9.14 - Brain Structure and its Origins
Spring 2005
Massachusetts Institute of Technology
Instructor: Professor Gerald Schneider

A sketch of the central nervous system and its origins

G. Schneider 2005

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, *continued*

Evolution of multi-cellular organisms: Suggestions based on phylogenetic comparisons

TOPICS, sessions 3 & 4:

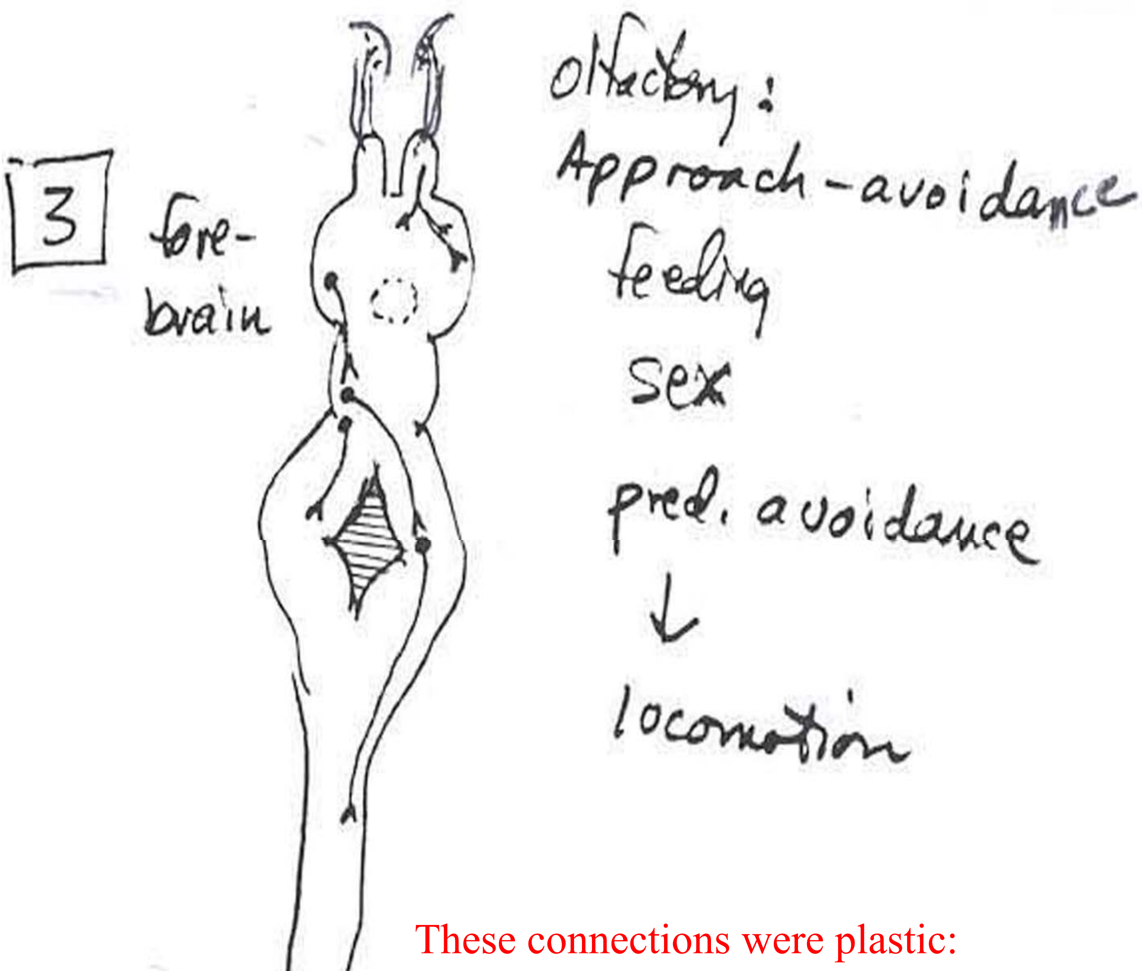
- √ Behaviors most fundamental for survival
- √ Intercellular conduction in Ctenophores and Coelenterates: *suggestions about evolution of the nervous system*
- √ A generalized conception of the CNS
- √ The body plan of primitive chordates, as suggested by Amphioxus (*Branchiostoma*)
- – **<u>Elaboration of the neural tube in evolution</u>**

Phylum Coelenterata: now often called Cnidaria. Animals with radial symmetry and stinging tentacles; includes free-swimming medusa forms like jellyfish, and sessile polyp forms like corals and sea anemones.

From last session

Evolution of Brain 3

(Concurrent with "Evolution 2")



These 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

Expansions, continued: 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

"Correlation centers"

- **Between the sensory analyzers and the motor apparatus:**
  - For maintaining "stability in space" by integration of vestibular, visual and tactile information;
  - For avoidance and approach movements, guided by olfaction as well as other senses.
- **Evolution of structures to improve head and body orientation**:
  - Midbrain tectum and pretectal cell groups;
  - Medial hindbrain reticular formation.
  - Medial cerebellar structures;
- ***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 the original crossing? It was more adaptive – supporting the better survival of the organism – because crossed pathways were able to reach crucial mechanisms most quickly. These mechanisms must have controlled rapid escape/avoidance movements*. We will argue this again later when we study the visual system.**

Hyodon tergisus (fresh water Mooneye)

