

# **A sketch of the central nervous system and its origins**

G. E. Schneider 2014

**Part 3: Specializations in the evolving CNS;  
introduction to connection patterns**

**MIT 9.14 Class 5**

The ancestors of mammals: Sketch of brain  
with some basic pathways

## Questions, chapter 5

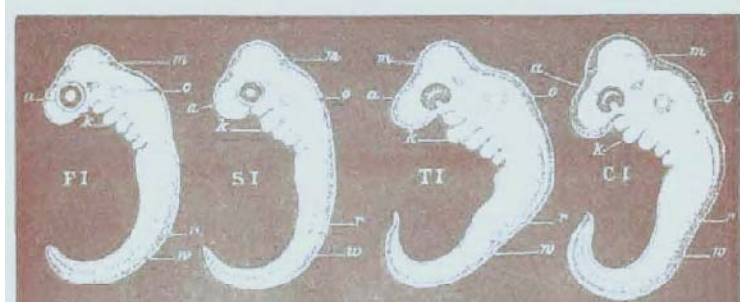
1. Does ontogeny really recapitulate phylogeny?  
What is a “phylotypic stage”? Explain the terms and discuss the concepts in terms of reliable data.

# Does "ontogeny recapitulate phylogeny"?

(Can development tell us something about evolution?)

- Early in development, the human embryo looks nearly the same as the embryo of a pig or monkey or ape. At later stages, the divergence from pig is more evident, while the similarity to monkeys and (finally) apes remains.
  - It appears that the earlier the stage of embryonic development, the greater the resemblance of different species—excluding, however, the very early (gastrula) stages.
  - Ernst Haeckel (in 1876) presented an oversimplified drawing of this, which became very well known.
- The next slides illustrate this. The first shows the similarities first noticed by Karl Ernst von Baer (1828) and illustrated by Haeckel. The second is based on Haeckel's simplified drawing.

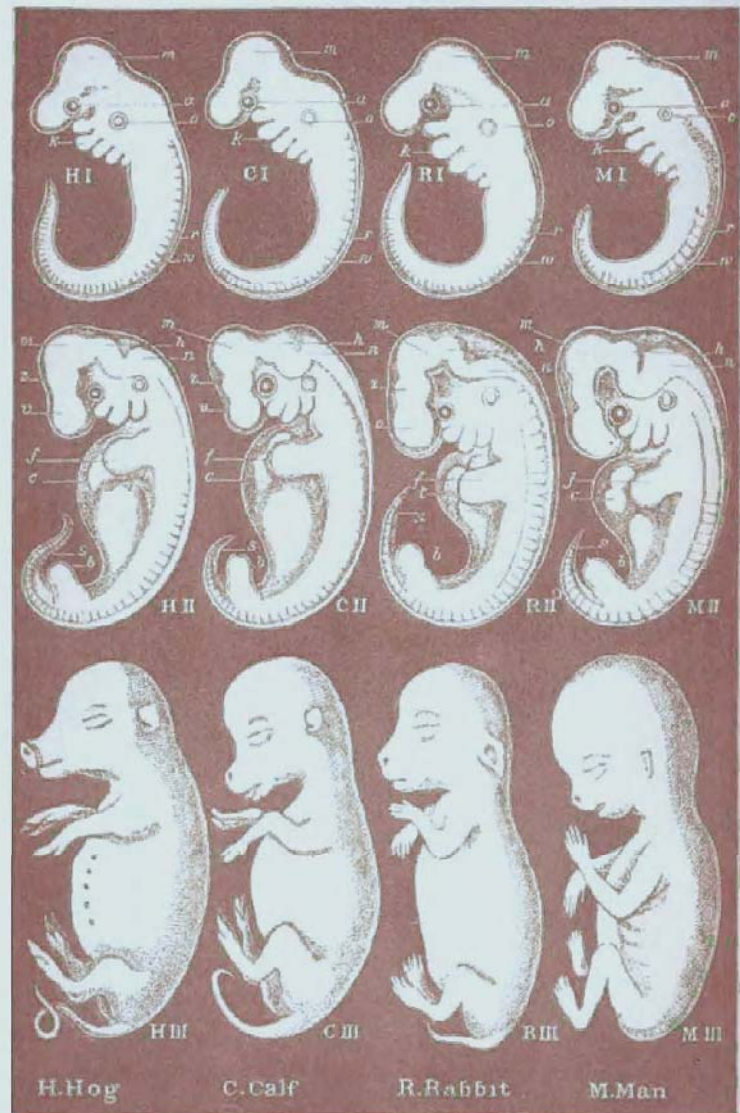
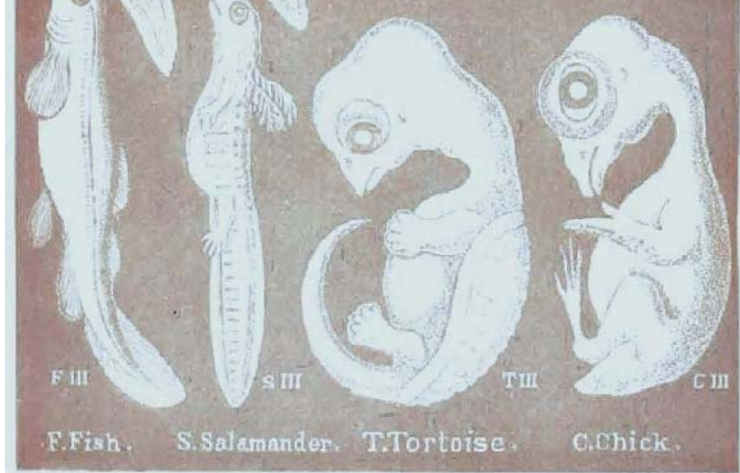
I



II



III



Fish Salamander Tortoise Chick Hog Calf Rabbit Human

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**Fig 5-2 Pictures by Ernst Haeckel (1879)**

# “The Developmental Hourglass”

A drawing based on one by Ernst Haeckel (1834-1919). It was greatly oversimplified but it became very well known.

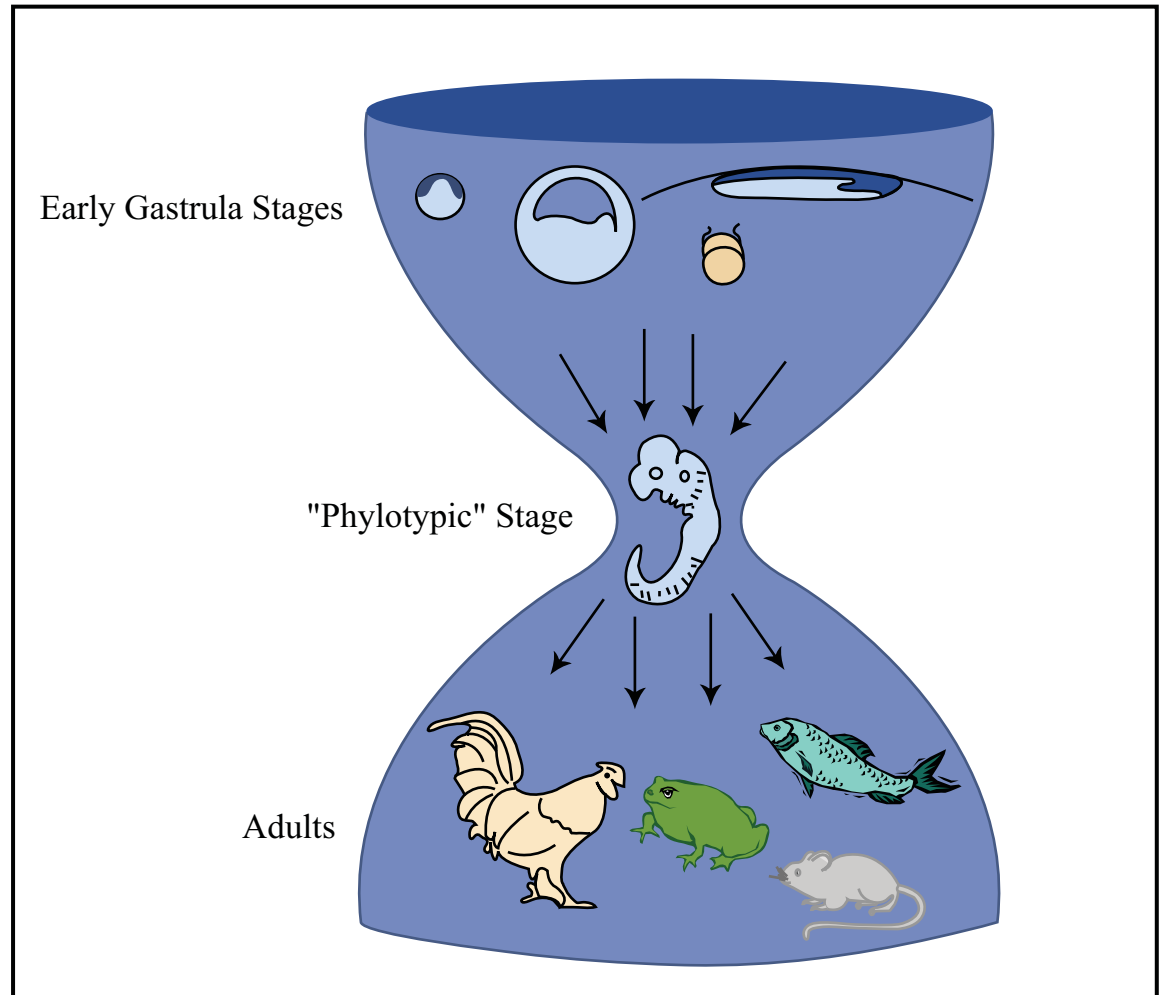


Image by MIT OpenCourseWare.

**Development does not strictly recapitulate evolutionary history, but the pictures nevertheless lead us to expect similarities in the CNS of all vertebrates; these have indeed been found.**

## Questions, chapter 5

2. What is a Cynodont? Why are cynodonts important in the story of brain evolution?

*A schematic outline of CNS organization in animals resembling the mammal-like reptiles that were the ancestors of mammals (Cynodonts) prepares the student for understanding mammals as well.*

Keep in mind the logic of evolution that brought about the changes in bodies and brains that led to mammals, including humans. This evolution occurred through a long series of adaptations focused on the basics of behavior enabling survival and better reproduction.



# Cynodonts: the mammal-like reptiles

Such animals existed from the late Permian through the Triassic, the Jurassic, and into the mid Cretaceous period.

Figure 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.

