removed the organ that would both define and haunt the rest of his life …" (From *Possessing Genius: The Bizarre Odyssey of Einstein's Brain*, by Carolyn Abraham)

Einstein's brain weight was not different from that of controls, clearly indicating that a large (heavy) brain is not a necessary condition for exceptional intellect.

Questions addressed in this course:

- How is the brain organized?
- How do different parts of the brain function?
- How to study the brain?
- What questions to ask?

The central question:

How does the brain control behaviors?

How to study the brain?

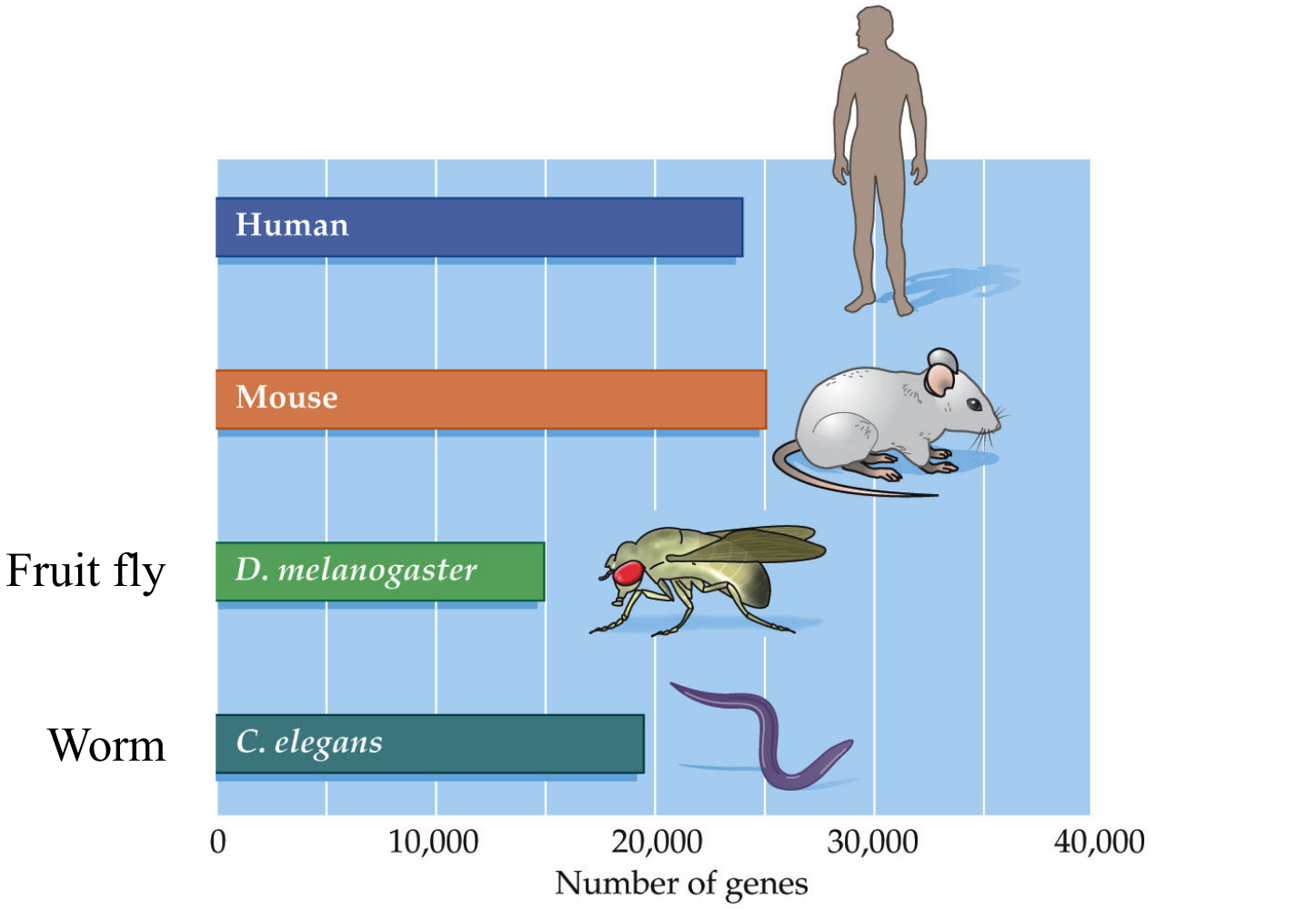
Genes → Neurons → Neural circuits → Behaviors