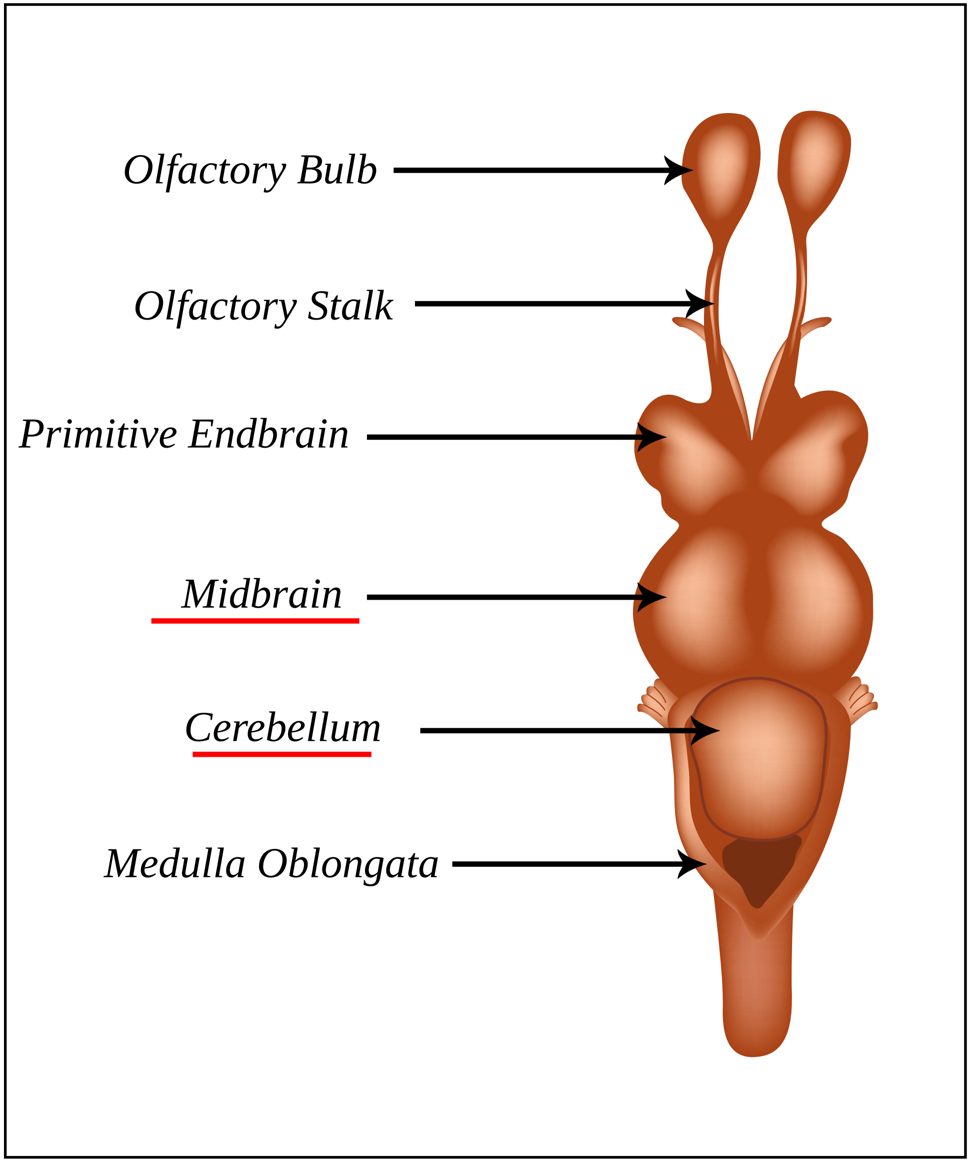


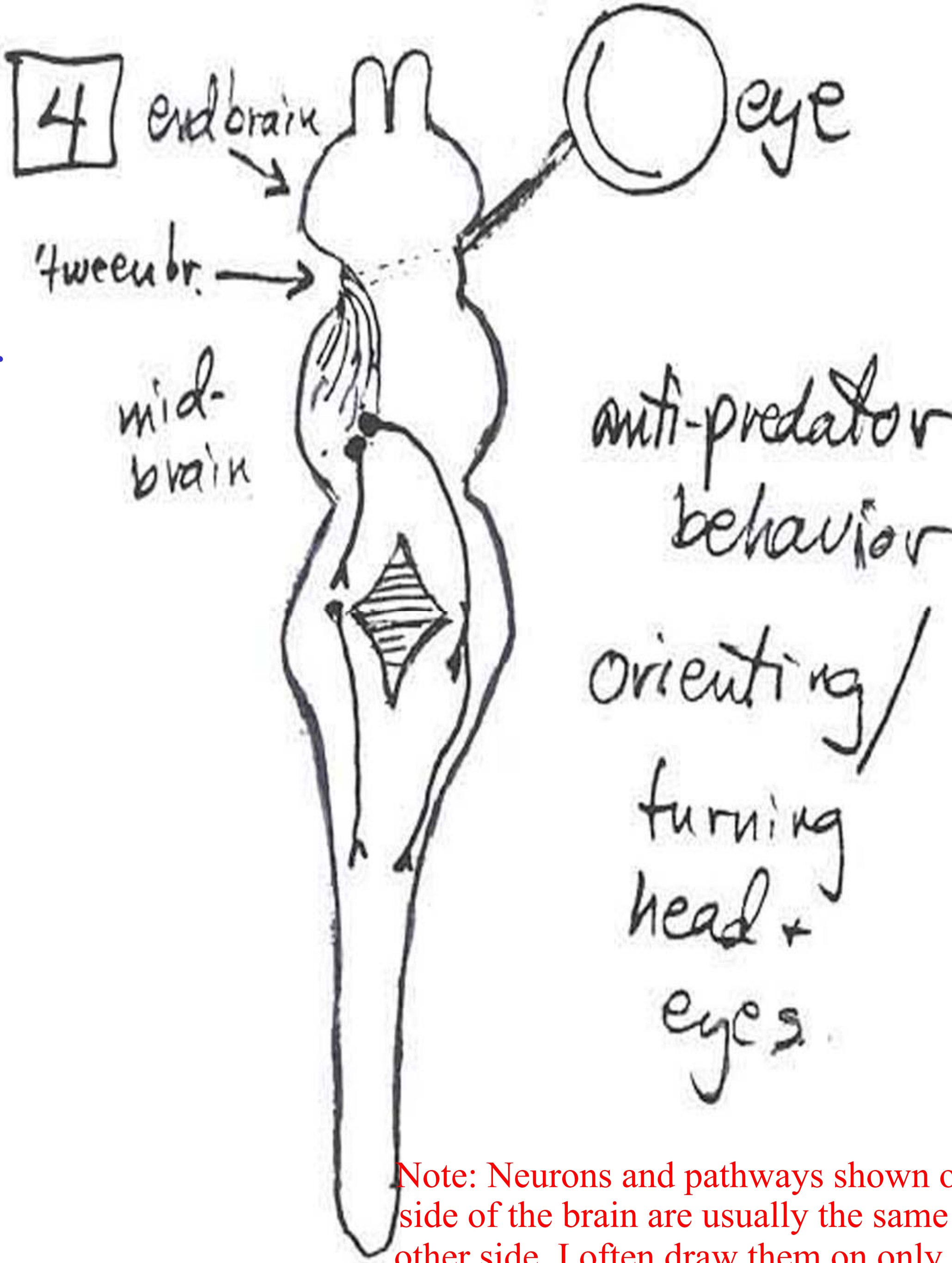
Figure by MIT OCW.

