

A sketch of the central nervous system and its origins

G. E. Schneider 2014

Part 1: Introduction

**MIT 9.14 Class 1**

**Brain talk, and**

**the ancient activities of brain cells**

# 1. Introduction

## a) The plan for this class

- 1) The goal: Students acquire an outline of vertebrate neuroanatomy with a focus on mammals
- 2) Reaching the goal will be facilitated by learning about origins, using information on comparative anatomy, development, and evolution.
- 3) Since adaptive function is the result of nervous-system evolution, we will pay close attention to functions.

## b) Initial topics [Chapter 1 of book]

- 1) Terminology
- 2) Neurons: their evolution and how neuroanatomists study their pathways and interconnections

# Materials

- General and resources
  - Book list
  - Schedule of classes and exams; grading scheme
  - Glossaries
    - Assignment: Suggest additions to the glossary for readers of the book
- Classes
  - Readings & Study Questions (for each class or group of classes)
    - Listing of assigned and recommended readings for each topic
    - Questions on readings, for class discussions
  - Most of the readings will be posted.

# Questions based on chapter 1

1. Should brain structures and their organization make sense to you? What kind of sense?

**in terms of evolution of adaptive functions**

2. Define “central nervous system” (CNS). What are its basic elements?

# Human brain & spinal cord, ventral view

# Child's brain & spinal cord, dorsal view of dissection

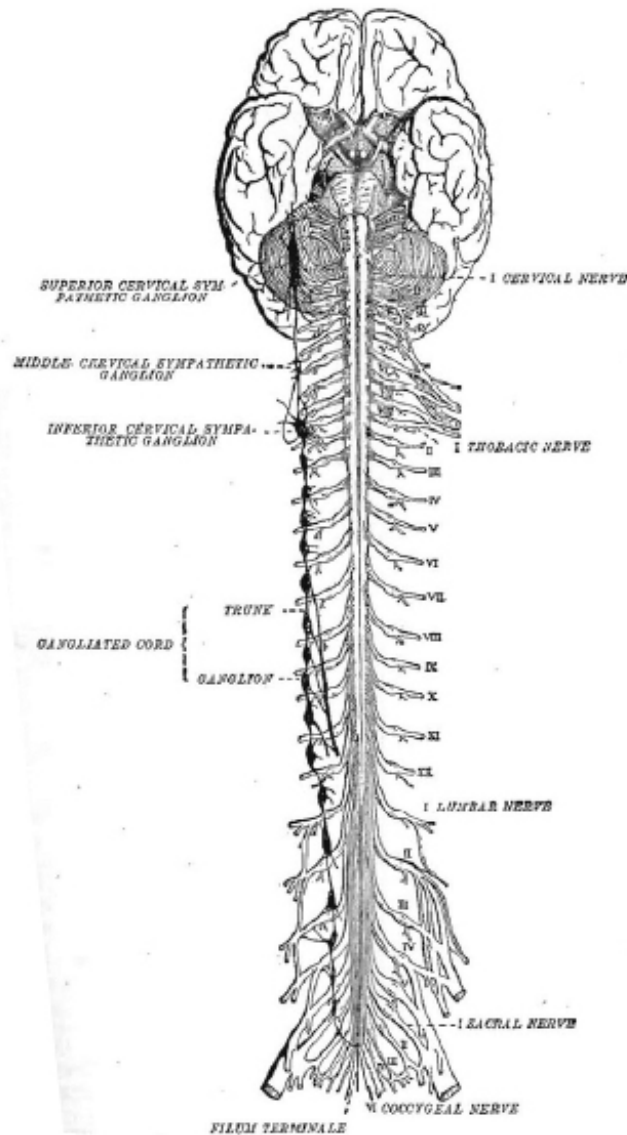


Photo removed due to copyright restrictions.  
Please see course textbook:  
Schneider, G. E. *Brain Structure and its Origins: In the Development and in Evolution of Behavior and the Mind*. MIT Press, 2014. ISBN:9780262026734.

Herrick, Charles Judson. *An Introduction to Neurology*. Saunders, 1918.  
Image is in the public domain.

The gross anatomy:  
A young human

from  
N. Gluhbegovic  
and  
T.H. Williams,  
1980  
(Harper & Row)

Note: *dura mater*;  
Spinal nerves vs CNS

Figure of the gross anatomy of the central nervous system of a young human was removed due to copyright restrictions. Please see:  
Gluhbegovic, Nedzad, and Terence H. Williams. *The Human Brain: A Photographic Guide*. Harper & Row, 1980.

Photograph of human central nervous system dissected free of the body, showing brain, spinal cord, and attached nerve roots removed due to copyright restrictions.

Please see:

Williams, Peter L., and Roger Warwick. *Functional Neuroanatomy of Man: Being the Neurology Section from Gray's Anatomy*. Churchill Livingstone, 1975.

Williams, P. L., & Warwick, R. (1975).  
Functional Neuroanatomy of Man: being the  
neurology section from Gray's Anatomy, 35<sup>th</sup> British  
edition. Philadelphia: Saunders.

# Questions, ch 1

3. Beginning at the caudal end of the central nervous system (CNS), what are the names of the major subdivisions?

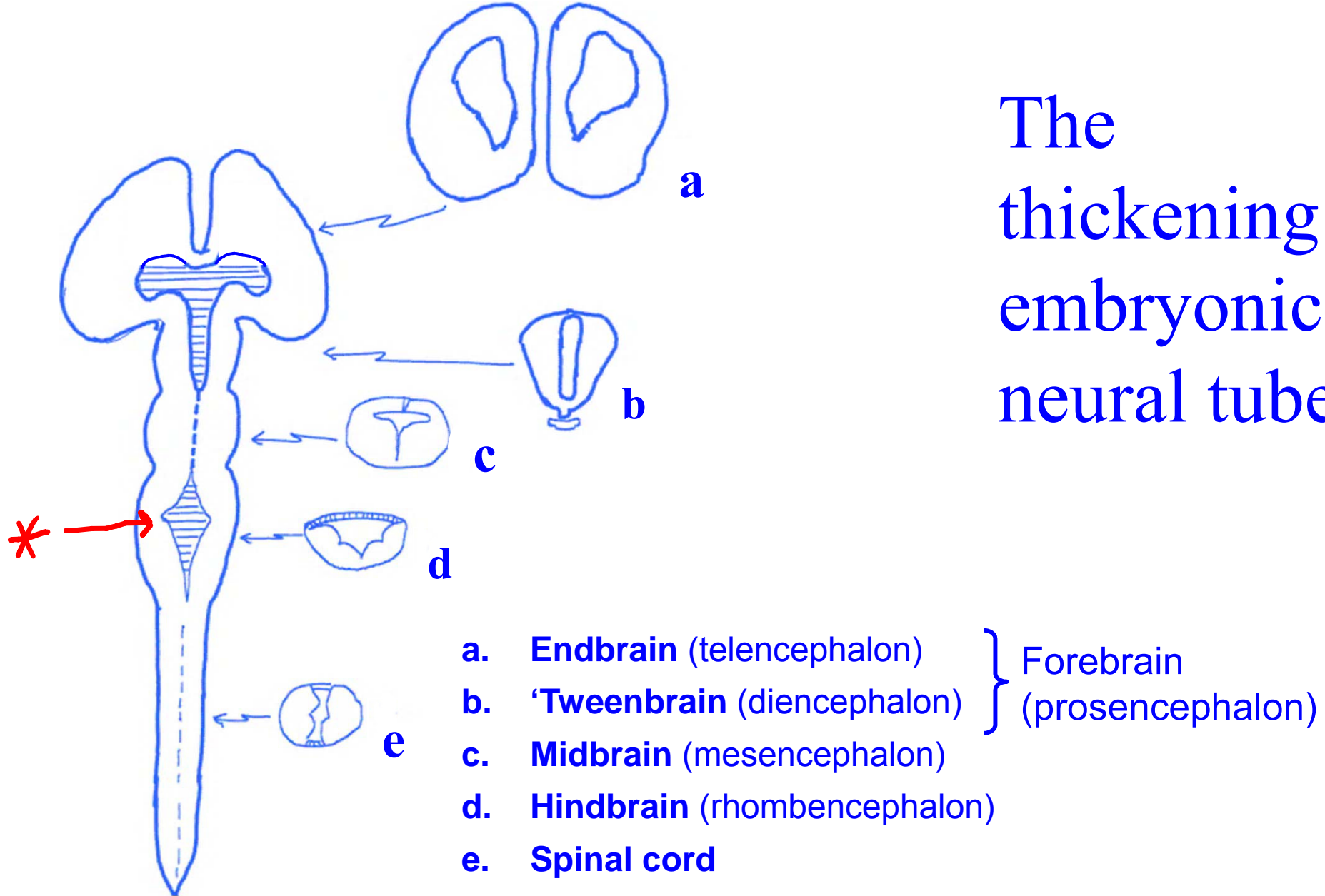
Next slide

4. Why is the hindbrain called the “rhombencephalon”?

Star on next slide: note shape of "roof plate" (more in later class)



# The thickening embryonic neural tube



Courtesy of MIT Press. Used with permission.

Schneider, G. E. *Brain structure and its Origins: In the Development and in Evolution of Behavior and the Mind*. MIT Press, 2014. ISBN: 9780262026734.

**Fig 1.3**

# Questions, ch 1

5. What coordinates are used by anatomists in discussing distances and directions within the brain? What are the most common synonyms for the words used?
6. What are the commonly used planes of section through the brain?