Approaches:

1. Molecular and cellular neuroscience (proteins, genes, cell cultures, brain slices)
2. Systems neuroscience (single to populations of neurons in intact models)
3. Computational neuroscience (theoretical, modeling and simulation)
4. Cognitive neuroscience (EEG, brain imaging, fMRI, PET, MEG)

Figure 1.1 Estimated number of genes in four animal genomes

- The number of genes does not correlate with organismal complexity
- There is a complex relationship between genetics and behaviors



NEUROSCIENCE, Fourth Edition, Figure 1.1

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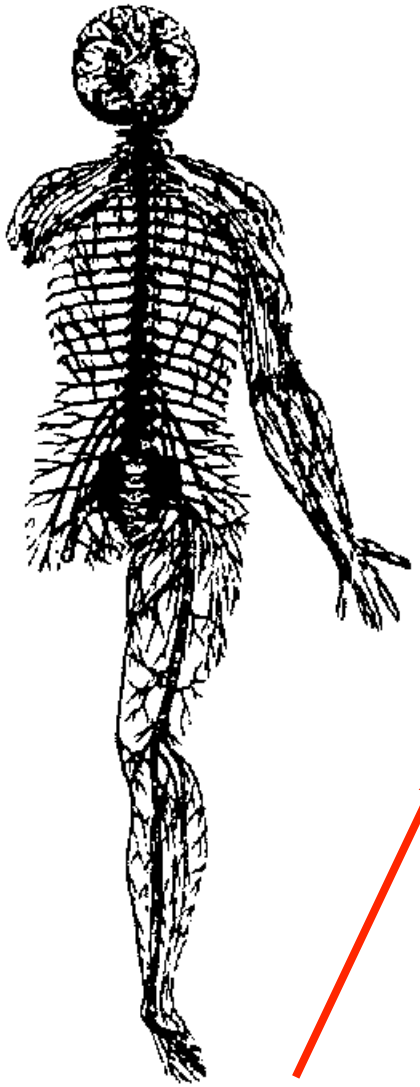
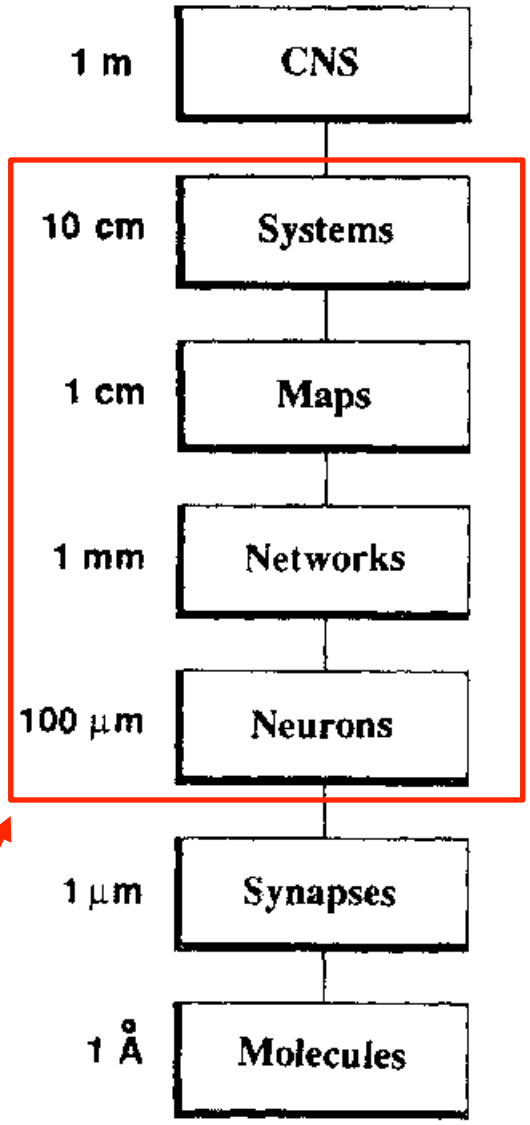
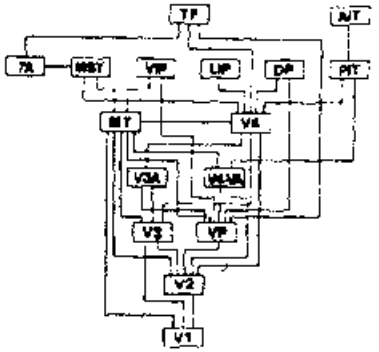
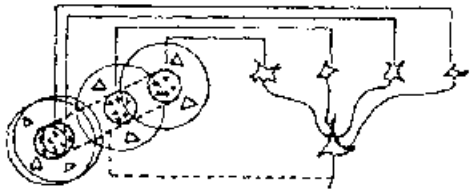
Scales of problems in neuroscience





