Cognition I: Functional macro and microanatomy of the cerebral cortex

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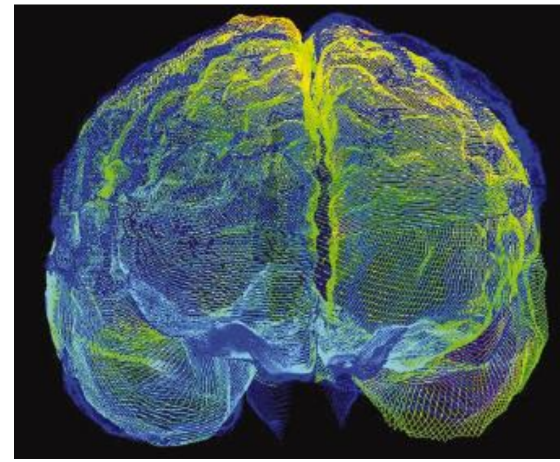


1. Development and evolution of the cerebral cortex
2. Anatomy of the cerebral cortex
   - Gross anatomy
   - Histological organization and cytoarchitecture
   - Columns (modules) as basic functional units
3. Autism

Literature:

Dudel et al., *Neurowissenschaft* (Springer)

Reichert, *Neurobiologie* (Thieme)

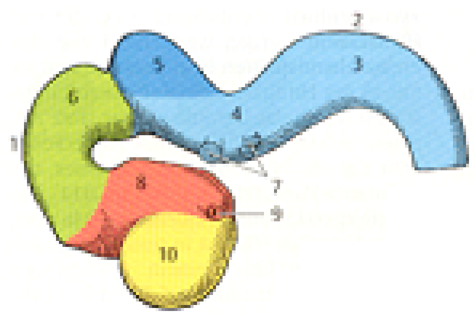
Kandel et al., *Principles of Neural Science* (McGraw Hill)

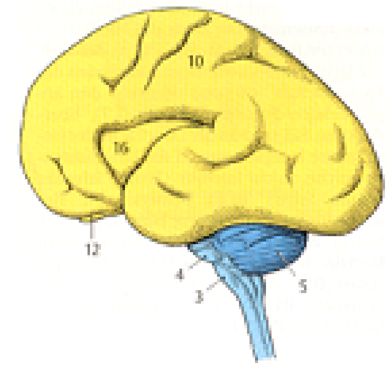
Kahle, *Taschenatlas der Anatomie, Band 3: Nervensystem und Sinnesorgane* (Thieme)

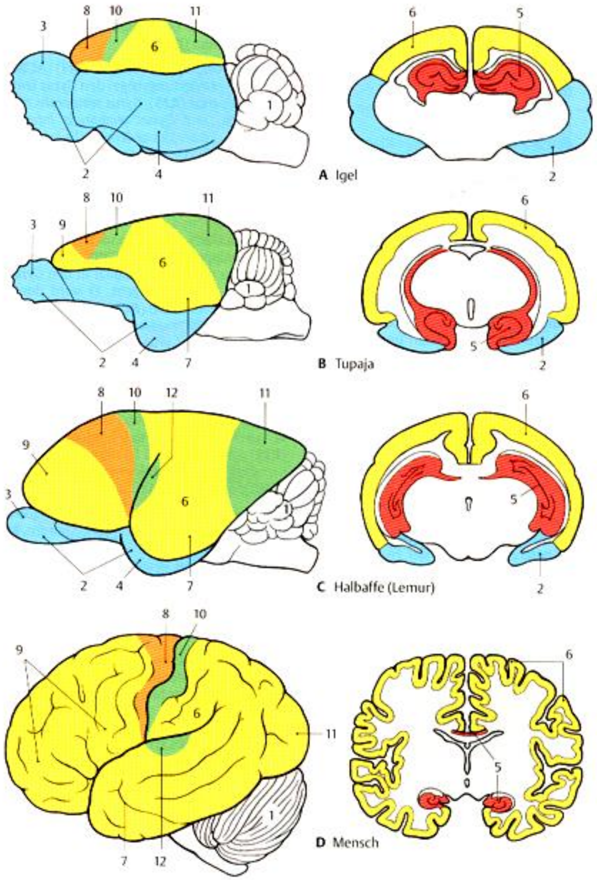
Greenstein and Greenstein, *Color Atlas of Neuroscience* (Thieme)

Development and evolution of the cerebral cortex

Enormous enlargement of the telencephalon in higher mammals



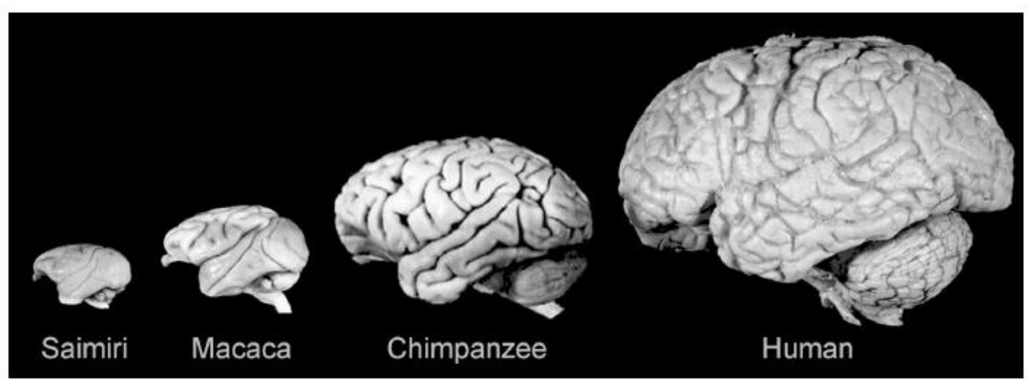




(Kahle, *Taschenatlas der Anatomie: Band 3*)

Particularly strong increase in the cortical areas (cerebral cortex) in the primates

Formation of furrows (**Sulci**) and turns (**Gyri**) (surface enlargement in humans to about 2,500 cm^2 (only 480 cm^2 would be available unfolded in the skull))



Development and evolution of the cerebral cortex

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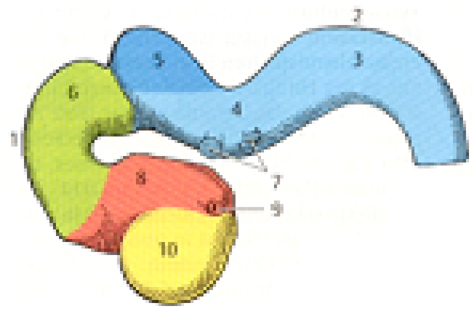

