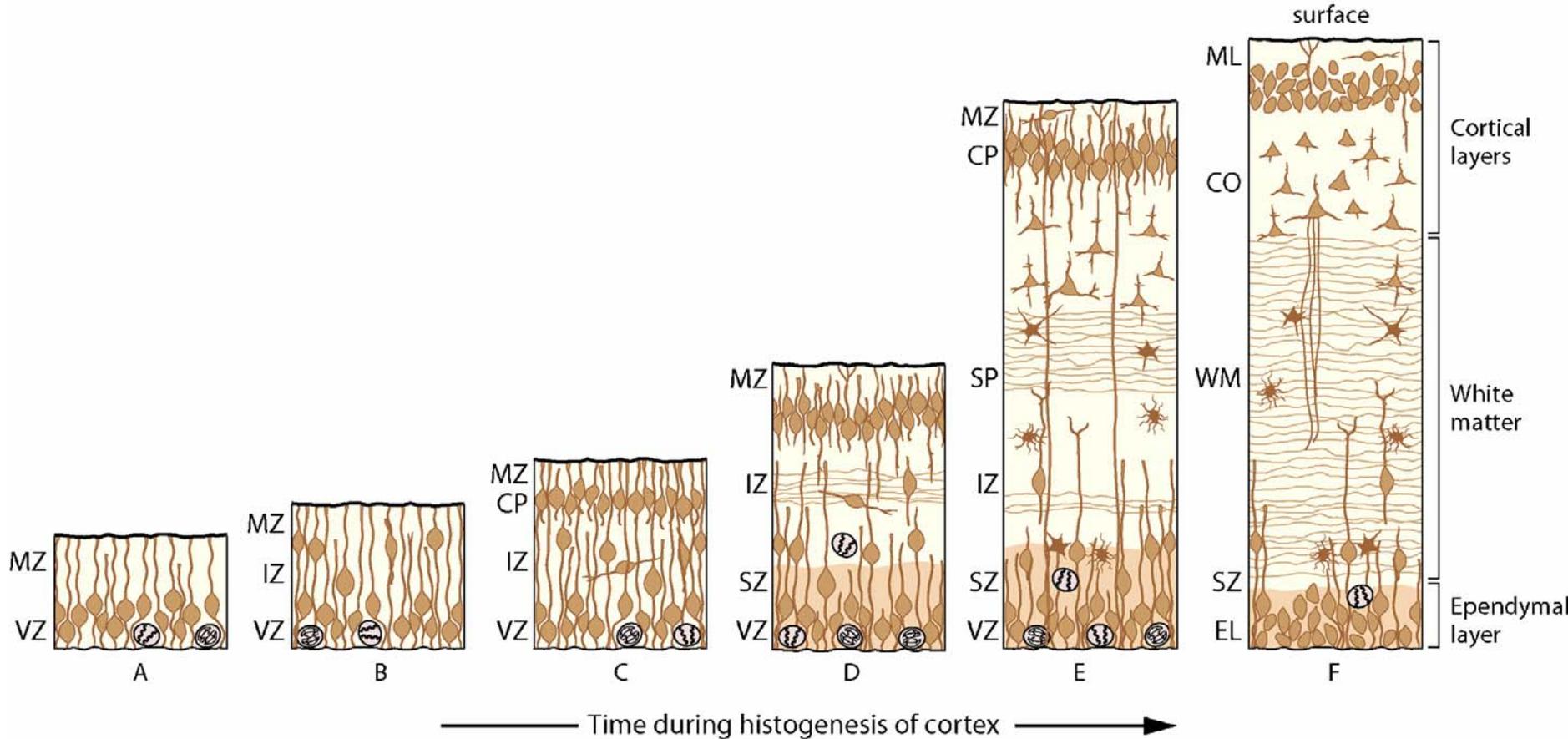
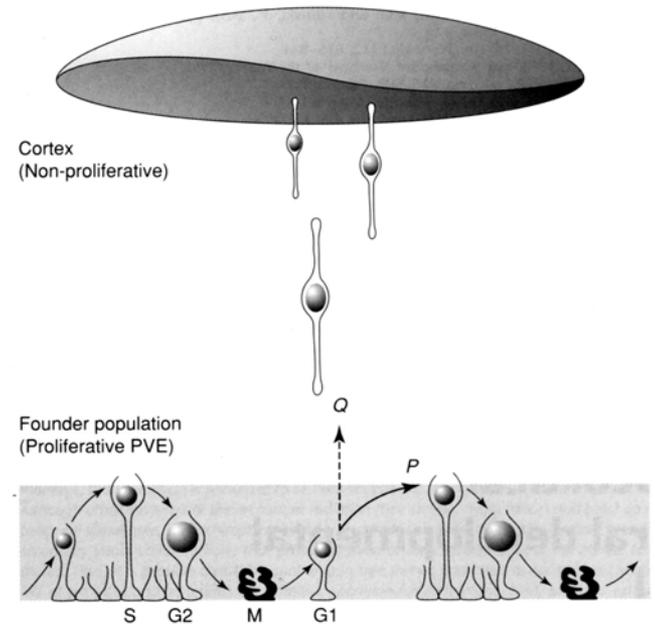
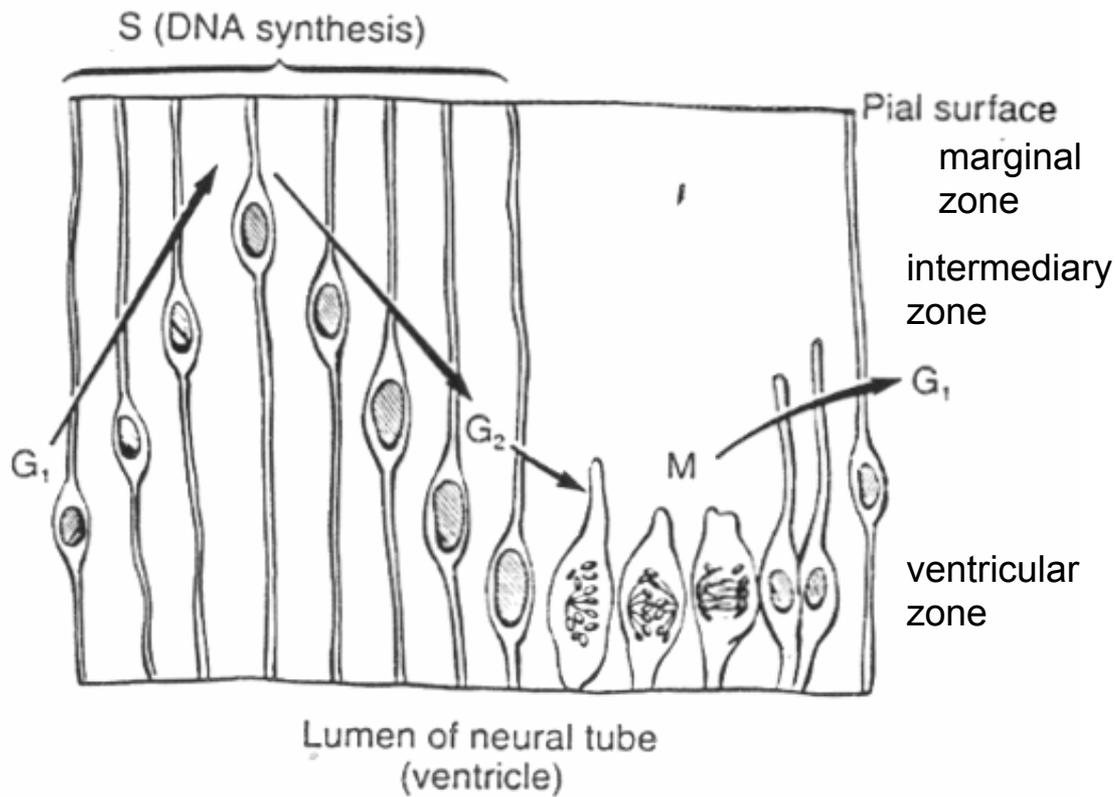


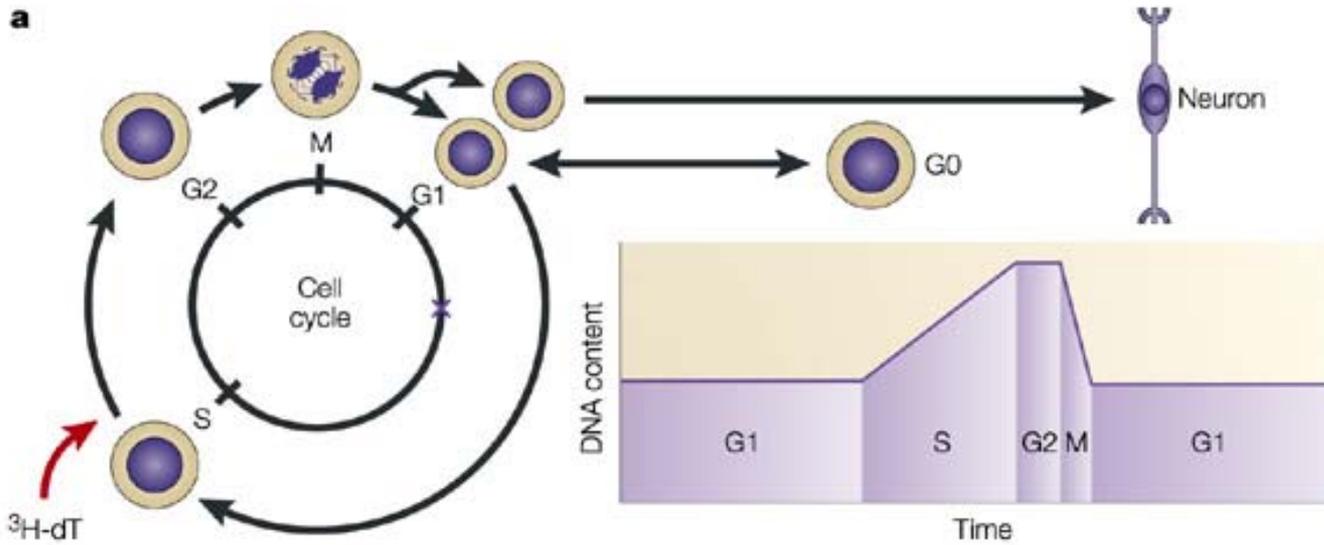
CORTEX



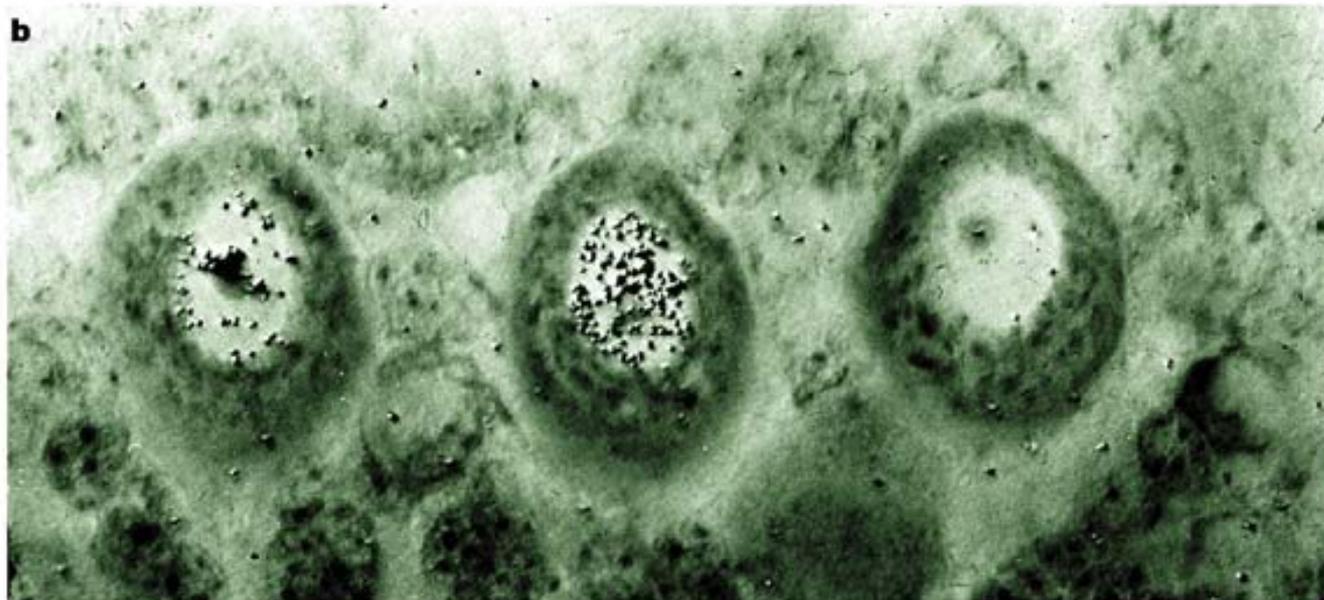
Developing wall of the telencephalic vesicle (A,B). Early stages of neural tube development, showing the ventricular zone (VZ) and marginal zone (MZ). In most brain vesicles and the spinal cord, differentiating neurons accumulate in the intermediate zone (IZ). In the telencephalic vesicle, neurons destined for cerebral cortex migrate through the intermediate zone and accumulate in the cortical plate (CP) and the subplate (SP) a transient layer of neurons that serve as temporary synaptic targets for cortical afferents (D-F). These plates form layers 2 through 6 of the cortex. The subventricular zone (SZ) is a secondary germinal zone that gives rise to interneurons and glia; WM=white matter; CO=layers 2-6; ML=stratum moleculare (after Sidman and Rakic)

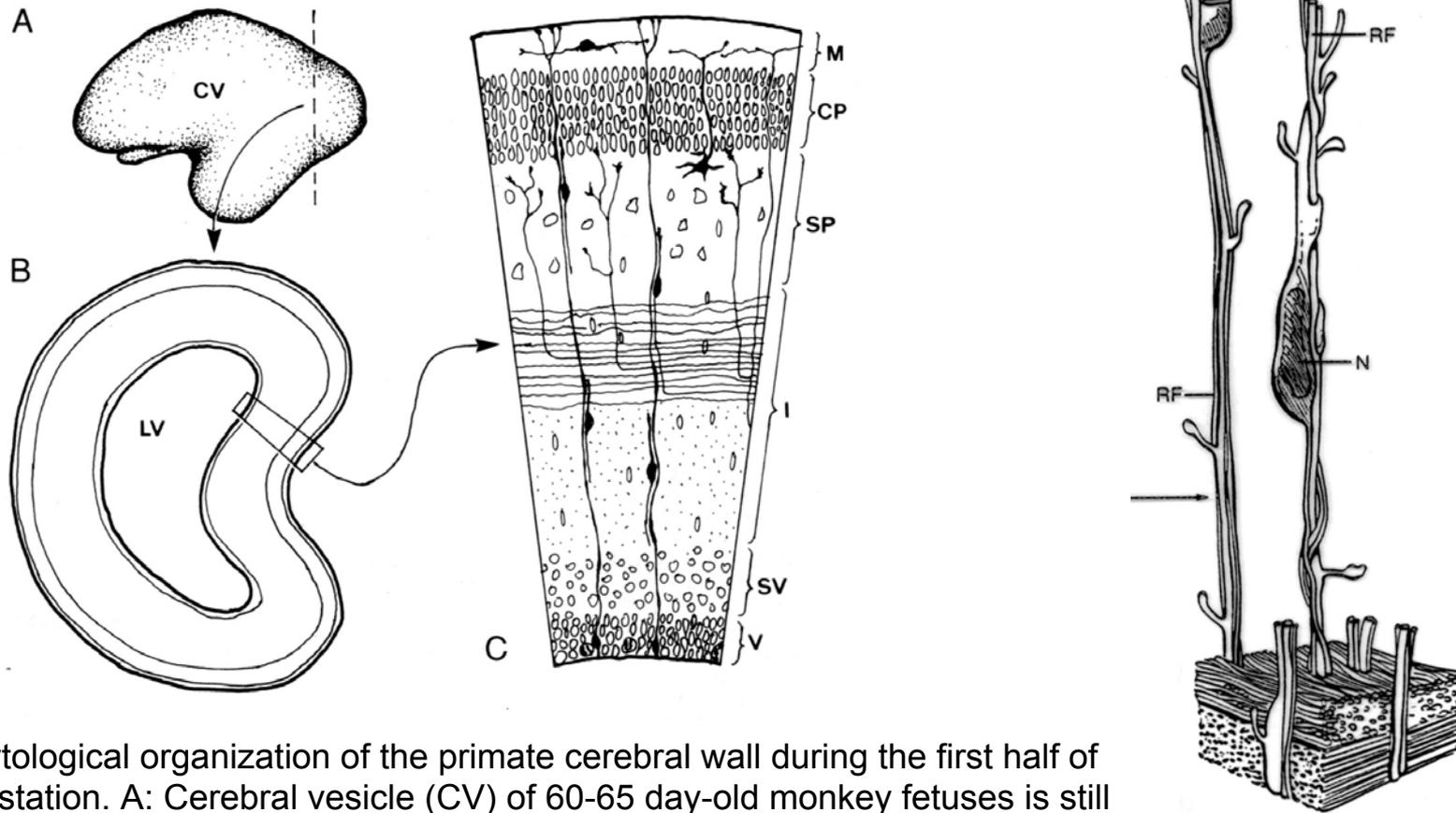


Cell proliferation in the neuroepithelium of the recently closed neural tube. The wall of the neural tube is composed entirely of proliferating neuroepithelial cells at this stage and appears as a pseudostratified epithelium in histologic sections. This effect is created by interkinetic nuclear migrations occurring during G₁ to S (DNA synthesis), and G₂ phases of the cell cycle. During mitosis (M), the cells retract their distal processes, become rounded, and divide next to the lumen of the ventricle. (From Cohen). A fraction of the cells becomes postmitotic permanently (Q) and a fraction continues to cycle (P). The cells of the Q fraction migrate to an ever-expanding cortex in which they differentiate and grow or might be eliminated by histogenetic cell death (Caviness et al., 1995)



Incorporation of ^3H -thymidin as a marker of cell division. (a) DNA synthesis during different phases of cell cycle (G1, G2 gap phases, M-mitotic division; S=synthesis phase. $^3\text{H-T}$ is readily incorporate into DNA during the S-phase. Intensive radiolabeling indicates the time of the neuron's birthday. In cases in which the cell has not divided, the cell is not labeled. (b) Purkinje cells in the middle and on the left are heavily labeled, whereas the neuron on the right can be interpreted as not divided (Rakic, 2002).





Cytological organization of the primate cerebral wall during the first half of gestation. A: Cerebral vesicle (CV) of 60-65 day-old monkey fetuses is still smooth and lacks convolutions. BL coronal section across the occipital lobe at level indicated by a vertical broken line in (A). C: A block of tissue dissected from the upper bank of calcarine fissure. At this early stage six embryonic layers can be recognized: ventricular zone (V), subventricular (SV), intermediate zone (I), subplate (SP), cortical plate (CP) and marginal zone (M). Note the presence of spindle-shaped migrating neurons moving along radial glia fibers, which span the full thickness of the cortex. Afferents from the brainstem, thalamus and other cortical areas accumulate in the SP where they make transient synapses before entering the cortical plate. LV=lateral ventricle (Rakic, 1995).

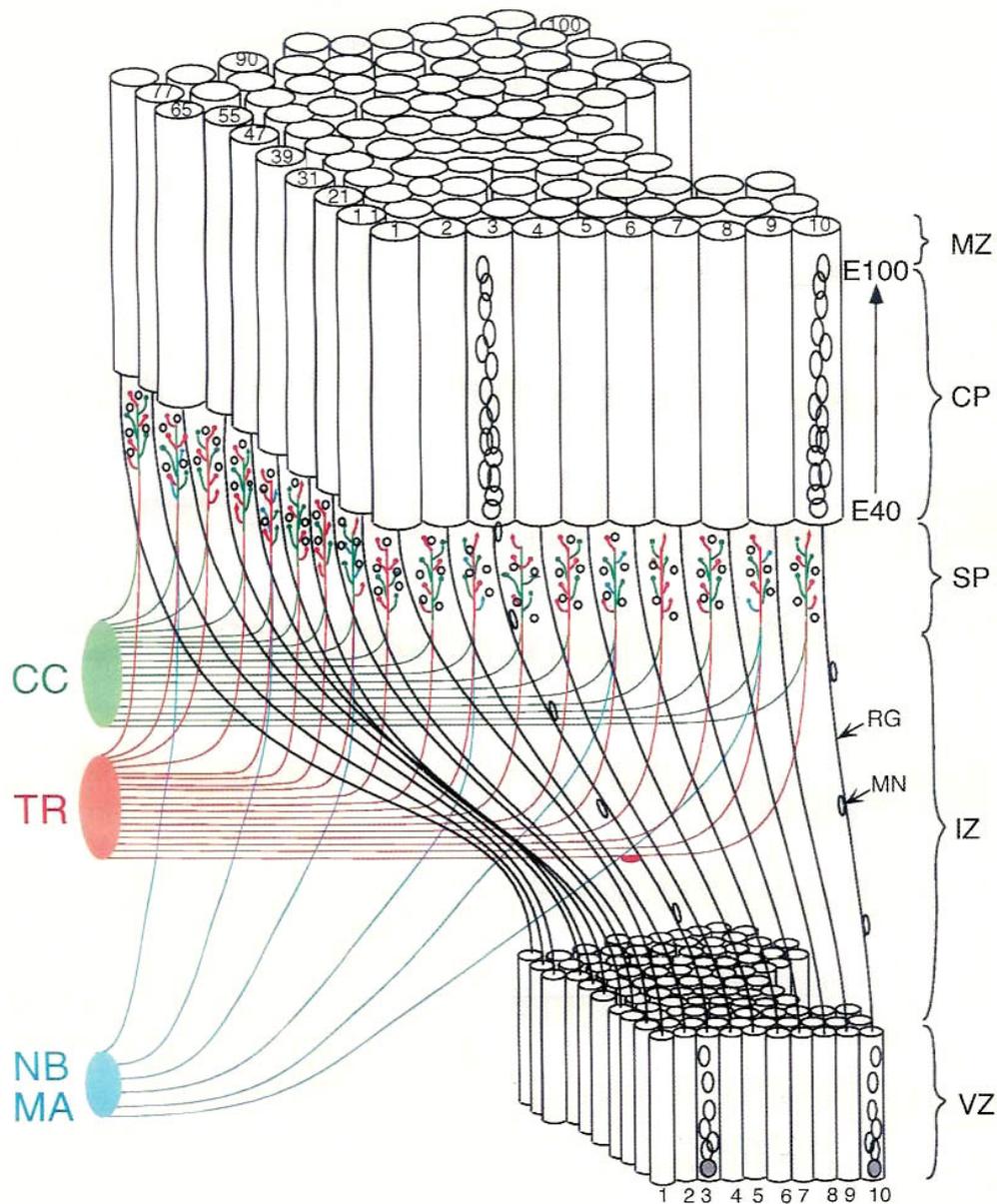
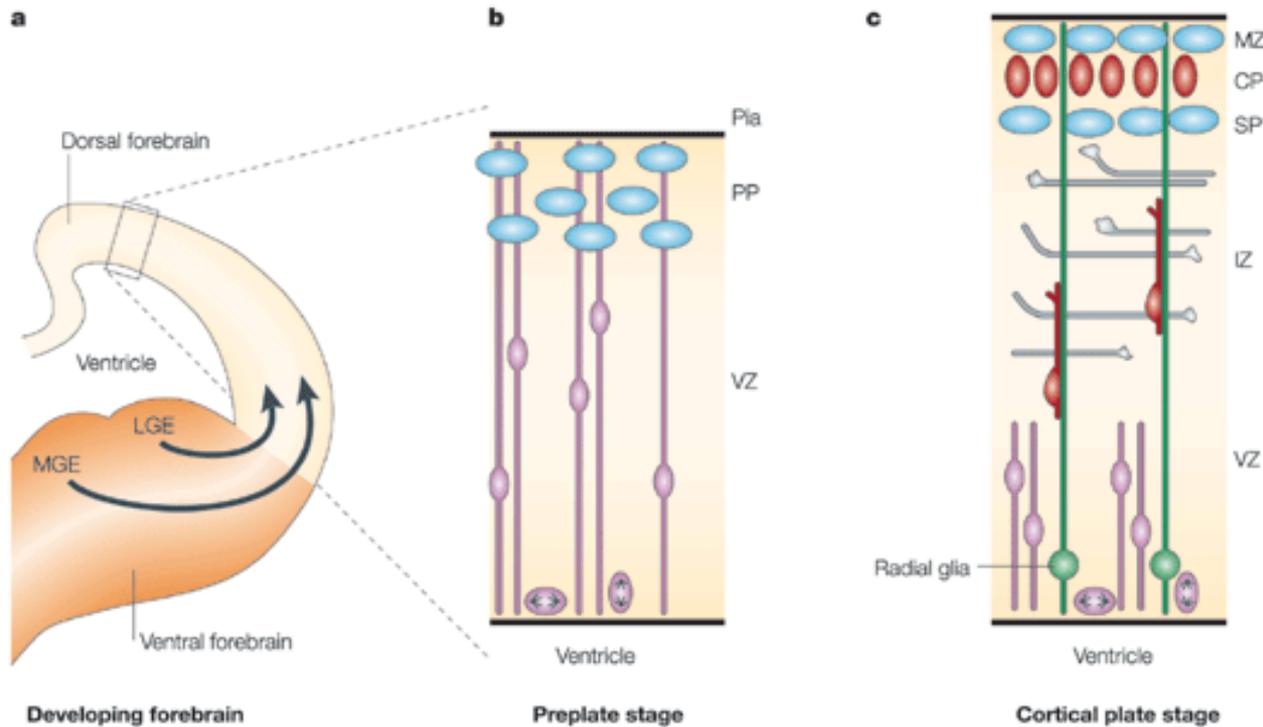
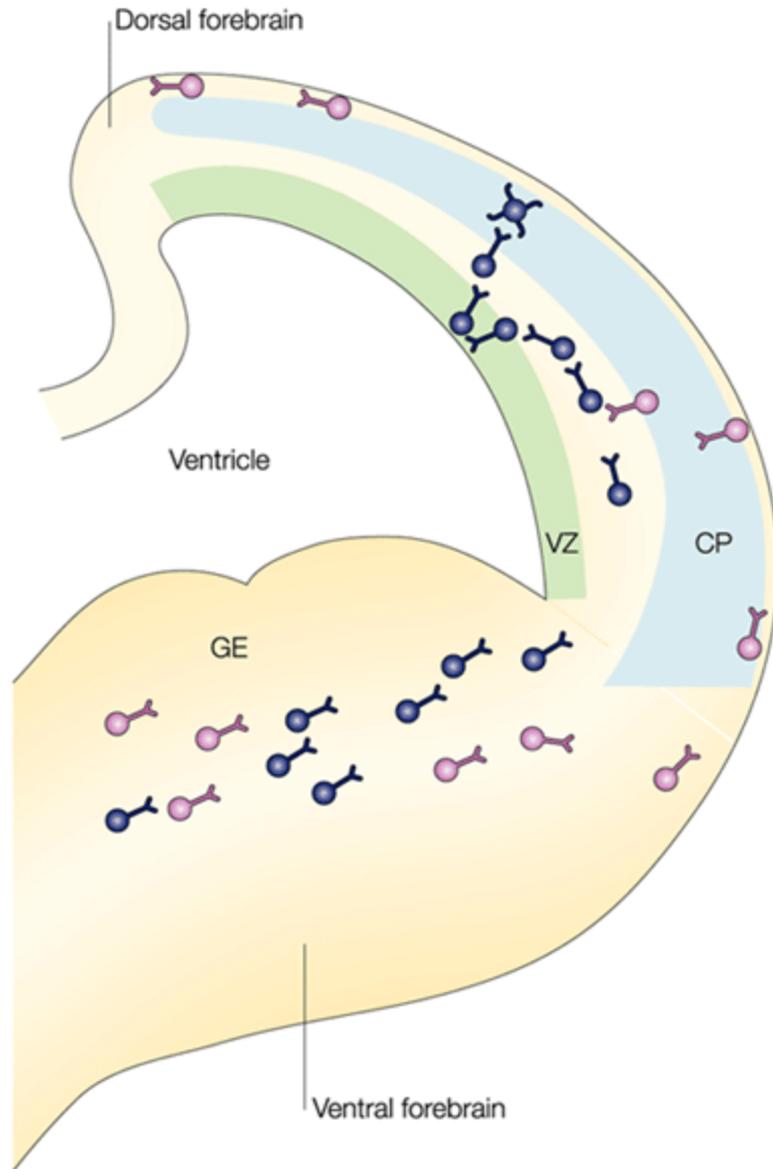


Diagram of the radial unit hypothesis. Radial glial cells (RG) in the ventricular zone (VZ) project their processes in an orderly map through the various cortical layers, thus maintaining the organizational structure specified in the ventricular layer. After their last division, cohort of migrating neurons (MN) first traverse the intermediate zone (IZ) and then the subplate zone (SP) where they have an opportunity to interact with ‘waiting’ afferents that arrive sequentially from the nucleus basalis (NB), monoaminergic axons (MA), from the thalamic radiation (TR) and the contralateral cortex (CC). After newly generated neurons bypass the earlier generated ones that are situated in the deep cortical layers, they settle at the interface between the developing cortical plate (CP) and the marginal zone (MZ), and eventually, form a radial stack of cells that share a common site of origin but are generated at different times. (Rakic, 1995)

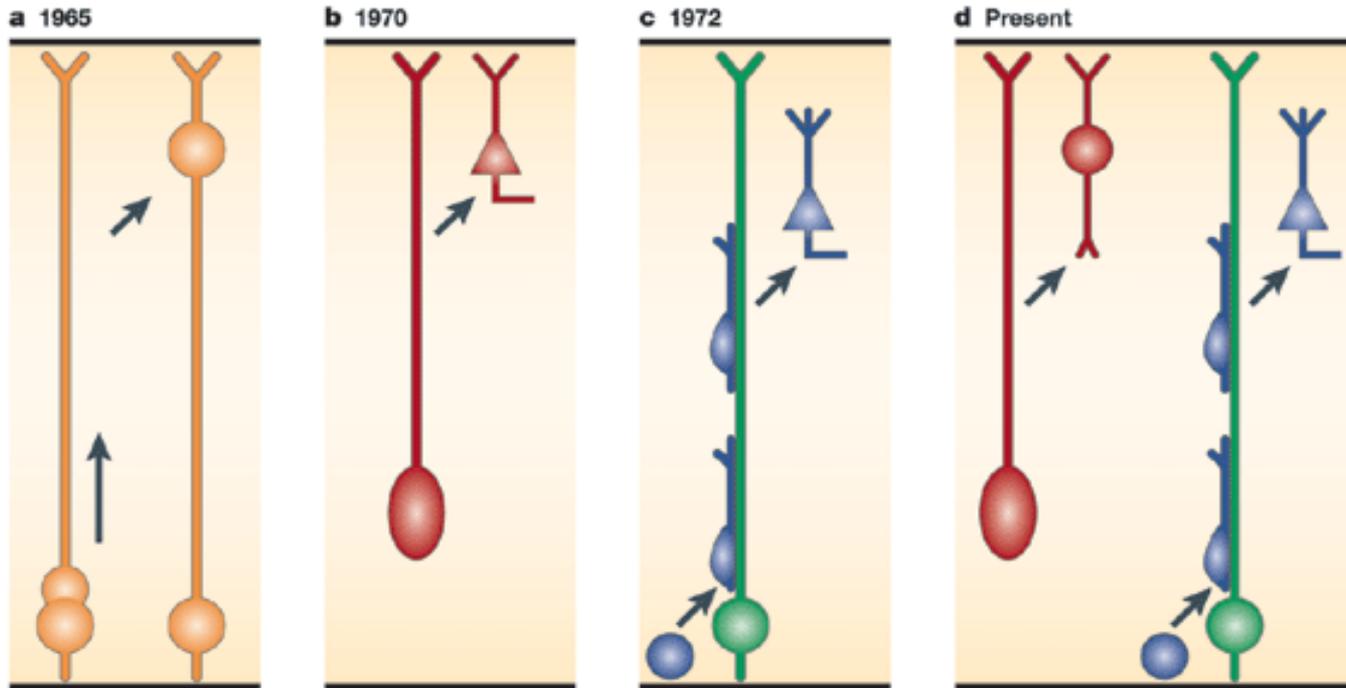


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Schematic diagram of a section through the developing rodent forebrain. The lateral and medial ganglionic eminence (MGE, LGE) of the ventral forebrain generate the neurons of the basal ganglia and the cortical interneurons, the latter follow tangential routes to the cortex (arrows). In the dorsal forebrain (boxed are in a) migration begins when the first cohort of postmitotic neurons moves out of the ventricular zone (VZ) to form the preplate (PP). Subsequent cohorts of neurons (pyramidal cells) migrate aided by radial gli, through the intermediate zone (IZ) to split the PP into outer marginal zone (MZ) and inner subplate (SP). CP=cortical plate. (Nadarajah and Parnavelas, 2002).

