*From Brodal,*
*$2^{nd}$ ed. fig 20.1;*
*$3^{rd}$ ed. Fig 21.1*

*Note the names of the layers--named for cell types rather than for axonal stratification.*

Figure removed due to copyright restrictions. Please see figure 21.1 of:
Brodal, Per. *The Central Nervous System, Structure and Function*. 3rd ed. Oxford University Press, 2003. ISBN: 9780195165609.

Note: The source of this particular figure is usually not cited accurately!

# Question on cortical fiber architecture:

What are the **radial fascicles** of the neocortex *(Nauta & Feirtag p. 293-295)* ? What are three major groups of cortical output axons found in these fascicles?

…and what are their destinations?

# Question on cortical fiber architecture:

What are the **radial fascicles** of the neocortex *(Nauta & Feirtag p. 293-295)* ? What are three major groups of cortical output axons found in these fascicles?

1) Axons of pyramidal cells in layer 3
2) Axons of pyramical cells in layer 5
3) Axons of pyramidal and fusiform cells in layer 6.

**Destinations:**

- From layers 2-3 via U-fibers to other neocortical areas, including areas in the opposite hemisphere.
- From layer 5 to various subcortical destinations
- From layer 6 to thalamic cell groups.

## *Question about tangential fibers (orthogonal to the radial fascicles):*

**What is the line of Gennari** *(see Nauta & Feirtag, fig. 112)* ? It gives the striate cortex its name.

Gennari's line is a layer of mostly tangential fibers in the human primary visual cortex, named after the Italian medical student who first called attention to it (in 1776). It is located in the middle of layer 4 and gives the striate cortex its name—it is more prominent in area 17 than in other areas.

(Note in slides 10 and 11 that there are other tangentially arranged bands of fibers in the neocortex: within layer 1, within layer 5, within layer 6 and also the white matter below layer 6.)

**Area 17-18 border region, Nissl stain, developing human brain at 32 weeks gestation: Area 17 occupies the left half of the photo.**

line, or stripe, of Gennari within layer 4.

Figure removed due to copyright restrictions. Please see course textbook or: Larroche, J. Cl. "*The Development of the Central Nervous System During Intrauterine Life*." Human Development. Saunders, 1966.

**Fig 33-3**

**The same region in a myelin stained section**

**Fig 33-4**

# Area 17-18 border, Nissl stain, adult human brain *(Nauta & Feirtag fig. 112b)*

Figure removed due to copyright restrictions. Please see:
Nauta, Walle J. H., and Michael Feirtag. *Fundamental Neuroanatomy*. Freeman, 1986. ISBN: 9780716717232.

# Area 17-18 border, myelin stain *(Nauta & Feirtag fig. 112a)*

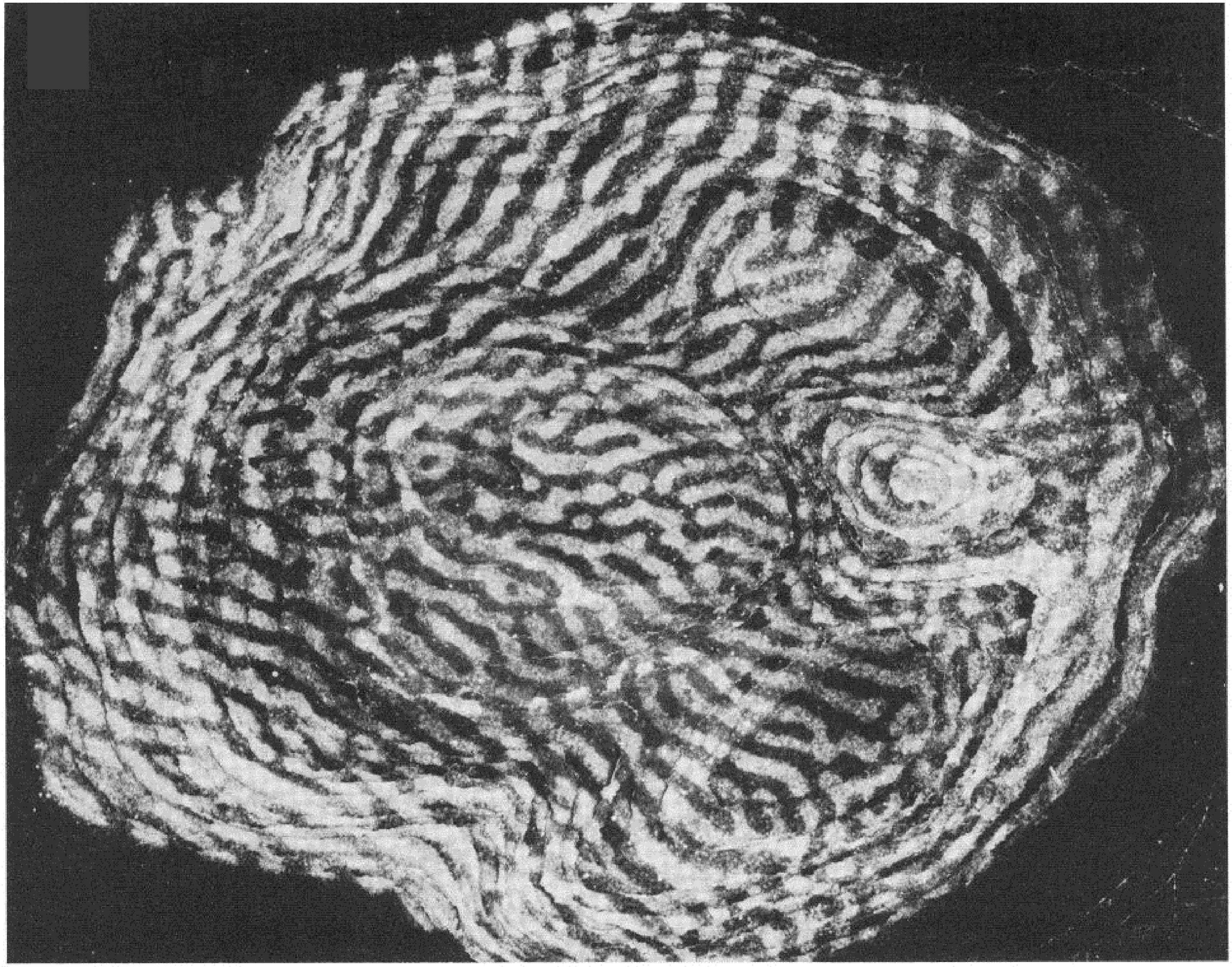
Figure removed due to copyright restrictions. Please see:
Nauta, Walle J. H., and Michael Feirtag. *Fundamental Neuroanatomy*. Freeman, 1986. ISBN: 9780716717232.

# *Specialized cortical columns:*

A. How could an anatomist visualize the ocular dominance stripes in striate neocortex *(see Nauta & Feirtag fig. 116)* ?

B. Compare: Patricia Goldman-Rakic's discovery, with Nauta, of columns in the retrosplenial cortex (posterior limbic system cortex near the posterior end, or splenium, of the corpus callosum) -- see fig. 117.

A.



Courtesy of the Society for Neuroscience.
Source: LeVay, Simon, Michelle Connolly, et al. "The Complete Pattern of Ocular Dominance Stripes in the Striate Cortex and Visual Field of the Macaque Monkey." *The Journal of Neuroscience* 5, no. 2 (1985): 486-501. 

**Fig 33-6** Projections of one eye seen in tangentially cut sections through layer 4 after transneuronal transport of 3H-prolein from one eye

B. Columnar patterns of axon termination are a common feature of many inputs to neocortical areas:

*Nauta & Feirtag fig.117:* Projections to retrosplenial association neocortex of monkey from prefrontal association cortex at the frontal pole



(Many such columnar projections have not been mapped in surface views.)

# What are the different <u>types</u> of cortex? How do various regions of neocortex differ from each other?

***MAJOR TYPES**: **Neocortex (isocortex) and allocortex.***

*Allocortex is limbic cortex, and includes paleocortex (olfactory) laterally and archicortex (hippocampus) medially and caudally.*

*In addition, there are **transitional** types of cortex between neocortex and allocortex, sometimes referred to as "juxtallocortex" or "paralimbic cortex" (next slide).*

Within these major types:

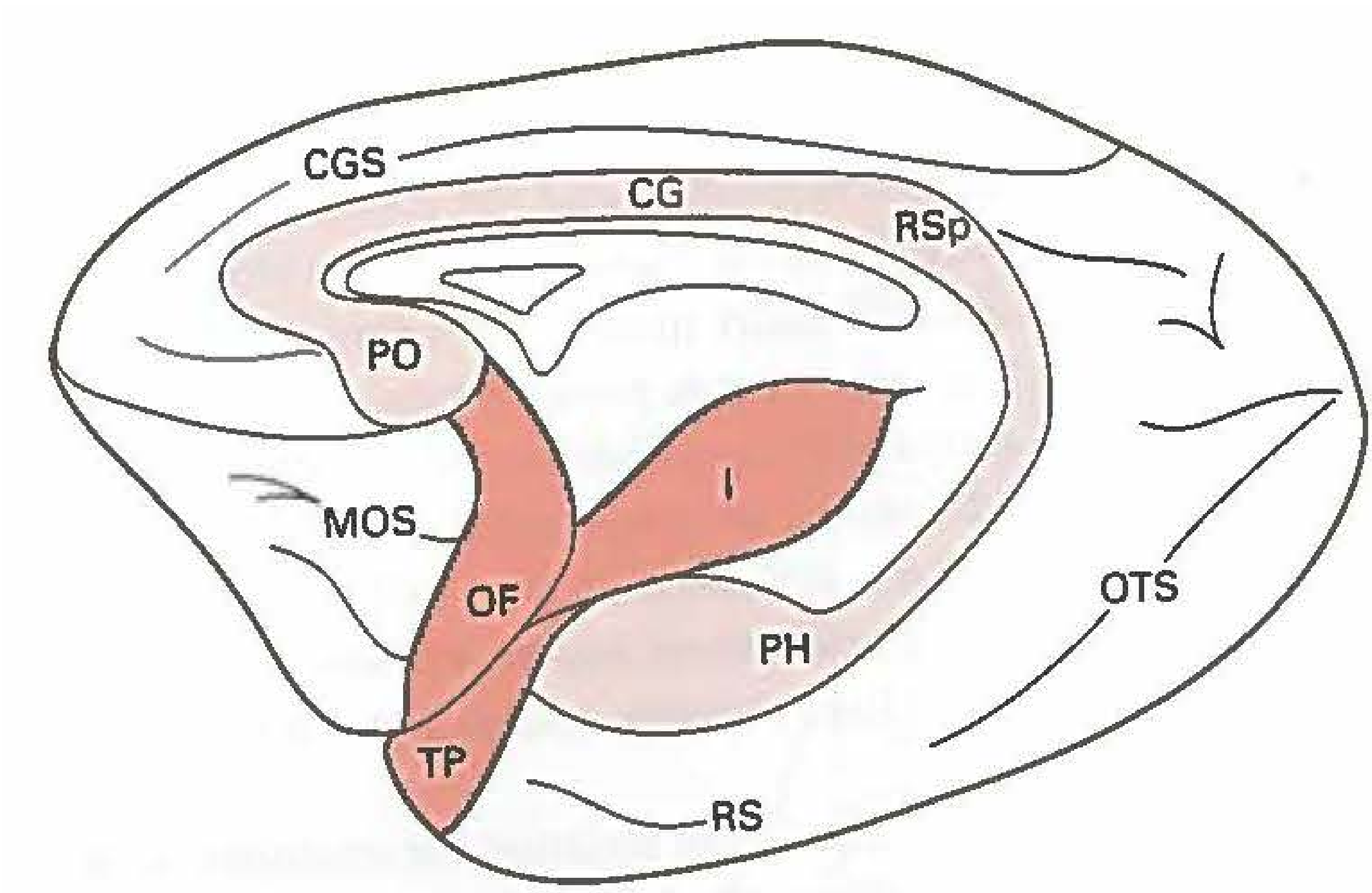
***REGIONAL DIFFERENCES**: Various neocortical areas with granular and agranular extremes; differences in thickness of the different layers, etc.*

## Illustrations of two types of grouping of cortical regions

1. By major connections
2. By cytoarchitecture as seen with Nissl stains

Based on connections:

# The girdle of paralimbic areas: olfactocentric & hippocampocentric





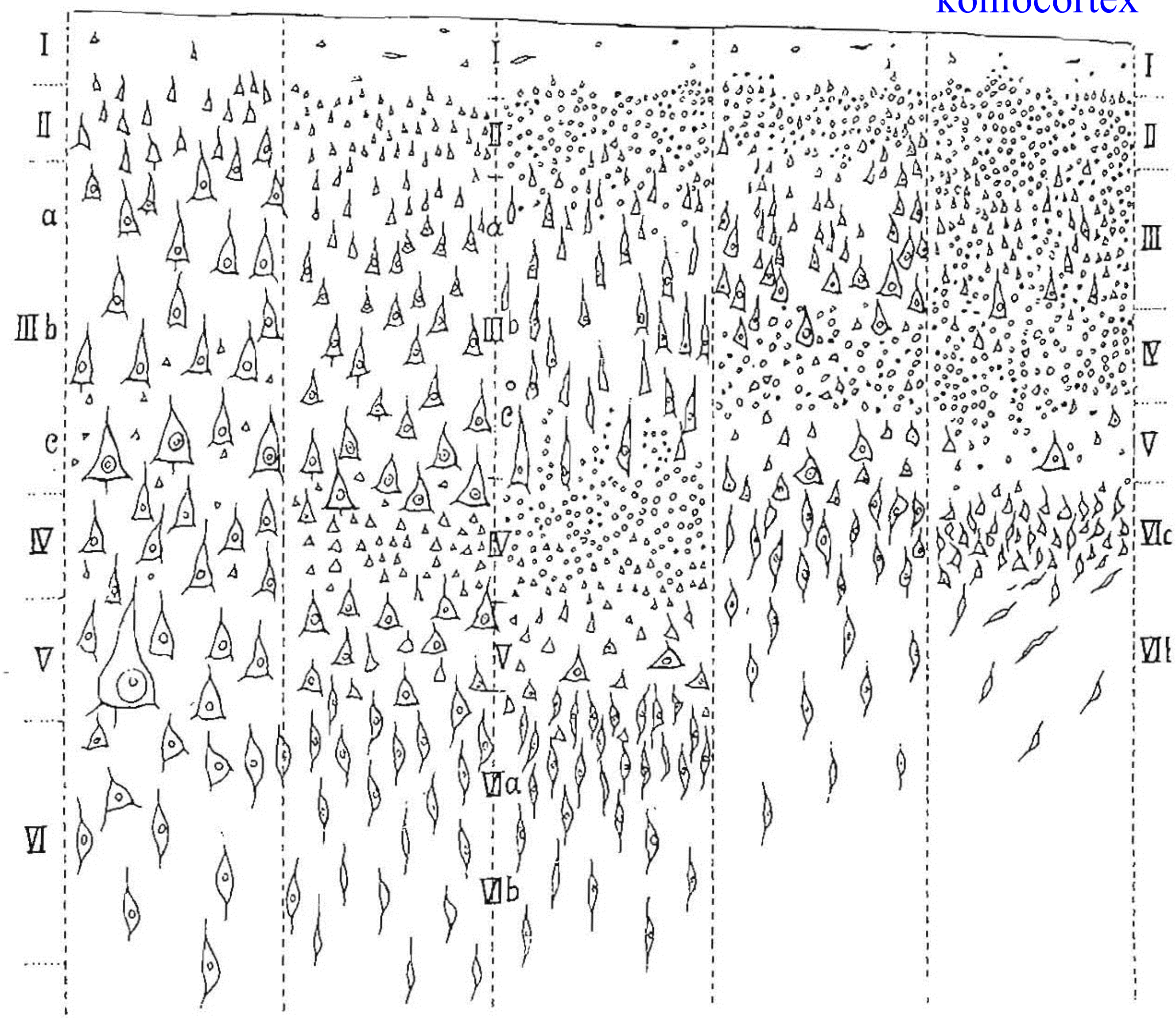

Schneider, G. E. *Brain structure and its Origins: In the Development and in Evolution of Behavior and the Mind*. MIT Press, 2014. ISBN: 9780262026734.

