

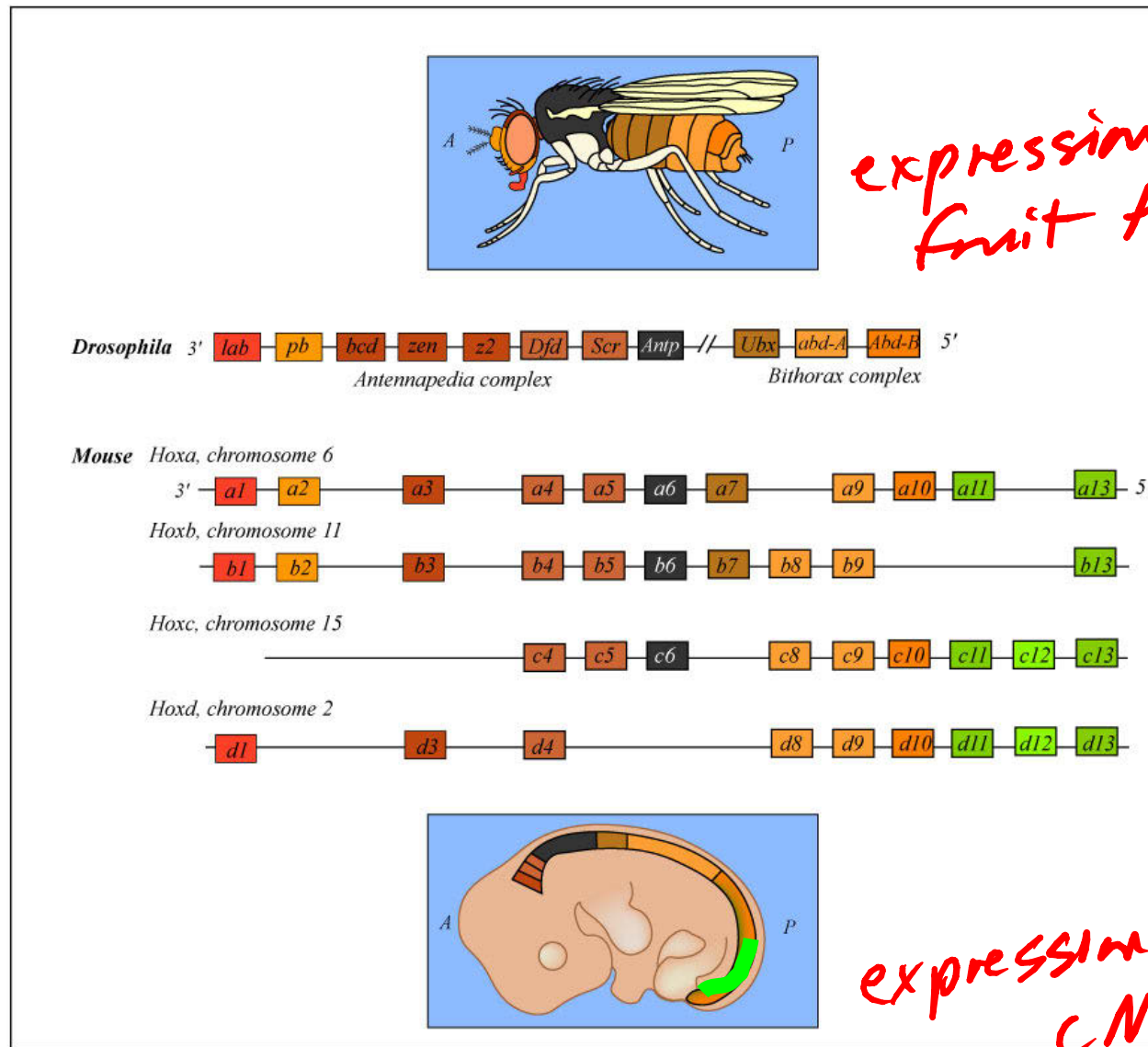
Genes underlying segmentation *topics*

- Ancient origins of segmentation along the A-P axis, with corresponding nervous system differentiation
- The homeobox genes: What are they?
- Examples of gene expression patterns

next

a family of genes for transcription factors

Homeobox genes in Drosophila, and 13 paralogous groups in 4 chromosomes of mouse



expression in fruit fly

expression in mouse CNS

Image by MIT OpenCourseWare.

Hox gene expression in the mouse embryo after neurulation

Figure removed due to copyright restrictions.

Please see course textbook or figure 4.11 of:

Wolpert, L., J. Smith, et al. *Principles of Development*. 3rd ed. Oxford University Press, 2006.

**E 9.5 mouse embryos, immunostained using antibodies specific
For the protein products of the indicated Hox genes.**
(Wolpert, 2002, fig. 4.11)

Hox gene expression along the antero-posterior axis of the mouse mesoderm

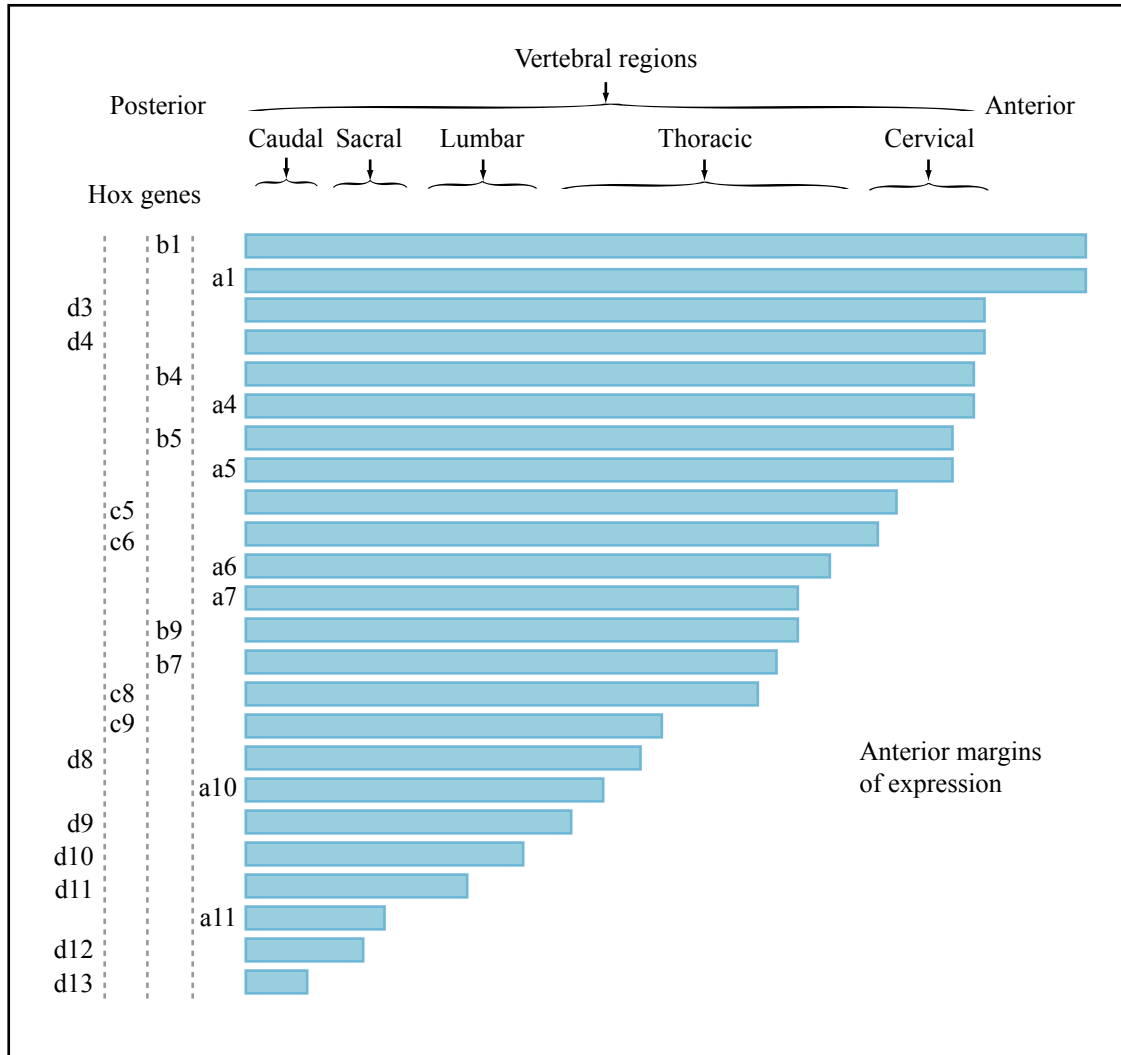


Image by MIT OpenCourseWare.

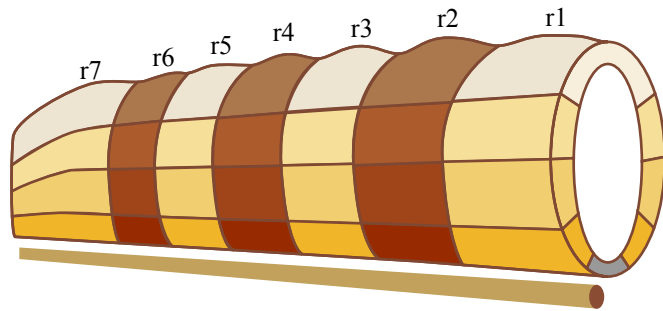
Image removed due to copyright restrictions.

Please see:

Allman, John Morgan. *Evolving Brains*. Scientific American Library:
Distributed by W. H. Freeman and Co., 1999. ISBN: 9780716750765.

Rhombomeres: the segments of the rhombencephalon

*(Scanning e.m. photo
from Allman, 2000)*



Gene Expression and Rhombomeres

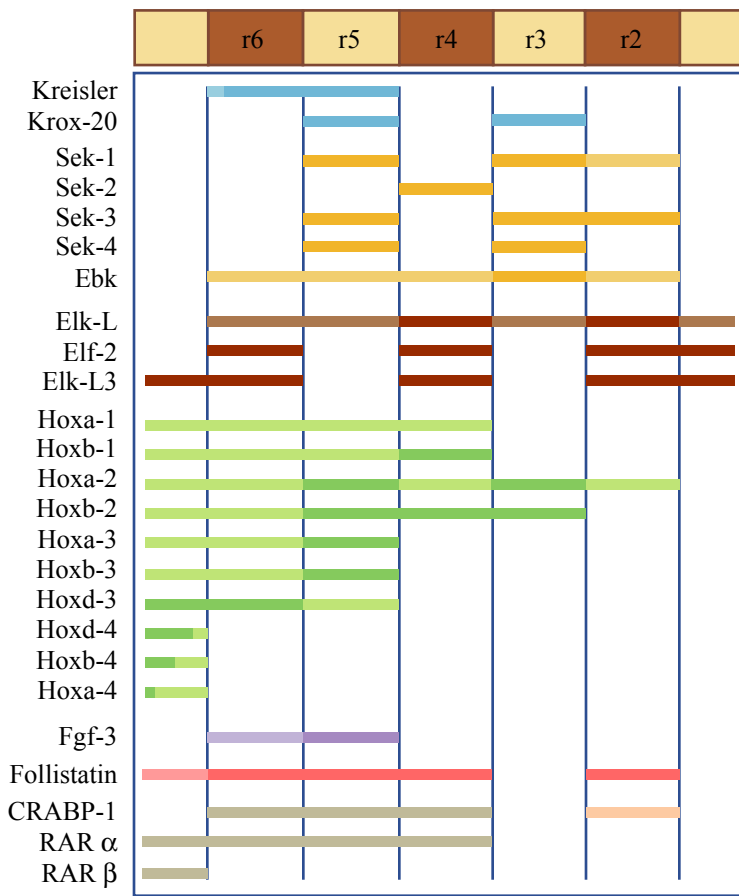


Image by MIT OpenCourseWare.