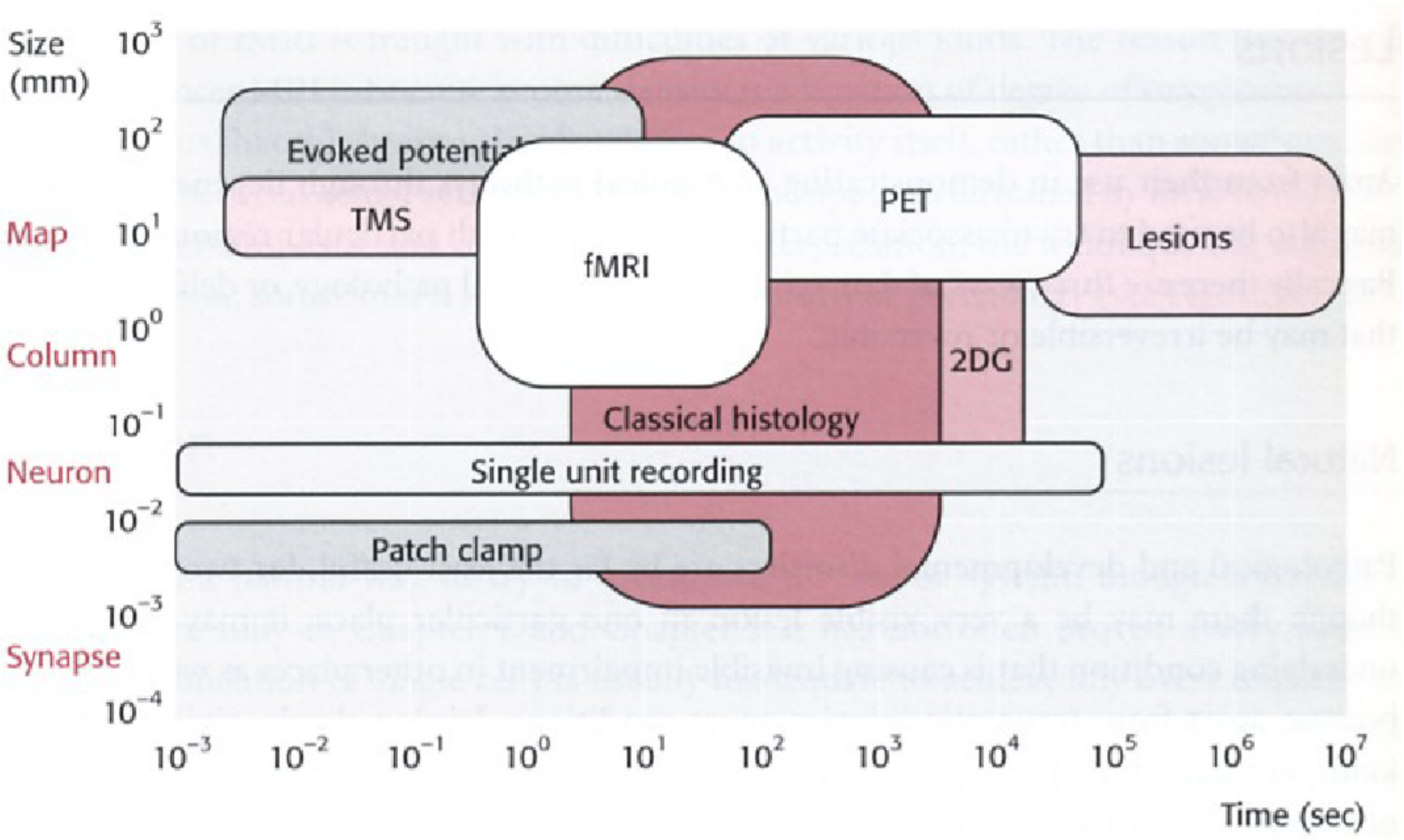




Systems and computational neuroscience

Churchland and Sejnowski (*Science*, 1988)