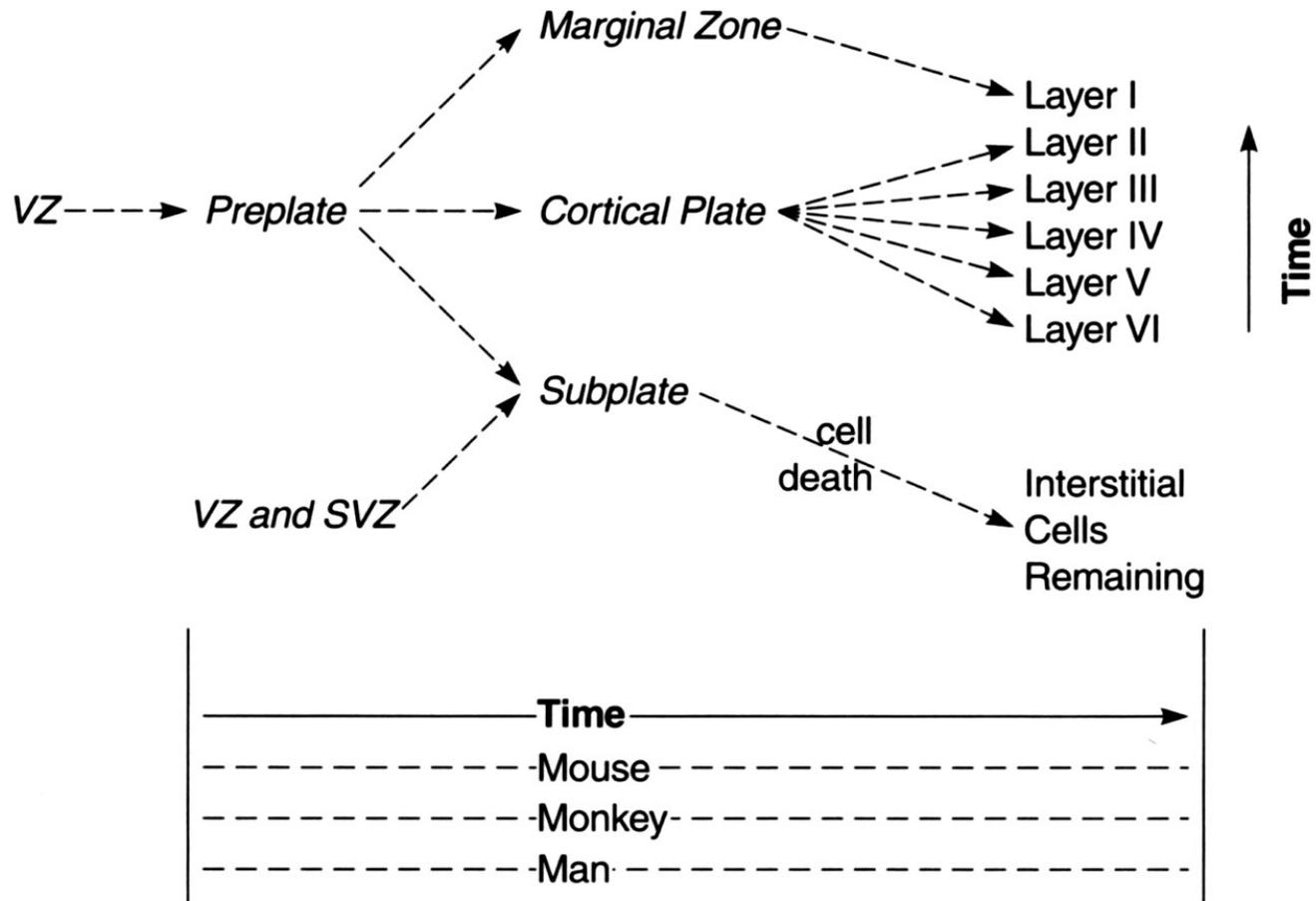


Movement of cortical interneurons in the developing cerebral cortex. Interneurons that arise in the ganglionic eminence (GE) migrate into the neocortex through the intermediate zone (blue cells) and through the marginal zone (pink cells). A subset of interneurons (blue cells) that migrate through the intermediate zone are attracted to the ventricular zone by chemoattractants that are secreted in the ventricular zone (VZ). These interneurons might receive positional information in the VZ that is required for their subsequent migration to the correct layers of the developing cortex (Nadarajah and Parnavelas, 2002).

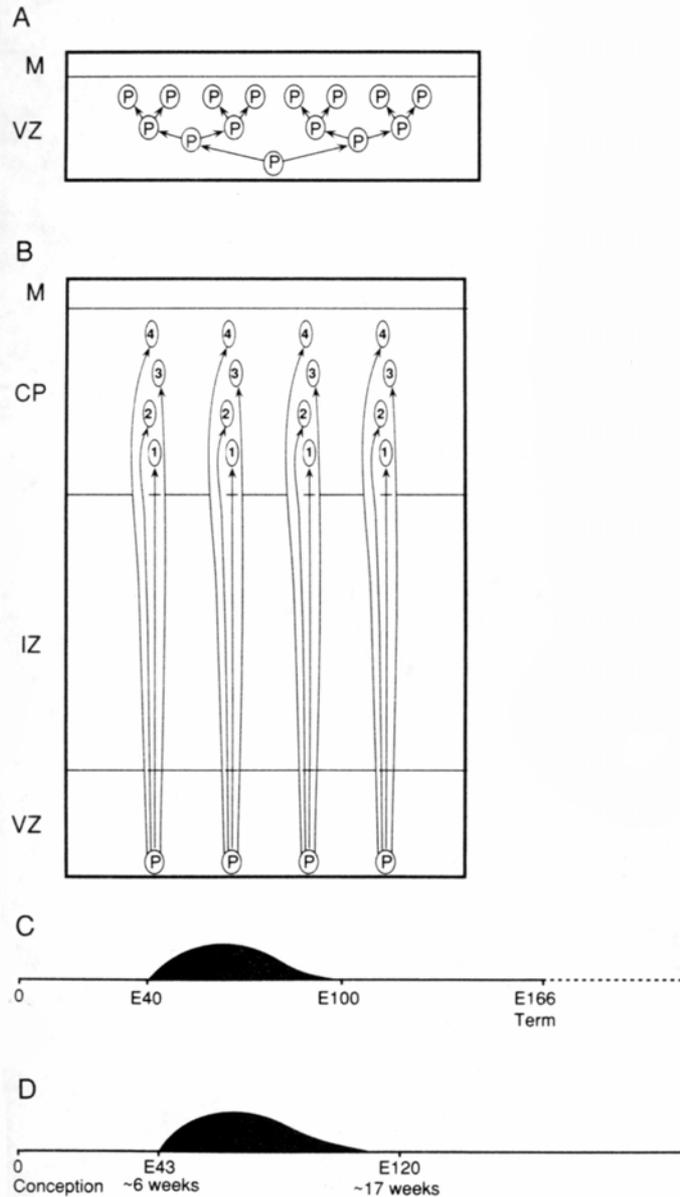


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Models of cortical neuronal migration. Berry and Rogers suggested that after cell division, the nucleus of one daughter cell moves towards the cortical plate through the long radial processes, while the other cell remains in the ventricular zone (a). In a similar model, Morest suggested that young neuroblasts lose their ventricular attachments and translocate their somata through radially oriented processes that terminate at the pial surface (b). Subsequently, Rakic proposed that young postmitotic neurons use radially oriented glial fibers as a scaffold to reach their positions in the cortical plate (c). Evidence now indicates that somal translocation is the predominant mode of movement during early corticogenesis, whereas glia-guided migration is more prevalent at later stages, when the cerebral wall is considerably thicker (Parnavelas, 2002).

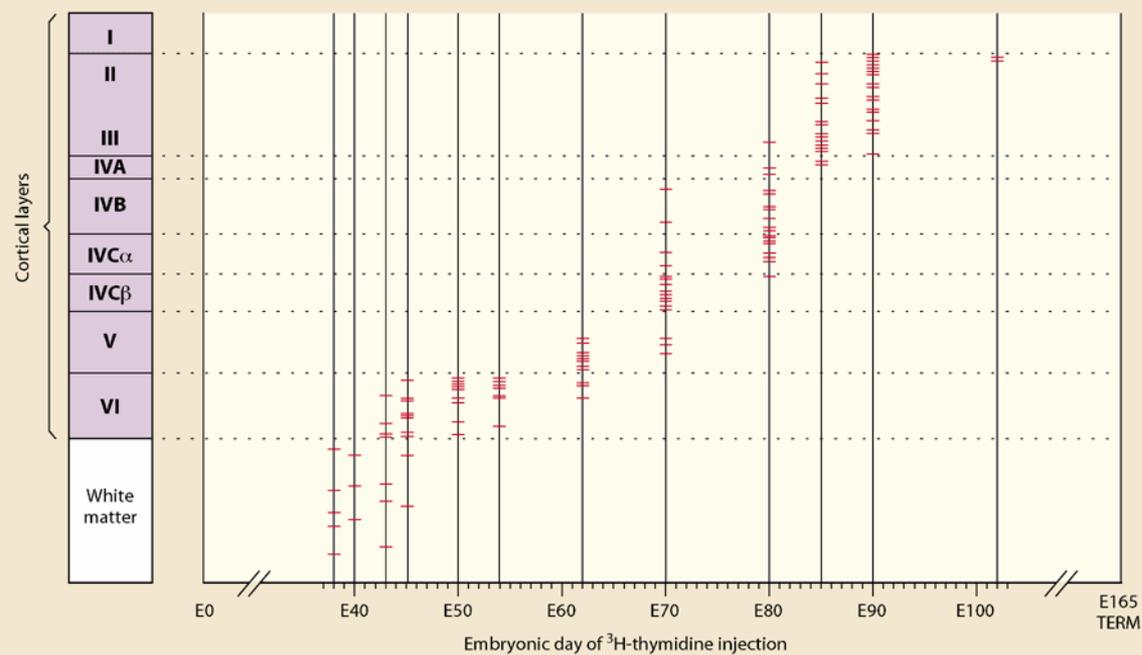


Schema of processes in generation of the neocortex (Mountcastle, 1998)



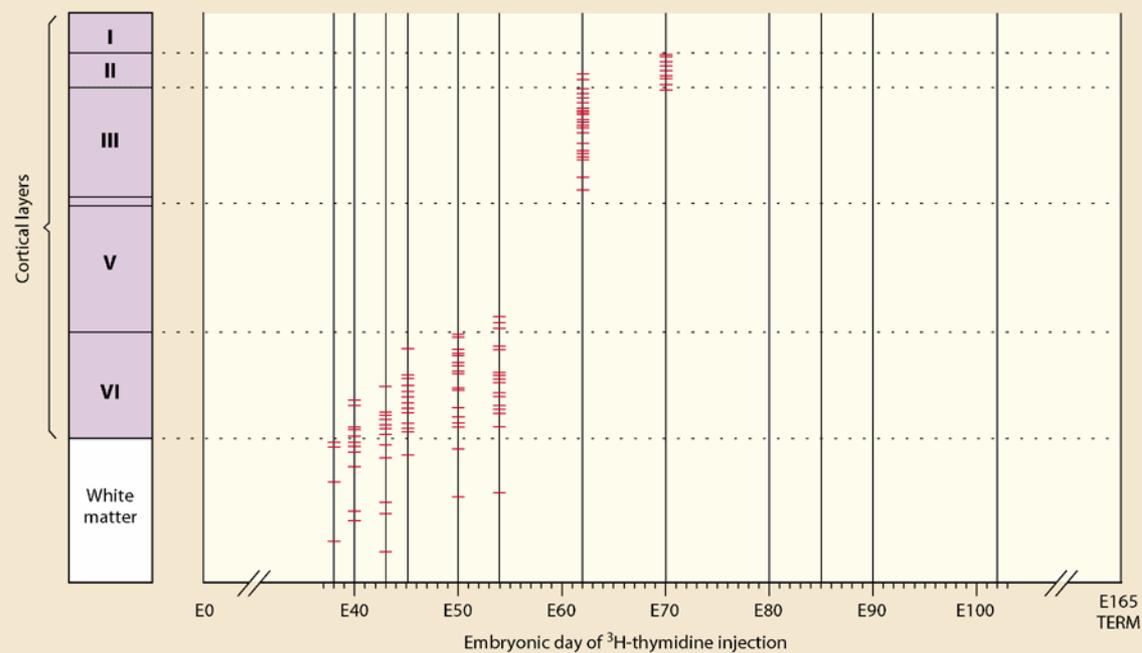
The relationships of modes of cell division to duration of corticogenesis. **A:** Schematic model of symmetrical cell division that predominate before the 40th embryonic day (E40). At this early embryonic age, the cerebral wall consists of only the ventricular zone (VZ), where cell proliferate, and the marginal zone (M) where some of them extend their radial processes. Symmetric division produces two progenitors (P) during each cycle, and causes rapid horizontal lateral spread. **B:** model of asymmetrical division that becomes predominant in the monkey after E40. During each asymmetrical division, a progenitor (P) produces one postmitotic neuron that leaves the ventricular zone, and another progenitor that remains within the proliferative zone and continues to divide. Postmitotic cells migrate rapidly across the intermediate zone (IZ) and become arranged vertically in the cortical plate (CP) in reverse order of their arrival (1-4). **C:** Diagrammatic representation of the time of neuron origin in macaque monkey. **D:** Estimate of the time of neuron origin in the human neocortex (Rakic, 1995).

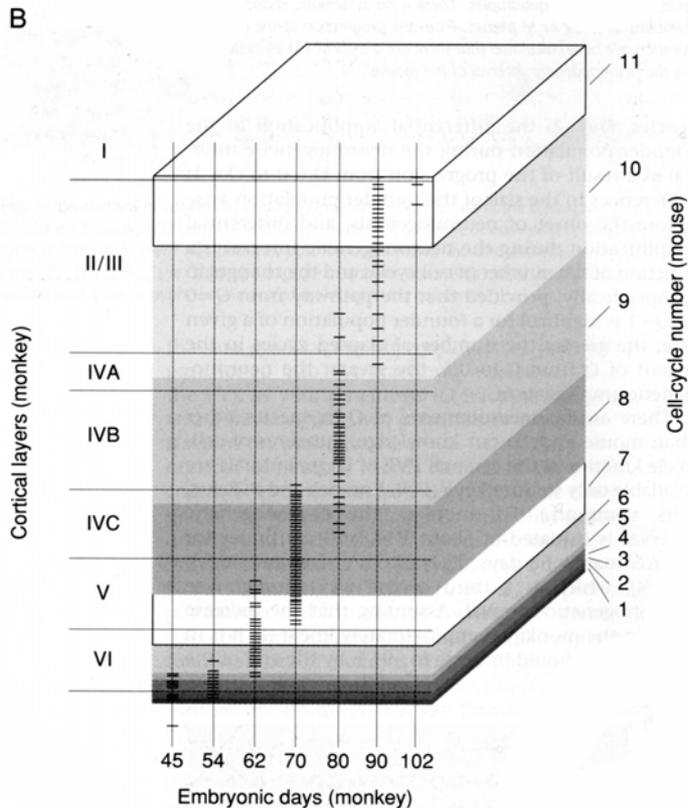
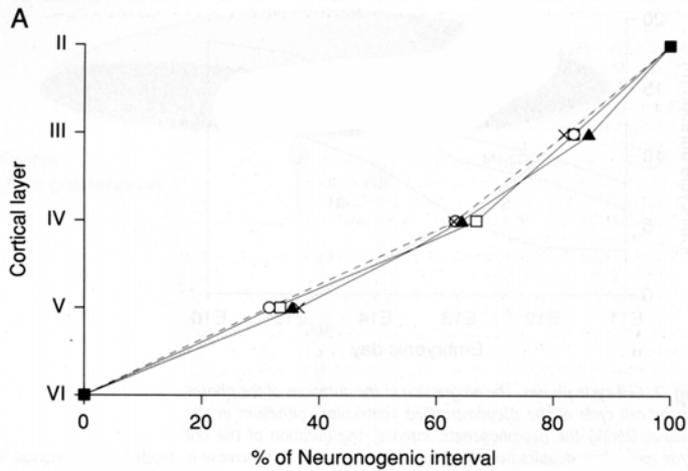
Area 17 (striate cortex)



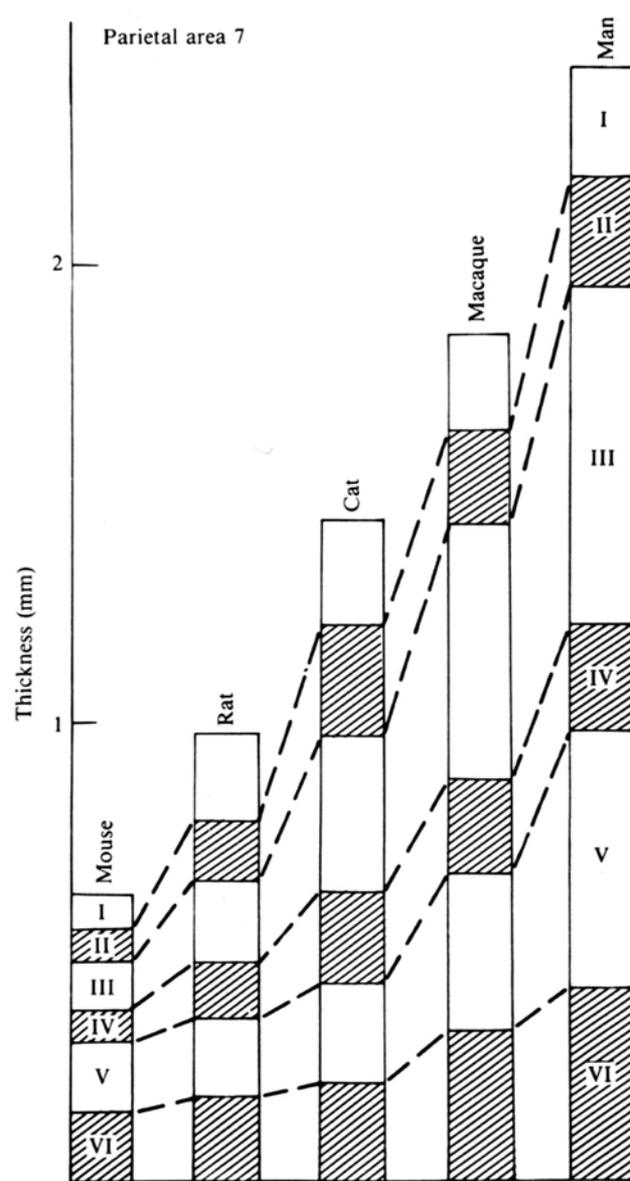
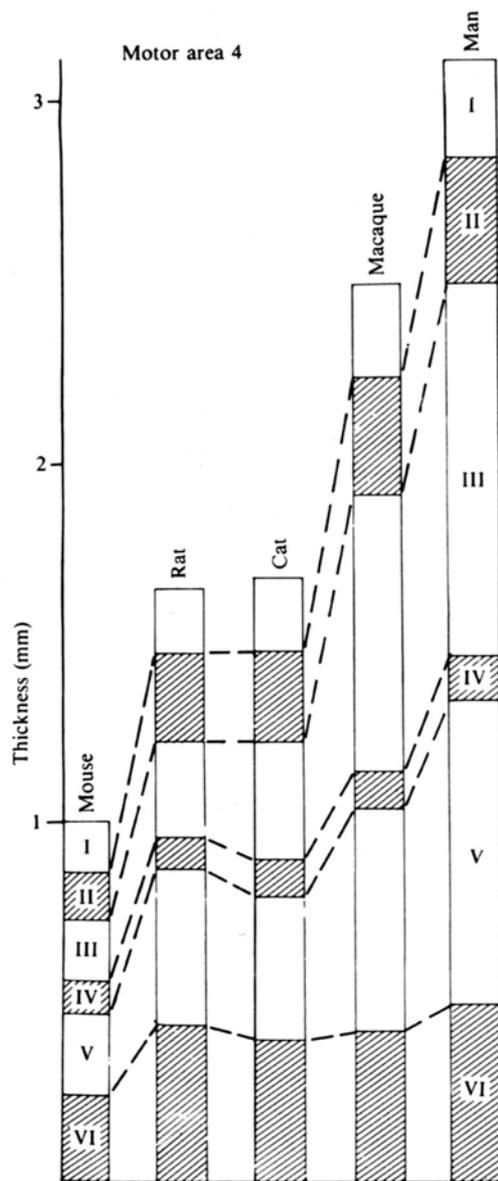
Births ages of cortical neurons. Radiolabeled thymidin was used to label cells at different embryonic days in two cortical areas. Cells with birth dates later in gestation are found in more superficial layers (inside-out) (Rakic, 1995).

Area 24





Scaling of neurogenetic processes across species. A: The time of production of neurons for each layer of the cortex is compared in four different species, mouse (squares), rat (triangles), cat (circles) and monkey (crosses), as a function of the percentage of the neurogenetic interval in each species that has elapsed at the time the cortical layer is produced. B: The proportion of neurons generated at each of the 11 cell cycles in the neurogenetic interval of the mouse is shown as a volume that reflects the proportional contribution to a final cortical volume. An overlay of the schedule of neurogenesis of the successive layers of the monkey visual cortex, scaled to the mouse time base, illustrates the commonality of scaling of the time of origin, number and laminar positions of neurons generated in the two species. (Caviness, Takahashi, Nowakowski, 1995).

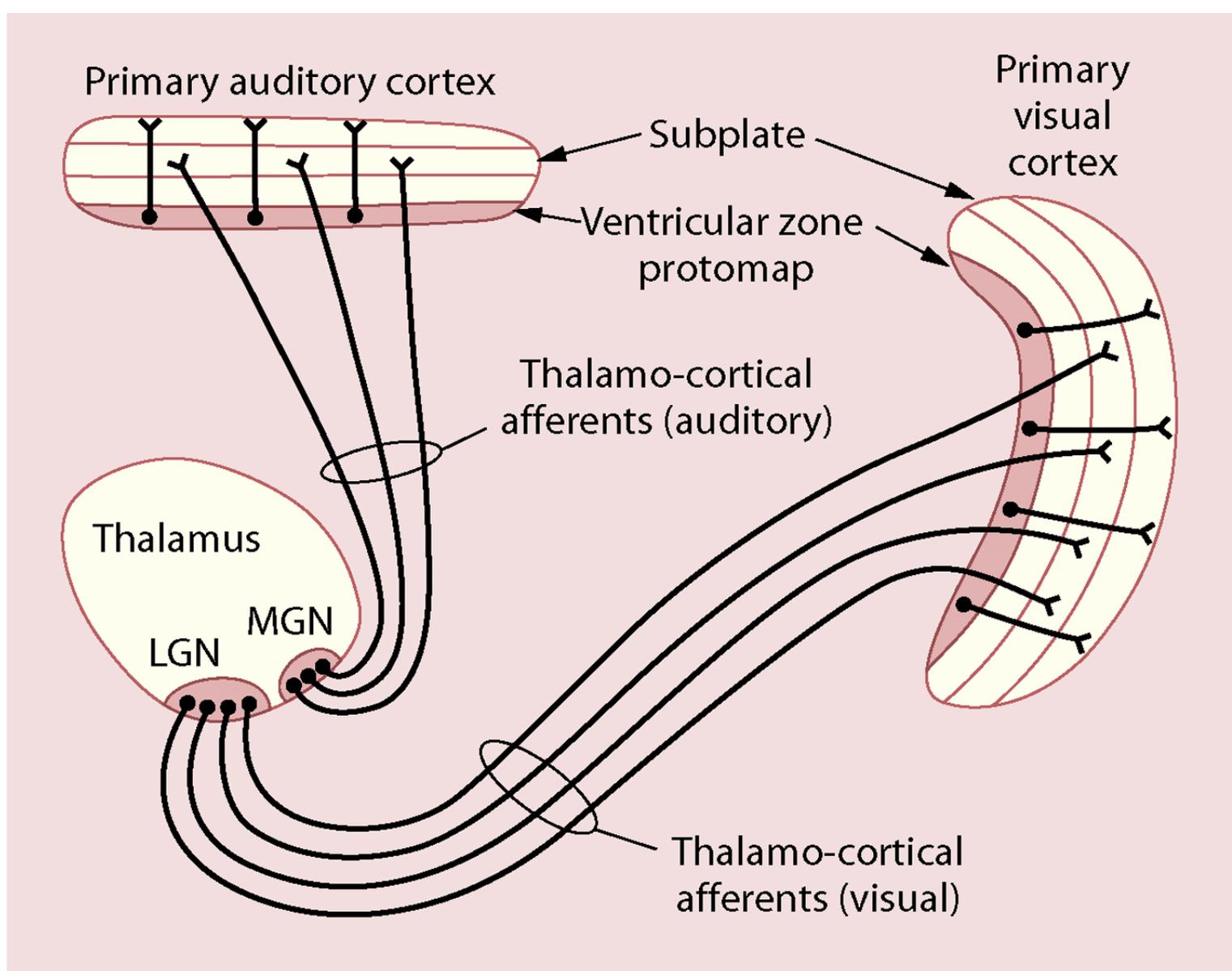


Comparison of total cortical thickness and thickness of each cortical layers in area 4 (left) and 7 (right) of mouse, rat, cat, macaque monkey and man. The total number of cells is virtually the same in the vertical dimension of the cortex, except for primate area 17 (Mountcastle, 1998)

Table 4-2. Number of neurons beneath pial patches ($25 \times 30 \mu\text{m}$) in several areas of the cerebral cortex in five mammals.