Evolution of Brain 4

<u>Expansion of midbrain</u> 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.

…………………………………

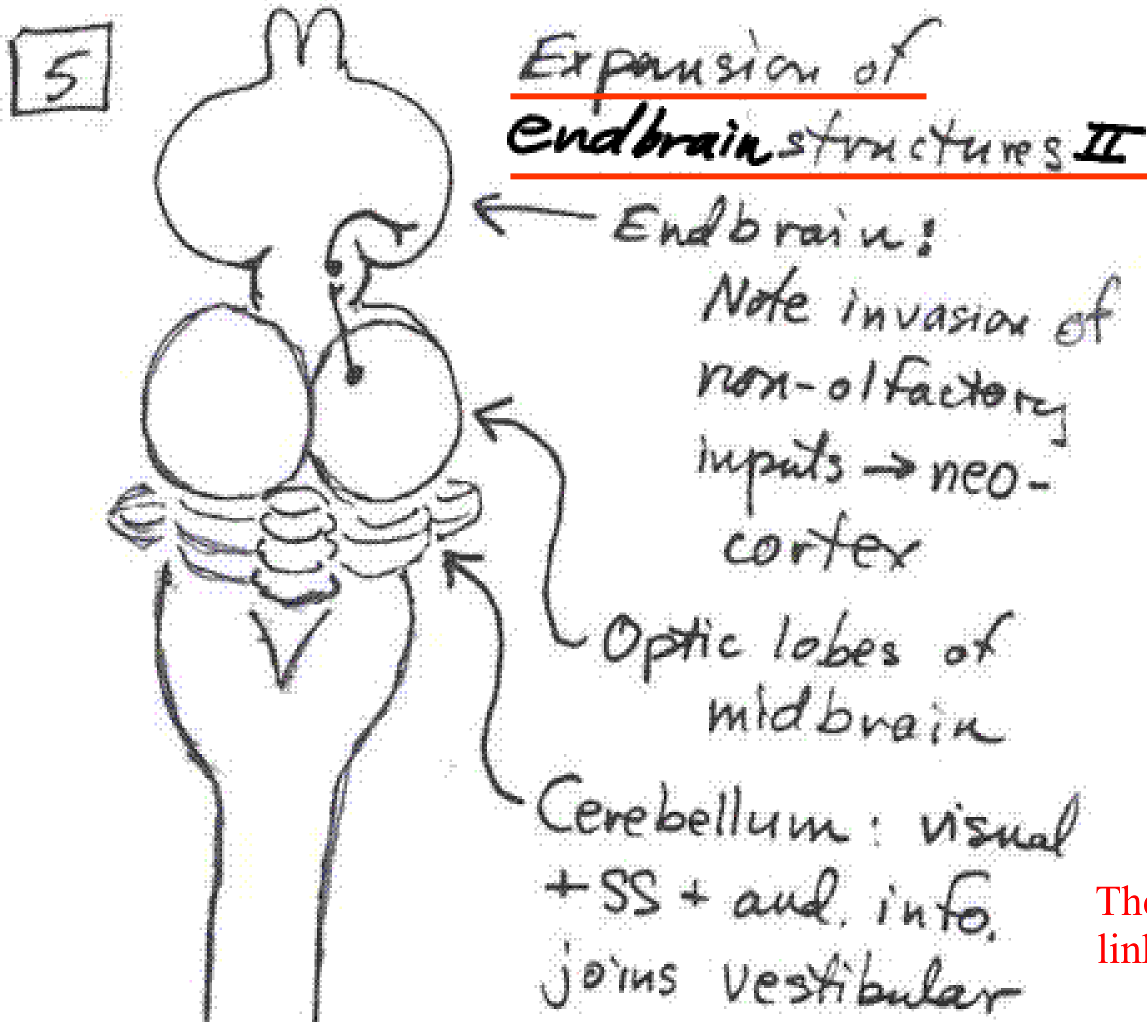
Motor side: **turning of head and eyes** with modulation by motivational states, including those triggered by olfactory sense.



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 drawings simpler.

Evolution of Brain 5a

(*introduction*): non-olfactory systems invade the ‘tweenbrain and endbrain in primitive proto-mammals.



These systems took advantage of the plastic links in the striatum.

Thalamic axons carrying visual, somatosensory & auditory information reached the corpus striatum and the dorsal cortex. The latter connection resulted in pronounced expansion of that cortex.

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

- Sensory analyzing mechanisms
- Corresponding motor apparatus
- "Correlation centers" –e.g., the midbrain tectum
- **<u>Elaboration of complex programs for goal-directed activities</u>**
- Systems for modulating other brain systems in response to visceral and social needs
- Systems for anticipating events & planning actions

Elaboration of complex programs for goal-directed activities

- “Fixed action patterns" of the ethologists (FAPs)
  - Not the same as reflexes; “fixed” in the genes
  - Examples in humans (Instinctive movements)
- Correlated structural elaborations
  - Hindbrain and spinal-cord control of movement patterns with motivational control, and some sensory control, *via* midbrain & forebrain
  - Elaborations that were particularly prominent in mammals: Mechanisms for reward-driven **learning** and habit formation, using corpus striatum and neocortex linked to motivation systems

Systems for modulating other brain systems in response to visceral and social needs

- Control of motivation (cyclic and episodic): present in the most primitive animals, but elaborated with forebrain expansion
- Elaboration of goal hierarchies
- Communication of needs & desires

- Structures that achieve this:
  - Hypothalamus, epithalamus, & associated midbrain & hindbrain systems
  - Evolution of "limbic forebrain", connected to these systems