# Based on cytoarchitecture:

Regional differences in neocortical areas:

Agranular

Granular, koniocortex



| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Primary motor | Prefrontal type | Parietal type | Polar type | Primary sensory |

From Constantin von Economo (1927, English trans. 2009)

**Fig 33-8**

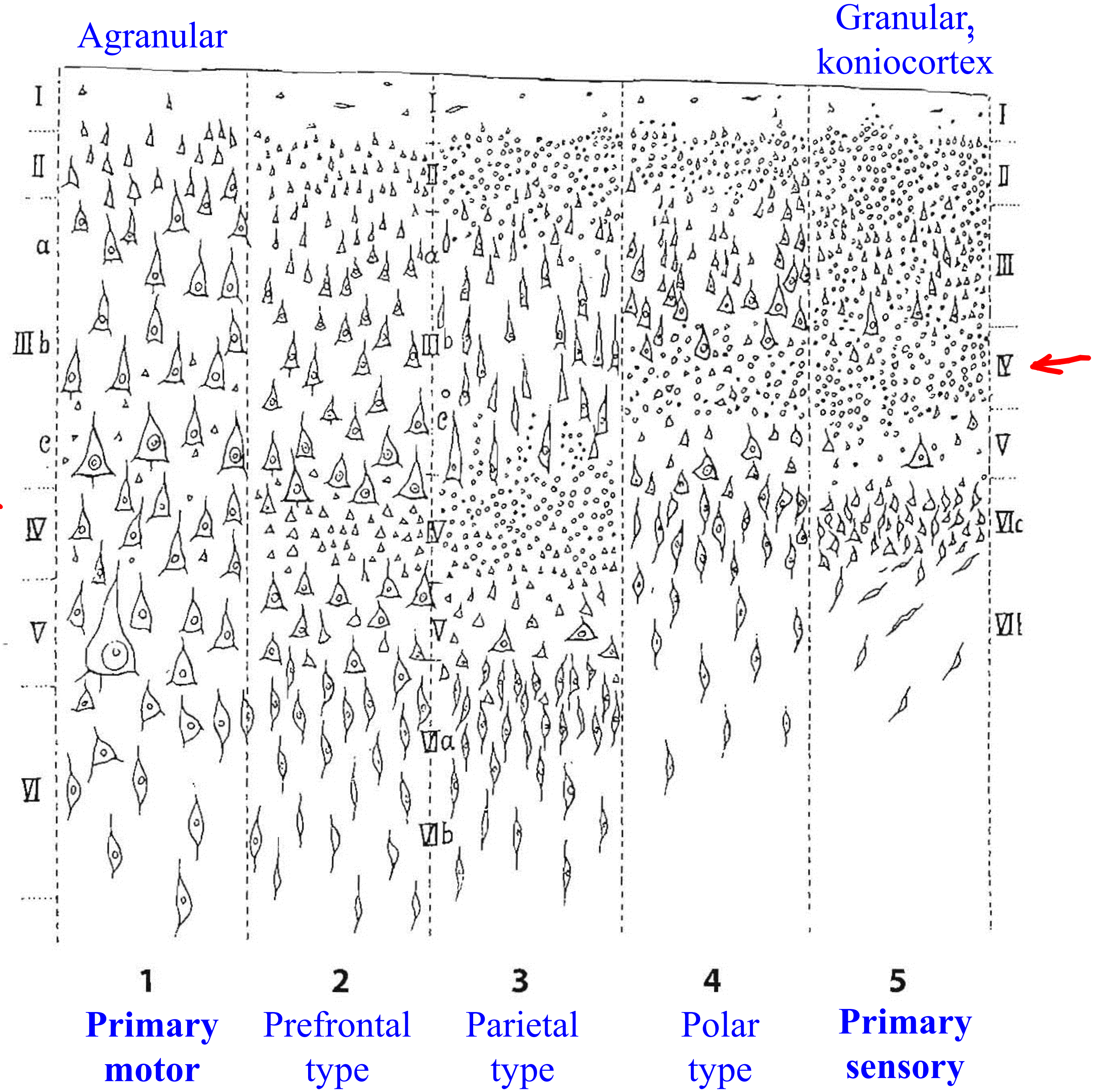
# *Question about layer 4 extremes:*

Layer four of the neocortex is most different in two areas: the motor cortex and the primary visual cortex. Summarize the structural differences.

Regional differences in neocortical areas:

"Granular" refers to high density layers of small, non-pyramidal neurons. They occur esspecially in layer 4 of primary sensory areas.

In motor cortex, layer 4 is difficult to discern.



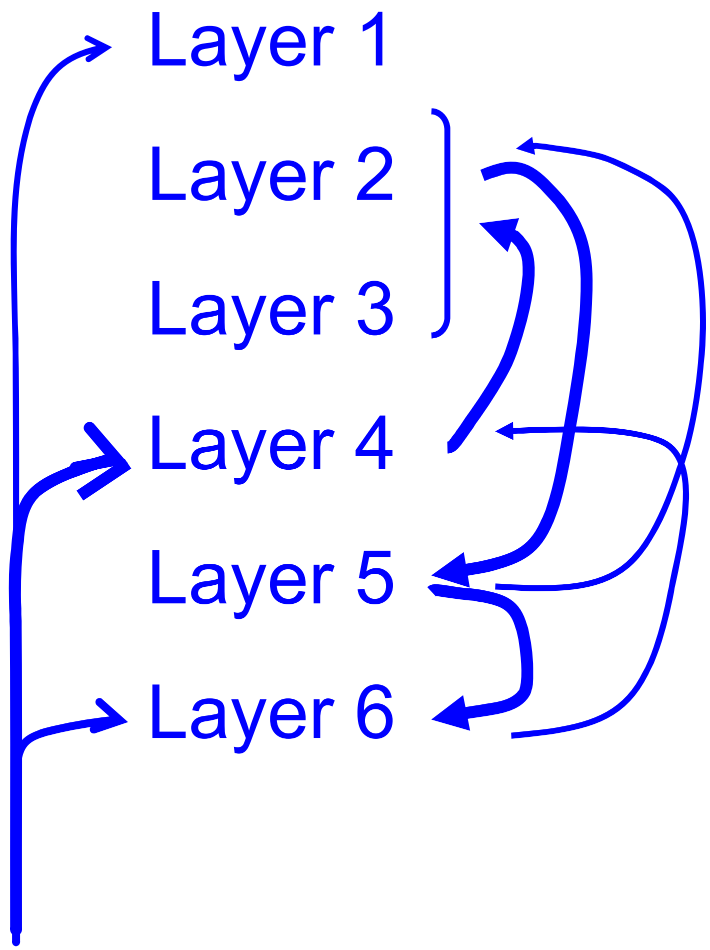

From Constantin von Economo (1927, English trans. 2009)

**Fig 33-8**

**Next**: What are the connections of the different neocortical layers? Are they consistent across areas?

# Connections of neurons in the different cortical layers

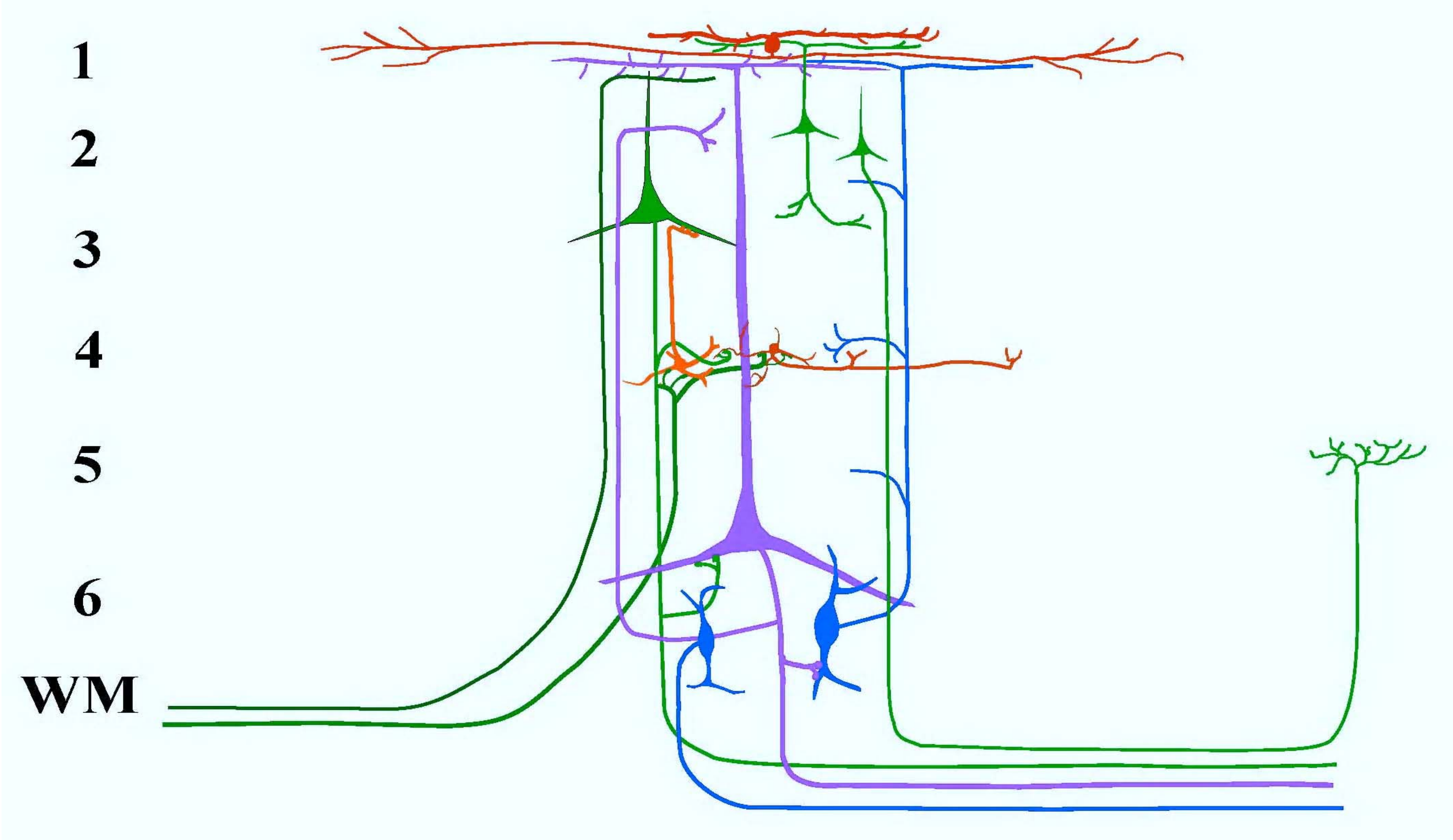
(We described this once before, but less schematically: see fig 32.2.)




Omits all lateral interconnections and long-distance projections

Why does layer 1 have no outputs?


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





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 32-2**

Sketch of a column of cells in the neocortex. Note the different types of axons: afferent, efferent, association

## *Question about layer 4 extremes again:*

Layer four of the neocortex is most different in two areas: the motor cortex and the primary visual cortex. Summarize the differences in synaptic number, an indicator of convergence of inputs on the neurons.

# **Convergence in neocortical connections**:

## Mean number of synapses per neuron in monkey

- ~4,000 per neuron in primary visual cortex (area 17)
- ~60,000 per neuron in primary motor cortex (area 4)

Included are synapses of thalamocortical axons, intracolumnar association axons, local transcortical axons within the layers, transcortical U fibers, callosal axons.

(Which are probably the dominant ones in areas 17 and 4?)

Area 4: much greater convergence of inputs from adjacent neocortical areas.
Area 17: relatively more input from thalamus (LGd).

*(Data from e.m. studies by Cragg.)*

A What are four major **functional** types of neocortical areas?

B What are "Brodmann's areas" and what is the basis of their differentiation?

A The first question has various answers. Most simply:

*Primary sensory, primary motor, association, limbic.*

*Later, we will use (again) Mesulam's types: primary sensory or motor, unimodal association, multimodal association, limbic.*

B. Brodman studied cytoarchitecture, using Nissl methods.

*See following illustration of Brodmann's cytoarchitectonic map.*

Brodmann's map of human neocortex, based on Nissl-stained sections.

His numbering scheme is very widely used.

Published in 1909, English translation in 1999.

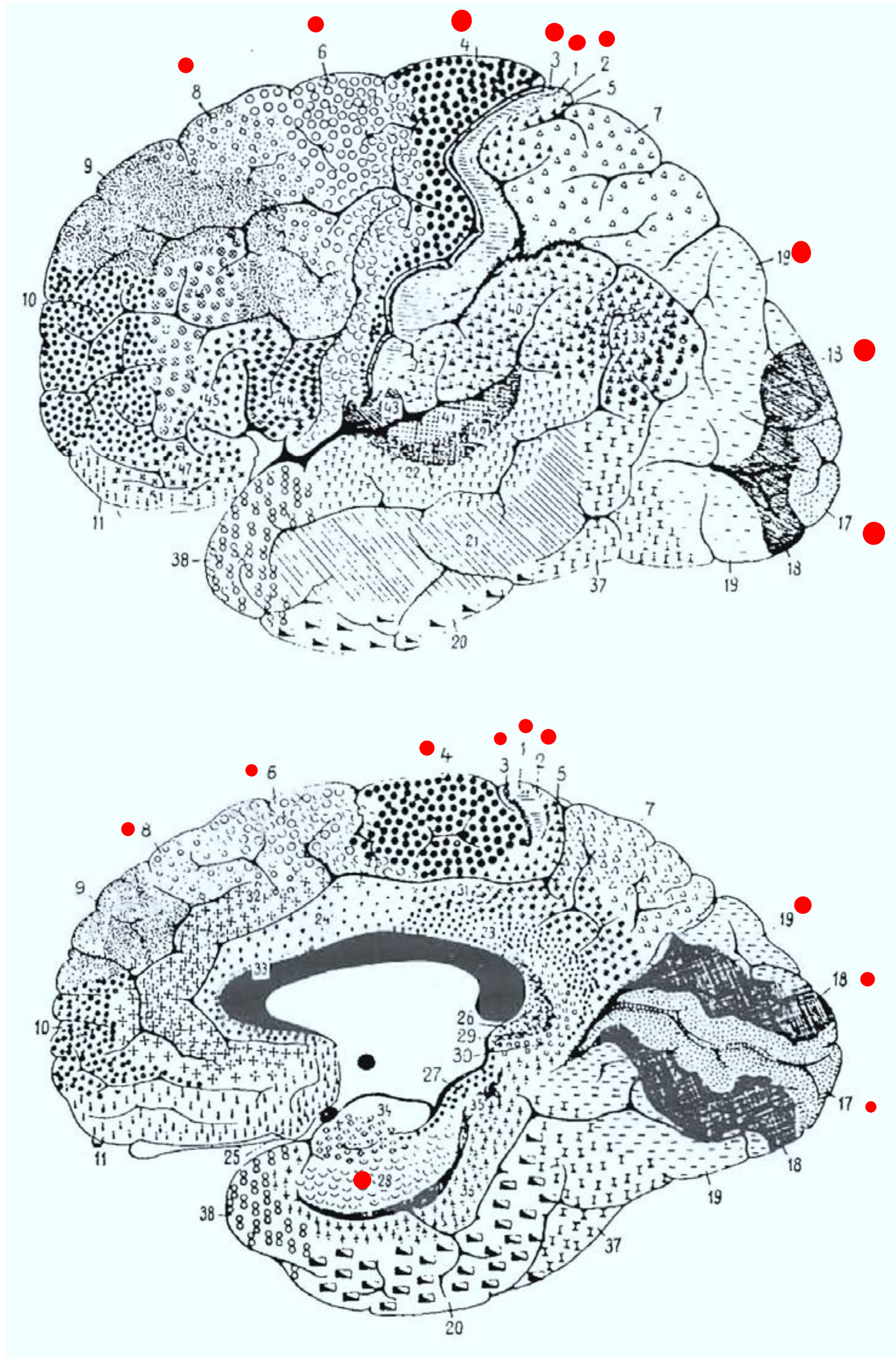


Image is in public domain.