# DIRECTIONS

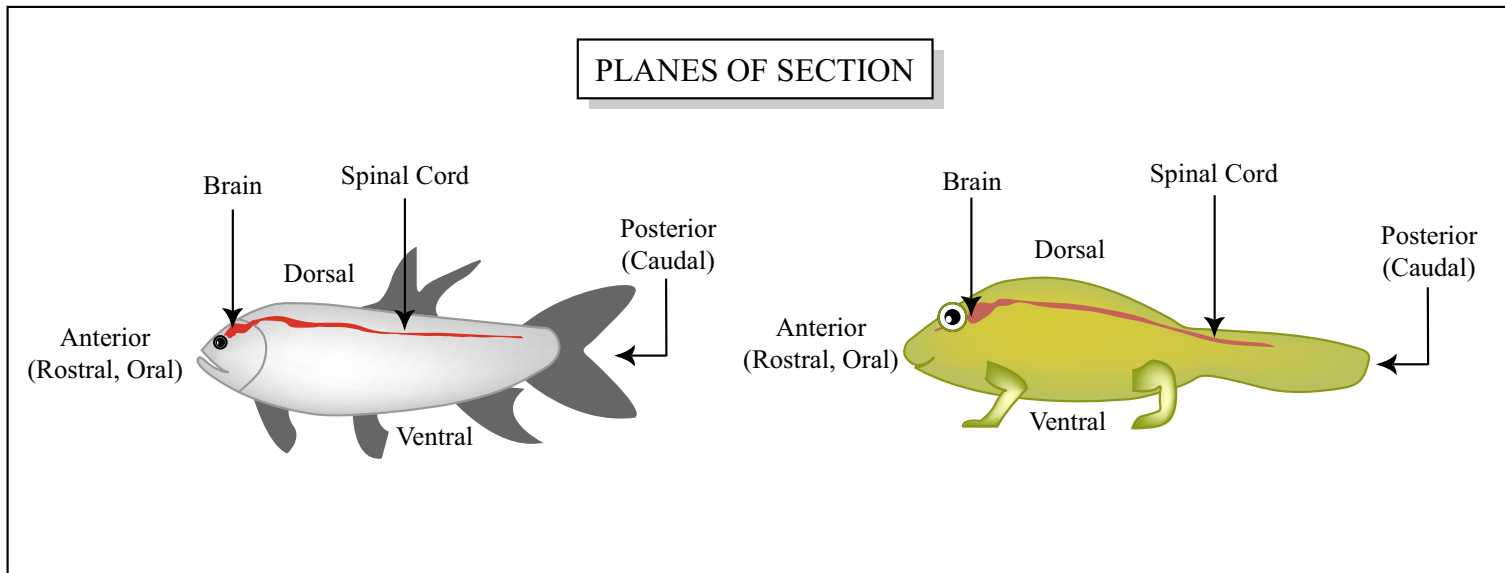


Image by MIT OpenCourseWare.

**Fig 1.1a**

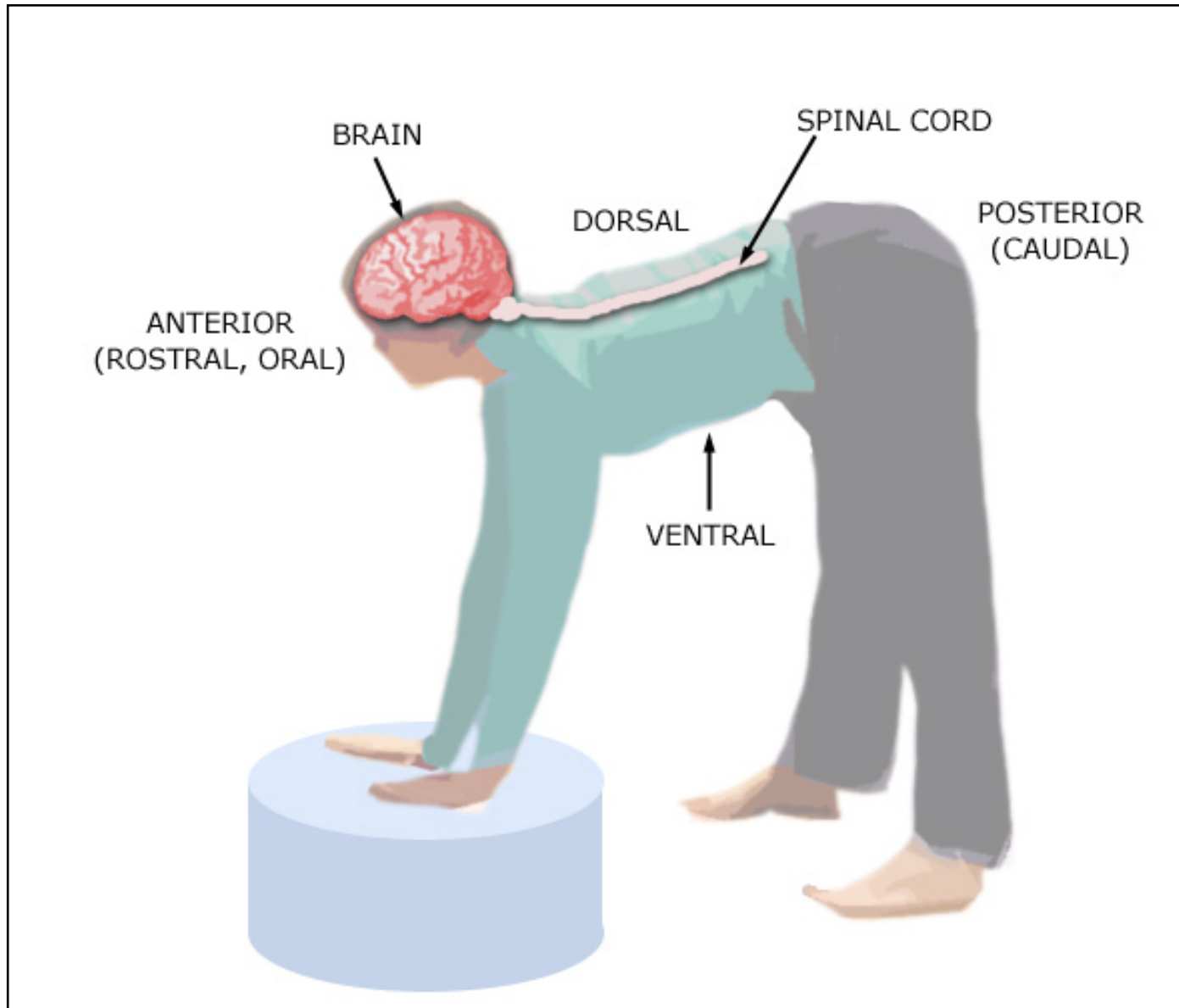


Image by MIT OpenCourseWare.

**Fig 1.1b**

# Man and Bird

## TERMS USED IN NEUROANATOMY

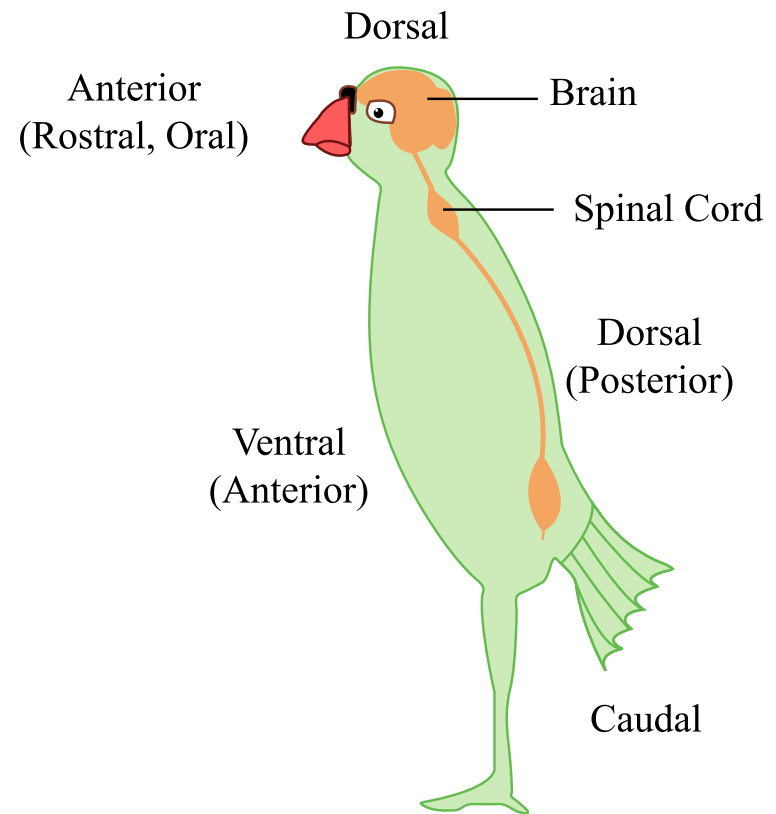
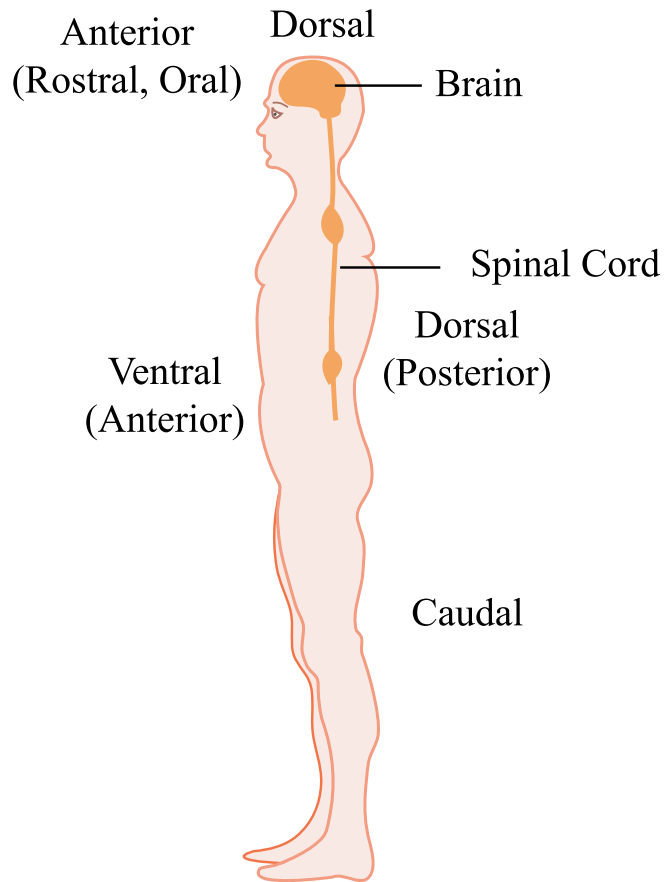
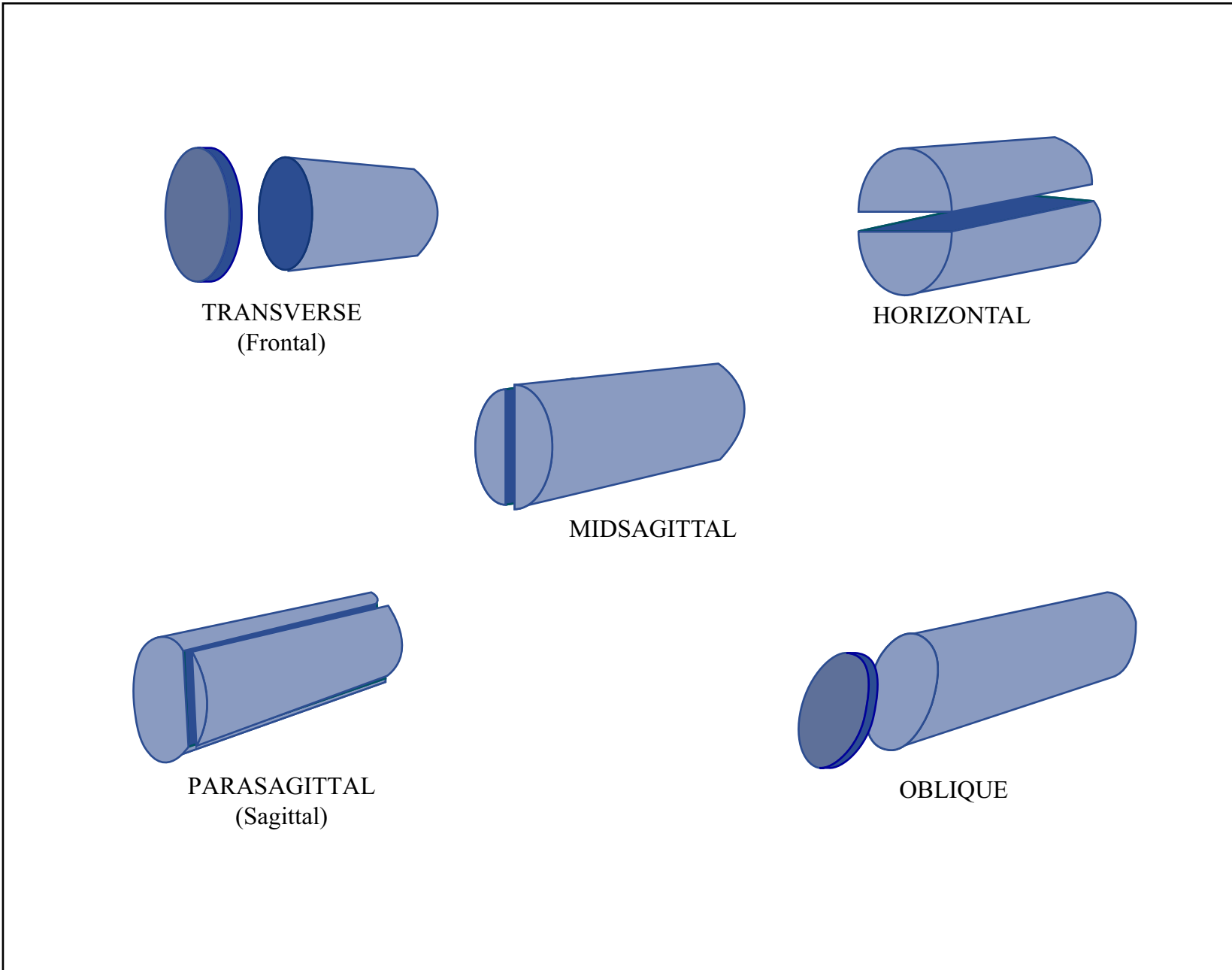


