CORTICAL-SUBCORTICAL NETWORKS AND A DUAL TIERED MODEL OF COGNITION – THEORY AND PRACTICE
Part II

LFK

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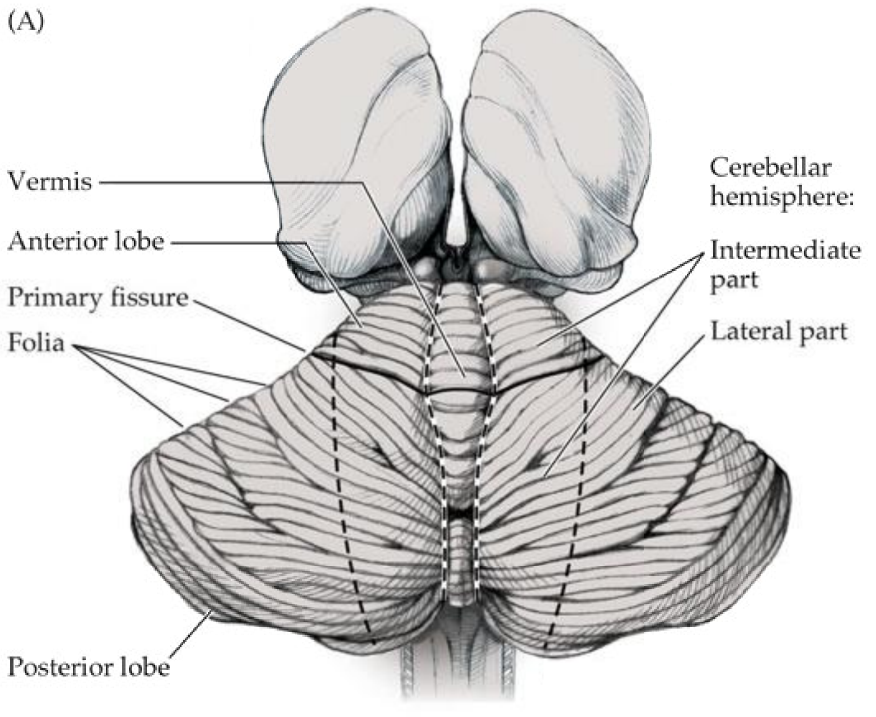
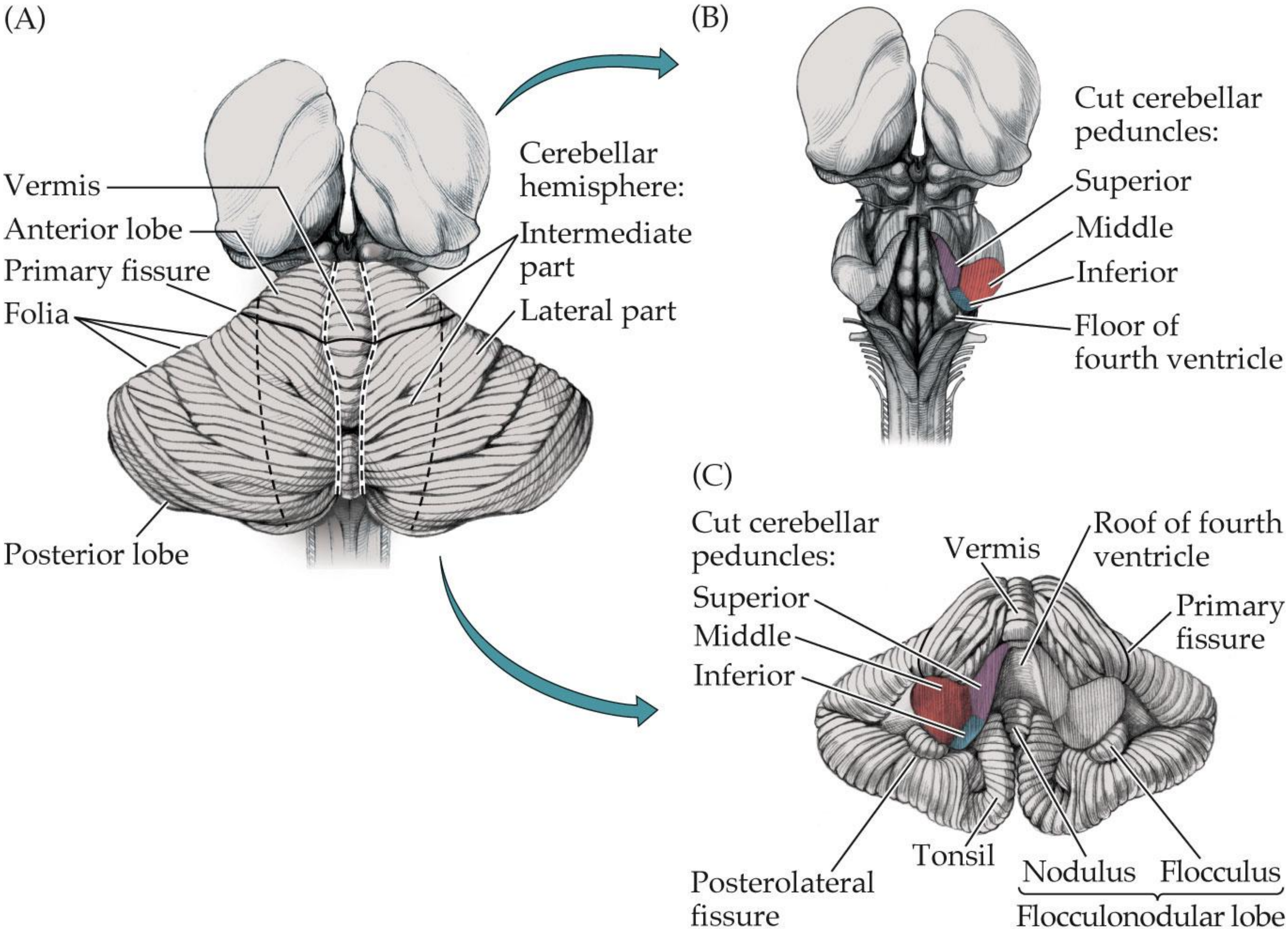
The Cerebellum – Structural Divisions