Red marks: Brodmann areas best known to neuroscientists.
17, 18, 19: visual areas
3,1,2: somatosensory areas
4, 6: motor, premotor areas
8: frontal eye fields (caudal prefrontal)
28: entorhinal area

**Fig 33-5**

## *Questions, chapter 33*

4) What methods have been used, and are being used, to find functional differences between different cortical areas?

   This is a discussion question. An answer is not illustrated in these slides. Think of the contributions of widely different methods used in neuroscience over the years.

# Review:

- Temporalization of the hemisphere in mammals
- Axons to and from neocortex

# The great neocortical expansion: Temporalization

What is "temporalization of the hemisphere"? *(Nauta p. 221; figs. 88, 94)*

Where would you look for the rodent equivalent of the primate inferotemporal cortex?

# Temporalization of the cerebral hemisphere

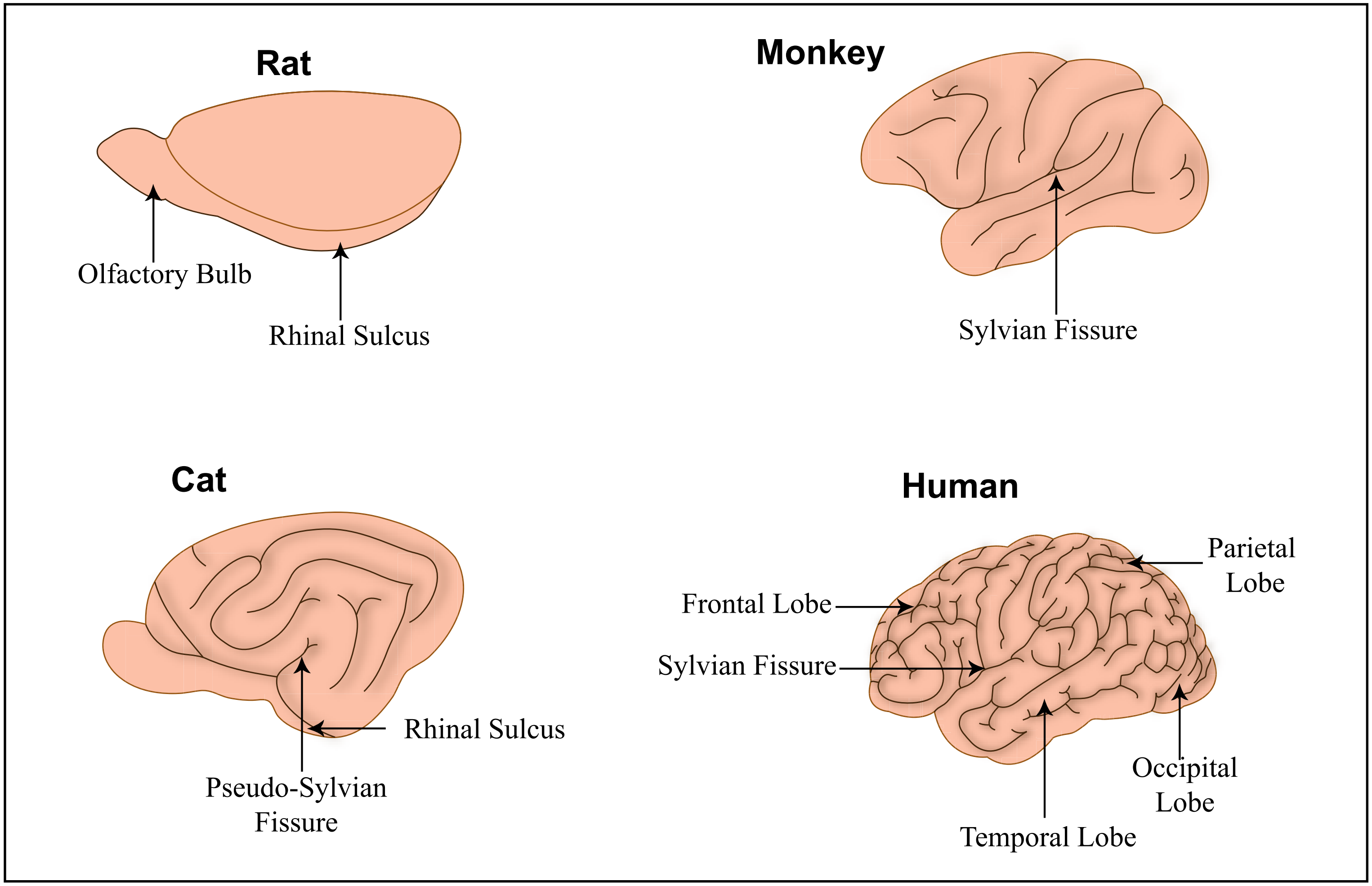
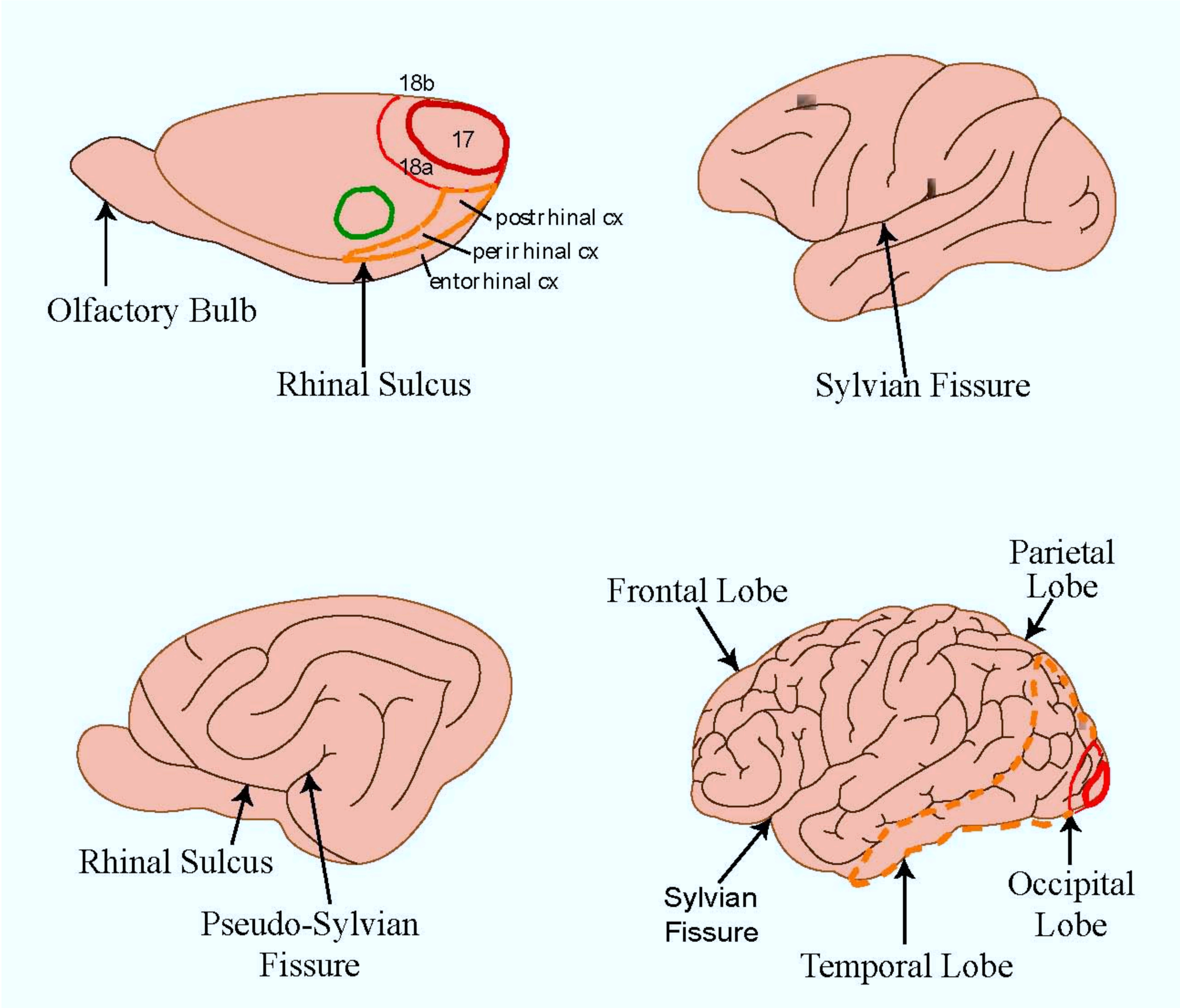



Image by MIT OpenCourseWare.

# Temporalization of the cerebral hemisphere



# *Questions, chapter 33*

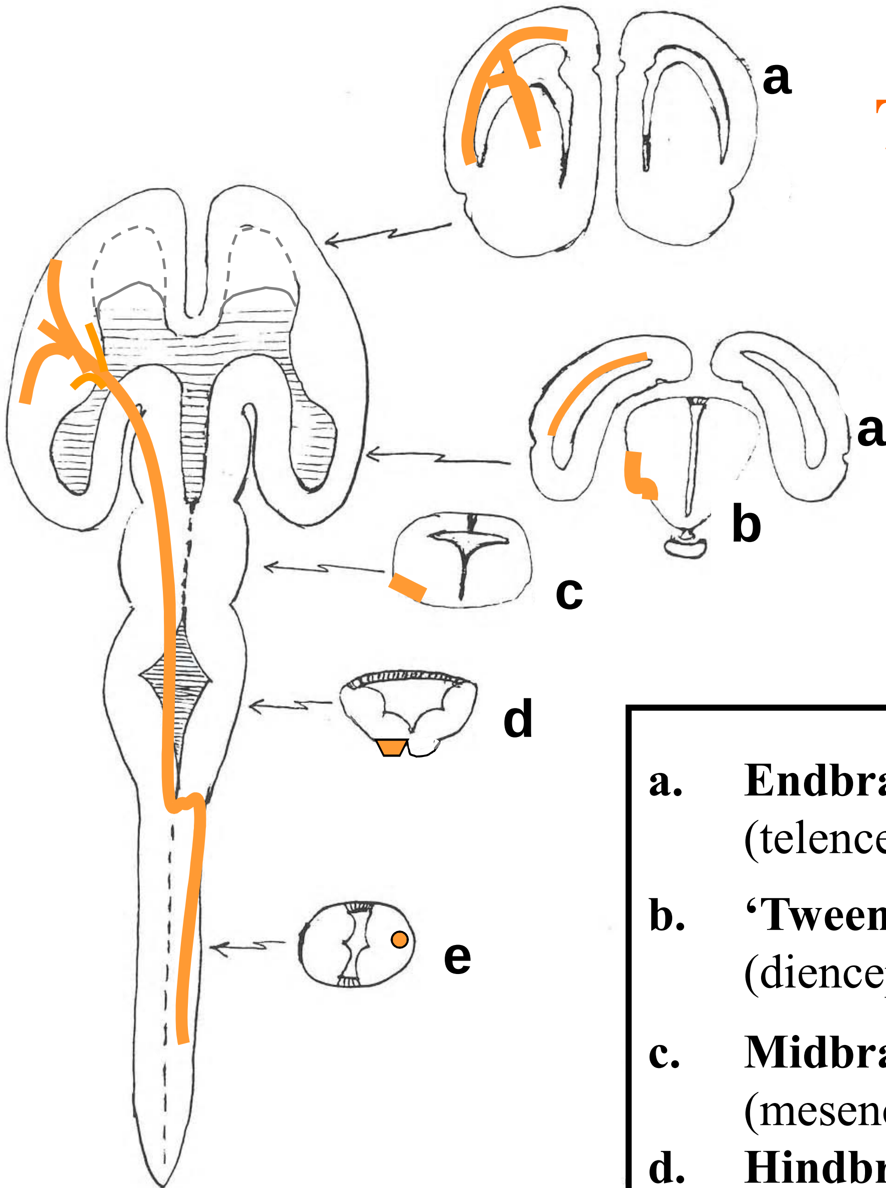
5) Following axons from the somatosensory and motor areas of the neocortex to the spinal cord, the name of the group of axons that includes them changes. Give the names of the axon groups in succession, beginning with the neocortical white matter.

# Axons to and from neocortex

- The “corona radiata, the “internal capsule, the “cerebral peduncle” and the “pyramidal tract” are continuous, from the neocortical mantle to the hindbrain and then to spinal cord.
- Name one type of axon which is present in <u>all</u> of these named structures.
- Then try and name some axons which are <u>not</u> present in all of them.