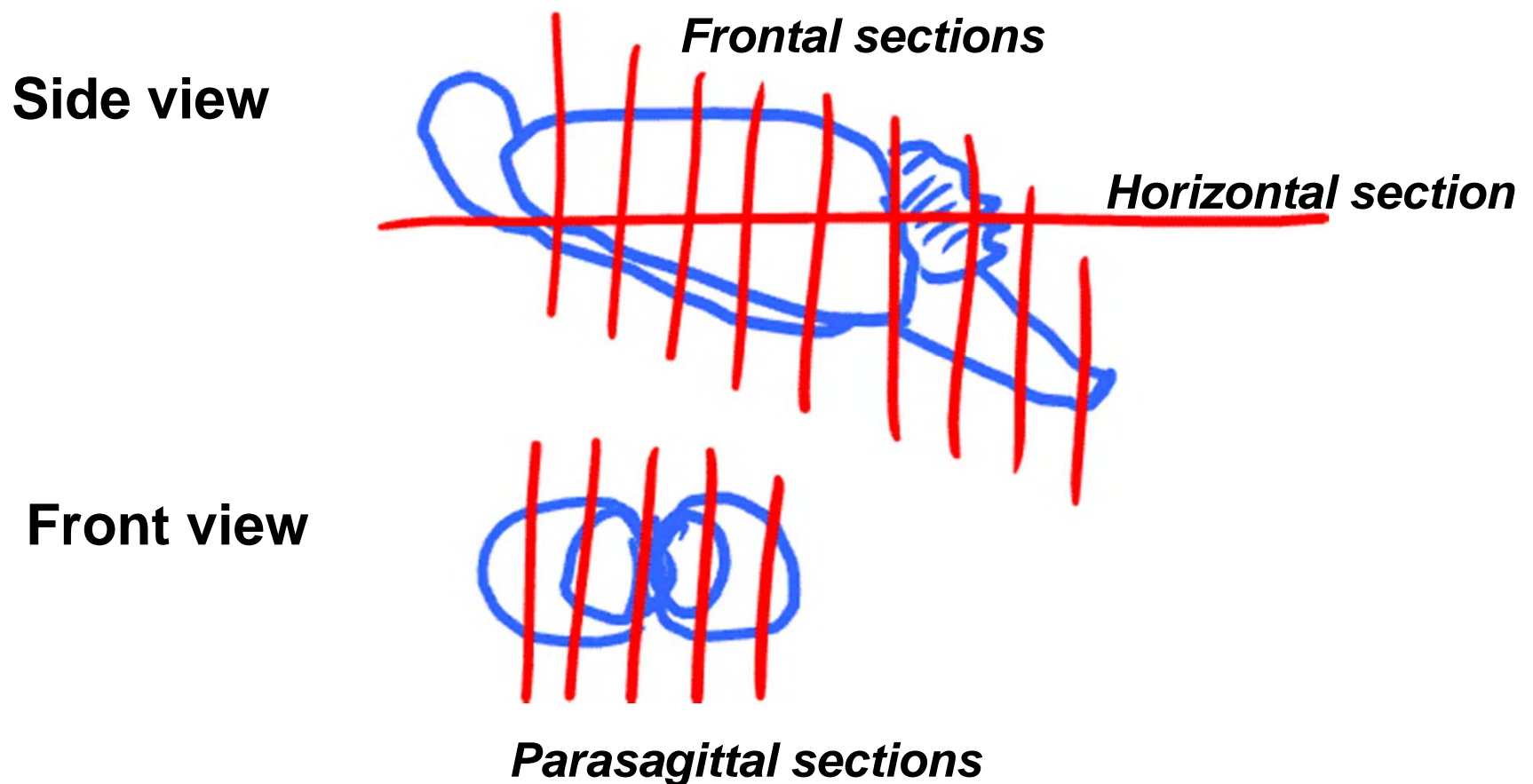
Image by MIT OpenCourseWare.



**Fig 1.2a**

Image by MIT OpenCourseWare.

# Standard planes of section, brain of small rodent



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Schneider, G. E. *Brain structure and its Origins: In the Development and in Evolution of Behavior and the Mind*. MIT Press, 2014. ISBN: 9780262026734.

**Fig 1.2b**

# Chapter 1 questions

*“One of the difficulties in understanding the brain is that it is like nothing so much as a lump of porridge.”*

—R.L. Gregory, 1966 (an experimental psychologist)

7. What kind of tissue constitutes the CNS? This can be answered by using the name of the tissue in the embryo that gives rise to the developing CNS. **ectodermal tissue--derived from the embryonic ectoderm (surface layer)**
8. How do we define and recognize specific cell groups in the CNS? **Sections stained for cell bodies, or for fibers, or from specific chemical substances**



## Chapter 1 questions

9. What is meant by the phrase "primitive cellular mechanisms" in a discussion of the nervous system?
  
10. What was the nature of communication between conductive cells in primitive organisms, before the evolution of chemical synapses?  
Preview of chapter 3 topic