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
- **<u>Systems for anticipating events & planning actions</u>**

Systems for anticipating …

- Sensory side: images that simulate objects & events

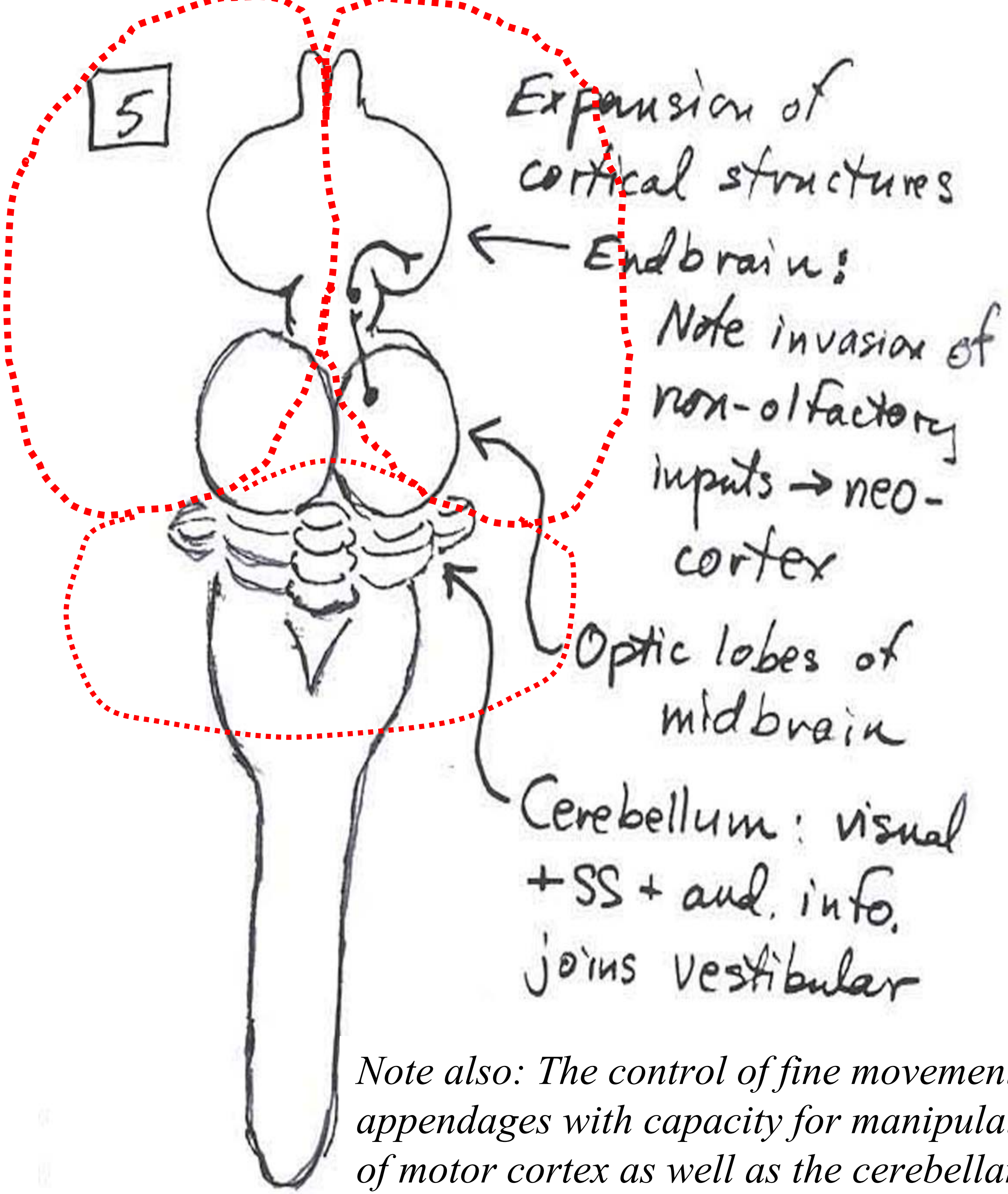
  Motor side: planning of and preparing for actions
  - These are non-reflex functions involving memory and internal representations of the external world.
- Evolution of structures that accomplish these functions: **forebrain**, especially in the **neocortex** of the endbrain

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

- 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"
- Also the parts of the corpus striatum and the cerebellum closely connected to those areas of neocortex.



Evolution of Brain 5b:

