# A sketch of the central nervous system and its origins

G. E. Schneider 2014

**Part 2: Steps to the central nervous system,**

*from initial steps to advanced chordates*

# MIT 9.14 Class 4

## Elaboration of the neural tube in evolution of chordates

# Questions, chapter 4

1. There are no fossils of the brains of ancient or extinct animals. So how can we learn anything about brain evolution?
   - Endocasts of skulls
   - DNA
   - Comparative anatomy of extant species

2. In the very early evolution of the chordate neural tube, what led to changes at the rostral end? What kinds of changes?

# With head receptors and forward locomotion there evolved an increasing sophistication of sensorimotor abilities

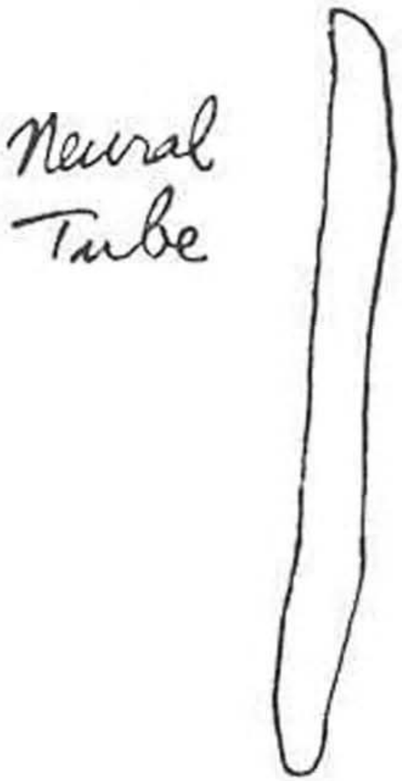
- **Sensory analyzing mechanisms**
  - Connected to inputs from cranial nerves
- **Associated motor apparatus**
  - For directing the receptors (orienting movements)
  - For controlling alterations in posture and locomotion under guidance from these receptors.
- **Crucial background**: maintenance of stability of the internal mileau

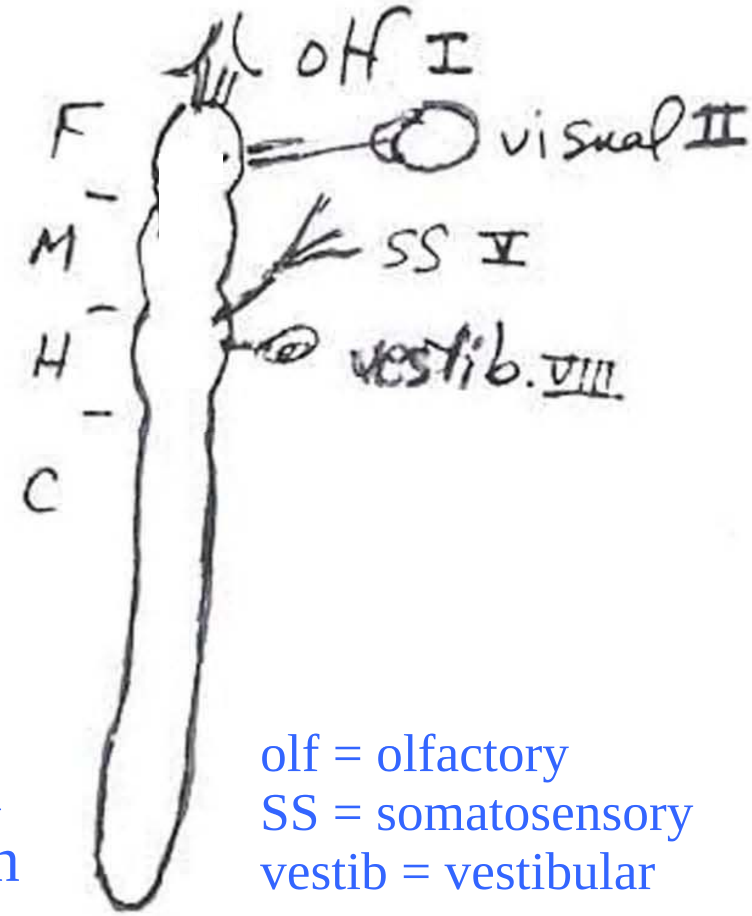
# Structures that accomplished those functions

- New sensory apparatus at rostral end of the tube
  - Hindbrain, midbrain and forebrain mechanisms connected to head receptors are added to primitive spinal somatosensory mechanisms.
- Added motor control
  - Hindbrain & midbrain: Control of mouth, eyes, ears, head turning, added to basic spinal & hindbrain control of the body
- Forebrain vesicle evolves, with:
  - **Olfactory** & **visual** inputs
  - Endocrine & **visceral control**

# Evolution of Brain 1

## The neural tube, forward locomotion & head receptors




F=forebrain
M=midbrain
H=hindbrain
C=spinal cord

olf = olfactory
SS = somatosensory
vestib = vestibular

(Examples of cranial nerve inputs)

**Fig. 4-1**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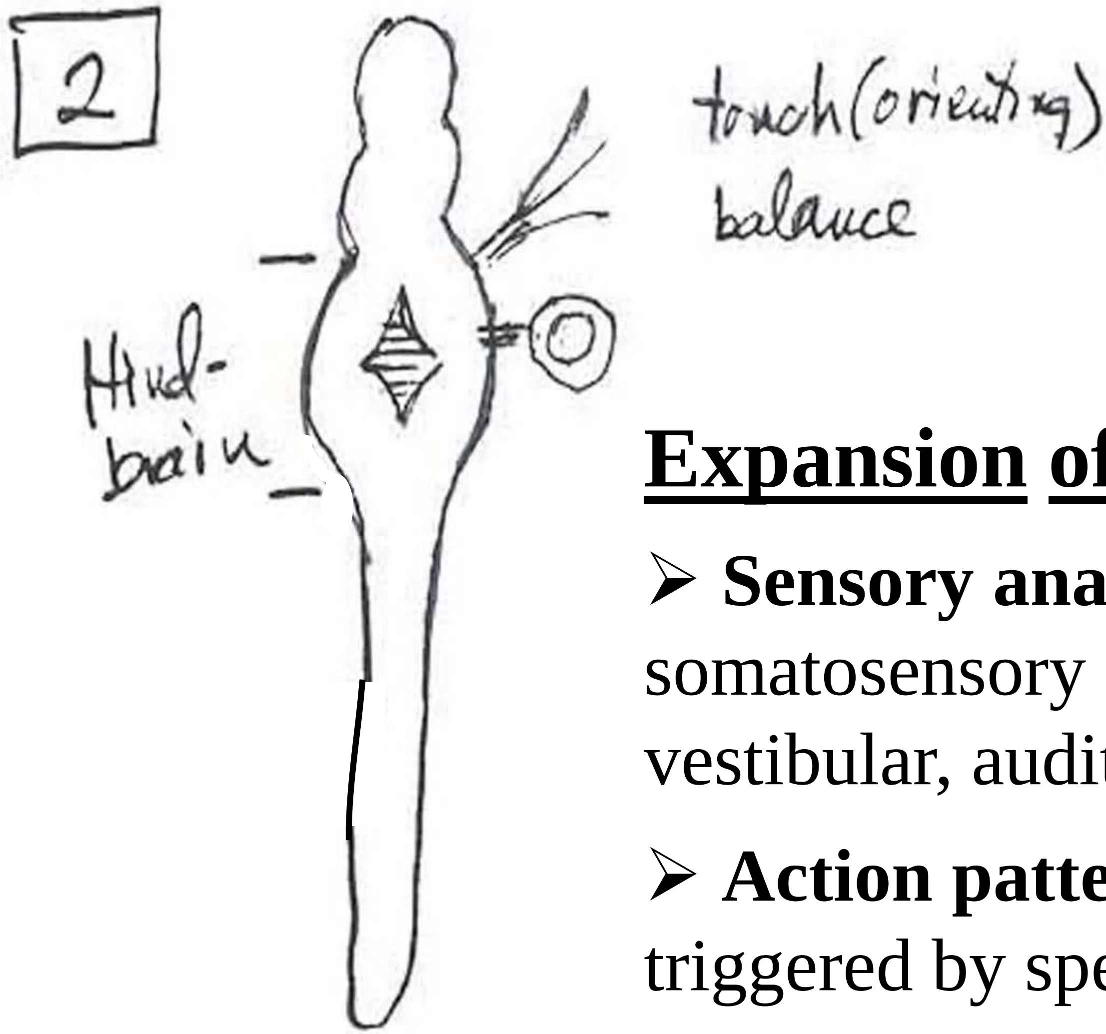
# Questions, chapter 4