The hindbrain neuromeres (= rhombomeres):

A) Expression of transcription factor genes;

B) Fate of embryonic precursor cells injected before and after rhombomere formation

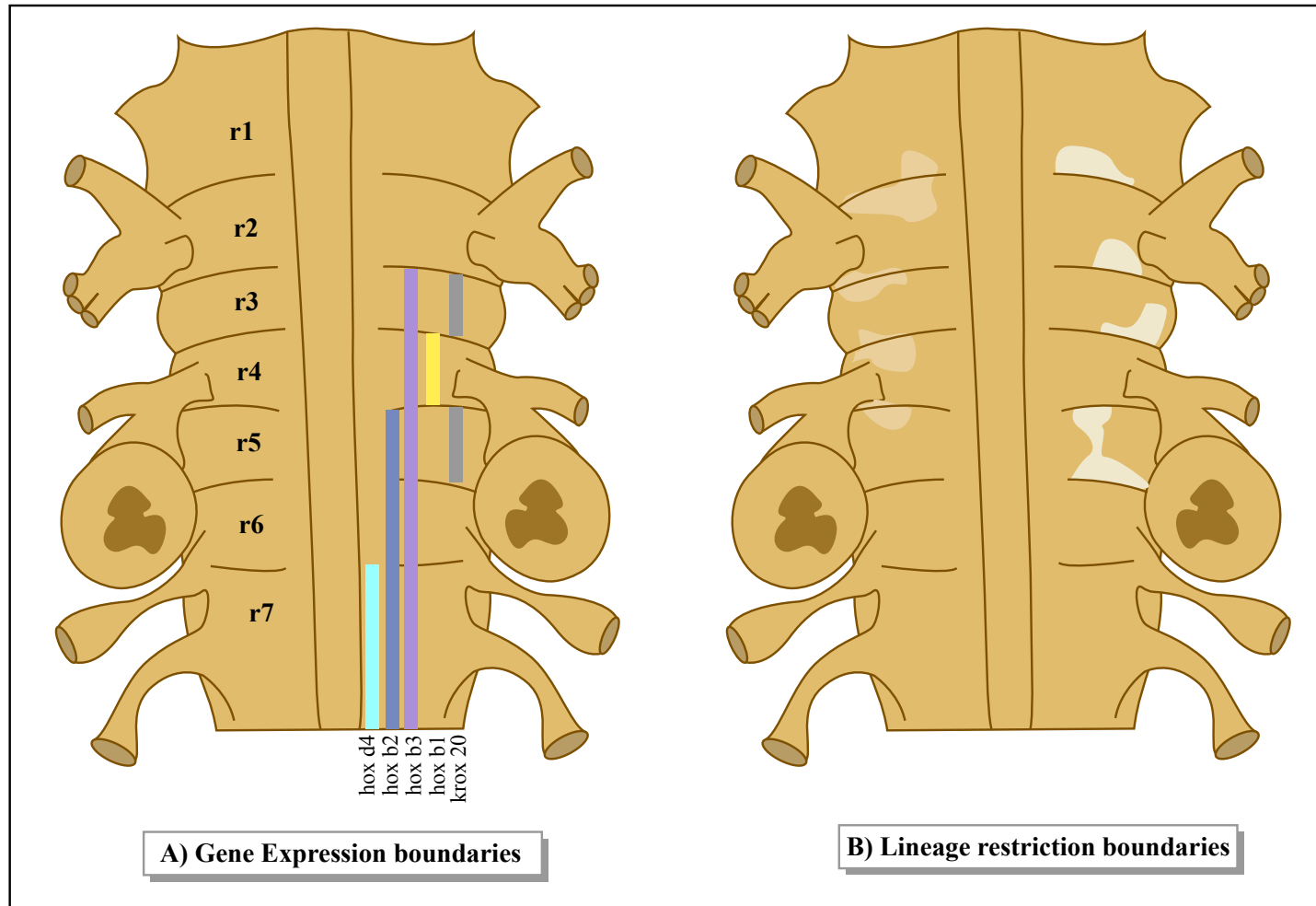


Image by MIT OpenCourseWare.

A sketch of the central nervous system and its origins

G. E. Schneider 2014

Part 5: Differentiation of the brain vesicles

MIT 9.14 Class 10

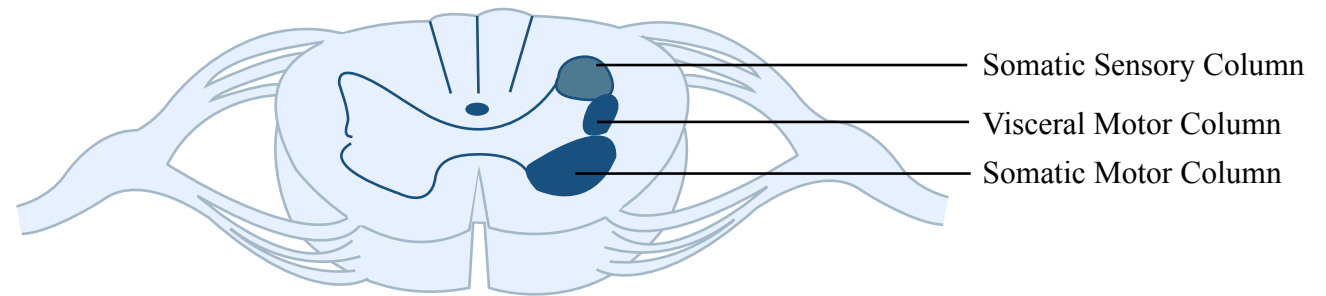
Hindbrain & cranial nerves;
hindbrain specializations

Columns of secondary sensory and motor neurons, comparing hindbrain & spinal cord

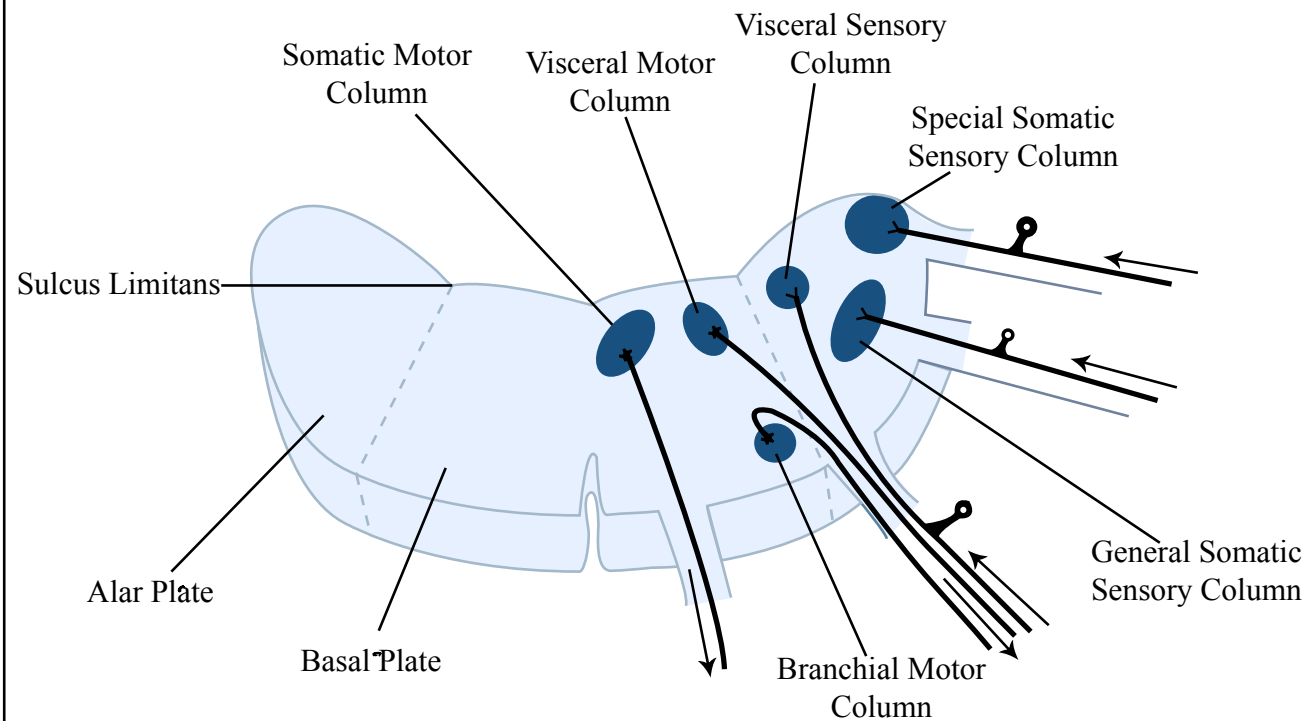
- **This time, these should begin to enter your long-term memory!**
- **Trajectories of associated cranial nerves have been included in the following figure.**

Based on Nauta & Feirtag

Columns in spinal cord



Columns in Hindbrain



The variety of cranial nerve types

- Study the picture in the previous slide. Note the four types of cranial nerves depicted. **The figure is a good one to memorize.**
- Next, some more details about
 - cranial nerves;
 - hindbrain:
 - Names of cell groups;
 - fibers passing through, between the cord and more rostral brain structures.

Questions, chapter 10

- 9) What is a sensory placode? Contrast neural-crest and placodal origins of secondary sensory neurons.
- 10) How many cranial nerves are there? Discuss this in terms of comparative anatomy.

[Note: students should study table 10.1 a number of times so that soon you will memorize the numbers, names and basic functions.]

[a later quiz: not this week]

Questions, chapter 10

What is a sensory placode? Contrast neural-crest and placodal origins of secondary sensory neurons.

A placode is a thickening of the embryonic ectoderm; neurogenic portions give rise to primary sensory neurons.

The **trigeminal placode** (a dorsolateral placode in the embryo), made up of ophthalmic and maxillo-mandibular portions, is the origin of the cells of the trigeminal ganglion.

The **otic placode** (also a dorsolateral placode) is the origin of organs of hearing and of the vestibular system.

The **olfactory placode** is the origin of the olfactory epithelium.

Note: In the hindbrain area, the epibranchial (epipharyngeal) placodes are the origin of some of the ganglion cells of cranial nerves VII, IX and X.

The inadequacy of the **traditional enumeration of 12 cranial nerves** *(a note from Butler & Hodos)*

- More than 12 are seen in embryonic development in humans.
- **25 cranial nerves** are listed by Butler & Hodos. But some are found only in certain groups of vertebrates. **e.g., the lateral line nerves**
- The facial (#7), glossopharyngeal (#9) and vagus (#10) each contain two distinct parts.
- However, it has become traditional to list just **12** cranial nerves. For the adult human brain, it is an adequate description.

The caudal hindbrain of an adult mammal

- Locations of cell groups
 - Secondary sensory neurons in the alar plate
 - Motor neurons in the basal plate
- Locations of axons passing through

The neuroanatomical names add to the apparent complexity of the following picture, but it will seem simpler as we study the brain more and more.

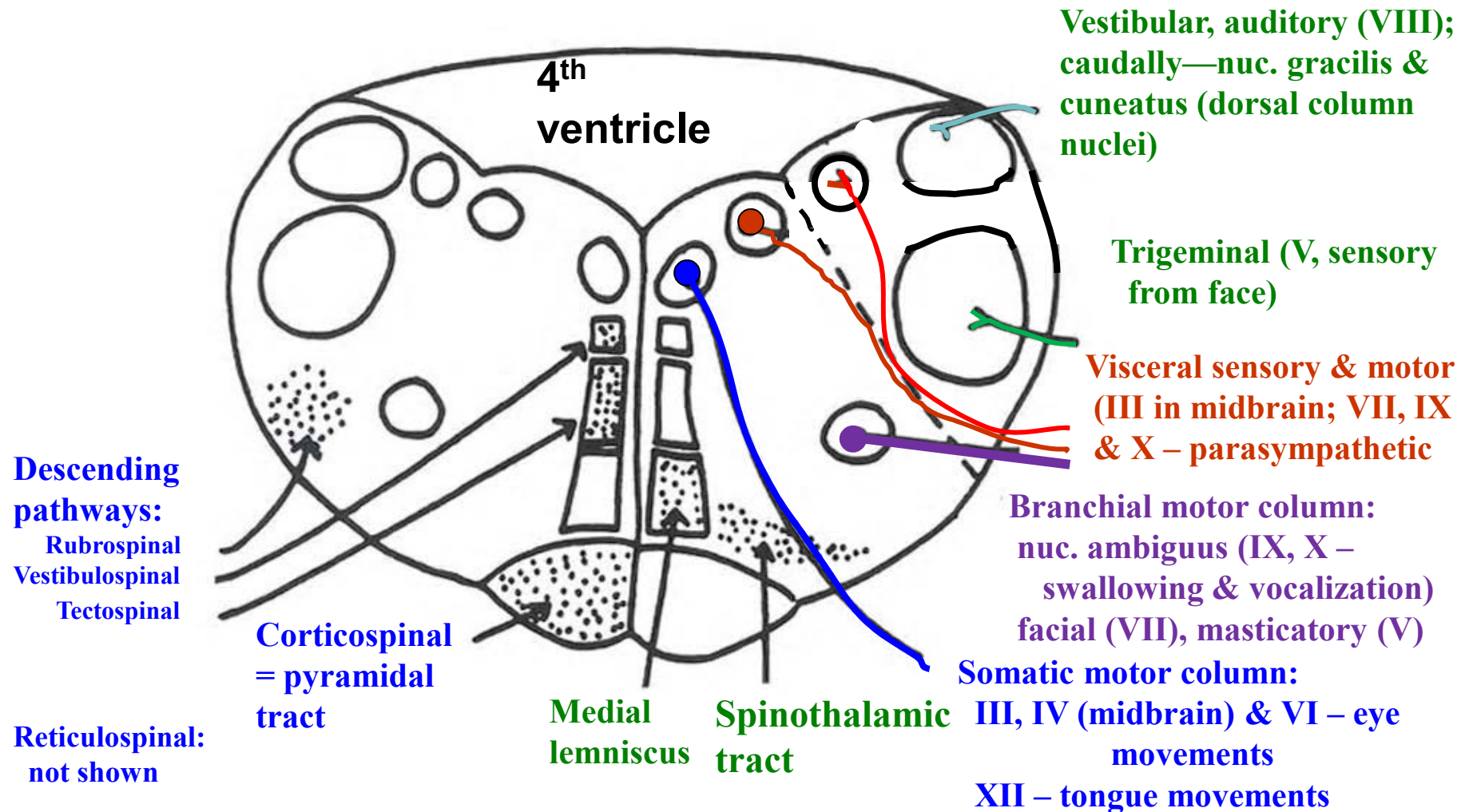
Use the figure for reference. (No need to memorize it.)