This group of axons has been pictured in previous slides:

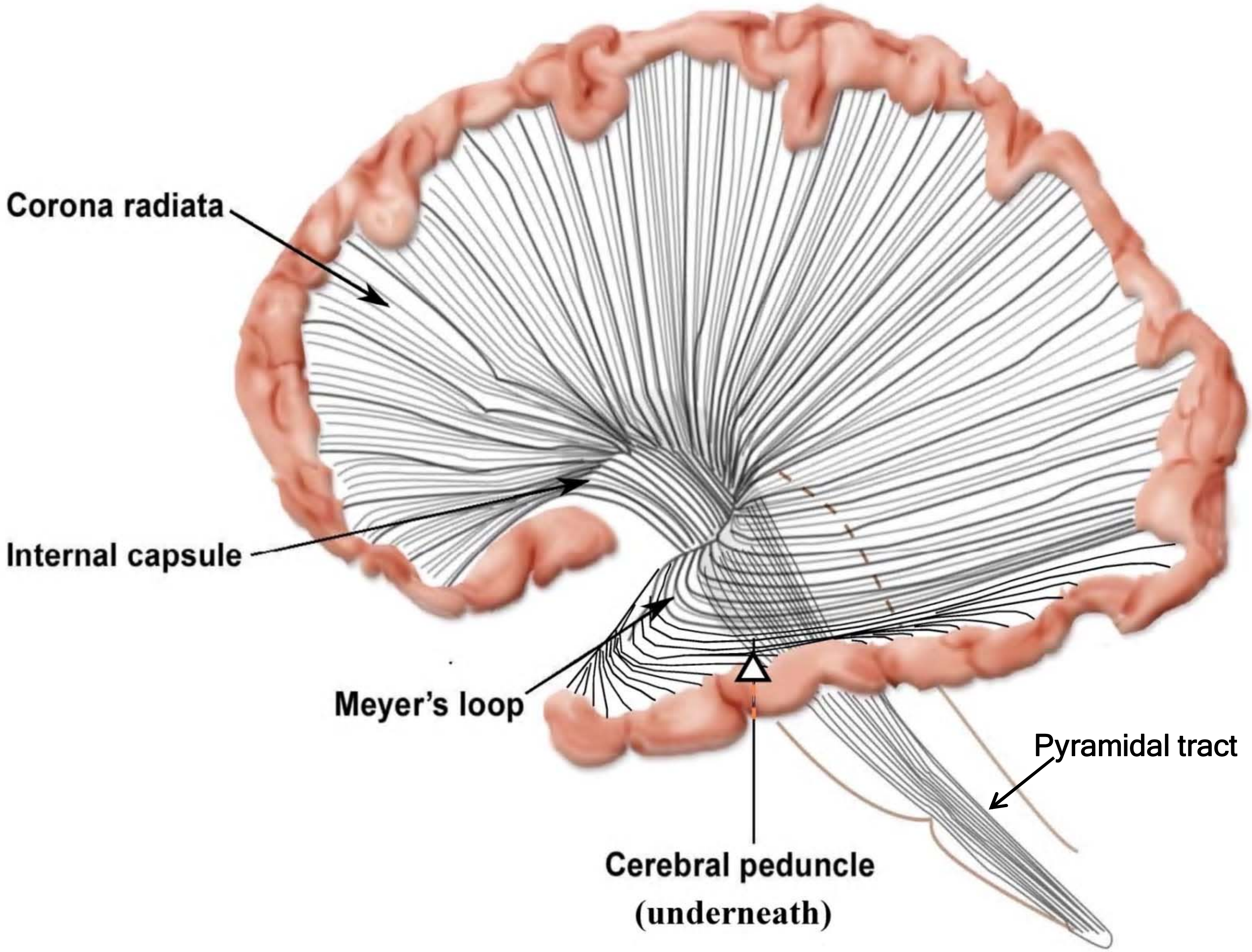
# The lateral forebrain bundle






| | | |
|---|---|---|
| a. | **Endbrain** (telencephalon) | **Cortical white matter to Internal capsule** |
| b. | **'Tweenbrain** (diencephalon) | **Cerebral peduncles** **(includes fibers to 'tweenbrain, midbrain, pons, remainder of hindbrain, spinal cord)** |
| c. | **Midbrain** (mesencephalon) | **Cerebral peduncles** |
| d. | **Hindbrain** (rhombencephalon) | **Pyramidal tract** |
| e. | **Spinal cord** | **Corticospinal tract** |

**Fig 12-6**





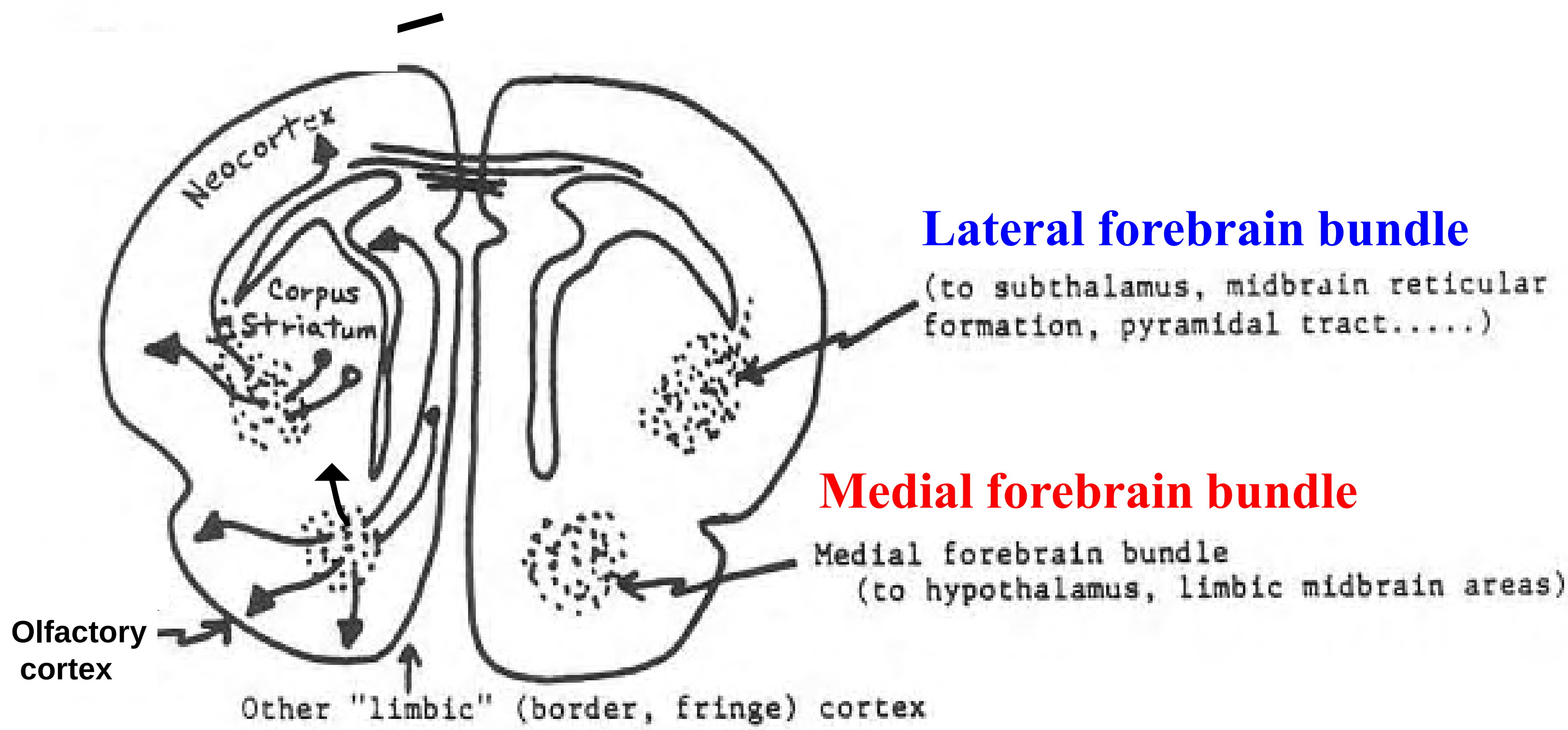
Schneider, G. E. *Brain Structure and its Origins: In the Development and in Evolution of Behavior and the Mind*. MIT Press, 2014. ISBN: 9780262026734.

**Fig 22-8**

LFB

- This is one of the **two** major axonal bundles leading in and out of the mammalian forebrain.
- What is the other one? the MFB

# Endbrain (telencephalon)





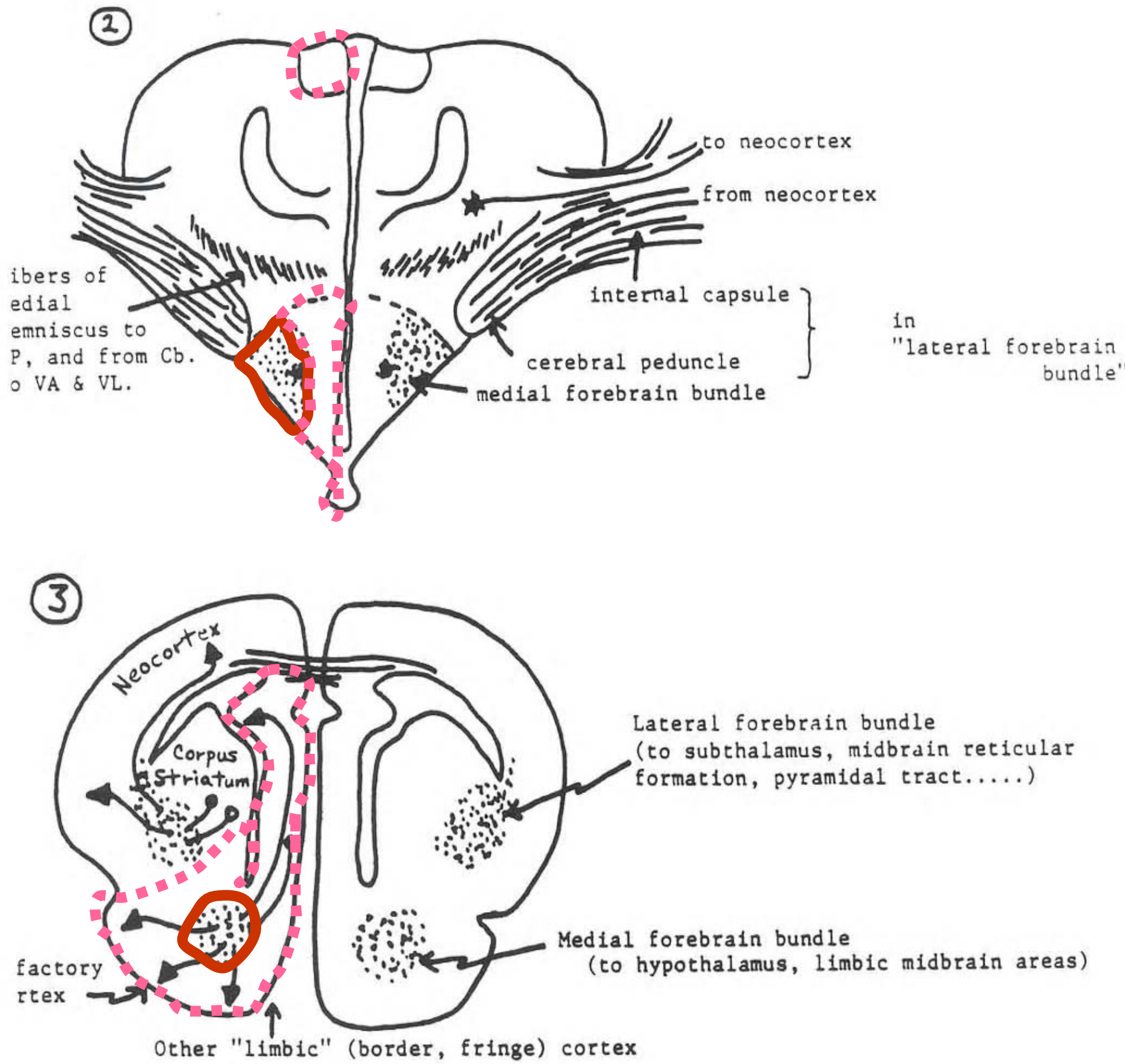
Schneider, G. E. *Brain Structure and its Origins: In the Development and in Evolution of Behavior and the Mind*. MIT Press, 2014. ISBN: 9780262026734.

**Fig 12-5**

# 'Tween-brain and Endbrain

limbic sys.

& MFB





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

# Origins and course of 2 major pathways:

- **Lateral forebrain bundle**
  - From corpus striatum
  - From neocortex through neocortical white matter
  - Through internal capsule
  - Through cerebral peduncle
  - Through pyramidal tract
  - To all levels of CNS
- **Medial forebrain bundle**
  - From olfactory cortex
  - From limbic cortex
  - From subcortical limbic structures: amygdala, basal forebrain (ventral striatum)
  - To and from lateral hypothalamic area
  - To and from limbic midbrain areas

# Brain structure and its origins

MIT 9.14 2014

G. E. Schneider

## Class 37

## Thalamocortical organization; transcortical connections and association cortex; thalamic evolution

*Chapter 33 issues and questions, continued*

# *Topics*

- ✓ Session 1
  - Evolution and functions of endbrain structures (introduction with review)
- ✓ Session 2
  - Cell types and their connections
  - Regions of the expanding neocortex
  - Major fiber routes in and out of endbrain
- **Session 3**
  - **Thalamocortical connections**
  - **Association cortex and transcortical connections**
  - **Thalamic evolution**
- Session 4
  - Cortical development
  - Cortical plasticity with effects of activity

Sensory inputs to cortex: Begin with review of what came first in evolution: **olfactory inputs**

What is the rhinal sulcus, also called the rhinal fissure?

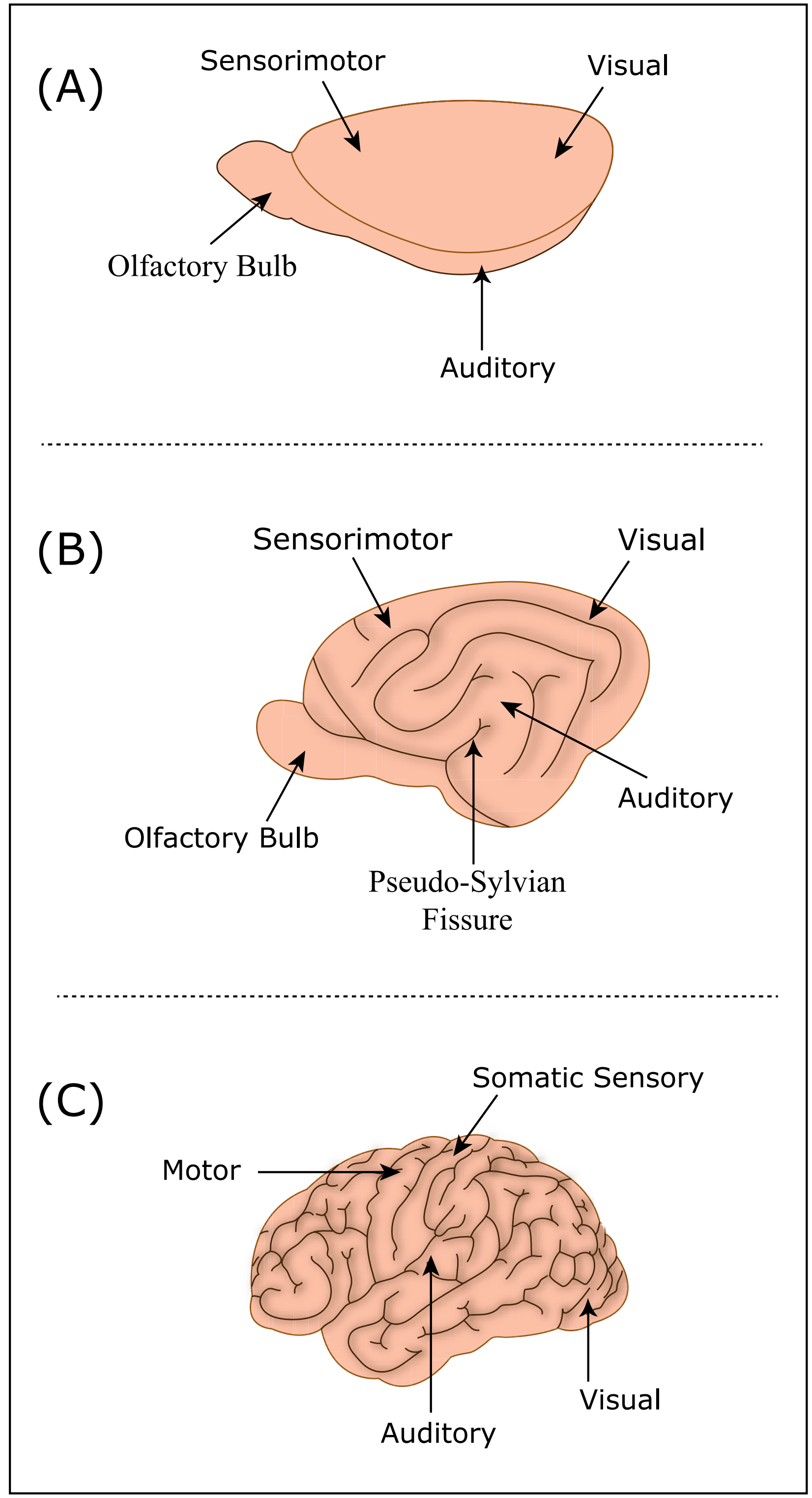



Image by MIT OpenCourseWare.