Mammal	Translaminar cell count (\pm SD)						Means
	Motor	Sensory	Frontal	Temporal	Parietal	Visual	
Mouse	73.4 \pm 4.5	75.2 \pm 4.6	74.5 \pm 6.8	74.3 \pm 4.4	70.4 \pm 6.8	75.4 \pm 4.30	73.8 \pm 4.6
Rat	72.7 \pm 3.9	71.9 \pm 6.8	70.1 \pm 6.8	72.4 \pm 6.2	70.7 \pm 4.6	72.4 \pm 5.3	71.6 \pm 4.9
Cat	69.8 \pm 5.1	71.6 \pm 6.8	72.6 \pm 4.2	76.5 \pm 4.9	74.3 \pm 6.7	73.8 \pm 6.7	73.6 \pm 4.9
Monkey	74.1 \pm 6.3	73.5 \pm 6.3	75.3 \pm 7.5	73.8 \pm 6.9	77.0 \pm 6.7	180.0 \pm 9.2	—
Man	68.7 \pm 6.5	69.7 \pm 3.9	69.4 \pm 5.8	72.4 \pm 5.0	70.0 \pm 8.4	174.0 \pm 10.6	—

Note: Numbers transformed from original counts of Rockel et al. (1974) to account for section shrinkage. Patches of area $25 \times 30 \mu\text{m} = 750 \mu\text{m}^2$ were noted to display linear shrinkage of 18 percent. Original size of the patches was therefore $25/.82 \times 30/.82 = 1,116 \mu\text{m}^2$. A conversion factor of $750/1,116 = 0.672$ was therefore multiplied by the original counts.



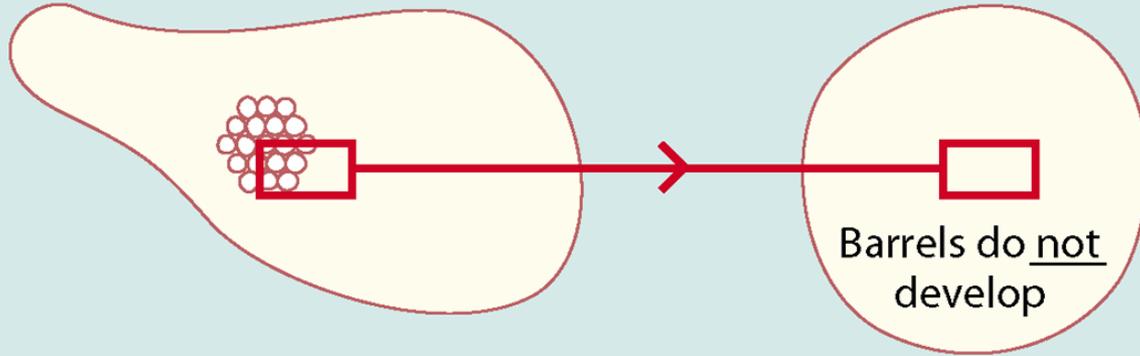
The **protomap hypothesis** of cytoarchitectonic diversity. The protomap model proposes that the neurons in the ventricular layer form a protomap that attracts the axons of neurons in the subcortical projection structure in a modality-specific manner. Thus, auditory fibers are attracted to auditory cortex, and visual fibers are attracted to visual cortex during embryogenesis (Rakic, Gazzaniga)

Donor

Host

Embryonic somatosensory cortex

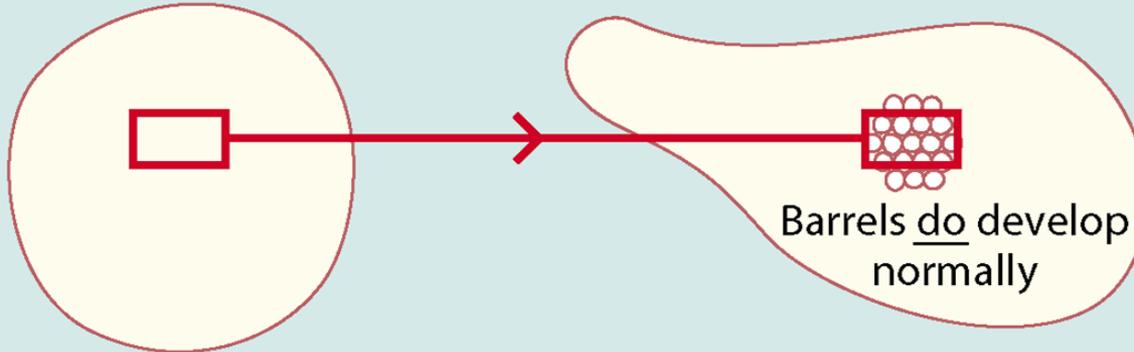
Embryonic visual cortex

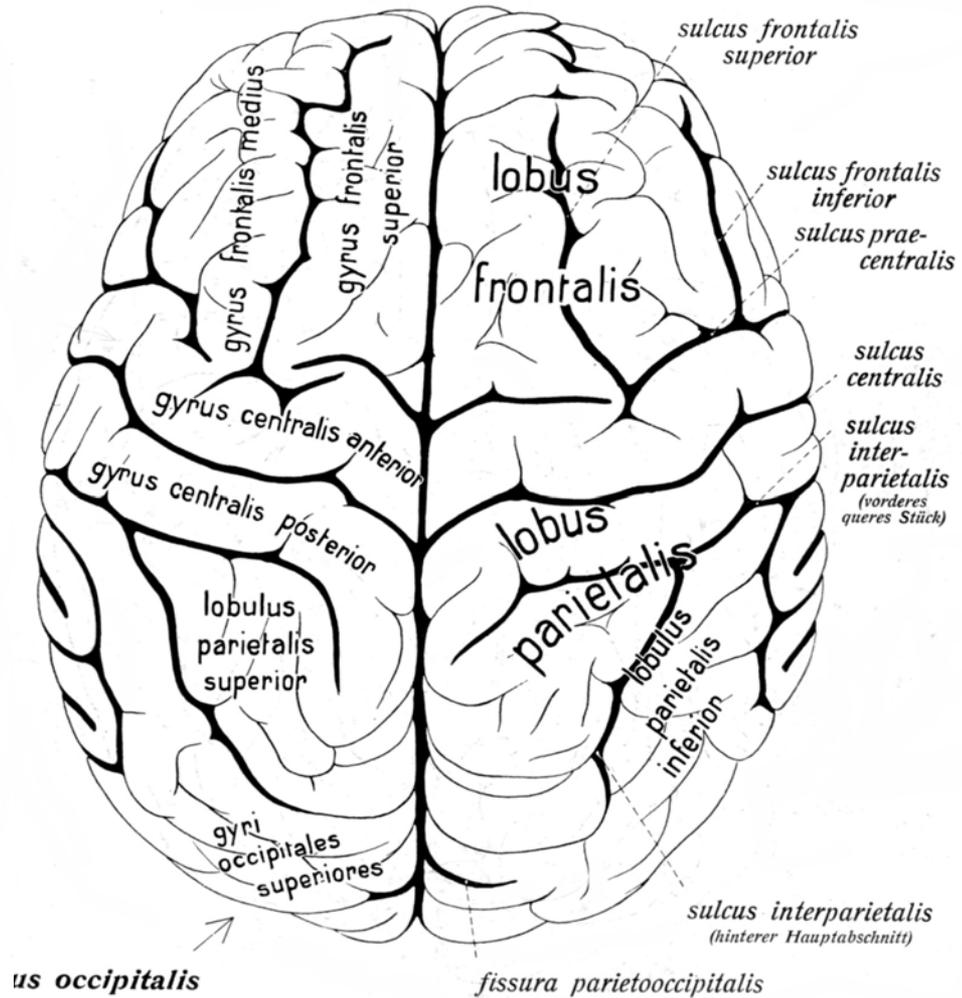
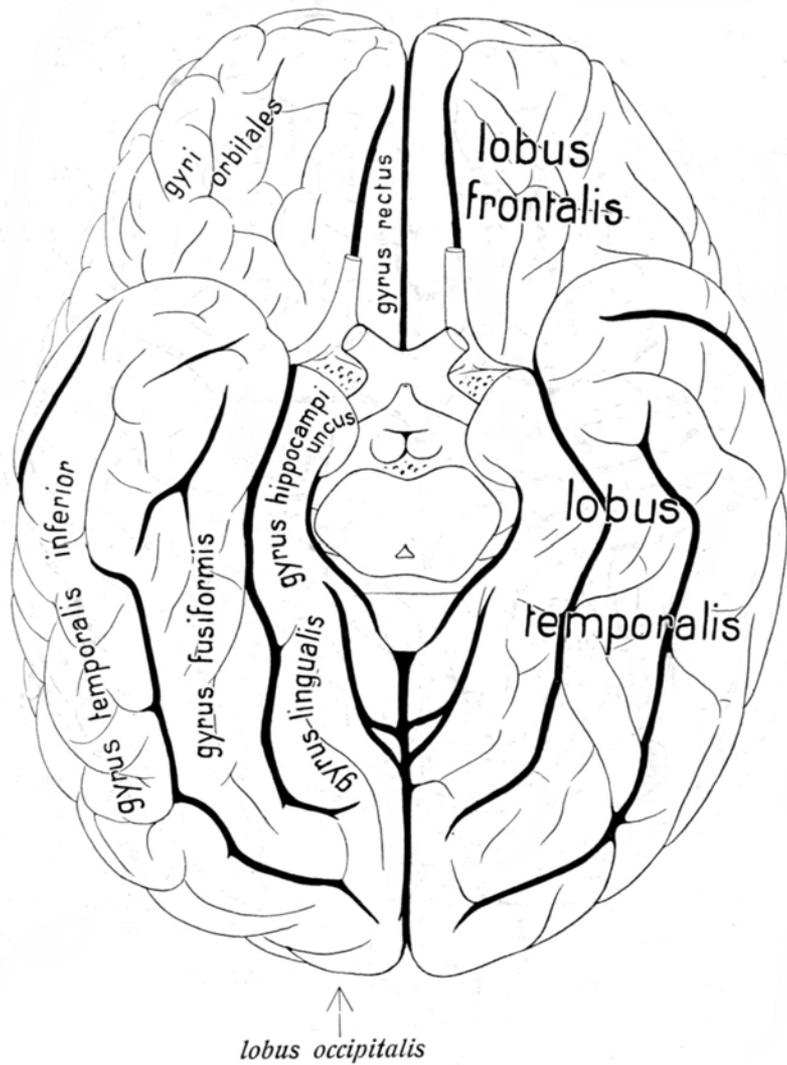


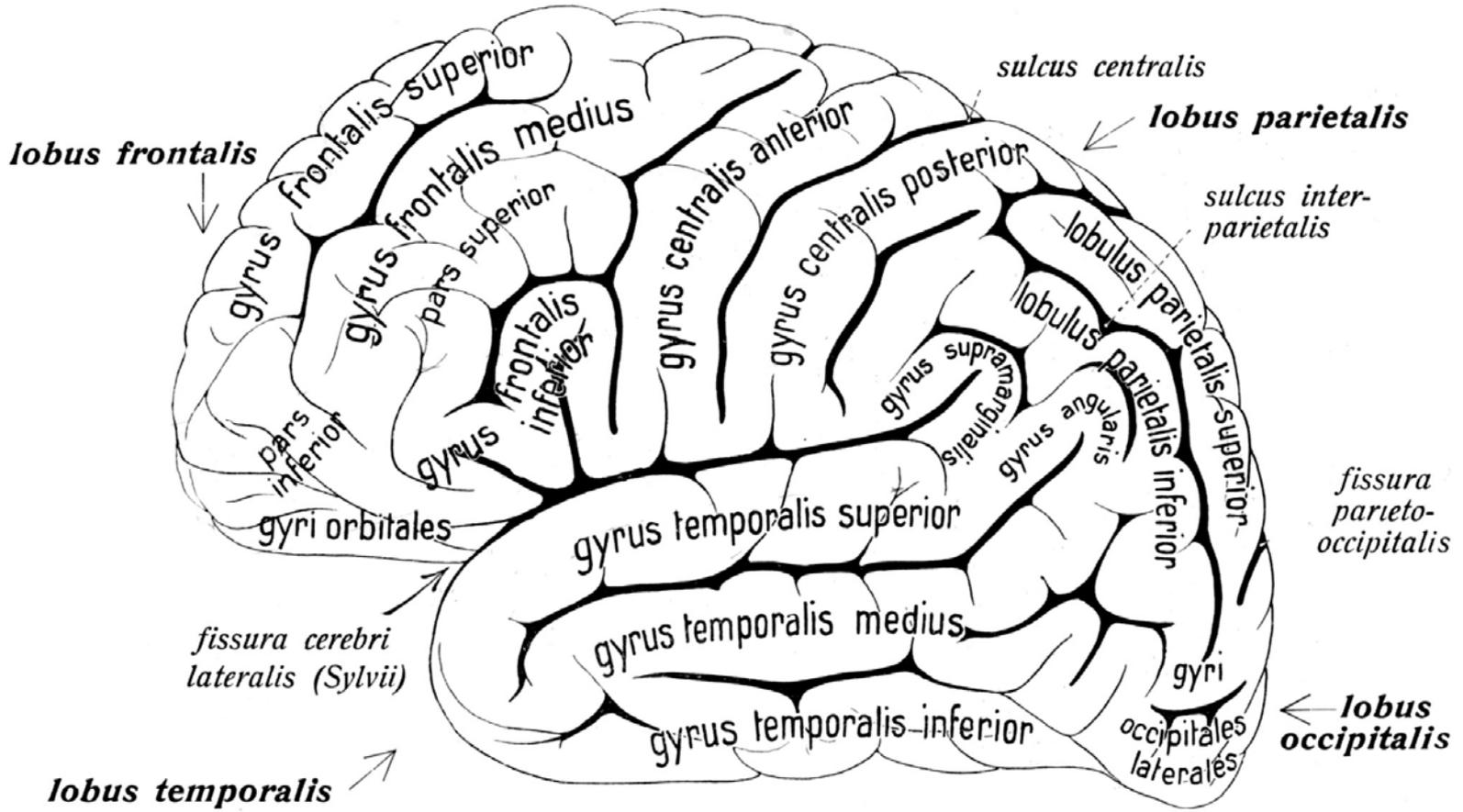
Transplanted tissue interacts with host neurons. If portions of the barrel cortex in fetal somatosensory cortex are transplanted into the visual cortex *before* the barrels arise, this tissue does not form the characteristic barrels. However, visual cortical neurons can be induced to form barrels, if transplanted from visual to somatosensory cortex (Gazzaniga et al., 2002).

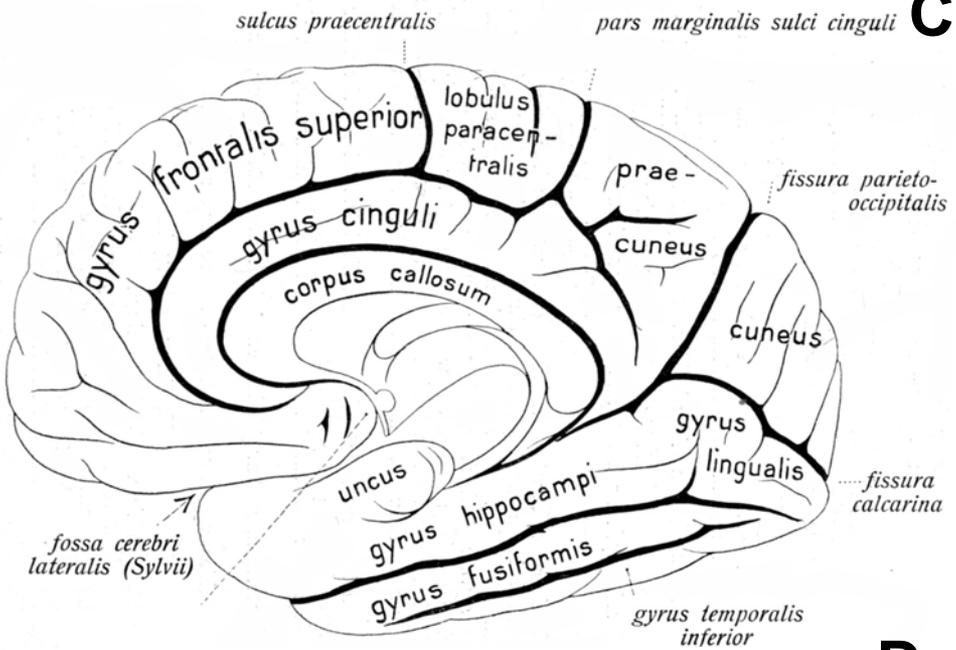
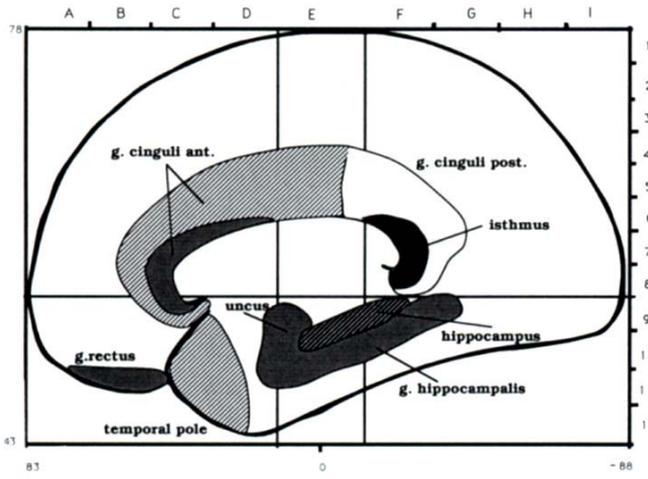
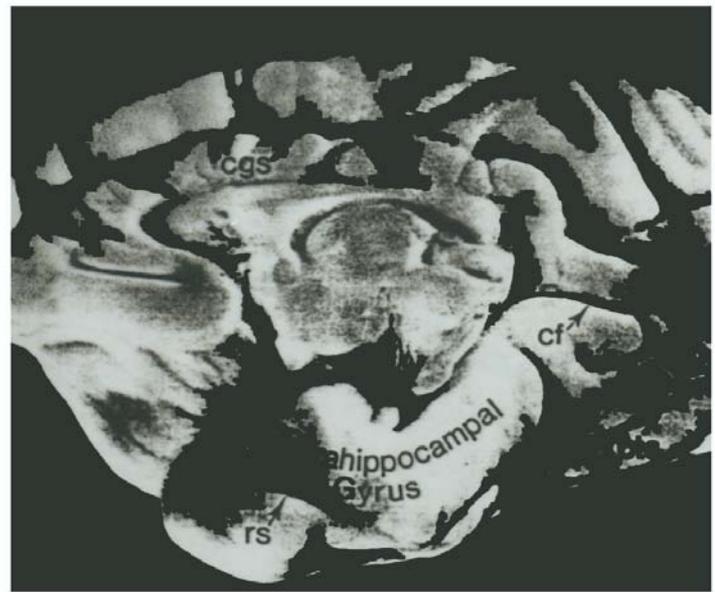
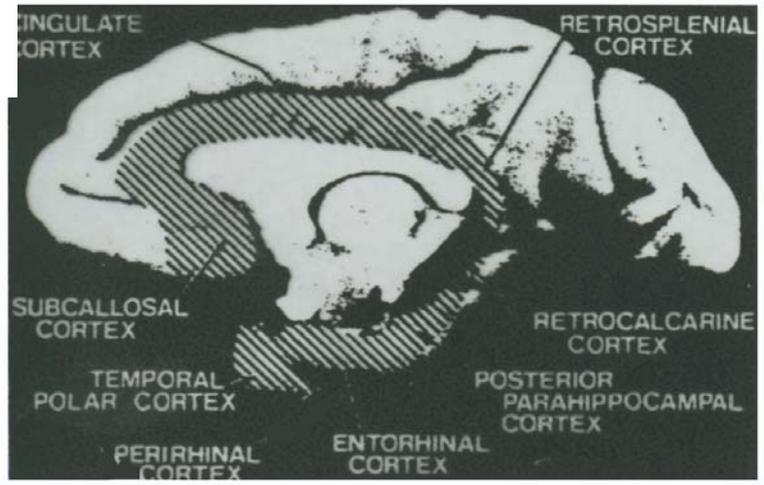
Embryonic visual cortex

Embryonic somatosensory cortex







A**B****C****D**

Median sagittal surface of the human (A , B, C) and macaque monkey(D) brain. In (D) the limbic lobe is labeled by hatching. A: Sobotta, B: Roland, C,D (Damasio and Van Hoesen) In (B) the scheme is drawn in the Talairach coordinates.

Golgi stain

Nissl stain

Weigert stain

I. Molecular layer

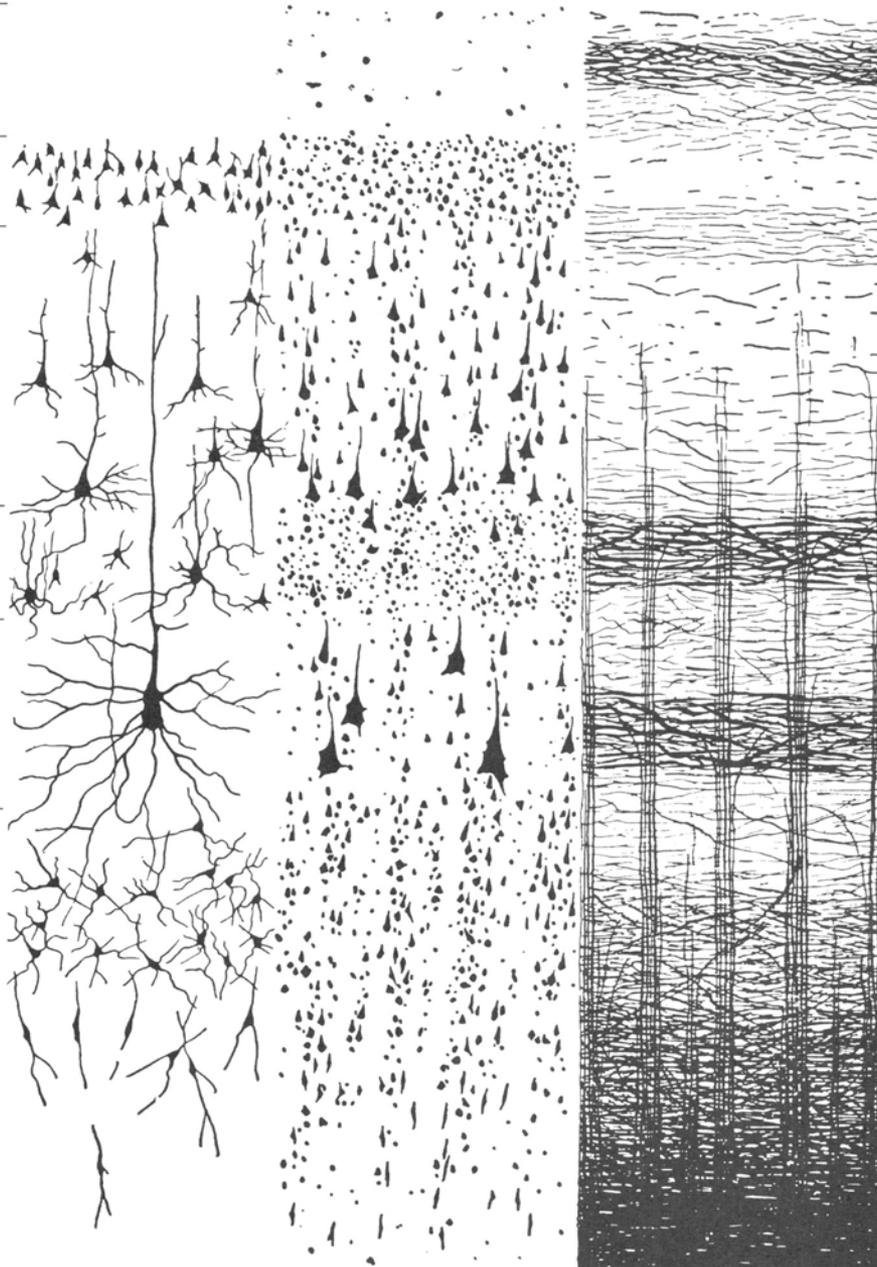
II. External granular layer

III. External pyramidal layer

IV. Internal granular layer

V. Internal pyramidal layer

VI. Multiform layer

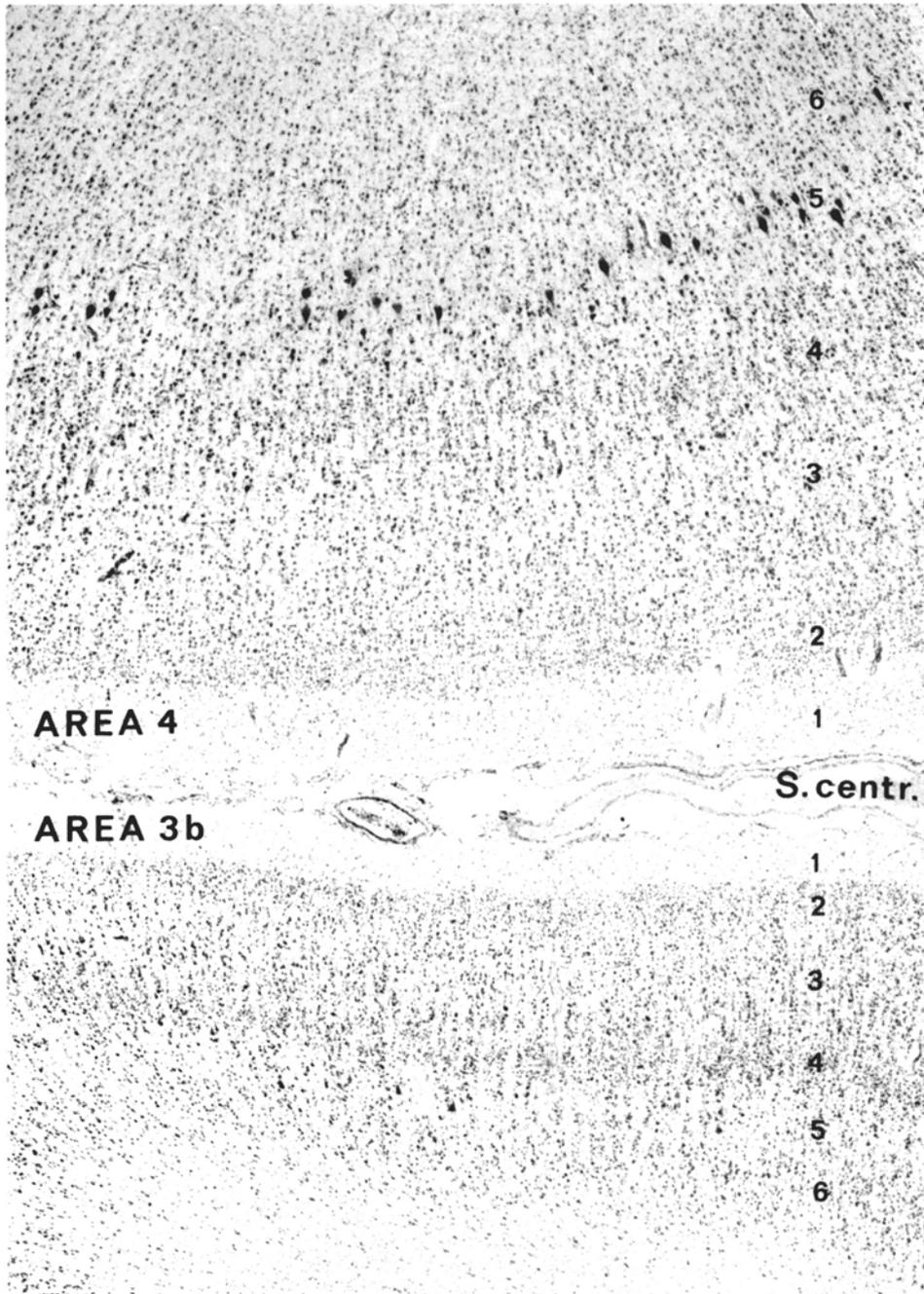


Cross section of neocortex stained by three different methods. The Golgi stain reveals the complete axonal and dendritic arborizations of a small percentage of neurons. The Nissl method stains the cell bodies of all neurons showing their shape and packing densities. The Weigert method stains myelin, revealing horizontally and vertically oriented bands (Brodman, 1909; Nolte)