Questions, chapter 10

- 11) Look at figure 10.10 of the adult caudal hindbrain (the medulla oblongata). Which sensory modalities are represented at this level of the brainstem? See also figure 10.11.
- 12) Which cranial nerve carries somatosensory input from the face into the brain? Give the number of the nerve as well as its common name. Where are the primary sensory neurons of this nerve? Where are the secondary sensory neurons?

Adult caudal hindbrain of mammal

principle cell columns and fiber tracts (schematic)



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 10-10

Locations of cell groups in human brainstem

- Imagine the brainstem to be transparent, and that the secondary sensory cell groups and the motor nuclei are bright or dark objects
(based on Nauta & Feirtag)
- You should understand the pictures in the following figure, but there is no need to memorize them.

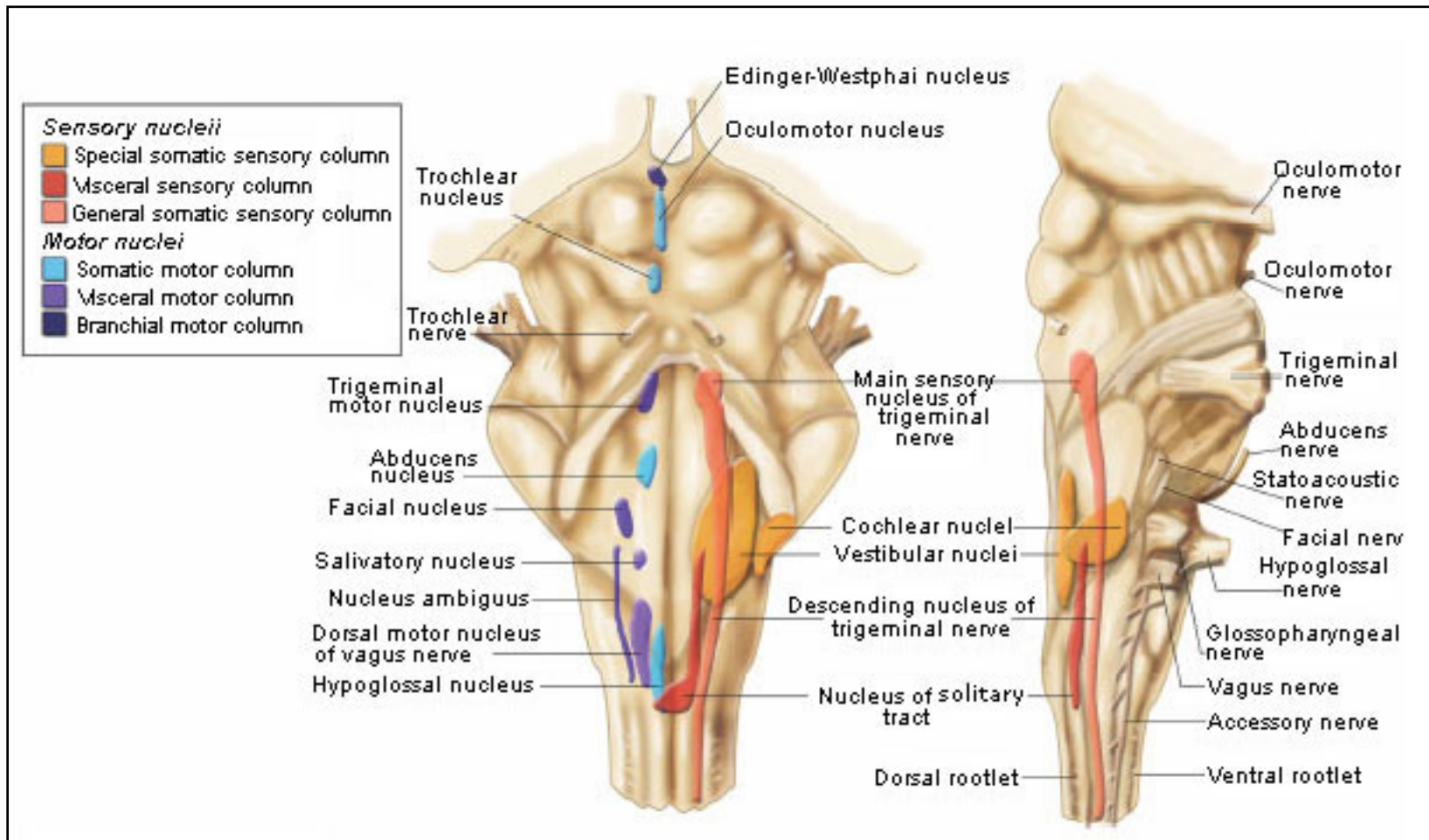


Image by MIT OpenCourseWare.

Brainstem Nuclei: secondary sensory and motor neuron columns

NEXT:

- We will study the sensory pathways of the trigeminal system, following 5th nerve axons to their terminations in the hindbrain and cervical spinal cord.

We begin by
The axons are from trigeminal ganglion cells--primary sensory neurons.

- These pathways and their regions of termination were important factors influencing the evolution of the hindbrain and more rostral structures.

The trigeminal nerve input (from the face): where does the information go?

- **Local reflex channel:** see following figures
 - Example: Pathway for eyeblink reflex
 - There is also a role of endogenous activity in eyeblink control, so the eyeblink is like a fixed action pattern in that respect.
- **Lemniscal pathways:**
 - Mammalian “trigeminal lemniscus”, leading to the ventrobasal nucleus of thalamus (the part called VPM, or *ventralis posteromedialis*).
 - **Hypothesis:** The decussation of axons to the midbrain and forebrain evolved with or after the evolution of the crossed retinal projection to the ‘tweenbrain and midbrain.
 - The earliest projections were ipsilateral or bilateral..

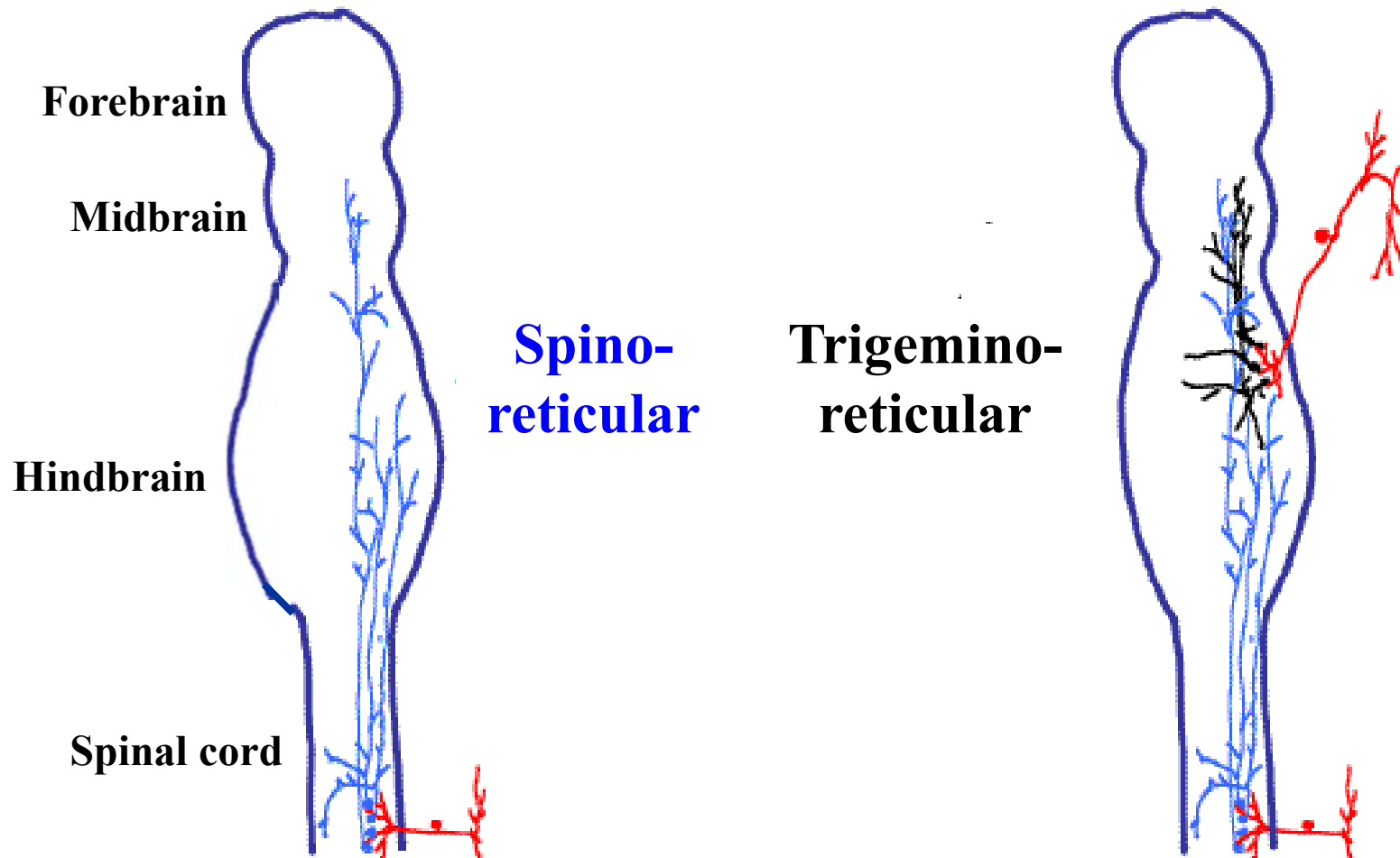
Questions, chapter 10

14) What was most likely the most ancient ascending pathway from the secondary sensory neurons of the trigeminal system?

Trigeminothalamic axons: mostly ipsilateral.

15) Describe the hypothesis for how the somatosensory and visual system pathways to the midbrain and forebrain evolved to become predominantly crossed.

A lemniscal pathway in mammals, bilateral, inherited from ancient chordates, carrying sensory information from the face (right-hand figure)



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.