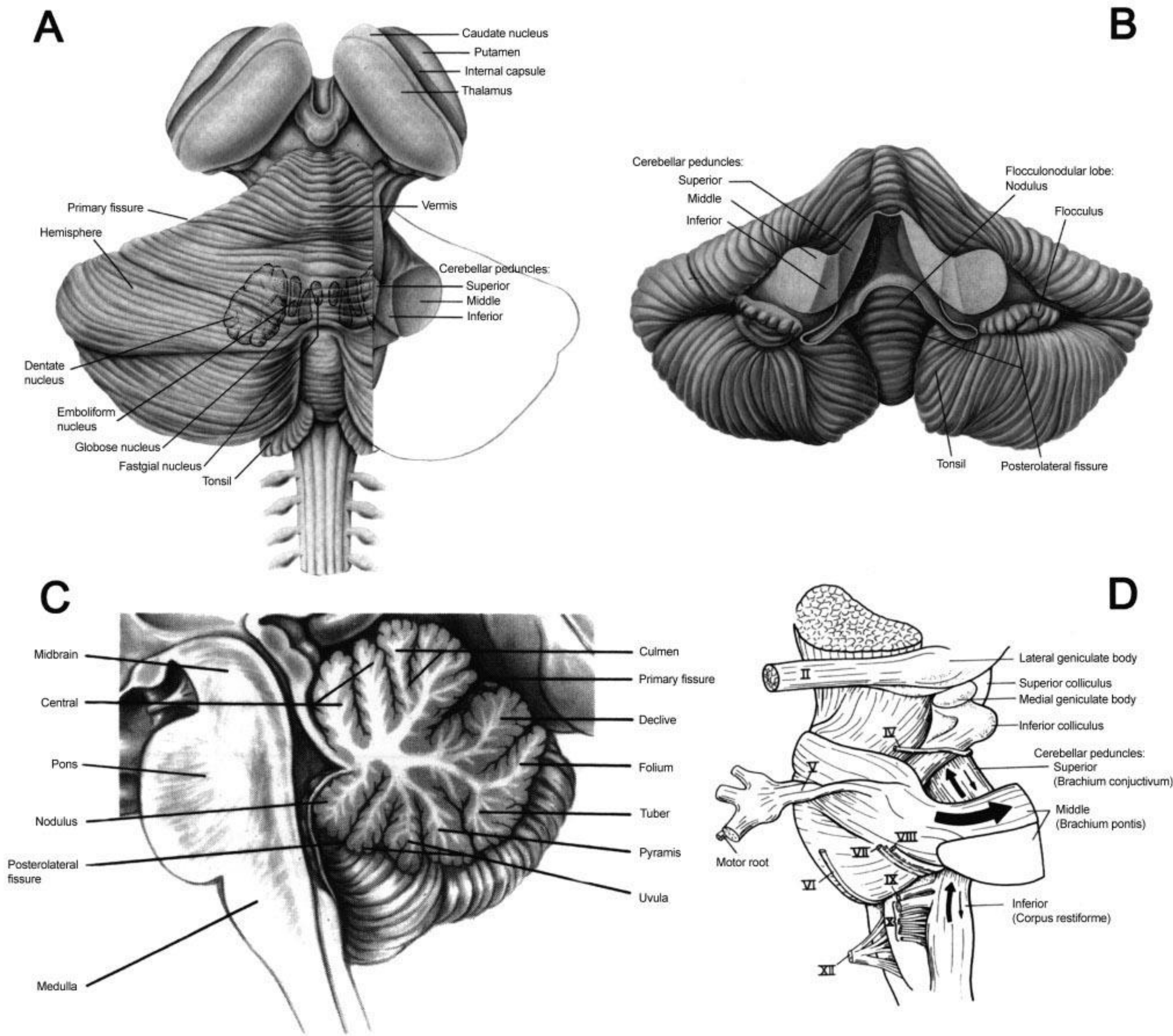


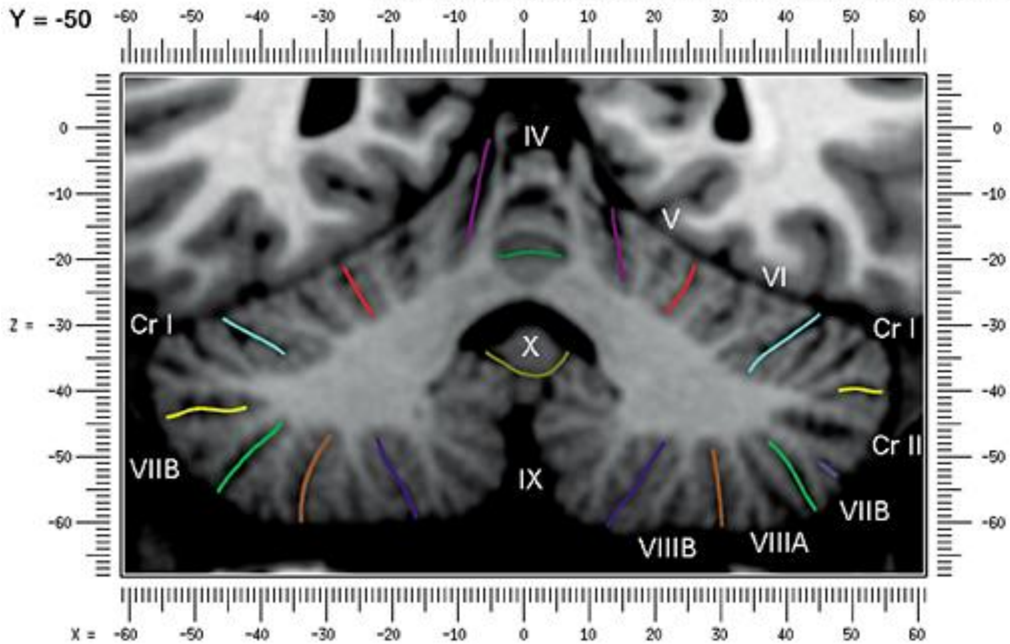


(A)
Vermis
Anterior lobe
Primary fissure
Folia
Posterior lobe
Cerebellar hemisphere:
Intermediate part
Lateral part
(B)
Cut cerebellar peduncles:
Superior
Middle
Inferior
Floor of fourth ventricle
(C)
Cut cerebellar peduncles:
Superior
Middle
Inferior
Vermis
Roof of fourth ventricle
Primary fissure
Posterolateral fissure
Tonsil
Nodulus
Flocculus
Flocculonodular lobe

The Cerebellum – Lobes and Deep Nuclei

- The anterior lobes and posterior lobes are divided by the primary fissure
- The anterior and posterior lobe together form the corpus cerebelli
- A ventral view reveals the nodulus and flocculus which together are called the flocculondular lobe
- Deep cerebellar nuclei


A
Caudate nucleus
Putamen
Internal capsule
Thalamus
Vermis
Primary fissure
Hemisphere
Cerebellar peduncles:
Superior
Middle
Inferior
Dentate nucleus
Emboliform nucleus
Globose nucleus
Fastgial nucleus
Tonsil
B
Cerebellar peduncles:
Superior
Middle
Inferior
Flocculonodular lobe:
Nodulus
Flocculus
Tonsil
Posterolateral fissure
C
Midbrain
Central
Pons
Nodulus
Posterolateral fissure
Medulla
Culmen
Primary fissure
Declive
Folium
Tuber
Pyramis
Uvula
D
Lateral geniculate body
Superior colliculus
Medial geniculate body
Inferior colliculus
Cerebellar peduncles:
Superior
(Brachium conjuctivum)
Middle
(Brachium pontis)
Inferior
(Corpus restiforme)
Motor root
II
IV
V
VI
VII
VIII
IX
X
XII


Y = -50
-60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60
0
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Z = -30
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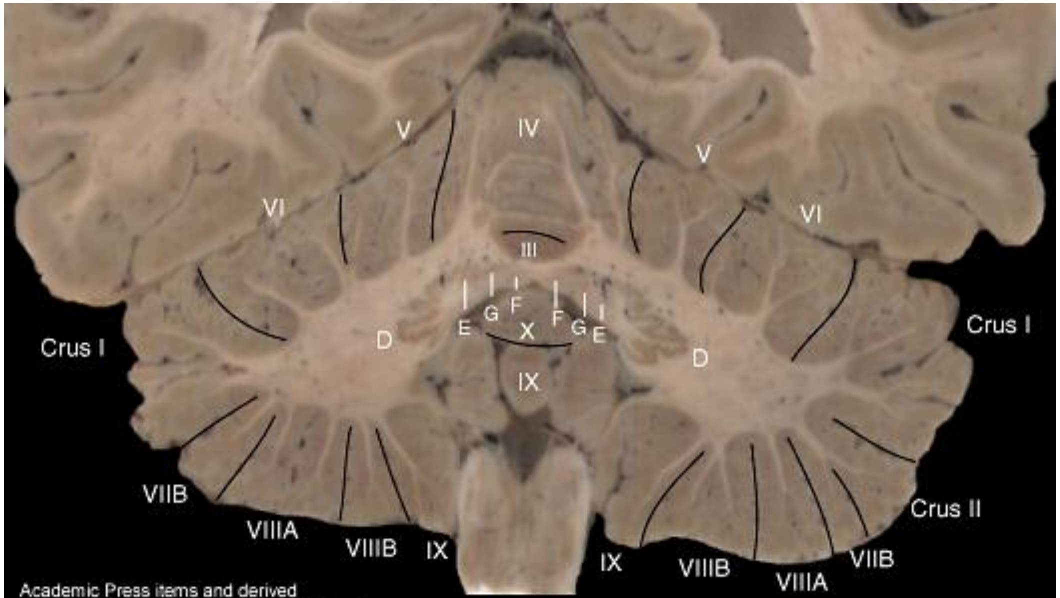
VIIIA
X = -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60