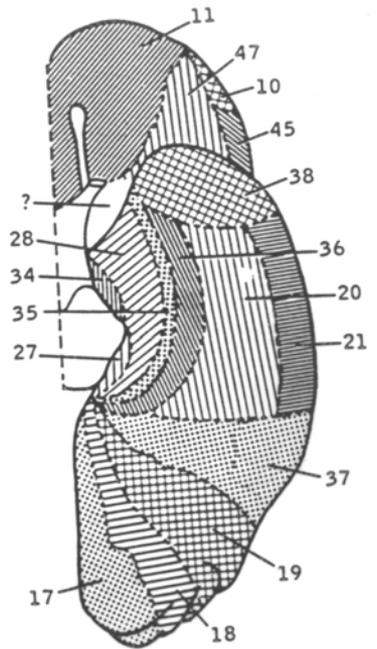
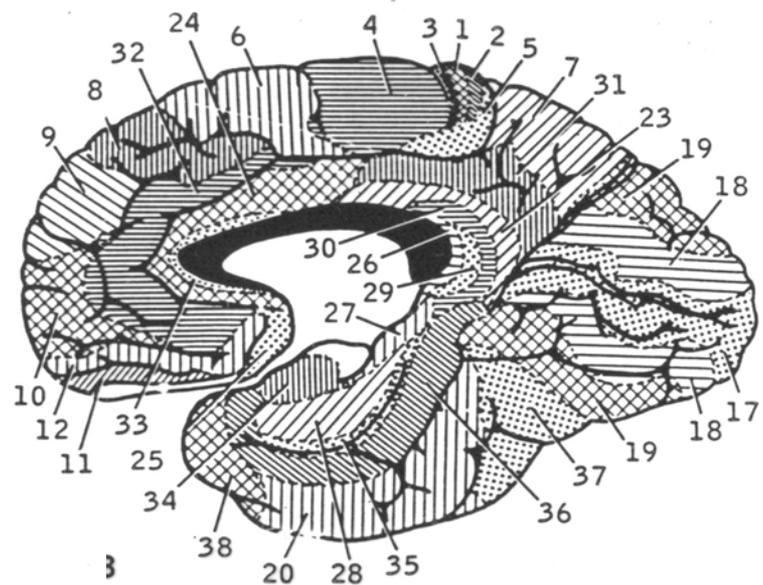
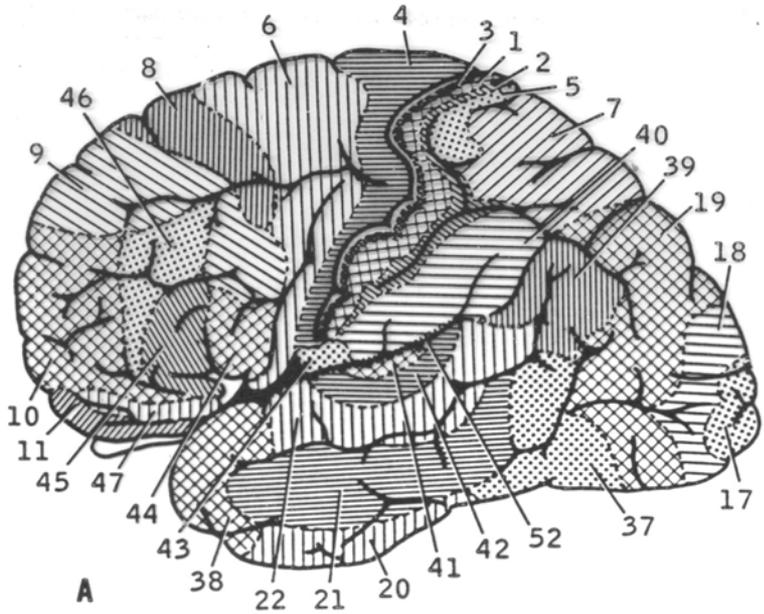
Outer band of Baillarger

Inner band of Baillarger

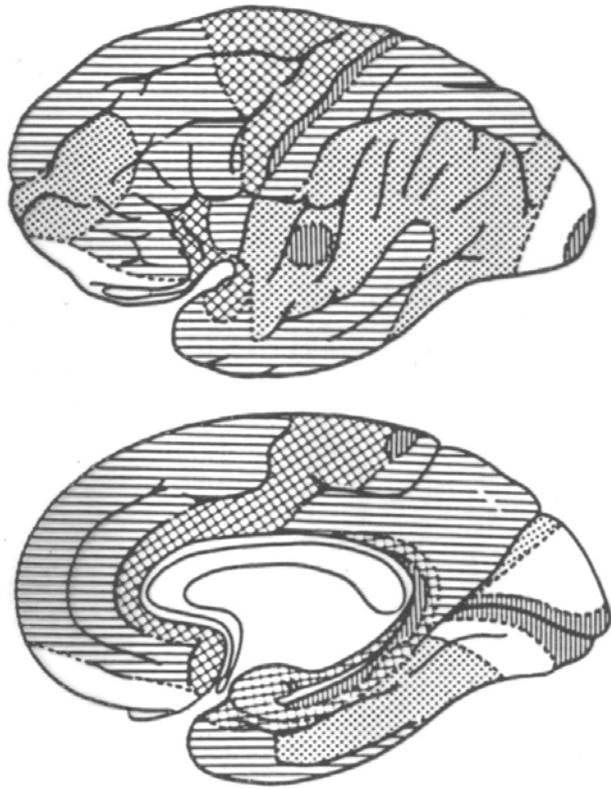
Cytoarchitectonics of the cerebral cortex



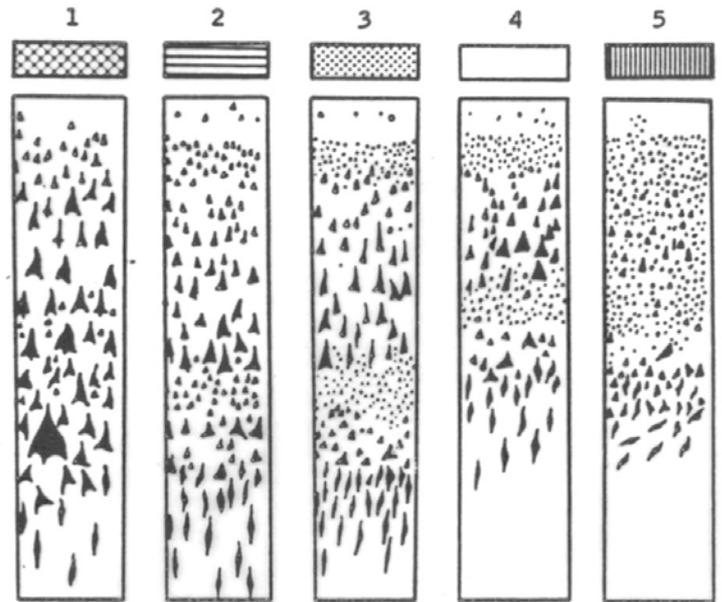
Photomicrograph of a thionin-stained section through the central region of the human brain. The section is perpendicular to the direction of the central sulcus. The six-layered structure is evident in area 4 (M1) and in area 3b (S1). Note, however, the difference in appearance of the various layers in the two areas, especially with regard to layers 4 and 5. The large pyramidal (Betz) cells in layer 5 are especially apparent (Brodal, 1992)

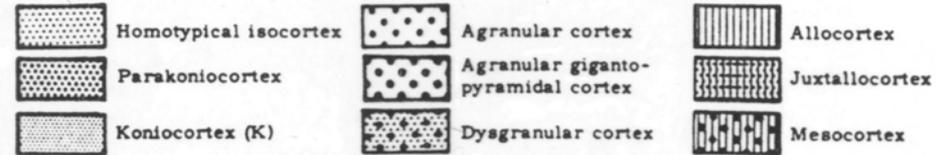
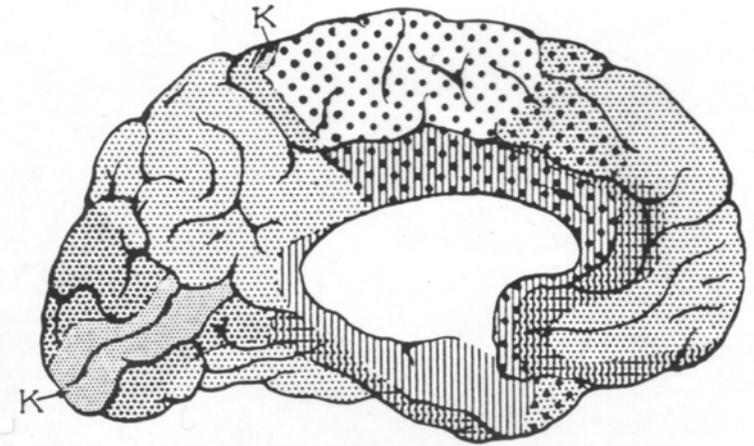
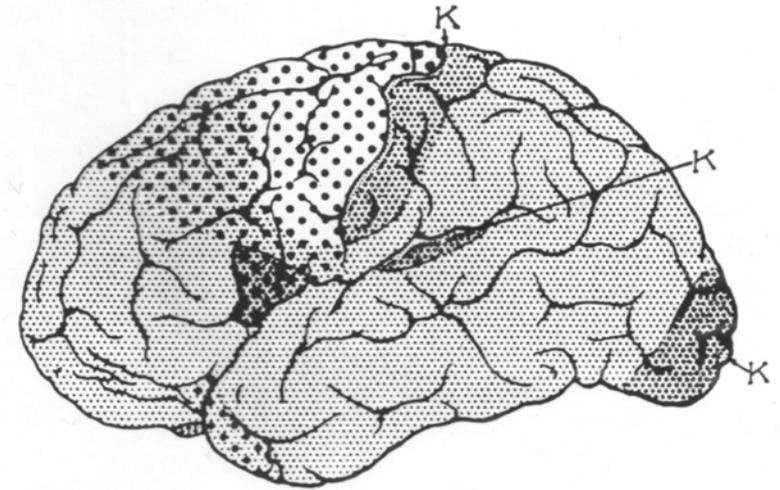
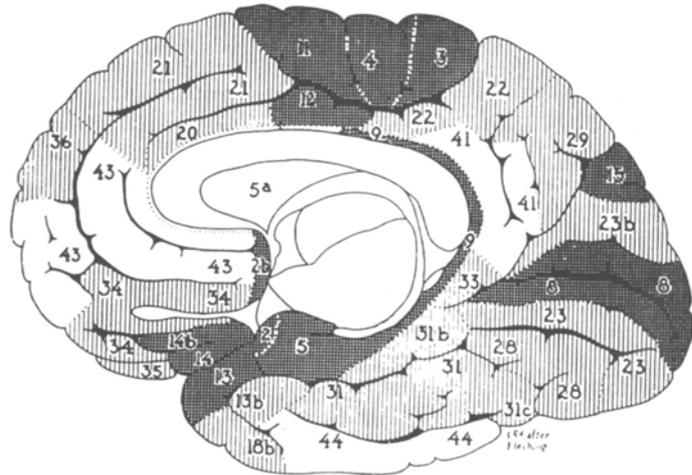
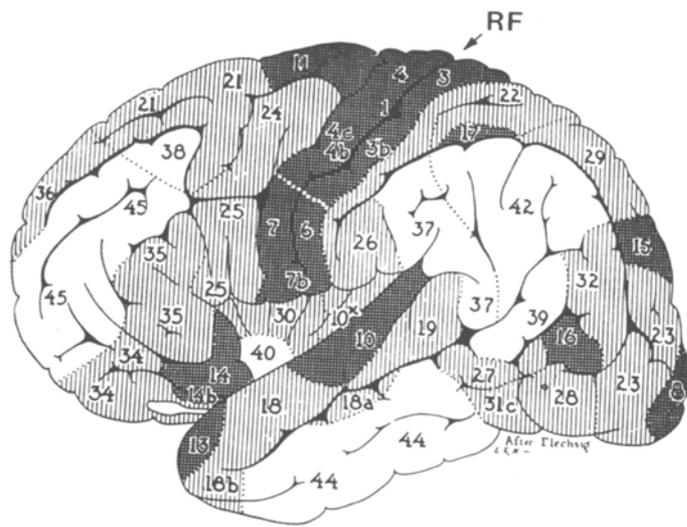


Cytoarchitectural zones of the human cerebral cortex, according to Brodmann.



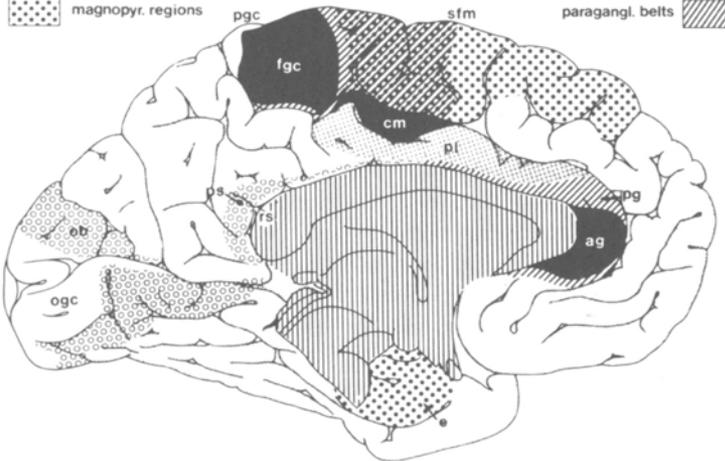
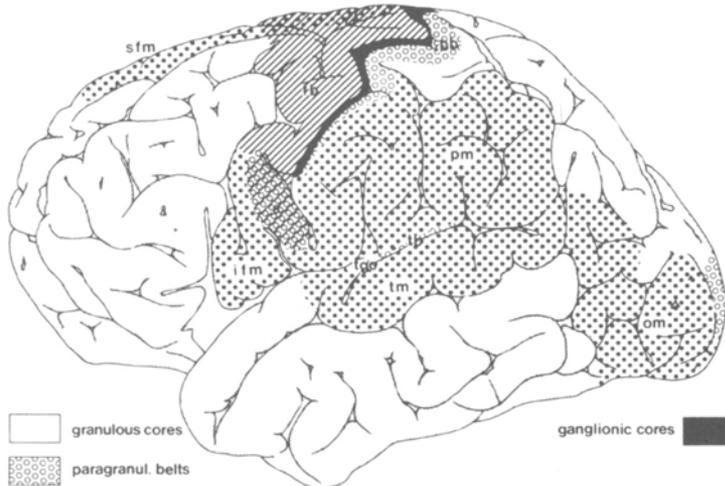
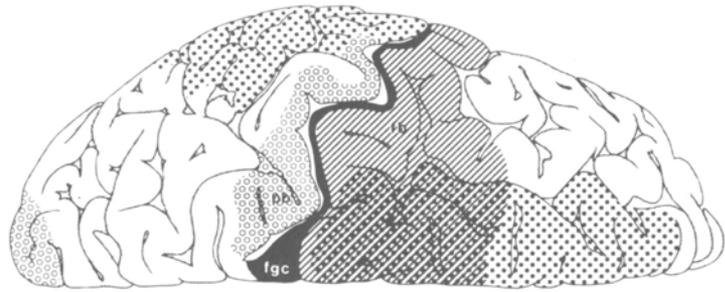
The five fundamental types of cerebral cortex, according to von Economo: 1, agranular; 2, frontal; 3, parietal; 4, polar; and 5, granular.



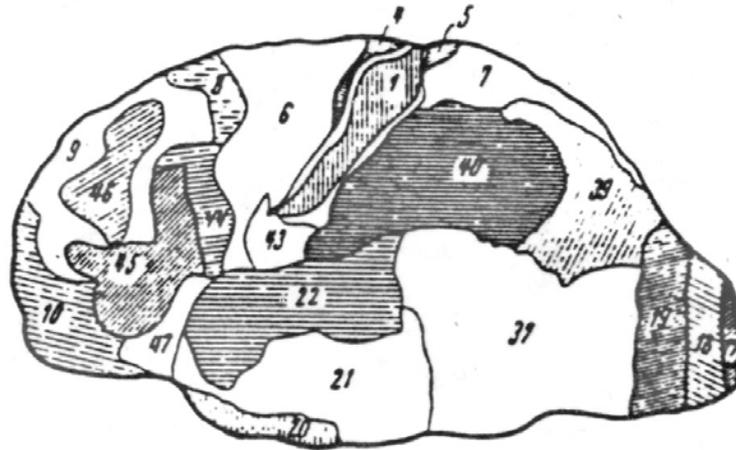
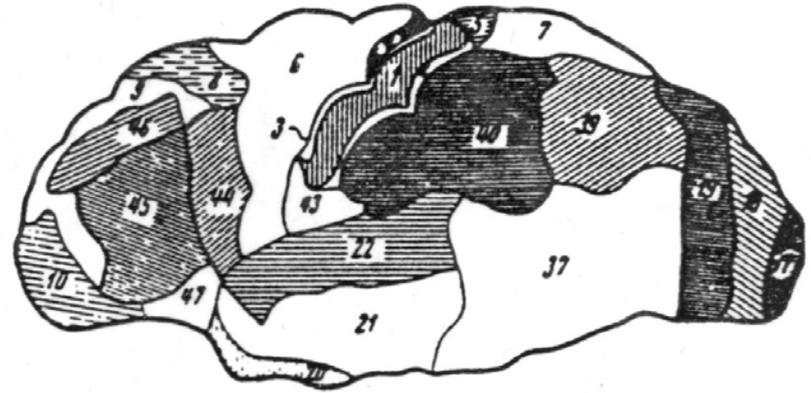
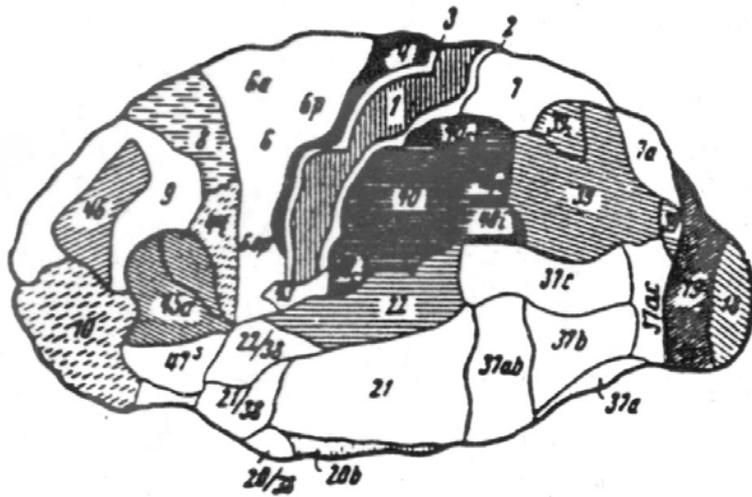


Flechsig's myeloarchitectural map (1920). Cortical fields are numbered in their order of myelination. Shaded zones with low numbers are those whose afferent and efferent fibers are myelinated earliest, unshaded areas with high numbers are myelinated later in ontogenesis and in the neonatal period.

Baily and von Bonin's cytoarchitectural map.

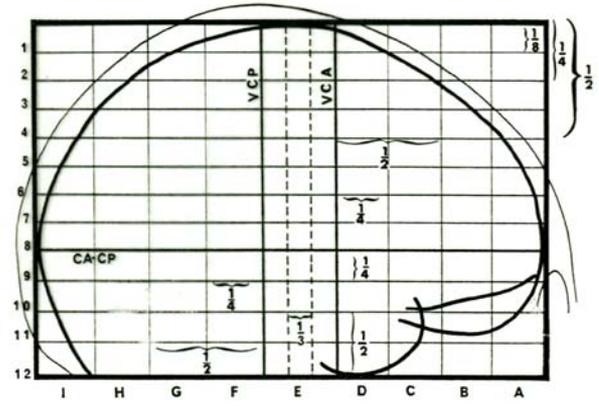
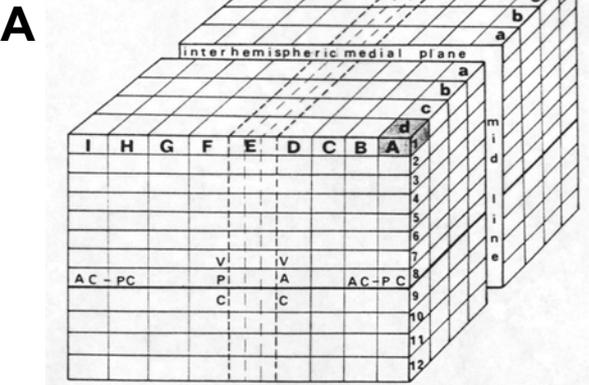


A map of the major regions of the human neocortex, prepared with the method of pigment staining (Braak, 1980).

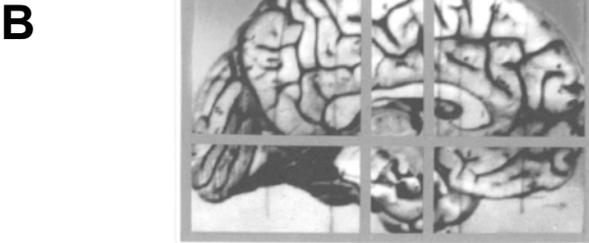


Cytoarchitectural maps of the human cortex and the variability of the individual regions (Sarkisov, 1960)

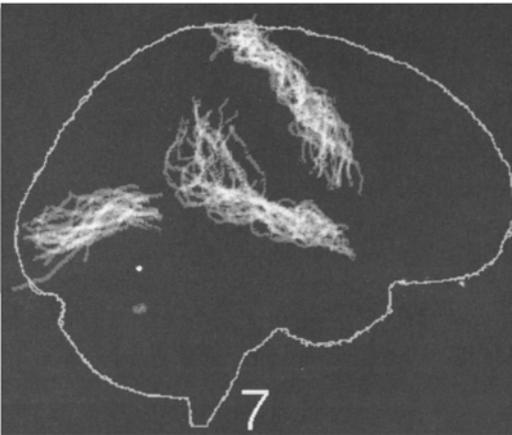
Intersubject registration. Atlasing.



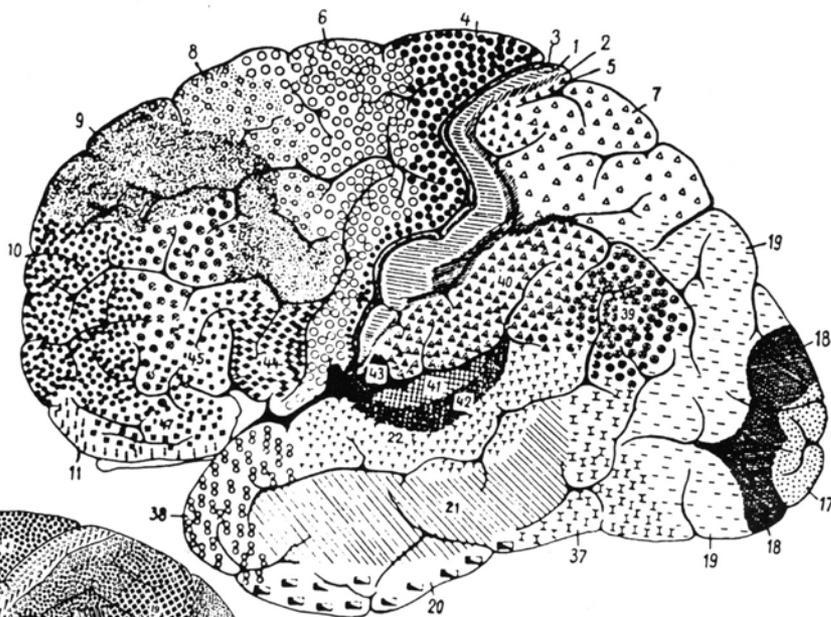
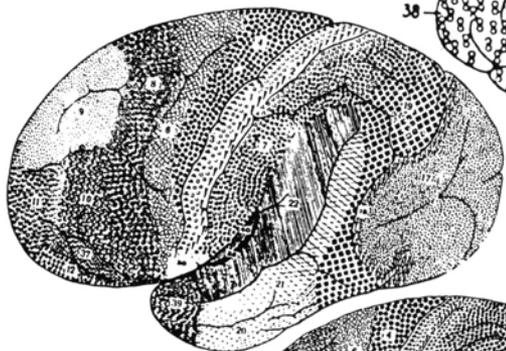
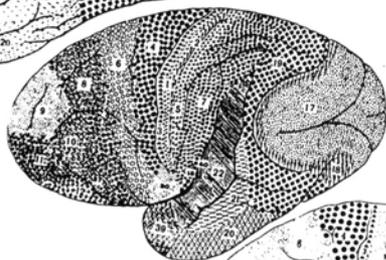
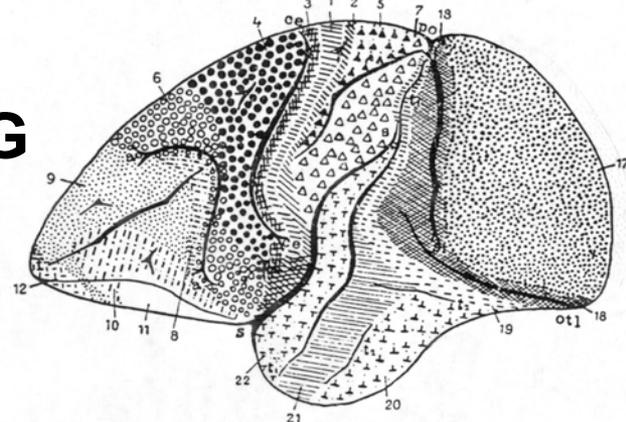
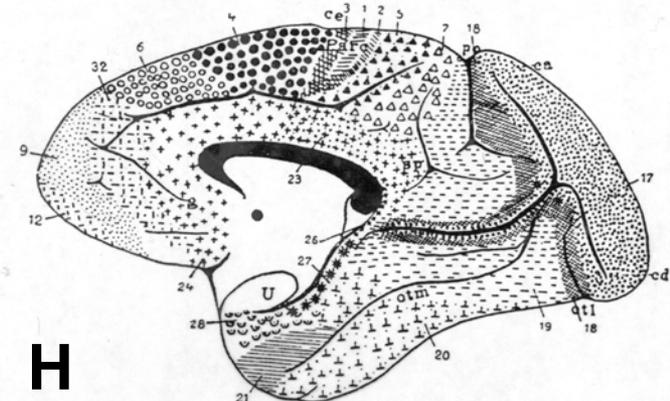
A: In the Talairach-Tournoux (1988) atlas the brain is divided into orthogonal parallelograms, the dimension of which vary with the principal axes of the brain. Each of these volumes is defined by a capital letter, a lower case letter and a number.