## Fig 5-3

*Cynodontia: Increasingly small-sized proto-mammals with higher metabolism than in other reptiles. It is currently unknown whether mammal-like reptiles possessed mammalian characteristics like body hair and mammary glands, as the only real evidence is provided by fossils that to date only suggest differences in skeletal structure.*

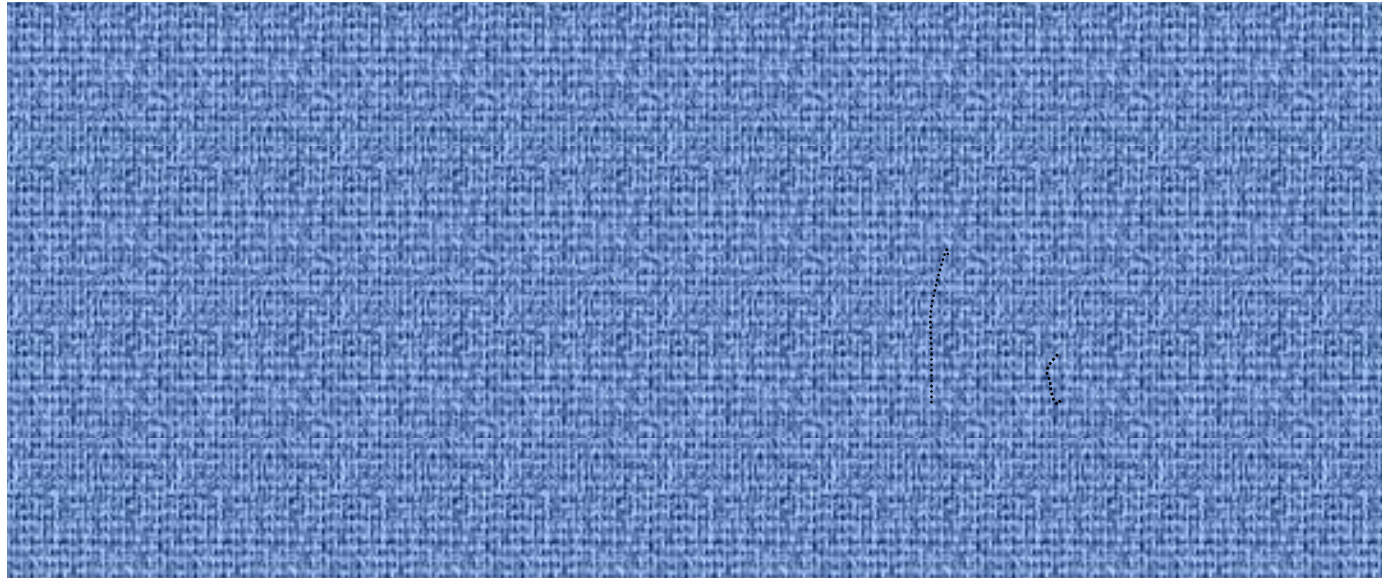
## Perspectives on the following schematic brain diagrams

- From the perspective of evolution, it could represent **an early Cynodont**, a group that existed from the late Permian through the Triassic, the Jurassic, and into the mid Cretaceous period. This group included the **mammal-like reptiles ancestral to the mammals** (*see Allman ch 5*).
- The first sketch could also be taken to represent a **generalized amphibian** brain, based on the work of C.J. Herrick and more recent neuroanatomists.
- Relevance to mammals, including human: This is **the “old chassis” upon which new parts were built in evolution**. Little is really discarded. (You still have that ancestral brain in the core of your human brain!)
  - Note also that “old” is a relative term. The amphibian brain, for example, is very advanced in comparison to brains of more primitive chordates.
- Later we will discuss in more detail some of the evolutionary transitions that gave rise to major changes in the CNS.

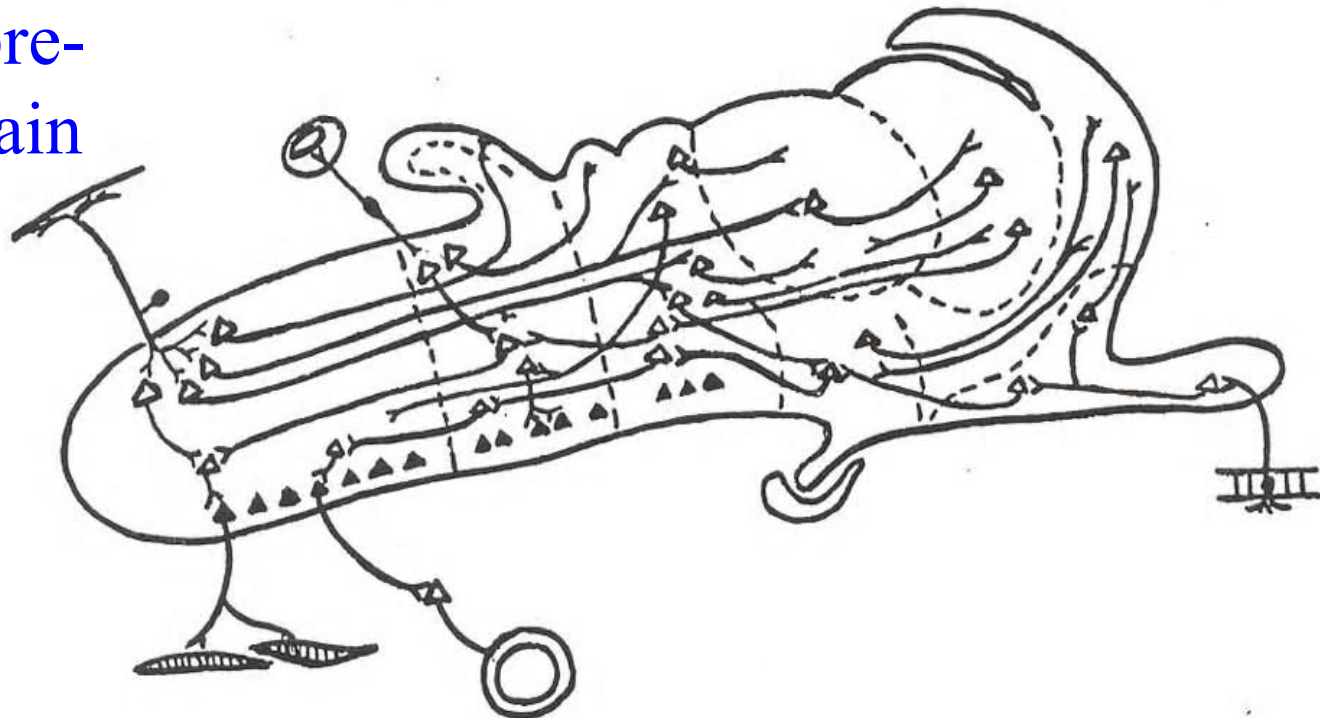
## Questions, chapter 5

3. From memory, list all the major brain subdivisions of the kind of brain an early Cynodont must have had.

Study the names of these subdivisions. Learn which is which.



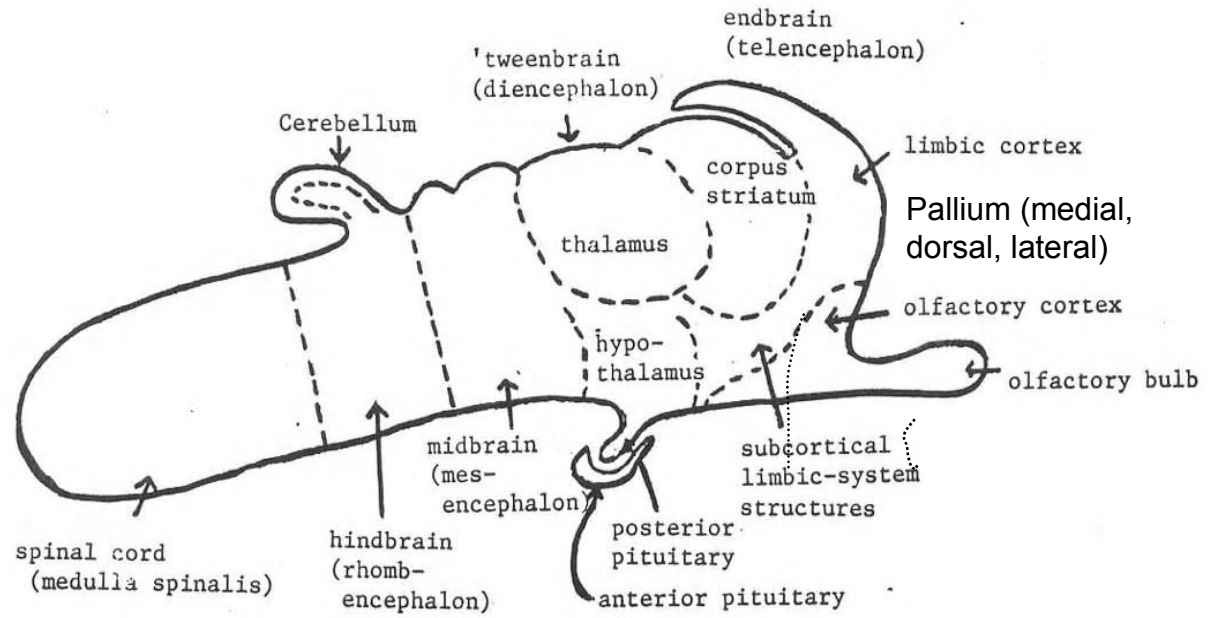
## Schematic of pre-mammalian brain



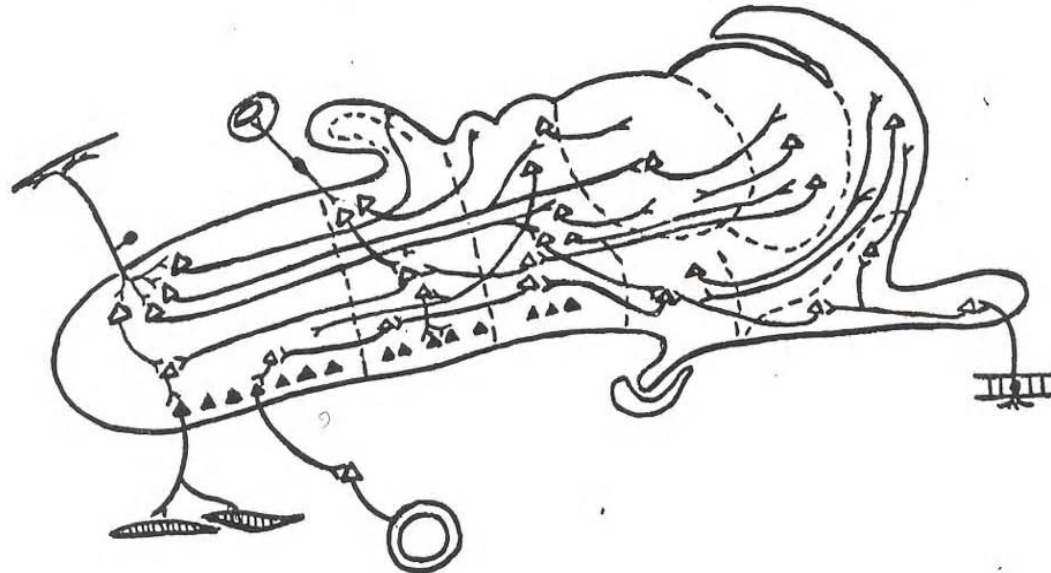
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**Study the names of these subdivisions. Learn which is which.**