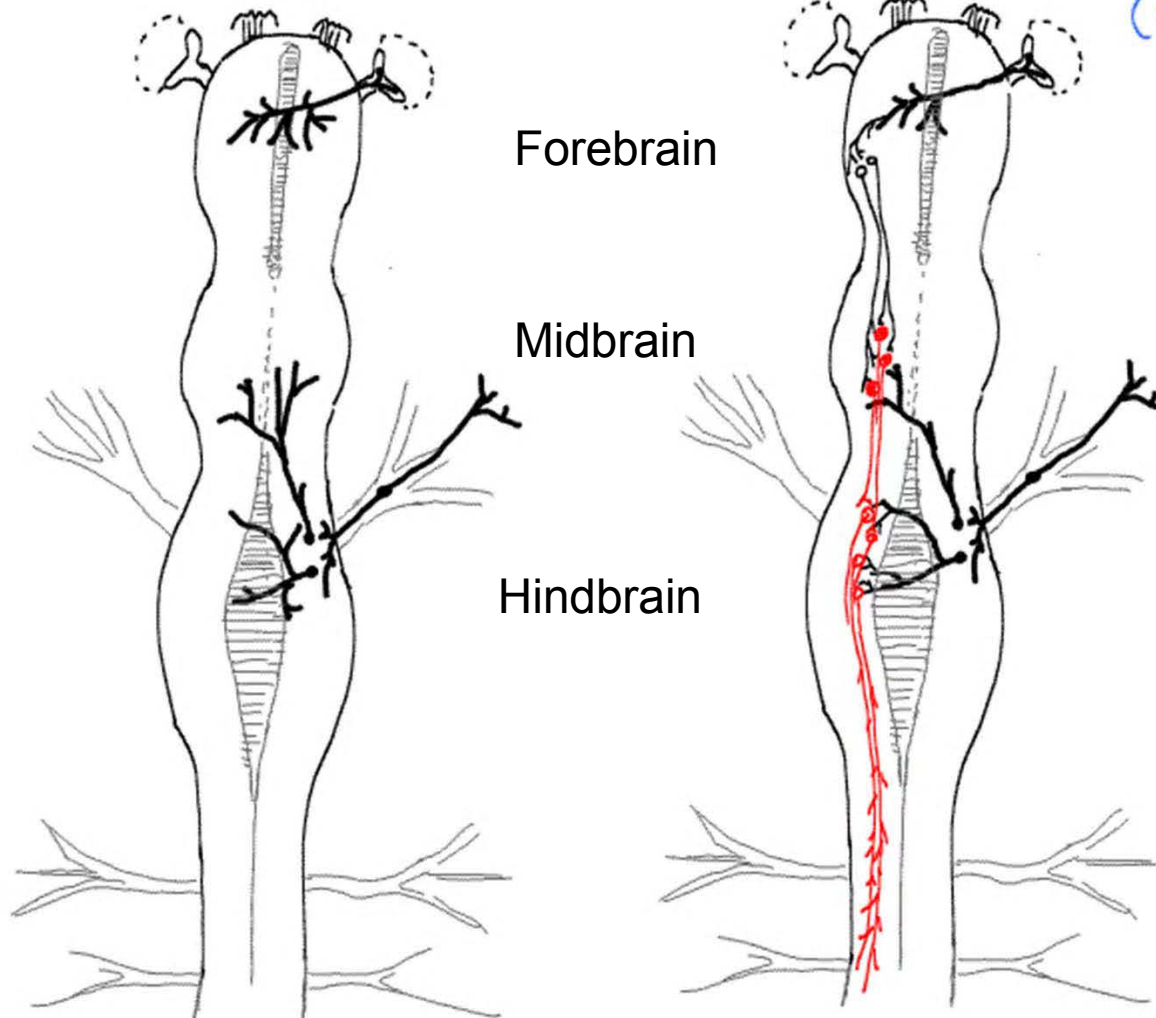
How did such projections lead to a predominantly crossed pathway?

- The following drawings illustrate the hypothesis.

Some bilateral projections became mostly contralateral for eliciting rapid escape/avoidance (see next slide)

1. Bilateral optic and somatosensory connections

2. Contralateral optic and SS → body flexion (escape)



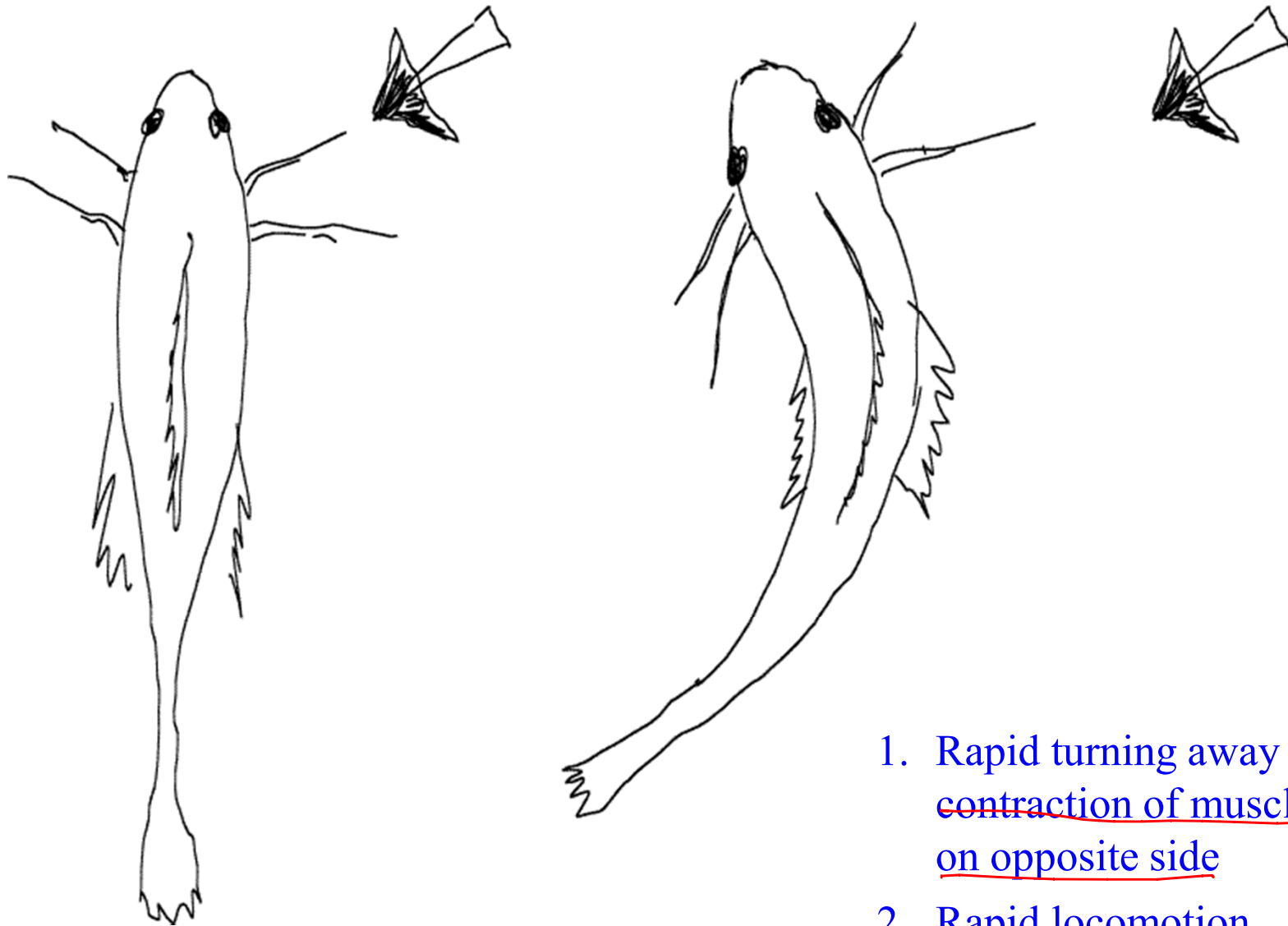
Optic stimuli:
Shadows moving,
sudden novelty,
intense light.

SS stimuli:
Novel, sudden,
intense or
painful.

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.

The primitive escape response



1. Rapid turning away via contraction of muscles on opposite side
2. Rapid locomotion

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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.

Thus, very early in chordate evolution, the bilateral projection from the lateral eyes to the hypothalamus expanded to become a crossed projection which reached structures eliciting escape movements.

1. This probably happened even before image-forming eyes evolved. Even with simple light detectors, an animal could discriminate right from left.
2. Image-forming eyes added to the ability of an animal to escape from a particular danger. The retinal projection to the midbrain became topographically organized.
3. Once a greater ability to distinguish different locations evolved, vision became useful also for orienting towards things for exploration and approach.

Further evolution resulted in crossed representation of the space around the head at both midbrain and forebrain levels:

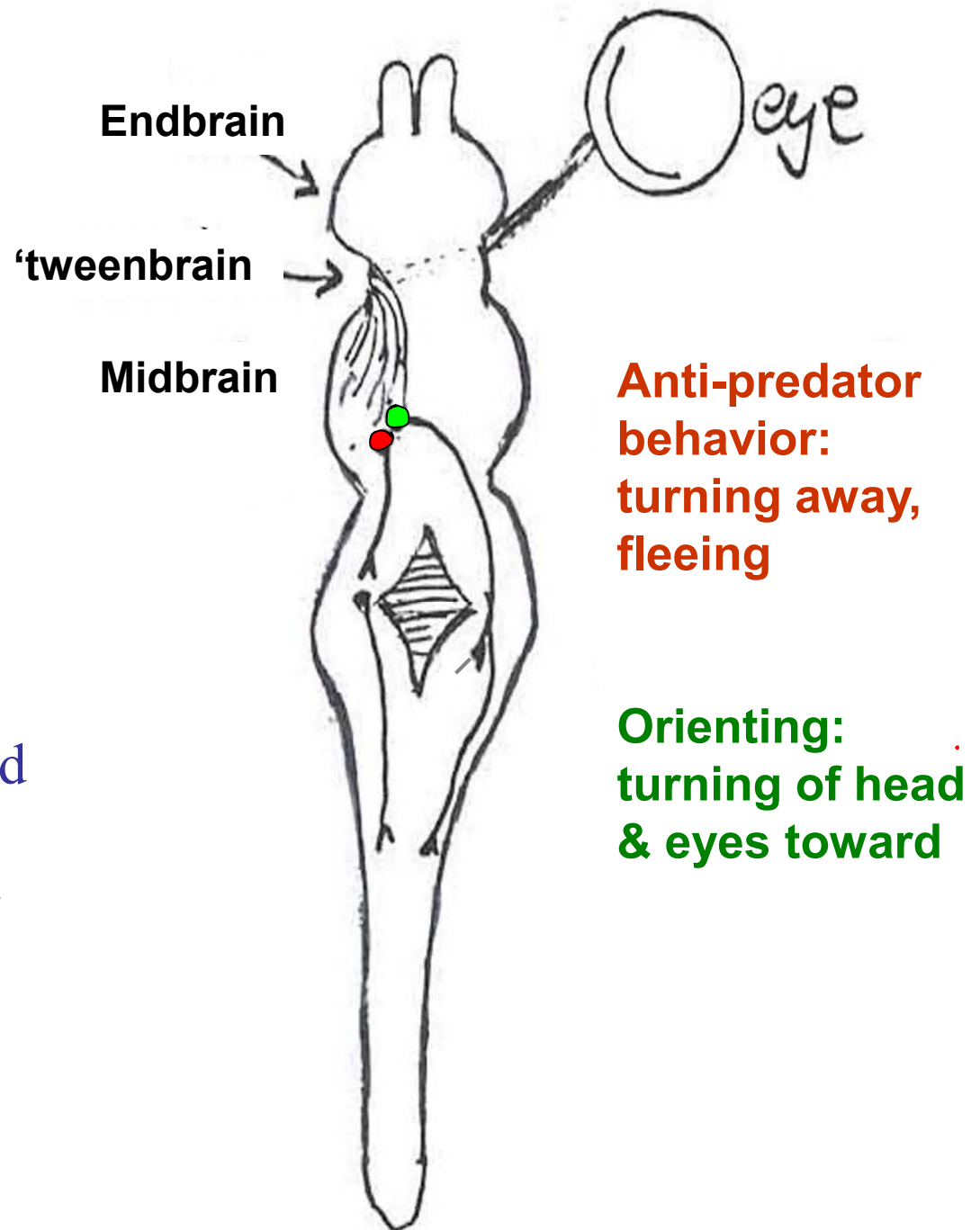
- The usefulness of orienting towards visually detected objects led to the evolution of a second descending pathway, separate from the uncrossed pathway. Rapid orienting towards a stimulus required contraction of muscles on the same side of the neck.
 - The second descending pathway therefore crossed the midline of the midbrain: the “tectospinal” tract descends to hindbrain and cervical spinal cord.
- The somatosensory inputs to the midbrain tectum evolved into a predominantly crossed pathway in order to match the visual projection. They responded to the same areas of space around the head and were useful for triggering the same responses.
- Thus, the right side of the space around the head came to be represented on the left side of the midbrain, and subsequently the forebrain as well. The other side developed in mirror-image fashion.

**Sketch of two descending pathways
from the midbrain tectum
(from class 4)**

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.

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



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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.