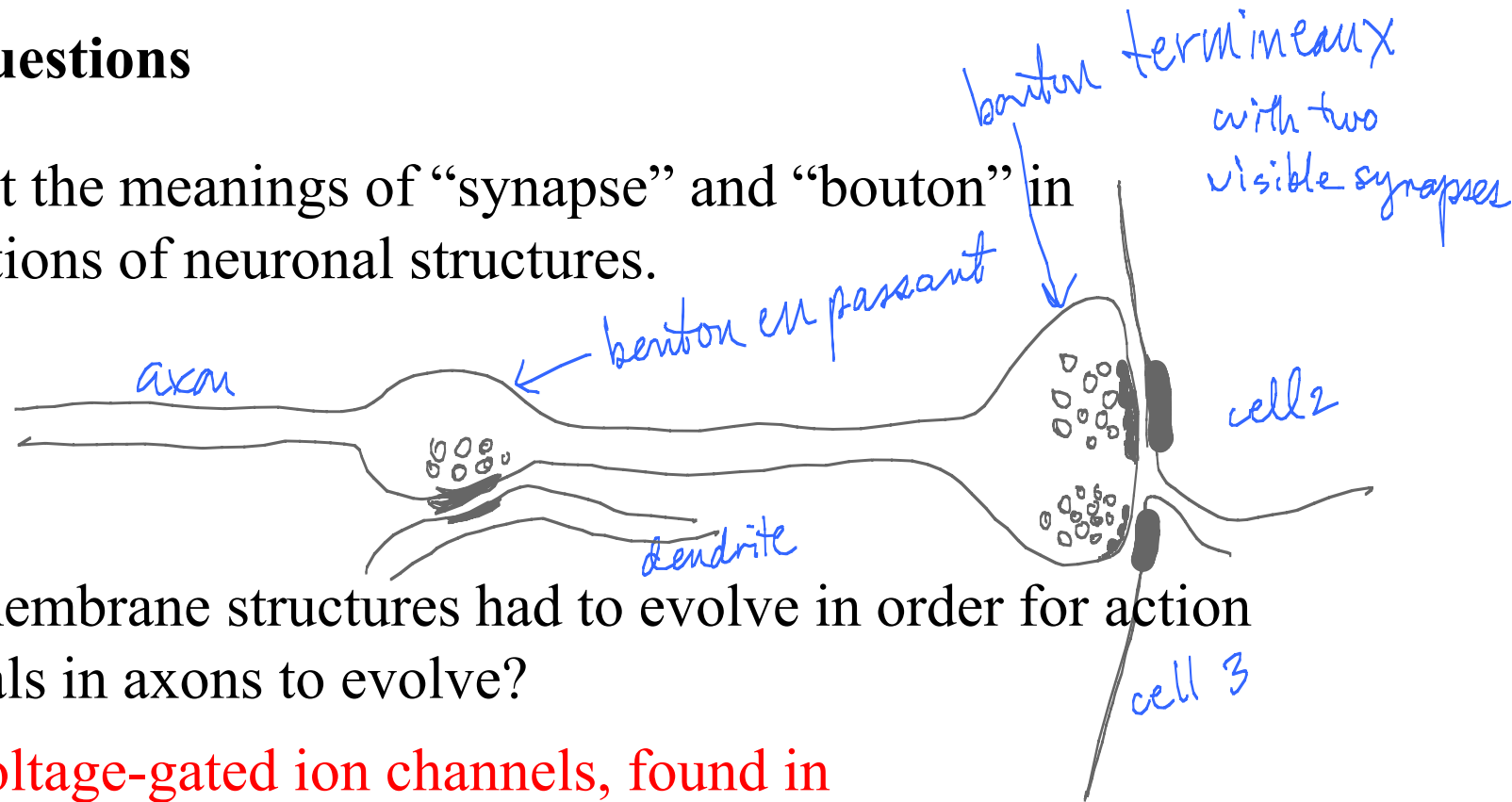
# Primitive cellular mechanisms

present in one-celled organisms and retained in the evolution of neurons

- Irritability and conduction
- Specializations of membrane for irritability
- Movement
- Secretion
- Parallel channels of information flow; integrative activity
- Endogenous activity

## Chapter 1 questions

11. Contrast the meanings of “synapse” and “bouton” in descriptions of neuronal structures.



12. What membrane structures had to evolve in order for action potentials in axons to evolve?

voltage-gated ion channels, found in jellyfish neurons and in all more advanced creatures

# Chapter 1 questions

13. Contrast excitatory and inhibitory post-synaptic potentials.

next slide

14. Contrast the nature of conduction in a dendrite and in an axon. --decremental, graded; speed is very fast

--non-decremental, all-or-nothing; speed varies with axon size

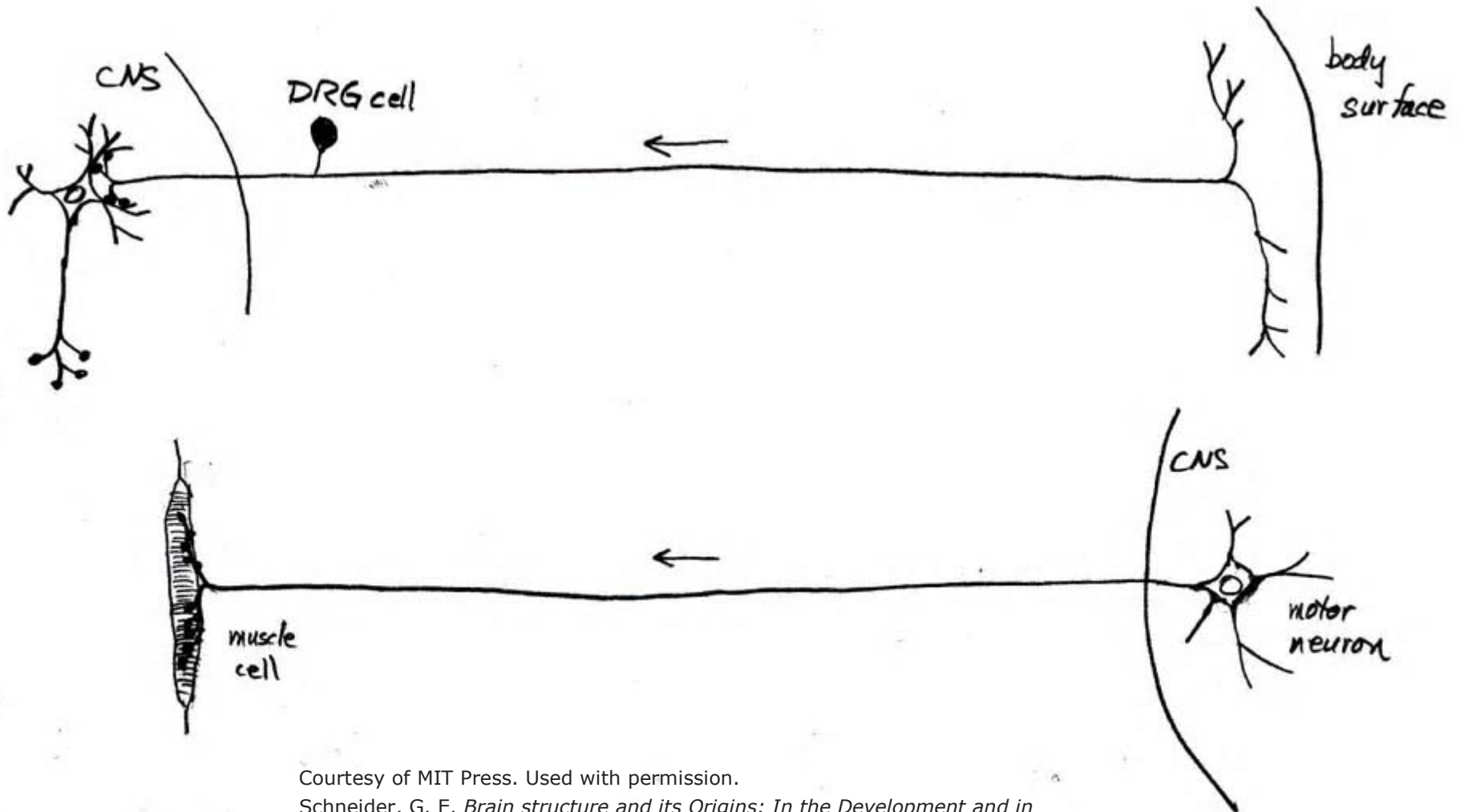
15. What is the functional purpose of an active pumping mechanism in the axonal membrane?

Sodium-potassium pump: a molecular, energy-using pump in neuronal membranes that restores normal distribution of ions after alteration by many action potentials

# Recording EPSPs and IPSPs

Images of excitatory or inhibitory postsynaptic potentials removed due to copyright restrictions.  
Please see course textbook or:  
Breedlove, S. Marc, Mark R. Rosenzweig, and Neil Verne Watson. *Biological Psychology: An Introduction to Behavioral, Cognitive, and Clinical Neuroscience*. Sinauer Associates, 2007.

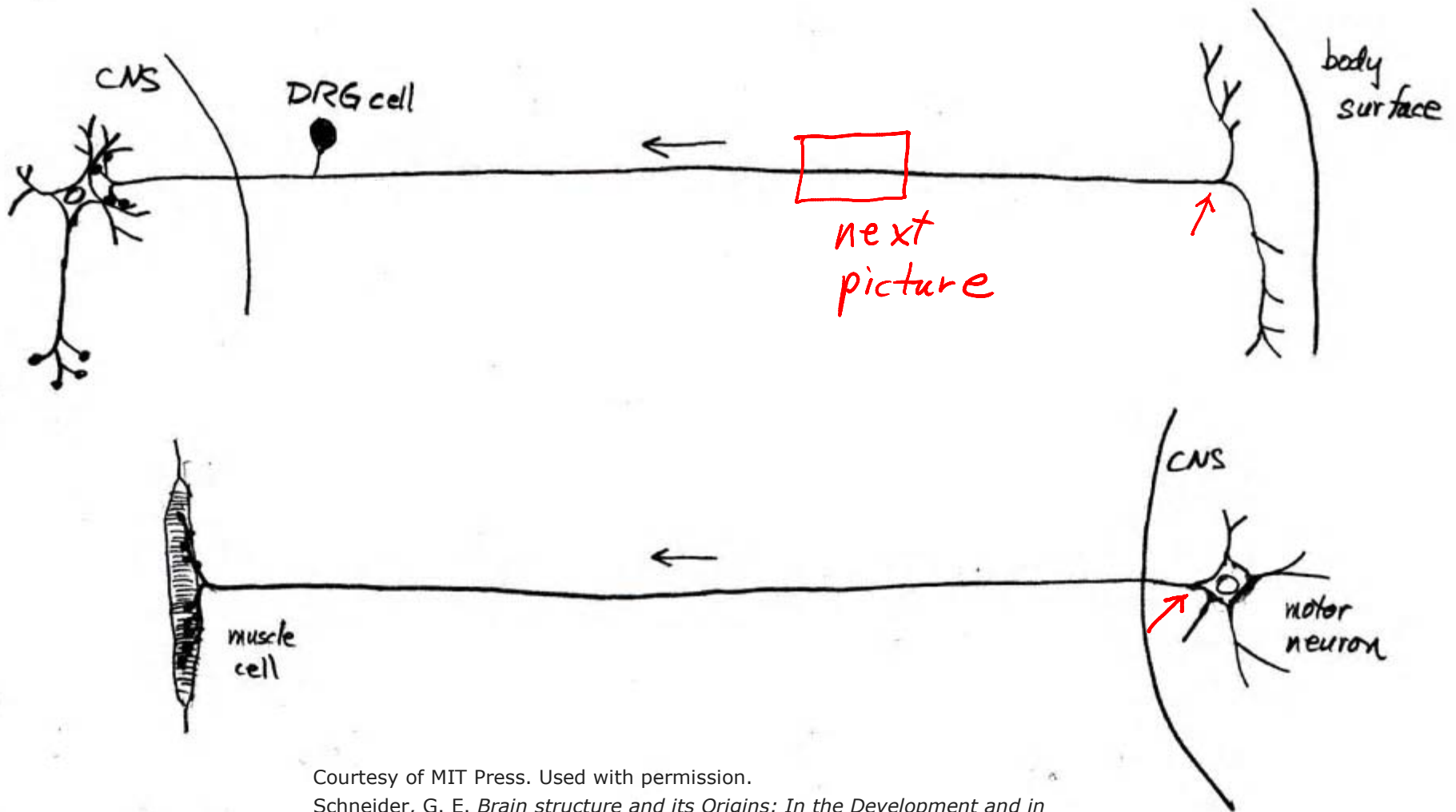
# Irritability and conduction: Examples of two neurons of the mammalian embryo



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Schneider, G. E. *Brain structure and its Origins: In the Development and in Evolution of Behavior and the Mind*. MIT Press, 2014. ISBN: 9780262026734.