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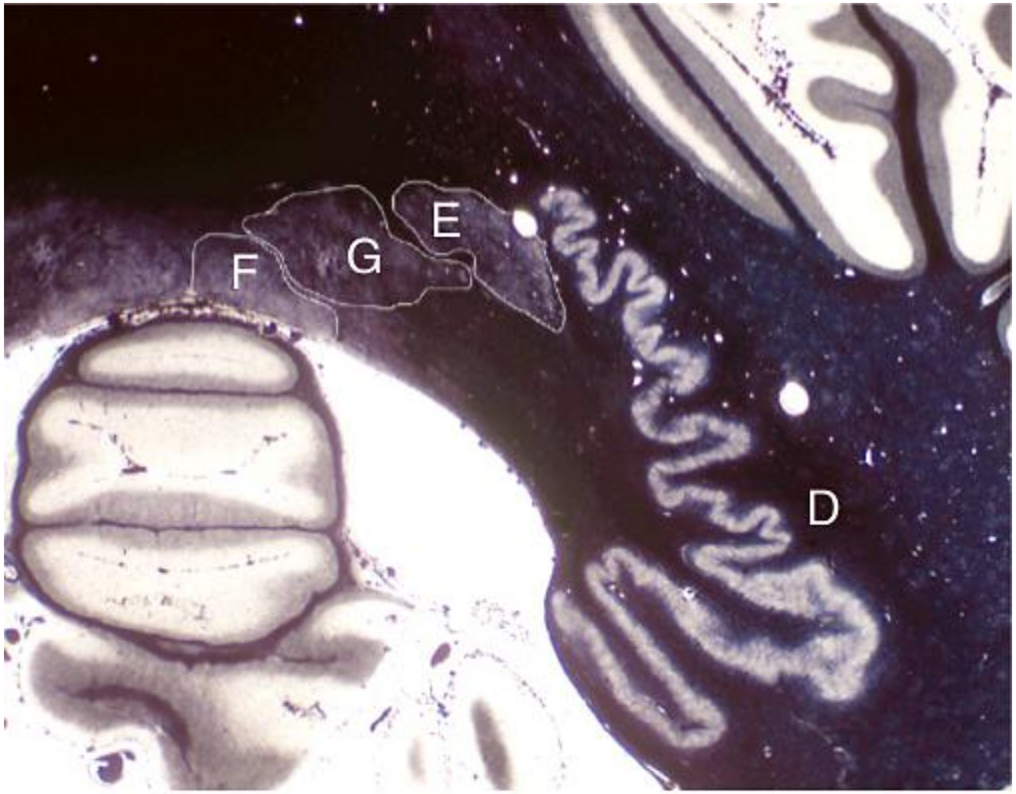
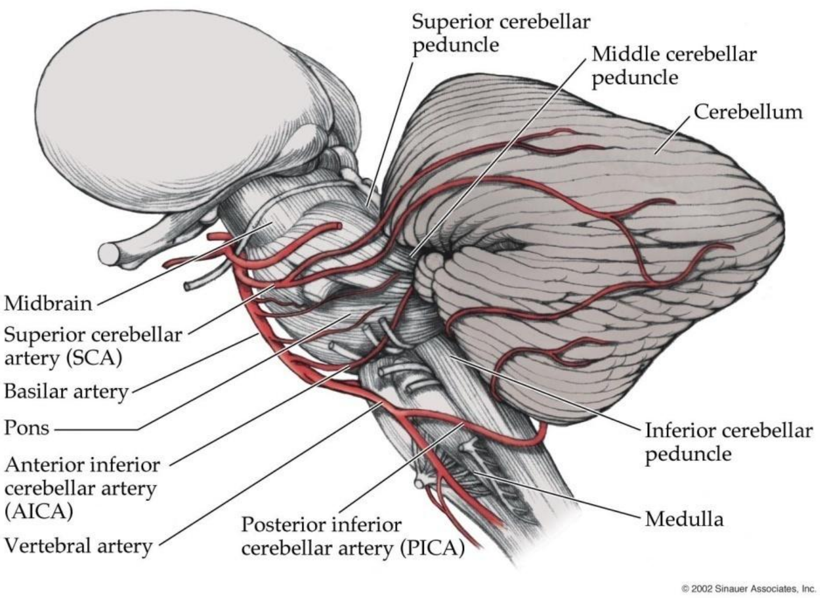
Crus II

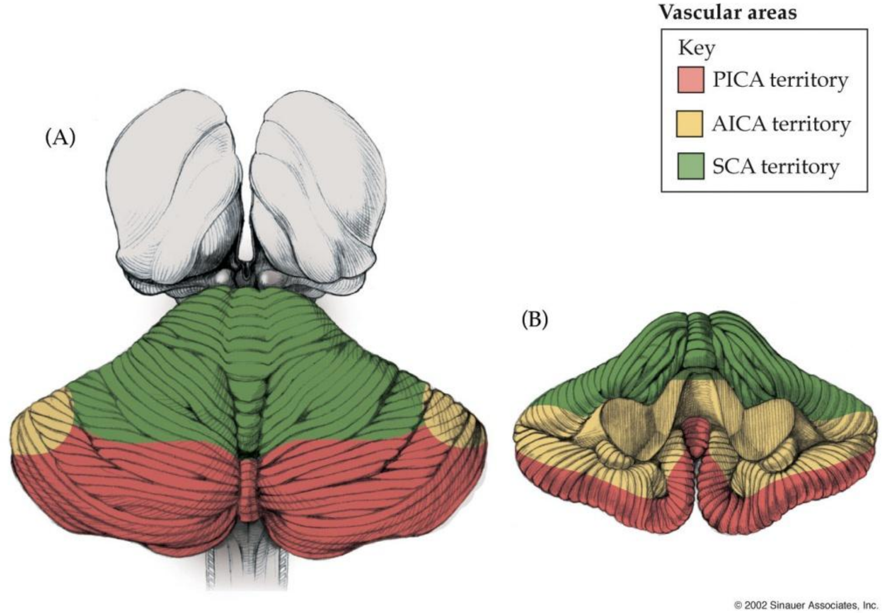

E
G
F
D

The Cerebellum – Functional Divisions

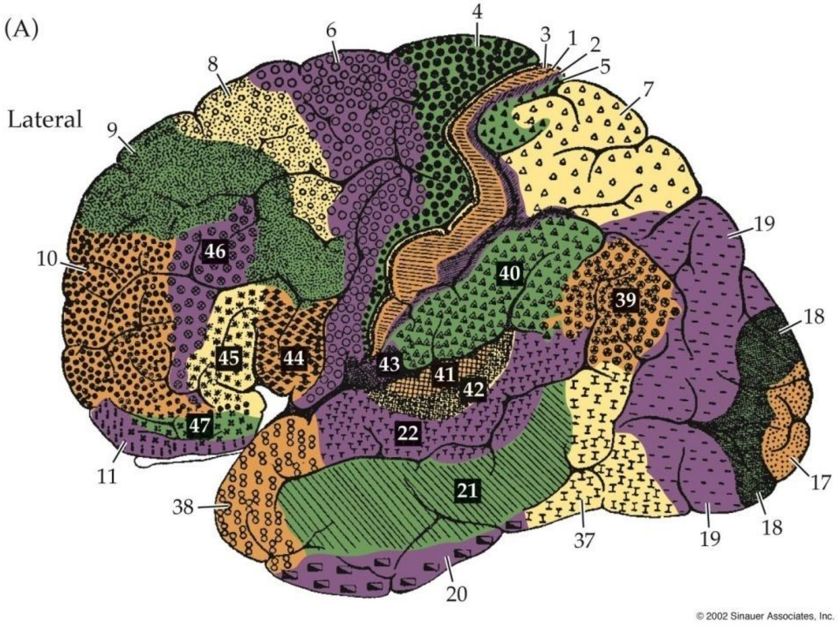
- Vestibulocerebellum – involved in making postural adjustments to vestibular stimulation
- Spinocerebellum – responsible for maintaining muscle tone, for coordinating the muscles involved in balance, for changes in posture, and for adapting motor programs for varying conditions, including walking and running
- Cerebrocerebellum – plays a role in learning new motor skills and in modulating non-motor, cognitive, and affective processing