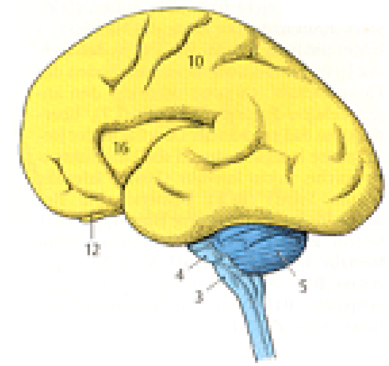

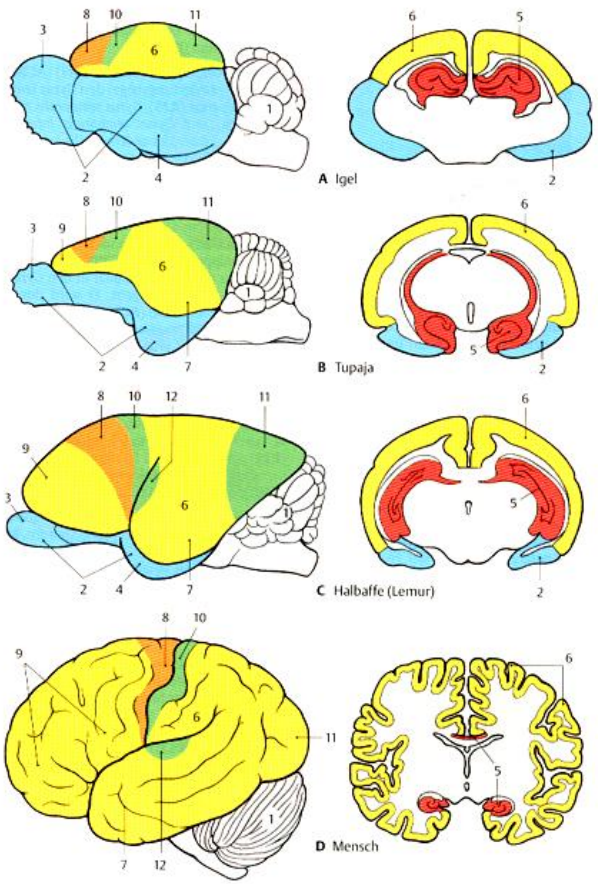

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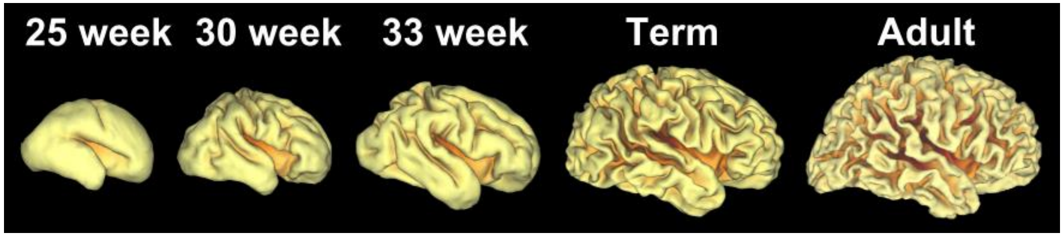
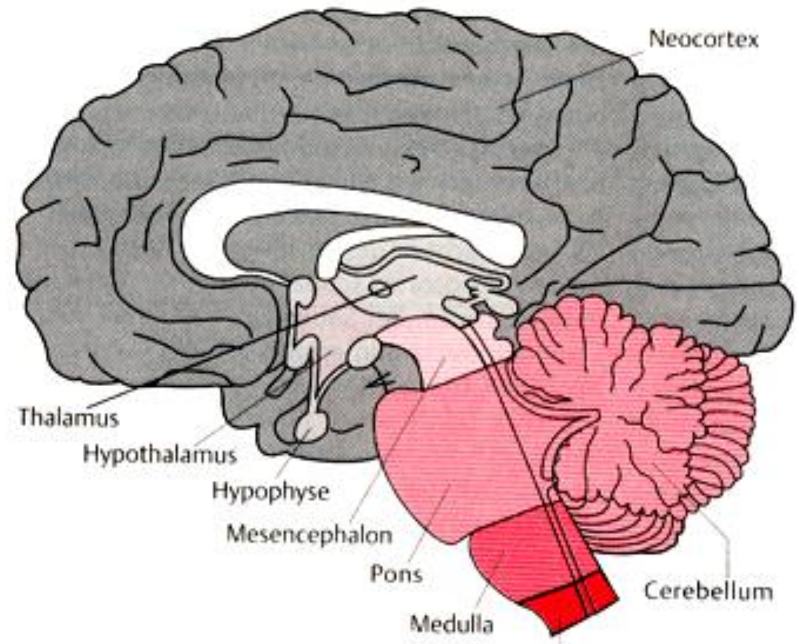


Development and evolution of the cerebral cortex

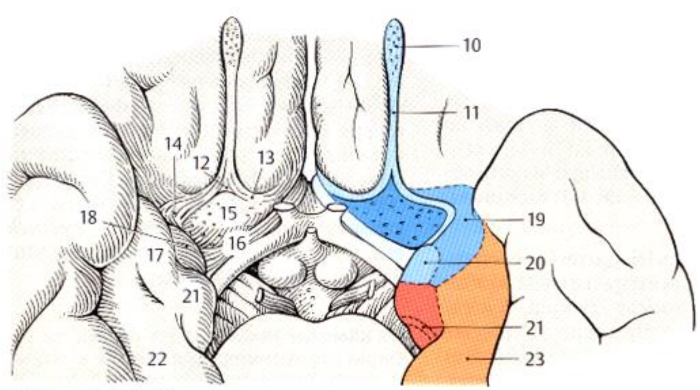
„old“ and most simple organized part is paleocortex (*Bulbus olfactorius*)

Evolutionary „newest“ and most complex part is neocortex (isocortex) (6-layer-structure)

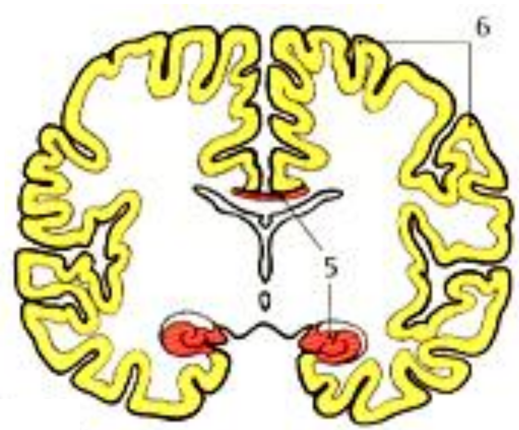
At the edge a special fold forms: the *hippocampus* (part of the archecortex)



(Reichert, *Neurobiologie*)



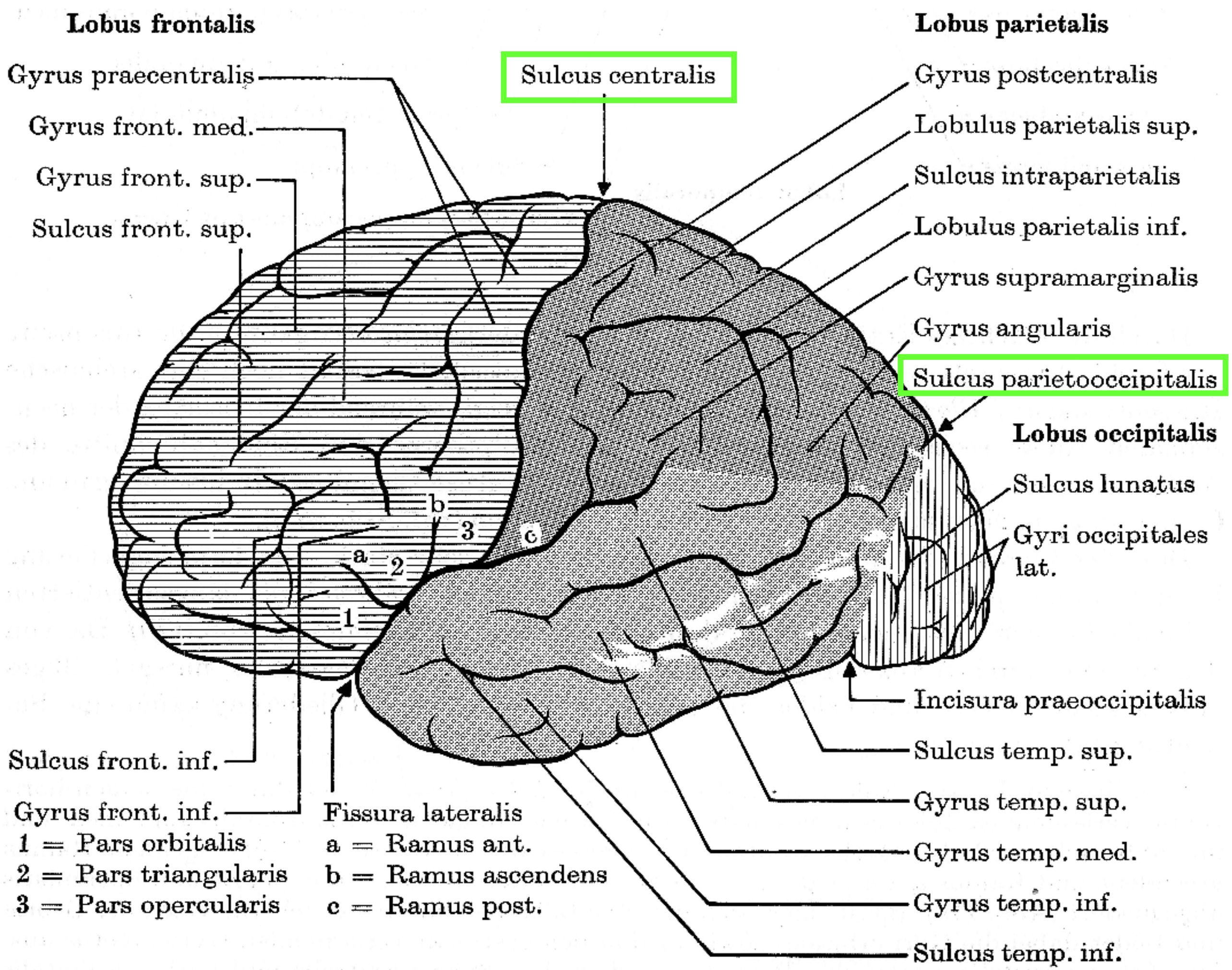
B Hirnbasis beim Menschen



Anatomy of the cerebral cortex

Differentiation in primary, secondary and tertiary sulci

Primary sulci (e.g. *Sulcus centralis, S. parietooccipitalis*) appear first and are similar in all brains