**Fig.1-6** What are the three major, functionally distinct, parts of a neuron?

# Irritability and conduction: Examples of two neurons of a mammalian embryo

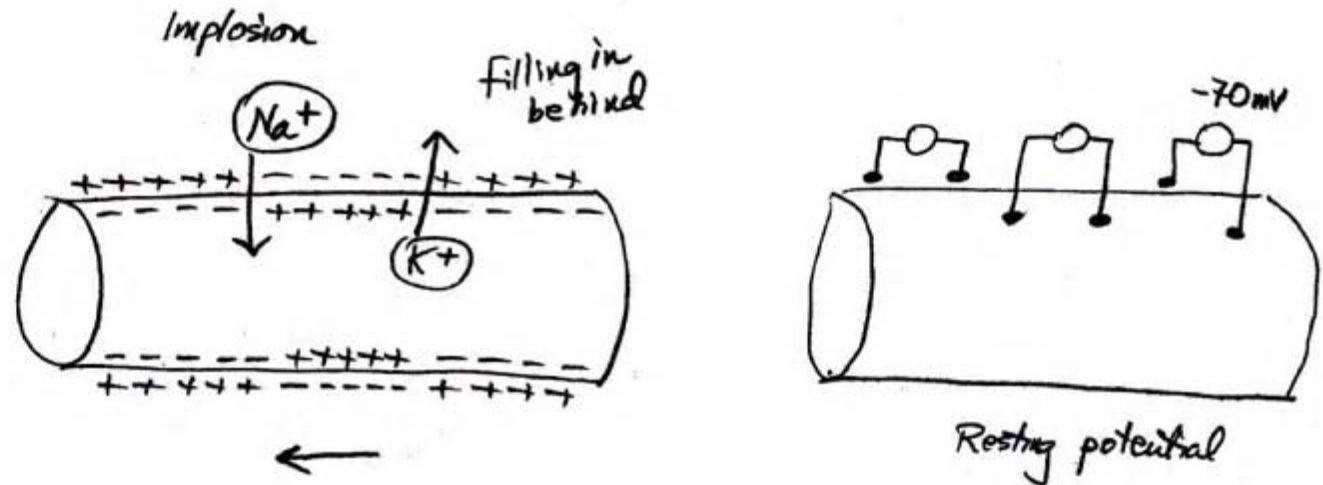


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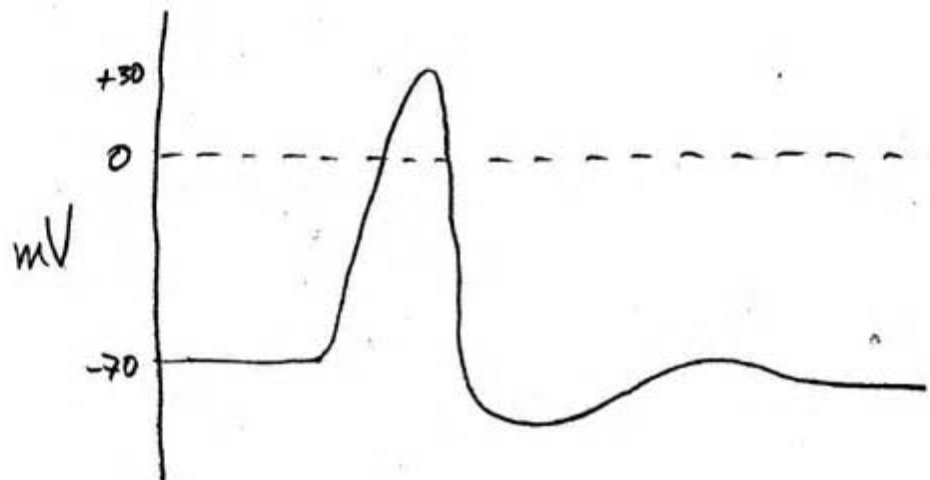
**Fig.1-10a**

# Membrane potentials in axons

Action potential at a point in time



Recording by a microelectrode at a constant position inside the axon,  
**OR**  
a snapshot spatial distribution of the membrane potential



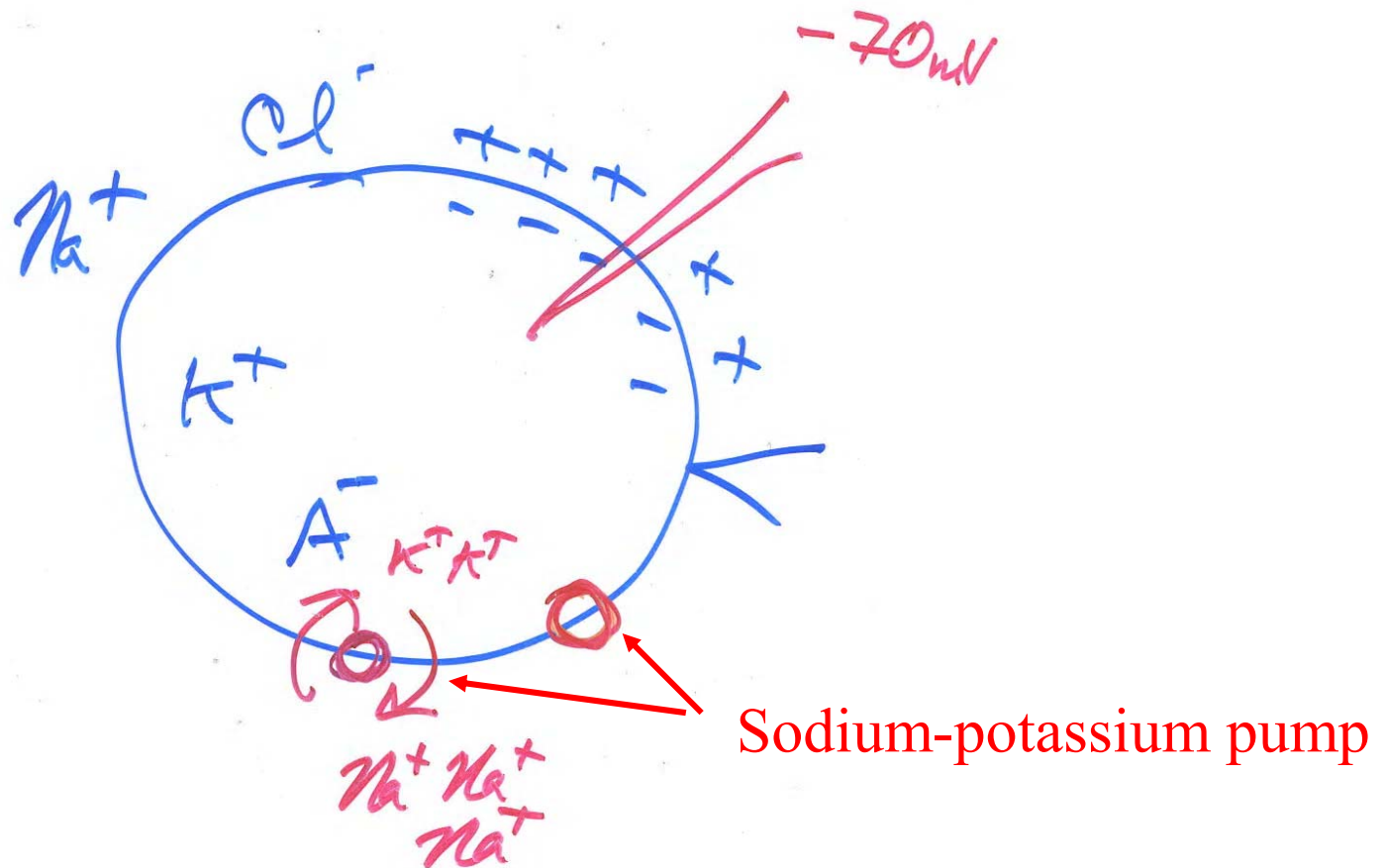
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Schneider, G. E. *Brain structure and its Origins: In the Development and in Evolution of Behavior and the Mind*. MIT Press, 2014. ISBN: 9780262026734.

**Fig.1-10b**



## *A cartoon:*

Distribution of major ions inside & outside the resting neuronal membrane; recording of electrical potentials