3. Hindbrain expansions in chordates resulted from the evolution of adaptive sensory and motor functions. Give examples of these functions: sensory; motor.

Sensory: see next slide

Motor: ear movement, oral grasping and chewing, tongue movements, many other examples

# Evolution of Brain 2




## <u>Expansion</u> <u>of hindbrain</u>:

- **Sensory analysers**: somatosensory (face), gustatory, vestibular, auditory, electroreceptive.
- **Action pattern programs** triggered by specific sensory patterns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# Questions, chapter 4

4. Compare the specializations for taste senses of two fish, the fresh-water buffalofish and the catfish, and how the hindbrain is affected.

Specialized taste systems:
**Buffalofish** uses a palatal organ that filters particles from water by taste and trapping movements; inputs via vagus nerve (cranial nerve 10)
**Catfish** taste system uses both 10th and 7th cranial nerves; 7th (facial nerve) innervates not only barbels but also the surface of most of the body.

# Examples of evidence from comparative neuroanatomy: Functional demands result in expansion of CNS components

- Some particularly dramatic examples have been found in studies of fish
  - Pictures from CL Herrick, who together with his brother, CJ Herrick, helped establish the field of comparative neurology

1st part of 20th century

# **Functional adaptations cause expansions in CNS**: illustrations from comparative anatomy (*from C. L. Herrick*):

- Brain of a fresh water mooneye: for comparison
- Brain of a freshwater buffalo fish:
  - huge "vagal lobe“ (receives input from specialized palatal organ)
- Brain of a catfish:
  - "facial lobe" and "vagal lobe“ (for processing taste inputs through two different cranial nerves)
- Catfish 7$^{th}$ cranial nerve distribution, re:
  - taste senses (explains facial lobe)

# *Hyodon tergisus* (fresh water Mooneye)

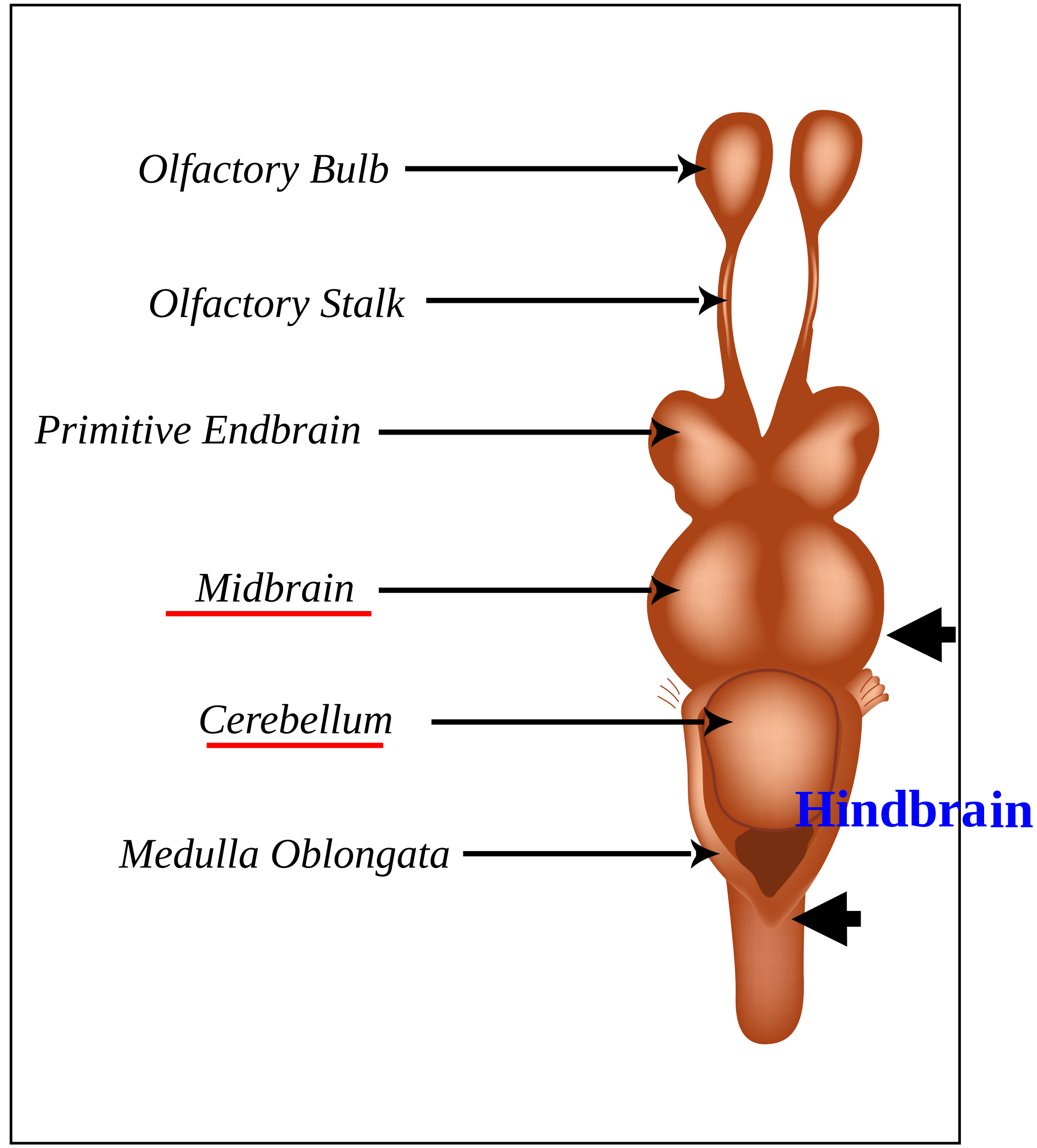
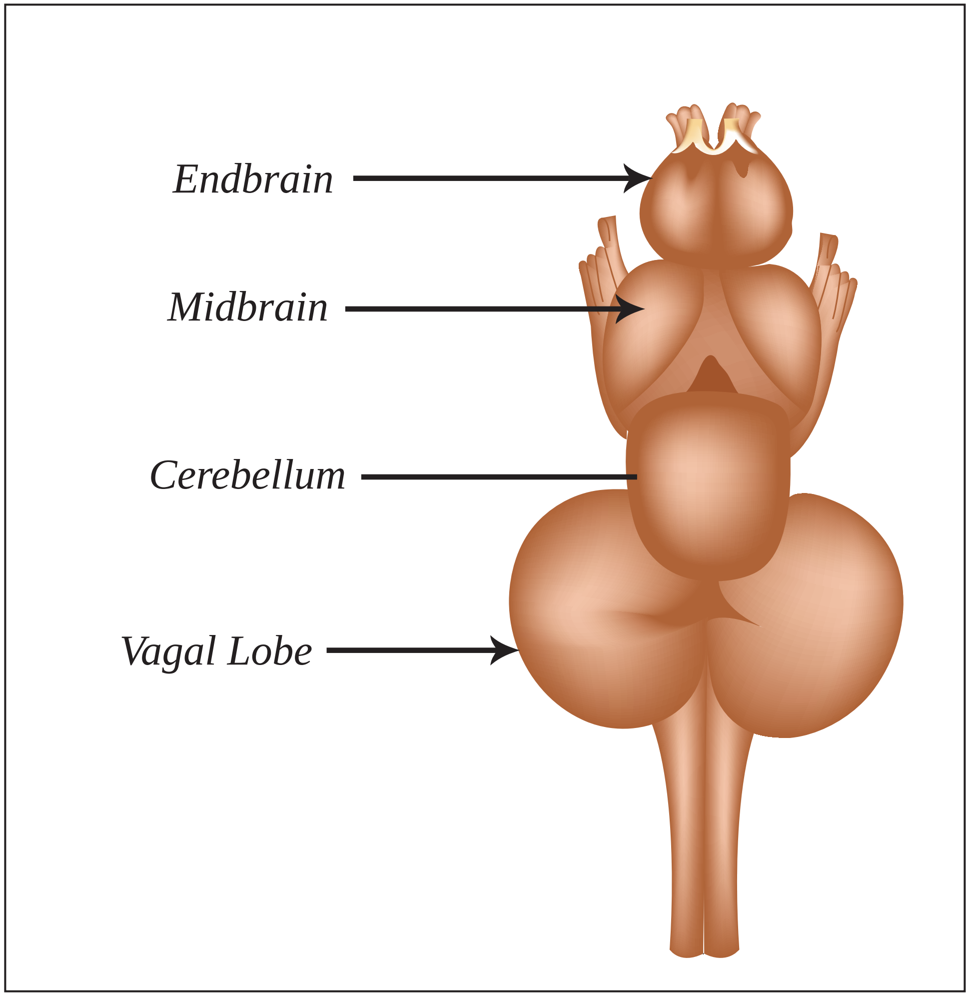