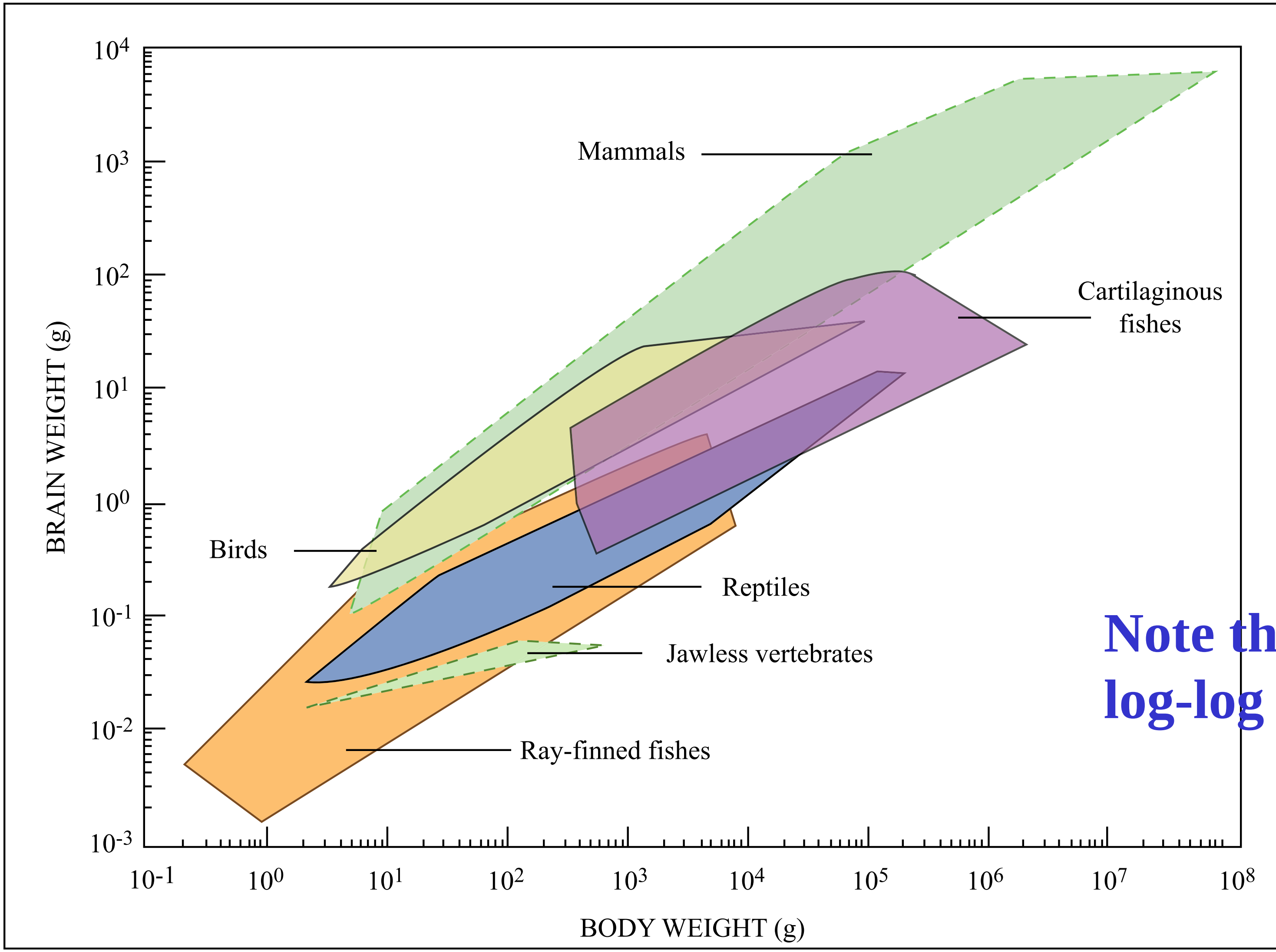
The expansion of the endbrain, dominated by the expanding area of the neocortex in mammals.

Correlated with this was an expansion of the cerebellar hemispheres, and also the "neostriatum"

Note also: The control of fine movements, especially with evolution of distal appendages with capacity for manipulation, results eventually in evolution of motor cortex as well as the cerebellar hemispheres.

Vertebrate brain-body scaling

(Based on Jerison, 1973)



Note the use of log-log coordinates

Figure by MIT OCW.

Brain & body weights: animal groups

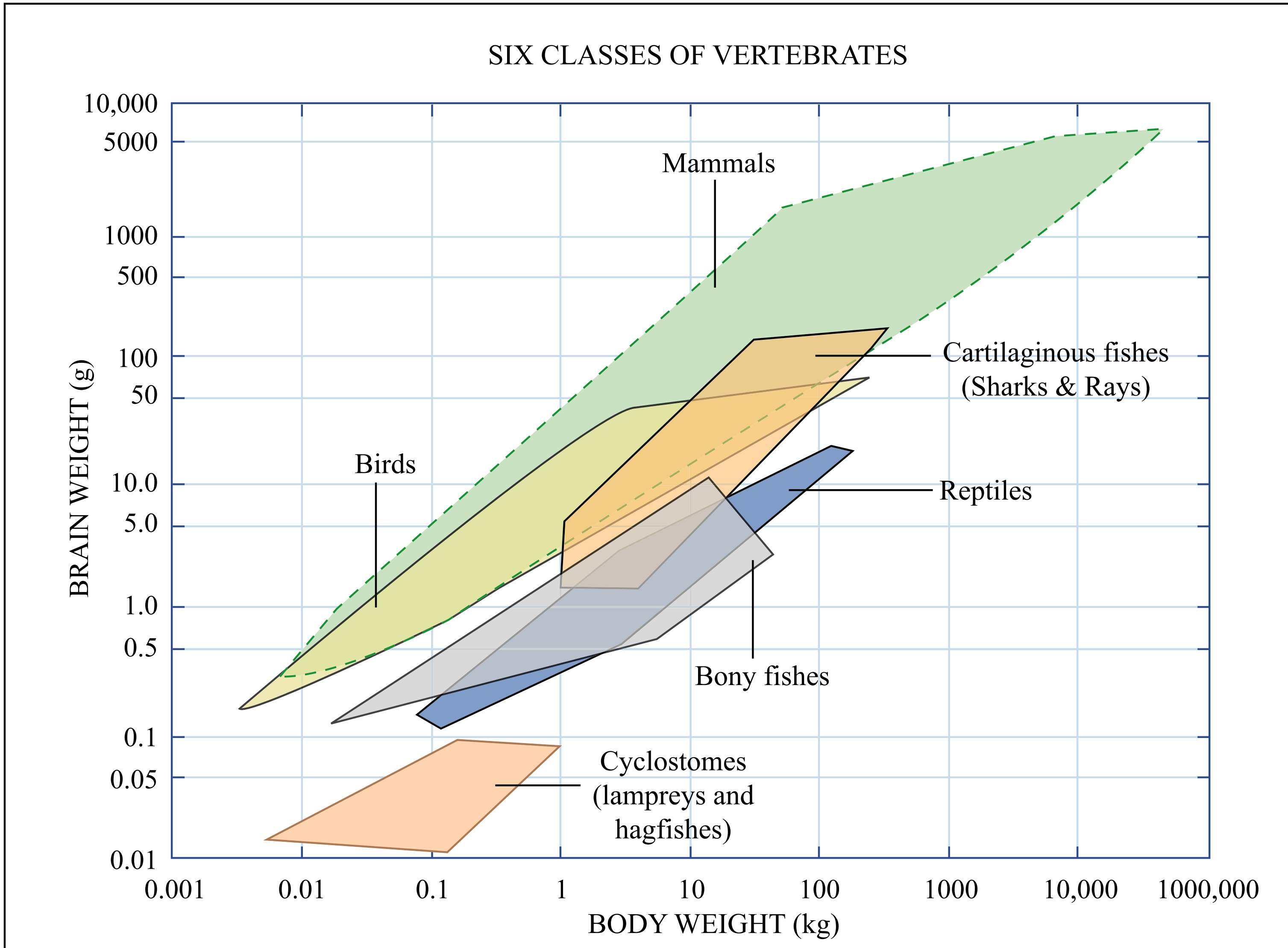


Figure by MIT OCW.