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**Fig.1-9**

# Chapter 1 questions

16. What is a dorsal root ganglion? **DRG - next slide**

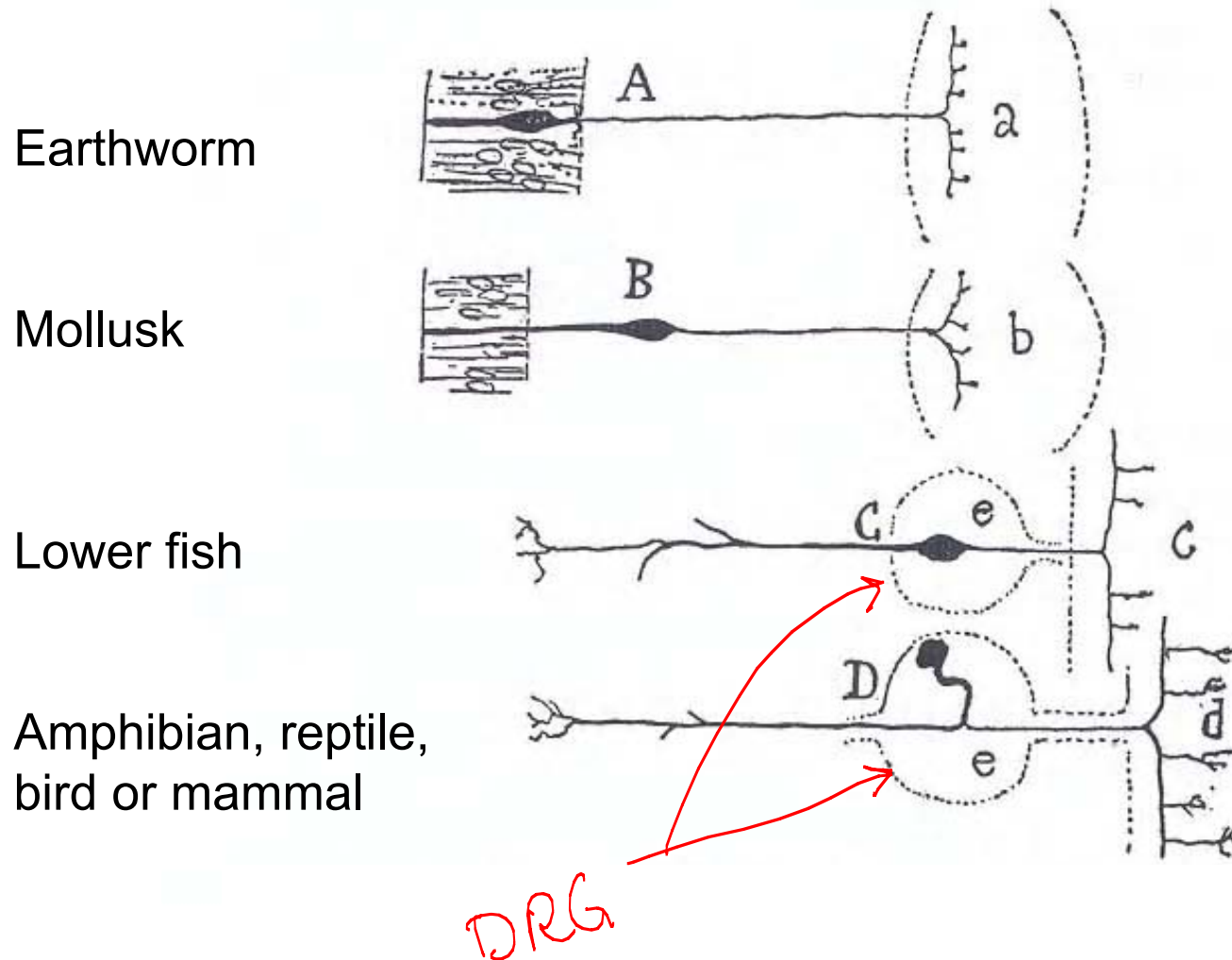
17. What are oligodendrocytes and Schwann cells?

**Glial cells that form myelin sheath around axons of CNS and PNS,**

18. What is the major function of a myelin sheath? What is saltatory conduction?

**Speeds axonal conduction by forcing action potential to jump from one node of Ranvier to the next node (small section of bare membrane)**

# Primary somatosensory neurons in an animal series



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Schneider, G. E. *Brain structure and its Origins: In the Development and in Evolution of Behavior and the Mind*. MIT Press, 2014. ISBN: 9780262026734.

**Fig 1-7**

## Chapter 1 questions

19. Many sensory receptor cells are not actually neurons. How are they different from neurons, and how do they interact with neurons?

They have polarized membranes that change membrane potentials in response to specific kinds of stimulation. They are in close contact with dendritic regions of sensory neurons, which respond to them.

# Specializations of the membrane for irritability

- At **post synaptic sites**: receptors for specific molecules released by other neurons
- **Sensory receptors**: In neurons or associated cells found in, or extending into, skin and other peripheral organs, for detection of specific kinds of energy
  - chemicals in air or in mouth,
  - light,
  - pressure,
  - stretch,
  - hot or cold,
  - electrical potential changes,
  - sounds
- Some of these specializations occur with the evolution of modified cilia, e.g., the olfactory and the visual receptor specializations.

# Chapter 1 questions

20. What kind of molecule are actin and myosin? When is actin found most abundantly in neurons?

- contractile proteins
- during growth periods

## Chapter 1 questions

21. Describe the dream of Otto Loewi that led him to make one of the greatest discoveries of neuroscience in the early twentieth century. What was the discovery?

# Otto Loewi's discovery: chemical transmission at the synapse

- The controversy in the early years of the 20<sup>th</sup> century: Are synapses electrical or chemical?
- The **story of Loewi's dream**: He saw, first in a dream, how chemical transmission at the synapse could be demonstrated . He proved it in his lab.
  - Innervation of the frog heart: accelerator nerve and decelerator nerve
  - Two frog hearts in saline, in separate petri dishes...
  - Evidence for “Acceleransstoff” (later identified as norepinephrine) and “Vagusstoff” (later identified as acetylcholine)
- Electrical synapses are also found, less commonly, in the form of “gap junctions”. These are found already in sponges. (This will be discussed in ch 3.)



**End session 1** Students should study remaining slides, answer the questions. Bring questions to next class.

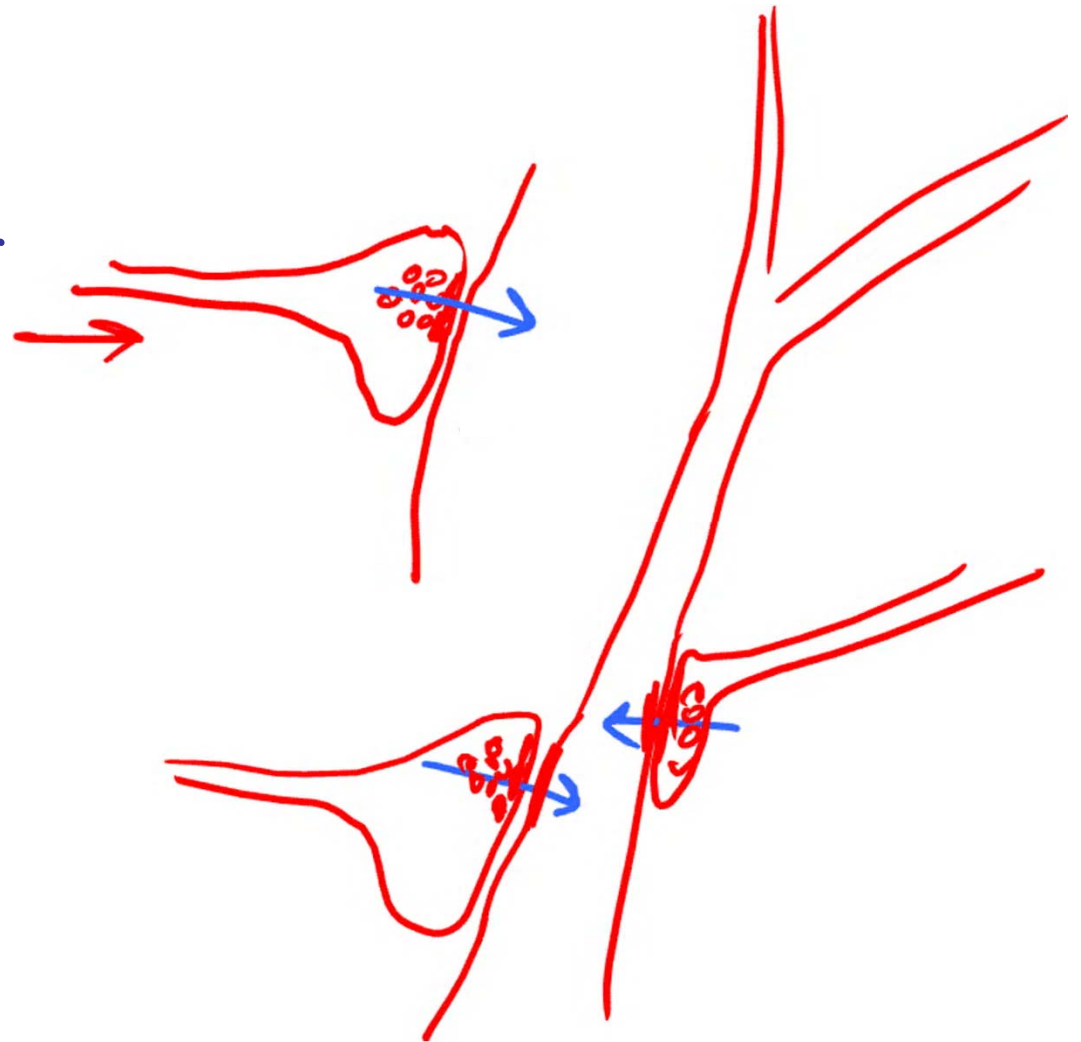
## Chapter 1 questions

22. Describe the major characteristics of a synapse when tissue of the CNS is examined with an electron microscope? What are some of the various synaptic arrangements seen with the electron microscope? **see next slides**

# Synapses: varied structural arrangements:

Consider the functional possibilities

1. **Axo-somatic**
2. **Axo-dendritic**  
(to dendritic shaft or dendritic spine)



**Fig 1-13**

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Schneider, G. E. *Brain structure and its Origins: In the Development and in Evolution of Behavior and the Mind*. MIT Press, 2014. ISBN: 9780262026734.

# Synapses: varied structural arrangements:

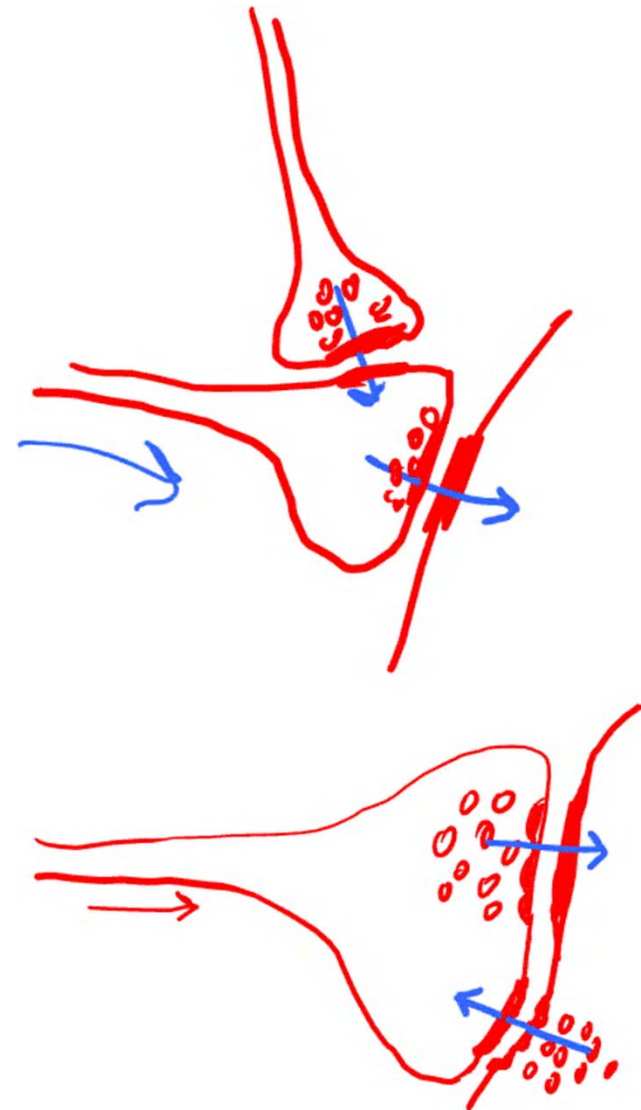
Consider the functional possibilities

## 3. Axo-axonal

*Presynaptic inhibition and facilitation*

4. (Also: dendro-dendritic, dendro-axonal...)