## Schematic of pre-mammalian brain



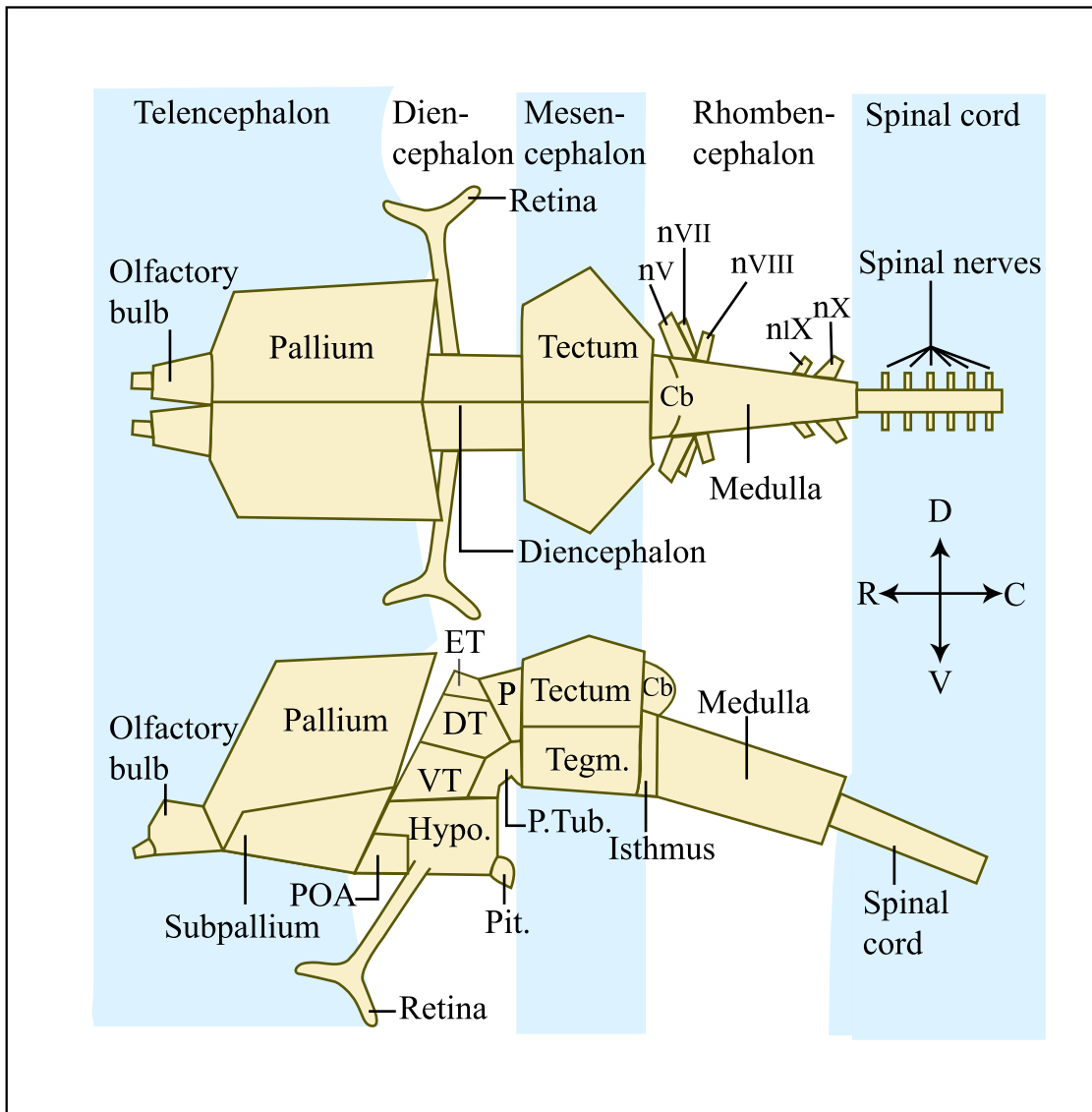
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# The vertebrate brain archetype

Dorsal view

Side view



(includes some additional details)

*cf "cortex" = bark*

Pallium = cloak (L.)

Tectum = roof

Tegmentum = covering

Medulla = inner core

Image by MIT OpenCourseWare.

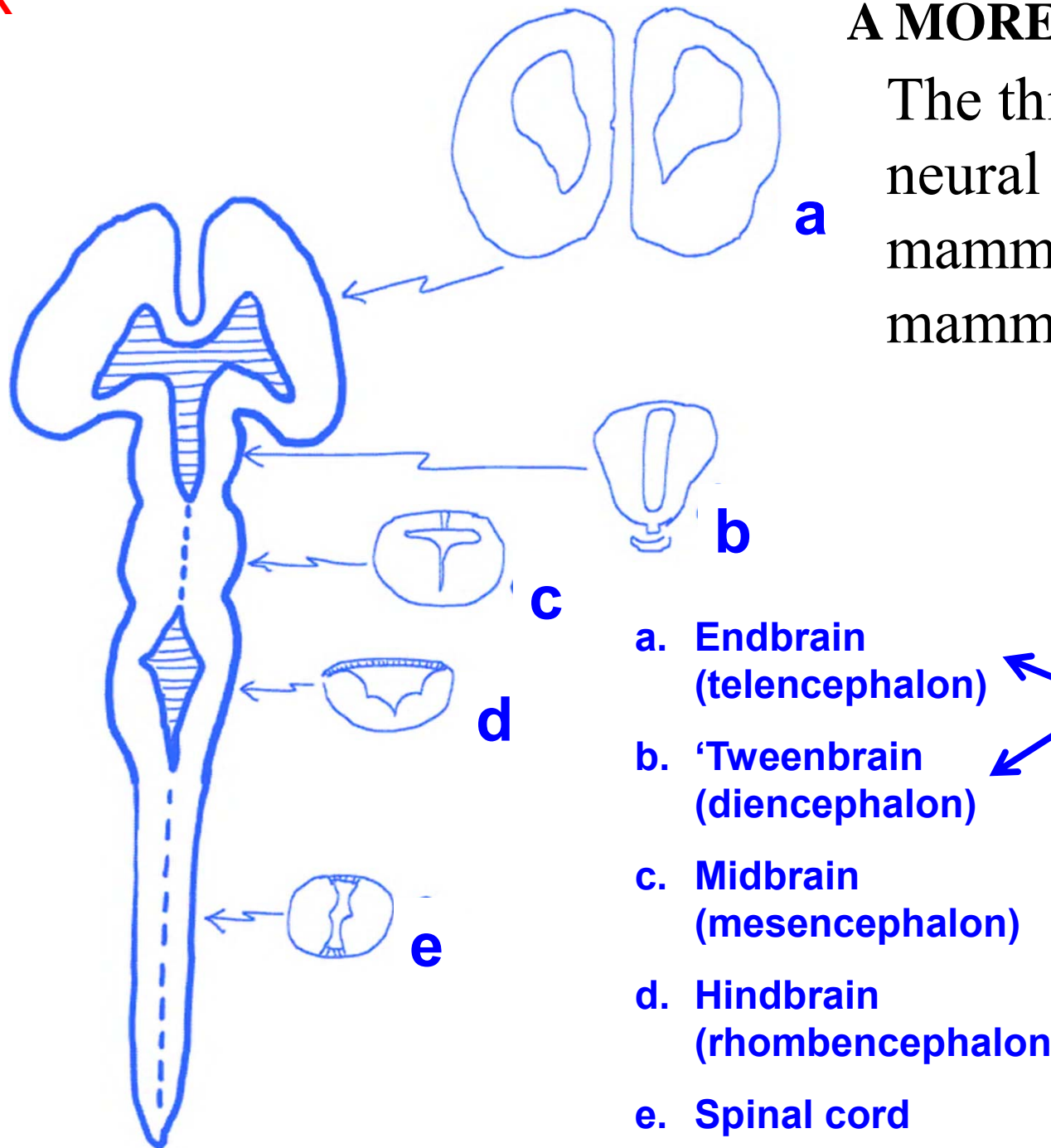
X



X

## A MORE REALISTIC VIEW:

The thickening embryonic neural tube in proto-mammals (or in a mammalian embryo)



Forebrain  
(prosencephalon)

a. Endbrain  
(telencephalon)

b. Tweenbrain  
(diencephalon)

c. Midbrain  
(mesencephalon)

d. Hindbrain  
(rhombencephalon)

e. Spinal cord

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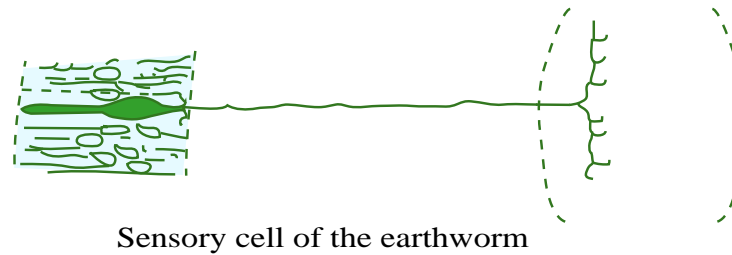
## Questions, chapter 5

4. What are three different types of primary-sensory-neuron structures? Where are these three types found in a mammal?



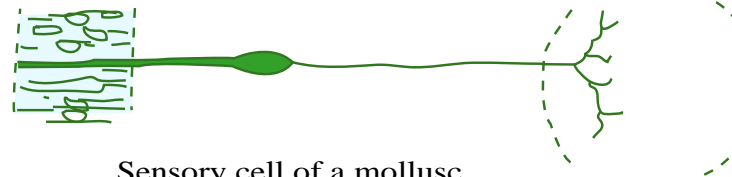
# Primary somatosensory neurons in an animal series: Earthworm, mollusc, lower fish, higher vertebrates (from Ramon y Cajal)