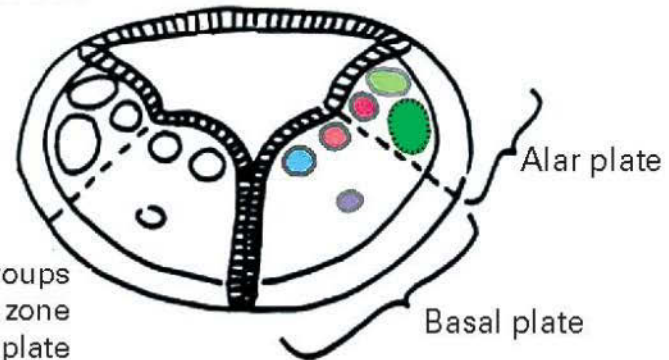
Now, more on the brainstem's
trigeminal nuclei

Mammalian trigeminal nuclei (of the 5th cranial nerve)

Embryonic hindbrain

Secondary sensory cell
groups in intermediate
zone of alar plate

Motor neuron groups
in intermediate
zone of basal plate



Adult hindbrain, principal cell columns and fiber tracts

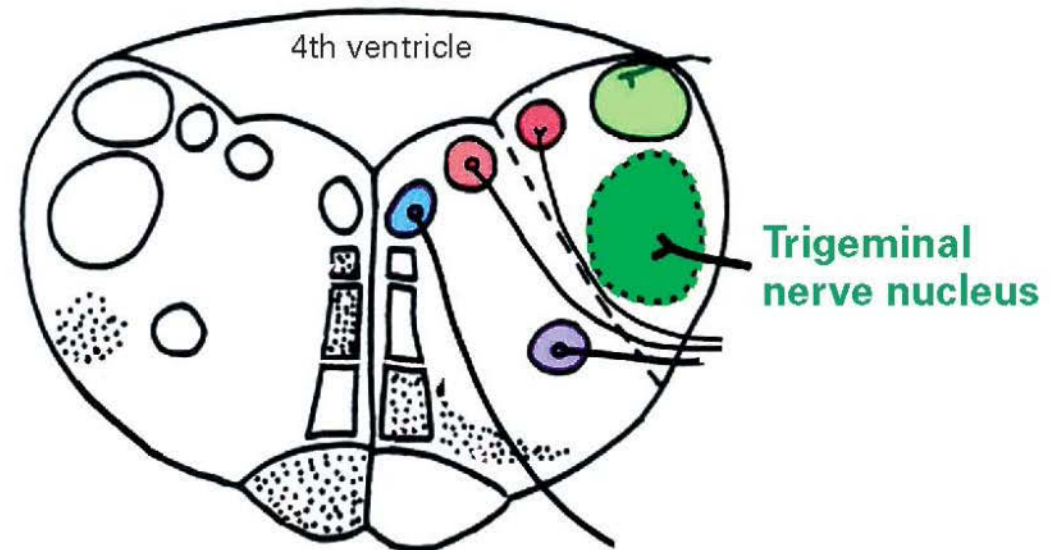
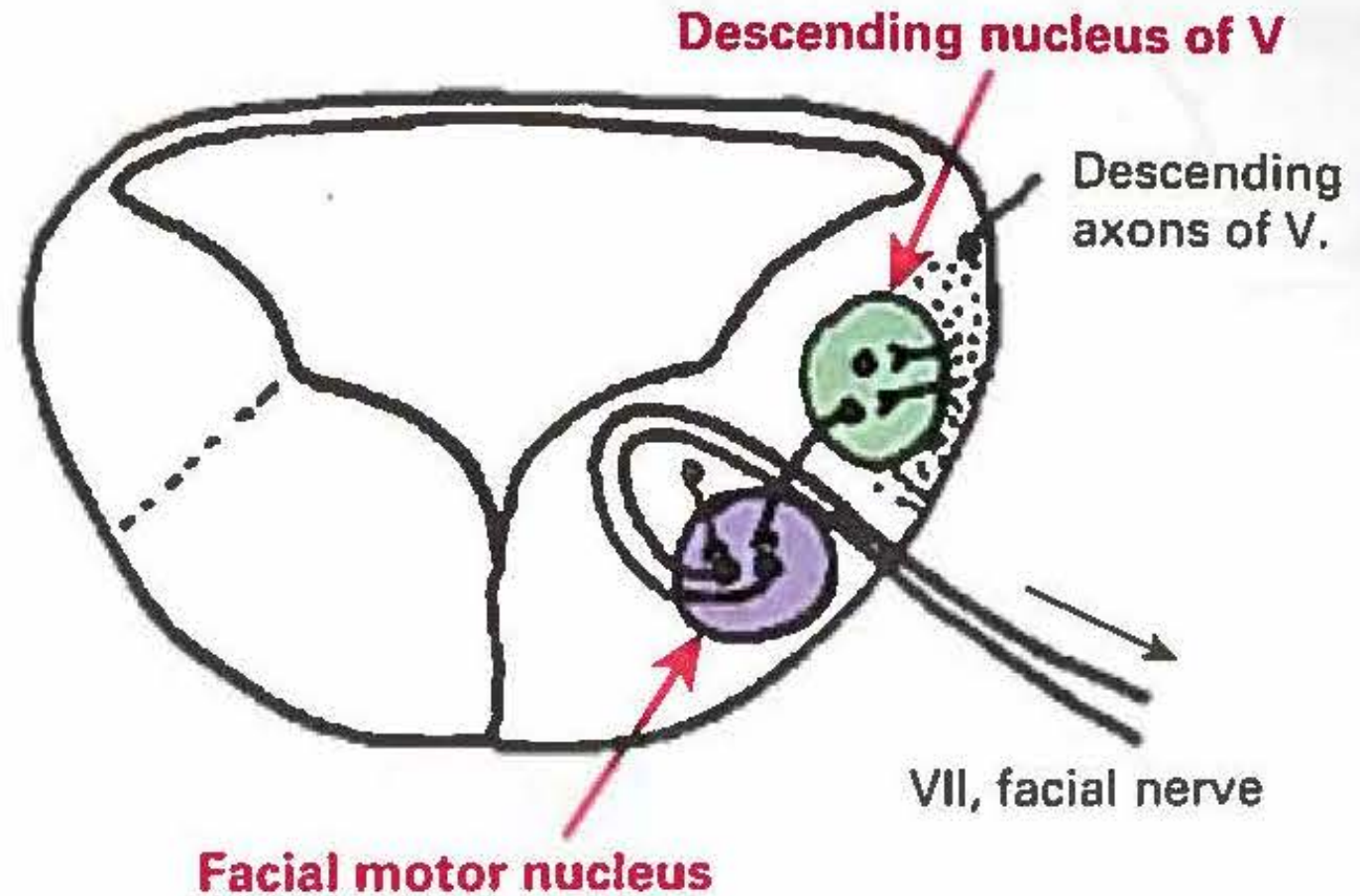


Fig 10-15

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Pathway for the eyeblink reflex



**Cranial n. VII,
facial nerve**

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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 10-16

Questions, chapter 10

13) Contrast trigeminal nerve and trigeminal lemniscus.

primary sensory

secondary sensory

The following figure is not as complex as it first appears. The elongated secondary sensory cell group of the trigeminal nerve, plus the inclusion of various groups of motor neurons, makes it seem complicated.

Hindbrain and the Trigeminal system of mammals

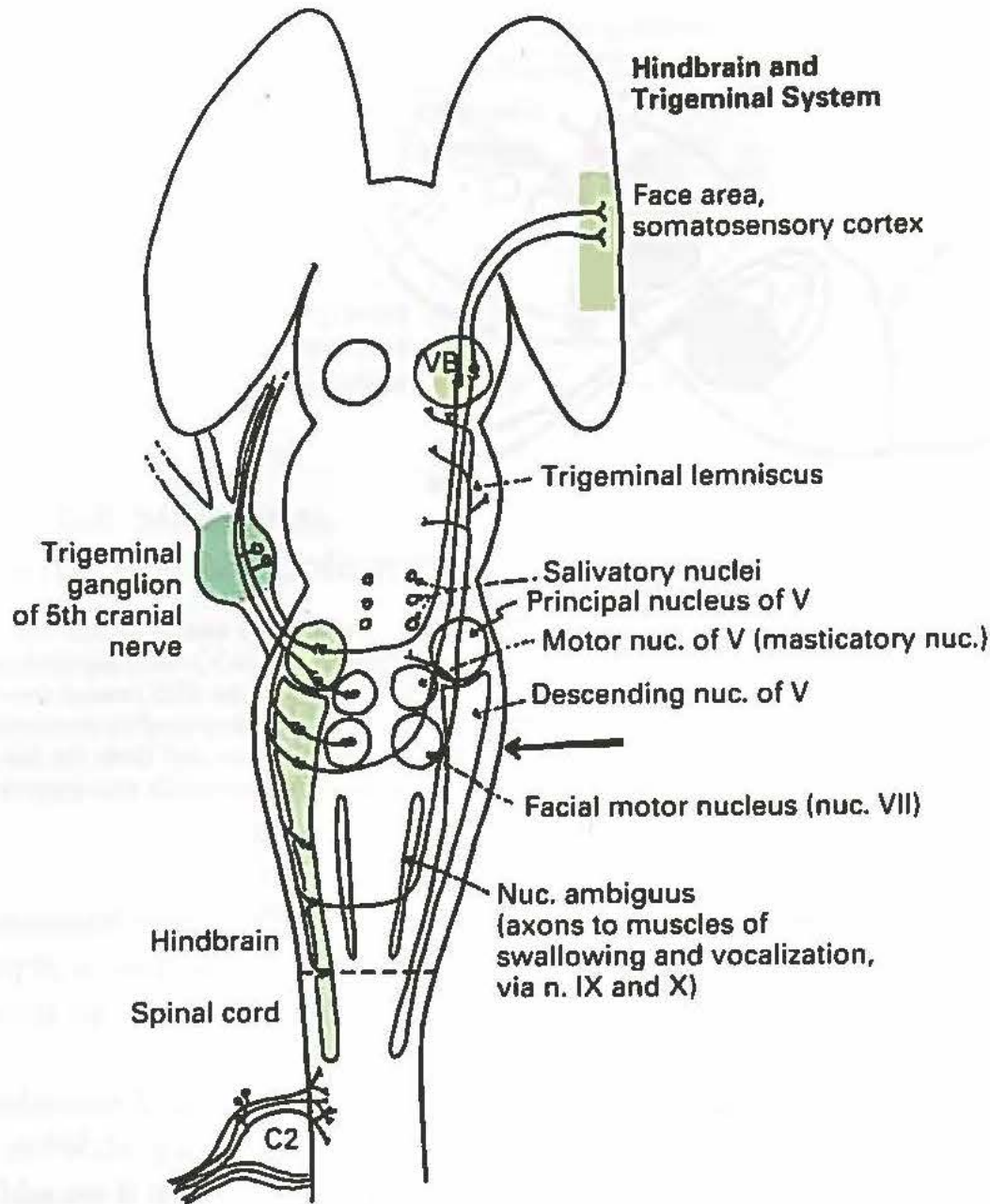


Fig 10-17

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Sensory channels are like those of spinal cord, including extensive bilateral connections with neurons of the reticular formation of hind- and midbrain (not shown).