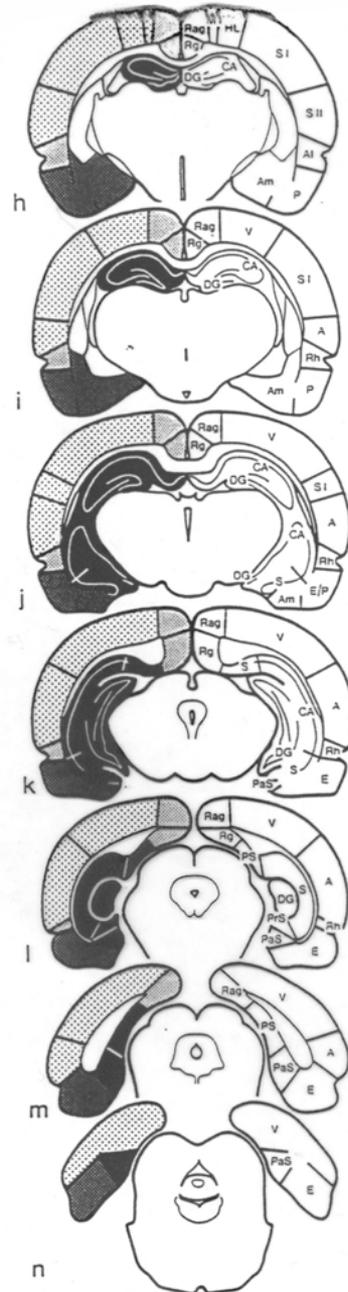
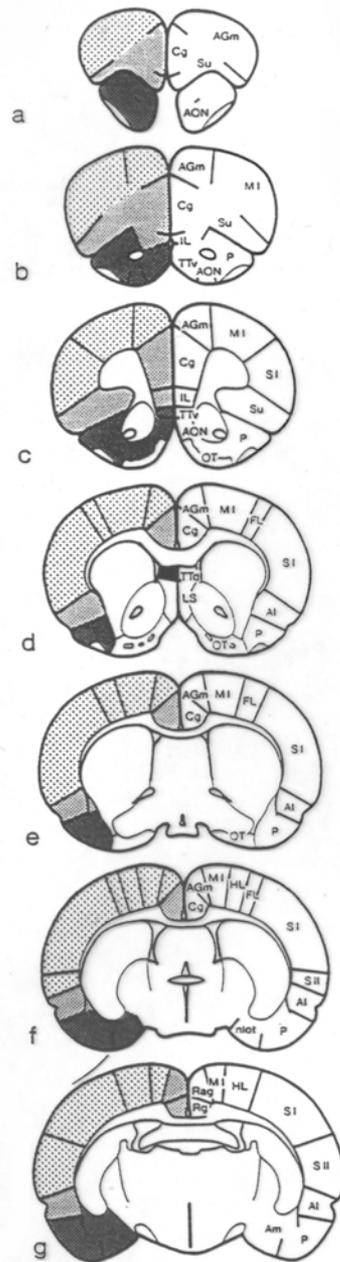
B: Photograph of an autopsy brain in the Talairach proportional grid system (Mai et al., 1997)



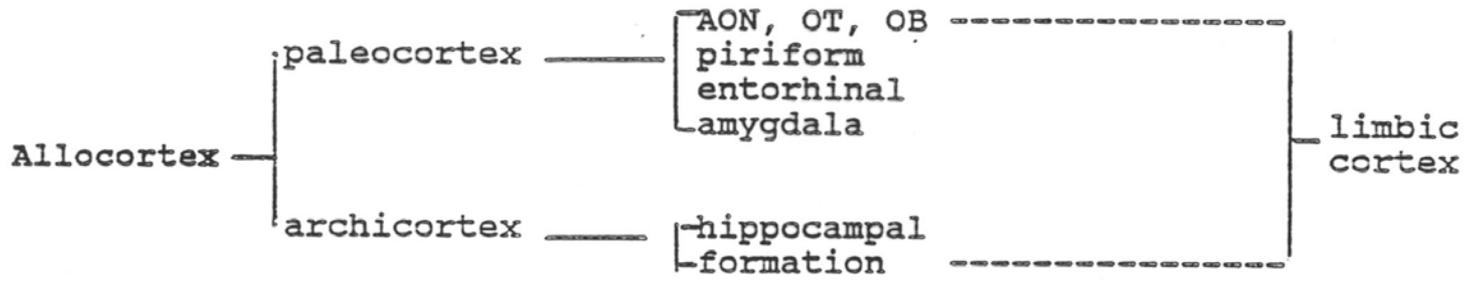
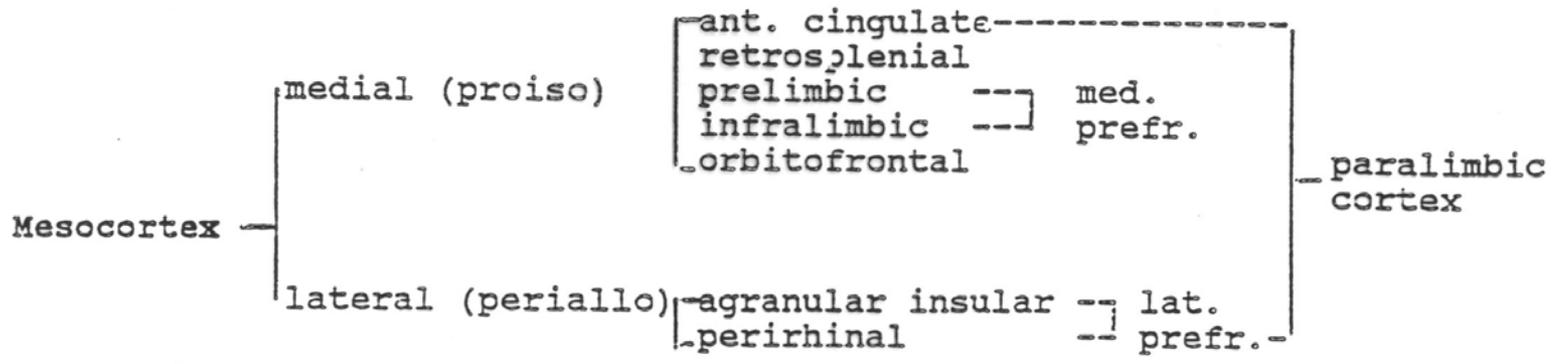
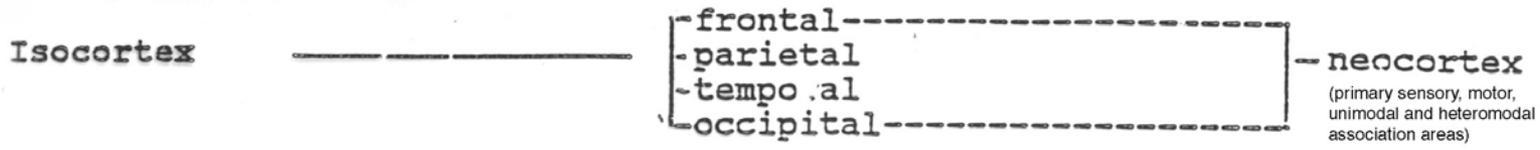
C: Three cortical landmarks (right calcarine sulcus, right precentral gyrus, and right superior temporal gyrus [STG] and its posterior extension) from 22 subjects have been mapped into a common frame of reference using a linear image registration algorithm incorporating 7 parameters. Note the marked variability of the posterior aspect of the STG (Woods, 1996).

A**B****C****D****E****F****G****H**

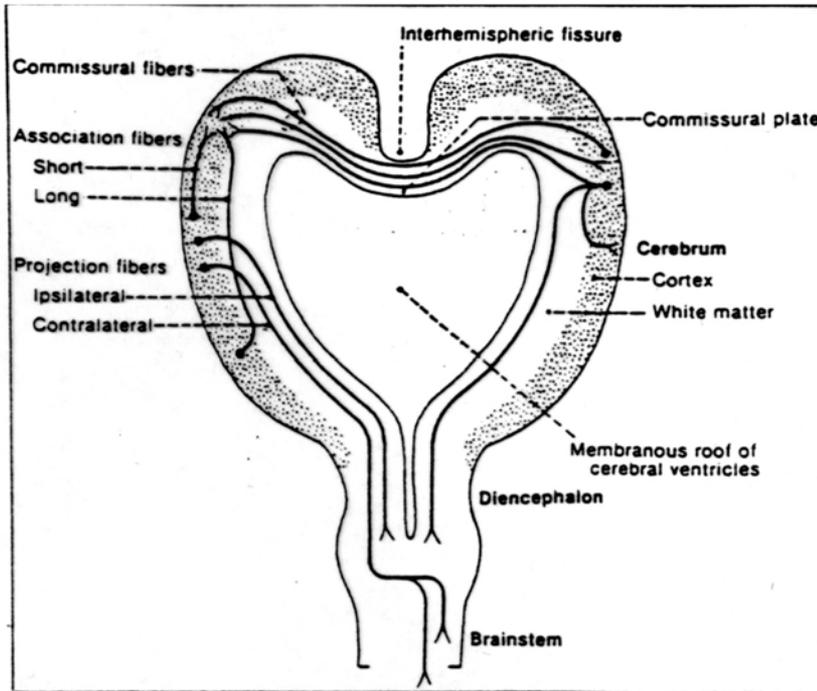
Cytoarchitecture of a series of primates and an insectivore. A: man, B: orangutan, C: gibbon, D: macaque; E: lemur; F: an insectivore; G, H: Brodmann's map of a monkey (A: Brodmann, 1912; B-E: Mauss, 1910; G, H: Vogt and Vogt, 1919)



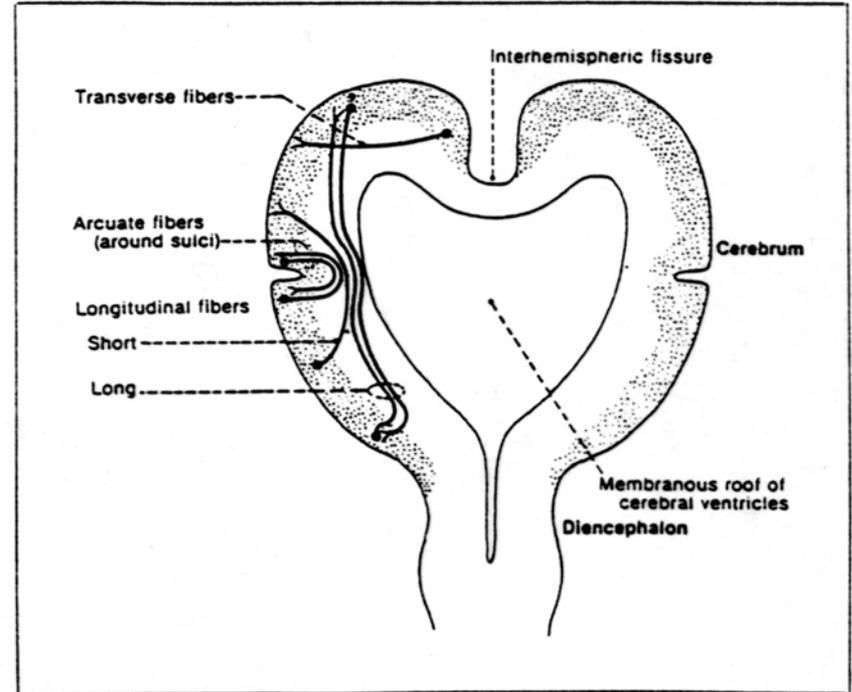
The subdivision of the cerebral cortex in rat. The neo (iso) cortex is stippled; the mesocortex is shown in light tone and is divisible into medial and lateral subdivisions; and the two subdivisions of the allocortex, the paleocortex and the archicortex, are shown respectively in dark tone and solid black (McGeorge and Faull, 1989)



Commissural, association and projection fibers

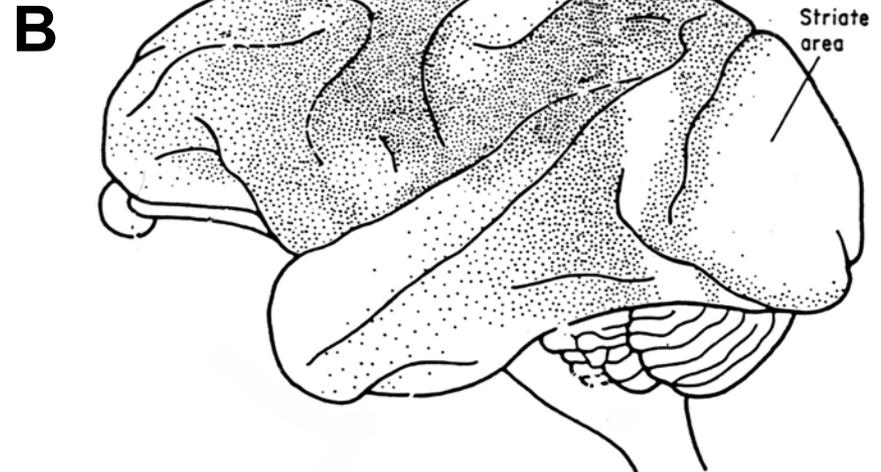
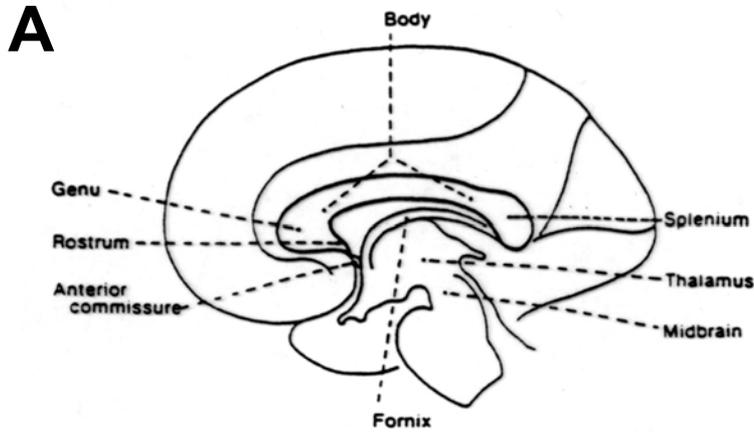


Dorsal view of the prosencephalon and brainstem showing the development of commissural, association and projection fibers (DeMyer, 1988).

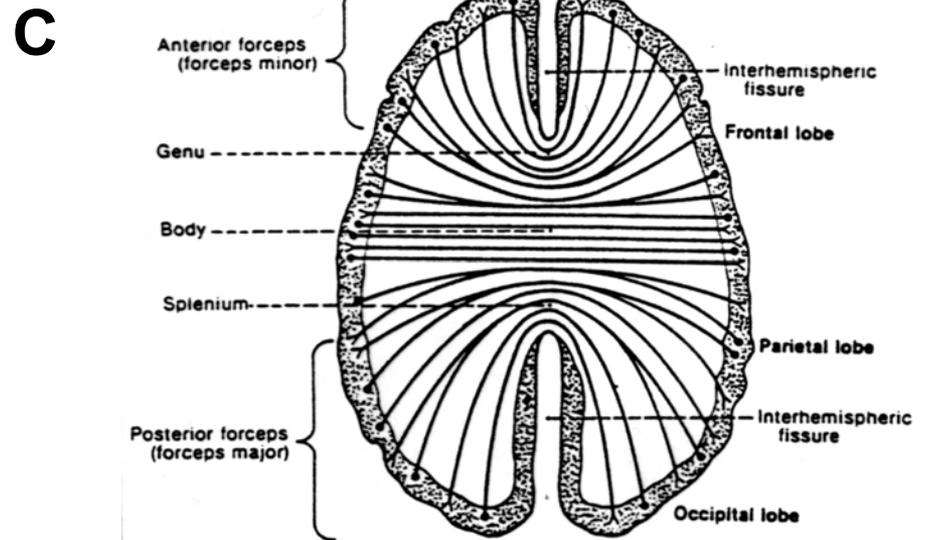


Dorsal view of the prosencephalon showing the development of the short, arcuate, association fibers. Transverse and vertical association fibers of intermediate length criss-cross the deep white matter (DeMyer, 1988)

The corpus callosum

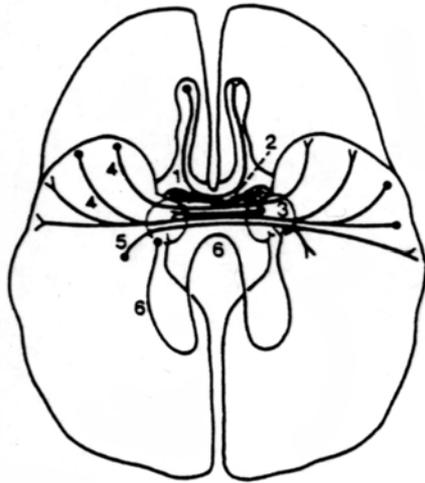


A: Sagittal section of the corpus callosum showing its division into four compartments: rostrum, genu, corpus, splenium (DeMyer, 1988). B: Distribution of degenerating fibers after transection of the entire cc. Note the absence of commissural fibers in area 17, the S1 and M1 hand region (this latter one is not visible because it is largely buried in the central sulcus (Myers, 1965). C: Horizontal section showing the pattern of crossing of callosal fibers (DeMyer, 1988).



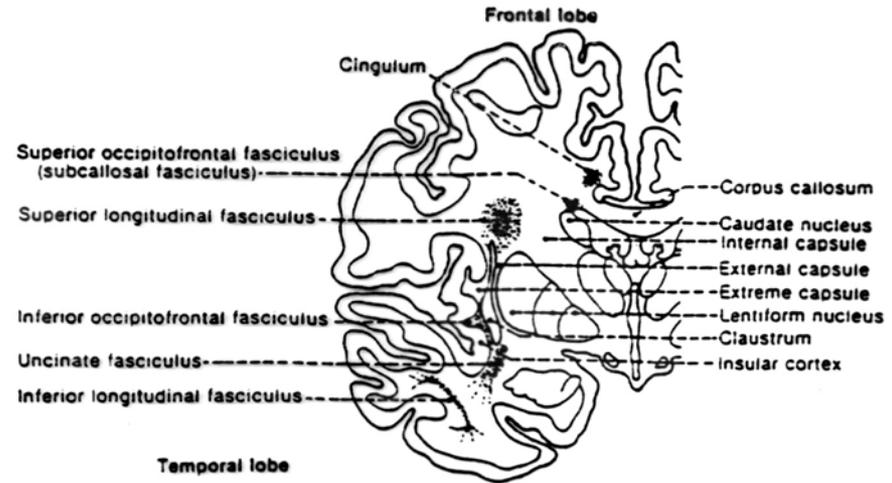
Anterior commissure and long association fibers

A

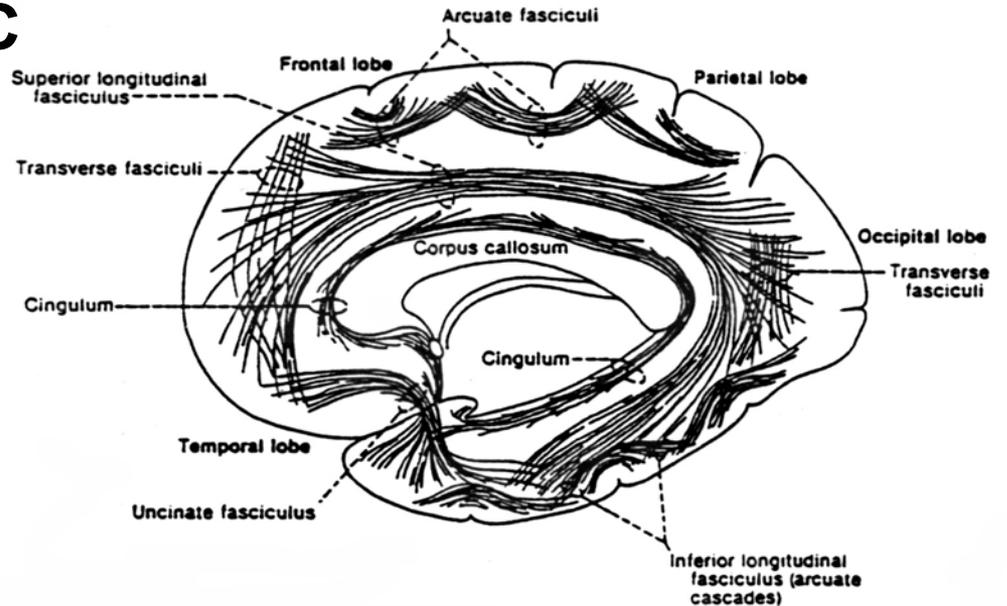


A: Ventral view showing of the fibers of the anterior commissure. 1: interbulbar (to bulbus olfactorius); 2: intertubercular (to olfactory tubercle); 3: interamygdaloid; 5: interparahippocampal; 6: stria terminalis (interamygdaloid). **B:** Coronal section showing several of the long association fibers; **C:** Sagittal section. Note the location of the superior longitudinal fascicle connecting fronto-occipital areas, the inferior longitudinal fascicle, the uncinate fascicle (fronto-temporal fibers), the cingulum (cingulate-parahippocampal fibers). The short association (arcuate fibres) are also shown (DeMyer, 1988).

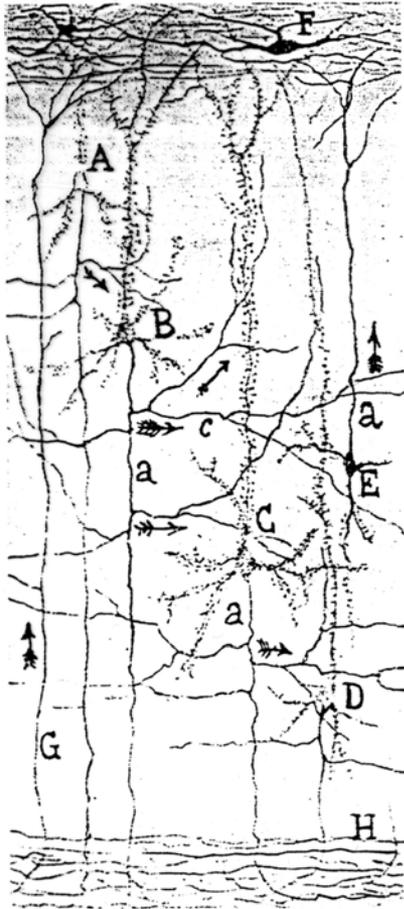
B



C



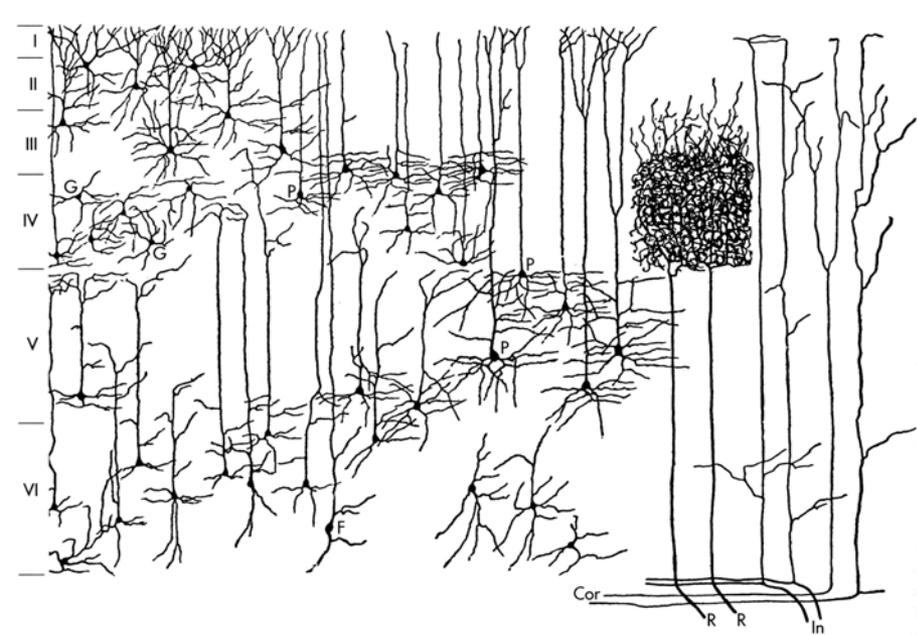
A



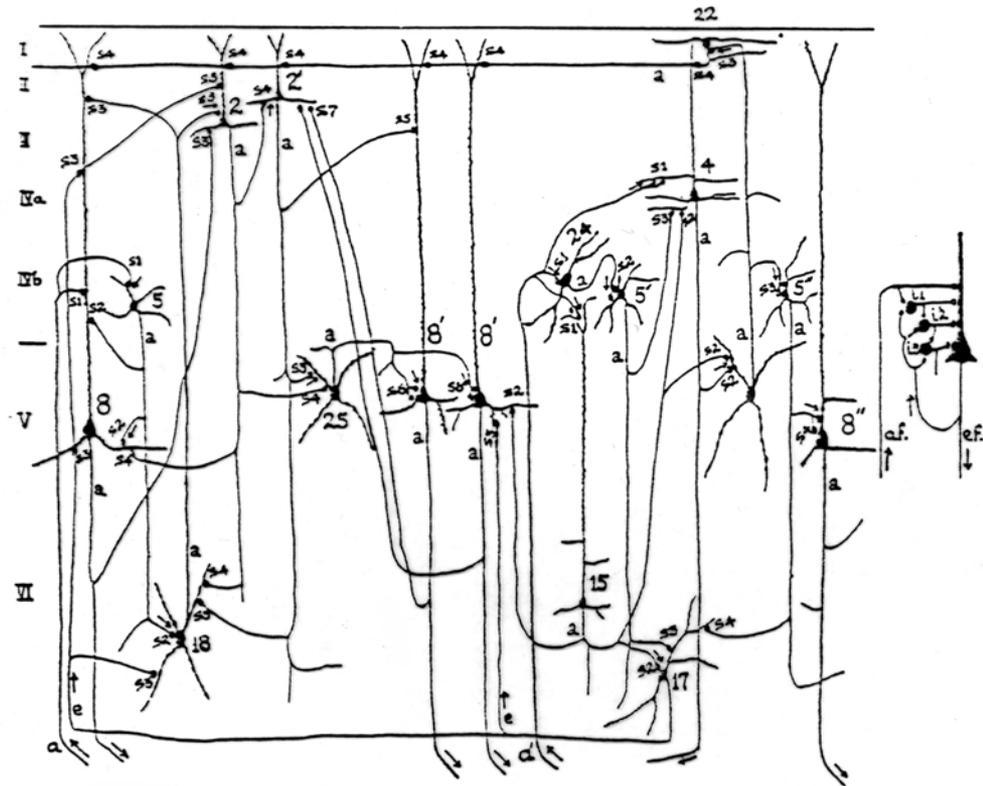
A: Cortical circuits. B: Type of spines of cerebral pyramids of rabbit, a child of two months, spines of a one-month-old cat; portion of a dendrite of a spinal motor neuron of a cat (Cajal, 1933)

B





Cells, arborization of corticopetal axons and intercalated circuits (Lorente de No, 1938). Note the recurrent (reverberating) circuits.