surface



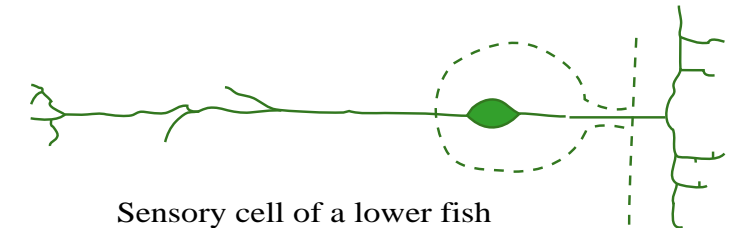
Sensory cell of the earthworm

bipolar cell



Sensory cell of a mollusc

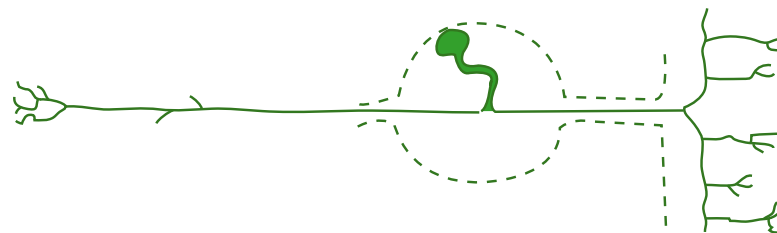
bipolar cell



Sensory cell of a lower fish

pseudo-unipolar  
cell in ganglion

**1) Find one like this in  
the ancestral brain  
(and mammals).**

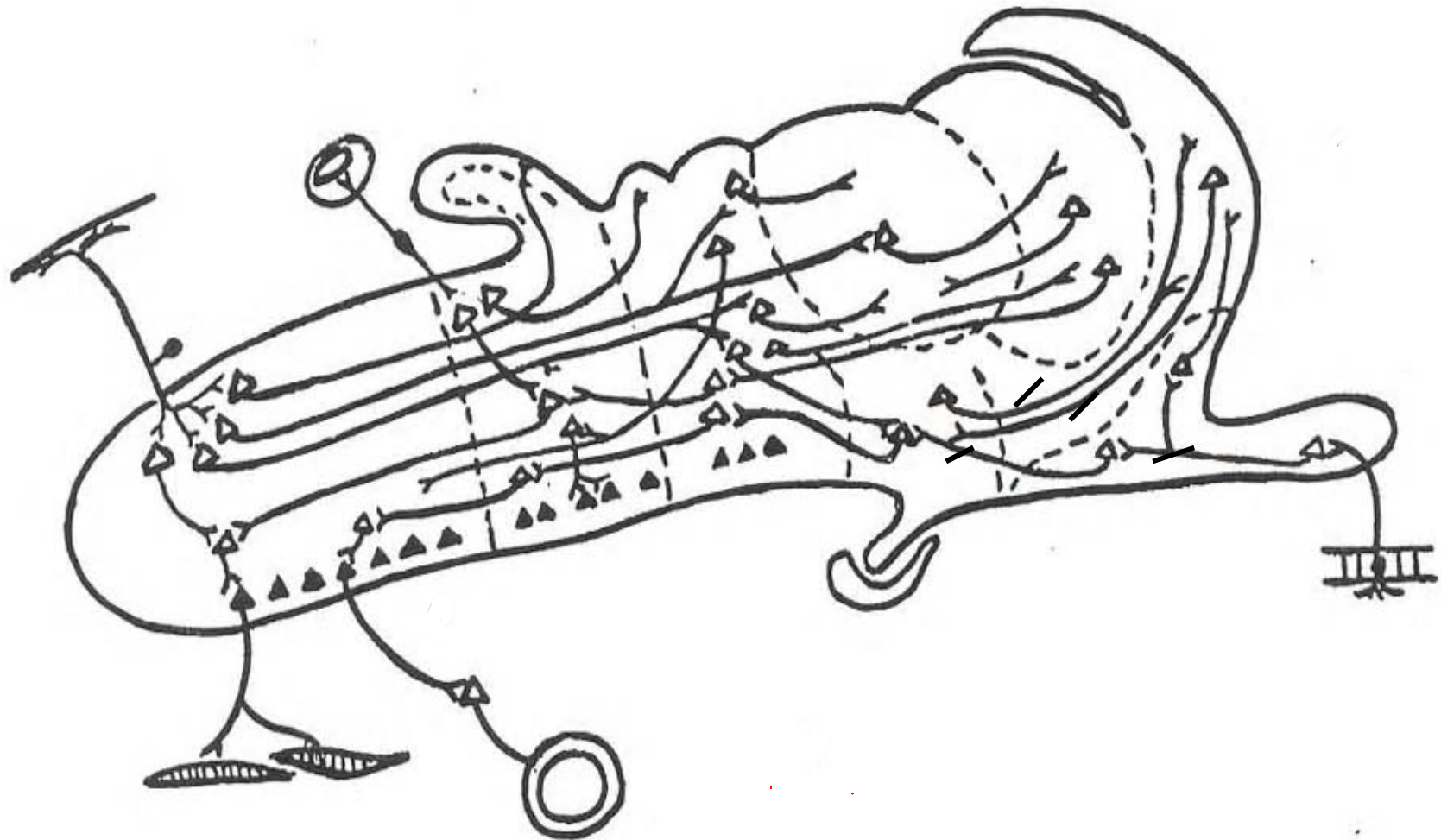


Sensory cell of amphibian, reptile, bird, or mammal

**2) Find one like this in  
the ancestral brain  
(and mammals)**

**3) Find one like this  
in the ancestral brain  
(and mammals)**

# Sketch of a pre-mammalian brain



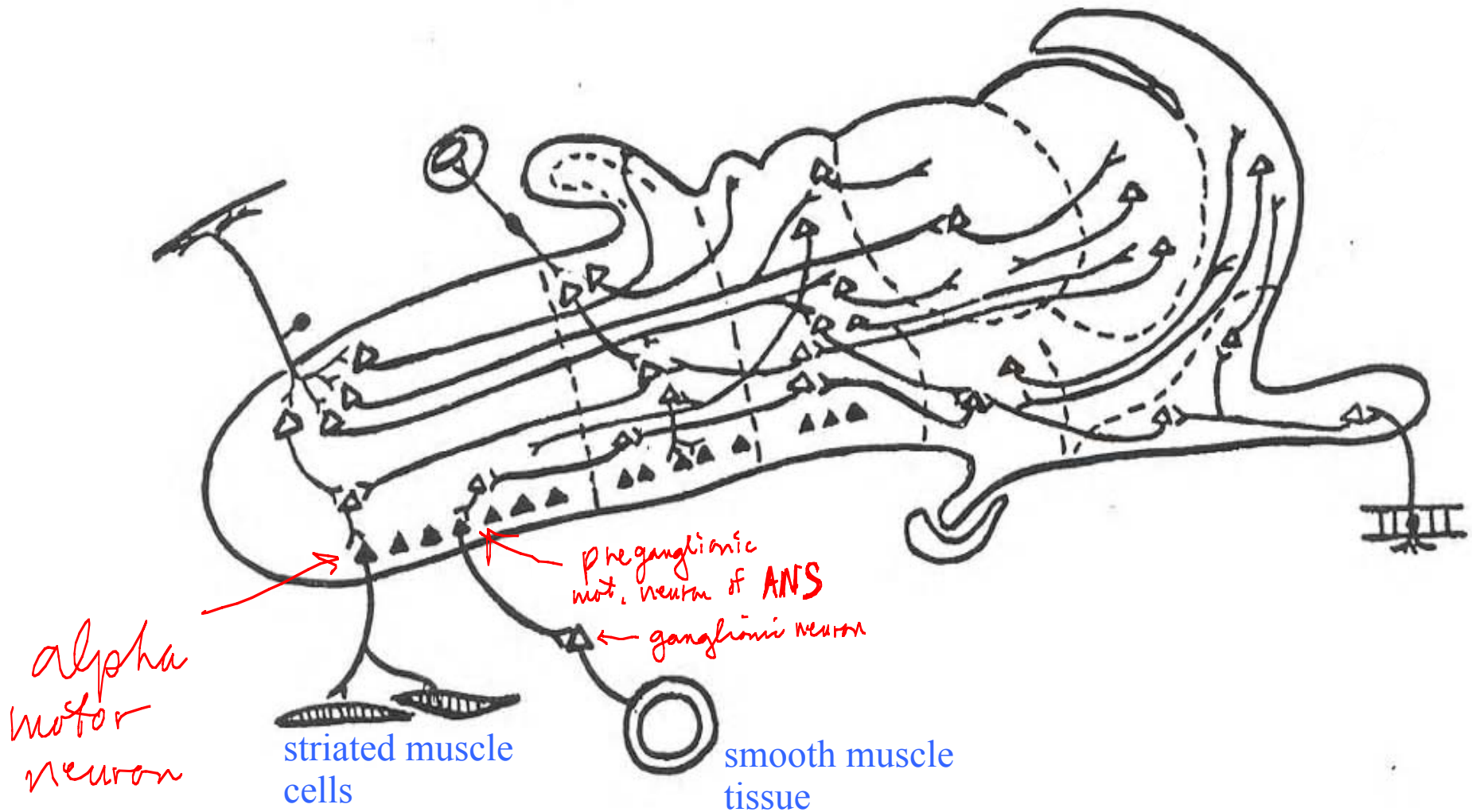
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Note: Almost all axons were much more widely branching than shown in this schematic. Dendrites, also highly branched, are omitted

## Questions, chapter 5

5. What are the different <sup>main</sup> types of muscle cells? <sup>striated</sup>  
<sup>smooth</sup>
6. What secondary sensory nuclei receive input from axons of the eighth cranial nerve? <sup>and</sup>  
<sup>vestib.</sup>
7. What are the two main types of motor neuron depicted in this introductory chapter? <sup>see next slide</sup>

# Sketch of a pre-mammalian brain



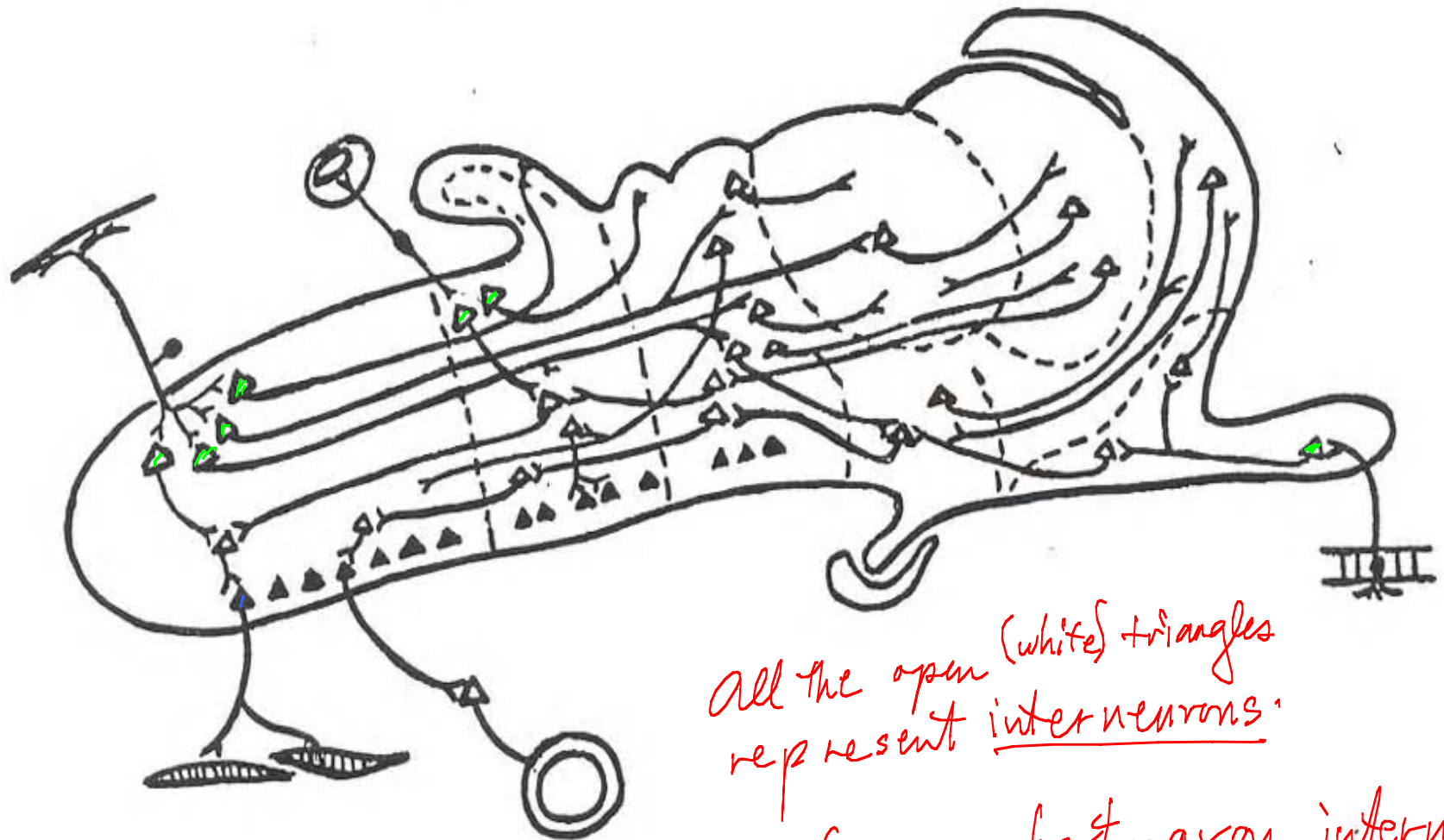
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## Questions, chapter 5

8. Discuss the term “interneuron.” It has a broader meaning and also a more commonly used meaning in discussions of neuroanatomy.