Sensory inputs to cortex: Begin with review of what came first in evolution: **olfactory inputs**

What is the rhinal sulcus, also called the rhinal fissure?

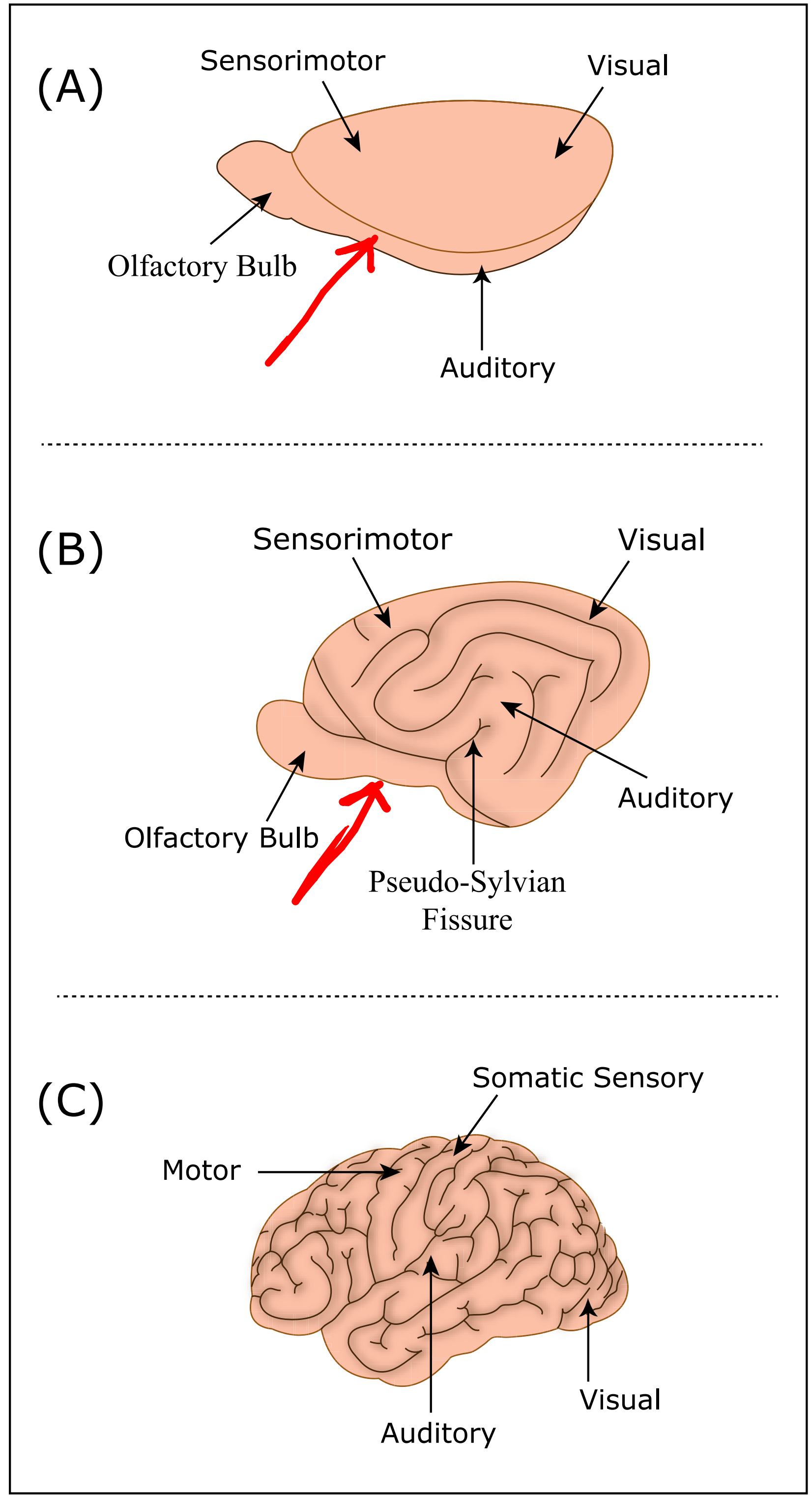
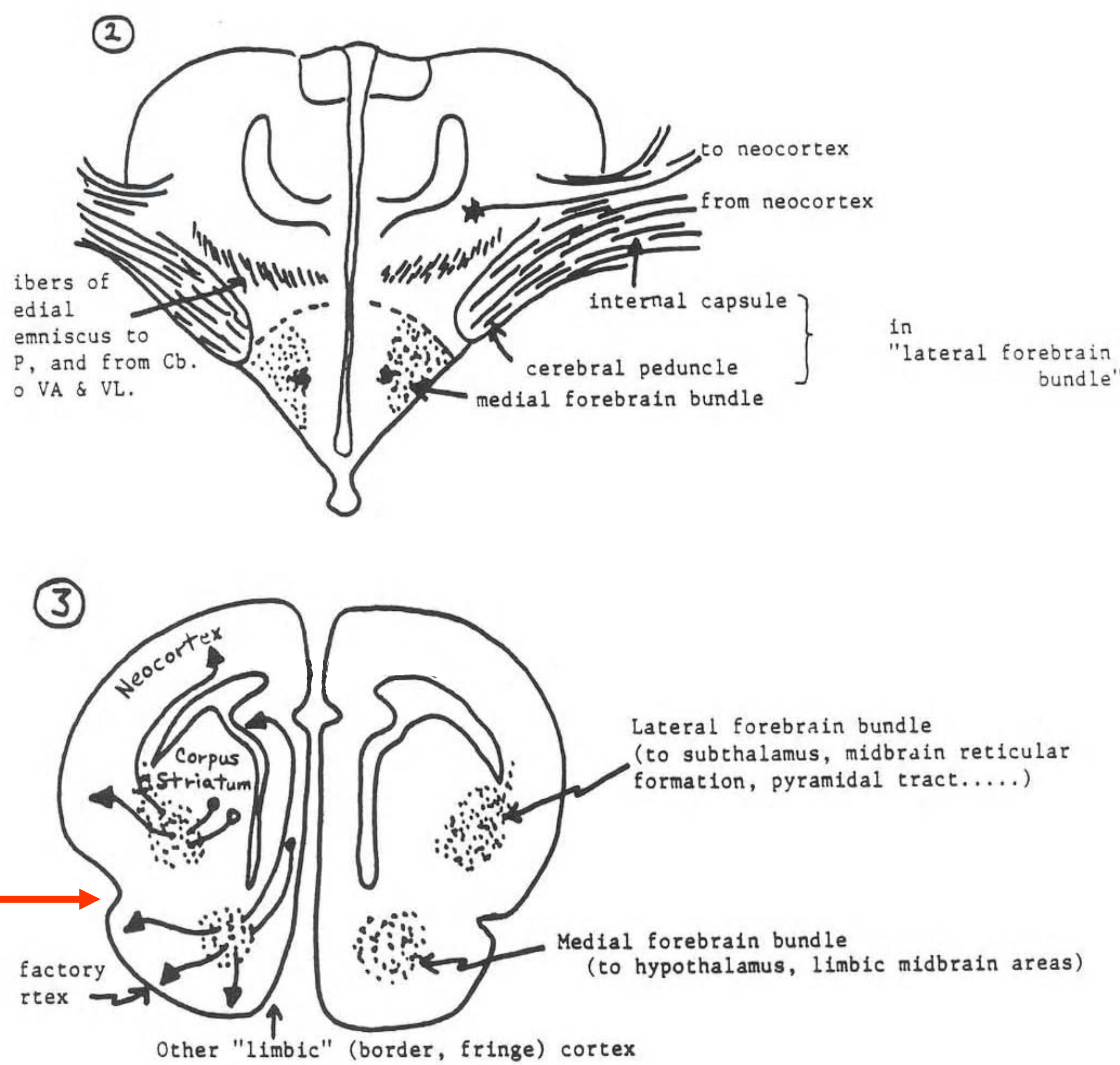



Image by MIT OpenCourseWare.

# ‘Tween-brain and Endbrain





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

# Olfactory peduncle

Why did early anatomists mistakenly consider the olfactory peduncle, in the human brain, the most rostral cranial nerve?

Because without histology, they did not discern an olfactory bulb, just a long nerve-like structure attached to the ventral surface of the brain rostral to the olfactory tubercle.

The true olfactory nerve is made up of the axons of the primary sensory neurons of the olfactory epithelium, which course through the cribiform plate at the base of the skull to end in glomerular structures of the olfactory bulb, where they synapse on mitral cell dendrites.

Thus, they do not form a compact bundle of fibers.

# Cranial Nerves in Human brain, and the olfactory peduncle

Figure removed due to copyright restrictions.

## *Questions, chapter 32*

6) Secondary sensory neurons of the olfactory system, the mitral cells of the olfactory bulb, terminate in the olfactory cortex, or paleocortex. How does olfactory information go from this cortex to the neocortex? Which region of the neocortex receives such information?

**REVIEW:**

## Olfactory bulbs project directly to cortex, but not to neocortex. How does olfactory information reach the neocortex?

- There are projections from olfactory cortex, amygdala, and basal forebrain structures to the mediodorsal nucleus (medial part) of the thalamus MDm
- MDm projects to orbitofrontal neocortex.

in the portion of this cortex that extends into the insula.

# *Questions, chapter 32*

7) What thalamic cell groups project to the major territories of the human neocortex, namely, the central cortical regions, the prefrontal regions, and the posterior association cortex?

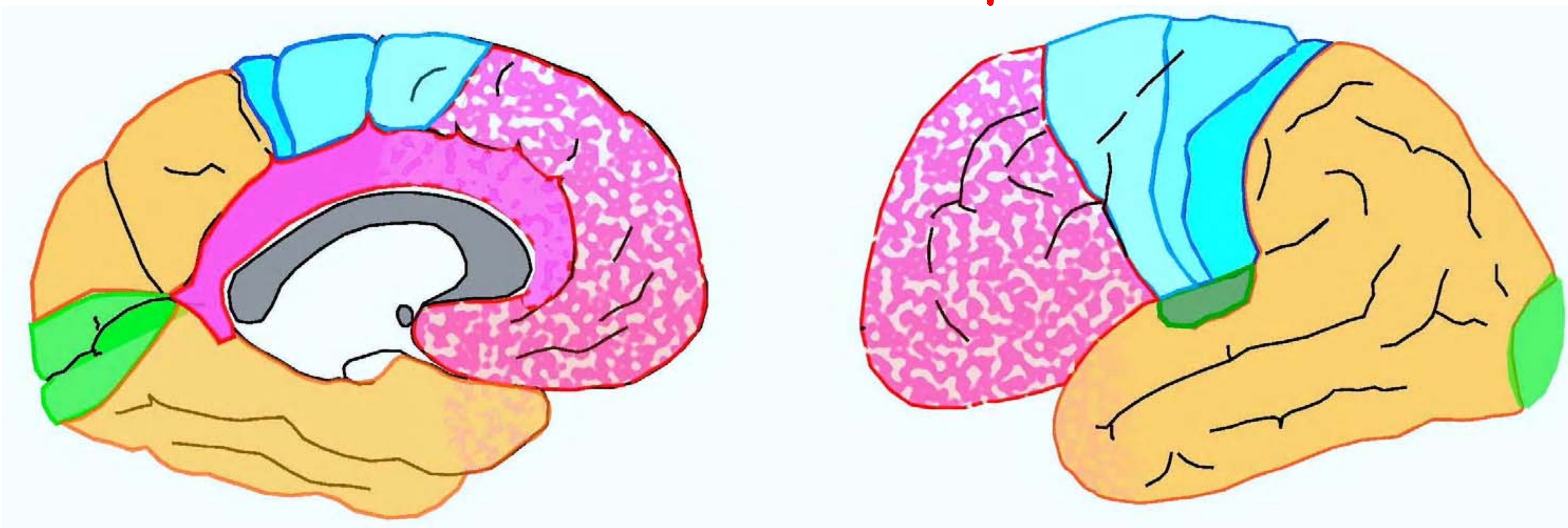
Note the color code in Figures

## Non-olfactory pathways to the endbrain do not go directly to a cortex: Most go through the thalamus.

**Describe the neocortical territories of the main thalamic cell groups (areas they project to).**

- the lateral thalamus (LD, LP, Pulvinar, Po)
- the geniculate bodies ("external geniculates") (LGBd, MGB)
- the ventral thalamus: ventral posterior nuclei (ventrobasal) (VPL, VPM); ventral anterior and ventral lateral nucleus (VA-VL)
- the medio-dorsal thalamic nucleus (MD)
- the anterior nuclei (AD, AV, AM)
- the intralaminar and midline nuclei (“paleothalamus”)