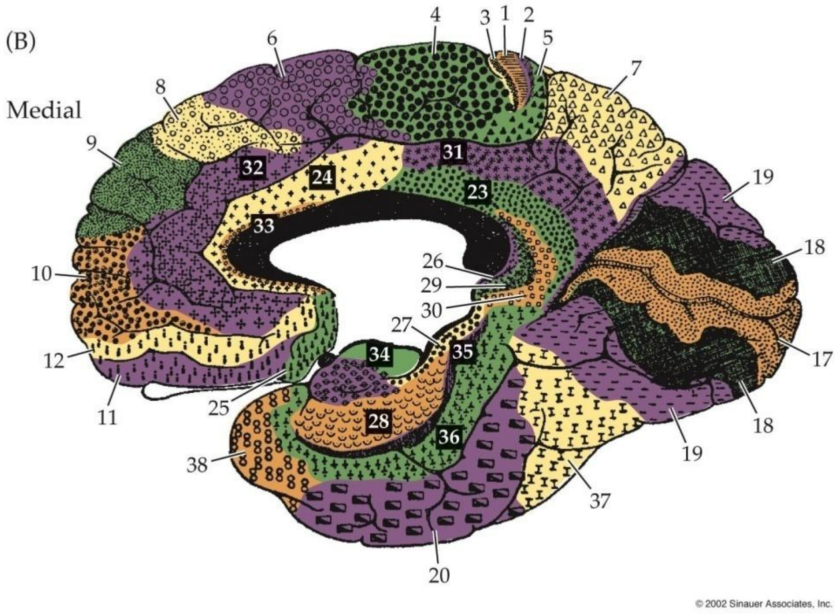
Vascular System

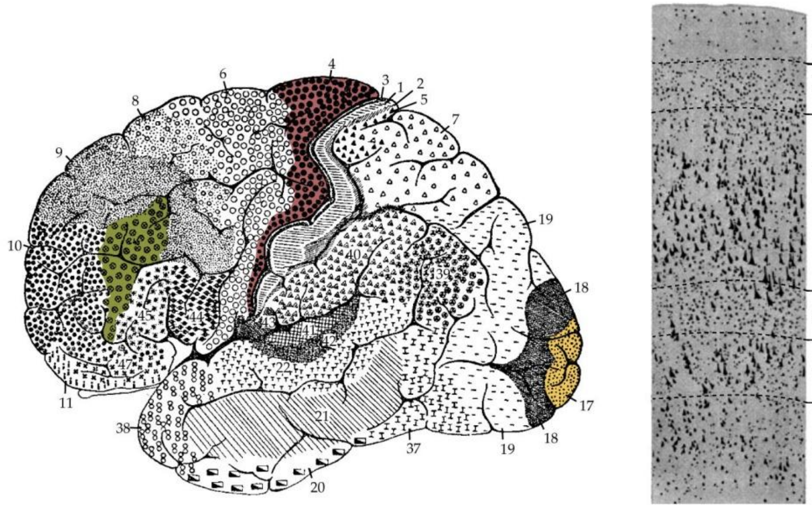




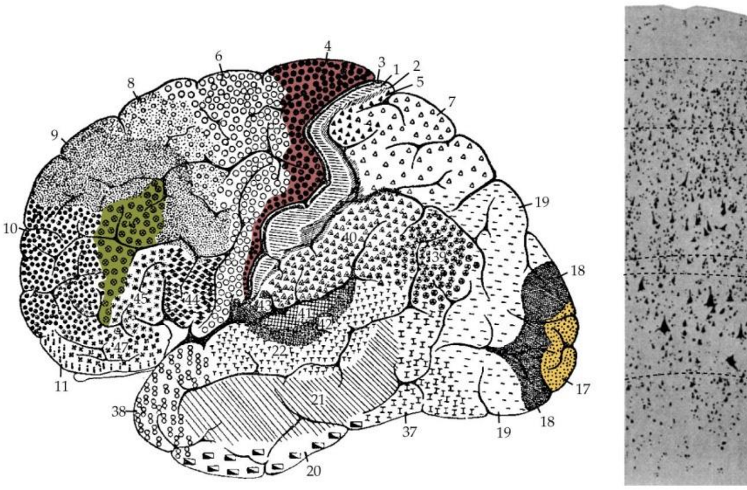
Neocortex and Cerebellar Infrastructure



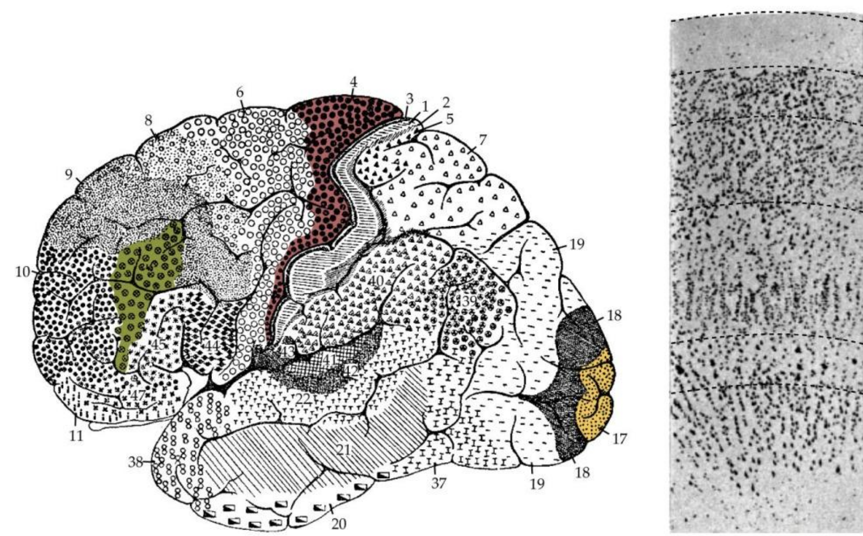




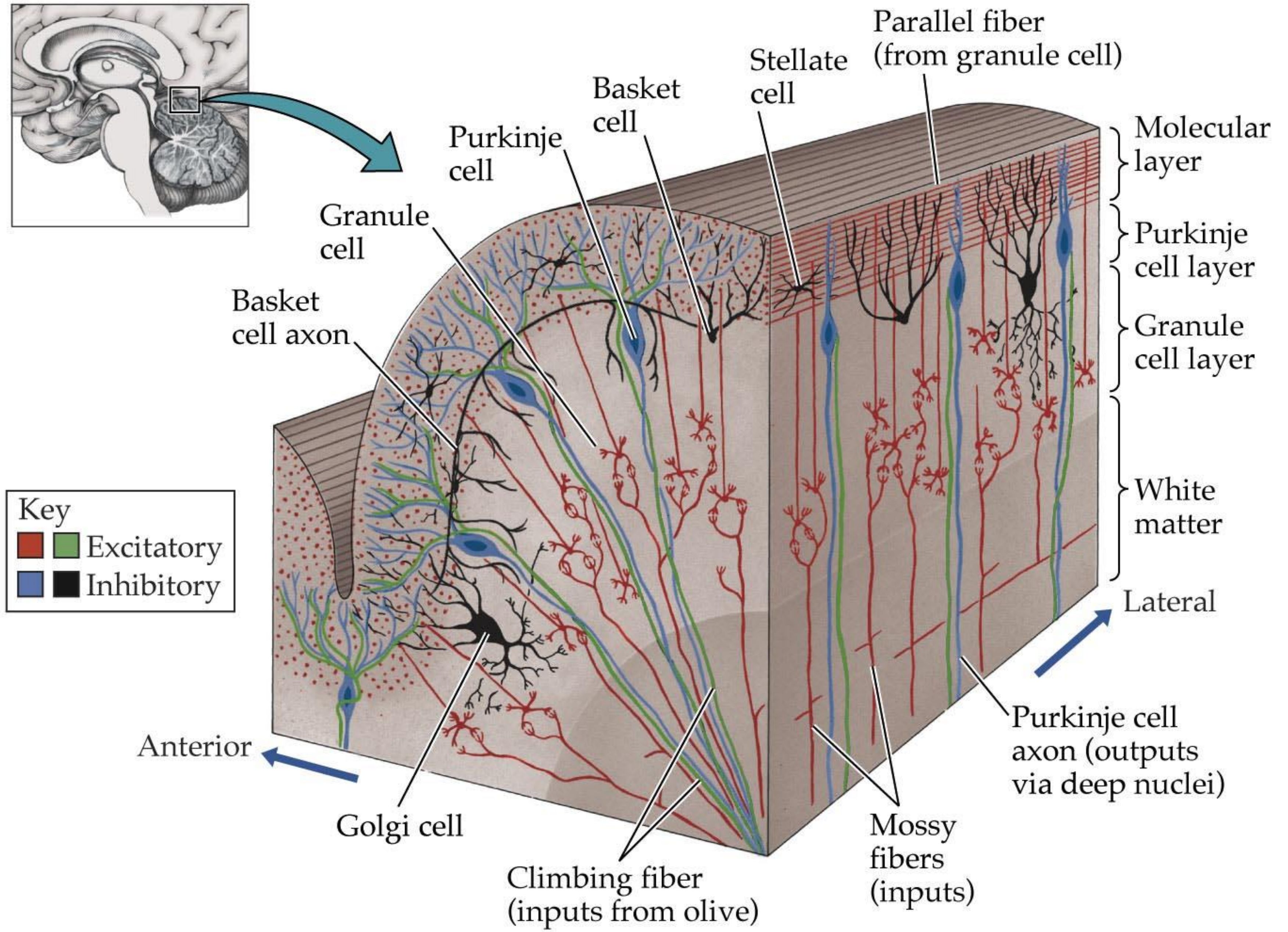
(A) Prefrontal association cortex

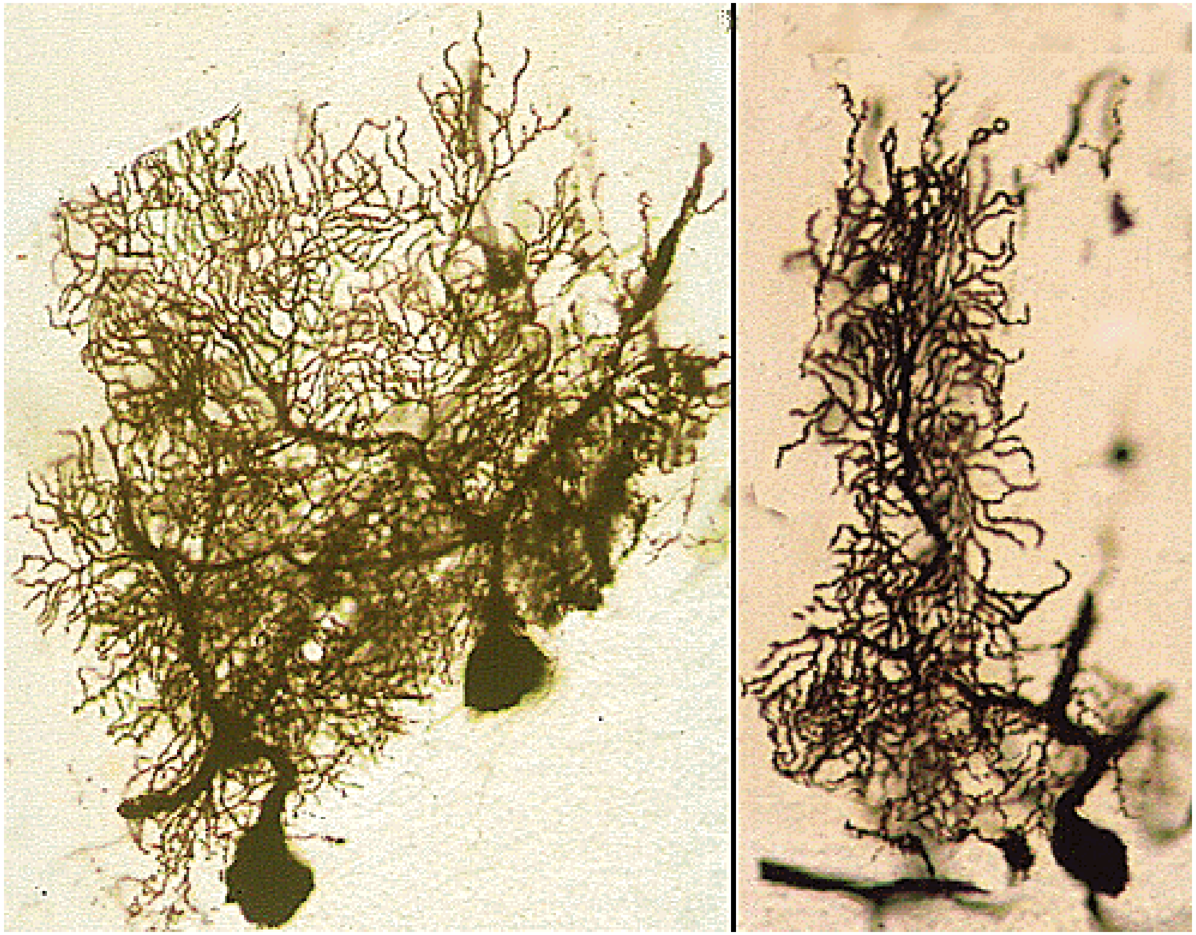


(B) Primary motor cortex (area 4)



(C) Primary visual cortex (area 17)


Parallel fiber
(from granule cell)
Stellate
cell
Basket
cell
Purkinje
cell
Granule
cell
Basket
cell axon
Molecular
layer
Purkinje
cell layer
Granule
cell layer
White
matter
Key
Excitatory
Inhibitory
Lateral
Anterior
Golgi cell
Climbing fiber
(inputs from olive)
Mossy
fibers
(inputs)
Purkinje cell
axon (outputs
via deep nuclei)