# Sketch of a pre-mammalian brain



all the open (white) triangles  
represent interneurons  
a few are short-axon interneurons

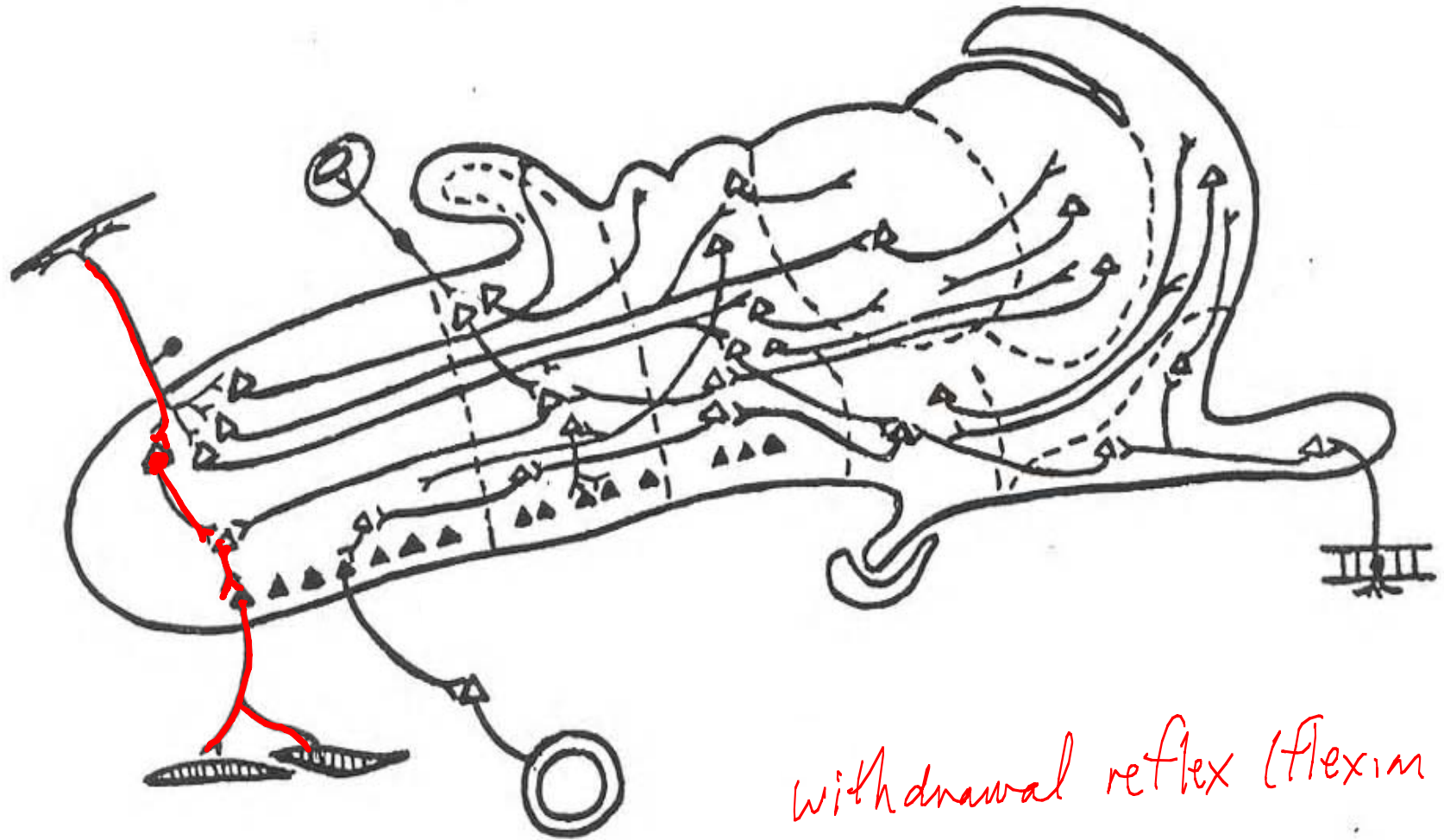
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## Questions, chapter 5

9. What is a local reflex channel of conduction, in its strictest sense?

Locate a local reflex channel. What function might such a pathway serve?



withdrawal reflex (flexion reflex)

$\geq 2$  synapses

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## Questions, chapter 5

10. What is a dermatome? Why are maps of the human dermatomes important in clinical neurology? Why is the face not included in dermatome maps?

*5th cranial n.*

# Dermatome map

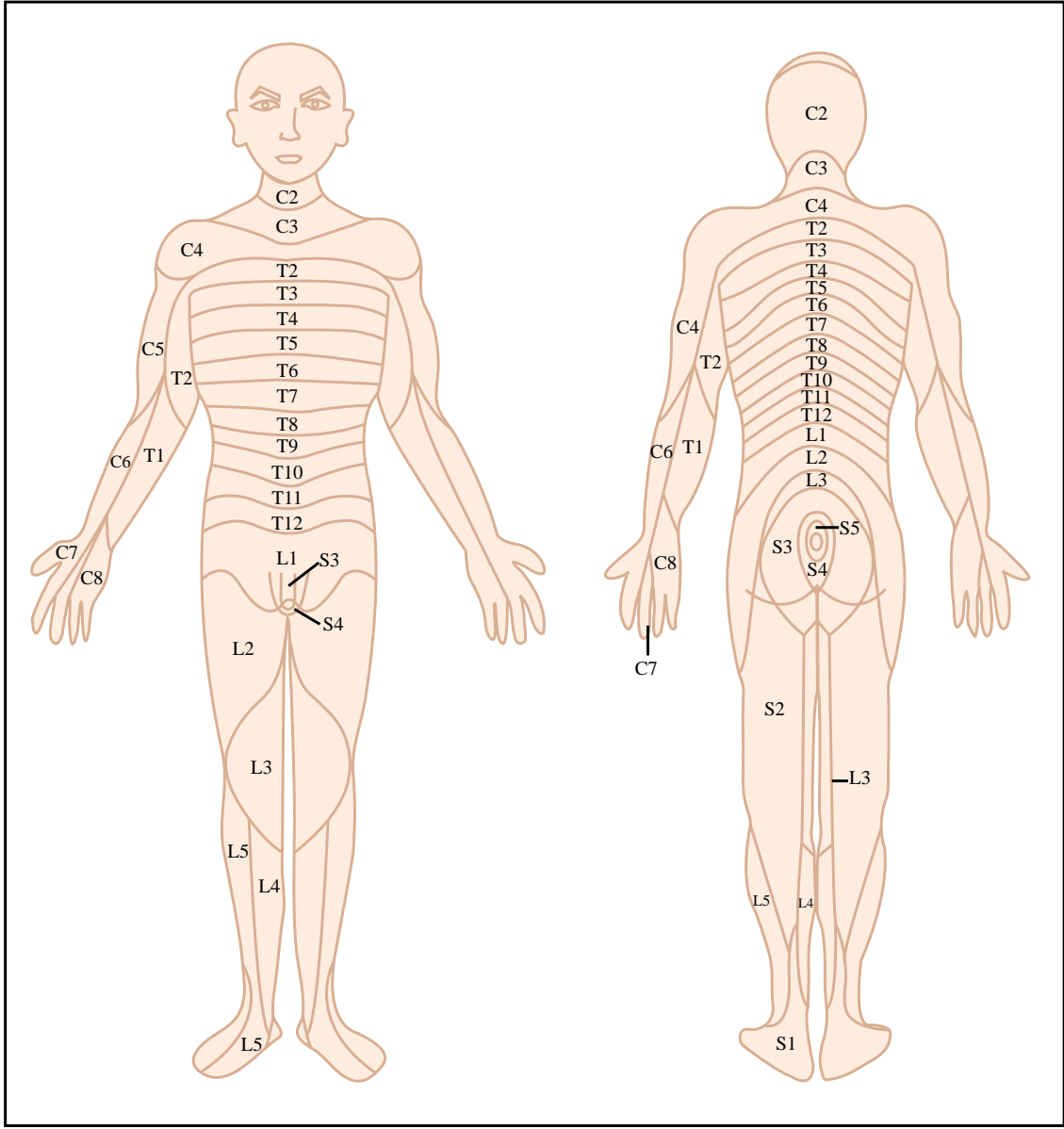


Image by MIT OpenCourseWare.

# Dermatome map, quadruped position, & spinal segments

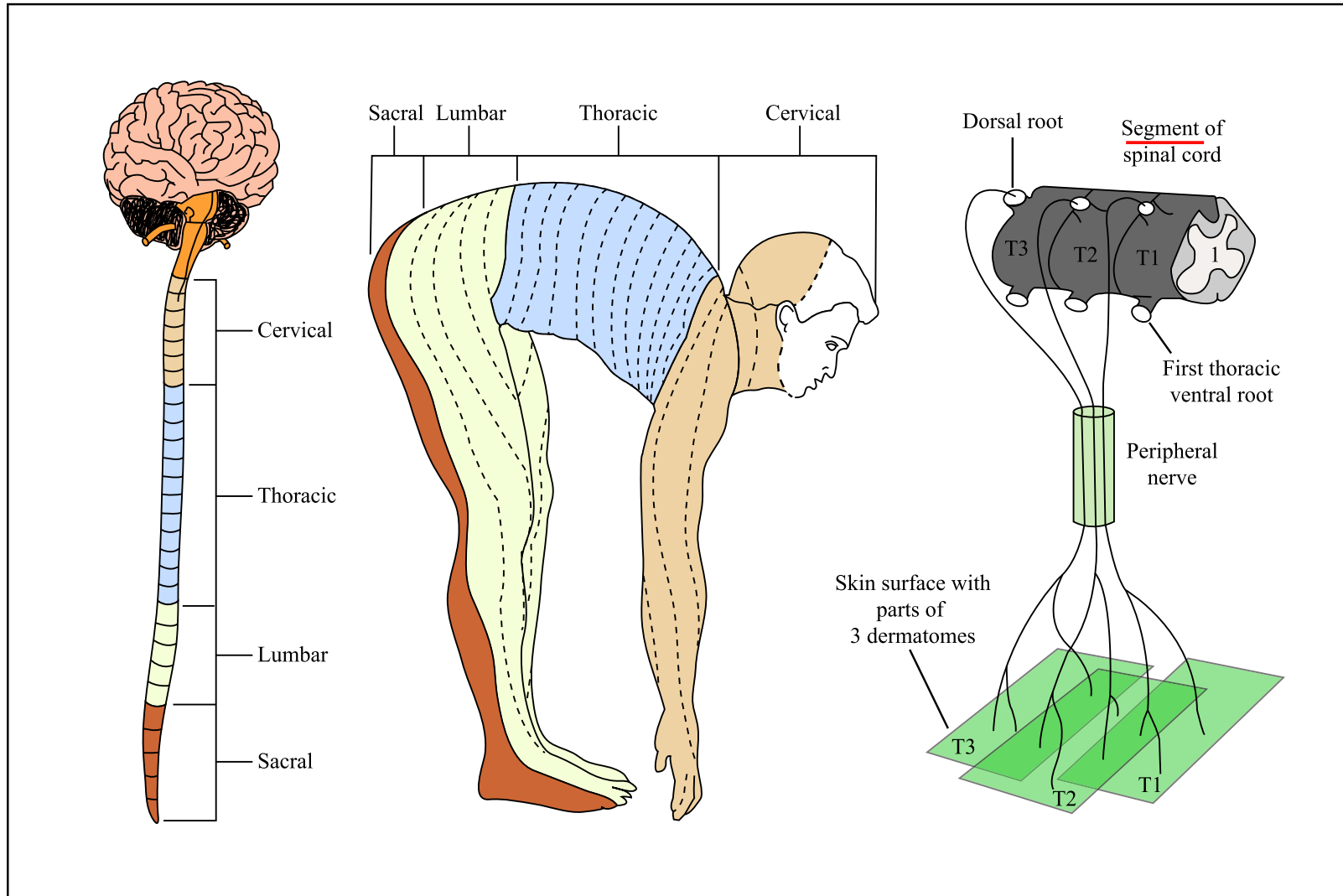


Image by MIT OpenCourseWare.

**Fig 5-9**

*note overlaps*

# How were the dermatomes mapped?

- Hypersensitive regions, resulting from irritation of single spinal roots, e.g., from a herniated intervertebral disk.
- Remaining sensibility, after severance of adjacent spinal nerves or dorsal roots.
- Cf. “myotome”

## REVIEW:

The gross anatomy:  
A young human

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

Note:

**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.

# How do we define “local” in “local reflex”?

- In the periphery: the dermatome
- In the CNS: the segment

## Questions, chapter 5

11. What is the oldest ascending somatosensory pathway that reaches the brain? Contrast this pathway with another pathway that ascends from the spinal cord—a pathway that has often been called the “paleolemniscus” (the ancient ribbon)?