Experimental methods used to explore the brain



(Figure from "Neurophysiology" by Carpenter)

A Central Question of Neuroscience:

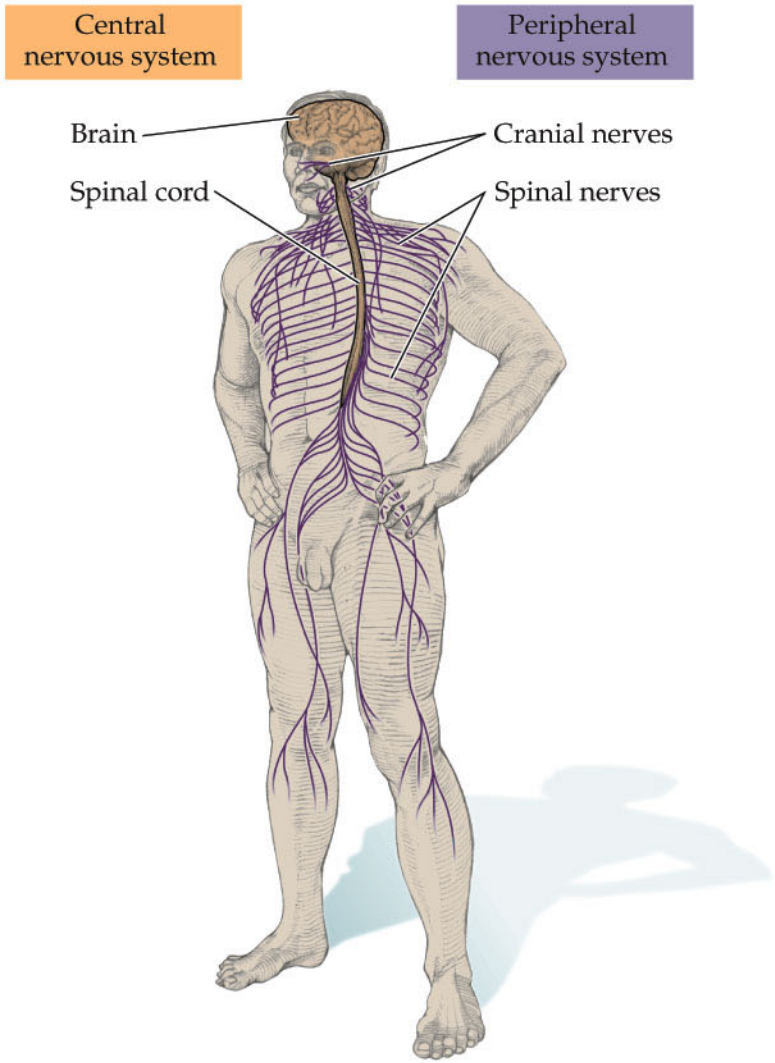
How does the brain generate complex behaviors?

How does the brain generate complex behaviors?

Yelena Isinbayeva, Gold Medalist, Woman's Pole Vault, 2008 Beijing Olympics

Figure 1.10 The major components of the nervous system and their functional relationships

(A)