Image by MIT OpenCourseWare.

Note the size and shape of the hindbrain. (The hindbrain includes the medulla oblongata and the cerebellar region, between the two black arrows.

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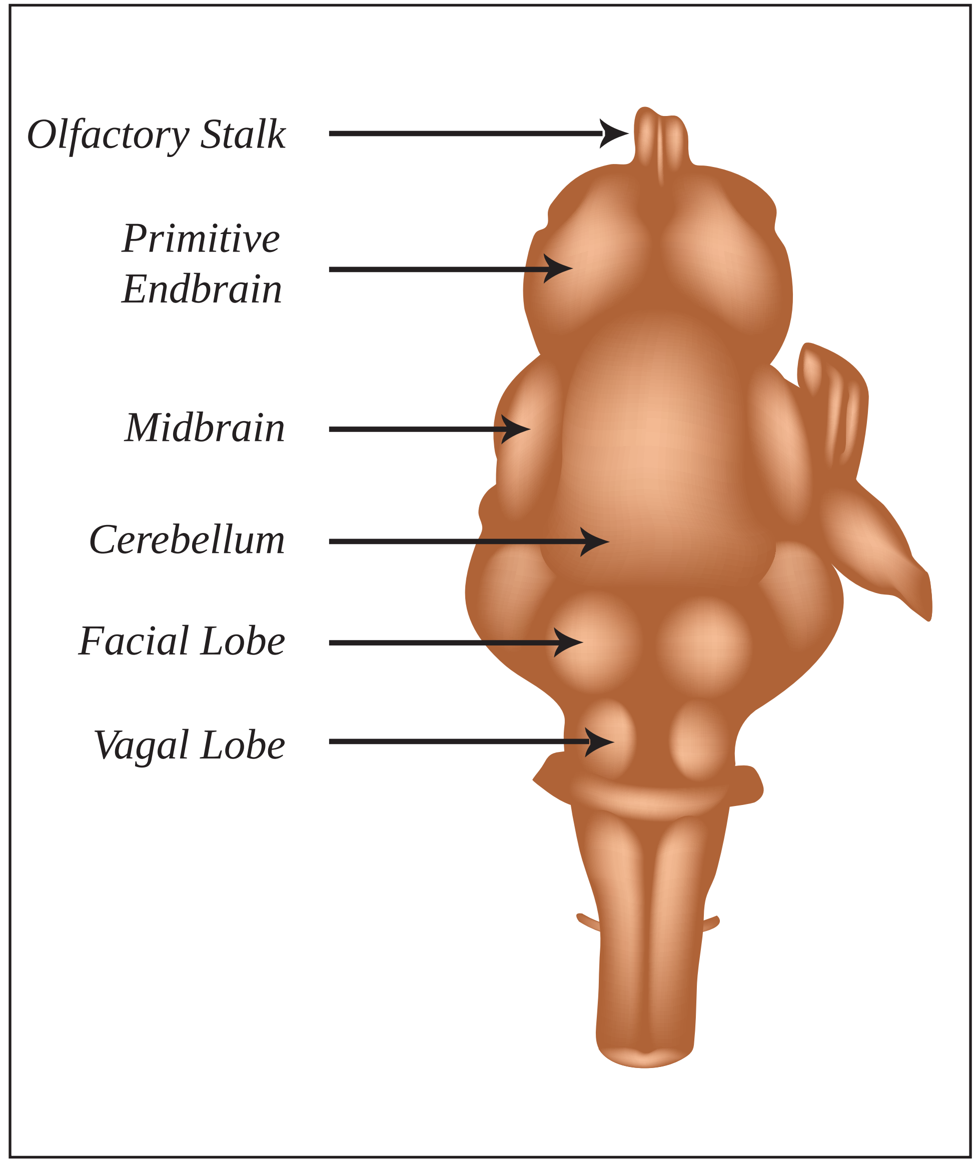
# *Carpiodes tumidus* (buffalofish)

The “vagal lobe” of the hindbrain is huge. It receives and processes taste input from a specialized palatal organ.

# *Pilodictis olivaris* (catfish)

The vagal lobe is enlarged, although less than in the buffalo fish. An enlarged "facial lobe" is also evident. It receives taste inputs from all over the body surface.