# Pre-mammalian sensory channels of conduction

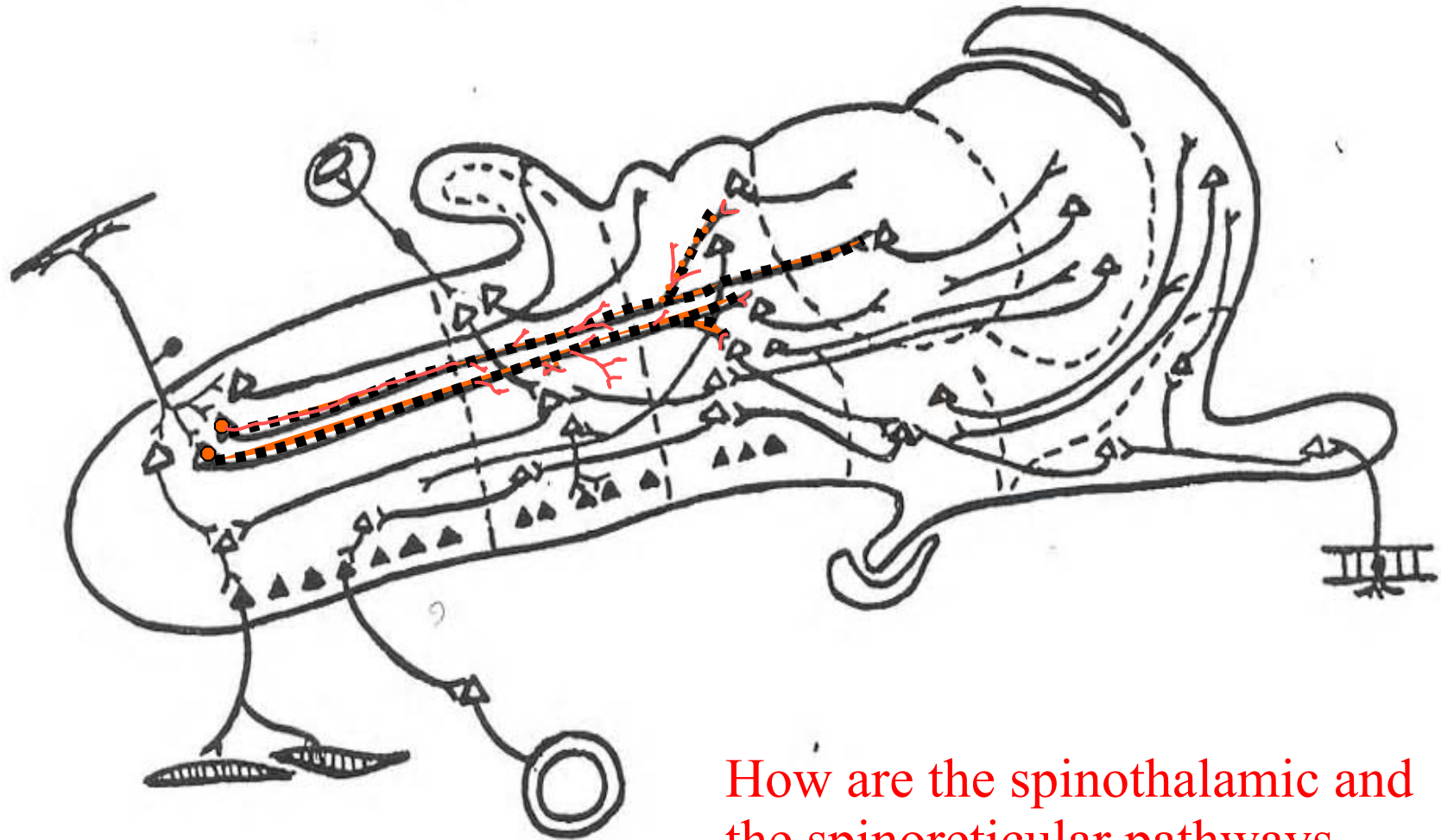
- Local reflex
- **Lemniscal 1**
  - **1a (spinoreticular)**
  - **1b (spinothalamic)**
- Lemniscal 2 (spinocerebellar)
- **Terms:** segmental, intersegmental, suprasegmental, dermatome, myotome, reticular formation, thalamus, decussation, cranial nerves.



# The oldest lemniscus: Spinoreticular

- A rostral extension of “propriospinal” fibers
- Bilateral projections but mostly **ipsilateral** to the core of the brainstem, the “reticular formation”
- Functions (*most likely—because these functions are present in animals that have no other ascending somatosensory pathways*):
  - Sensory modulation of autonomic activity (e.g., heart rate, blood pressure, breathing rate and volume)
  - Autonomic and defensive behavioral responses to pain inputs
  - Temperature regulation
  - Inputs for control of sexual behavior patterns
- **This is the least studied of the somatosensory pathways**

# The old lemniscal pathways: the spinoreticular and the “spinothalamic” tracts



How are the spinothalamic and the spinoreticular pathways different?

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**Fig 5-10**

# **Some data on the most primitive living vertebrates**

Comparison of a cephalochordate  
(**top: *Amphioxus***)  
and two jawless vertebrates:  
**(middle) Hagfish**  
**(bottom) Lamprey**

**o** = olfactory bulb  
**t** = telencephalon  
**d** = diencephalon  
**m** = mesencephalon

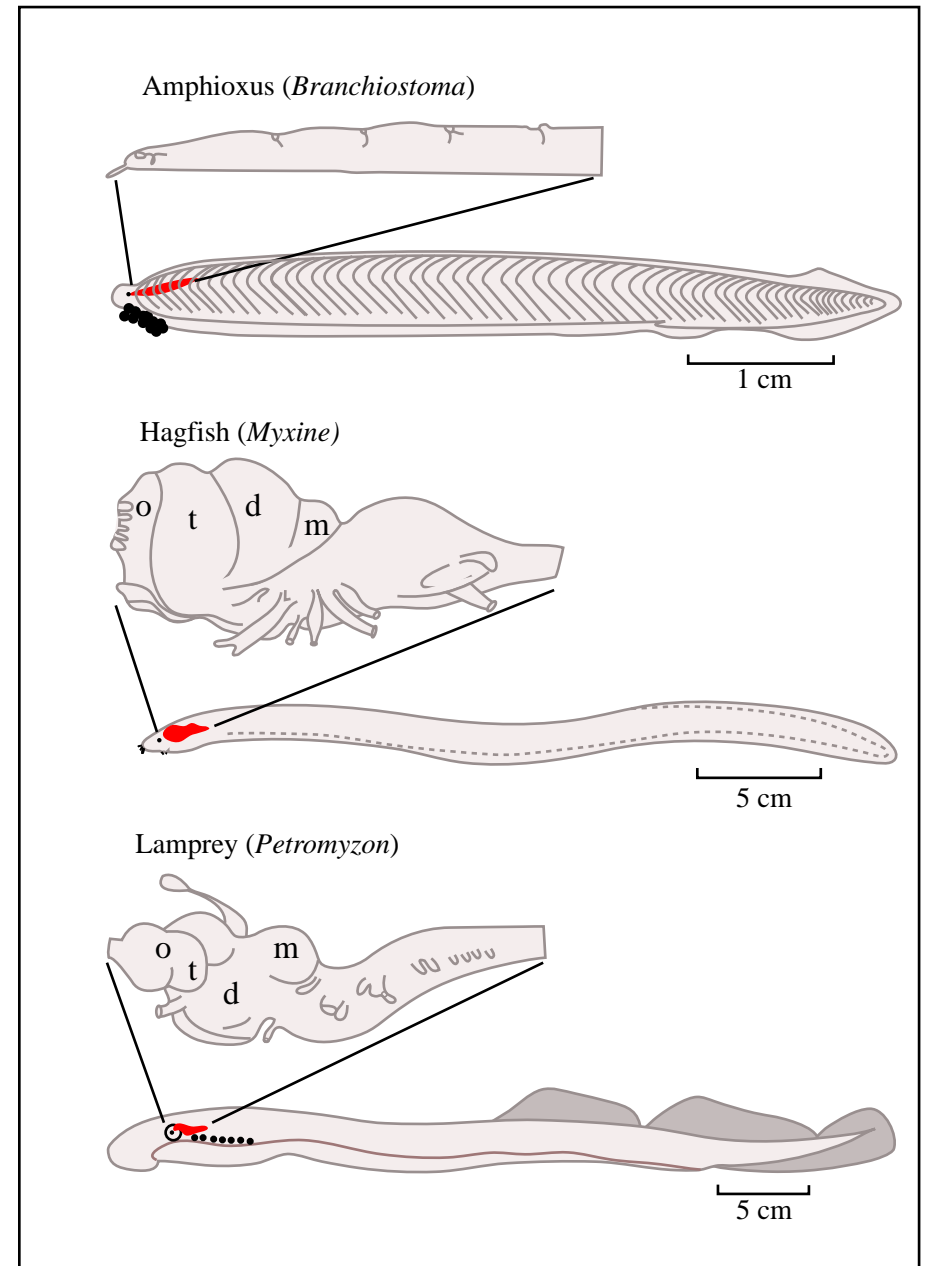
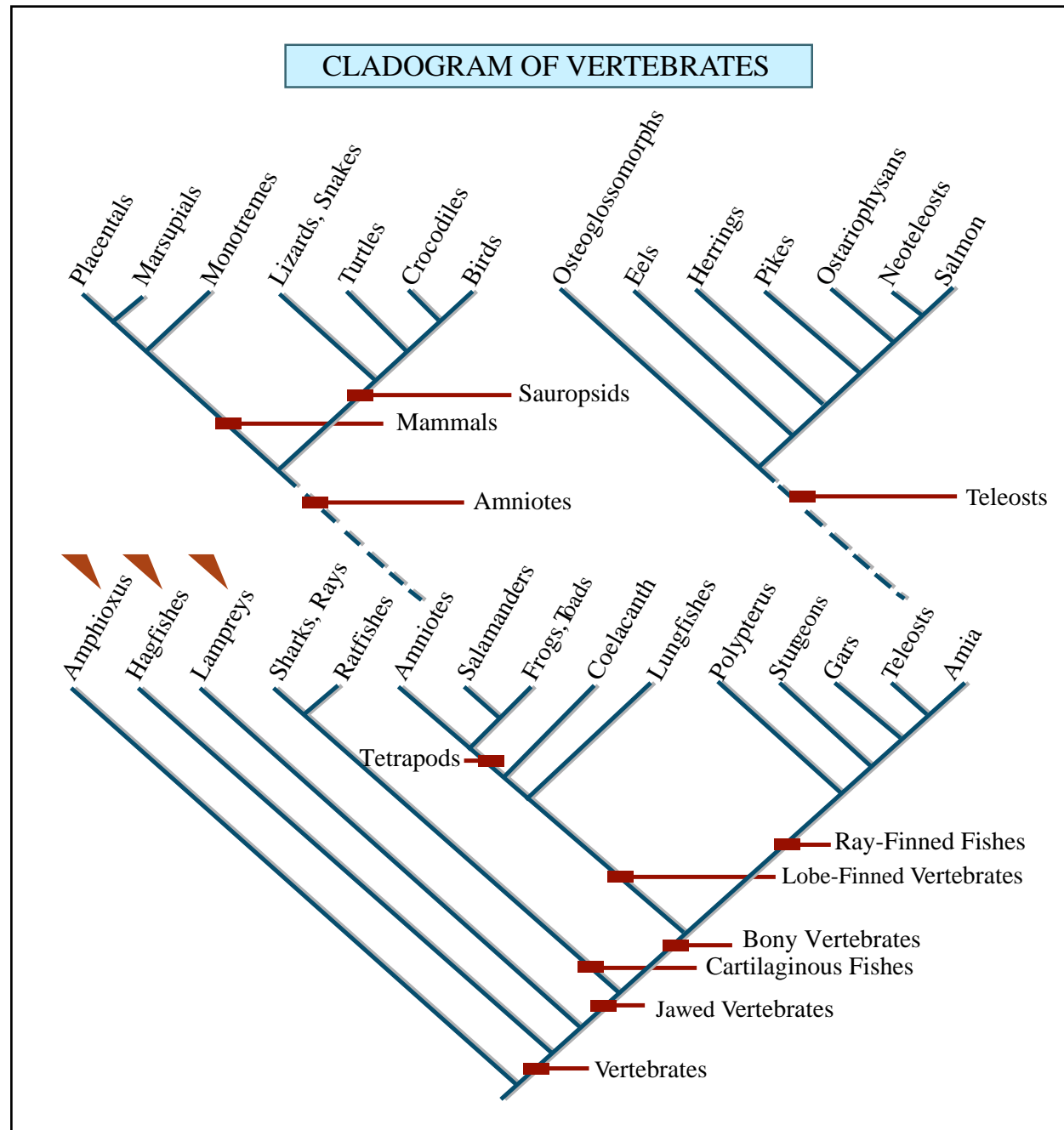


Image by MIT OpenCourseWare.