Purkinje Cells, Unknown Source

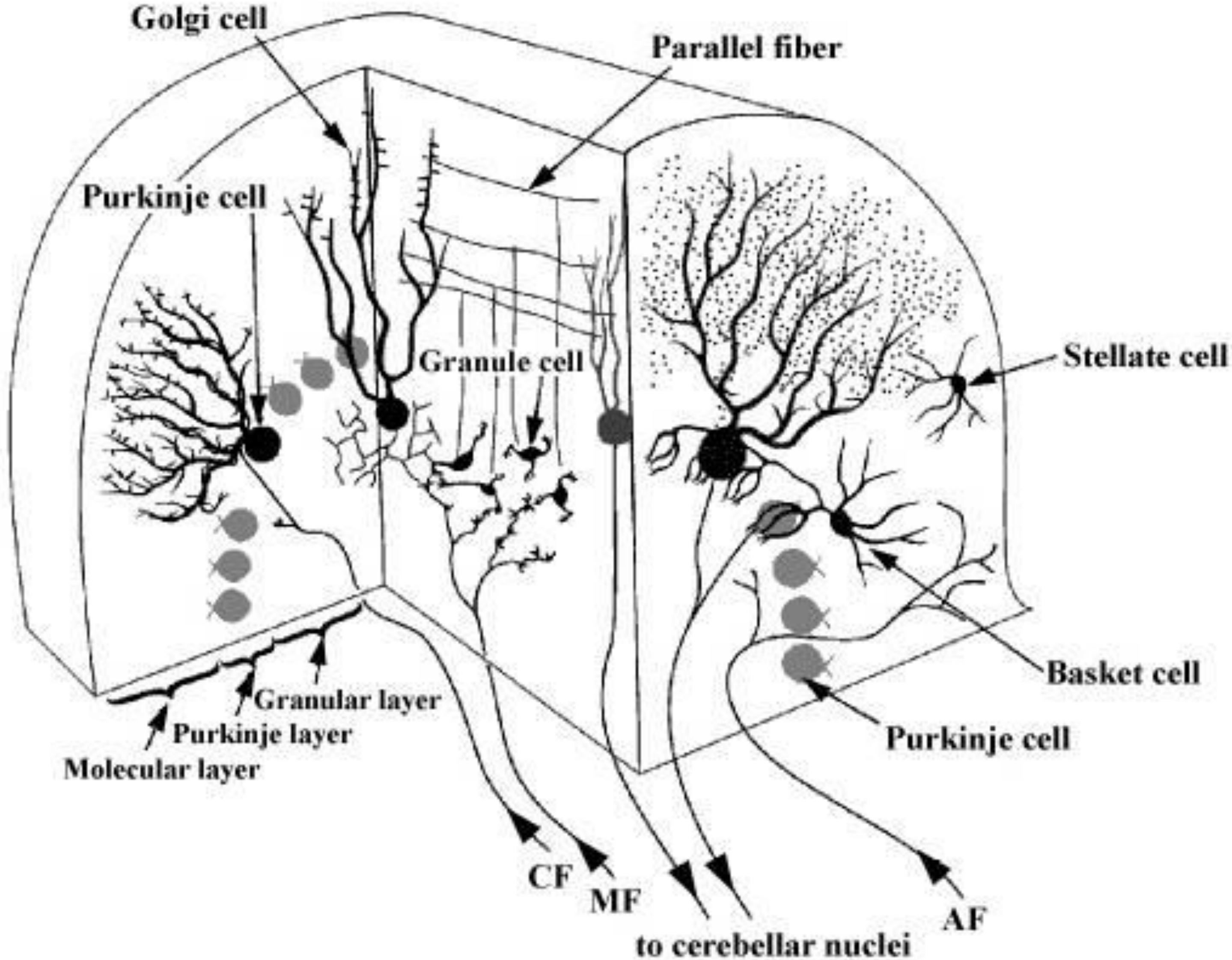


Figure 4. Cross secton of cerebellar cortex. Abbreviations: AF, aminergic fibers; CF, climbing fibers; MF, mossy fibers. Figure adapted from Mendoza and Foundas (2008), by permission from Springer.

What Does The Cerebellum Do?

- The cerebellum regulates neural signals in other parts of the brain
- The cerebellum accomplishes this through “loops” of interaction
- Copying the content of cortical working memory
- This allows the cerebellum to generate models of what the brain wants to do so that behavior becomes efficient

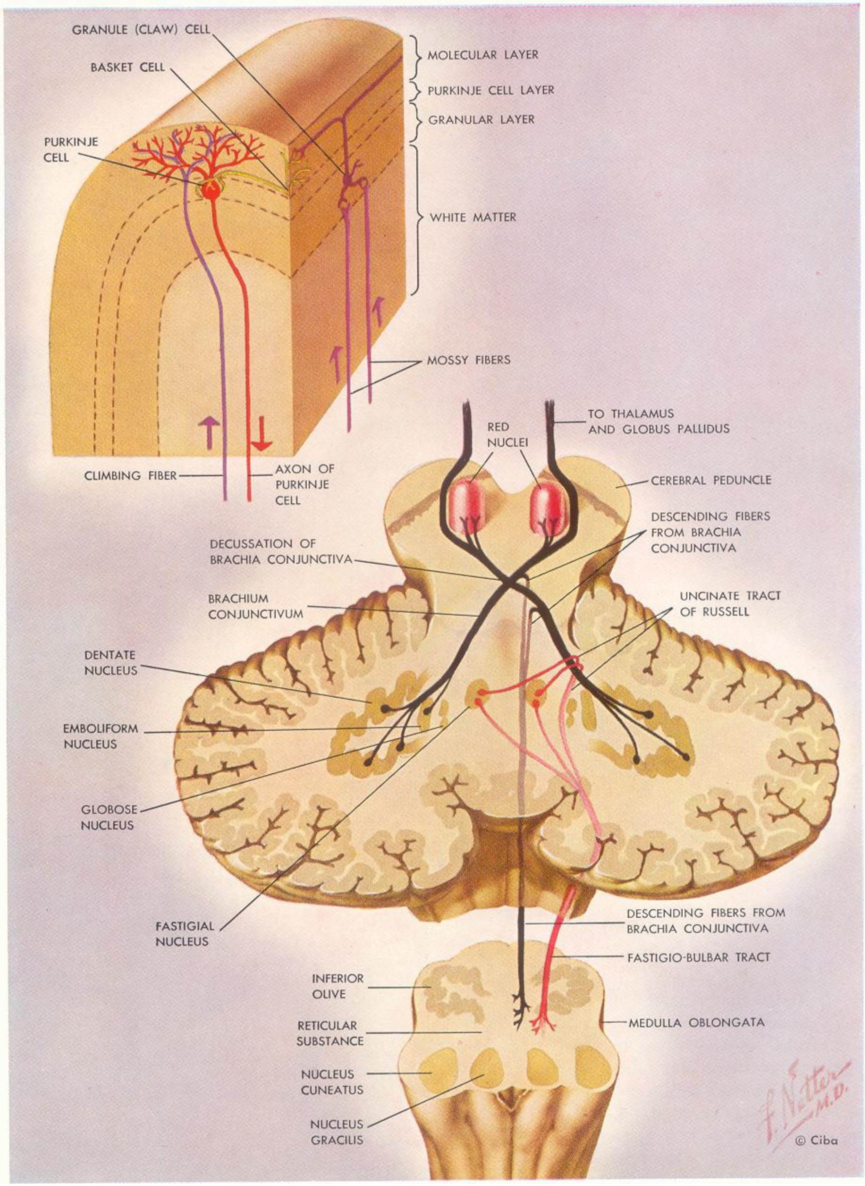
Cerebral Cortex

Thalamus

Pontine Nuclei

Red Nucleus

Cerebellar cortex/Dentate Nucleus



Cerebro-cerebellar-thalamic connections

- The circuits that connect the neocortex to the cerebellum are highly segregated (as are the circuits connecting the cortex and BG)
- The organization of mossy fiber inputs remain segregated in the granular layer
- Projections to/from the deep cerebellar nuclei are also highly specific and segregated