Similar to fig. 4.3 in Striedter (2005)

Mammalian brain-body scaling

(Based on several earlier studies)

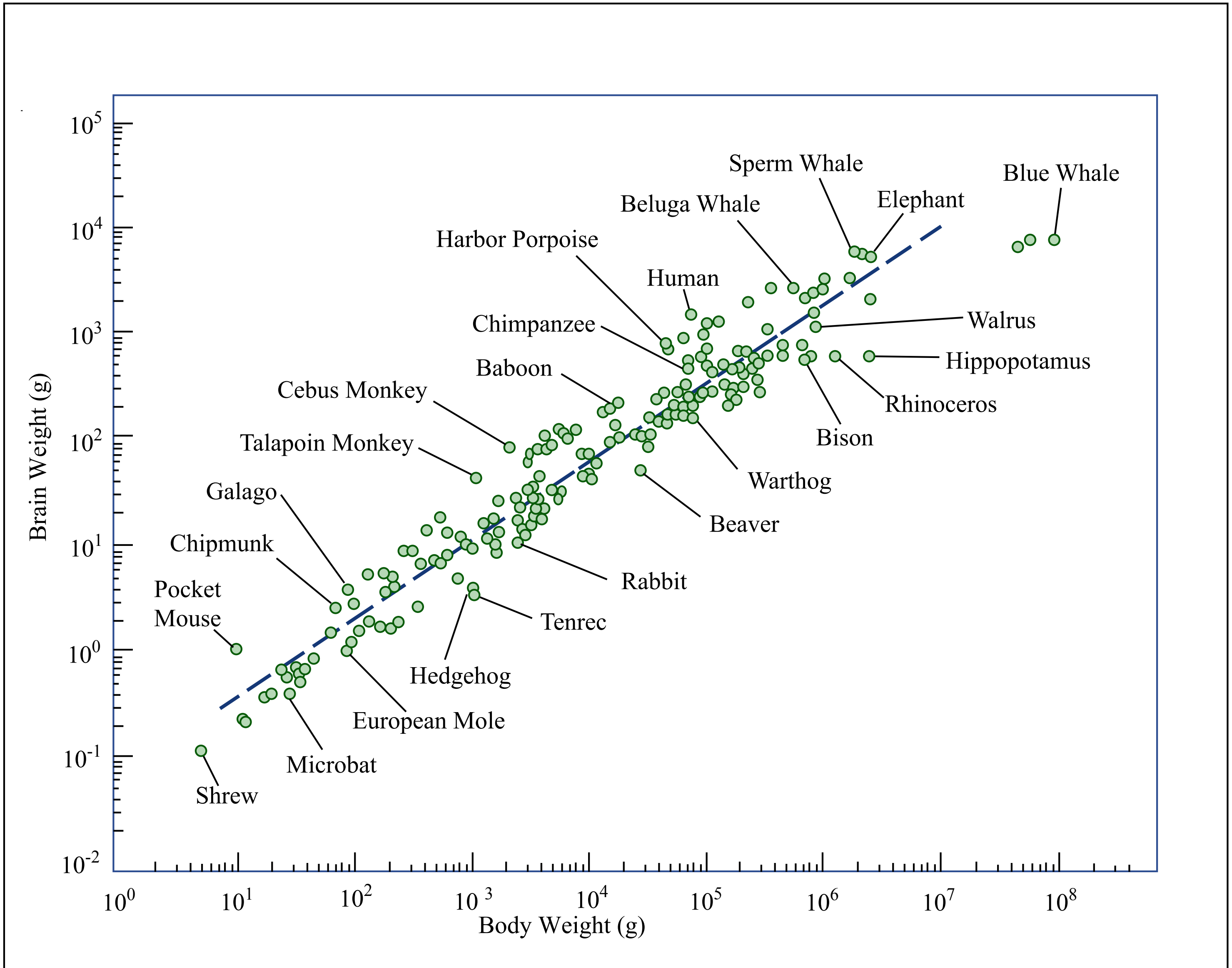


Figure by MIT OCW.