***NEUROSCIENCE, Fourth Edition,* Figure 1.10**

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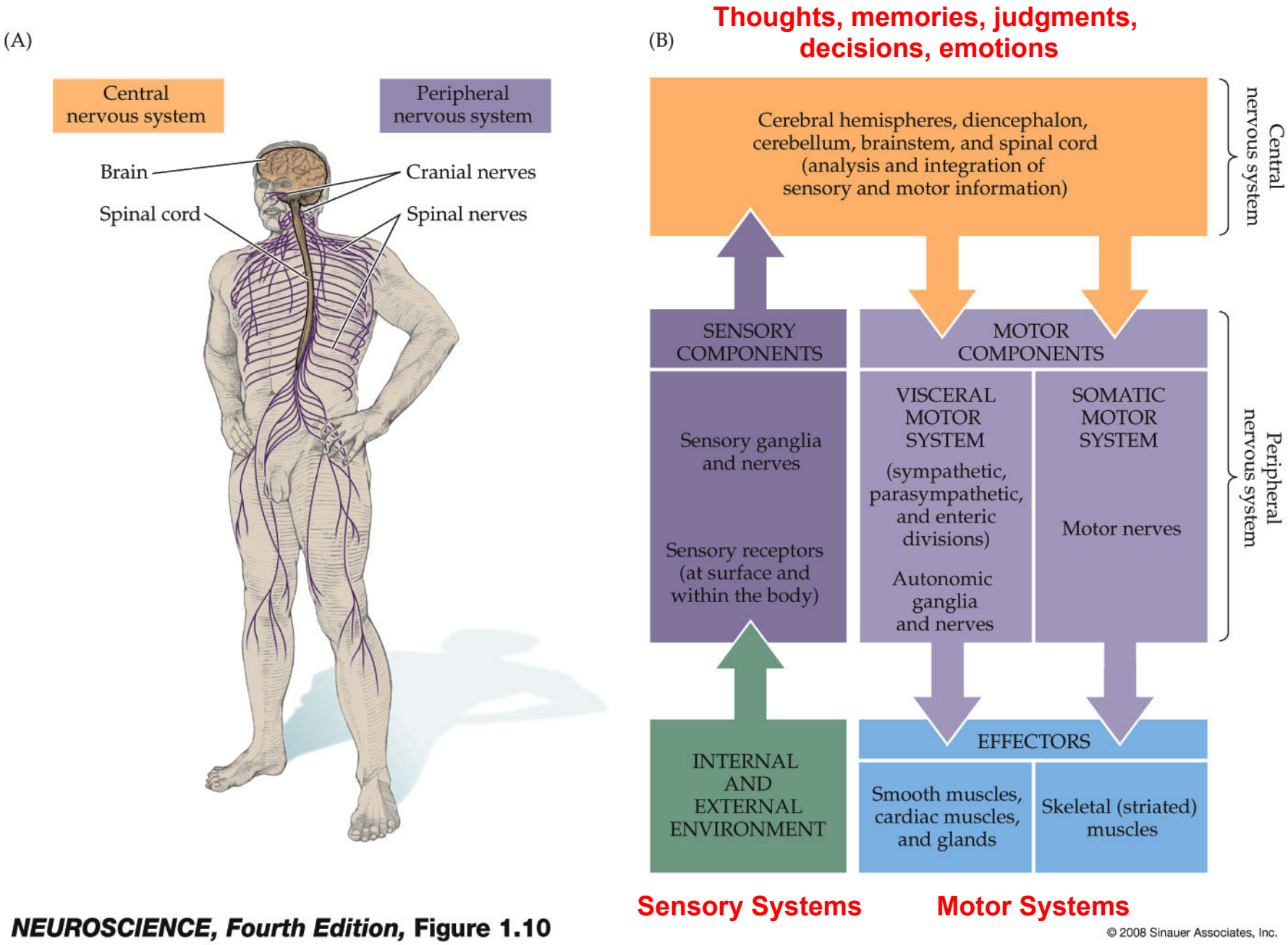
Figure 1.10 The major components of the nervous system and their functional relationships



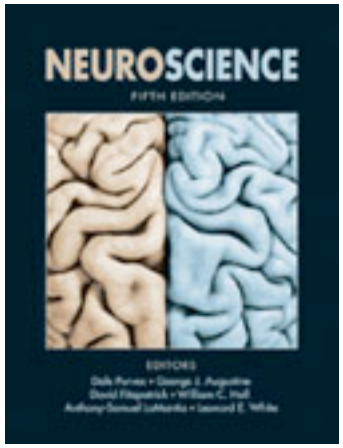
***NEUROSCIENCE, Fourth Edition*, Figure 1.10**

Suggested reading:

- Witelson SF, Kigar DL, Harvey T. The exceptional brain of Albert Einstein. Lancet. 1999 Jun 19;353(9170):2149-53.

http://www.thelancet.com/journals/lancet/article/PIIS0140-6736%2898%2910327-6/fulltext

Textbook



Neuroscience, 5th Edition

Edited by Dale Purves, George J. Augustine, David Fitzpatrick, William C. Hall, Anthony-Samuel LaMantia, James O. McNamara, and Leonard E. White, published by Sinauer Associates