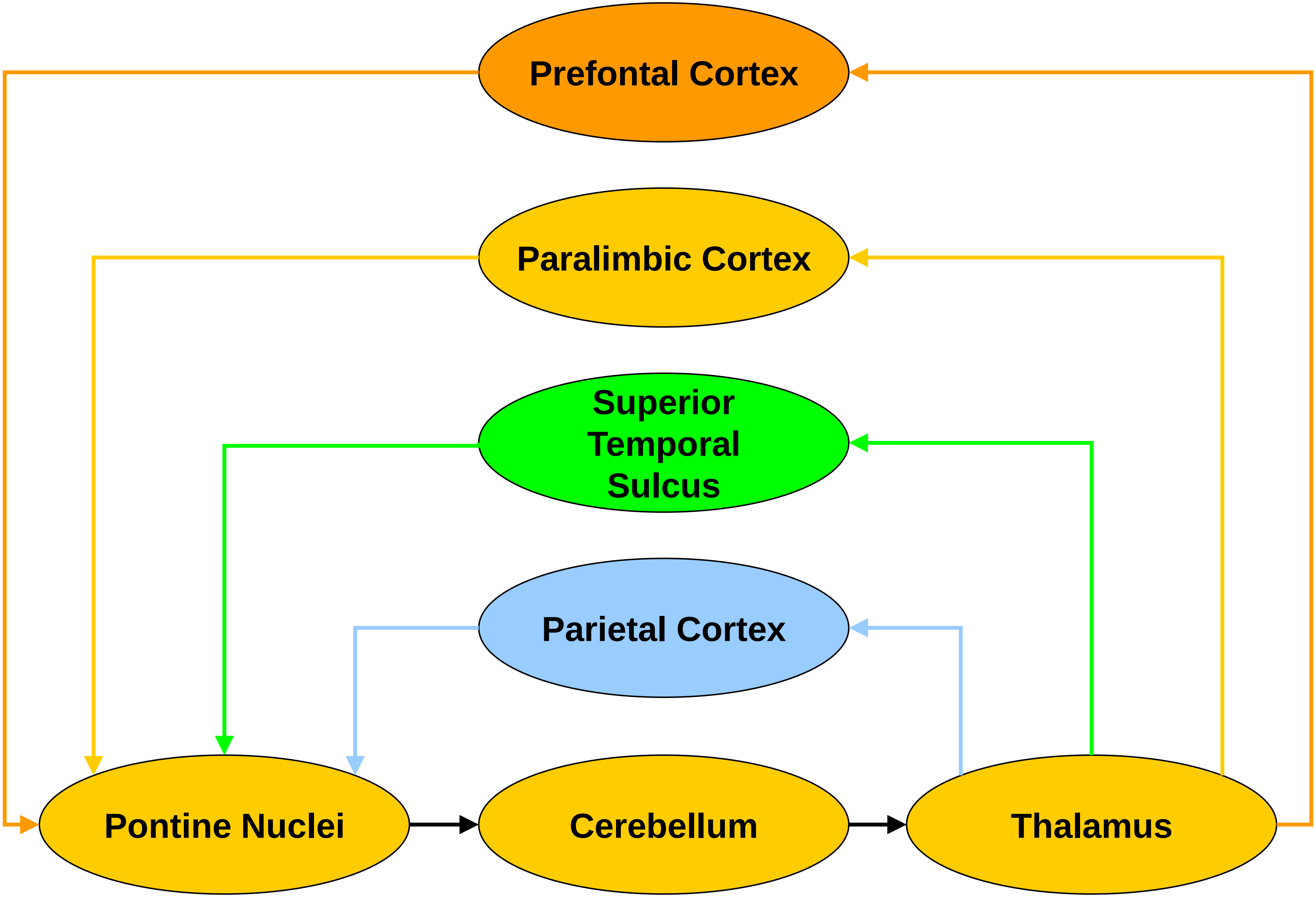
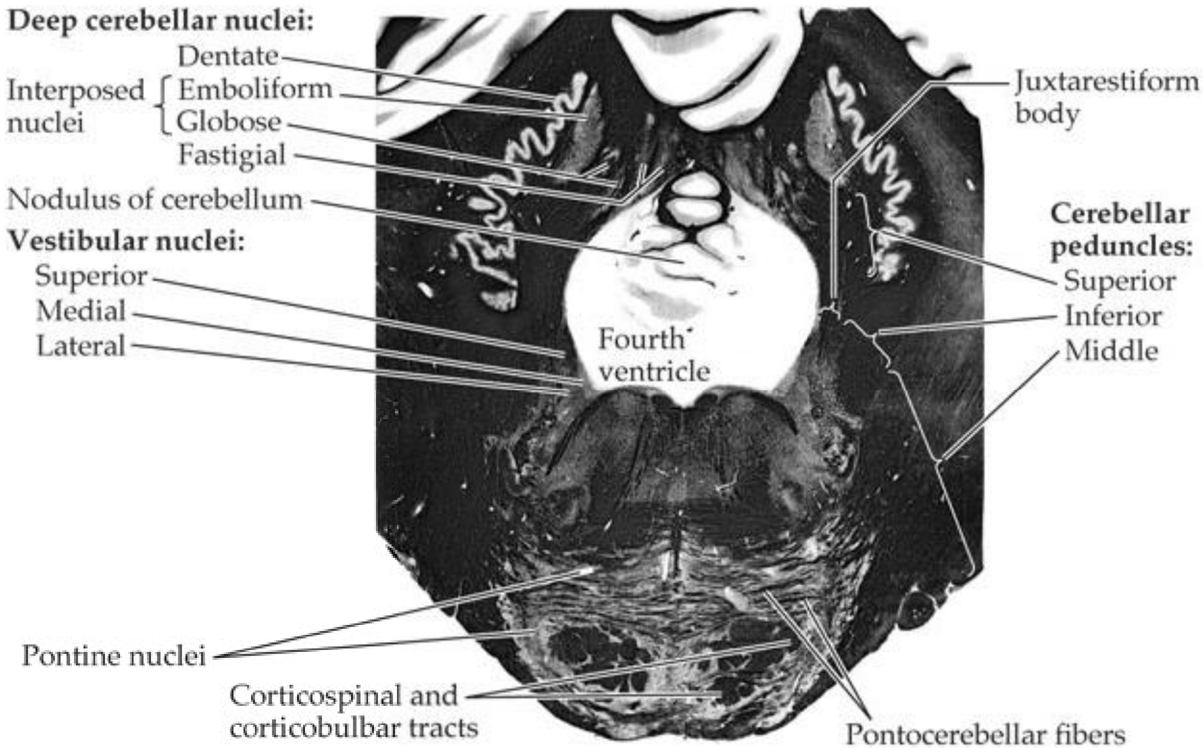
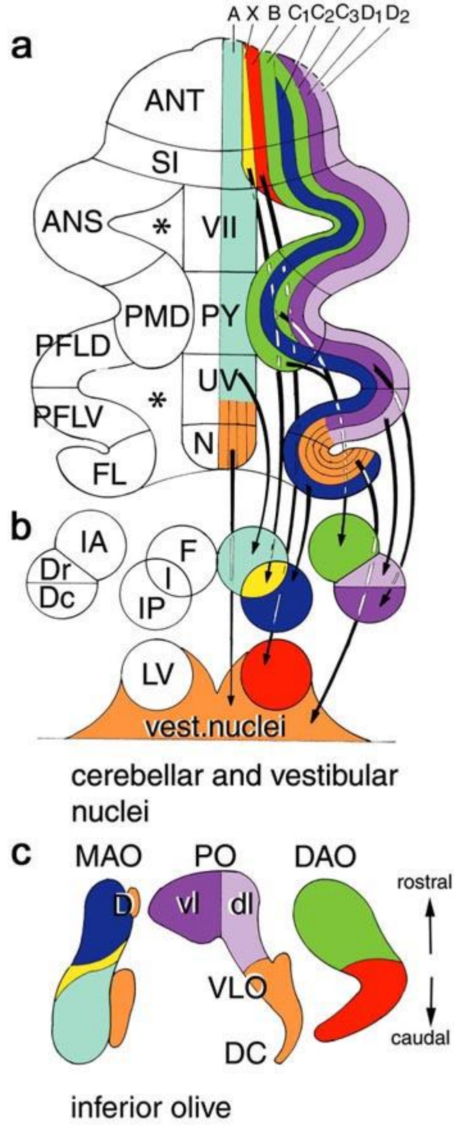


Fig. 5: Connections between the cerebellum and the neocortex Koziol, et al, 2010



(From Martin JH. 1996. *Neuroanatomy: Text and Atlas*, 2nd Ed. McGraw-Hill, New York.)


a
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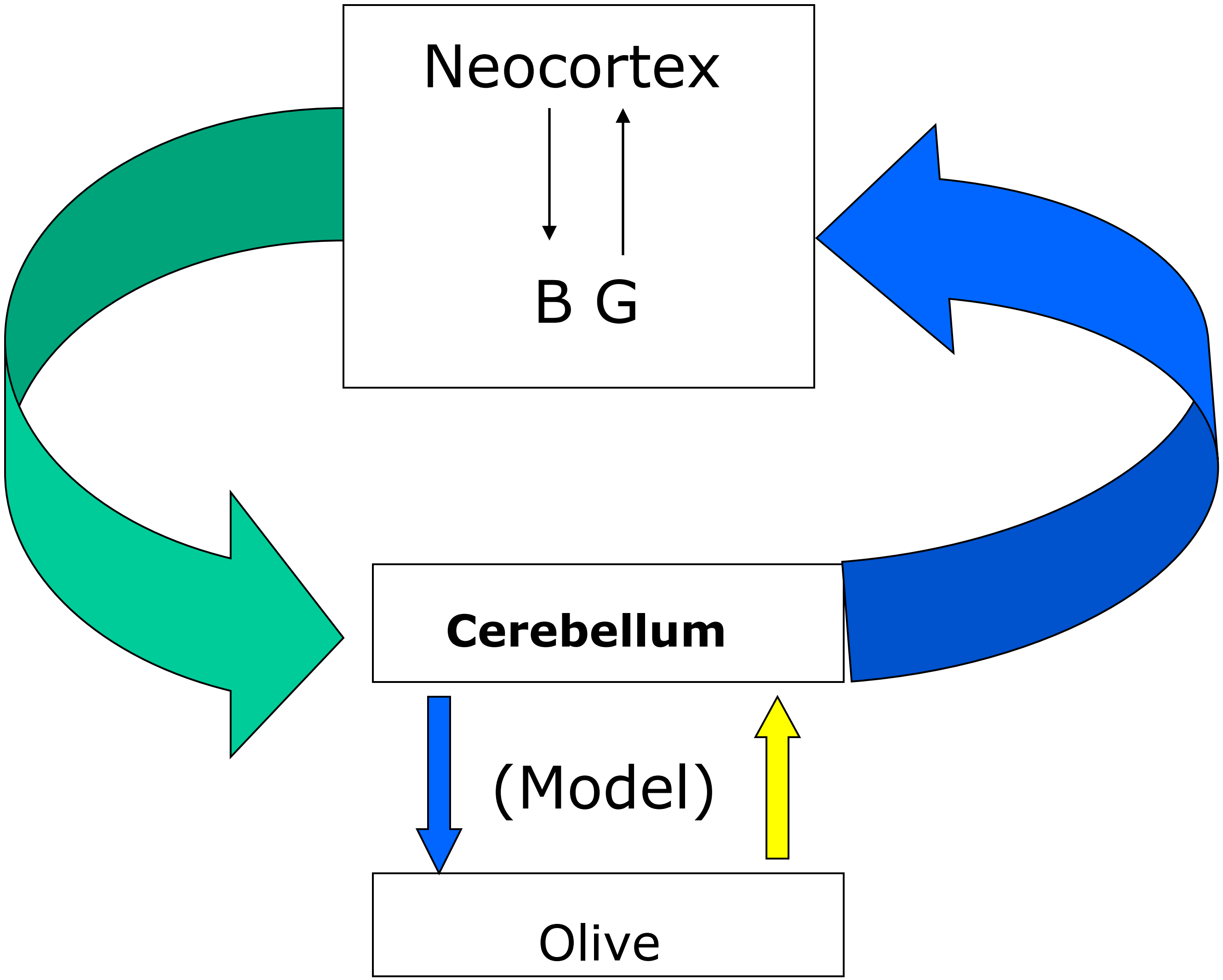
DC
rostral
caudal
inferior olive