Human left hemisphere



Thalamus

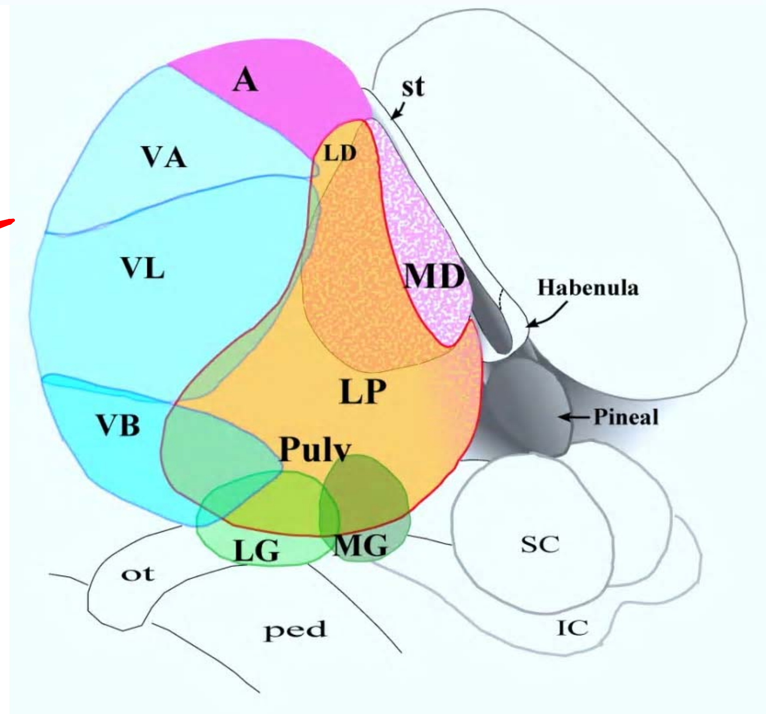
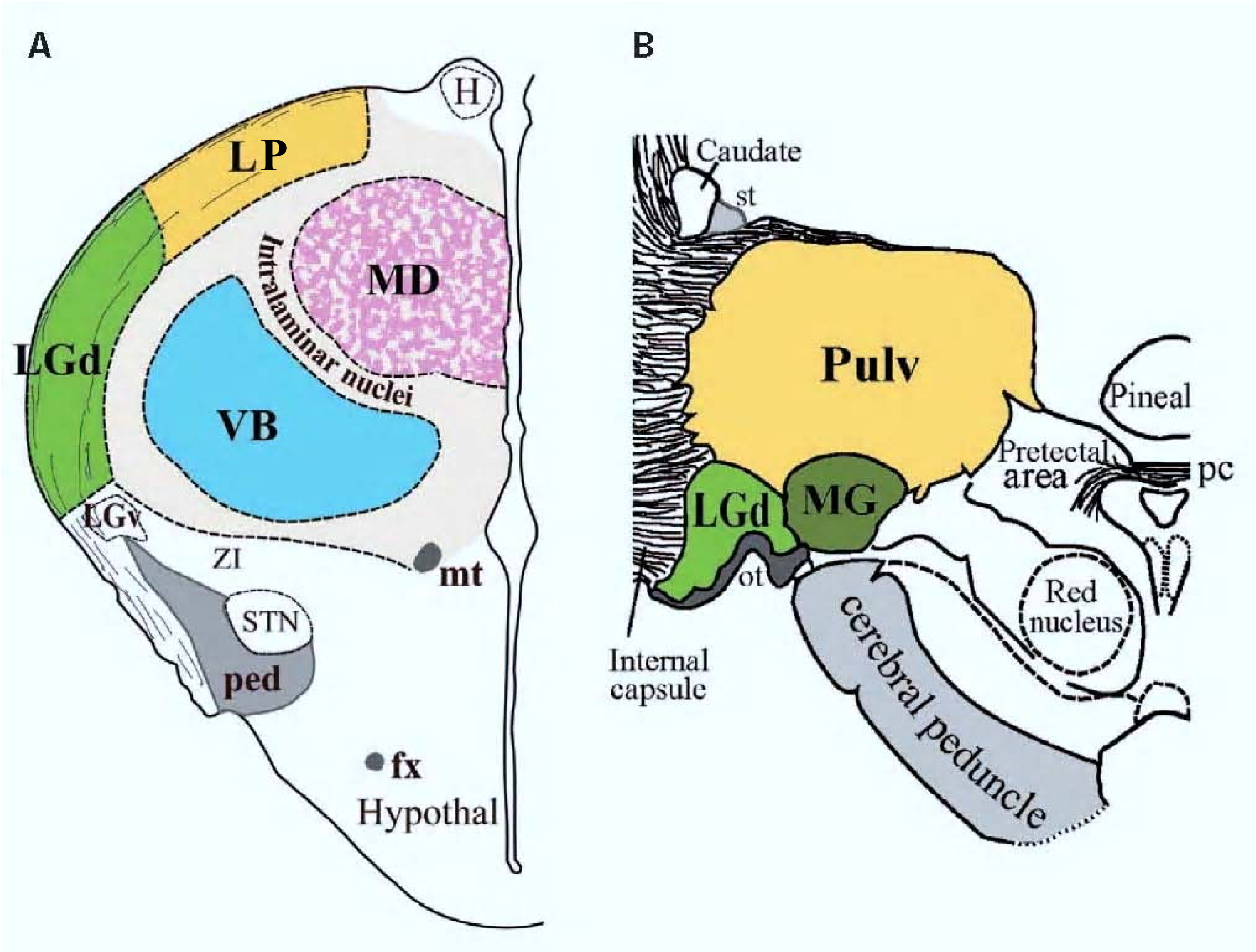



**Fig 33-10**


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 caudal diencephalon in frontal section

- **Left: embryonic human, resembling mature brain of many small mammals**
- **Right: Adult human**





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

# Rodent hemisphere

Same color coding

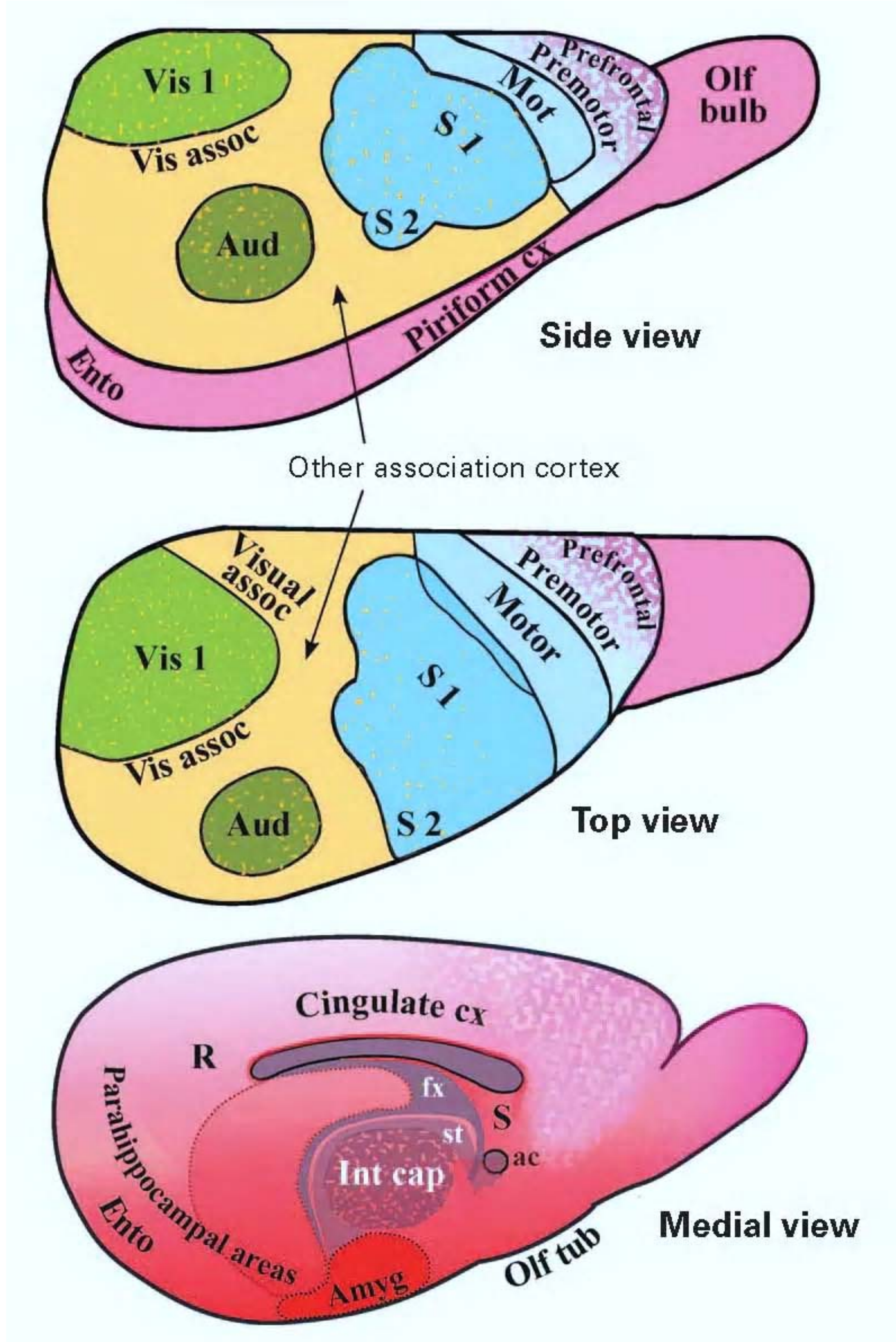



Figure 33.12


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

# What are "association areas"

What was Nauta's definition of association cortex *(p. 238)*? By this definition, we would have to say that the posterior association cortex of primates has been shrinking in recent years!

"…the association areas are the districts of neocortex that remain when one has eliminated the fields whose modality can be named."

"… areas whose function is hard to formulate, or simply unknown."

Other definitions?

# Association cortex can be defined by the nature of the connections.

Long transcortical association fiber bundles originate and terminate in these areas.

- What association fibers of the human cerebral hemisphere are prominent even in gross dissections of the brain *(Nauta & Feirtag fig. 115)* ? Next slide
- These are not so evident in brains of small animals like rodents, although some long association fibers do exist in these animals.

# Human brain: transcortical fibers

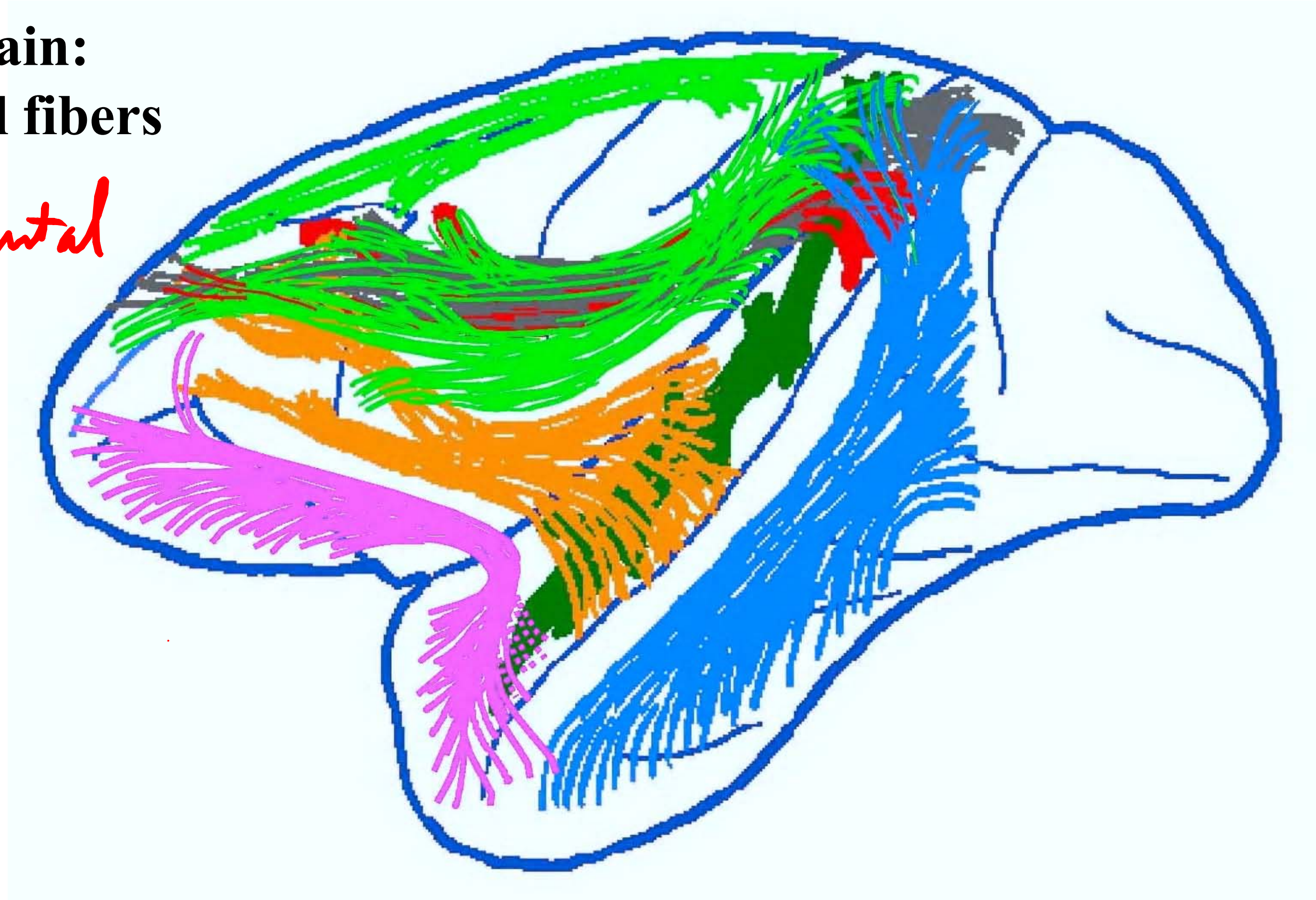


***Nauta & Feirtag***
***fig. 115***

**Fig 33-13**

# Macaque brain: transcortical fibers

From experimental tract-tracing studies



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.

Arcuate fasciculus
Extreme capsule
Fronto-Occipital fasc.
Inferior longitudinal fasc.
Middle longitudinal fasc.
Superior longitudinal fasc., components 1, 2, 3
Uncinate fasc.

Fig 33-14

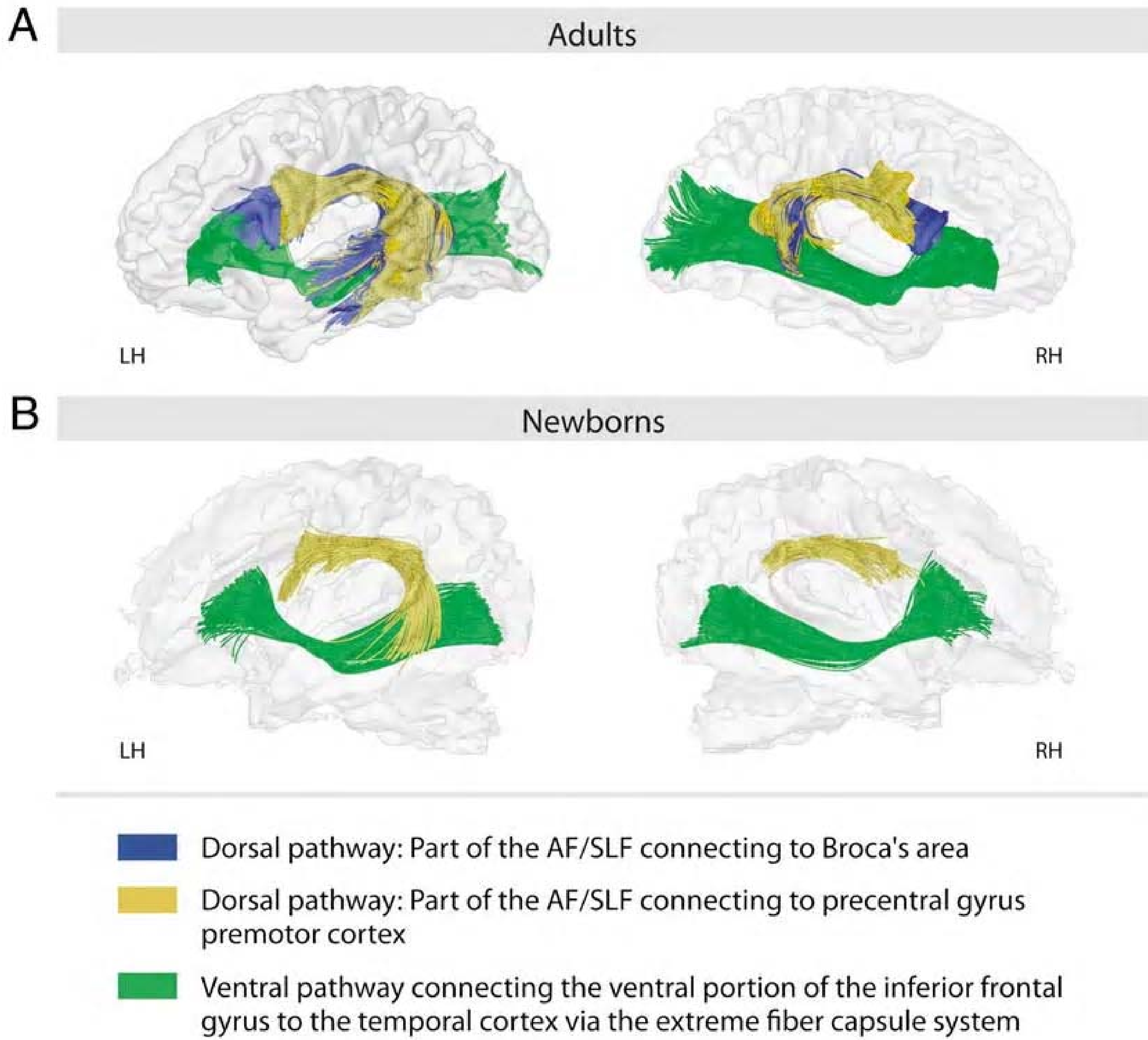
## *Questions, chapter 33*

10) How can long transcortical projections found in experimental studies of monkeys be verified for the human brain, other than the use of postmortem dissection? What are some of the limitations of the method?