# Cladogram of vertebrates



**Fig 5-10**

Image by MIT OpenCourseWare.

# Notes on *Amphioxus*: brain and somatosensory inputs

- As previously mentioned, gene studies indicate that this little creature is not brainless as once believed.
- Recent studies have indicated inputs from the body surface that enter the CNS and contact cells that distribute axons to both sides (like the spinoreticular pathways of vertebrates).
- (Earlier, we have noted evidence for visual inputs to a forebrain region.)

# Somatosensory pathways in hagfish and sea lampreys:

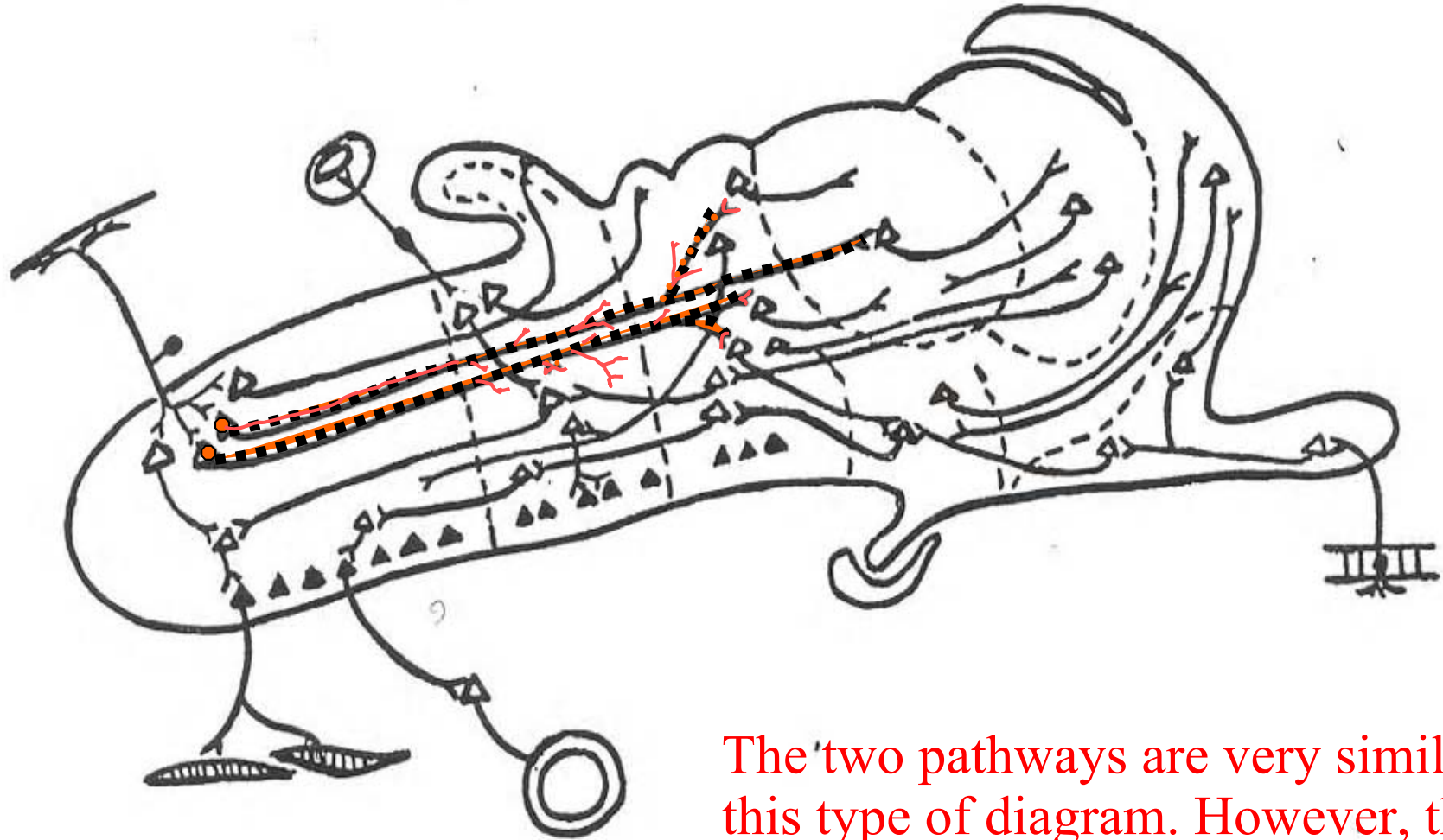
- Some secondary sensory neurons in the spinal cord have axons that extend rostrally, mostly on the ipsilateral side, reaching the brainstem.
- These axons are like the spinoreticular axons of mammals
- There is no apparent pathway ascending on the contralateral side to the brain. Such a pathway appeared in many vertebrates that evolved later, especially in the amniotes (lizards & snakes, turtles, crocodiles, birds, mammals) and also in cartilagenous fishes.

# Early evolution of a crossed pathway

- We call a crossed lemniscal pathway from the spinal cord the “spinothalamic tract”, although most of its axons never reach the diencephalon, as they terminate in the hindbrain and midbrain.
- It is sometimes called the “paleolemniscus” as it appears to have evolved long before the mammals. However, the spinoreticular axons are of more ancient origin.



# The old lemniscal pathways: the spinoreticular and the “spinothalamic” tracts



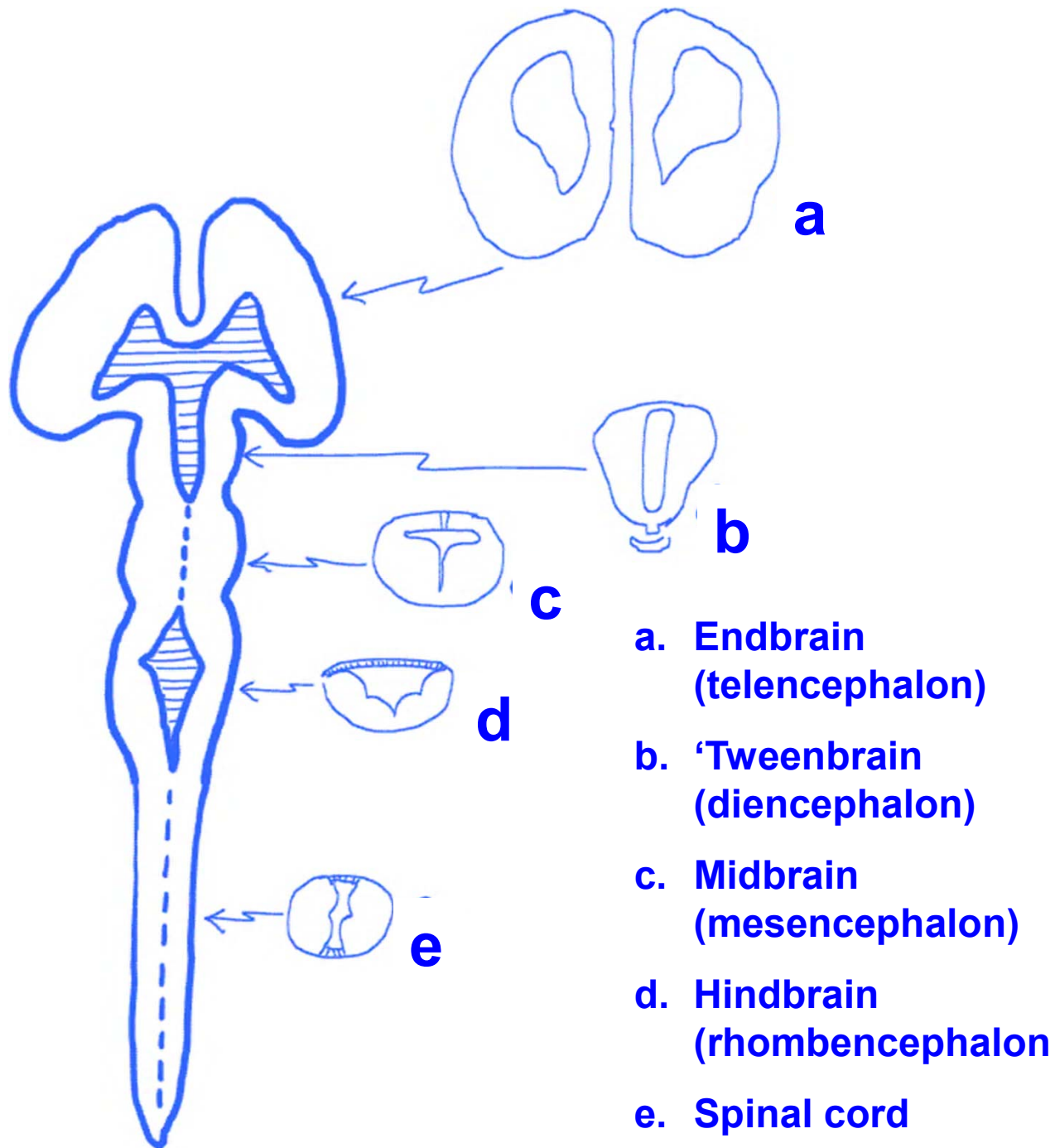
The two pathways are very similar in this type of diagram. However, the spinothalamic is a decussating pathway.

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**Fig 5-10**

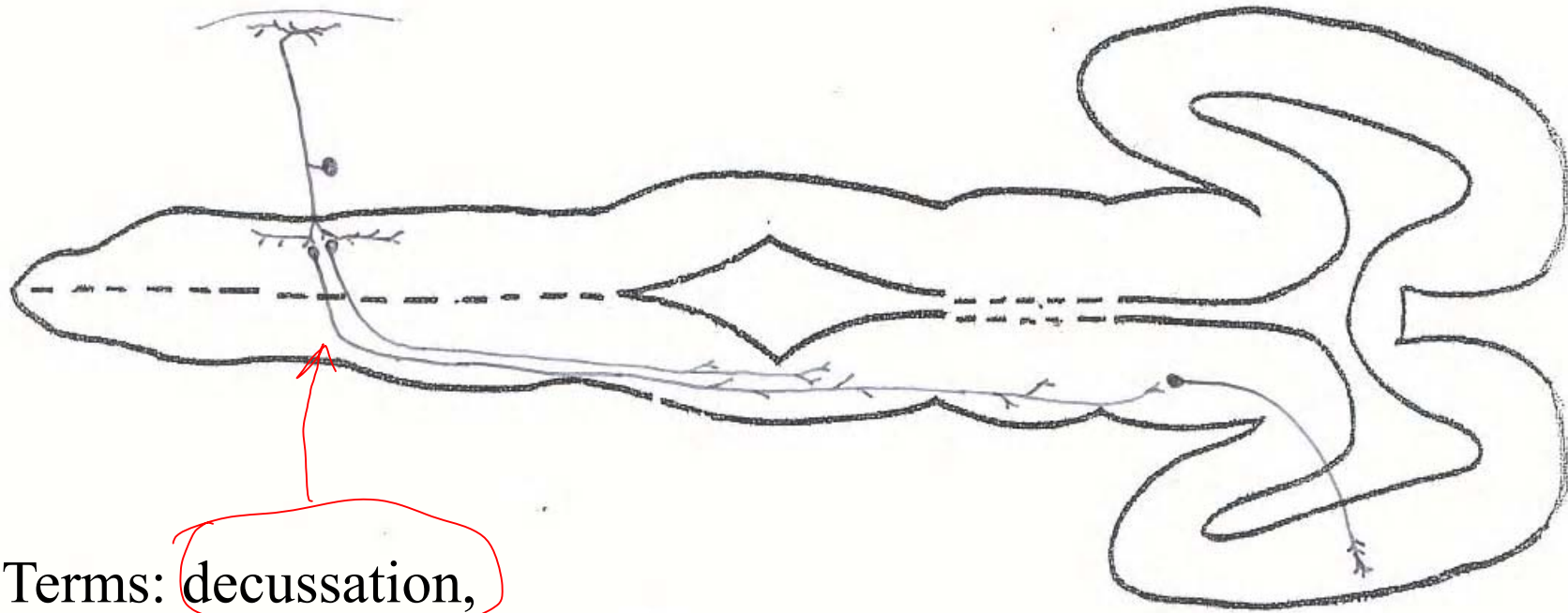
Where is the spinothalamic tract in a top view?