Companion Website: http://sites.sinauer.com/neuroscience5e/

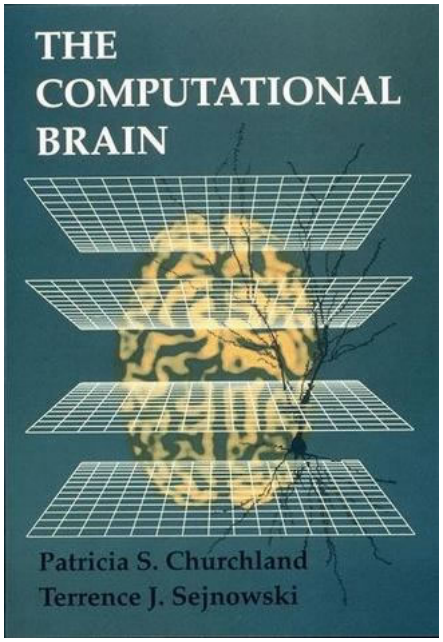
Human Neuroanatomy Atlas: www.sinauer.com/sylvius4

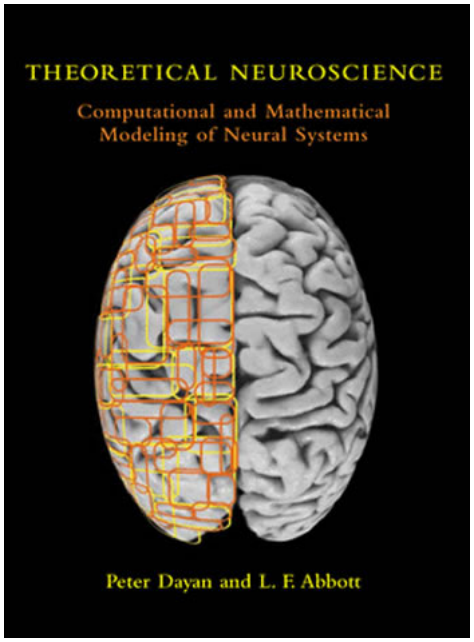
Sensory Systems

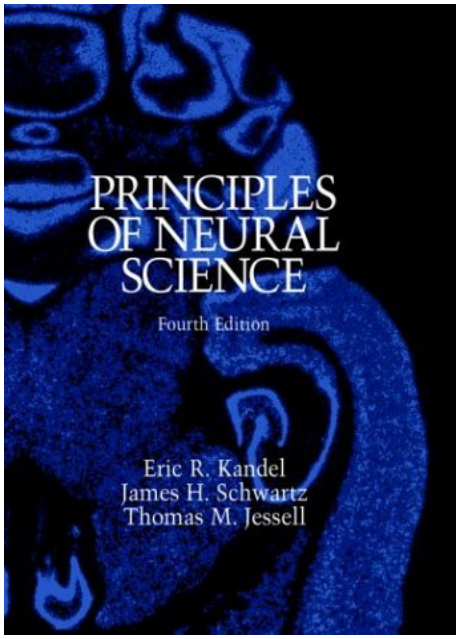
- Somatic sensory system: touch and proprioception (Chapter 9)
- Visual system (Chapters 11, 12)
- Auditory system (Chapter 13)

- Vestibular system (Chapter 14)
- Chemical senses: Olfaction, taste system (Chapter 15)

Recommended Books







The Computational Brain
Patricia Churchland and Terrence J. Sejnowski

Theoretical Neuroscience
Peter Dayan and L. F. Abbott

Principles of Neural Science
Eric R. Kandel, James H. Schwartz, Thomas M. Jessell

Major journals publishing Systems and computational Neuroscience research

- General:

  Science, Nature, PNAS
- Systems and computational neuroscience:

  Neuron, Nature Neuroscience, J. Neuroscience, J. Neurophysiology, European J. Neuroscience, Cerebral Cortex
- Computational neuroscience and neural engineering:

  Journal of Neural engineering, *Neural Computation, Journal of Computational Neuroscience*
- Methods:

  Journal of Neuroscience Methods
- Reviews:

  Annual Review of Neuroscience, Nature Review Neuroscience, Trends in Neuroscience, Current Opinion in Neurobiology
- Literature search:

  www.pubmed.org, scholar.google.com