DTI

AF = Arcuate Fasciculus
SLF Superior Longitudinal Fasciculus

**Fig 33-15**





Source: Figure 4 structural connectivity results from Perani, Daniela, Maria C. Saccuman, et al. "Neural Language Networks at Birth." *Proceedings of the National Academy of Sciences* 108, no. 38 (2011): 16056-061.

# Transcortical fibers of speech system

## *Questions, chapter 33*

8) What is the nature of Mesulam's idiotypic cortex, two types of homotypic cortex, and paralimbic and limbic areas? Answer by describing major functional characteristics. Also, describe the nature of transcortical connections connected to these areas.

next →

9) What are the "association layers" of the neocortex? What is implied by the presence of the growth-associated protein GAP-43 in these layers of the adult human brain?

layers 2 + 3

Recall the figure shown previously depicting the neurons in the neocortical layers and their axons. See also the discussion later in this class.

# M.-M. Mesulam's depiction of neocortical organization in human

- His figure 6 is useful to memorize (next slide). (You have seen it more than once previously)
- Terms:
  - Isocortex (iso=same): the neocortex
  - Idiotypic cortex: The most specialized type of isocortex, the primary sensory and motor areas.
  - Homotypic isocortex:
    - Unimodal association areas
    - Heteromodal (multimodal) association areas
  - Paralimbic areas: transitional cortex between neocortex and allocortex
  - Allocortex (allo = other): piriform cortex & archicortex (hippocampus)

# Transcortical pathways from specialized sensory and motor areas through association cortex to limbic system:

**Such transcortical connections increased in quantity and importance in larger mammalian brains.**

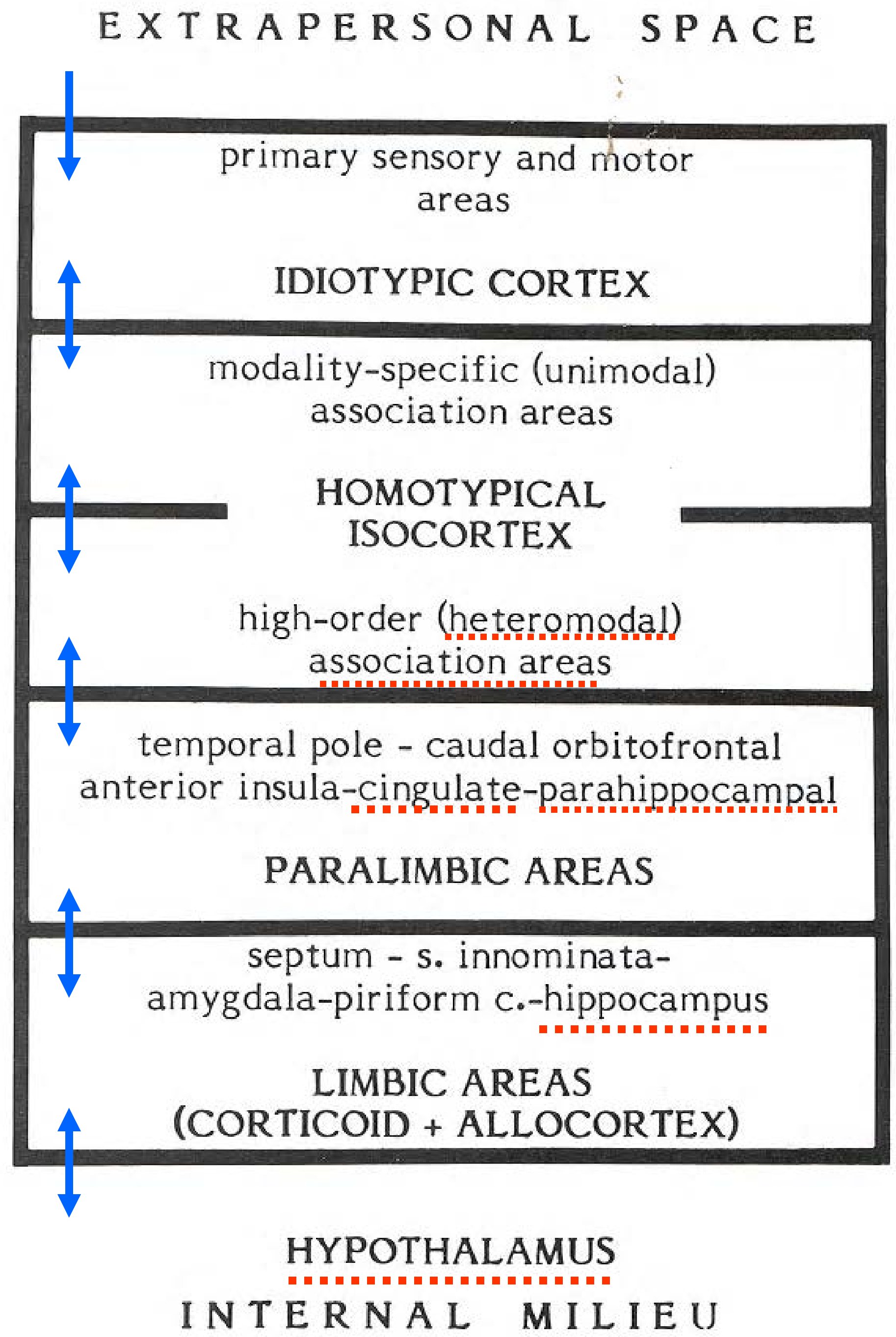



**Fig 26-9**


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

Transcortical pathways from specialized sensory and motor areas through association cortex to limbic system:

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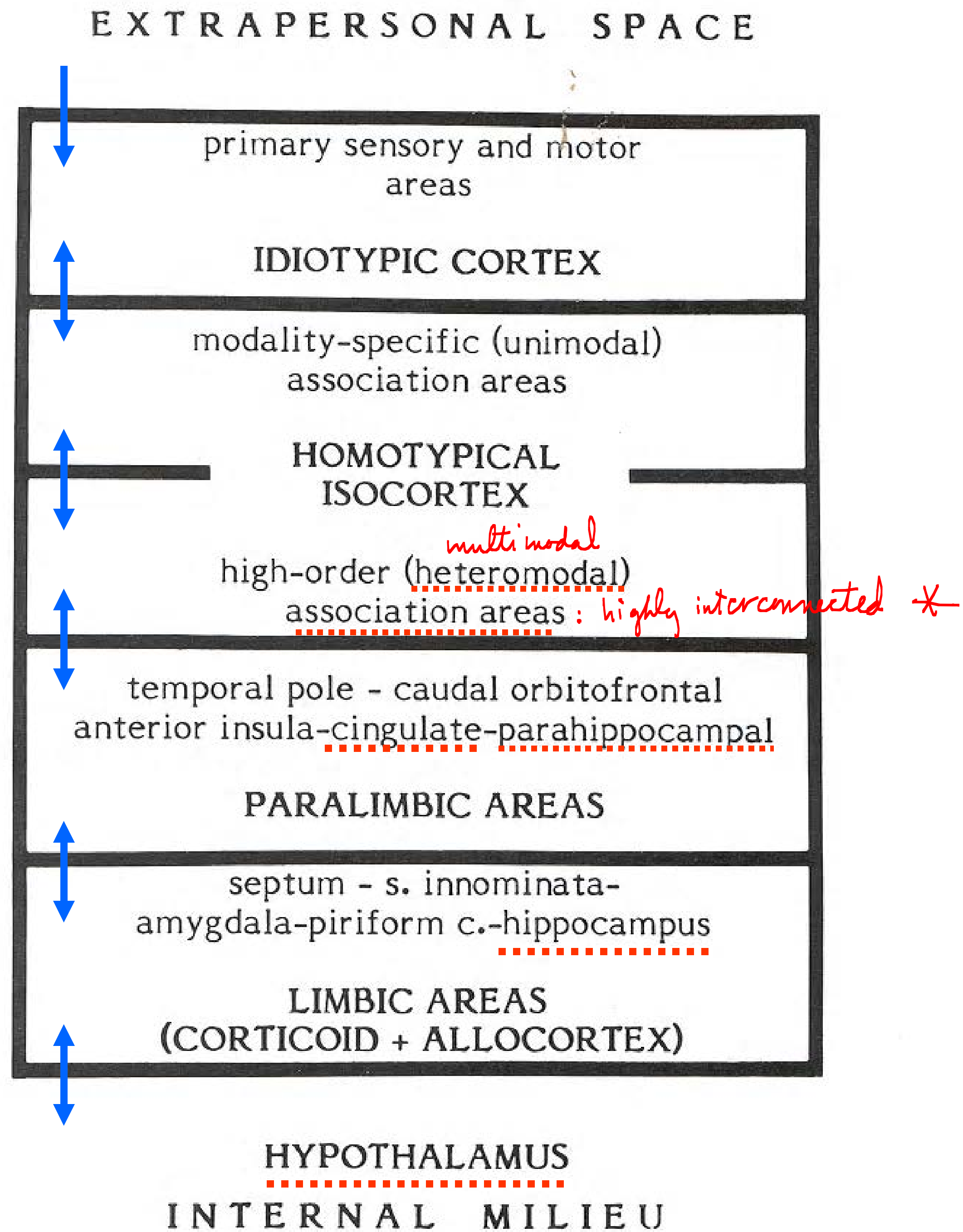



**Fig 26-9**



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

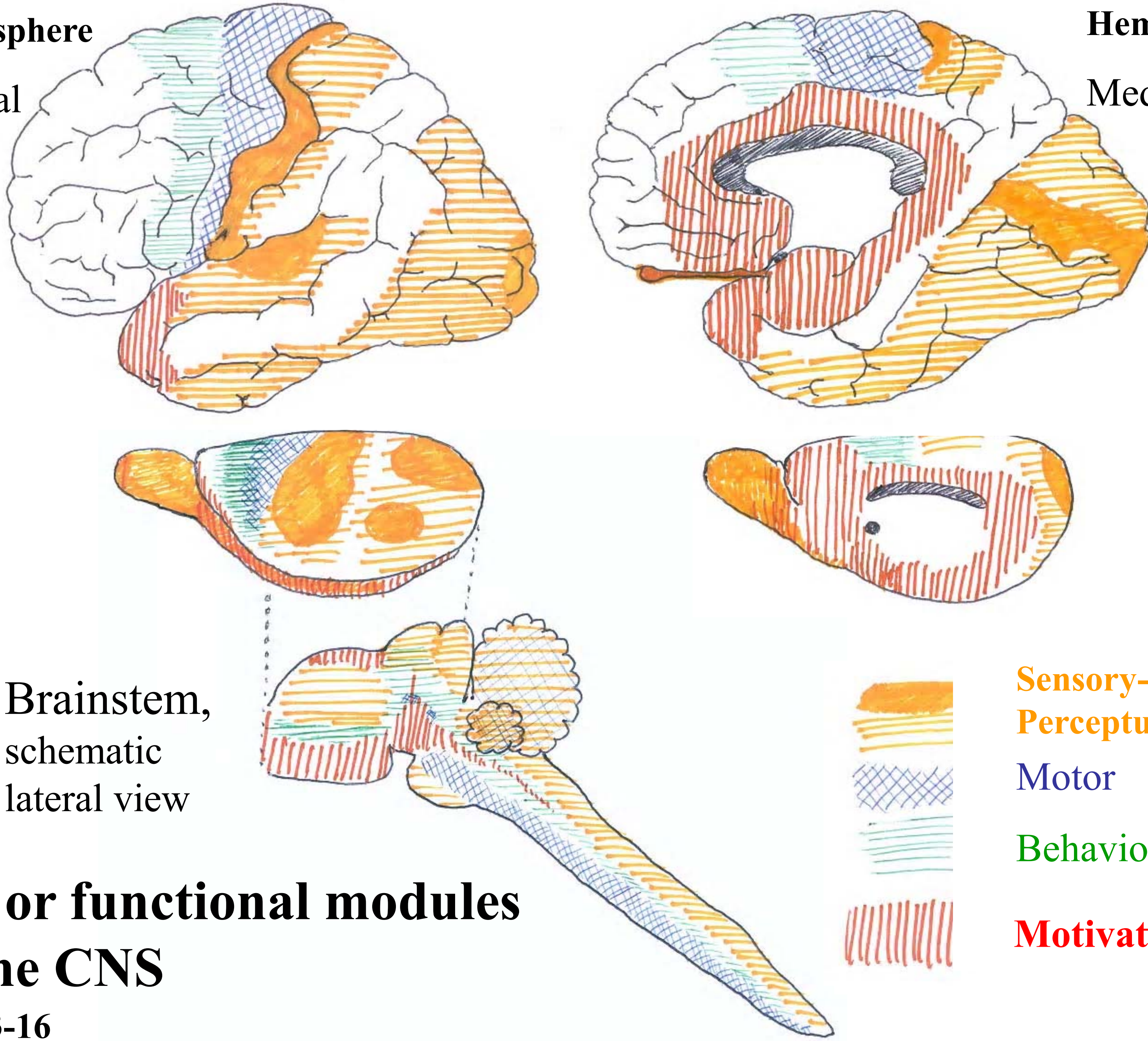
* Fig 33.13

# *Mesulam, fig. 1-7*



**In the next slide, this figure is re-drawn to illustrate the major function modules.**

**Added: Neocortex of rodent brain and brainstem.**




# Major functional modules of the CNS

**Fig 33-16**


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

What are the two "heteromodal fields" in the primate brain? Which is larger?

What thalamic nuclei connect with these two neocortical fields?

Lateral thalamus Pulvinar - LP

*(See also, Brodal fig. 20.7)* to posterior assoc. cx.

MD to prefrontal areas

*Mesulam, fig. 1-7:*

Note the frontal association cortex and the posterior association cortex.

Multimodal areas in pink

Figure removed due to copyright restrictions. Please see:
Mesulam, M-Marsel, ed. *Principles of Behavioral and Cognitive Neurology*. Oxford University Press, 2000. ISBN: 9780195134759.