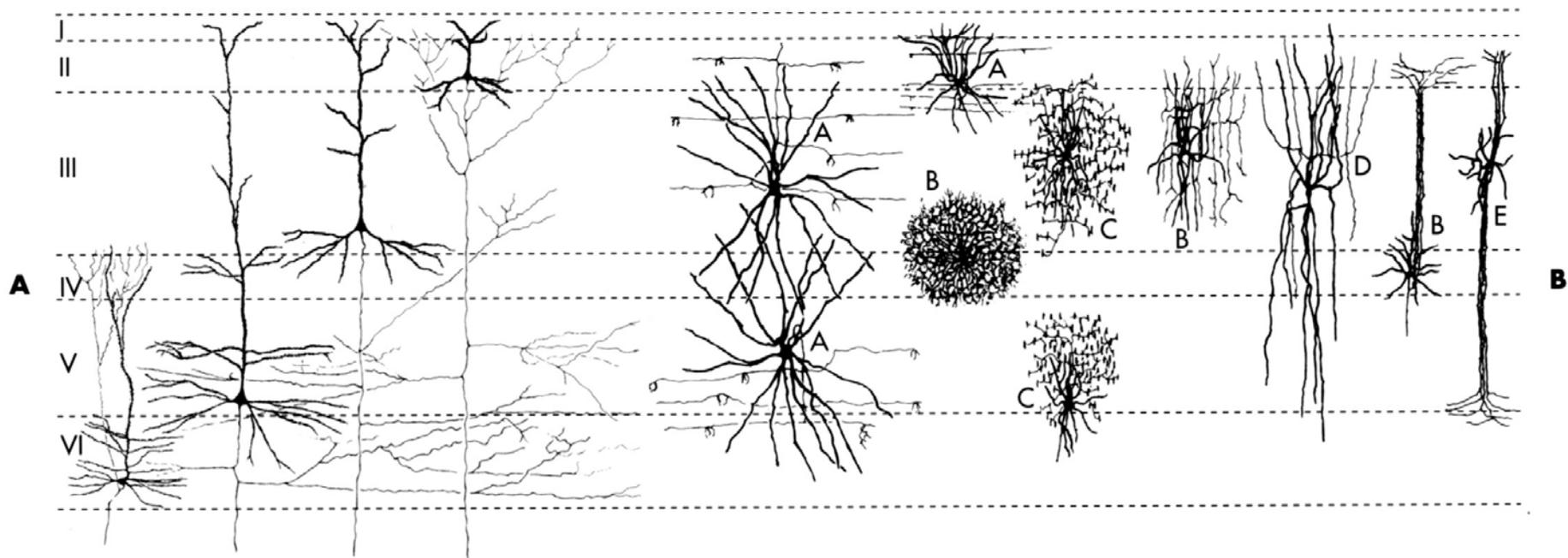
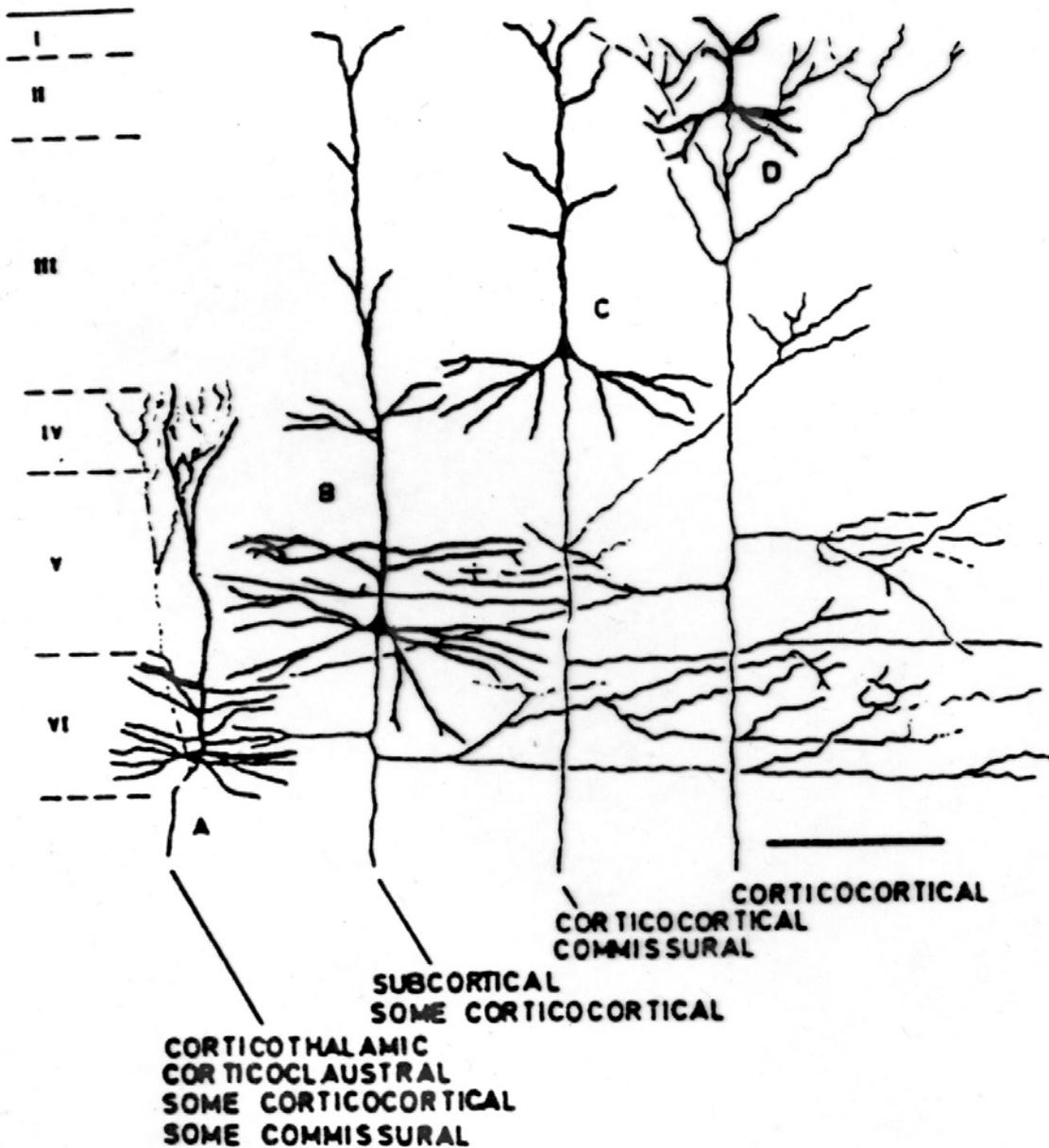


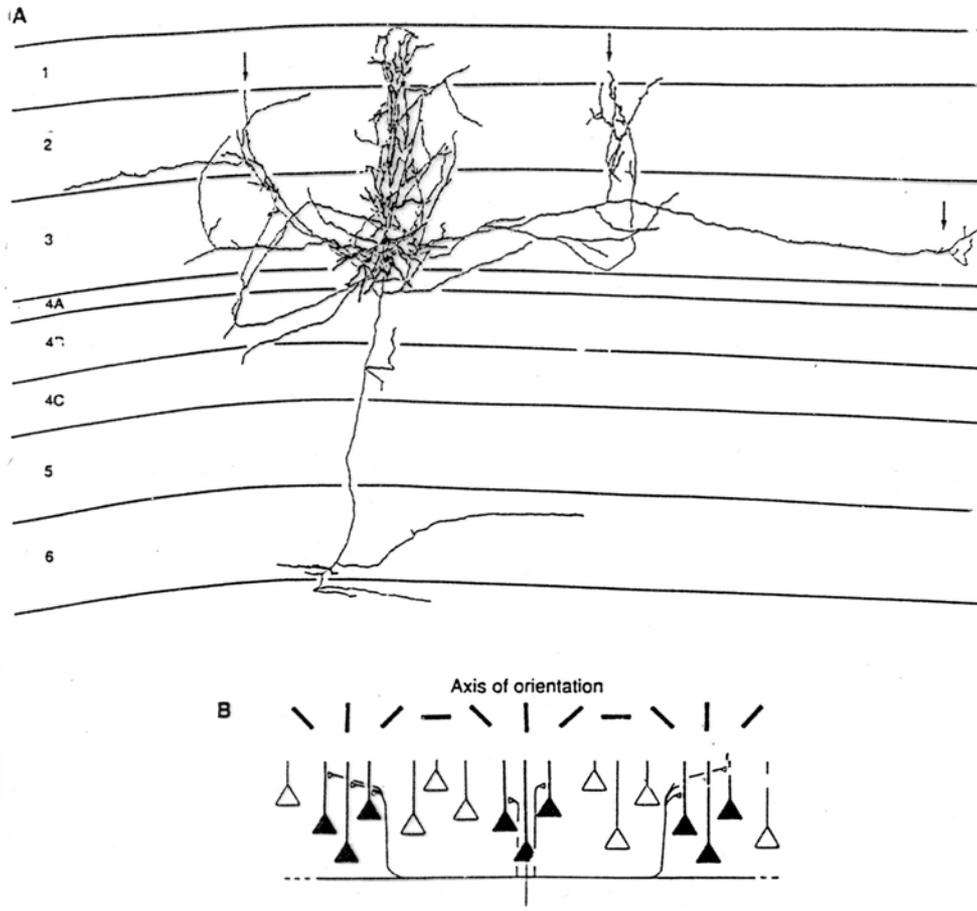
FIGURE 22-4

Neocortical neurons. **A**, Pyramidal neurons in different layers have characteristically different soma sizes and patterns of distribution of axon collaterals. **B**, Nonpyramidal neurons come in a variety of sizes and shapes; many have names attributable to their shapes. Basket cells (**A**) are usually large and make basket-shaped endings that partially surround the cell bodies of pyramidal cells. Other kinds of smaller multipolar cells (**B**) may have elaborate dendritic and axonal arborizations. Chandelier cells (**C**) have vertically oriented synaptic “candles” that end on the initial segments of pyramidal cell axons. Bipolar cells (**D**) have dendrites that both ascend and descend, and double bouquet cells (**E**) have axons that both ascend and descend. (**A** from Jones EG: Identification and classification of intrinsic circuit elements in the neocortex. In Edelman GM, Gall WE, Cowan WM, editors: *Dynamic aspects of neocortical function*, New York, 1984, John Wiley and Sons. **B** from Hendry SHC, Jones EG: *J Neurosci* 1:390, 1991.)

Pyramidal cells contain glutamate, most of the nonpyramidal cells, except the small spiny, putatively excitatory cell of layer IV are likely to be GABAergic. Long, bitufted cell colocalizes GABA and neuropeptides or acetylcholine and peptides.



Schematic drawing of the major targets of pyramidal cells in different layers of the of the somatosensory cortex in monkeys (Jones, 1985)



A: camera lucida reconstruction of a pyramidal cell injected with horseradish peroxidase in L 2-3 in a monkey. Several axon collaterals (arrow) branch off the axon and ramify near the dendritic tree and in three other clusters. This collateral system is thought to interconnect cells in different cortical columns with similar functional properties (McGuire et al., 1990). B: The functional specificity of the long-range clustered horizontal connections. The axon of one pyramidal neuron, in the center of the diagram, synapses on other pyramidal cells in the immediate vicinity as well as on pyramidal cells some distance away. The axon makes connection only with cells with the same functional specificity (Tso's, Gilbert, Wiesel, 1986)

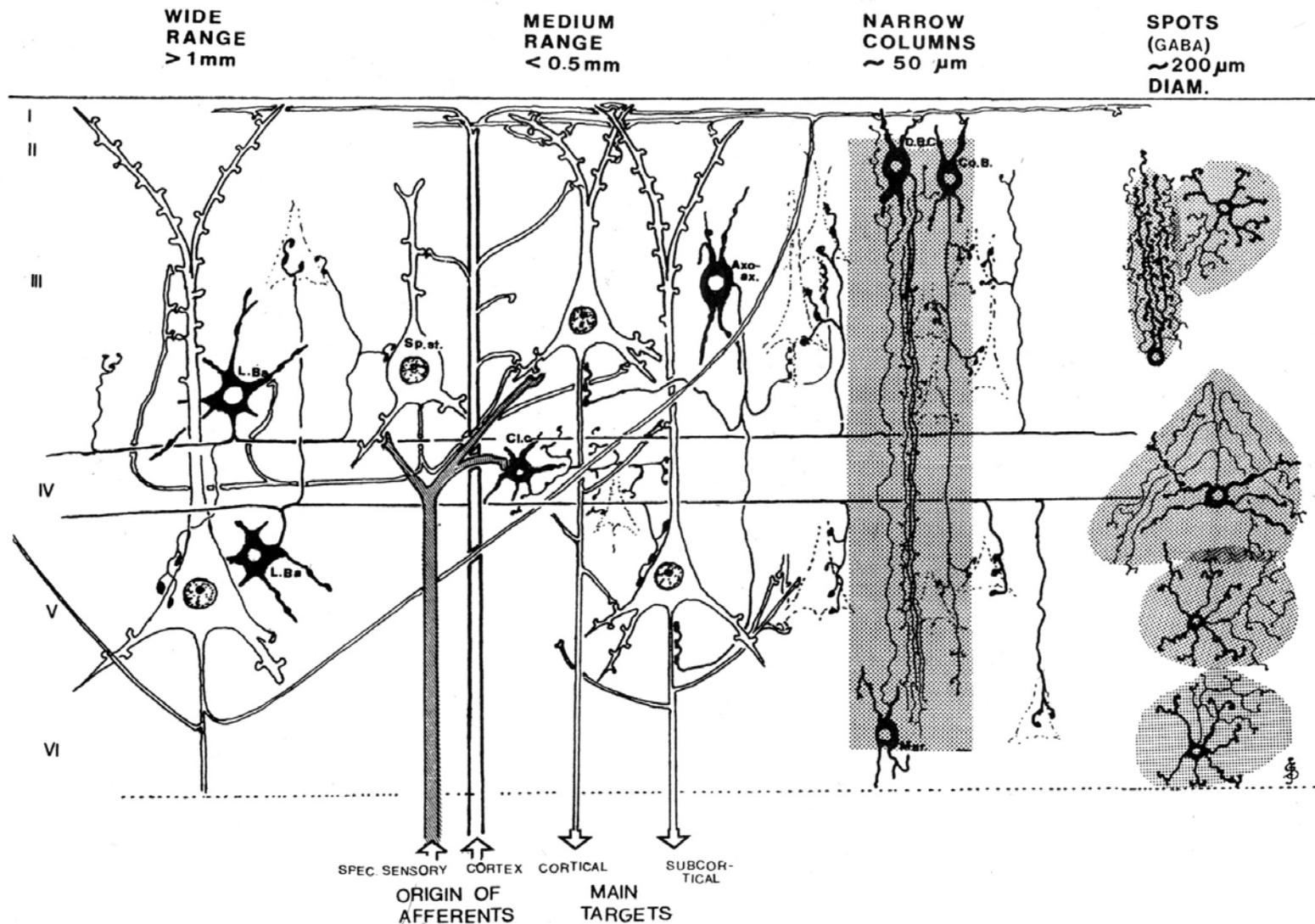
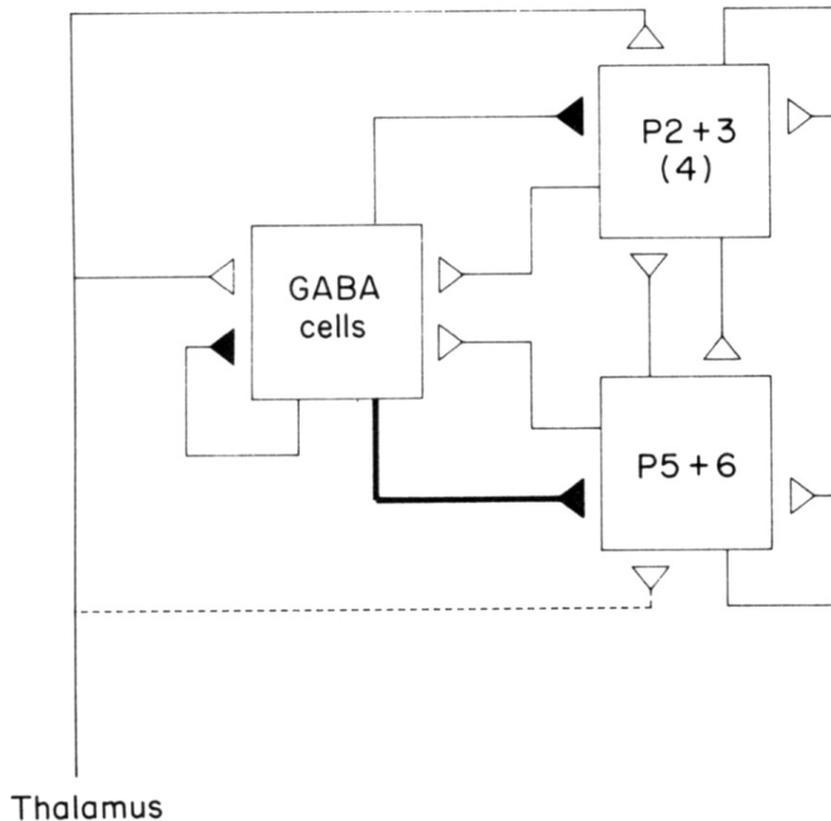


Diagram illustrating the main internal connections of the cerebral cortex. Excitatory neurons and their connections are drawn in outlines, inhibitory neurons in full black. Large-distance excitatory connections (1-5 mm) are given by large pyramidal cells of layer V. Large basket cell (L.Ba) are causing tangential inhibition at distances of 1 mm. The excitatory spiny stellate cells (Sp.st) act mainly at medium range distances. The two main input lines (specific sensory afferents indicated by hatching and cortico-cortical afferents) act at medium range. Inhibitory neurons: axo-axonic; columnar basket (CoB), double bouquet cells of Cajal (CBC), Martonotti (Mar). Various inhibitory neurons with spot-like regions are indicated at right (Szentagothai, 1993)



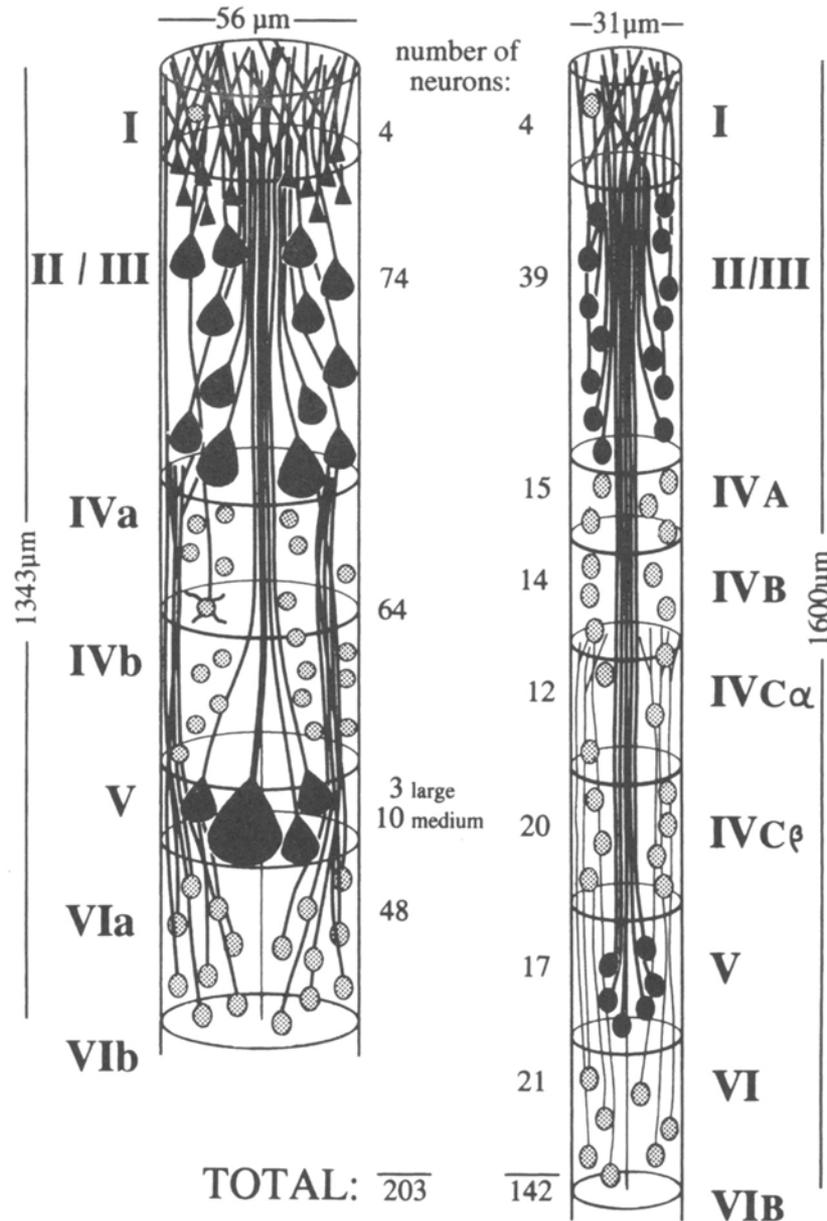
The canonical microcircuit. It is applicable to all cortical areas so far examined. Three population of neurons interact with one another. One population is inhibitory (GABAergic cells, solid synapses) and two are excitatory (open synapses) representing superficial (P2+3) and deep (P5+6) pyramidal neurons. The properties of L4 stellate (4), which contribute 10% of neurons in granular cortex, less elsewhere, are similar to those of the superficial pyramids. The thickness of the connecting lines indicates the functional strength of the input. Note that the dominant connections is between excitatory neurons, so that a relatively weak thalamic input can be greatly amplified by the recurrent excitation of the spiny neurons (Douglas and Martin, 1990).

AREA 17

CAT

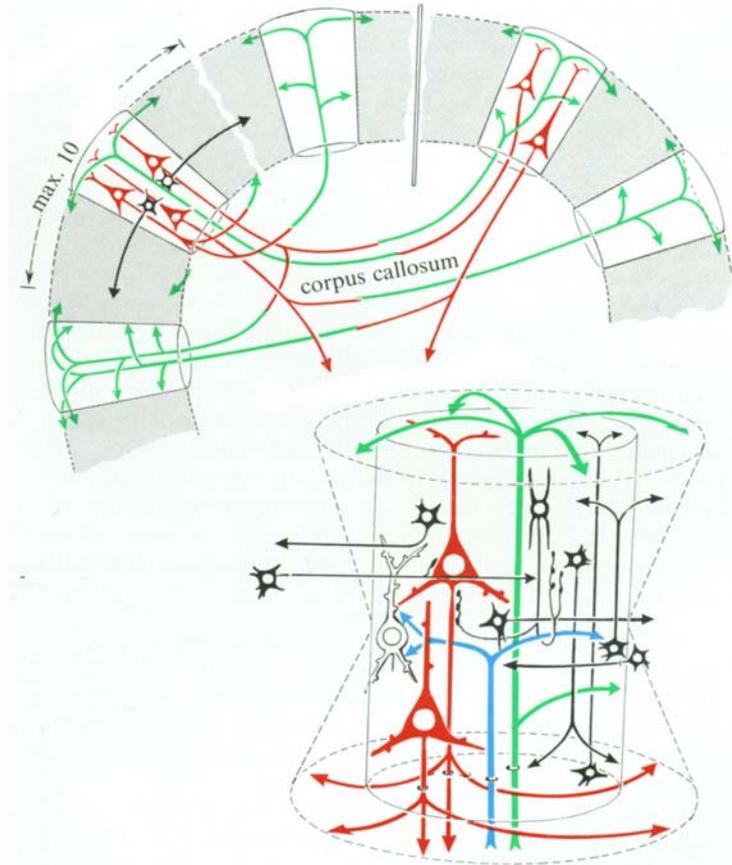
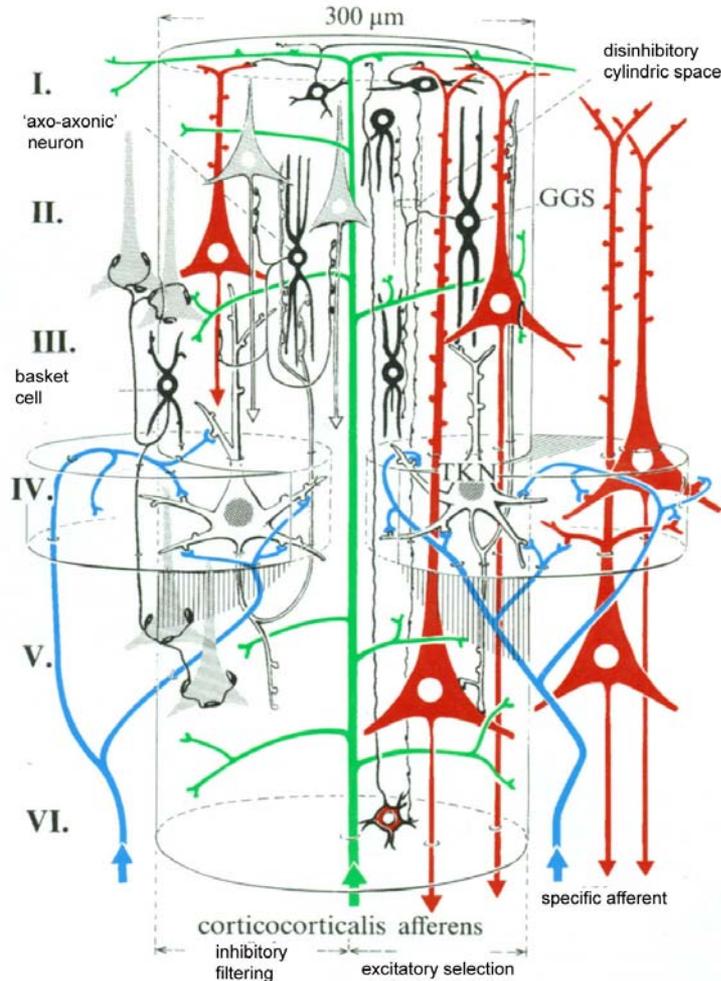
MONKEY

Cortical modules I. Dendritic bundles



The pyramidal cell modules in cat and monkey visual cortex, drawn to show the relative thickness of the cerebral layers, the numbers of neurons in each layer, and the dendritic bundles of L V pyramidal neurons. The inhibitory interneurons (16-20% of the total) are not shown. Cells of L IV shown without dendrites are spiny stellate cells, the excitatory interneurons (lightly shaded). The dendrites of L VI pyramidal cells (also lightly shaded) project vertically tp only to L IV. (Peters and Yilmaz, 1993).

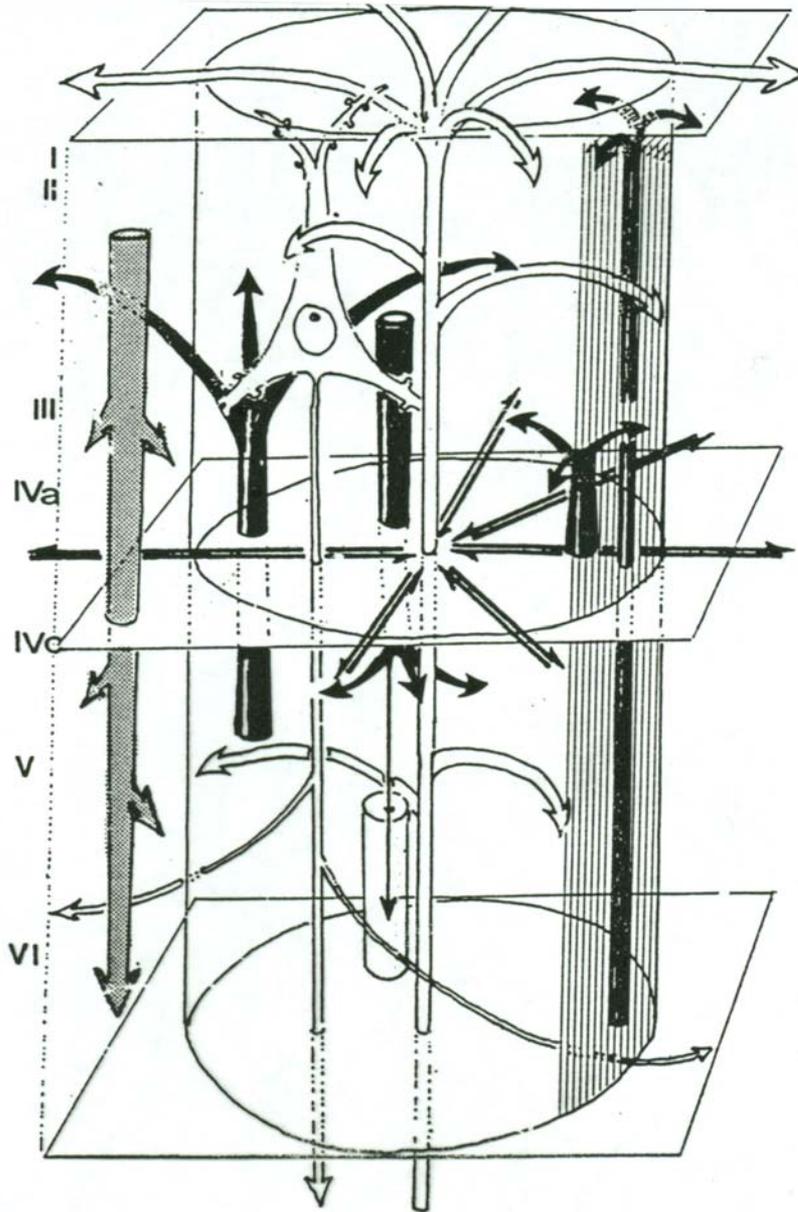
Cortical Moduls II. The callosal and associational columns



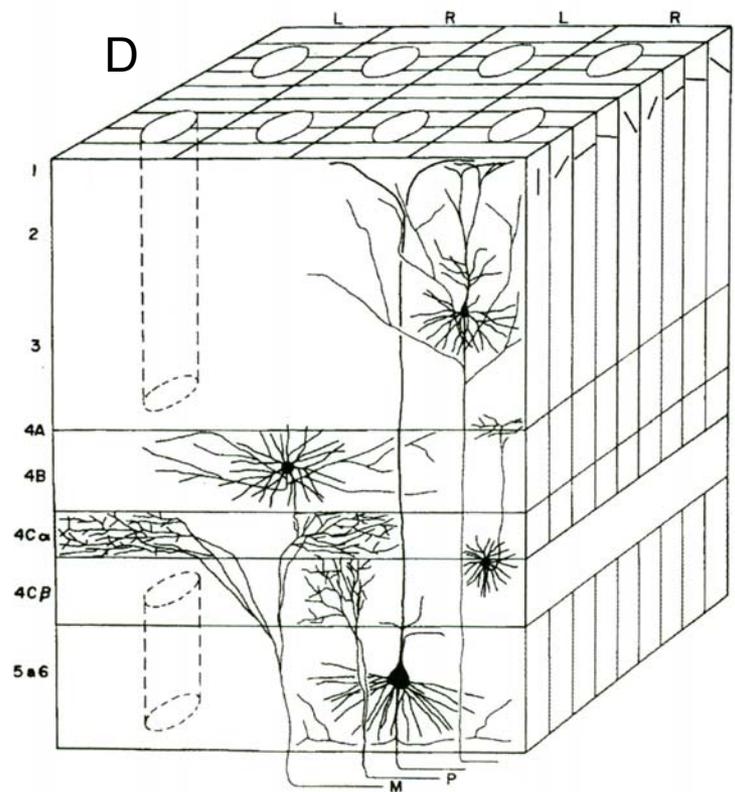
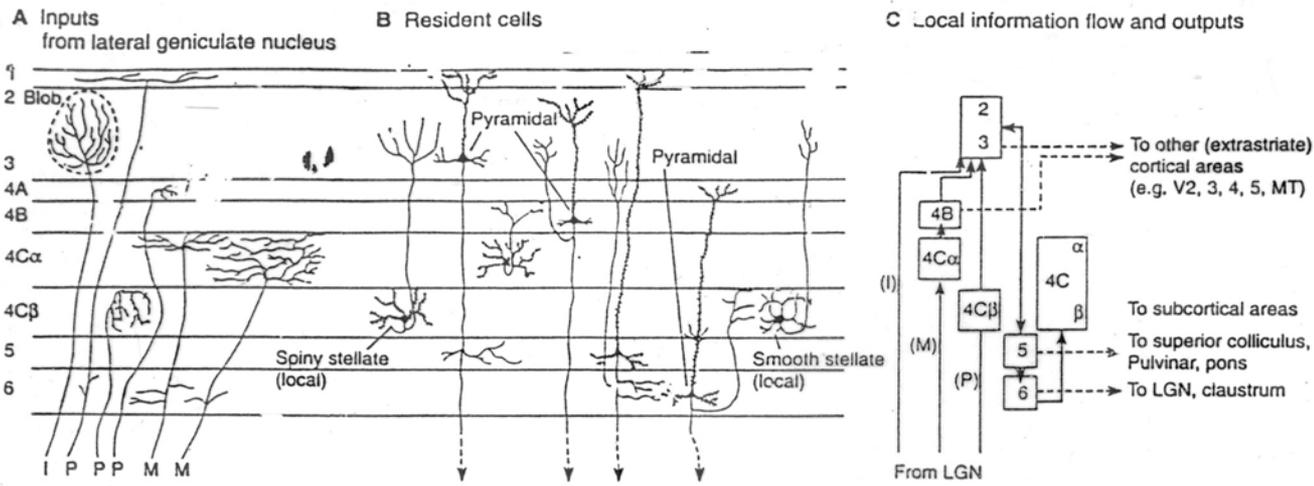
Interconnections of associational and callosal columns. The output of each column originate from pyramidal cells, their terminals axonal arborizations are labeled green. Ipsilateral connections maximally upto 10 columns. The lower right scheme shows some of the dynamic features: in L I and VI the excitation expands the diameter of the column, in L IV, the inhibition shrinks the cylinder (Szentagothai)

Arrangement of neurons and local circuits in one cortical columnar module. Pyramidal cells :red; specific afferents blue; cortico-cortical afferents: green; inhibitory neurons: solid black; TKN: spiny stellate excitatory neuron; GGS: inhibitory neuron (double-bouquet cell of Cajal) connected to other inhibitory neurons. The effect of the Martinotti cell in L VI spread upto LI (see fig. on following page)

Intracolumnar Inhibitory modules



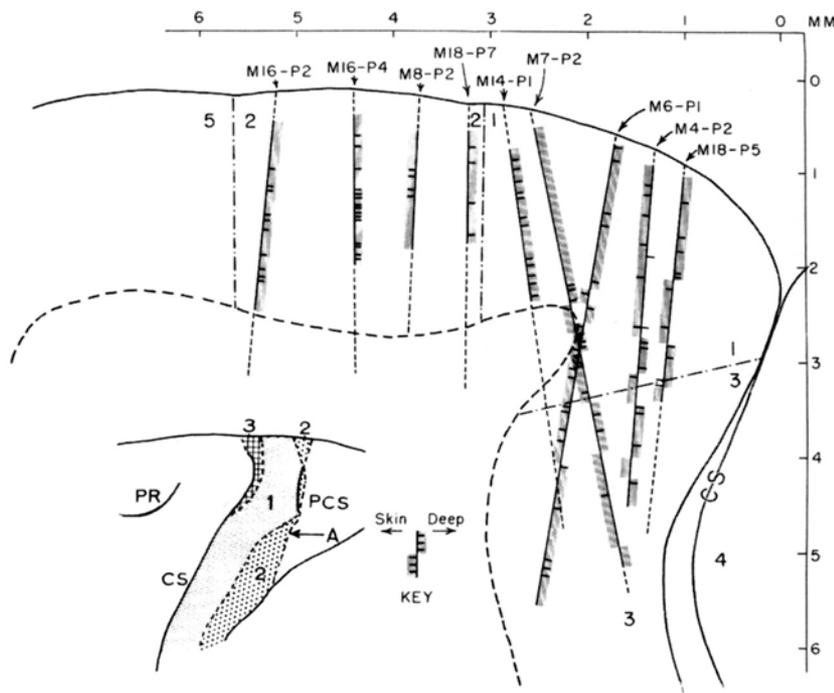
Interlaminar connexions for excitation and inhibition are shown by arrows connecting different layers of the visual cortex. A cortico-cortical (excitatory) afferent is drawn in the middle of the cylinder. Specific sensory afferents are omitted. A L III pyramidal cell is drawn in upper left. Inhibitory connections are most widely spread in L IVc and from L IVc to IVa (large basket cell). There is a major inhibitory input from L V cell into L III and from L VI to L I and II (extreme right: Martinotti cell). There is a massive inhibitory input from L III to the bottom of L IV and into the upper layers of L V. Descending stippled arrow at extreme left corresponds to vertically descending largely disinhibitory connexions by double bouquet cells (Szentagothai).