Secondary sulci

vary between brains and

Tertiary sulci

are different in every brain

"**Local gyrification index**": measure of regional complexity

Anatomy of the cerebral cortex

Anatomical distinction

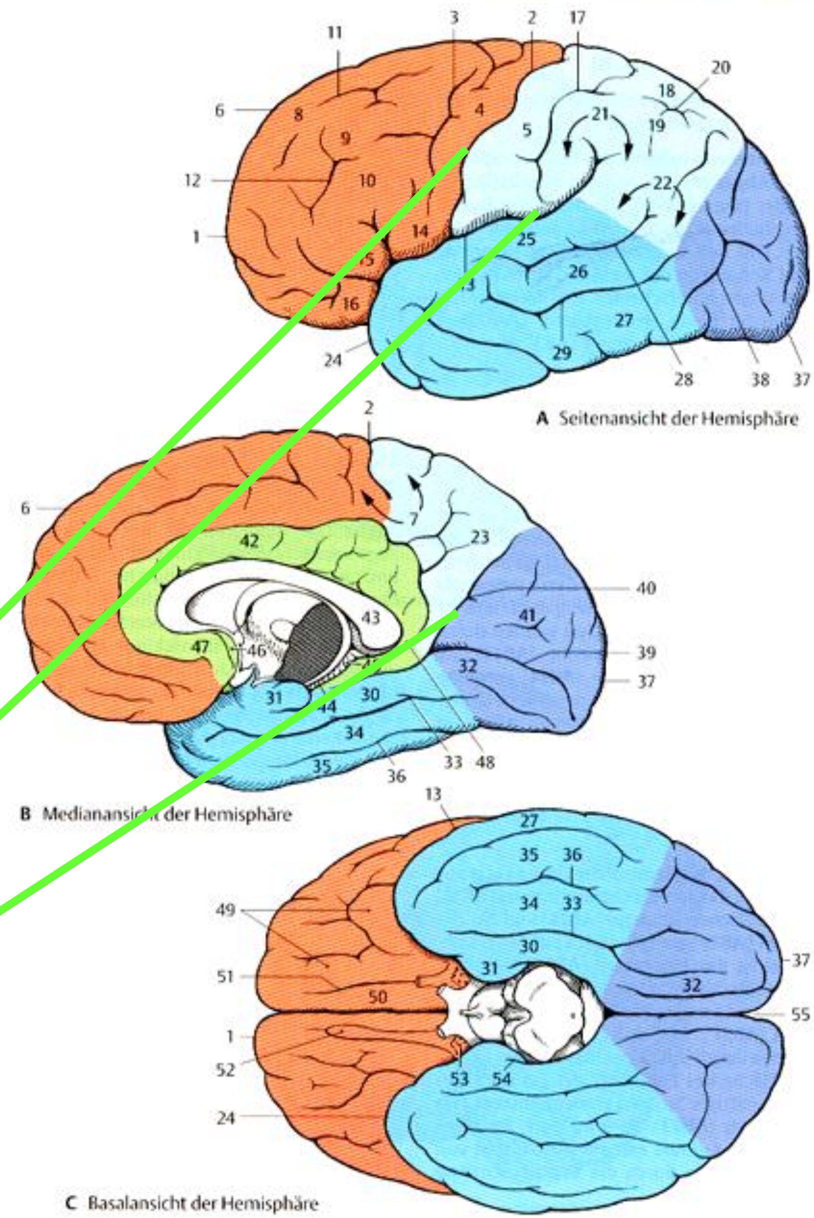
(Arbitrarily) divided into 4 major lobes:

- **frontal** (*lobus frontalis*, „Stirn oder Frontallappen“)
- **parietal** (*lobus parietalis*, „Scheitel- oder Parietallappen“)
- **temporal** (*lobus temporalis*, „Schläfen- oder Temporallappen“)
- **occipital lobe** (*lobus occipitalis*, „Hinterhaupts- oder Okzipitallappen“)

Sulcus centralis

Sulcus lateralis

Sulcus parietooccipitalis

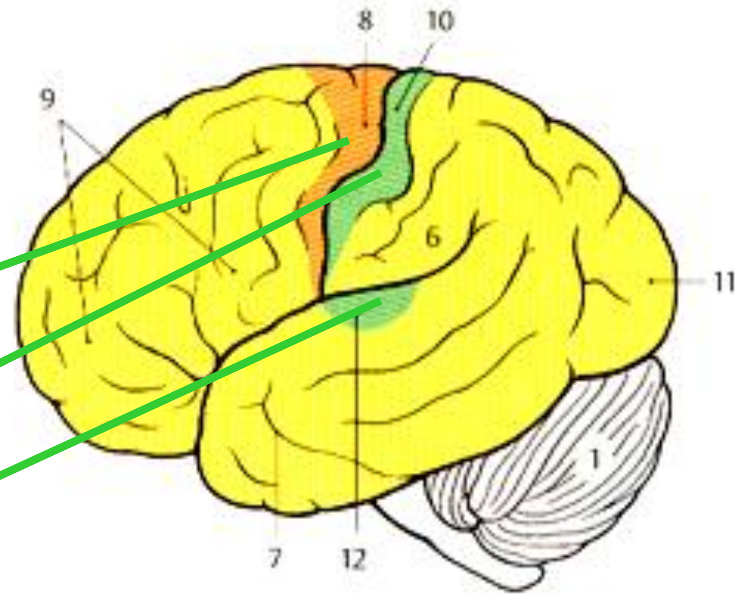


(Kahle, *Taschenatlas der Anatomie: Band 3*)

Anatomy of the cerebral cortex

Functional distinction

Primary afferent and efferent regions



Primary motor cortex

Primary sensory cortex

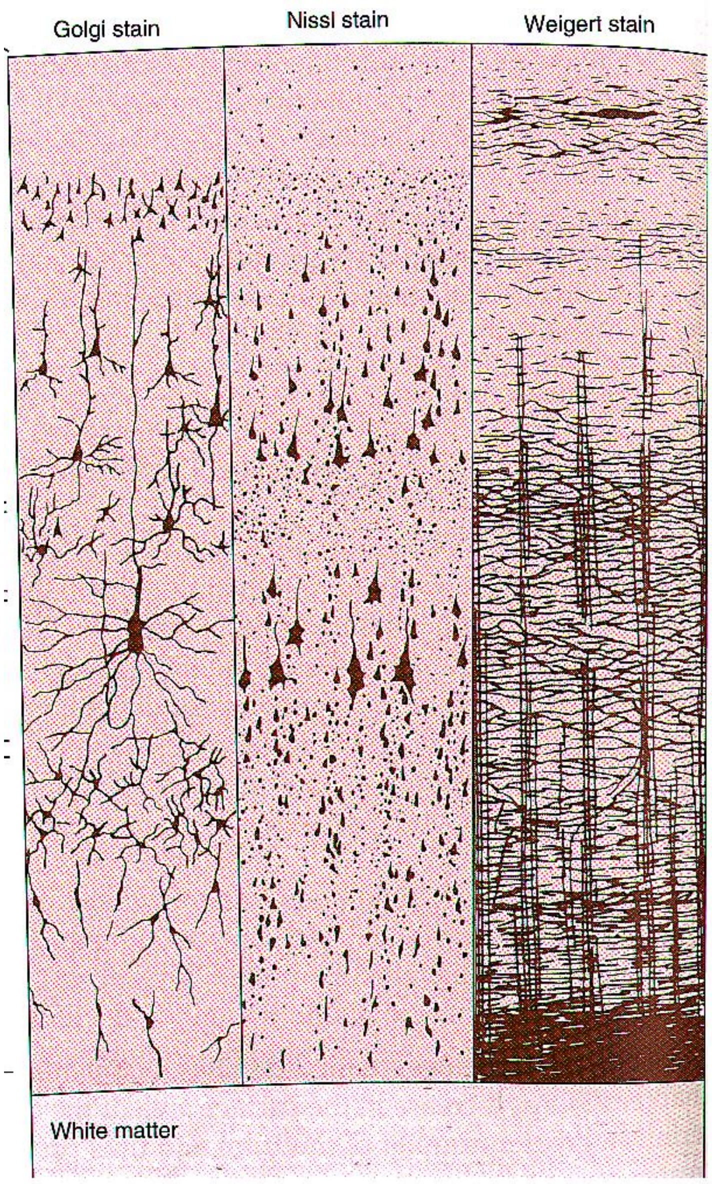
Primary auditory cortex

Major portion is covered by structures that associate different input and output information: <u>association cortices</u> – increase in size during evolution

→ Functional basis of cognition as „*indirect and modifiable coupling between stimulus and response that involves a nervous system*“