5. Reciprocal synapses



**Fig 1-13**

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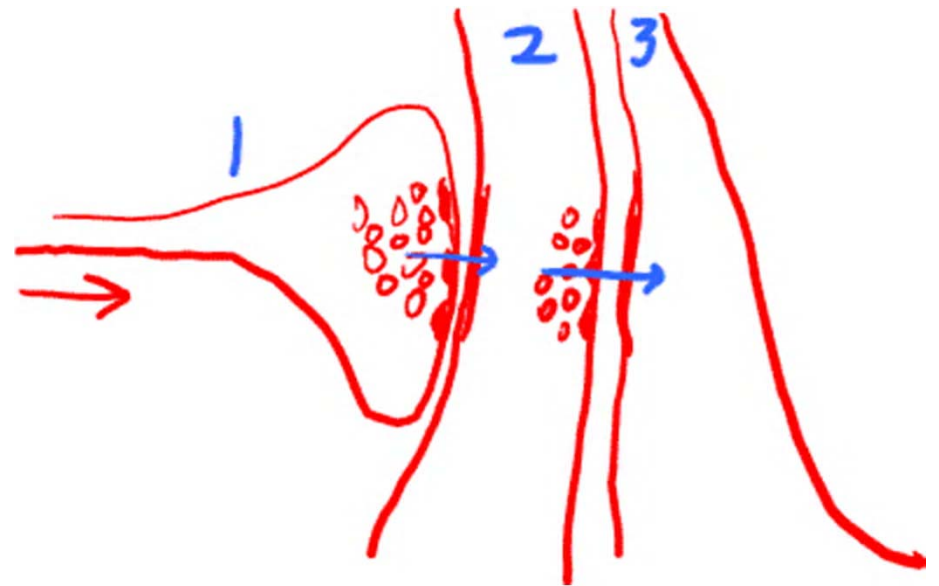
# Synapses: varied structural arrangements:

Consider the functional possibilities

## 6. Serial synapses

*Gating mechanisms...*

## 7. Synapses without a postsynaptic site (not illustrated)



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**Fig 1-13**

# Questions on axo-axonal synapses

- What are the consequences for cell 2 when the axons of cells 1 and 3 are both active and each result in depolarization of the postsynaptic membrane?
- Alternatively, what happens if action potentials in cell 3 result in hyperpolarizing currents in the ending of axon 1?

# Synapses: varied structural arrangements:

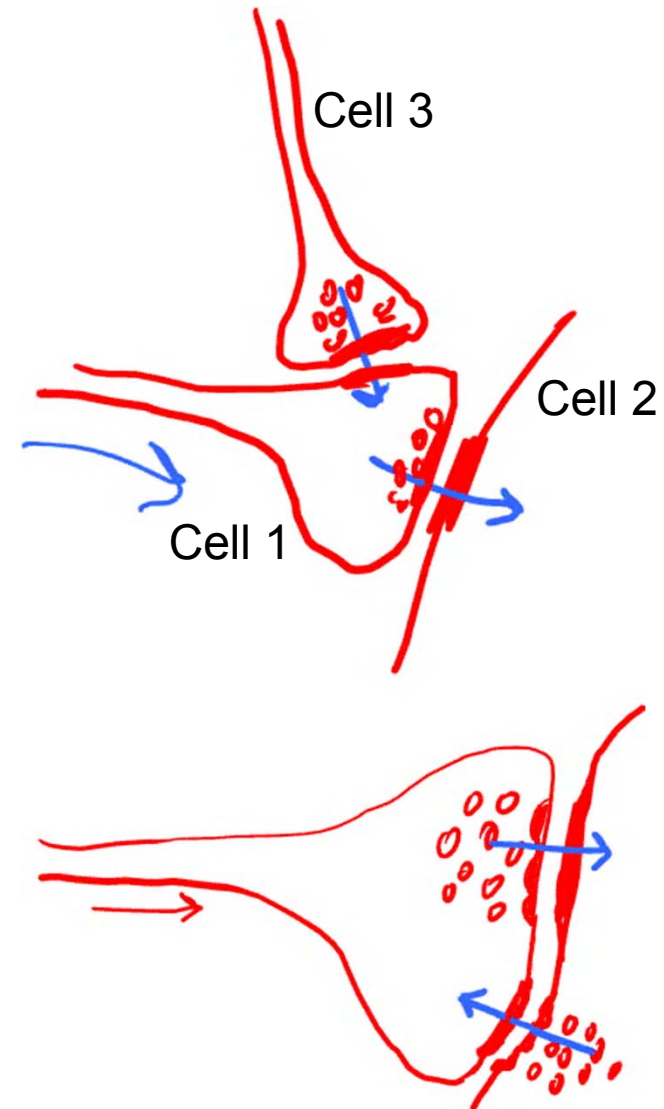
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**Fig 1-13**

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## Chapter 1 questions

23. Describe active transport mechanisms within the axons of neurons. How are the directions of such transport described?

next slide

24. What is endogenous activity of a neuron or an organism? Describe examples. next slides

# Common cellular dynamics with neuronal specializations

- exocytosis
- endocytosis
- **intracellular transport** of organelles and molecules
  - **Retrograde (involving dynein)**
  - **Anterograde (involving kinesin)**