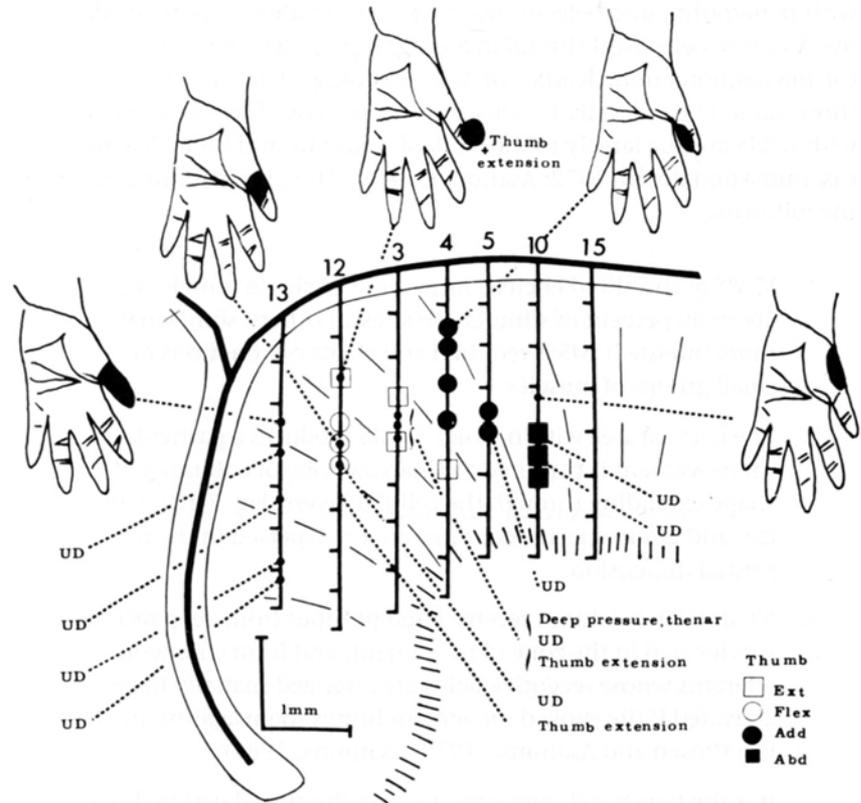
Orientation and ocular-dominance columns in the primary visual cortex. A: inputs from the LGB. B: resident cells. C: Afferents from M and P cells of the LGN end on spiny stellate cells in layer 4C, and these cells project axons to layer 4B and the upper layers 2 and 3. Cells from the interlaminar zones (I) in the LGN project directly to layers 2-3. From there, pyramidal cells project axon collaterals to L5 pyramidal cells, whose axon collaterals project both to L6 cells as well as back to cells in L2-3. Axon collaterals of L6 pyramidal cells then make a loop back to L4C onto smooth stellate cells. Each layer, except for 4C, has different outputs. The cells in L5 project to the superior colliculus, the pons, and the pulvinar. Cells in L6 project back to LGN and the claustrum (Lund, 1988) .

D: Ice cube model of visual cortex . L,R:ocular dominance columns. The narrower orientation columns run orthogonally. The cytochrome oxidase rich blobs appear as cylinders in the center of the ocular dominance columns (Douglas and Martin, 1998)

Columnar organization of the sensory and motor cortices

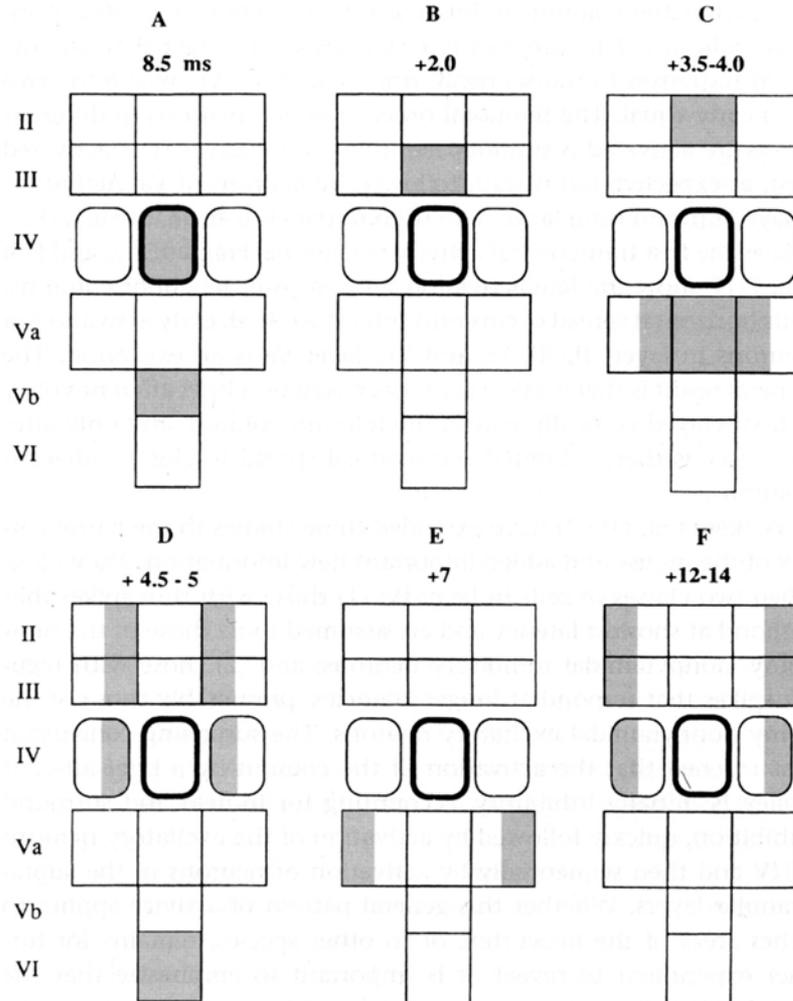


Lower inset shows the cytoarchitectural areas through which the electrode penetrations were made. Penetrations made perpendicular to the cortical surface and passing down parallel to its radial axis encountered neurons all of the same modality type. As the penetrations were made more anteriorly in areas 1 and 3, where the vertical axis of the cortex rolls, blocks of cells with different modality alternates (Powell and Mountcastle, 1959)



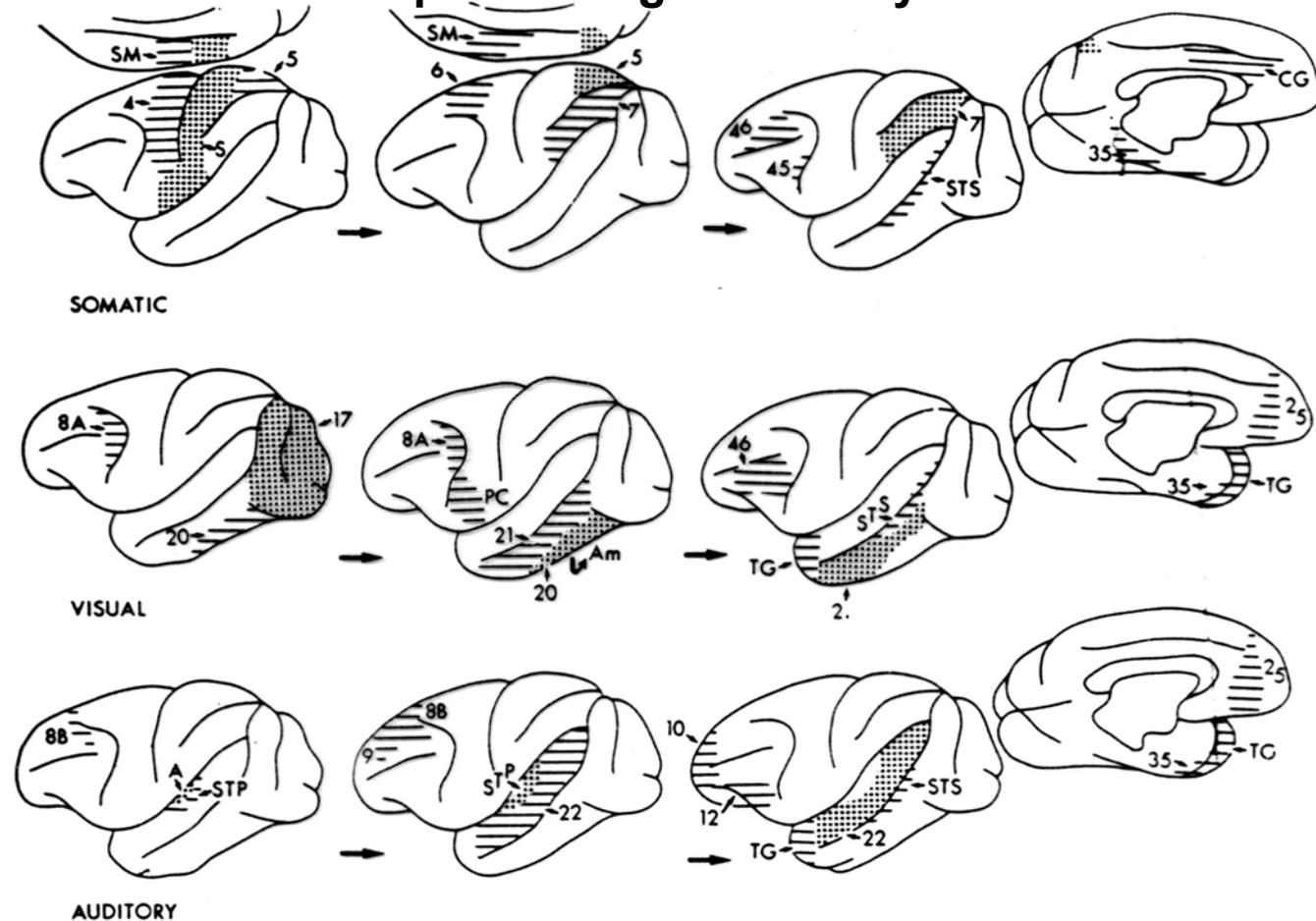
Intracortical microelectrode stimulation in the precentral motor cortex of a monkey that revealed some aspects of the input-output relation for the contralateral thumb and the columnar organization of this cortical area. Microelectrode penetrations are shown by solid lines and numbers. Short horizontal lines indicate sites at which weak currents did not evoke motor responses. Locations where movements were produced and receptive fields of the cells studied are marked by dots or squares and are connected by dashed lines to figurines showing the receptive fields (Asanuma, 1975)

Columnar organization in the barrel cortex



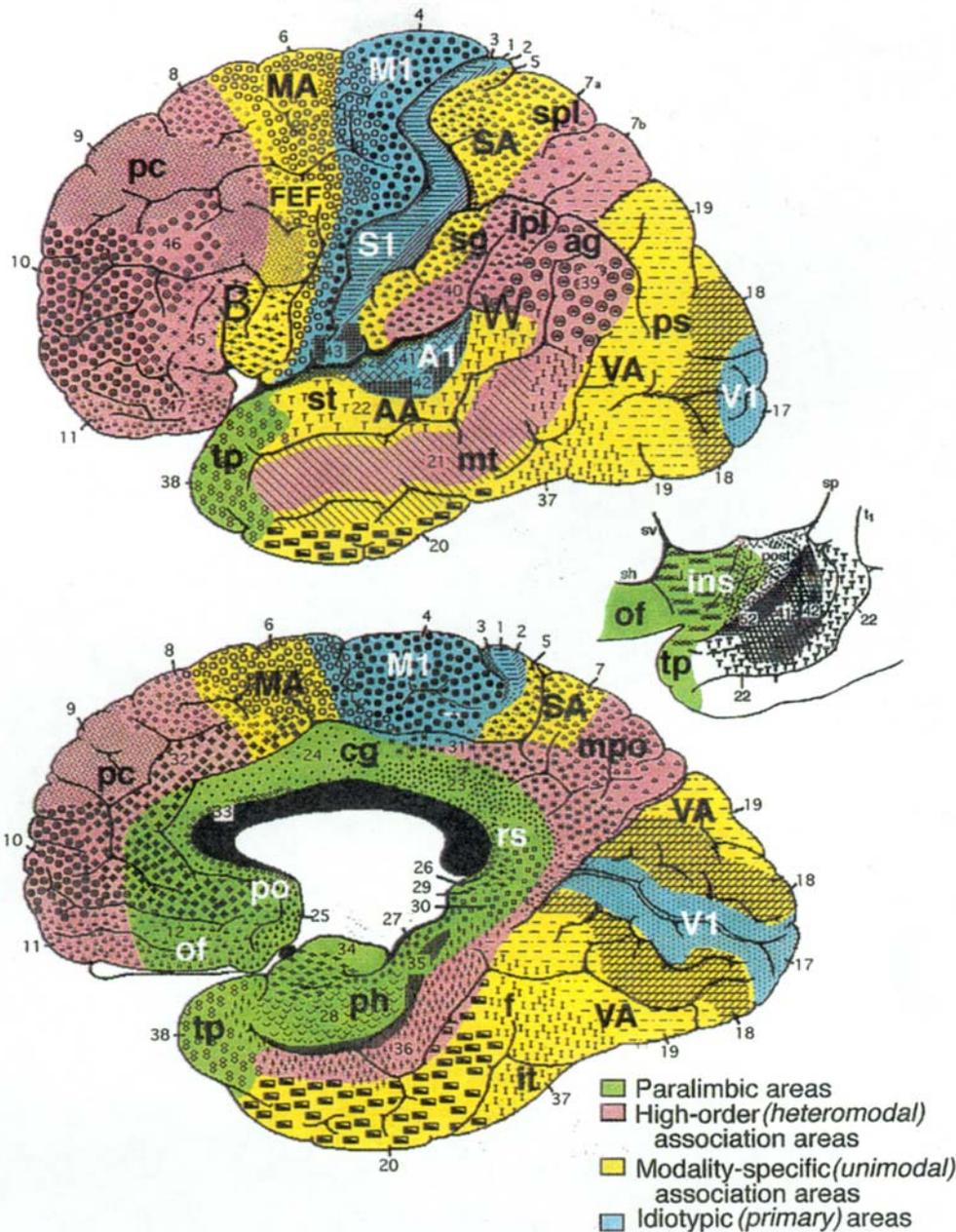
Intracolumnar and pericolumnar flow of activity in a barrel in the anesthetized adult rat, evoked by brief deflection of the related contralateral whisker. Cellulart discharges were recorded with extracellular microelectrodes. Cells in L IV are activated at a mean latency of 8.5 msec. Sequential activation of laminae and sublaminar units at the mean latencies after panel A. Cells within column in layer II and Vb are activated 2.4 msec after those of L IV, near simulataneously with L Va cells in near-neighbor columns (A-C). Activity then spreads to near-neighbor layers and columns (D—F) (Armstrong-Jones et al., 1992).

Hierarchical processing of sensory information



Summary diagram showing progression of connections from primary sensory cortices to unimodal association cortices and finally to polymodal association areas. In each diagram, dotted pattern shows projection *origins* and horizontal lines delimit *termination* regions. In the somatosensory systems, for example, S1 gives rise to projections to motor cortex (area 4) and to parietal association are (area 5). Area 5, in turn, gives rise to projections to premotor cortex (area 6) and to posterior parietal cortex (area 7). This latter region projects to polysensory zones in the superior temporal cortex (STS), cingulate gyrus (CG) and perirhinal cortex (area 35). (Jones and Powell, modified by Amaral, 1987)

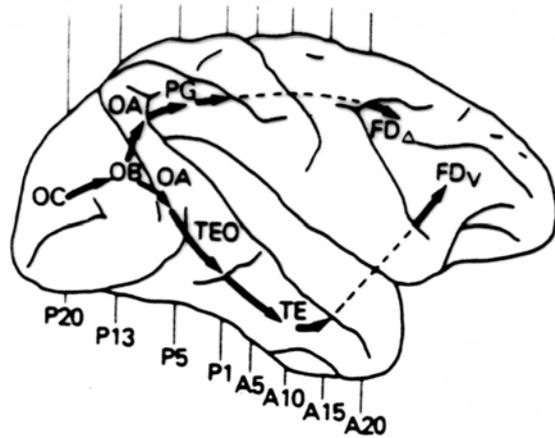
Distribution of functional zones in relationship to Brodmann's map of the human brain



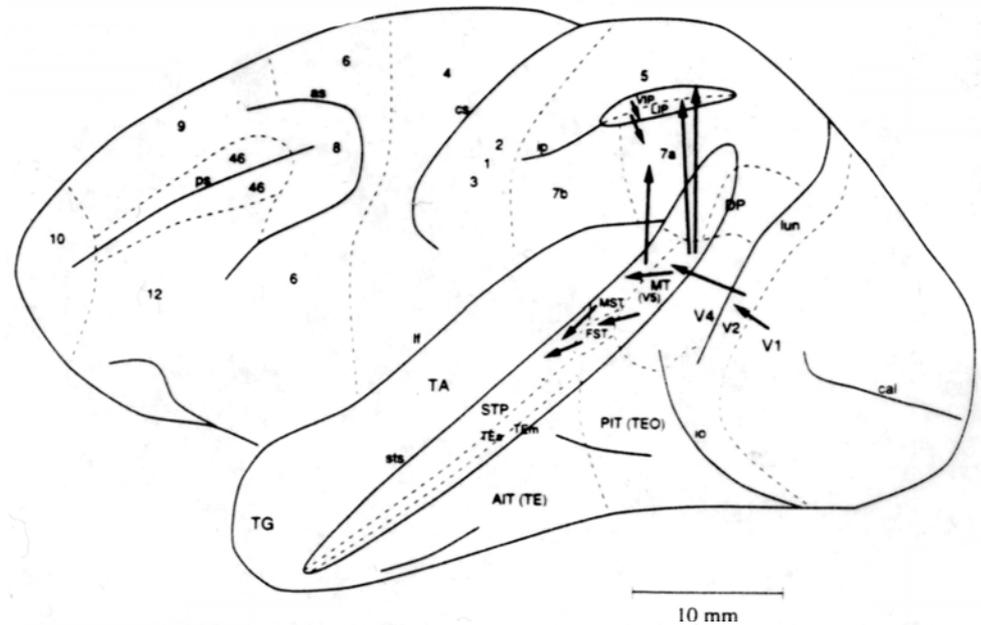
. Much of the information is based on experimental evidence obtained from animals and needs to be confirmed in humans. AA=auditory assoc. cortex; ag: angular gyrus; A1= primary auditory cortex; B: Broca's area; cg=cingulate cortex; f=fusiform gyrus; FEF=frontal eye fields; ins=insula; ipl=inferior parietal lobule; it=inferior temporal gyrus; MA=motor association cortex; mt-middle temporal gyrus; M1=primary motor cortex; of=orbitofrontal cortex; pc=prefrontal cortex; ph=parahippocampal region; po=parolfactory area; ps=peristriate cortex; rs=retrosplenial area; SA somatosensory association cortex; sg=supramarginal gyrus; spl=superior parietal lobule; st=superior temporal gyrus; S1=primary sensory cortex; tp=temporopolar; VA =visual association cortex; V1 primary visual cortex; W=wernicke's area

Visual associational connections

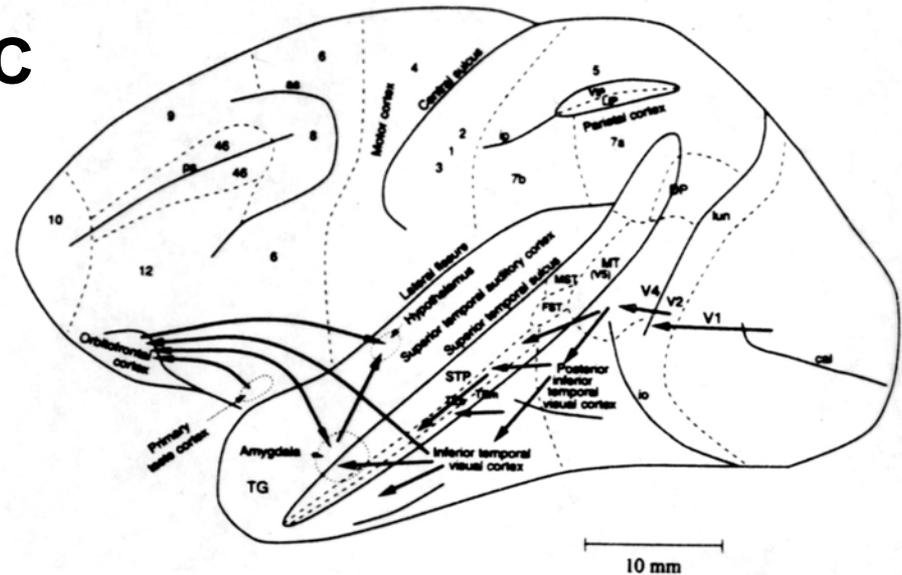
A



B

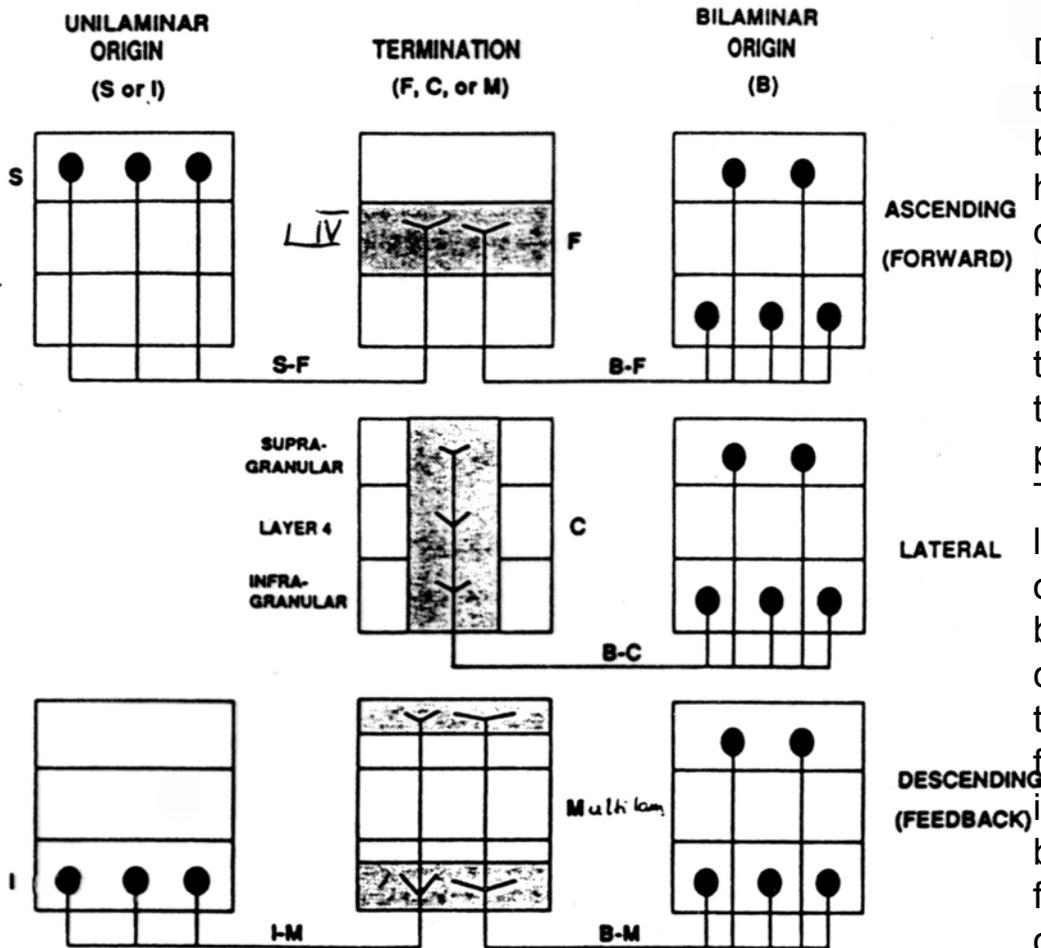


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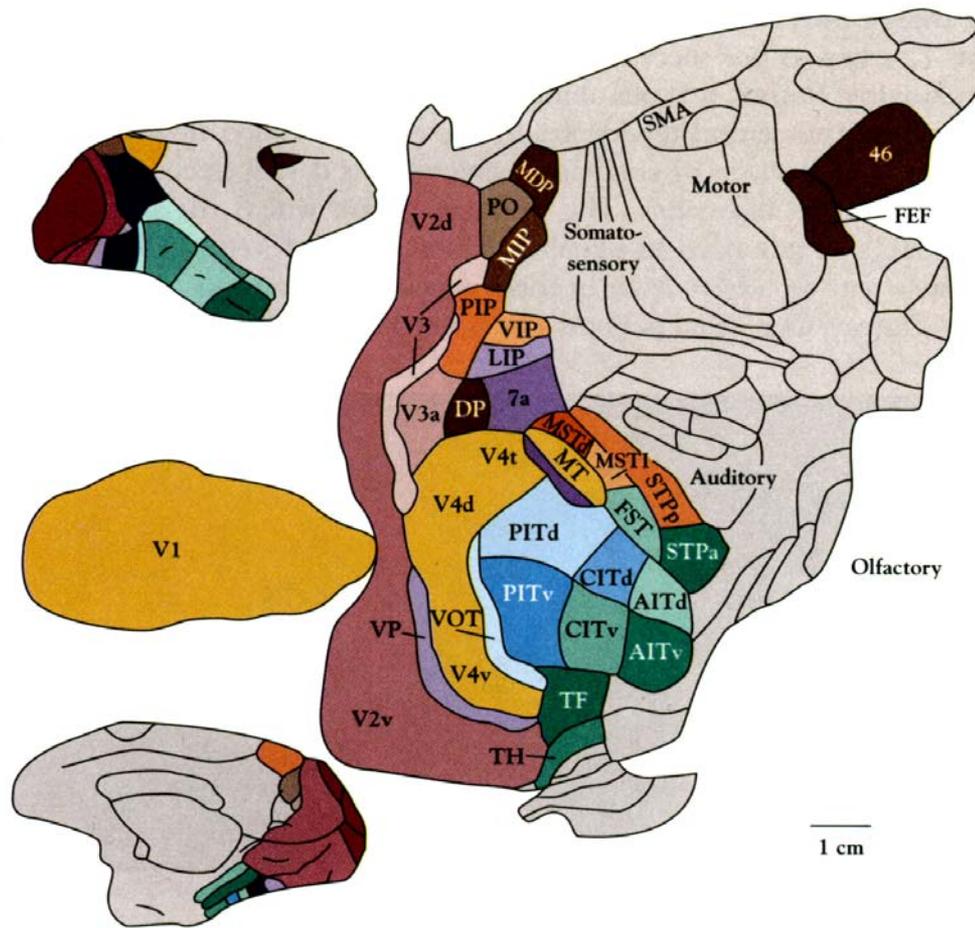