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***Amiurus melas*** (the small catfish): 7th cranial nerve (facial nerve) innervates **taste** buds in skin of entire body

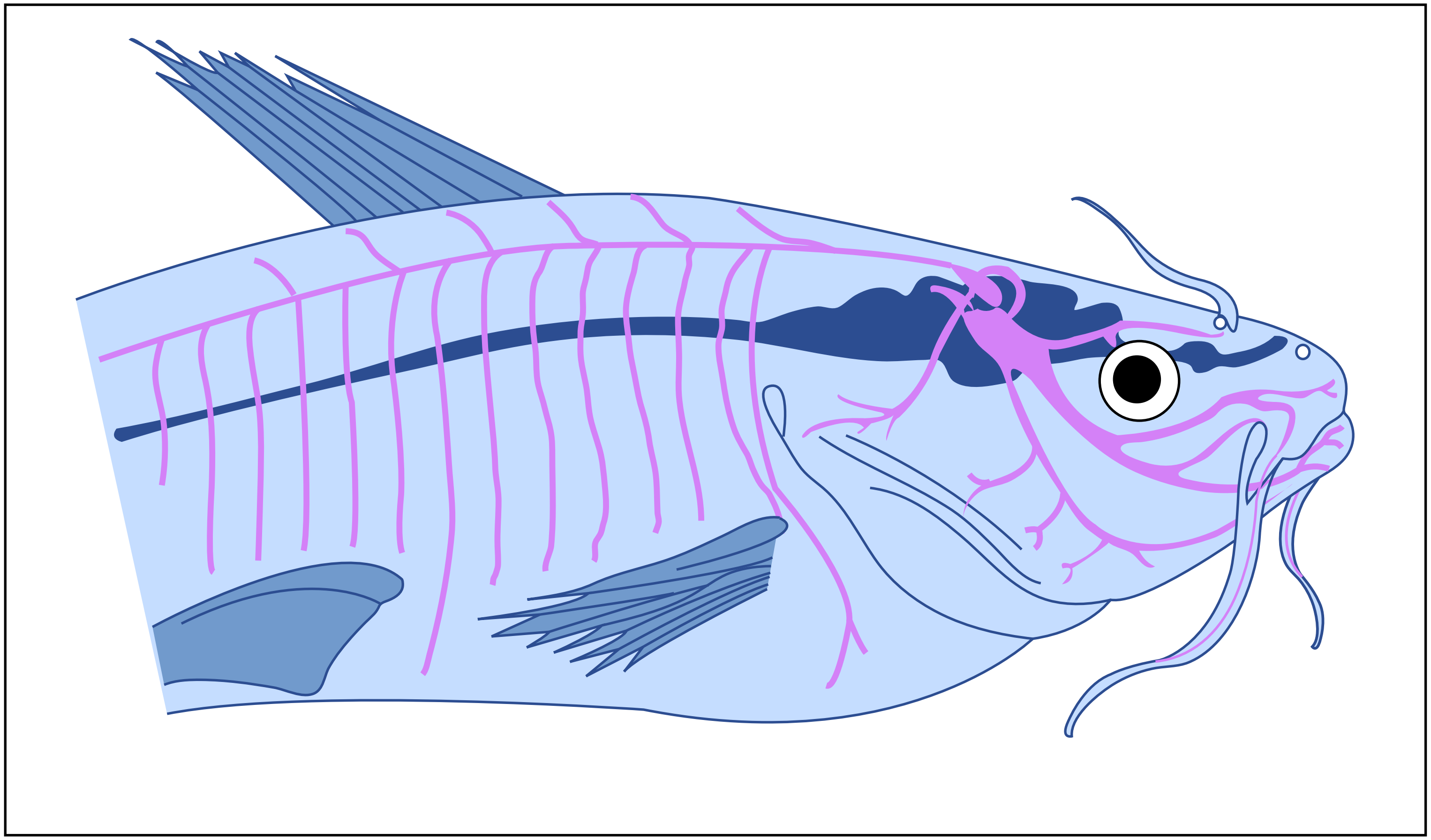

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**Fig. 4-6**

# Questions, chapter 4

5. Explain the proposal concerning the first expansion of the forebrain in evolution: What sensory input played a key role? What was special about connections in the striatum?

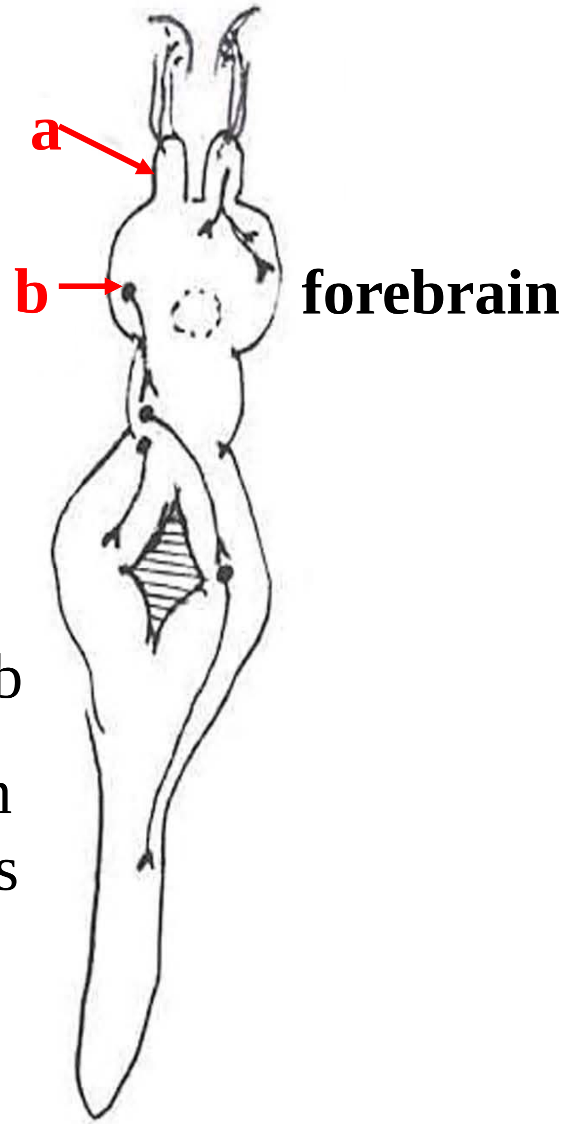
slides 17 – 18

# Important note concerning drawings of pathways

Neurons and pathways shown on one side of the brain are usually the same on the other side. I often draw them on only one side to make the drawing simpler.