**NEXT CLASS: How such cellular dynamics are used in experimental studies of the CNS**



# Endogenous activity in control of behavioral action patterns: Hydra

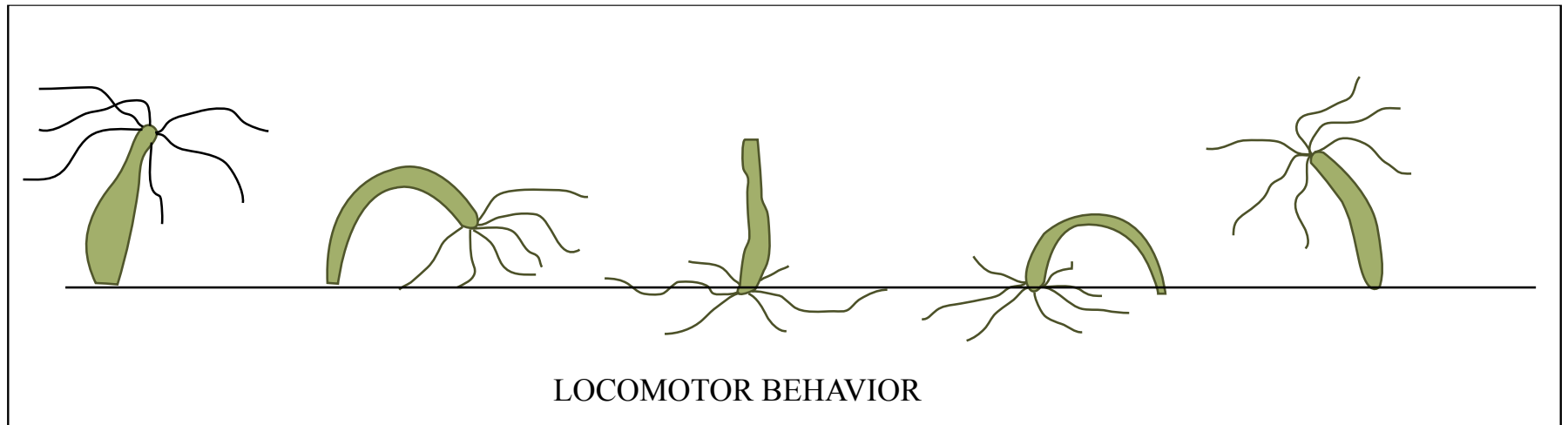


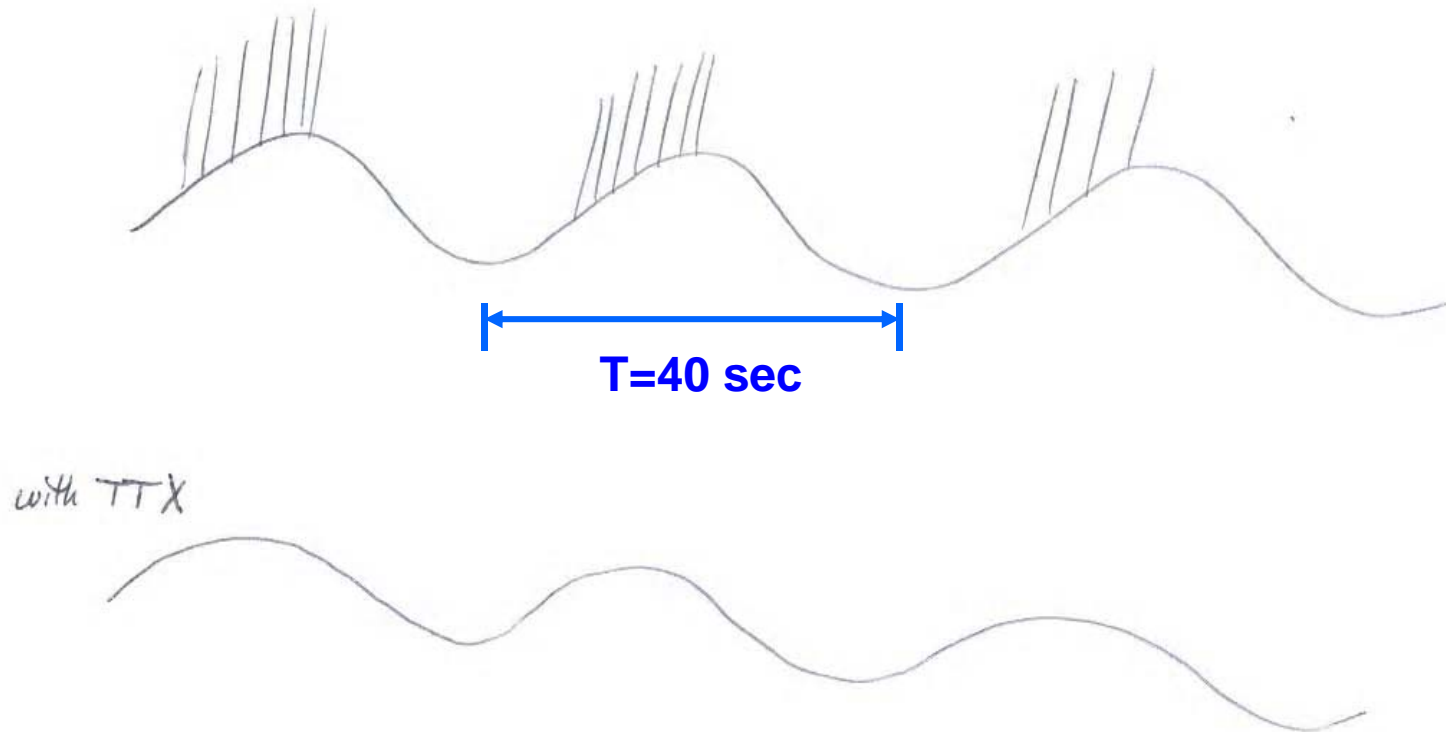
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**Fig 1-14**

# Example of endogenous activity in CNS (Spontaneous CNS activity)

- **Endogenously generated rhythmic potentials in neuronal membranes can cause bursting patterns of action potentials**
  - Felix Strumwasser's recordings in abdominal ganglion of *Aplysia* (sea slug) (1960s, early '70s)
  - There are many electrophysiological and molecular studies of endogenous activity in neurons since the early work.
- **The biological clock: Control of circadian rhythms in vertebrates**

# Endogenous oscillator



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Schneider, G. E. *Brain structure and its Origins: In the Development and in Evolution of Behavior and the Mind*. MIT Press, 2014. ISBN: 9780262026734.

**Fig 1-15**

# Felix Strumwasser's *Aplysia* (sea slug) experiments

- Recordings from an identifiable large secretory neuron of the abdominal ganglion:
  - 40 sec rhythm persists if action potentials are blocked with TTX,
  - but not if sodium pump is blocked with Ouabain.
- This cell also appeared to show a circadian rhythm that could be entrained by light.

# Circadian rhythms in vertebrates

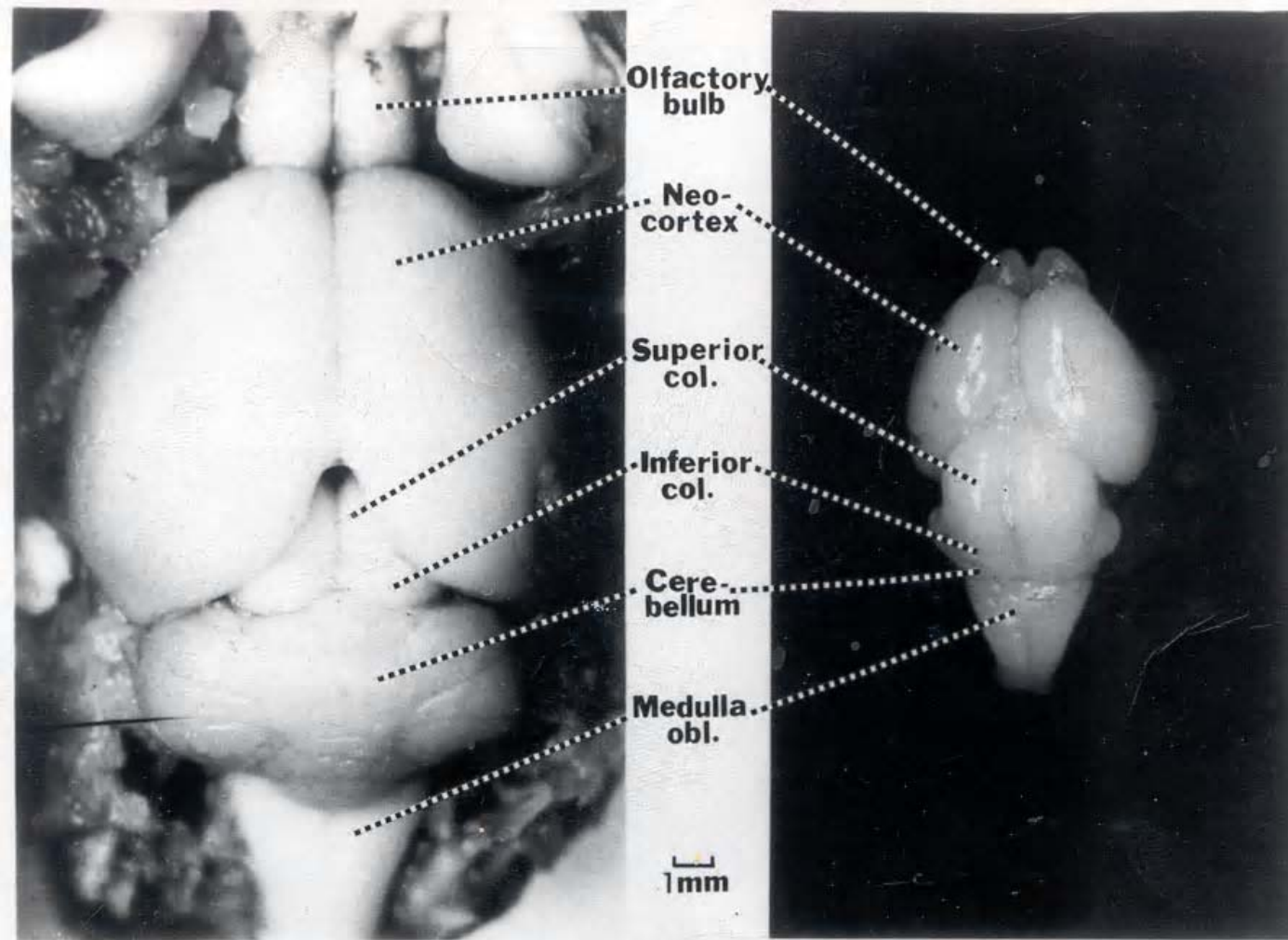
- Dependence on such “biological clocks” with a period of approximately 24 hr.
- Give mice heavy water,  $D_2O$ , and their free-running circadian activity rhythm slows down to a degree proportional to the %  $D_2O$  in their drinking water.

# Other examples:

- Especially in studies of invertebrates
- Molecular studies have increased.
- **Examples: the period gene in fruit flies and homologs in mammals**
  - Hardin PE, Hall JC, & Rosbash M (1990) Feedback of the *Drosophila* period gene product on circadian cycling of its messenger RNA levels. *Nature* 343: 536-540.
  - Zylka MJ, Shearman LP, David R Weaver DR & Reppert SM (1998) Three *period* Homologs in Mammals: Differential Light Responses in the Suprachiasmatic Circadian Clock and Oscillating Transcripts Outside of Brain. *Neuron*, 20:1103-1110

# Additional slides

# Hamster Brain (similar to rat)



Adult

Newborn

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Fig.1-5



Santiago  
Ramon y Cajal,  
drawing at his  
microscope



**Fig.1-8**

Image is in public domain. Courtesy of [www.wikimedia.org](http://www.wikimedia.org).

# Names for major parts and activities of neurons

- Cell body (soma) and its branches (dendrites)
  - Membrane potential
  - The cell's irritability: depolarization when stimulated. This is called excitation.
  - Graded conduction of membrane potential change away from the point of stimulation
- Axon and its end arborization (telodendria) with “synaptic” contacts on other neurons or muscle or gland cells
  - The axonal membrane is specialized for conduction of “action potentials.”
  - Action potentials are conducted in a non-decremental fashion.

**Action potentials are found even in jellyfish axons.**

**What membrane component had to evolve to accomplish this?**

## **Specializations for irritability,** seen in modern survivors of primitive species

- Protozoa: responses to stimulation
- Sponges and other metazoans: specialized cells responsive to contact or chemicals
- Cnidaria (formerly known as “Coelenterates”): primary sensory neurons plus neurons responsive to other neurons
- Bilaterally symmetric animals with forward locomotion: evolution of head receptors and their consequences

(We will return to these topics later.)

# Secretion as an output mechanism:

- For attacking prey
  - In protozoa
  - In sponges
- For cell-cell communication in sponges
- This process was retained, and evolved further, in neurons.

# Cartoon of a synapse

Figure removed due to copyright restrictions.  
Please see course textbook or:  
Becker, Jill B., ed. *Behavioral Endocrinology*. MIT Press, 2002.

**Fig. 1-11 Steps in transmission at a chemical synapse**

# *Secretion: terms*

- Neurotransmitters
- Neural hormones
- *Cf.* endocrine glands
- Multiple types of synapses
- **Exocytosis**
- **Endocytosis**
- **Intracellular transport**

# Primitive cellular mechanisms

present in one-celled organisms and retained in the evolution of neurons

- Irritability and conduction
- Specializations of membrane for irritability
- Movement
- Secretion
- **Parallel channels of information flow; integrative activity**
- Endogenous activity

# The need for integrative action in multi cellular organisms

- How does one end of the animal influence the other end?
- How does one side coordinate with the other side?
- With multiple inputs and multiple outputs, how can conflicts be avoided?
- Hence, the **evolution of interconnections** among multiple subsystems of the nervous system.



# How can such connections be studied?

- The methods of neuroanatomy (neuromorphology)
- The important roles of neurophysiology, neurochemistry, behavioral studies

*Neuroanatomical methods will be reviewed in the next class. Thereafter, the last primitive cellular mechanism, endogenous activity, will be explained further.*

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## 9.14 Brain Structure and Its Origins

Spring 2014

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