A: Two visual cortical pathways in the monkey. Both pathways begin in the primary visual cortex (OC) and diverge in the peristriate cortex (OA and OB) to end in inferior temporal (TEO and TE) and parietal areas (PG). The ventral area is essential for object, the dorsal for spatial vision (Mishkin et al., 1983). **B:** Lateral view of the macaque monkey showing the connection of the dorsal stream from V1 to V2, MST, with some connection reaching the frontal eye field. **C:** Connection of the ventral stream from V1, V2 and V4, the inferior temporal visual cortex, etc with some connections reaching the amygdala and orbitofrontal cortex (B and C from Rolls and Treves, 1998)

Analysis of the pattern of neocortical connectivity

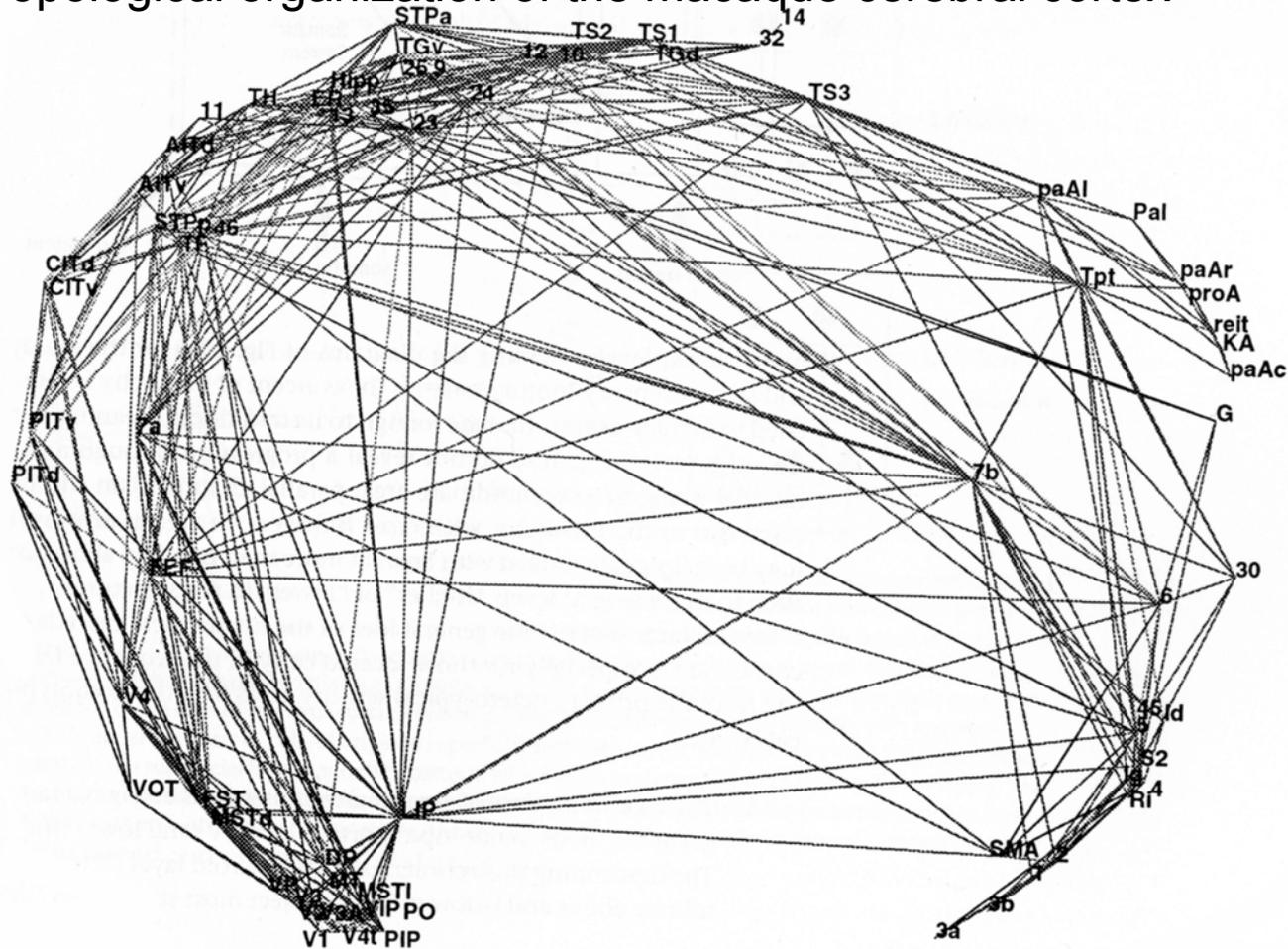


Diagrams of the laminar patterns of origin and termination of cortico-cortical connections used by Felleman and Van Essen (1991) to assign hierarchical positions to cortical areas. The central column shows the characteristic patterns of terminations: the F pattern –with preferential termination in L 4; the C pattern – the columnar pattern with equal density of terminations in all cortical layers; and the M pattern- a multilamellar pattern that avoids L 4. There are several characteristic patterns of locations of cells of origin. The S pattern, with origins in superficial layers and the B pattern: bilaminar with approximately equal numbers of cells of origin in superficial and deep layers with termination in L 4 are characteristic for feed-forward connections. The I pattern, with origins in the infragranular layers and the B pattern with bilaminar terminations are characteristic for feedback connections. Finally, the bilaminar origin and columnar termination is typical for lateral (equifunctional) connections.



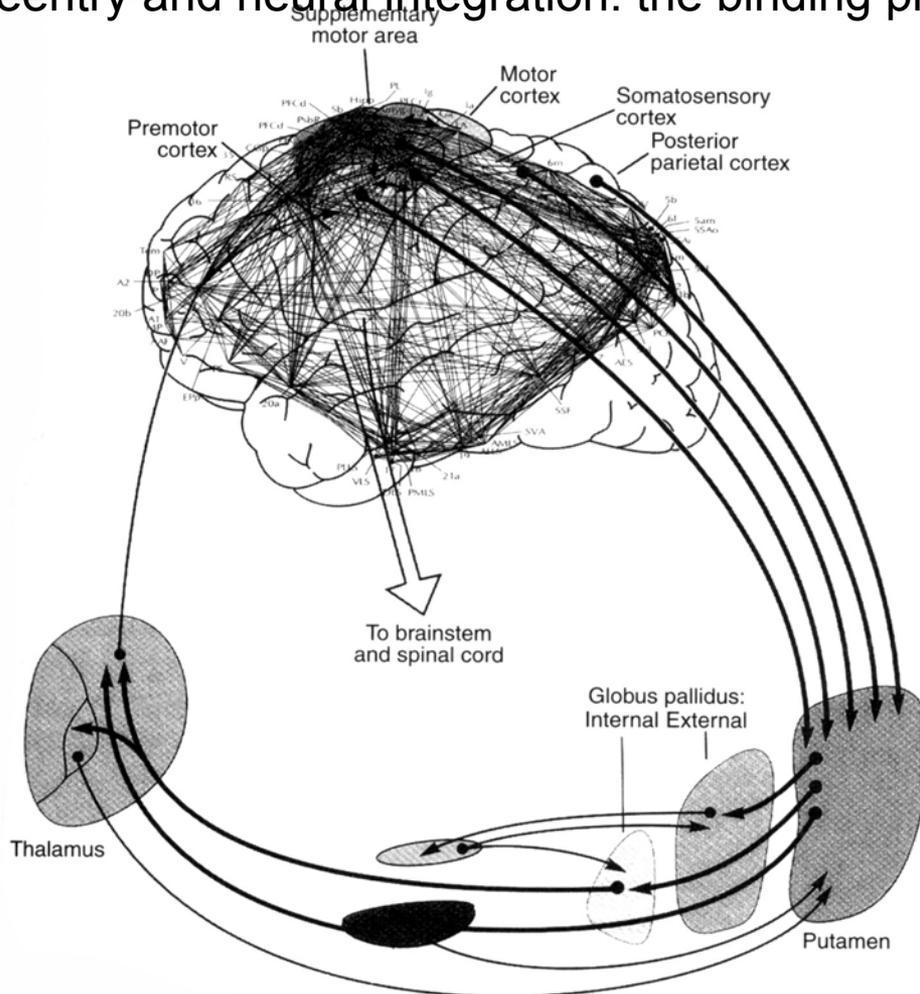
Two-dimensional flattened map of the cerebral cortex of the macaque monkey with different visual areas (Van Essen and Maunsell).

Topological organization of the macaque cerebral cortex



The topological organization of the macaque cortical areas in terms of their ipsilateral connections, as known prior to 1993. A total of 758 connections between 72 cortical areas are shown; of these 136 are one-way. The connections shown are only 15% of the total possible connections. The structure is a best-fit representation of the topology of the system in two dimensions. The position of each area is specified as to minimize distance between interconnected areas, and maximize distances to areas which is not interconnected. Areas with similar patterns of inputs and outputs tend to be placed close together, those with dissimilar patterns far apart. The cortex is represented in a state of connective tension, not in its true anatomical space (Young, 1993)

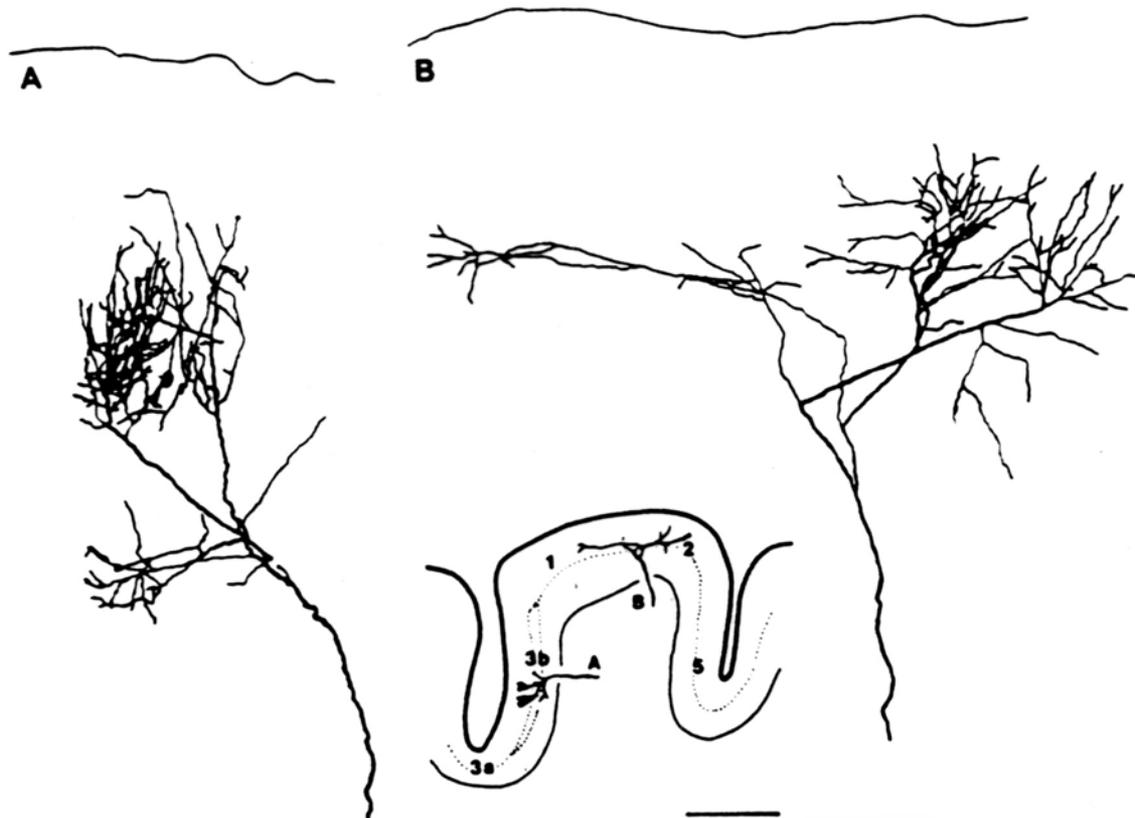
Reentry and neural integration: the binding problem



The topological diagram, overlaid the human neocortex, represents 64 areas from the cerebral cortex of cat with 1,134 connection path between them. Most conenction path are reciprocal. Areas are depicted close to each other if they are conencted and far away if they are not conencted The resulting topological organization reflects their conenctions, not their location in the brain, similar to the diagram in the previous figure by Young. The rest of the figure depict the output of L 5 pyramidal output from the motor cortex, reaching various components of the basal ganglia and certain thalamic nuclei and their return to the cortex. The large arrow represent output to the brainstem and spinal cord that mediate direct motor output (Edelman and Tononi, 2000).

TABLE 5.3. Cortical Afferents

Source	Axons	Distribution	Transmitter	Termination layer
VL, VPL, Pulv, LG, MG, LP	Specific thalamo-cortical afferents	Columnar	Glu	III, IV
Thalamus paralamina	Nonspecific thalamo-cortical afferents	Regional	Glu	I
Thalamus intralamina	Nonspecific thalamo-cortical afferents	Regional		V, VI
Cortex, other hemisphere	Callosal afferents	Columnar	Glu	III, IV
Cortex, same hemisphere	Corticocortical afferents	Columnar	Glu	II, III, IV
Nucleus of the raphe	Serotonergic	Diffuse	5HT	I + all layers
Substantia nigra	Dopaminergic afferents	Prefrontal, limbic archicortex	Dopamine	V, VI (prefrontally)
Locus coeruleus	Noradrenergic afferents	Diffuse	Noradrenaline	All layers
Basal forebrain nuclei	Cholinergic afferents	Regional	Acetylcholine	In particular lower layers



Thalamocortical axon collaterals permitting simultaneous spread of afferent information to widely spread columns (Jones and Wise, 1977).

Thalamocortical connections

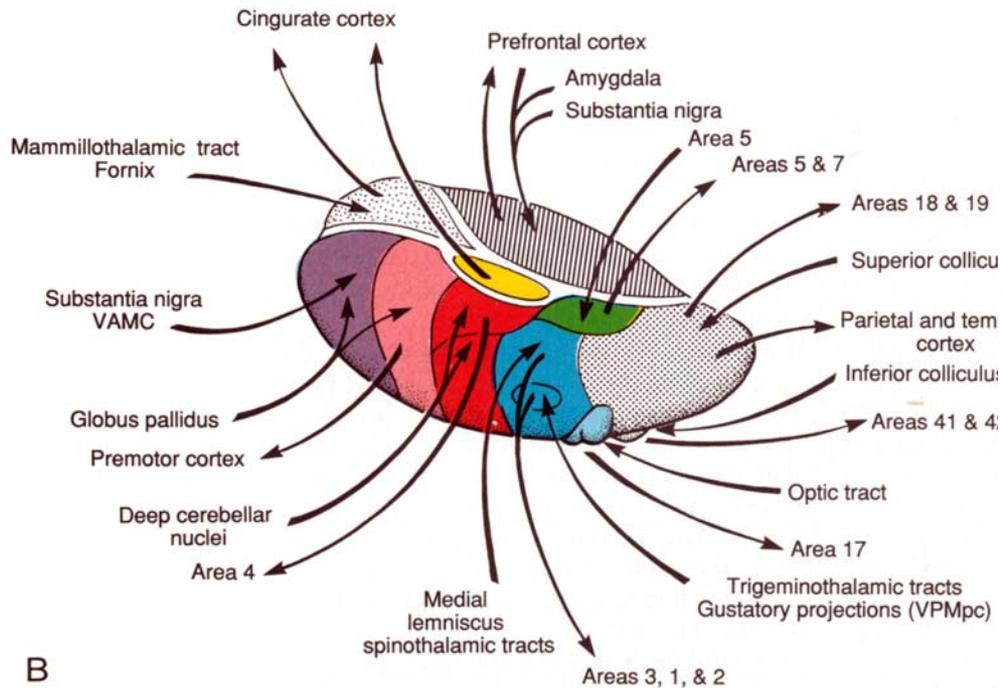
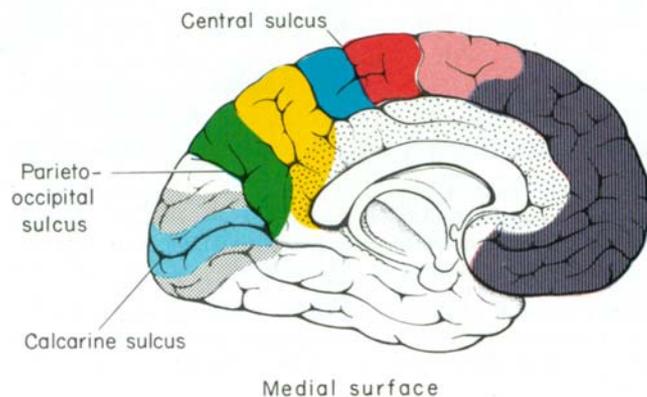
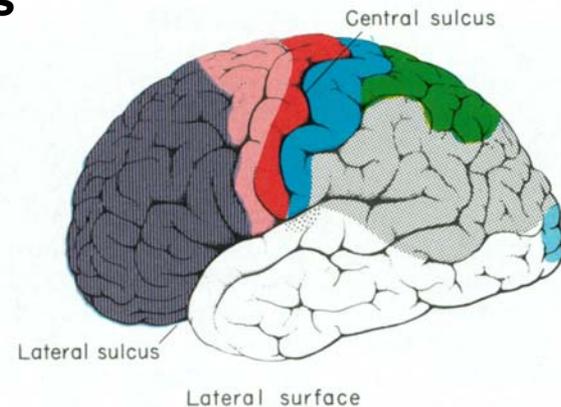
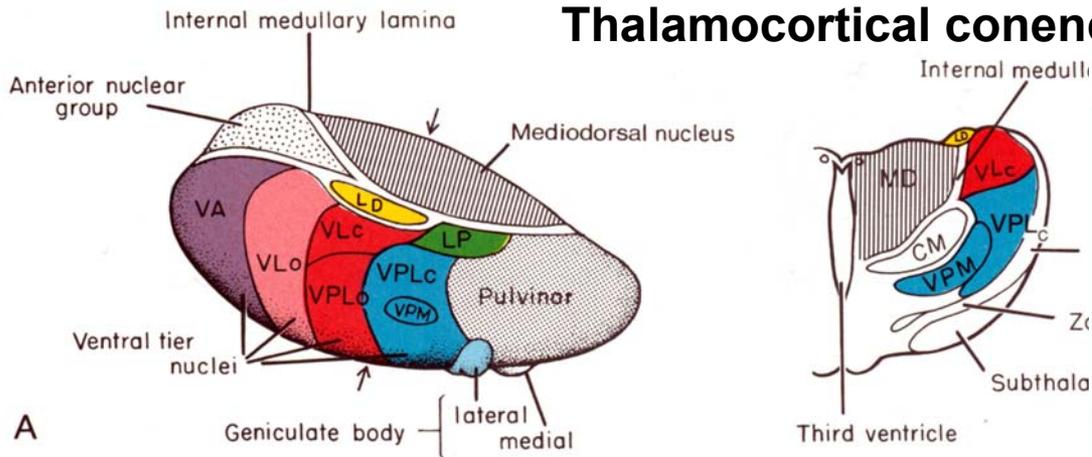
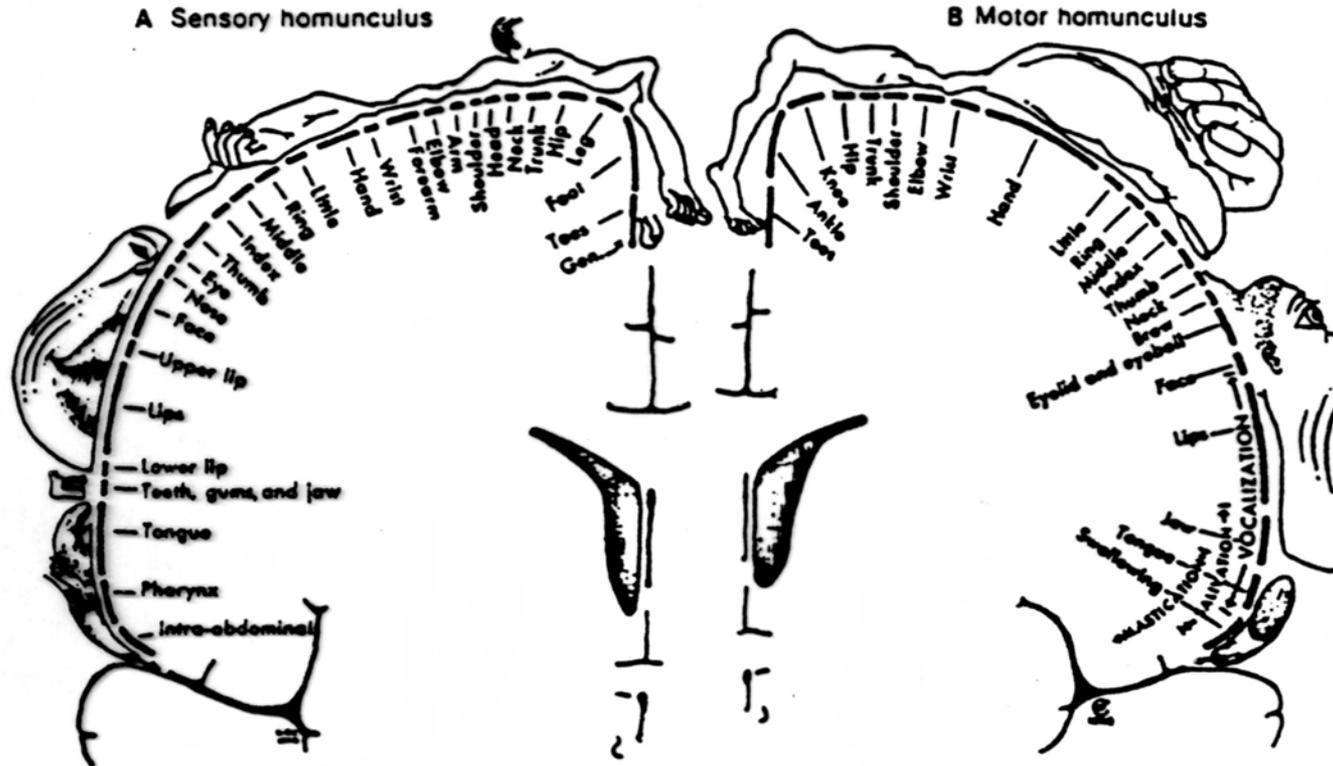


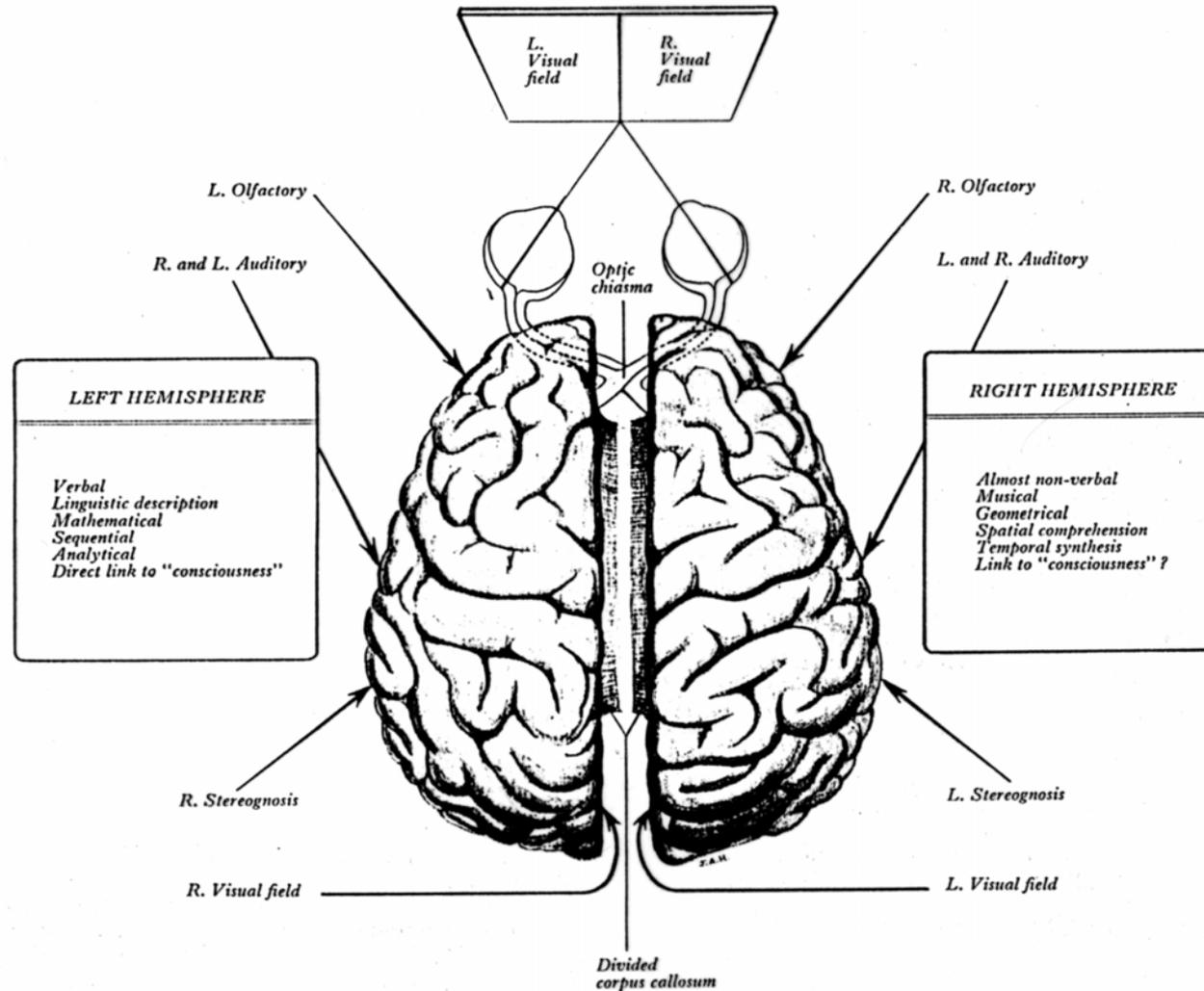
Diagram of the major thalamic nuclei, their inputs and their cortical projection areas. Color coding in the cortex is the same as for the thalamus (Carpenter, 1991)

Sensory-motor representations in the cerebral cortex



A Sensory representation in the postcentral gyrus. **B** Motor representation in the precentral gyrus (Penfield and Rasmussen, 1968).

Split-brain and localization of cognitive functions



Adaptation of the original 'split-brain' schema of Sperry. The right and left halves of the total visual field are projected into the contralateral hemispheres and are completely isolated; the right hand being 'controlled from the left hemisphere. The olfactory and auditory inputs also project to separate hemispheres, but in the former case ipsilaterally and in the latter bilaterally with a contralateral bias. On each side of the diagram the abilities listed refer to adjoining hemisphere. The diagram represents arrangements in an individual with left cerebral dominance (From Gray's Anatomy).