# Evolution of Brain 3

**1st expansion of forebrain,** concurrent with "Evolution 2"




**a** olfactory bulb

**b** connection in primitive corpus striatum



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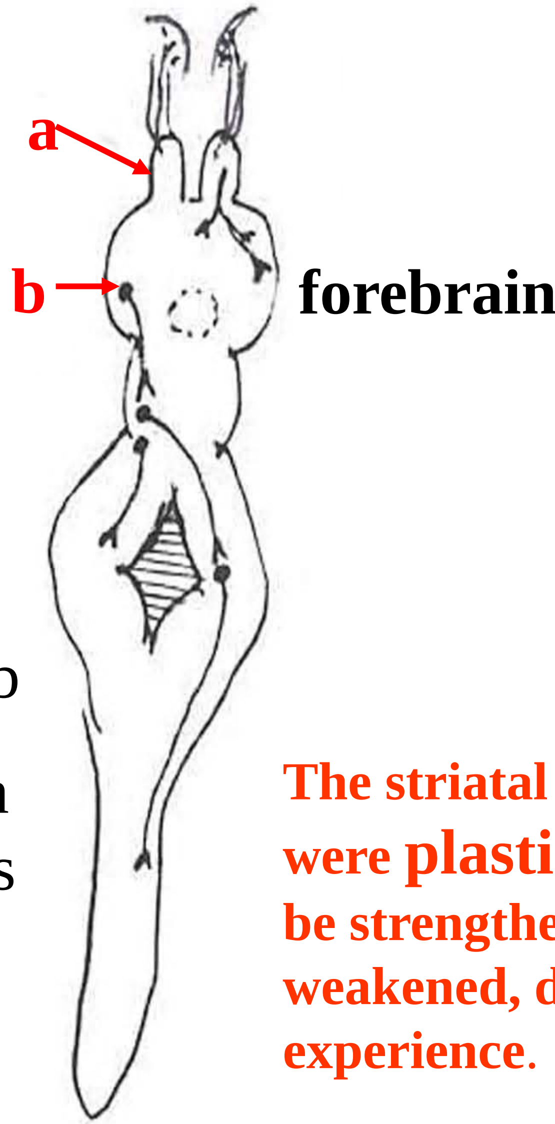
**Expansion of forebrain** because of **adaptive value of olfactory sense for approach & avoidance functions** (feeding, mating, predator avoidance, predation).

……………………………

**Outputs:** links to locomotion through the corpus stratum were most critical. These links were *via* the midbrain.

# Evolution of Brain 3

**1st expansion of forebrain,** concurrent with "Evolution 2"




**a** olfactory bulb

**b** connection in primitive corpus striatum

**The striatal connections were plastic: They could be strengthened or weakened, depending on experience.**

**Expansion of forebrain** because of **adaptive value of olfactory sense for approach & avoidance functions** (feeding, mating, predator avoidance, predation).

……………………….

**Outputs:** links to locomotion through the corpus stratum were most critical. These links were *via* the midbrain.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# Questions, chapter 4

6. What structure in the midbrain has become greatly enlarged in most predatory teleost fish.

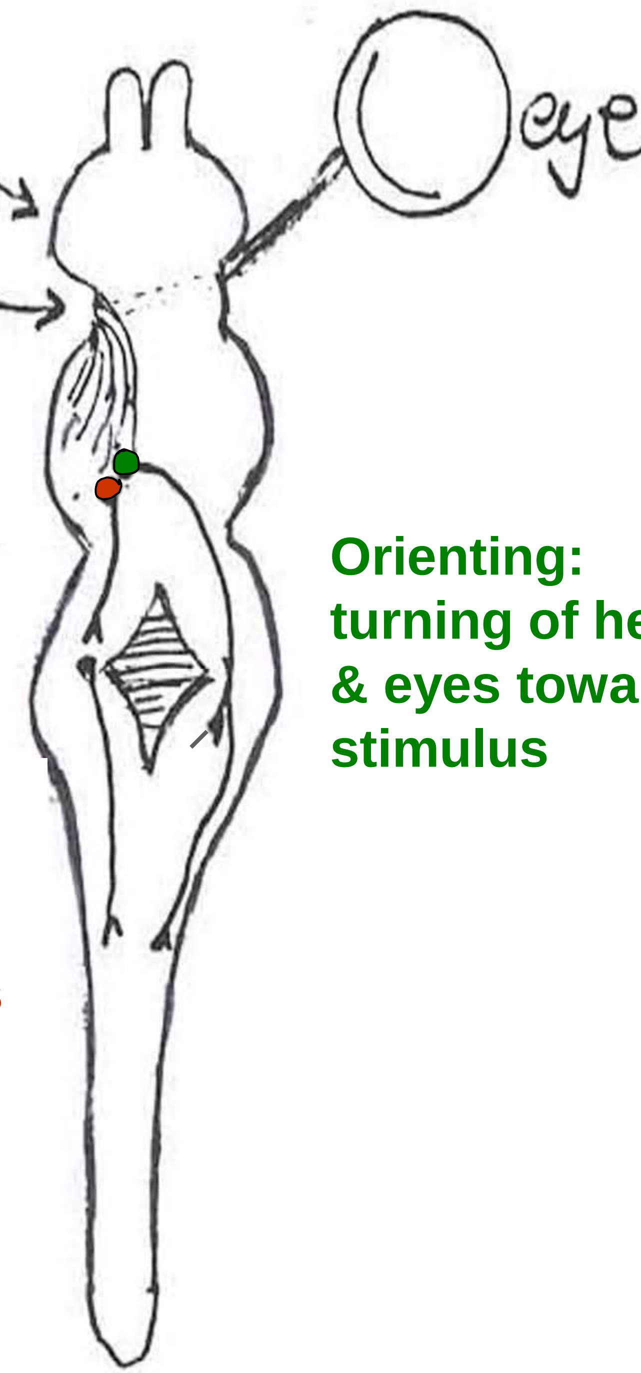
   Optic tectum of midbrain = Optic lobes

   Contrast the motor functions of two major outputs of this structure, one involving descending axons that cross the midline and the other involving an uncrossed descending projection.

# Evolution of Brain 4

## Expansion of midbrain

with evolution of distance-receptor senses: visual and auditory, receptors with advantages over olfaction for speed and sensory acuity, for early warning and for anticipation of events.





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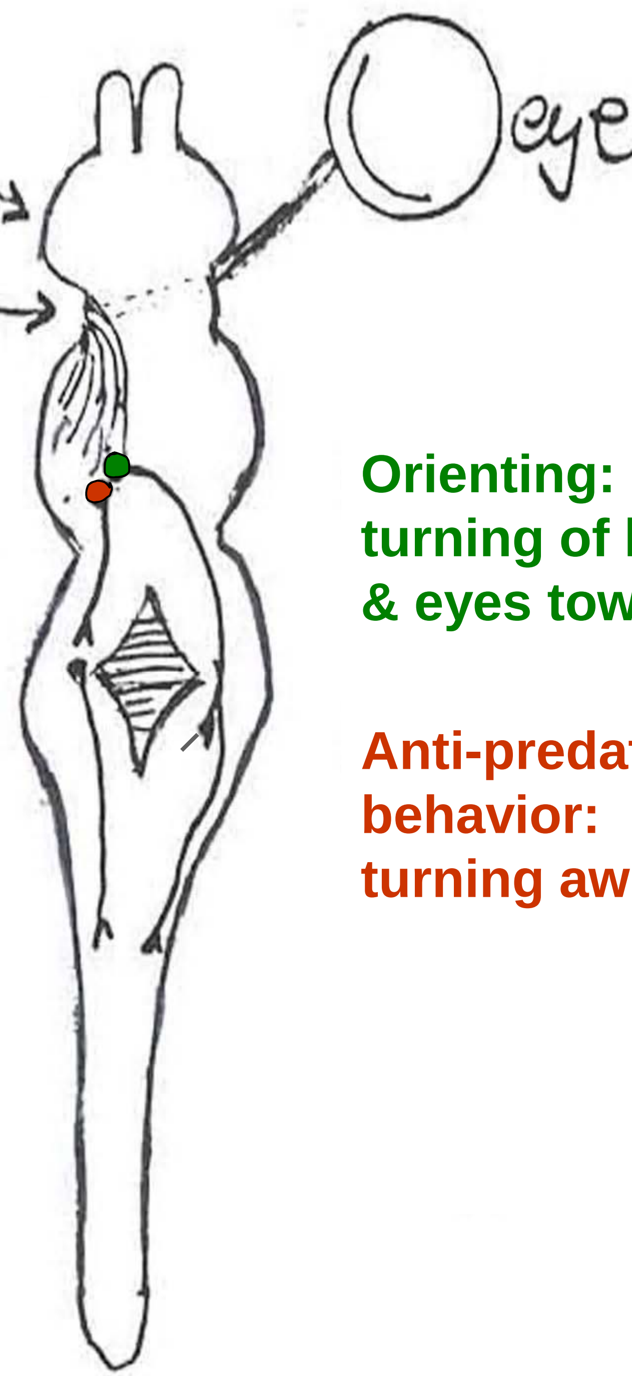
# Brain of a teleost fish, the great barracuda, which, like most predatory fish, has a large optic tectum (at the roof of the midbrain)