Anatomy of the cerebral cortex

Histological organization of the cerebral cortex



Typical layer structure – apparent in different staining protocols

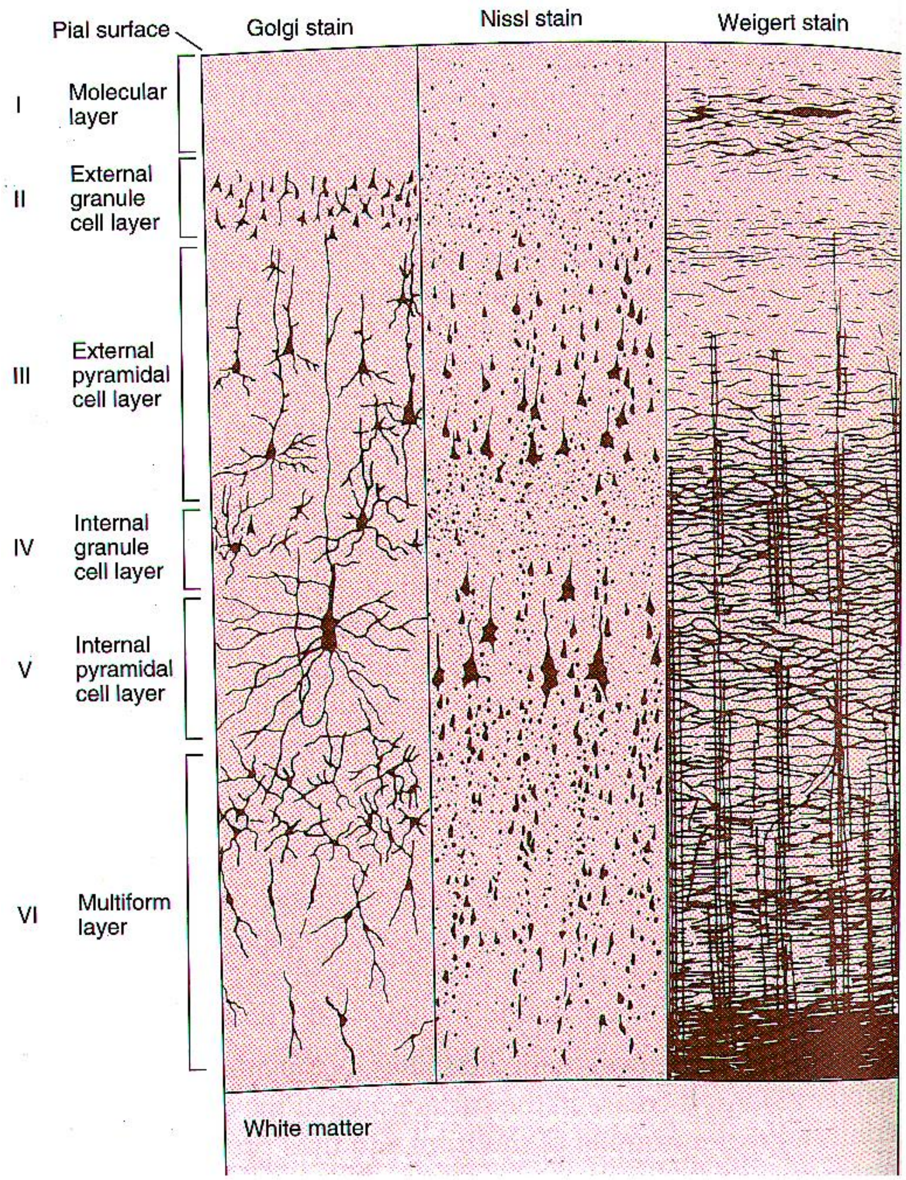
- Golgi stain (silver stain; stains individual cells with all processes)

- Nissl stain (cell body staining)

- Weigert stain (Myelin stain) – tangentially and radially oriented fibers

Anatomy of the cerebral cortex

Histological organization of the cerebral cortex



6-layer structure:

<u>I. Molecular layer</u> (*Lamina molecularis*, „Molekularschicht")

Acellular, occupied by dendrites and axons

<u>II. External granule cell layer</u> (*L. granularis externa*, „äußere Körnerschicht")

Contains mostly spherical cells (granule cells)

<u>III. External pyramidal cell layer</u> (*L. pyramidalis*, „äußere Pyramidenschicht")

Many cell types, most are pyramidically shaped

<u>IV. Internal granule cell layer</u> (*L. granularis* interna, „Innere Körnerschicht")

Similar to layer II

<u>V. Internal pyramidal cell layer</u> (*L. ganglionaris*, „innere Pyramidenschicht")

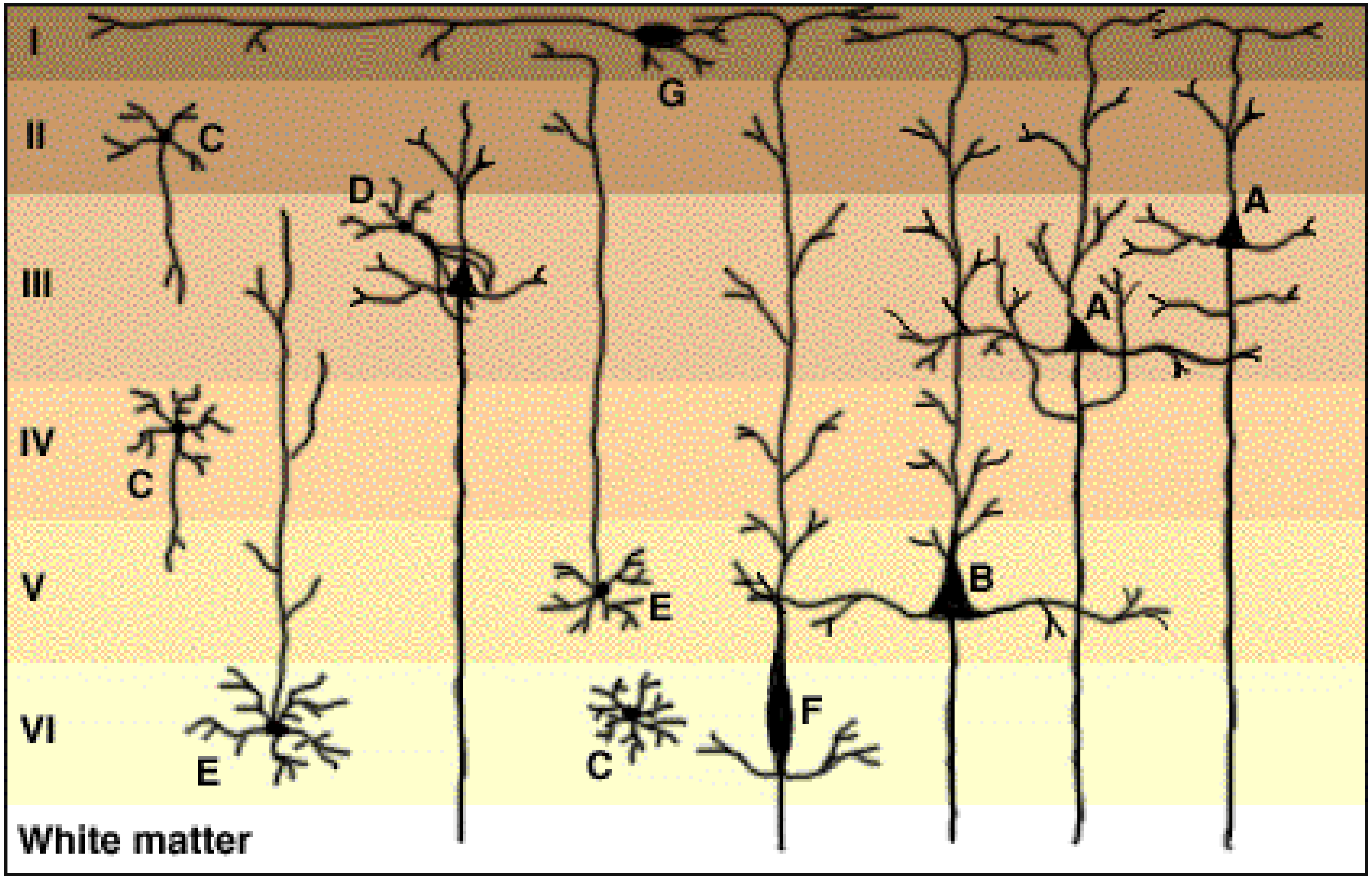
Similar to layer III, cell bodies are usually larger

<u>VI. Multiform layer</u> (L. multiformis)

heterogenous layer, different cell types

Anatomy of the cerebral cortex

Histological organization of the cerebral cortex



Layer I - Molecular layer
Layer 2 - External granular layer
Layer 3 - External pyramidal layer
Layer 4 - Internal granular layer
Layer 5 - Internal pyramidal layer
Layer 6 - Fusiform or multiform layer

A - Pyramidal cells
B - Betz cell (giant pyramidal cell)
C - Granule (stellate) cells

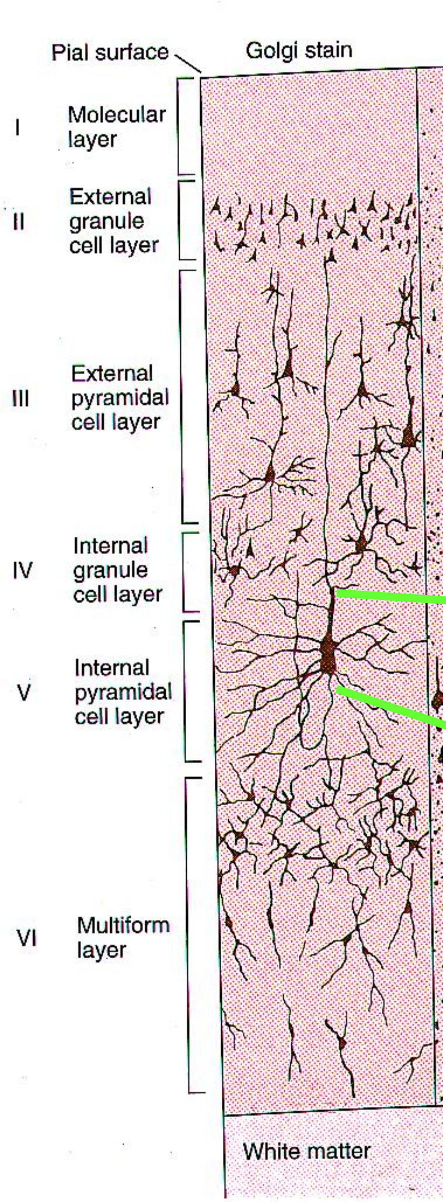
Excitatory neurons

D - Basket cell
E - Martinotti cells
F - Fusiform (spindle) cell
G - Horizontal cell