Hindbrain and the Trigeminal system of mammals

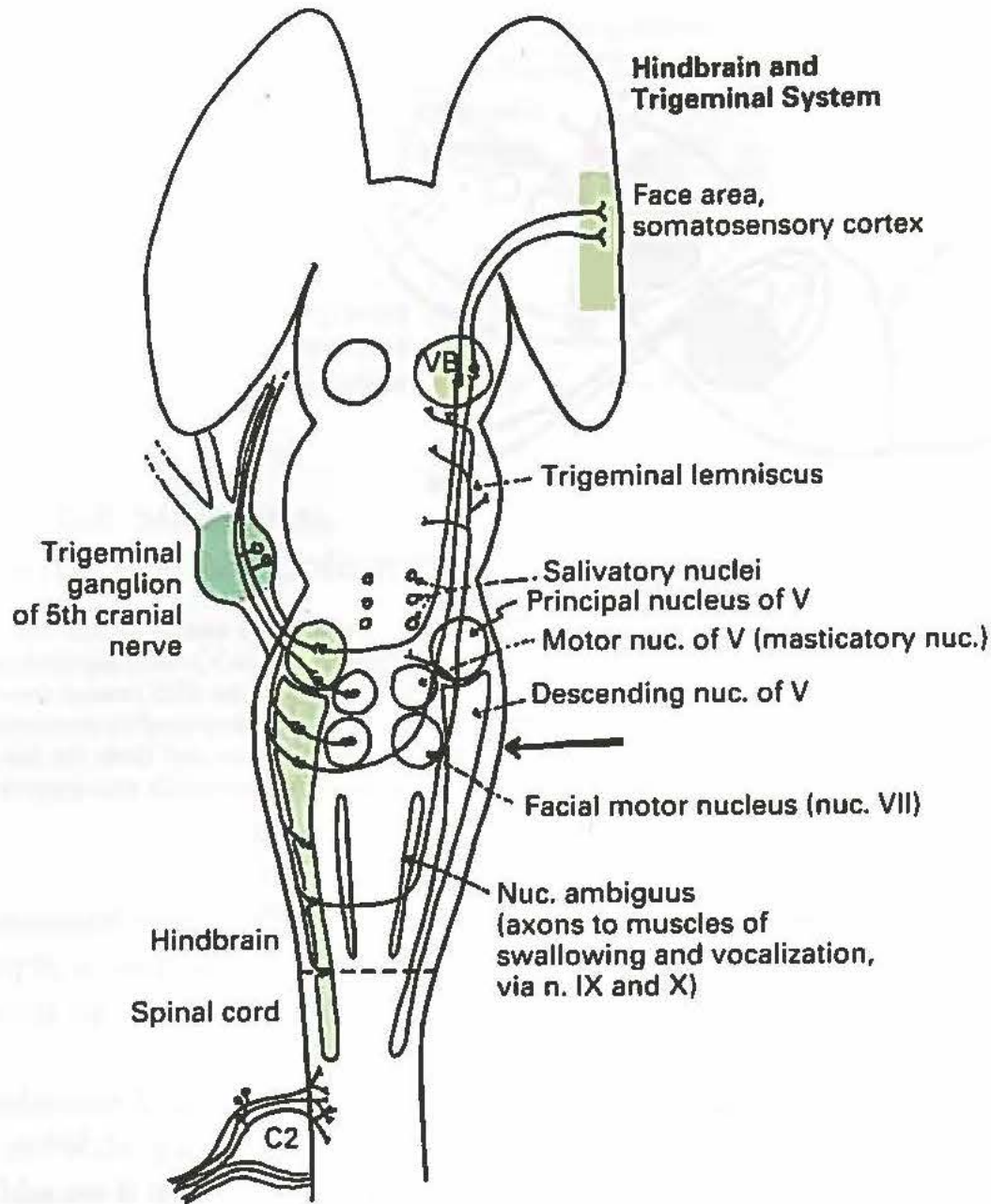


Fig 10-17

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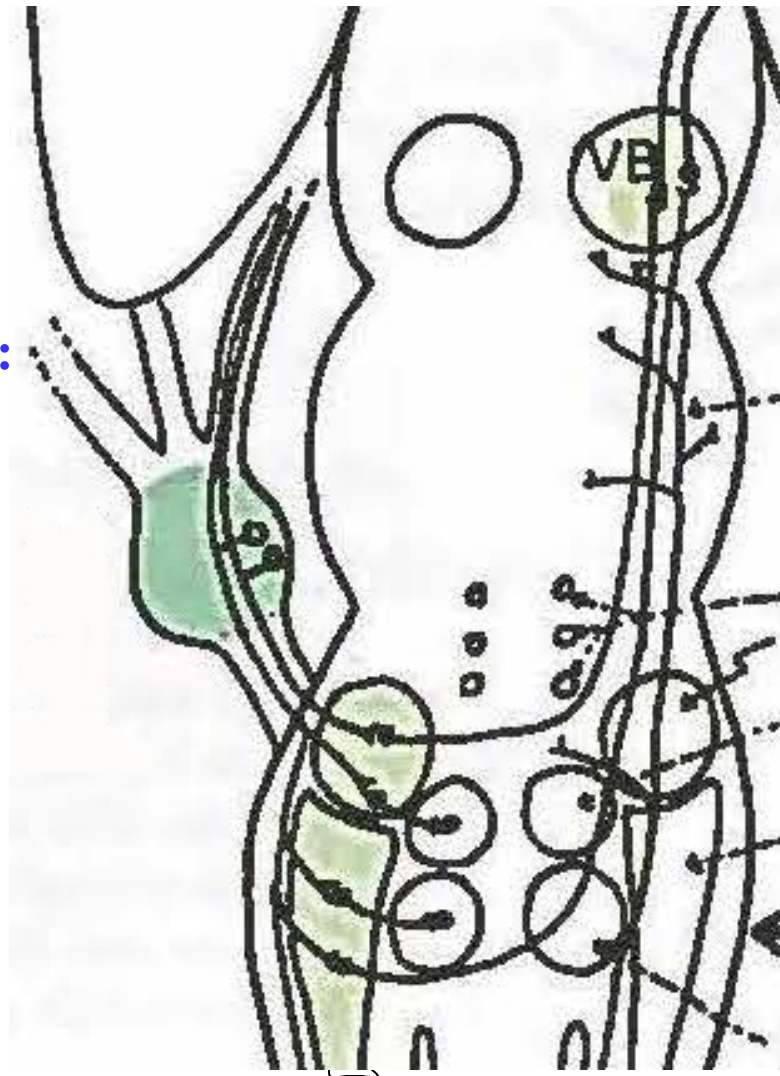
Schneider, G. E. *Brain structure and its Origins: In the Development and in Evolution of Behavior and the Mind*. MIT Press, 2014. ISBN: 9780262026734.

Trigeminal nerve (cranial nerve 5): Lemniscal channel and useful details

Three main branches of V:
Ophthalmic branch
Maxillary branch
Mandibular branch

Primary sensory neurons: in the trigeminal ganglion; axons enter the CNS through the pons (rostral hindbrain).

They synapse on **secondary sensory cells** of the principle nucleus of V and in the descending nucleus of V.



The Trigeminal Lemniscus: projections from the principle & Descending nuclei of V to the thalamus (longest axons end in the Ventrobasal nucleus)

Salivatory nuclei (parasympathetic)
Principal nucleus of V

Masticatory nucleus

Descending nuc. of V.

Facial motor nucleus

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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.

Questions, chapter 10

19) Try to describe the critical roles of the hindbrain in feeding behavior.

(If this was not answered in the previous class)

See the previous slide: the masticatory nucleus.
Also, the mouth area is innervated by V.

At this point, you could use a change of pace!

- We will look at some specializations of the 5th cranial nerve and the structures it innervates in some species.
- (Some of this was mentioned earlier.)

X

Sensory specializations, 5th cranial nerve and other hindbrain specializations (Review with additions)

- Snake sensory pit (in pit vipers) for infrared radiation detection
- Rodent vibrissae, for sensing the space around the head: *We will illustrate the brain representations.*
- Recall other specializations of the hindbrain mentioned earlier:
 - For taste functions in some fishes
 - For electrosensory abilities in weakly electric fish
 - Cerebellar expansions in large animals with highly developed manipulatory abilities

Rattlesnake trigeminal nerve: Innervation of a specialized distance sense

Rattlesnake trigeminal nerve: innervation of a specialized distance sense (*Butler & Hodos*)

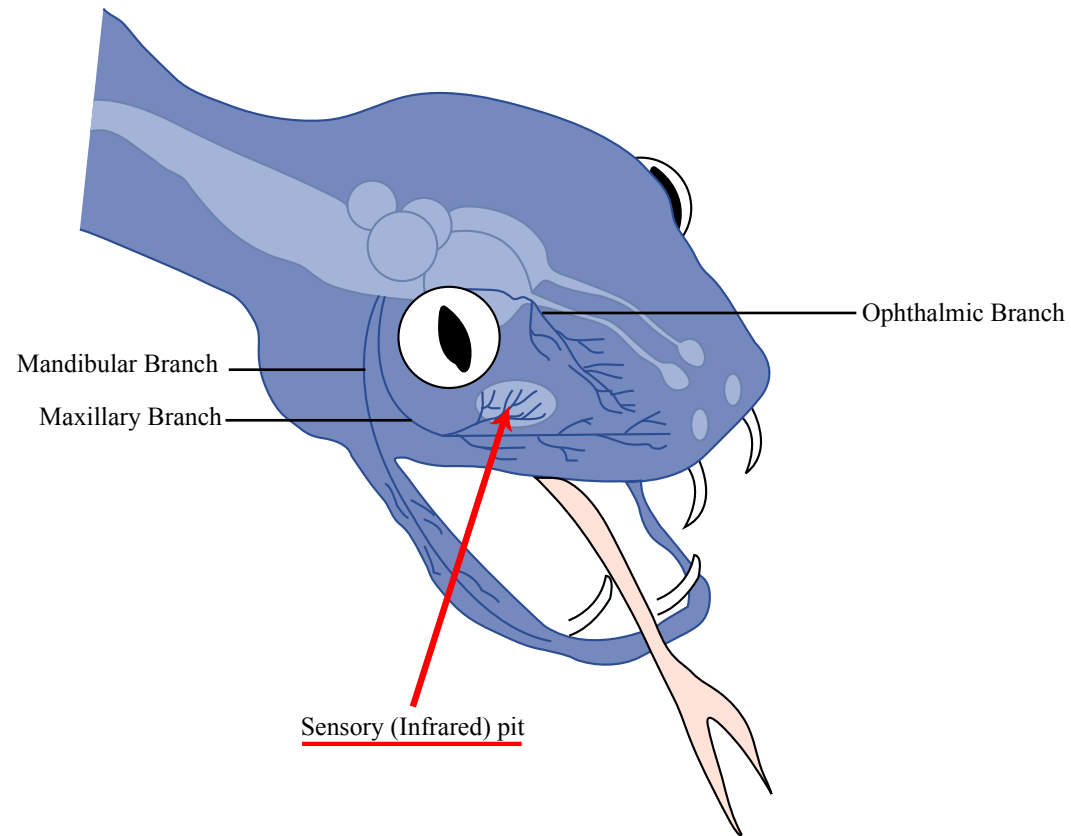


Image by MIT OpenCourseWare.

The evolution of changes in brain involve both size and architectural details

- Illustrated by the trigeminal system of moles and rodents
 - Relative size of central maps and sensory acuity are correlated.*
 - Organizational specializations: the “barrel fields” representing the vibrissae

** Studies of visual acuity and the visual cortex representation have shown this especially well.*

Somatosensory representation in mole neocortex

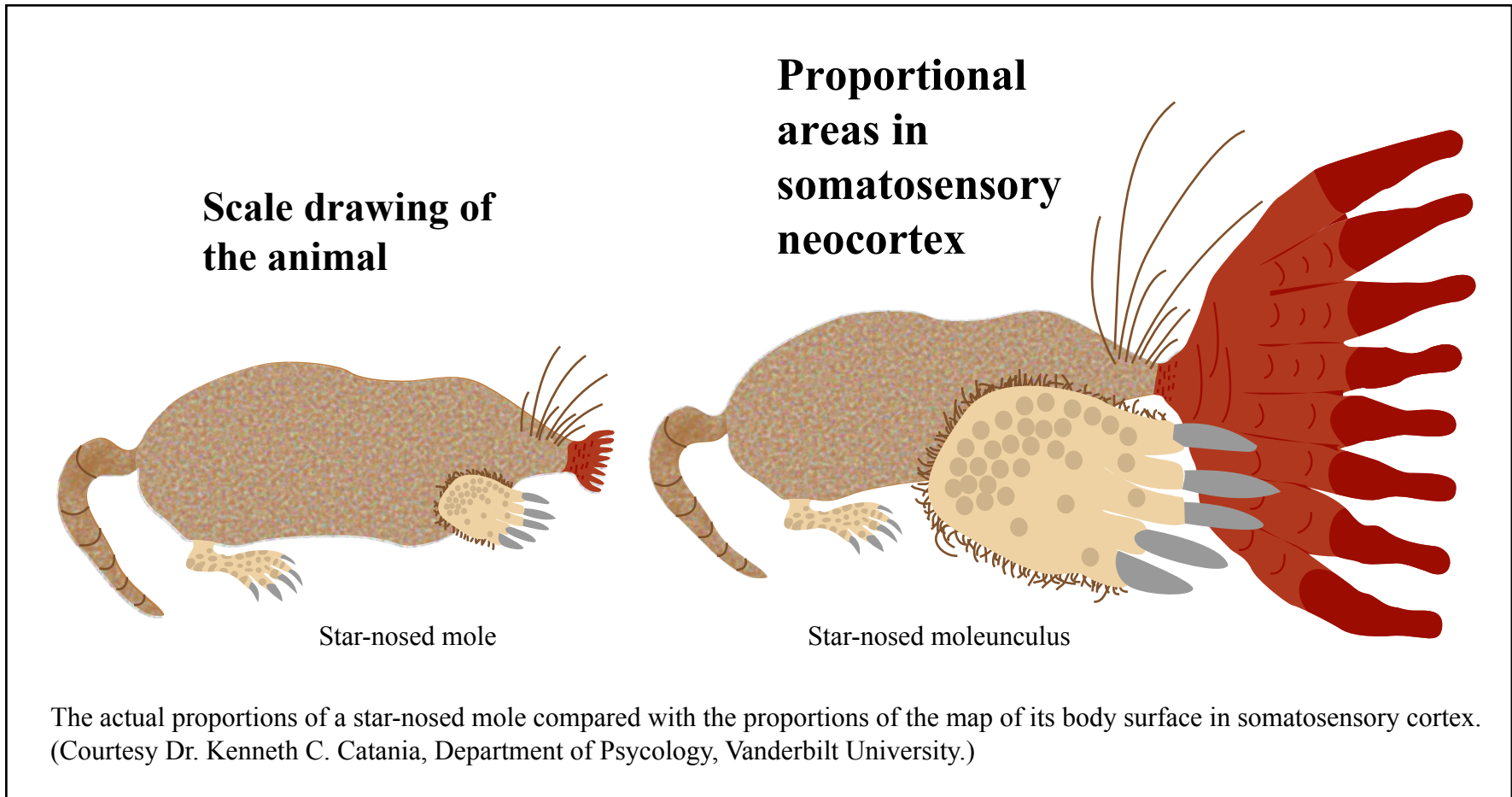


Image by MIT OpenCourseWare.