Figure removed due to copyright restrictions.
Please see course textbook or:
Schroeder, Dolores M. "The Telencephalon of Teleosts." In *Comparative Neurology of the Telencephalon.* Springer, 1980, pp. 99-115.

# Evolution of Brain 4

## Expansion of midbrain




Motor side: 1) escape loco-motion; 2) turning of head and eyes with modulation by motivational states, including those triggered by olfactory sense.

*Note: Neurons and pathways shown on one side of the brain are usually the same on the other side. I often draw them on only one side to make the drawing simpler.*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# Questions, chapter 4

7. Why do the pathways from each eye to the midbrain cross to the opposite side?

# Why do sensory pathways decusssate?

- This is a question that has given rise to various speculations, but there have been no firm answers.
- I present briefly a suggestion that will be developed later into an hypothesis that is more convincing than others that have been proposed.

# Thinking about the evolution of sensorimotor correlation centers like the midbrain tectum

- *Hypothesis:* Very early in the evolution of the midbrain and forebrain, before the hemispheres appeared, visual inputs from lateral eyes projected bilaterally but then in evolution became crossed. This resulted in later evolution of decussations of non-visual pathways.

  **Why** did the axons from the lateral eyes become crossed? Because it was more adaptive* – supporting the better survival of the organism: Crossed pathways were able to reach crucial output mechanisms most quickly. These mechanisms must have controlled rapid escape/avoidance movements. We will argue this again later when we study somatosensory connections in the hindbrain, and later when we study the visual system.

* in Darwinian sense

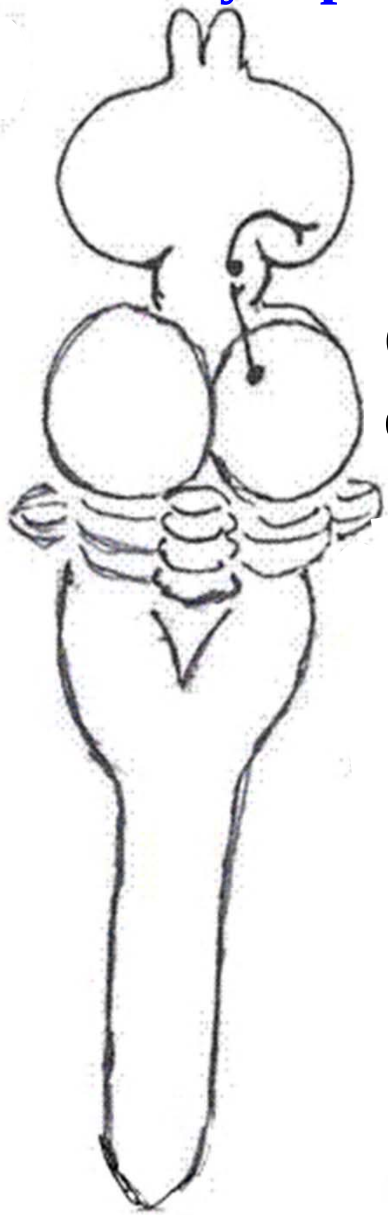
# Questions, chapter 4

8. What is likely to have led to a second major expansion of the forebrain in evolution?

2nd expansion of the forebrain as non-olfactory inputs reach it

# Evolution of Brain 5a

## (*introduction*):




**Non-olfactory systems invade the ‘tweenbrain and endbrain in pre-mammalian vertebrates.**

**(These systems took advantage of the plastic links in the endbrain.)**

***Thalamic axons carrying visual, somatosensory & auditory information reached the corpus striatum and the pallium.***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## Questions, chapter 4

9. A third major expansion of the forebrain has occurred in mammals, apparently because of the evolution of what structure?

# Functional demands result in progressive changes in the neural tube, to include:

- Sensory analyzing mechanisms
- Corresponding motor apparatus
- "Correlation centers"
- Elaboration of complex programs for goal-directed activities
- Systems for modulating other brain systems in response to visceral and social needs
- **Systems for anticipating events & planning actions (cognitive systems)**

# Evolution of cognitive systems of the brain

- Sensory side: images that simulate objects & events
  Motor side: planning of and preparing for actions
  - These are non-reflex functions involving memory and internal representations of the external world.
- Evolution of structures that accomplish these functions: **forebrain**, especially in the **neocortex** of the endbrain of mammals. (In birds, non-neocortical structures accomplish similar functions.)