**Posterior part of lateral thalamus: expands into Pulvinar**

**PT**: pretectal area

**LGBd**: dorsal nuc. of lateral geniculate body

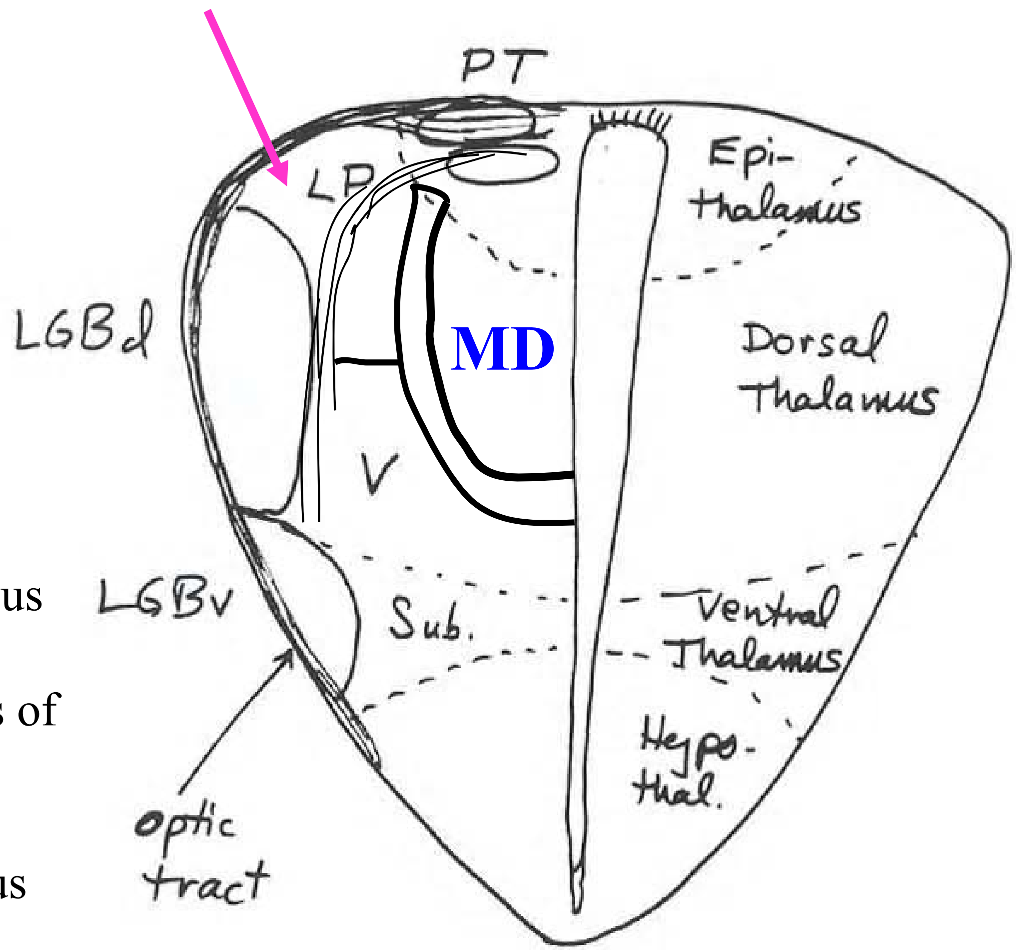
**LGBv**: ventral nuc. of lat. geniculate body

**LP**: lateral-posterior nucleus

**MD**: mediodorsal nucleus of thalamus

**V**: ventral nuc. of thalamus

**Sub**: subthalamus=the embryonic ventral thalamus

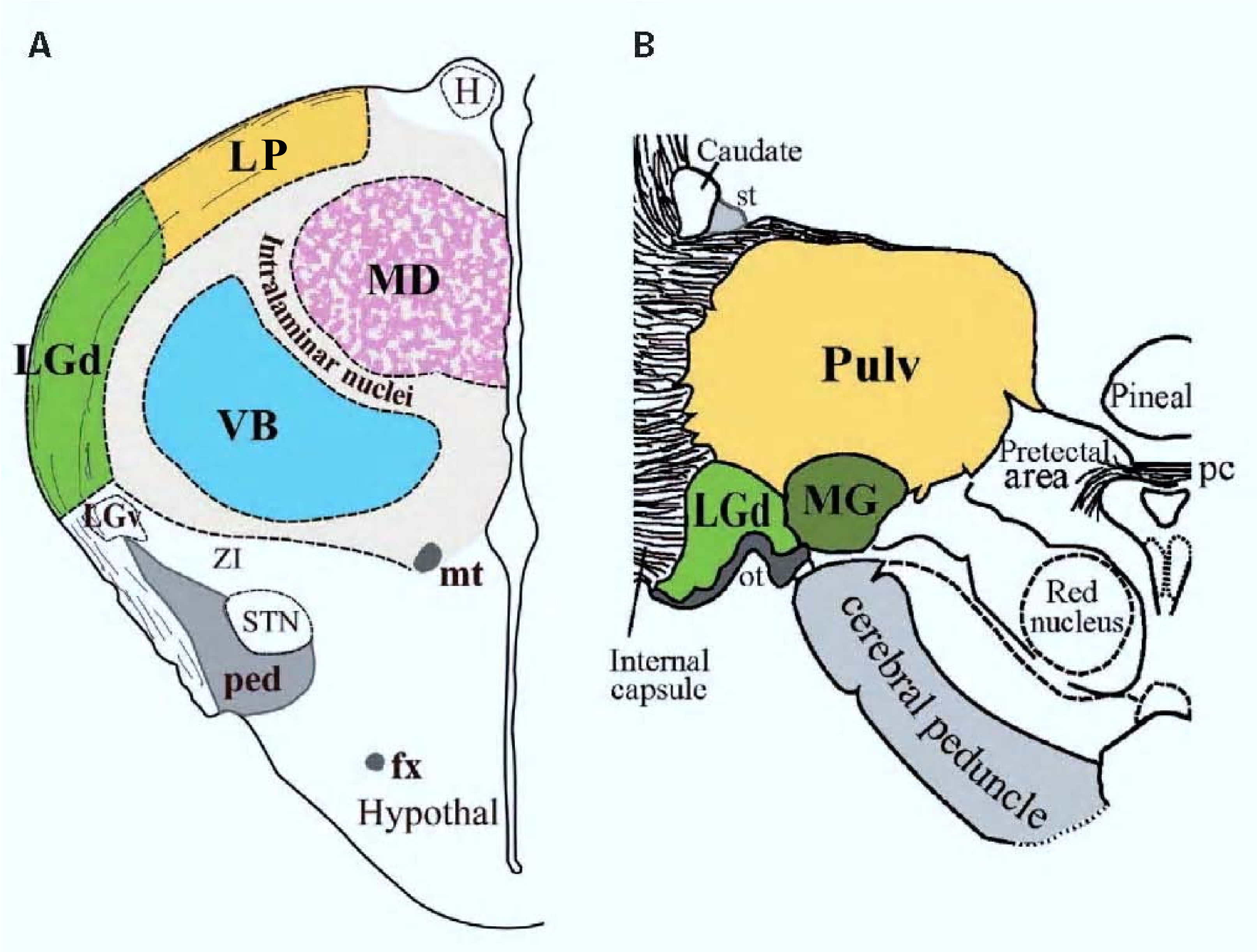




Schneider, G. E. *Brain Structure and its Origins: In the Development and in Evolution of Behavior and the Mind*. MIT Press, 2014. ISBN:9780262026734.

# The caudal diencephalon in frontal section

- **Left: embryonic human, resembling mature brain of many small mammals**
- **Right: Adult human**





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# Rodent hemisphere

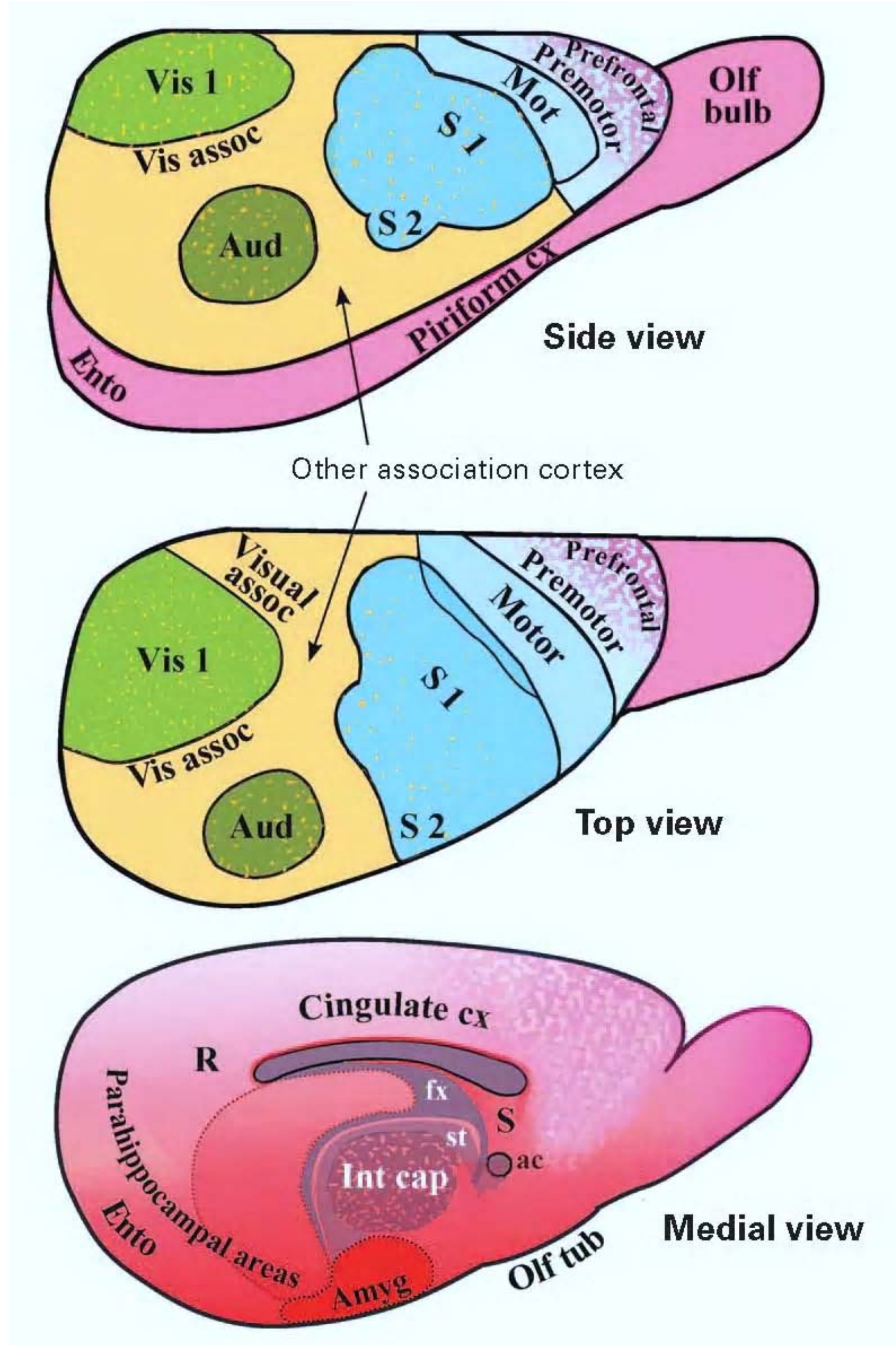


Figure 33.12



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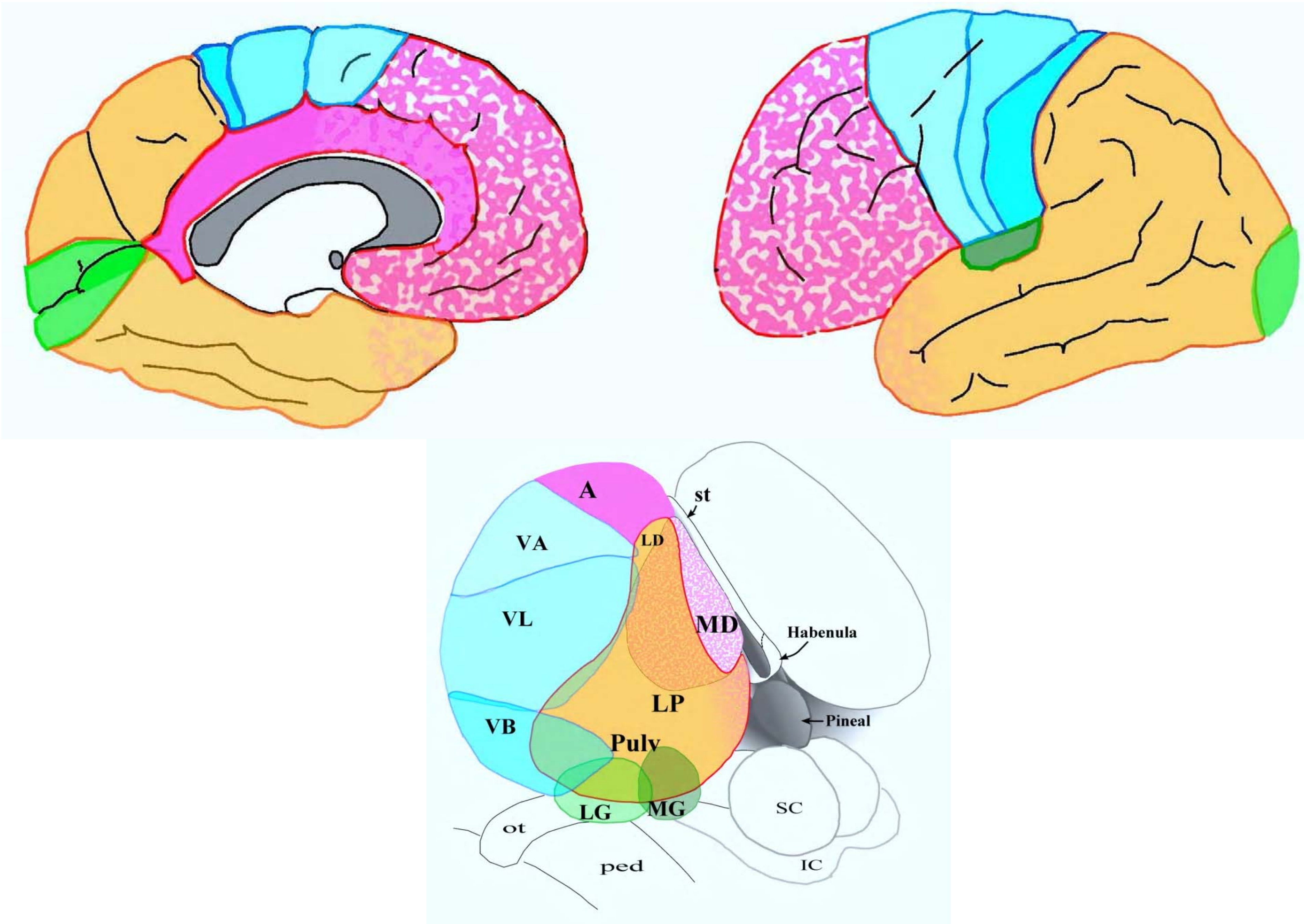


**Fig 33-10**


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# Human neocortical anatomy in Moscow

- Three types of cortex described by Polyakov (*illustrated by A. Luria, fig. 15*).
  - *Polyakov, G.I. (1966) Modern data on the structural organization of the cerebral cortex. Ch. I, sec. 2 (pp. 39-69) in Luria, A. R., Higher cortical functions in man. New York, Basic Books.* The Russian anatomist uses some terms not common in Western neuroscience, but some of the data collected and figures are unique.
- Polyakov's **primary** fields of the nuclear zones are equivalent to Mesulam's *idiotypic* cortex. His **secondary** and **tertiary** fields are in equivalent in part to Mesulam's *unimodal* and *heteromodal association* areas.
- Species comparisons: See next slide