Inhibitory neurons (interneurons)

Anatomy of the cerebral cortex

Structure of the pyramidal neuron



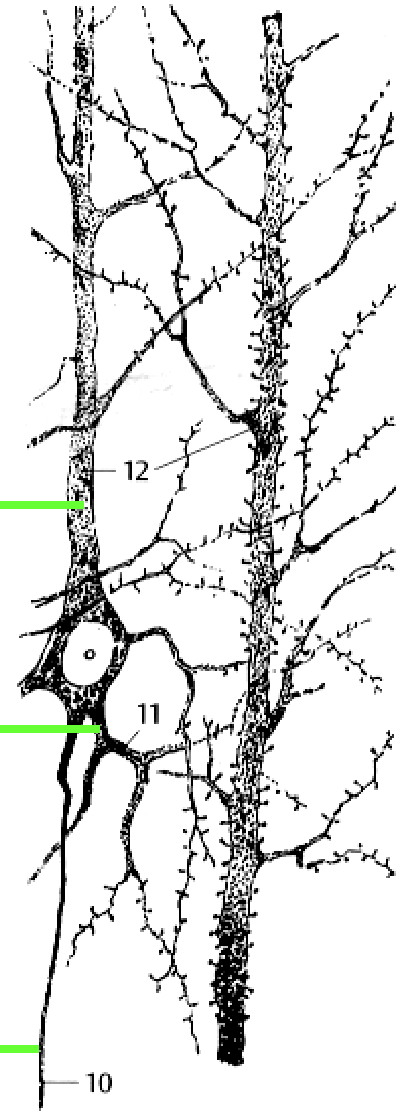
Characteristic cell type of the neocortex is the <u>pyramidal cell</u>

Excitatory (glutamic acid)
Axon leaves from the base
Basal dendrites branch from the edge of the base
Strong apical dendrite projects to the surface
Dendrites are covered with „spines“

apical dendrite

basal dendrite

axon



Anatomy of the cerebral cortex

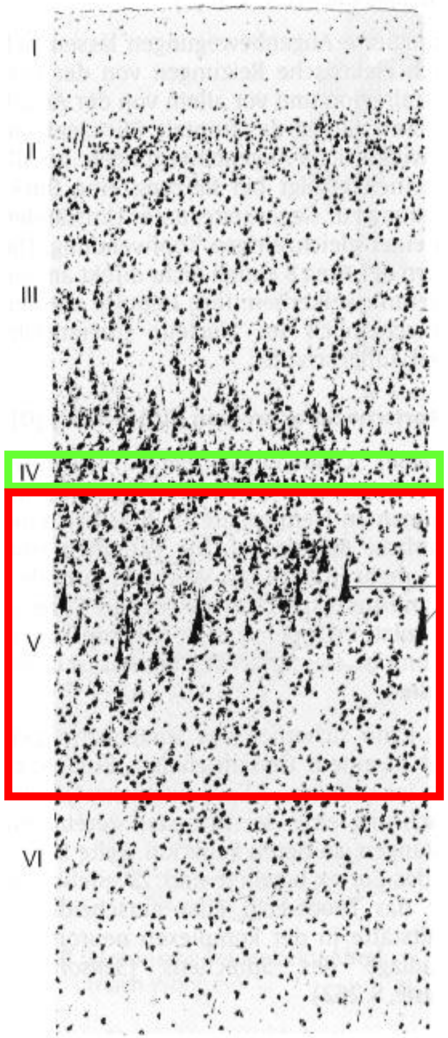
Cytoarchitecture of the brain

Korbinian Brodmann (beginning of the 20th century)

Variations of the layer structure → construction of a cytoarchitectonic „map“ of the cebral cortex („isocortex“) → distinction of 52 areas

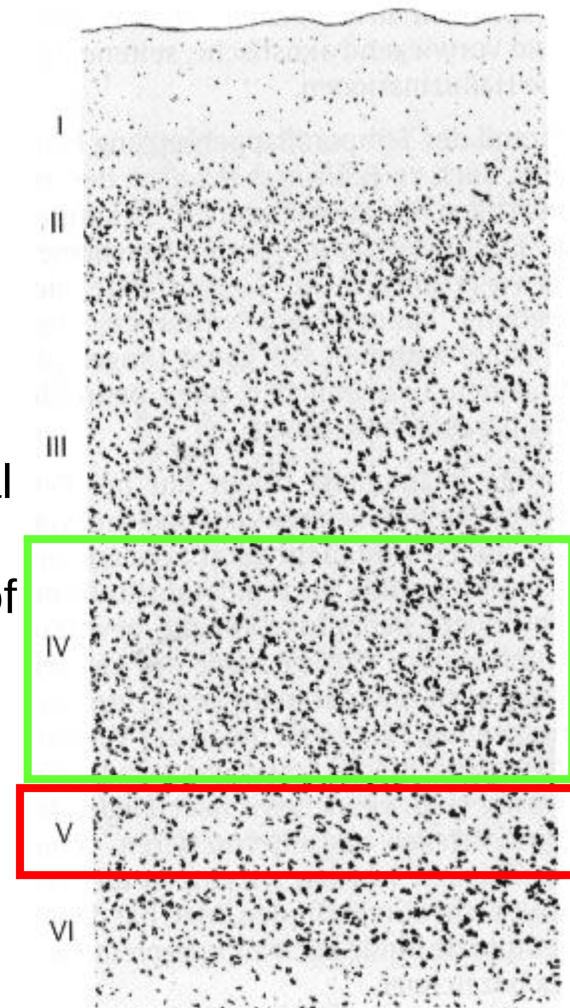
Area 4 (primary motor cortex) („agranular cortex“):

- reduction of the granule cell layer
- broadening of the pyramidal layer
- „Betz cell“ (giant pyramidal cell)



Area 3 (somato-sensory cortex) („granular cortex“):