Somatosensory representation in a mouse or rat, from whiskers to “barrels”

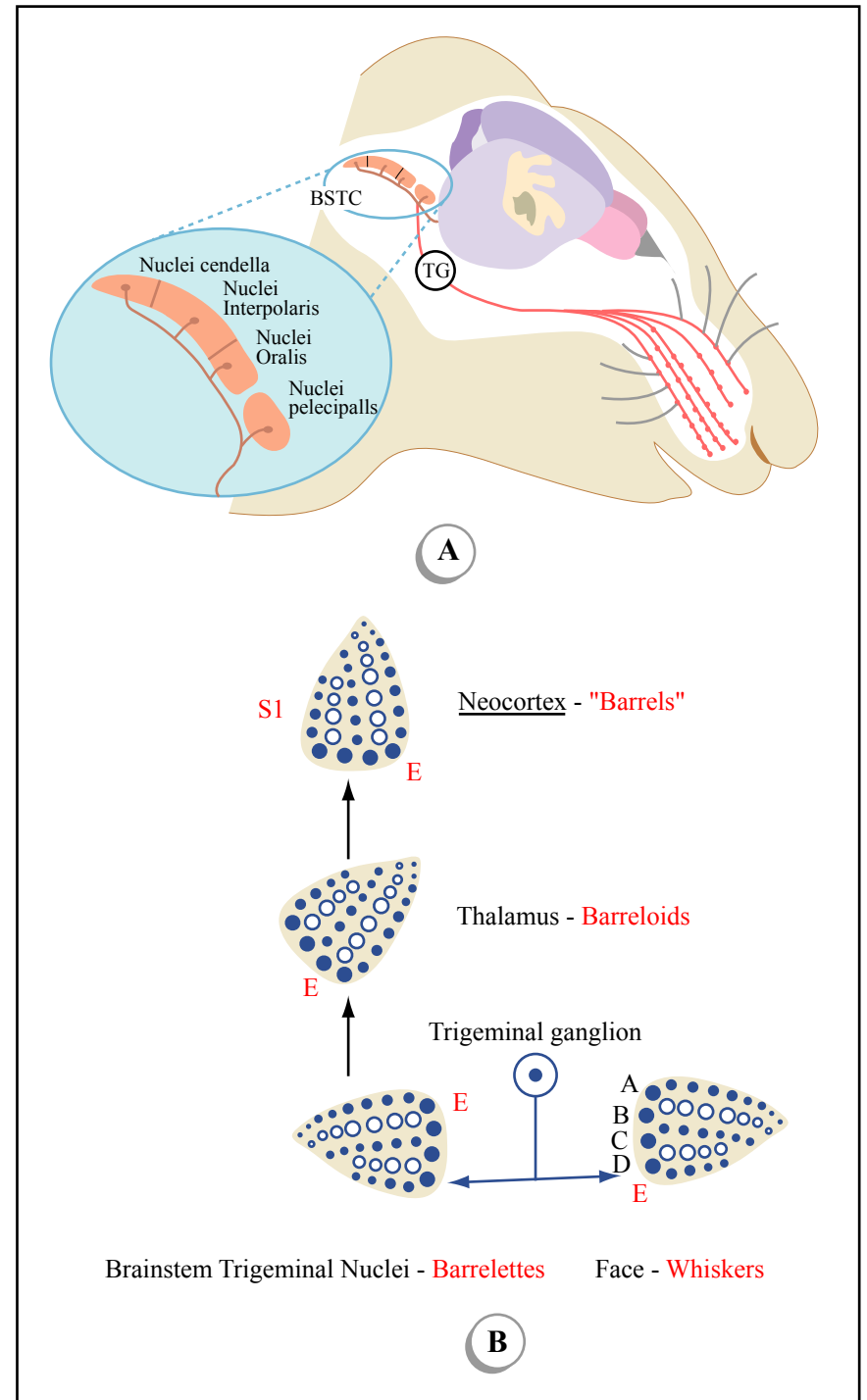


Image by MIT OpenCourseWare.

From class 6a:

Three successive tangential sections of mouse cerebral hemisphere, Nissl stain, showing the “barrel fields.” Each barrel represents one whisker.

Figure removed due to copyright restrictions.

Please see course textbook or:

Woolsey, Thomas A., and Hendrik Van der Loos. "The Structural Organization of Layer IV in the Somatosensory Region (SI) of Mouse Cerebral Cortex: The Description of a Cortical Field Composed of Discrete Cytoarchitectonic Units." *Brain Research* 17, no. 2 (1970): 205-42.

Fig.6-5a

P = Postnatal day

P4 rat neocortex, coronal section, DiI placed in

Ventrobasal nucleus of thalamus *and labels the*

(Jhaveri, Erzurumlu & Crossin, 1991)

axons to cortex

Figure removed due to copyright restrictions. Please see course textbook or: Jhaveri, Sonal, Reha S. Erzurumlu, YihU.
"Barrel Construction in Rodent Neocortex: Role of Thalamic Afferents versus Extracellular Matrix Molecules."
Proceedings of the National Academy of Sciences 88, no. 10 (1991): 4489-93.

Similar case, tangential section

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"Barrel Construction in Rodent Neocortex: Role of Thalamic Afferents versus Extracellular Matrix Molecules."
Proceedings of the National Academy of Sciences 88, no. 10 (1991): 4489-93.

P5 rat barrel fields, AChE stain, tangential section

Figure removed due to copyright restrictions. Please see course textbook or: Jhaveri, Sonal, Reha S. Erzurumlu, 'Yh'U'.
"Barrel Construction in Rodent Neocortex: Role of Thalamic Afferents versus Extracellular Matrix Molecules."
Proceedings of the National Academy of Sciences 88, no. 10 (1991): 4489-93.

Rat barrel fields, Cytochrome C tangential section

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"Barrel Construction in Rodent Neocortex: Role of Thalamic Afferents versus Extracellular Matrix Molecules."
Proceedings of the National Academy of Sciences 88, no. 10 (1991): 4489-93.

Cytochrome C: An electron carrier in the electron-transport chain; a small protein of just over 100 amino acids. The electron is passed to cytochrome oxidases.

From
whiskers
 to
barrelettes
 to
barreloids
 to
barrels

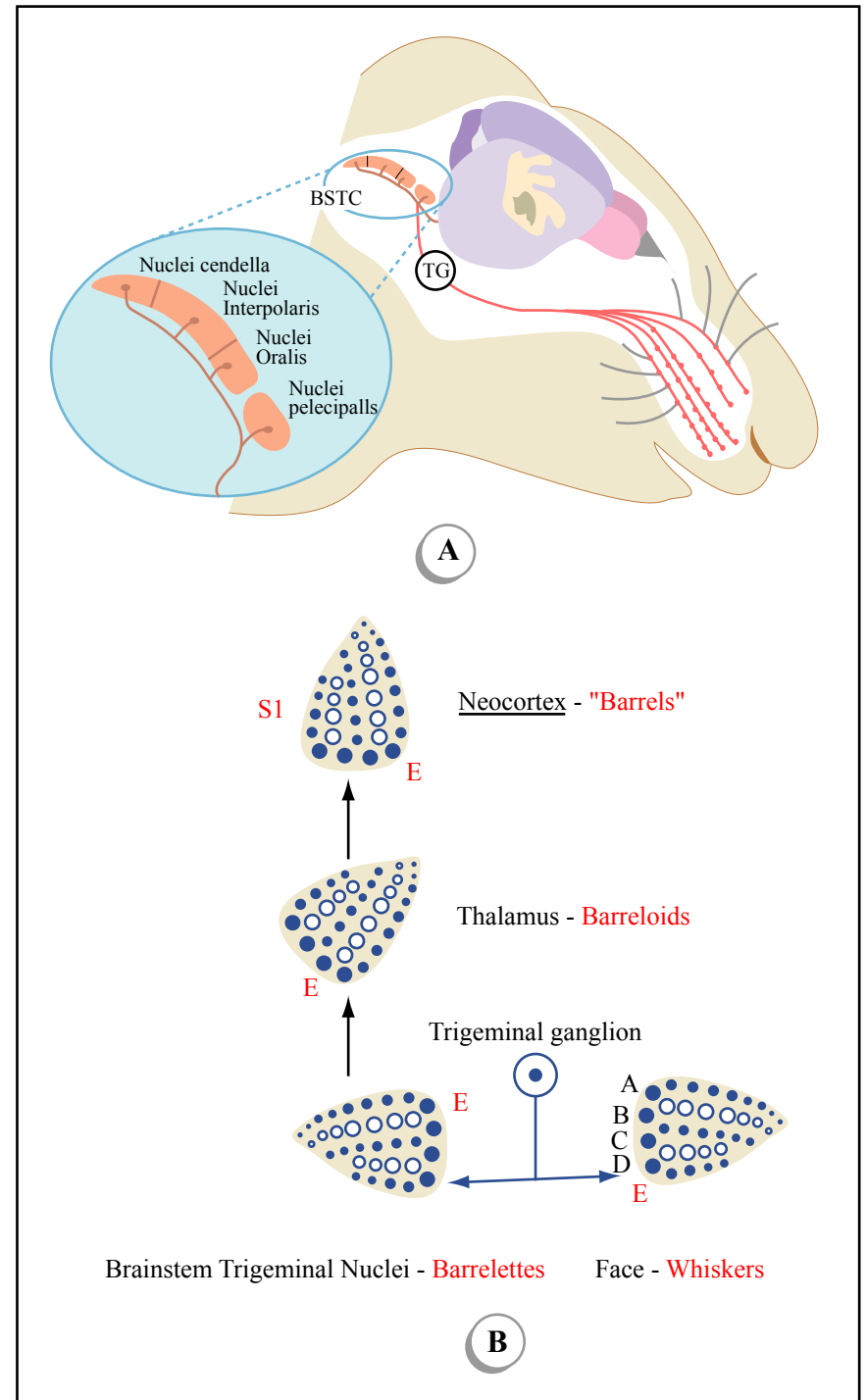


Image by MIT OpenCourseWare.

Examples of size increases and changes in architectural details within hindbrain systems

- Cerebellum of electric fish:
 - Electroreception and analysis: the lateral line receptor system for object detection (noted previously)
- Cerebellum of mammals
 - Coordination of fine movements influenced by multiple sensory pathways
- Somatosensory system of rodents (just reviewed)
- Taste cell groups in hindbrain in some ray-finned fishes
 - Enlarged vagal lobes and facial lobes of hindbrain (Review: see next slides)
 - Inputs from specialized receptors for bottom feeding,
 - *via* 7th, 9th, 10th cranial nerves

Large variations in size of specific brain parts are examples of “mosaic evolution” (Striedter, 2005, ch 5)

The changes cause "distortions" in the basic organization of the hindbrain

- **Variations in relative size of parts**
 - Huge vagal lobe of the fresh-water buffalofish [Review]
 - Vagal and facial lobes of the catfish [Review]
 - Electric fish have an enormous and specialized cerebellum. [Review]
- Cell migrations from the rostral hindbrain's alar plate—
from a proliferative region called the "rhombic lip":
 - To cerebellum
 - To pre-cerebellar cell groups – especially the cells of the pons

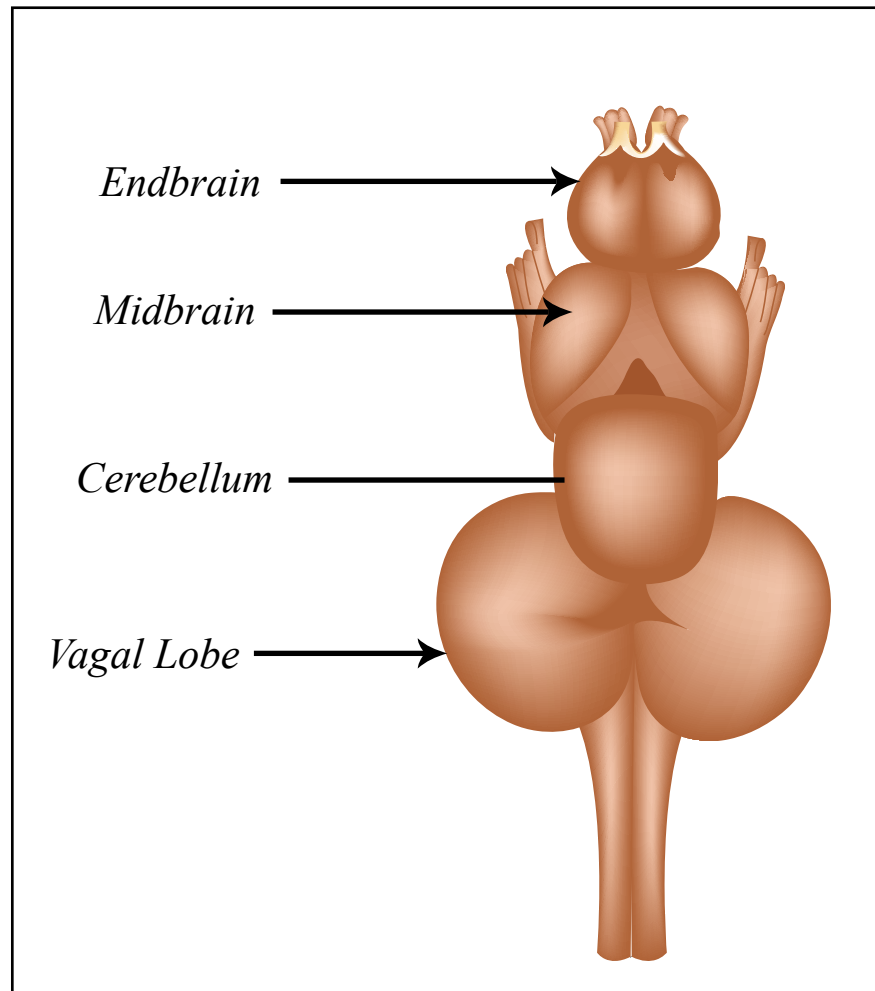


Image by MIT OpenCourseWare.