Brain & body weights in mammals

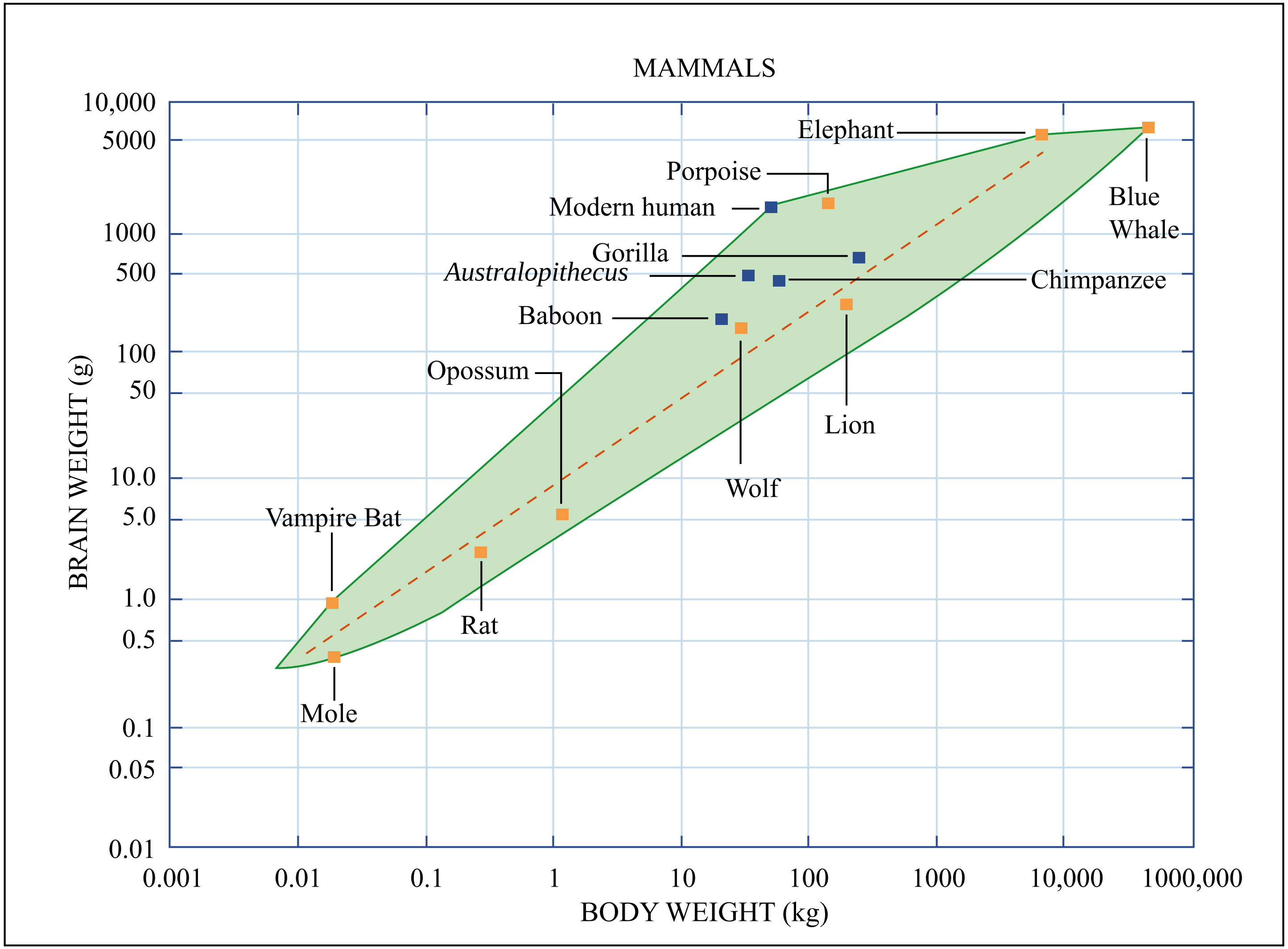


Figure by MIT OCW.

See also fig. 4.1 in Striedter (2005)

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

MIT 9.14 Class 5

Sketch of a pre-mammalian brain; some specializations and some basic pathways

Keep in mind:
Basics of behavior enabling survival

- The most basic (multipurpose) actions of individual organisms from amoebae to human:
  - Approach/avoid
  - Orient towards/away
  - Explore/forage/seek

- Each evolutionary advance had to incorporate these multipurpose actions, needed for various goal-directed activities.

Two Terms:

- "notochord" *vs*. "notocord"
  - (either one is accepted by me, but 1st is proper)
- "spinal chord" *vs*. "spinal cord"
  - (only the latter is proper)

Ontogeny & phylogeny re: Evolution

- Can development tell us something about evolution?
- Does "ontogeny recapitulate phylogeny"?
  - Early in development, the human embryo looks nearly the same as a pig embryo as well as the same as a monkey or ape embryo. 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 the very early (gastrula) stages.
  - Ernst Haeckel presented an oversimplfied 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). The second is Haeckel's drawing.

"Ontogeny recapitulates phylogeny"

from Romanes, 1901.