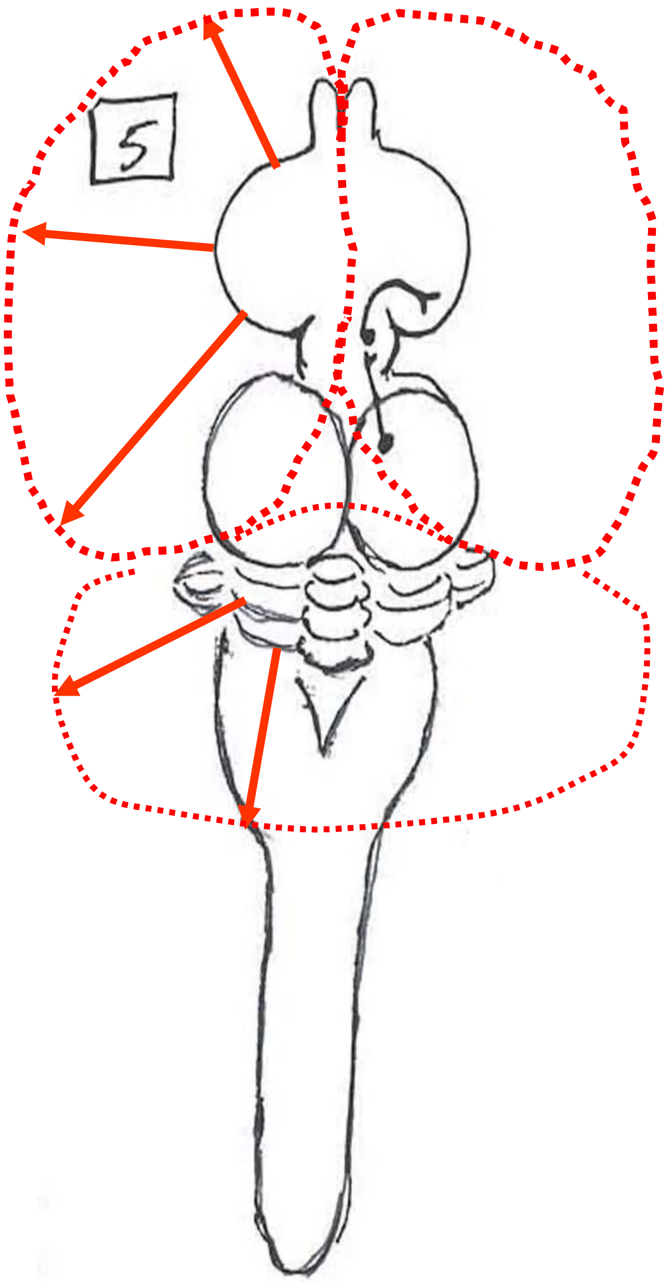
# With evolution of these cognitive functions, the endbrain expanded further.

- This was a third major expansion of the forebrain
- What structures in the endbrain expanded the most?

# What structures in the endbrain expanded the most?

- Expansion of the neocortex, especially the so-called "association cortex“ in the most recent evolutionary changes
- Also the parts of the corpus striatum and the cerebellum closely connected to those areas of neocortex.

3rd expansion of the forebrain




# Evolution of Brain 5b:

The expansion of the endbrain, dominated by the expanding area of the neocortex in mammals.

Correlated with this was an expansion of the cerebellar hemispheres, and also the "neostriatum"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*Also note:*

*The advantages of control of fine movements, especially with evolution of distal appendages with capacity for manipulation, resulted in evolution of motor cortex as well as the cerebellar hemispheres.*

## Questions, chapter 4

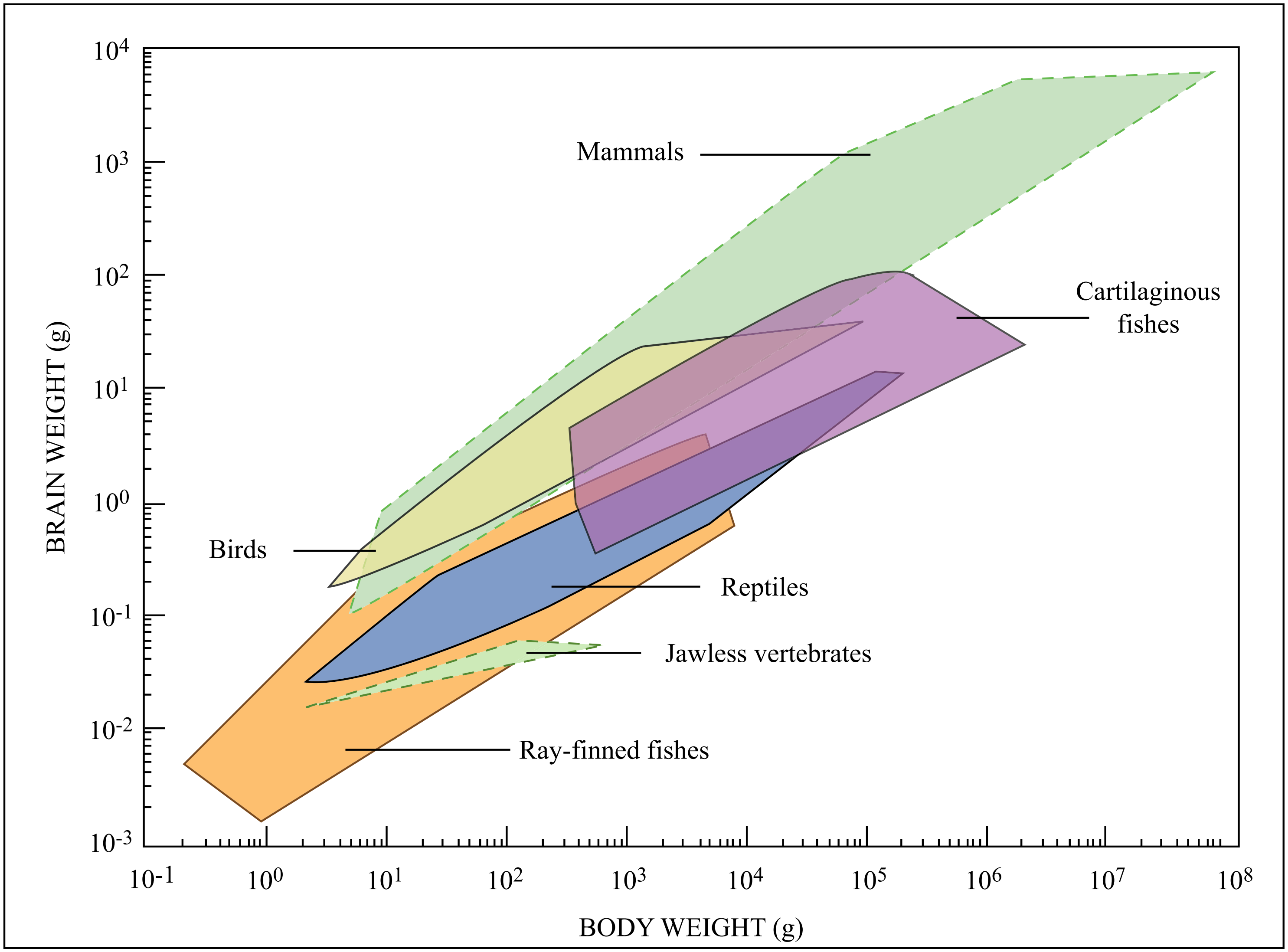
10. Describe the method of comparing brain size in the various major groupings of chordates. Describe a major result of such comparisons, from comparative studies.

# Question:
# How much brain expansion has occurred?

- Data have been collected on total size of the brains of many species of animals.
- Relative brain size can be seen by plotting brain weight *vs*. body weight.