Buffalofish (*Carpion*) has a specialized palatal organ for filtering the water for food; it is innervated by the vagus nerve.

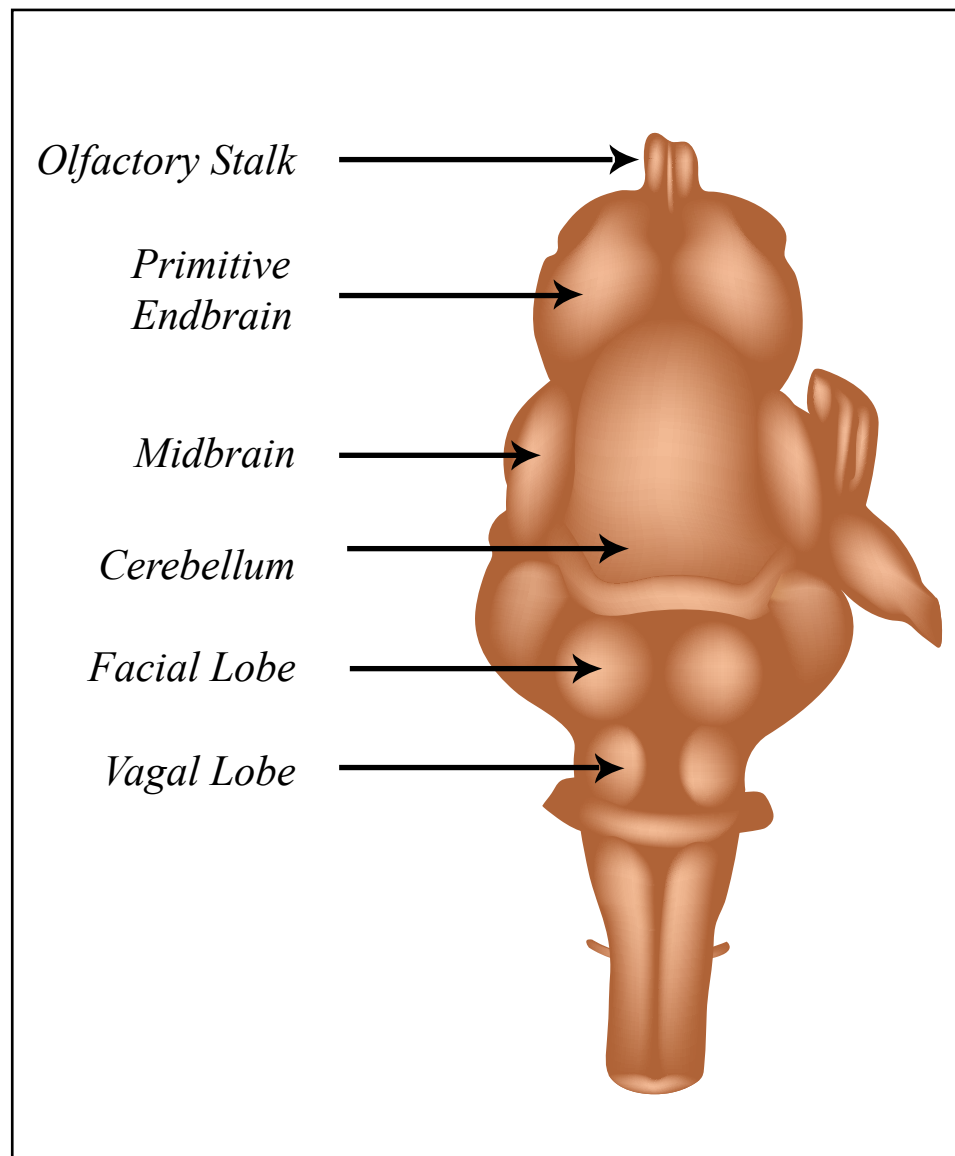


Image by MIT OpenCourseWare.

The catfish has taste receptors all over its body innervated by the facial nerve (7th cranial nerve)

Amiurus melas (the small catfish)

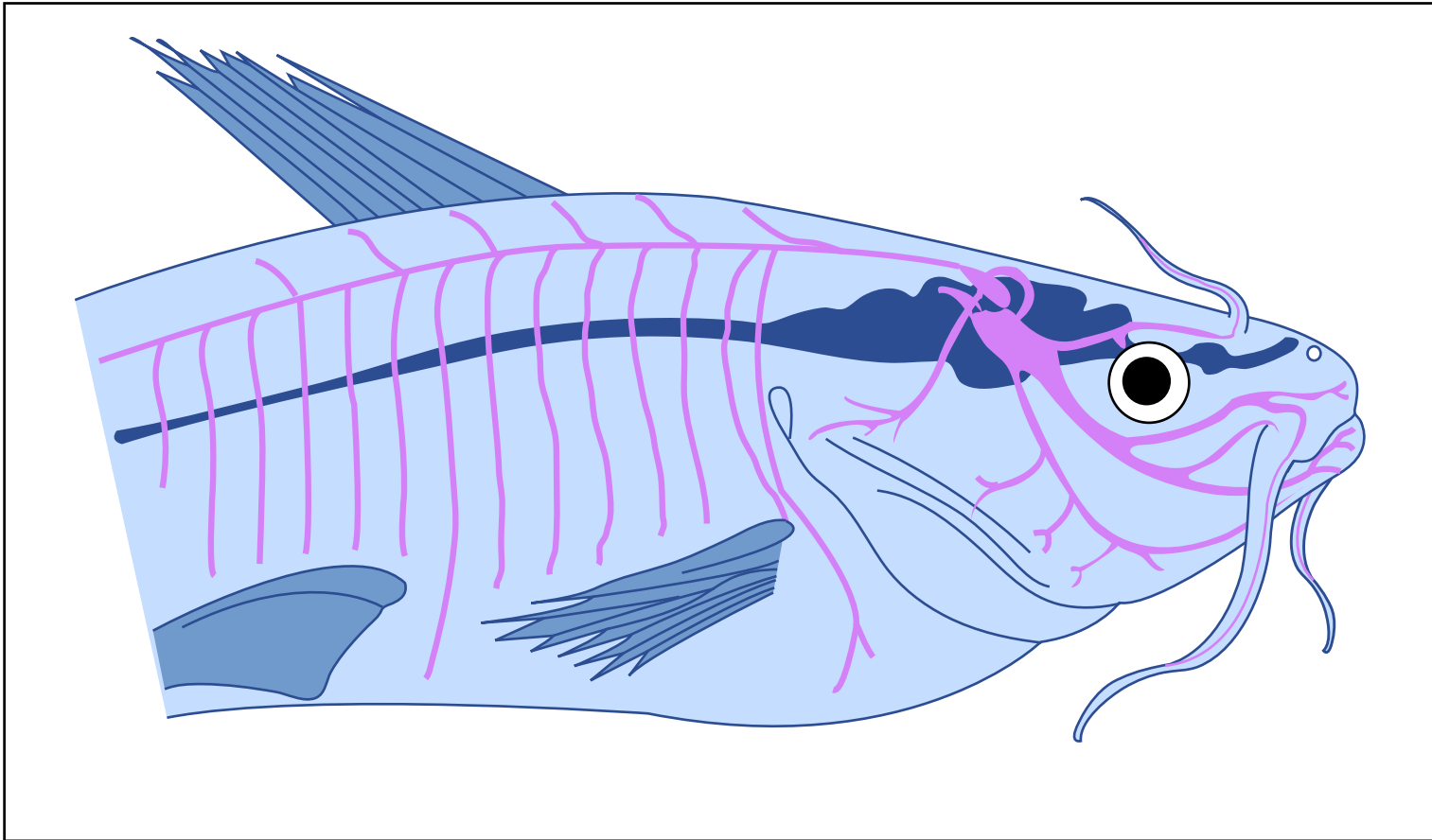
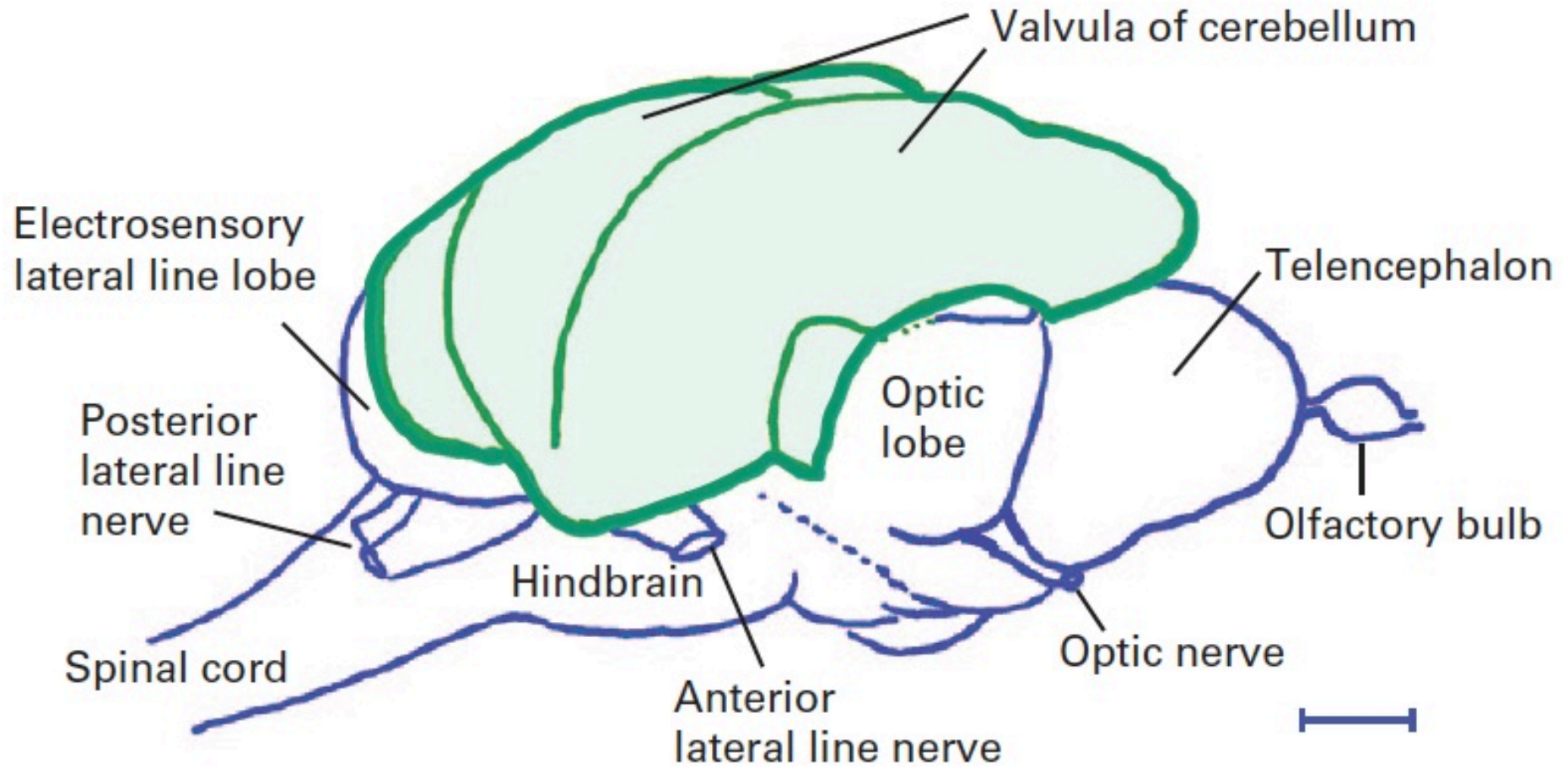


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The enlarged cerebellum of a Mormyrid fish

Fig.6-1

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9.14 Brain Structure and Its Origins

Spring 2014

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