- reduction of the pyramidal layer
- broadening of the granular layer

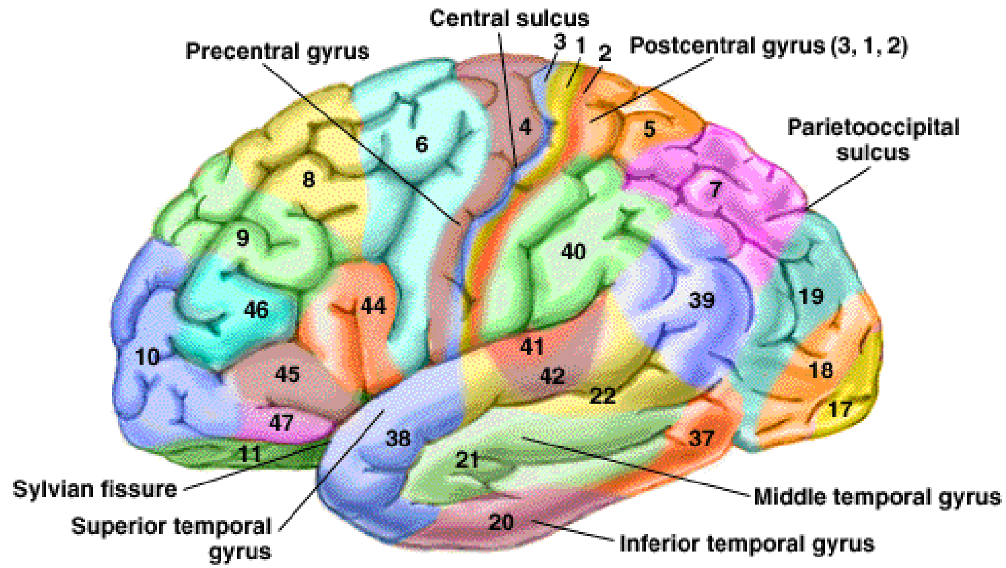


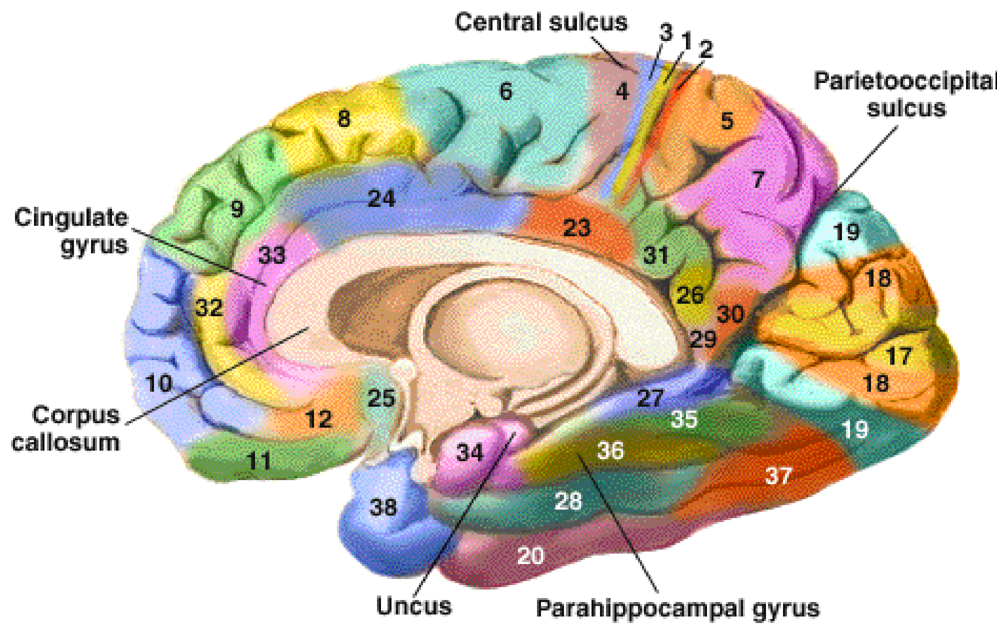
Anatomy of the cerebral cortex

Cytoarchitectonic „map“ of the cebral cortex

Area 4 (primary motor cortex) („agranular cortex“):

Area 3 (somatosensory cortex) („granular cortex“):





Anatomy of the cerebral cortex

Separation in gray and white matter

Functionality of the CNS requires optimization of two competing requirements:
- high interconnectivity
- short conduction delays

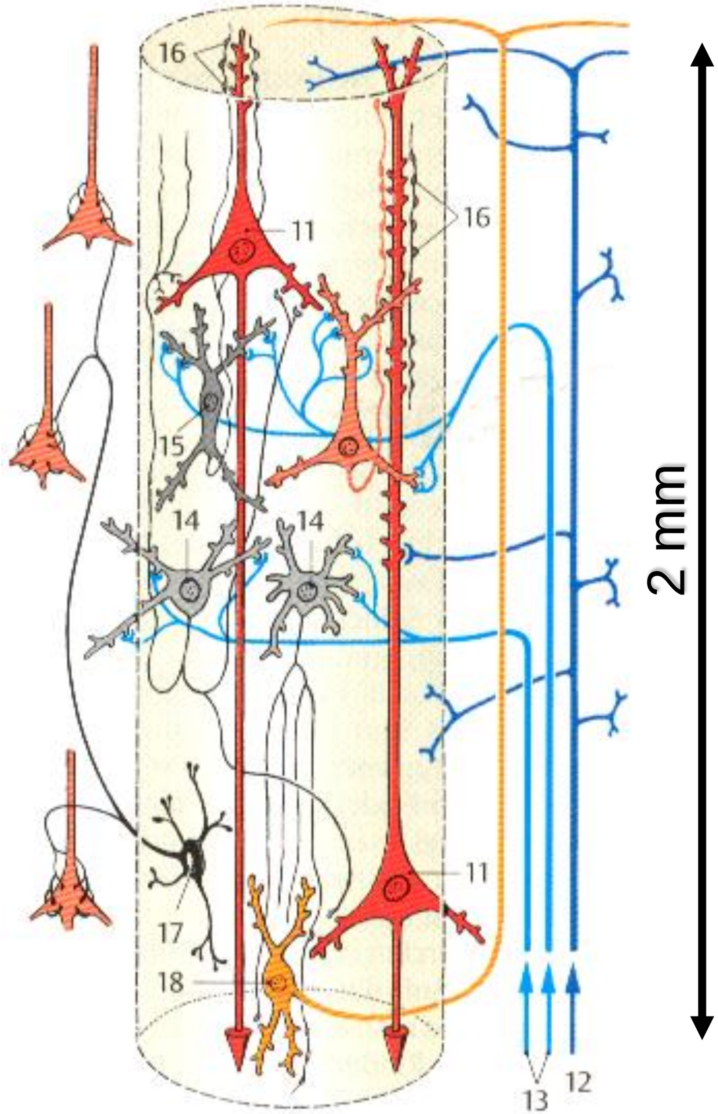
<u>Model calculation</u>: delay of several seconds if all nerve cells of the brain were connected to each other (in practice the delay is in the range of 20 ms)

→ Solution: Segregation between gray and white matter:
- High connectivity in small regions („*local connections*") (maximal number of cells: **about 10,000 neurons** with tolerable delay (ms range) → gray matter
- Fast connections with high conduction speed („*global wiring*") → white matter

(Lit.: Wen, Q., and Chlovskii, D.B. (2005) Segregation of the brain into gray and white matter: a design minimizing conduction delays. *PLOS Computational Biol.* **1**: e78-e87.)

Anatomy of the cerebral cortex

Column architecture of the cerebral cortex



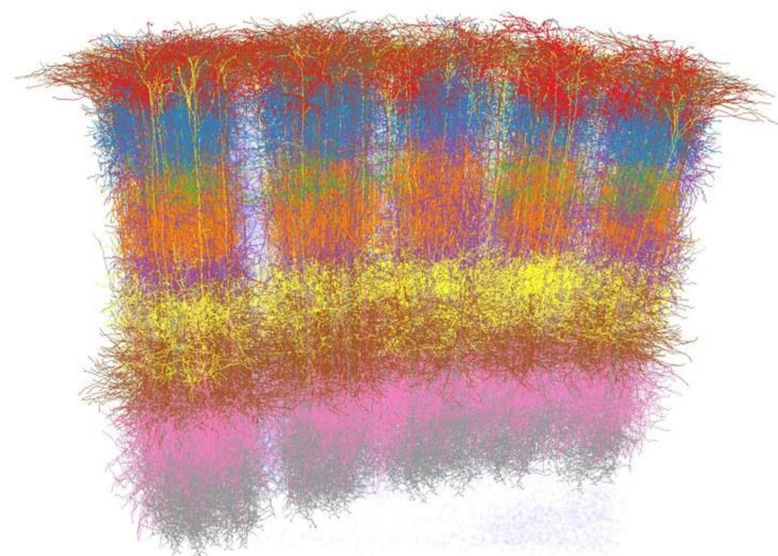
Vereinfachtes Modell einer Kolumne
(nach Szentágothai)

(Kahle, *Taschenatlas der Anatomie: Band 3*)

Neurons in the cortex are organized in vertical „columns“ (or „modules“) as basic functional units which respond <u>together</u> to a peripheral signal

Diameter about 200-300 µm, about 2500 neurons/column, about 100 pyramidal cells/column

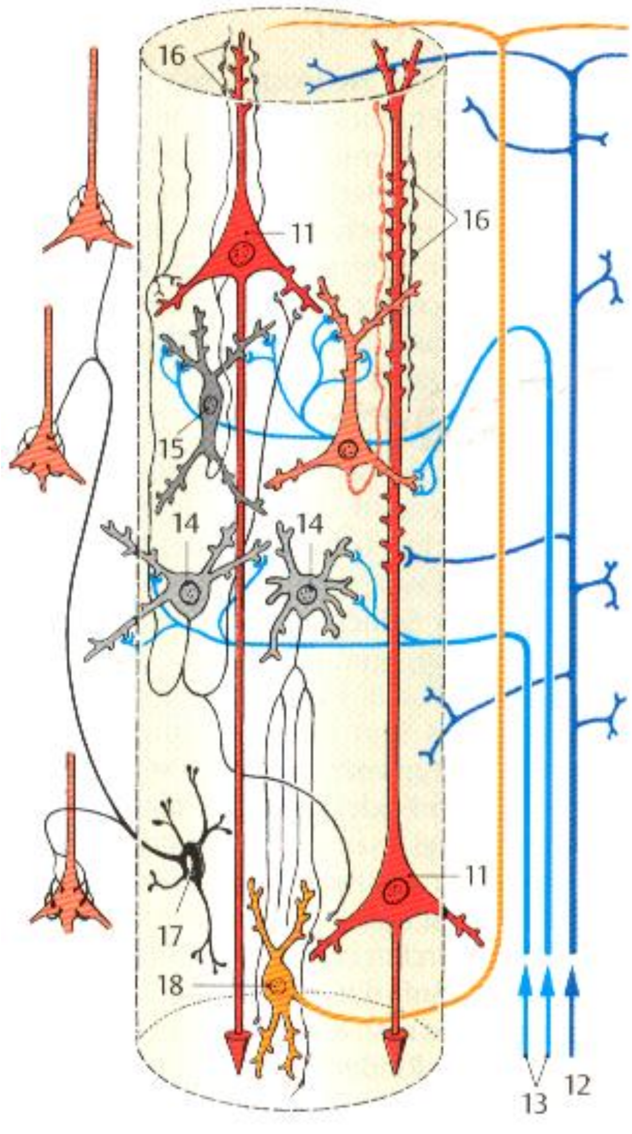
Cortex contains about 4 Mill. columns



(Marcel Oberlaender (Max Planck Florida Institute) NeuroInformatics 2012, Abstract)