Body size is a **major** determinant of brain size

# Vertebrate brain-body scaling

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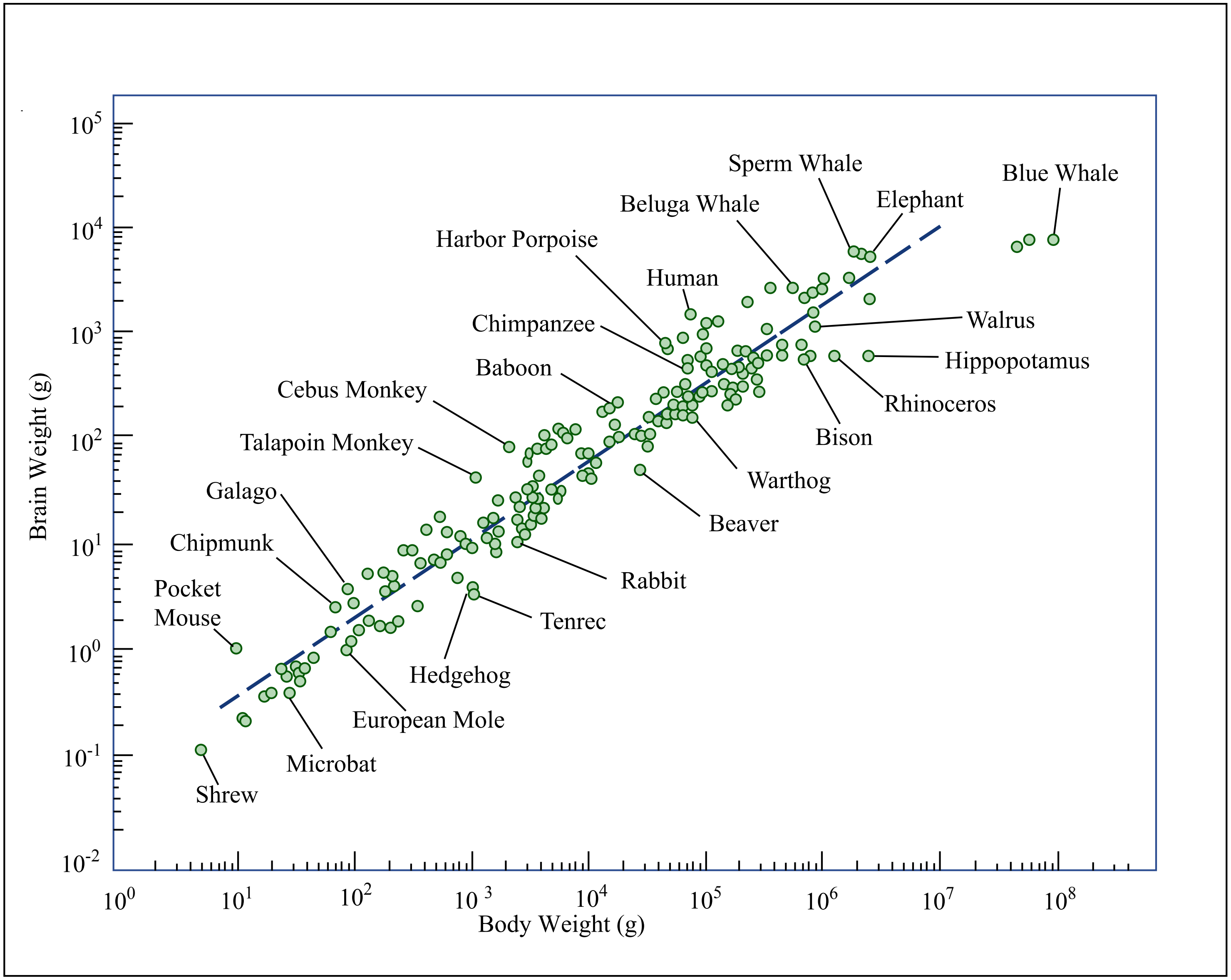
# Mammalian brain-body scaling

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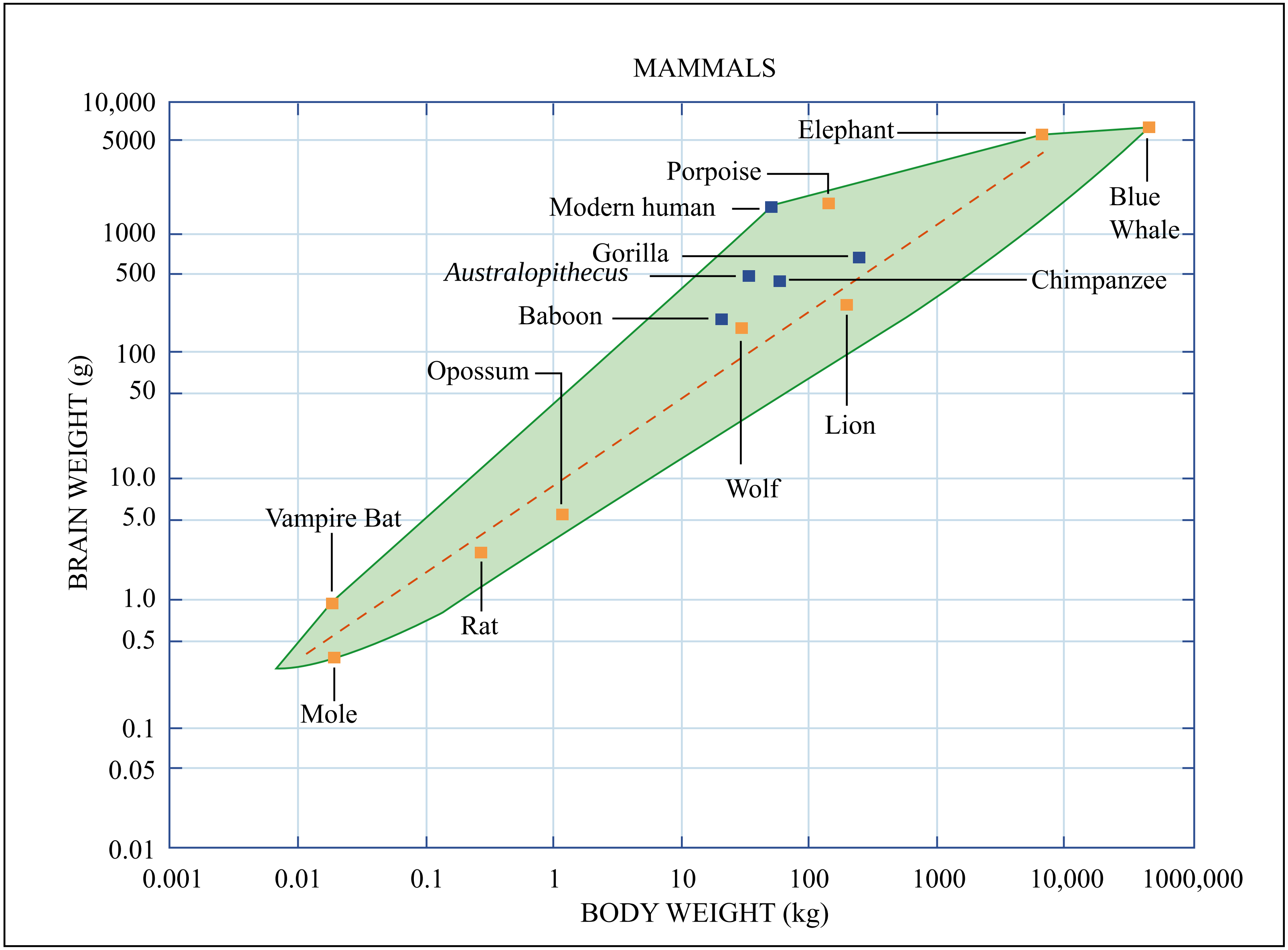
# Brain & body weights in mammals (primates in blue)

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Preview of next class (class 5):
--> Ontogeny and phylogeny: Is there a relationship?
-->What are the Cynodonts?