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# “Spinothalamic tract”



Terms: decussation,  
reticular formation,  
thalamus (in ‘tweenbrain),  
endbrain.

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Evolution of Behavior and the Mind*. MIT Press, 2014. ISBN: 9780262026734.

Fig 5-12

# Remember:

- We are not representing the earliest chordates here, but rather the pre-mammalian or mammalian brain.
- There was a long period of evolution between those early chordates and the ancestors of mammals.

## **Suggestion:**

- The spinothalamic tract probably evolved as a specialization of a portion of the widely branching spinothalamic axons.

# Questions for research on primitive somatosensory functions

- What can vertebrate animals do in the absence of direct somatosensory pathways to the forebrain?
- ...or in the absence of all crossed ascending pathways (from the cord)?

## Questions, chapter 5

12. Describe the hypothesis presented in chapter five concerning why the cerebellum evolved.

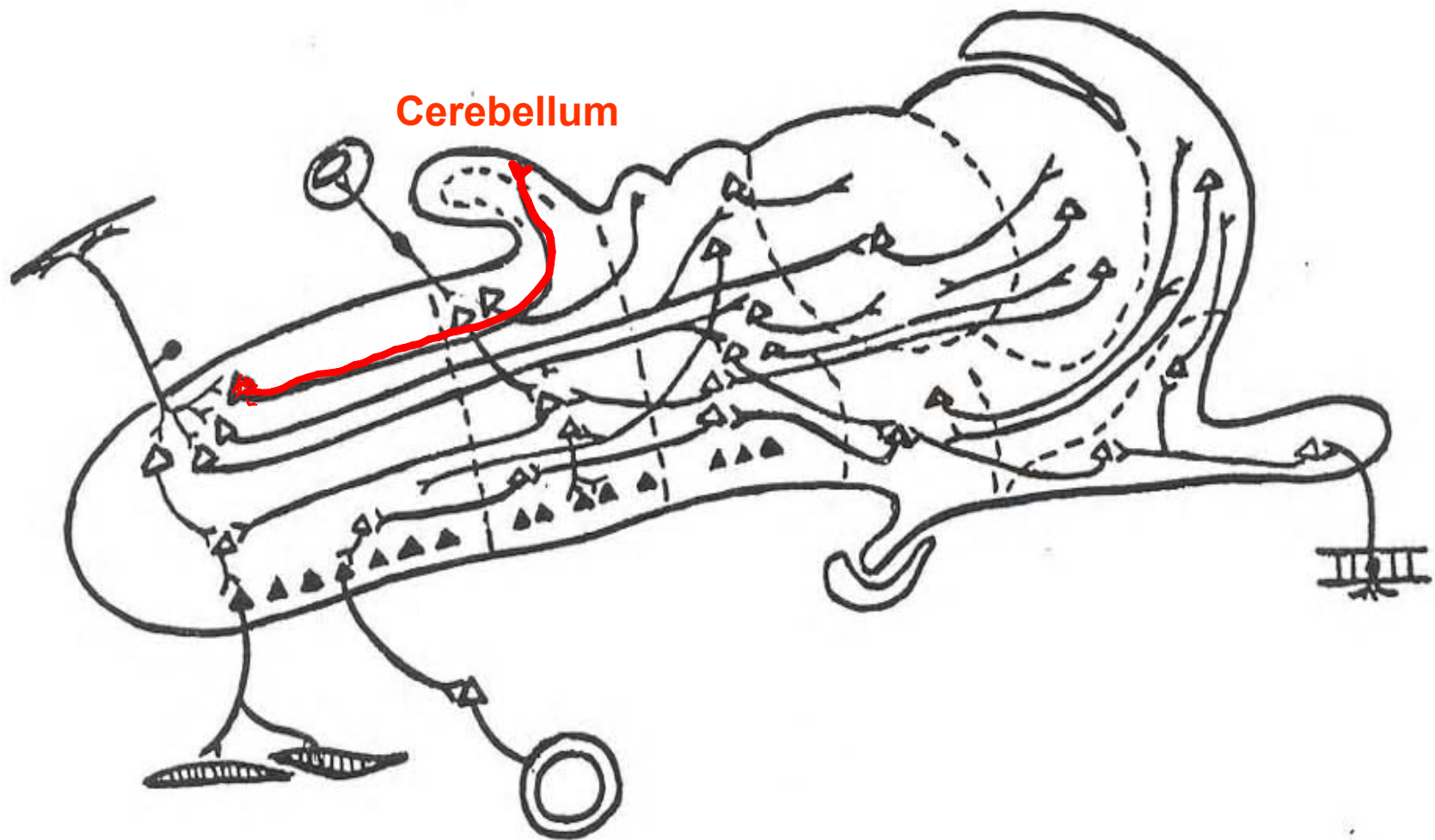
# Sensory channels of conduction:

- Local reflex
- Lemniscal 1
  - 1a (spinoreticular)
  - 1b (spinothalamic)
- **Lemniscal 2 (spinocerebellar)**
- **Terms:** segmental, intersegmental, suprasegmental, dermatome, myotome, reticular formation, thalamus, decussation, cranial nerves.

# Intro to the “cerebellar channel”, another kind of lemniscus

- A problem of multiple sensory pathways for control of the same outputs: Timing
- This problem increased with increasing body size, and an increased role of head receptors in control of movements.
- It increased further with need for precise coordination of larger numbers of muscles, especially the distal muscles of the limbs.
- Cerebellum appears to have evolved to deal with this problem: adjustments of relative timing which could be varied according to feedback.
- See the more specific but related suggestion by Allman (2000), p. 77-78: stabilizing the retinal image by comparing eye velocity with head velocity.





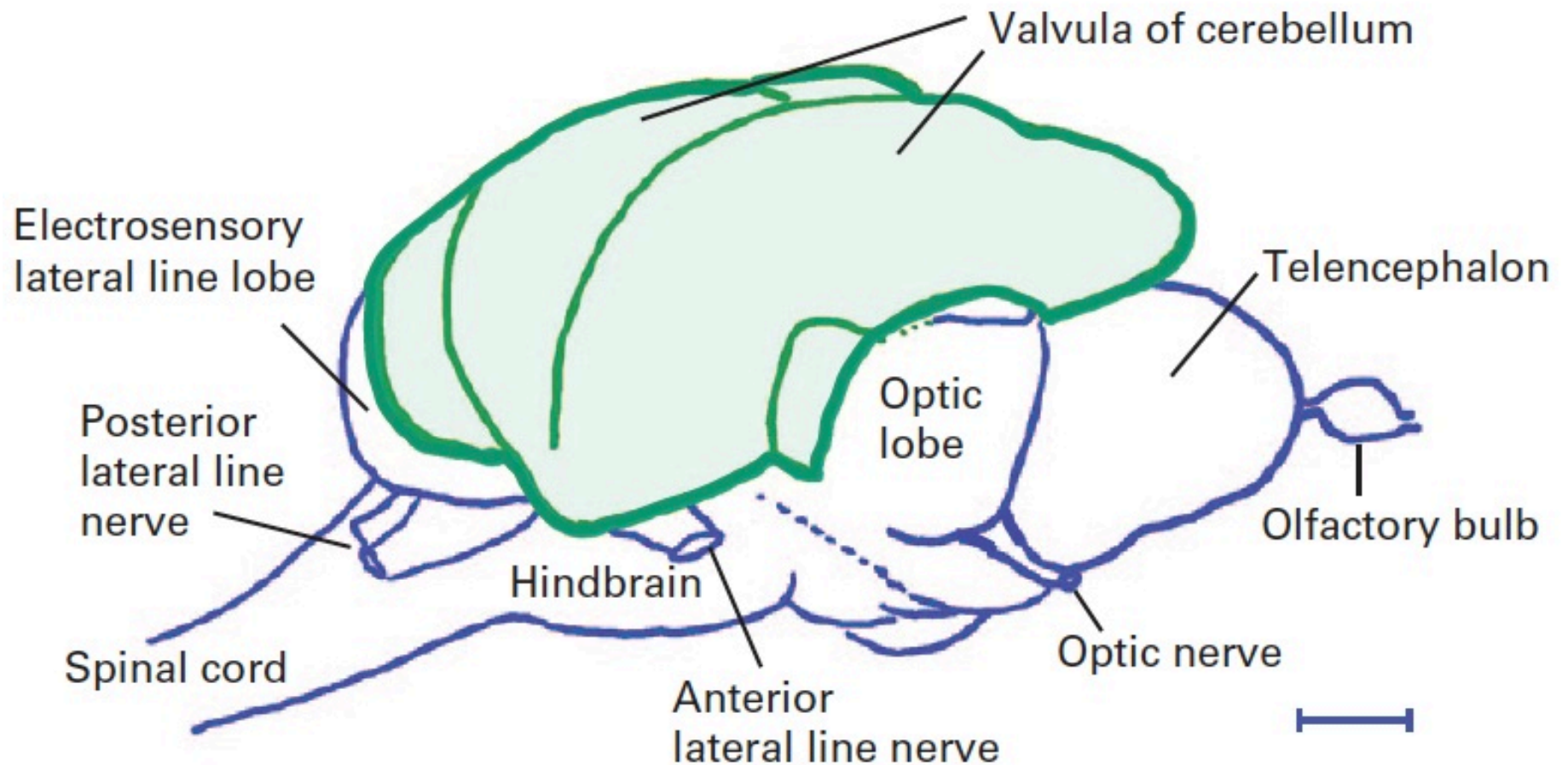
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# Notes on evolution of cerebellum

- **The basic cell types and circuitry are highly conserved in evolution**
  - Layering becomes more regular
  - New inhibitory cell types appear in tetrapods
  - Deep nuclei as the output structures appear in tetrapods
- **The size and form vary considerably**

## Questions, chapter 5

13. It is generally true that the larger the cerebral hemispheres, the larger the cerebellum. However, there are a few species of animals without large cerebral hemispheres in which a greatly enlarged cerebellum is found. What are these animals?



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## The enlarged cerebellum of a Mormyrid fish

**Fig.6-1**

# Notes on evolution of cerebellum

- The basic cell types and circuitry are highly conserved in evolution
  - Layering becomes more regular
  - New inhibitory cell types in tetrapods
  - Deep nuclei as the output structures appear in tetrapods
- The size and form vary considerably
  - Huge expansion in the weakly electric fishes, especially in the hyperfolded cerebellum of mormyrids
  - Dramatic lateral expansion and foliation as locomotor and manipulatory abilities increased in land animals: the growth of the cerebellar hemispheres and the lateral deep nuclei
- **Functions**
  - **Sensory:** especially in animals with lateral line receptors and electroreceptors
  - **Motor:** the coordinated timing of outputs; changes with experience (learning)
  - **Cognitive:** It may function in the coordinated timing of representations in the internal model of the external world.

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## 9.14 Brain Structure and Its Origins

Spring 2014

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