Anatomy of the cerebral cortex

Output of a cerebral column



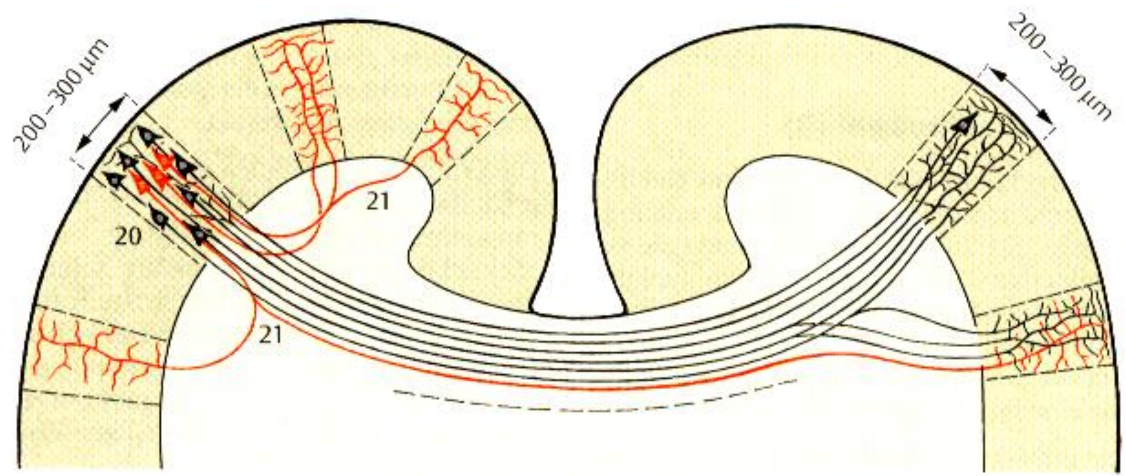
Vereinfachtes Modell einer Kolumne
(nach Szentágothai)

Output: Pyramidal cells of layer III and V excitatory neurons (glutamate)

Corticocortical connections (mainly layer III): connections within the cortex

Subcortical connections (mainly layer V): connections to other brain areas

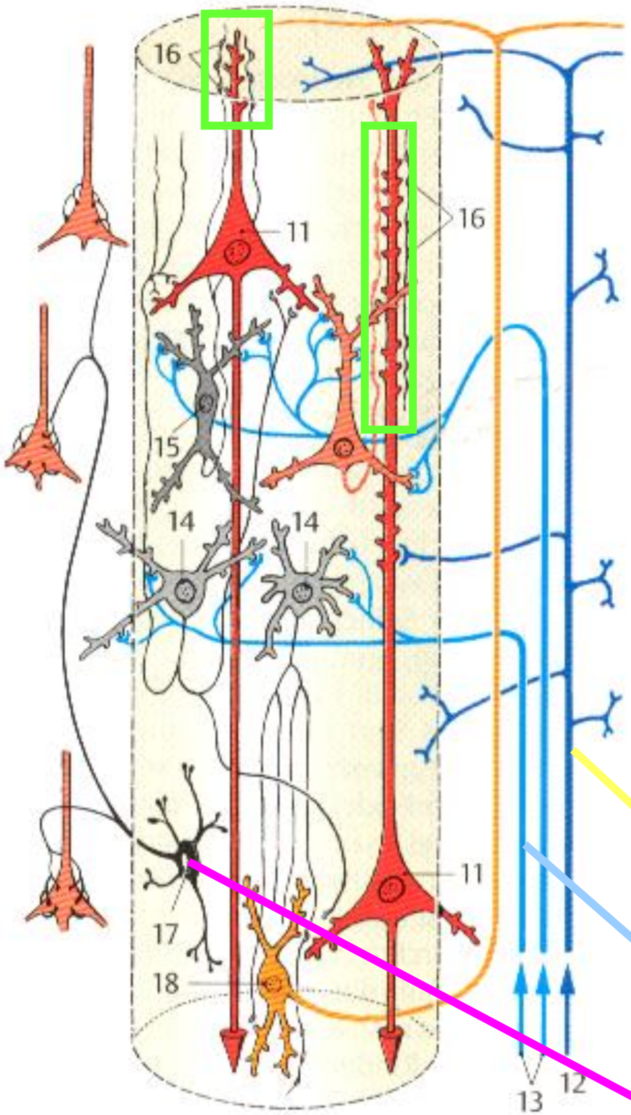
Corticocortical tracts can connect cortical columns of the same hemisphere or to the symmetrical column on the contralateral side



D Verbindung von vertikalen Kolumnen im Neocortex
(Szentágothai nach Goldman u. Nauta)

Anatomy of the cerebral cortex

Input of a cerebral column



Vereinfachtes Modell einer Kolumne
(nach Szentágothai)

(Kahle, *Taschenatlas der Anatomie: Band 3*)

Two types of afferent fibers:

- fibers from other columns (association fibers): reach up to the molecular layer and contact apical dendrites of the pyramidal neurons
- sensory fibers: end at interneurons in layer 4 (internal granule cell layer). Axons of interneurons ascend and contact apical dendrites of pyramidal cells where they from chains of synapses
  basket cells (inhibitory interneurons) inhibit neighboring pyramidal neurons → contrast enhancement?

association fiber

sensory fibers

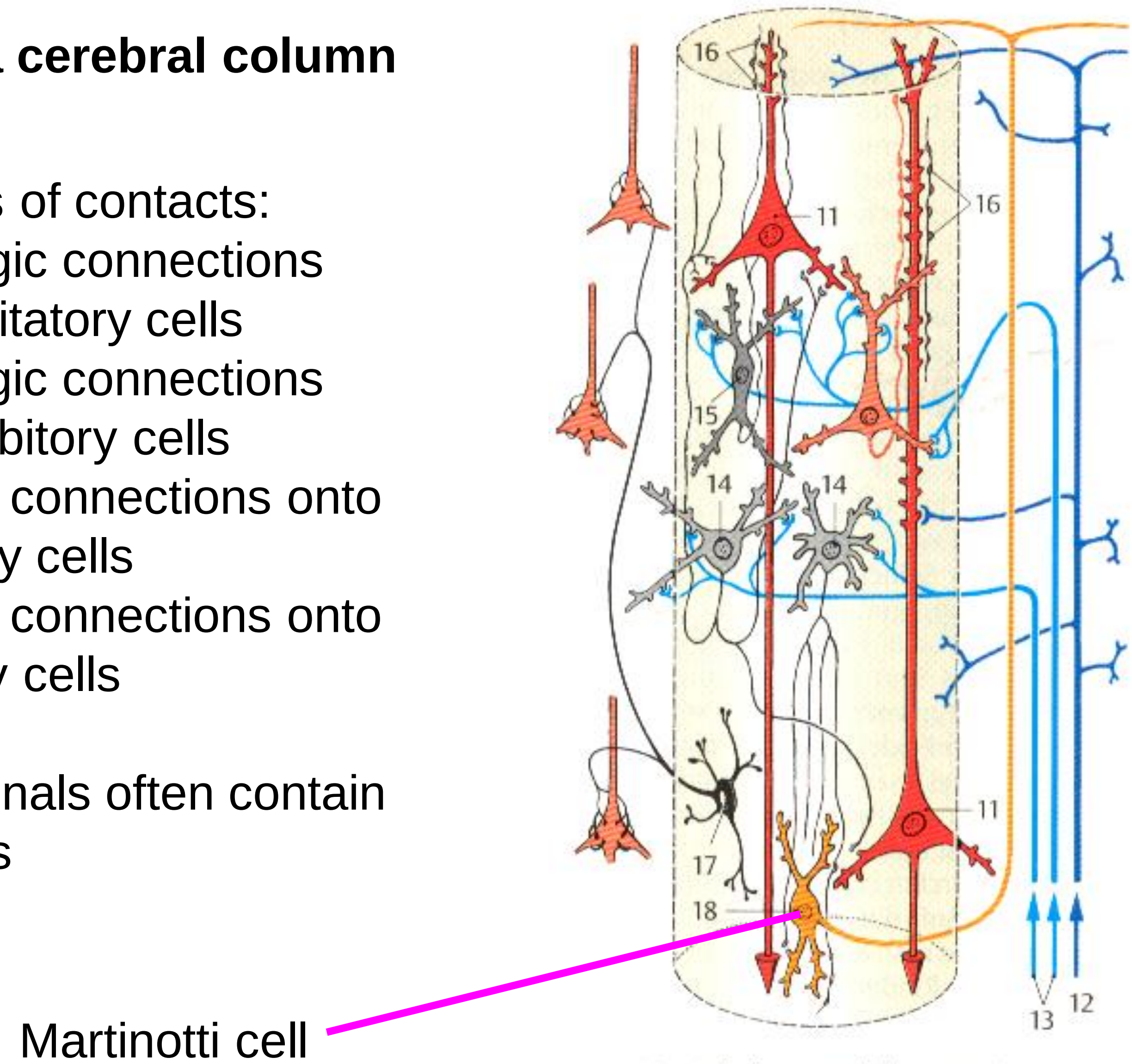
basket cell

Anatomy of the cerebral cortex

Contacts within a cerebral column

Mainly four types of contacts:
- glutamatergic connections onto excitatory cells
- glutamatergic connections onto inhibitory cells
- GABAergic connections onto excitatory cells
- GABAergic connections onto inhibitory cells