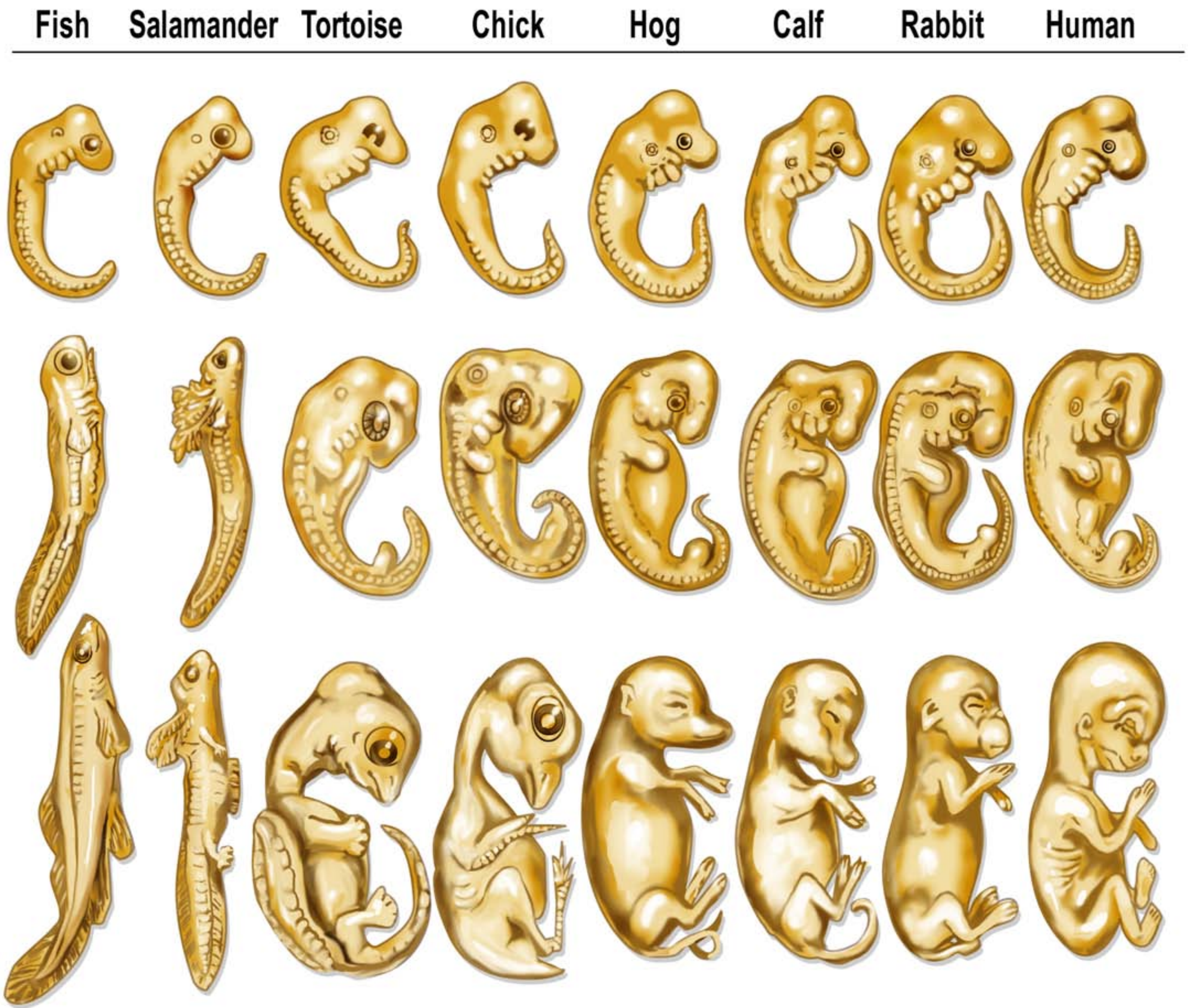

Figure by MIT OCW.

“The Developmental Hourglass” (Ernst Haeckel)

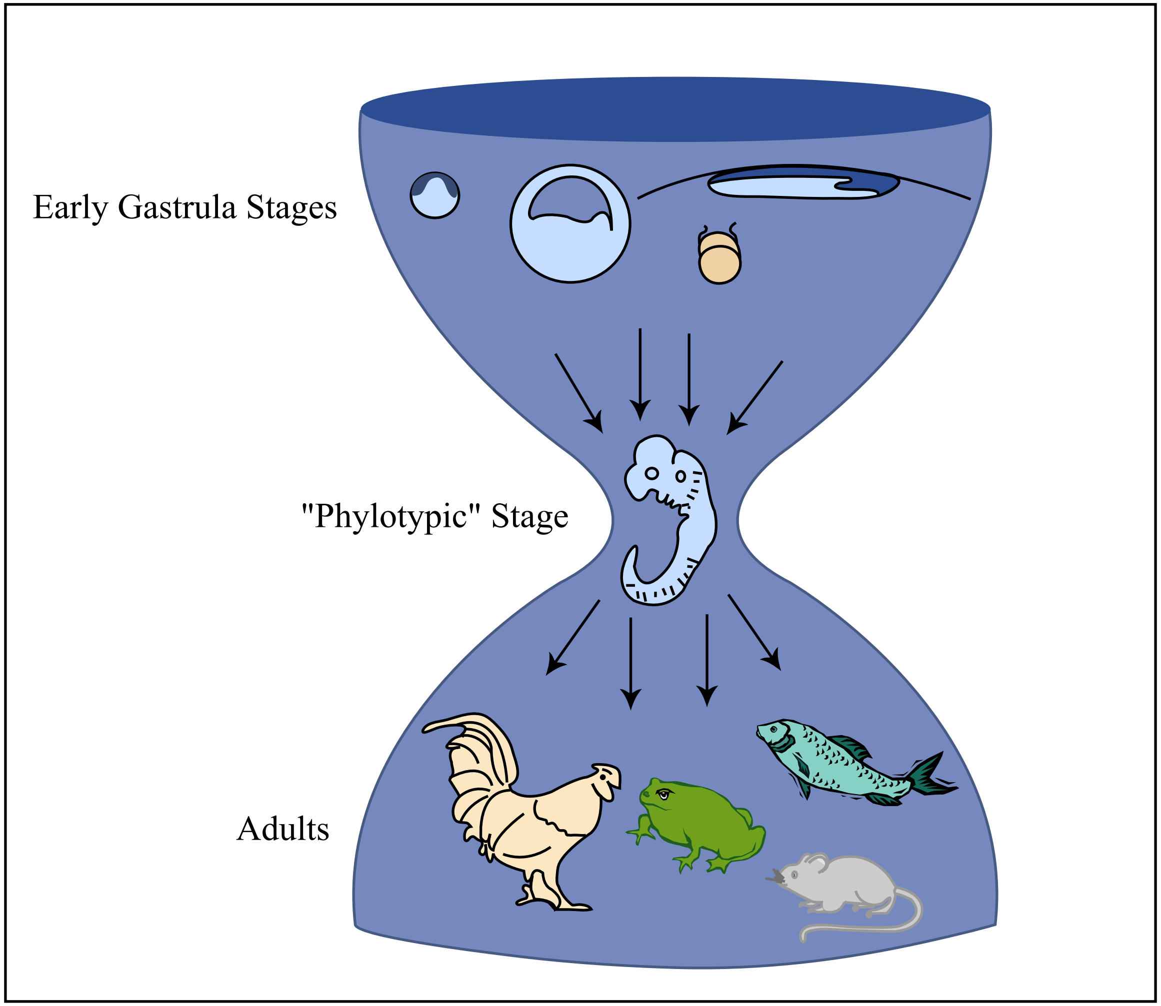

Figure by MIT OCW.

Review of Evolution

The outline of the high-priority behavioral demands:

- One purpose is to call your attention to the organization of behavior as seen throughout the chordate phylum,
- focusing first on pre-mammalian vertebrates,
- then on the mammals.

My outline of progressive changes in neuroanatomy:

- Although this comes from my imagination, it is a fantasy based on diverse information.
- It is supported by illustrations from comparative anatomy.
- More recent information comes from studies of gene expression.

Comments:

- Note the contrast between roles of somatosensory and distance receptor inputs in shaping brain evolution.
  - The most primitive distance receptor (not including receptors for light-dark detection) was probably olfaction: Recall the description of the early expansion of the forebrain in pre-mammalian vertebrates.
  - Later expansions of the forebrain involved other distance receptors, especially visual and auditory.

Selected References

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Slide 25: Darwin and after Darwin. An exposition of the Darwinian theory and a discussion of post-Darwinian questions, by George John Romanes. Published/Created: Chicago, The Open court publishing company, 1892-97.

Slide 26: Striedter, Georg F. *Principles of Brain Evolution*. Sunderland, MA: Sinauer Associates, 2005, p.78. ISBN: 0878938206.