GABAergic terminals often contain also LDCVs



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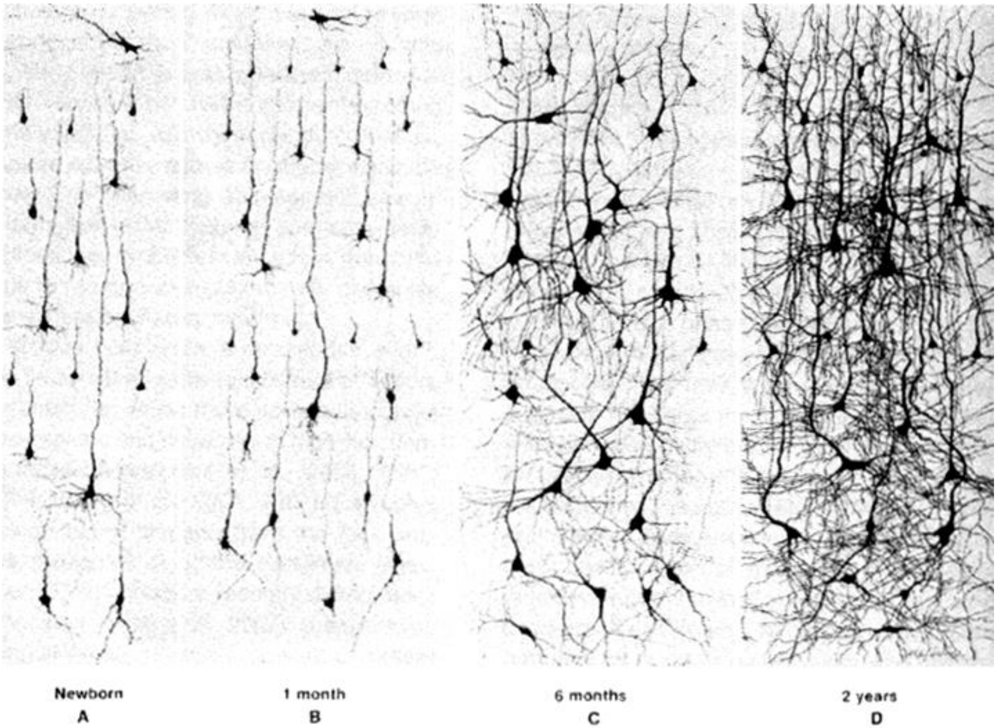
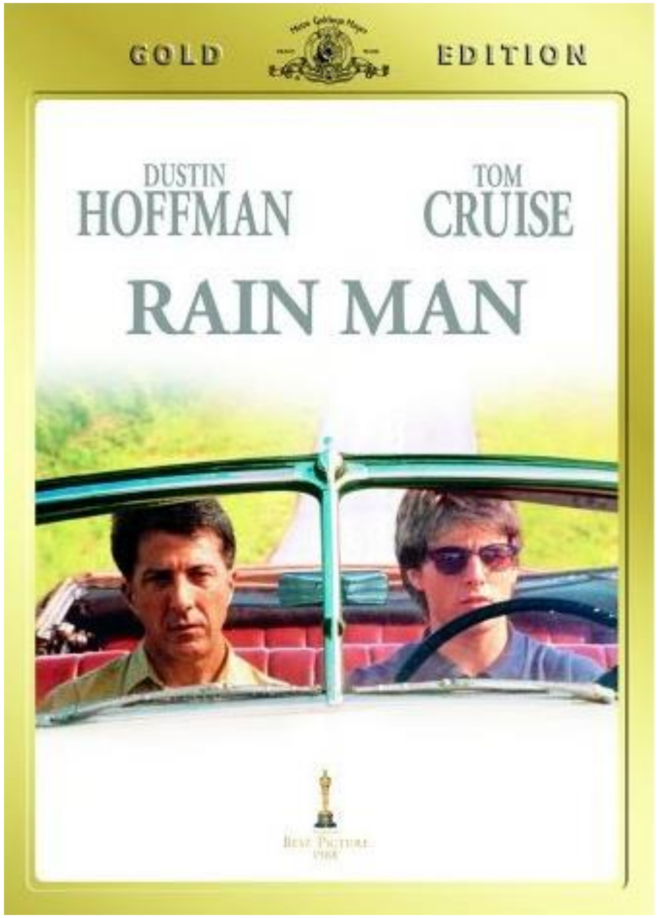
Autism

Hypothesis: Autistic disorder as a result of the formation of faulty cortical connections

„brain overgrowth" in the first years of life
→ formation of excessive local connections on the expense of far-reaching connections





(from: Courchesne et al. (2007) Mapping early brain development in autism. Neuron 56:399-413)

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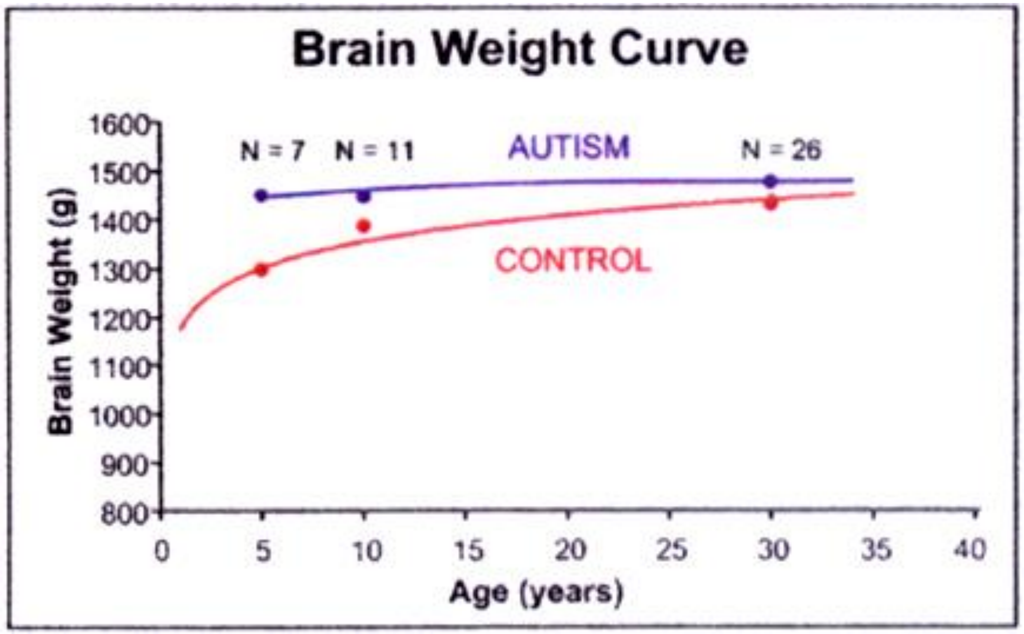

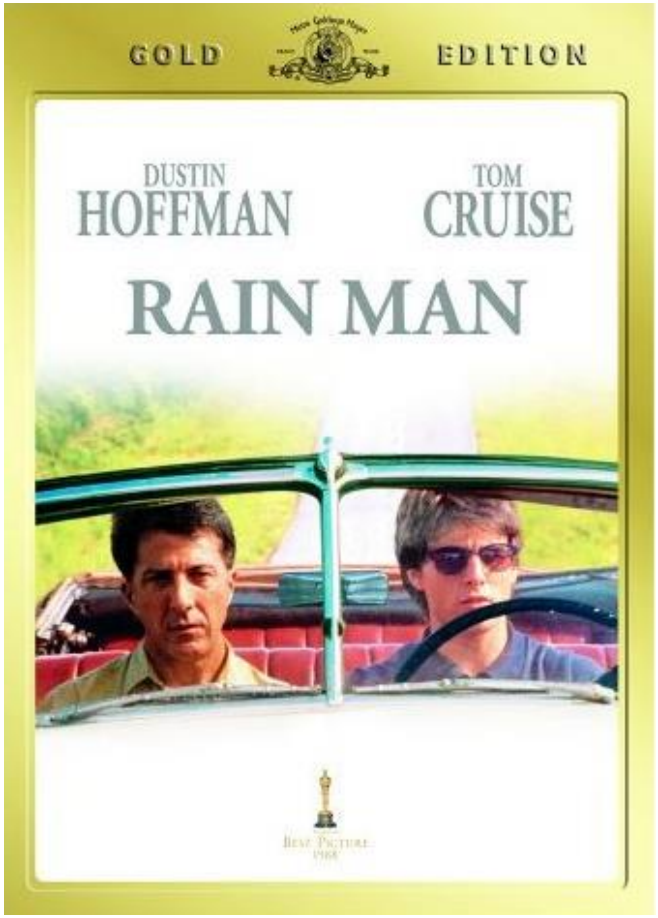

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