Koziol, 2007

Functions of the Cerebellum

- In the main, the cerebellum’s function is to refine the information it receives from the cortex
- It projects this modified or “corrected” neural signal (from the deep cerebellar nuclei) back to the primary point of origin of the circuit
- This “neural signal”represents the most efficient representation of the “behavior” in question
- This representation is then retained within the neocortex

- While the BG, through interactions with the neocortex, decide “when” to act by allowing the thalamus to release behavior, the cerebellum “teaches” the brain “how” to act within its specific circumstances.
- It performs this role through refining the rate, rhythm, and force of behavior
- It adjusts the amplitude of responses so that behavior is of appropriate “quality”for the given situation

The Organization of the Cerebellum and Cognition

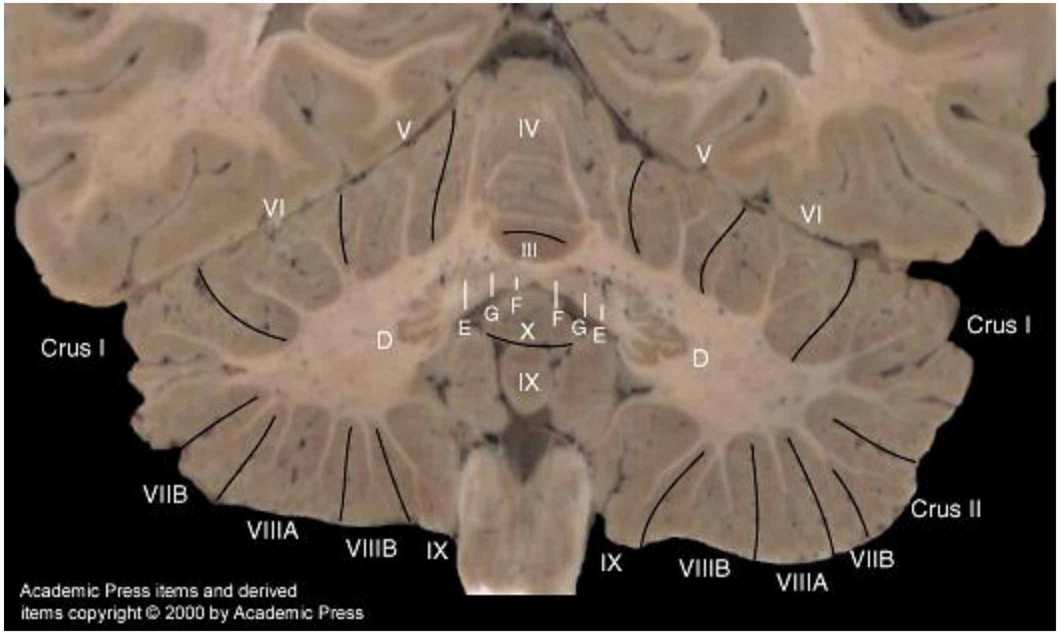
- The associative and paralimbic cerebro-cerebellar circuits are the neuroanatomic underpinning of the cerebellar contribution to cognition, emotion, and autonomic functioning.
- There are discretely organized anatomic subunits that subserve functional subsystems within the circuitry.

- Therefore, from an anatomic perspective, the cerebellum is an integral module in the distributed neural circuitry that subserves sensorimotor, cognitive, autonomic, and affective processing.

- The cerebellar cortex is anatomically homogeneous
- Different regions of the cerebellum modulate different functional domains.
- There is a topography of function within the cerebellum that has an anterior-posterior and a medial-lateral gradient.

Anterior-Posterior Gradient

- Sensorimotor functions are primarily mapped in anterior regions.
- This is primarily within the anterior lobe in lobules I-V with some representation in VIII and IX.
- Cognitive and affective functions are represented in the posterior hemispheres, in the vermal and hemispheric components of VI and VII.



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Crus I
Crus II
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VIIIA
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VIIIB
VIIIA
VIIB

Medial-Lateral Gradient

- The vermis and fastigial nucleus are involved in the mediation of autonomic and affective regulation.
- The lateral cerebellar hemispheres and dentate nucleus are involved in the regulation of executive, visuospatial, linguistic, and learning/memory functions.
- This anatomy predicts that regional involvement should lead to focal deficits.

Additional Organizational Features

- The cerebellum is topographically organized
- Within the cerebellum, functions are represented asymmetrically
- Information is processed within specific microzones or microcomplexes – discretely organized anatomic subunits/subsystems

From Movement to Thought

- For the brain, movement and thought are equivalent
- Once a movement or thought is “coded” within the neural circuitry of the brain, the brain will manipulate the input in the same way
- For the cerebellum, movement and thought are identical control objects

The Construction of Cerebellar Models

- The uniformity of the cerebellum’s infrastructure implies uniformity in the processing of information, regardless of its source of origin within the cerebral cortex
- How does the cerebellum perform its operations within the context of the circuitry that has been described?

- For the cerebellum to exert its influence, it needs to “know” what the neocortex has in mind and what it has decided to do
- Cortical cognitive control can be referred to as “working memory.”
- Working memory is modulated by interactions between the prefrontal cortex, posterior cortices, and the basal ganglia.

- Cerebro-cerebellar circuitry allows the cerebellum to “copy” the content of cortical working memory, or plans and intentions
- Sensory feedback is cortically based and it functions slowly
- For movement to be rapid, coordinated, and smoothly controlled, it cannot depend on sensory feedback alone.

- When the cerebellum copies the content of cortical working memory, it develops a “model” that contains all of the necessary motor, sensory (sensorimotor), cognitive, and affective information to perform the behavior in question.
- This is termed a Forward Model because the model is based upon prediction or anticipation, which by-passes direct cortical sensory feedback

- This short-cut, anticipatory control model comprises the most efficient neuronal pathways through which the repeated bodily movements can be executed most quickly and precisely
- In essence, an internal model of what the brain thinks it will do is based upon its storage of the multiple episodes during which it has already done so.

- As the movements are repeatedly executed and as anticipatory, predicted “feedback” is received from each instance, the cerebellum has more information and becomes increasingly accurate in its predictive capacities

- The cerebellum uses these increasingly accurate predictions to inform successive executions of the behavior.
- This allows behavioral execution to become smoother and faster and allows the brain to store the most efficient representation of that behavior.
- This becomes the Inverse Model

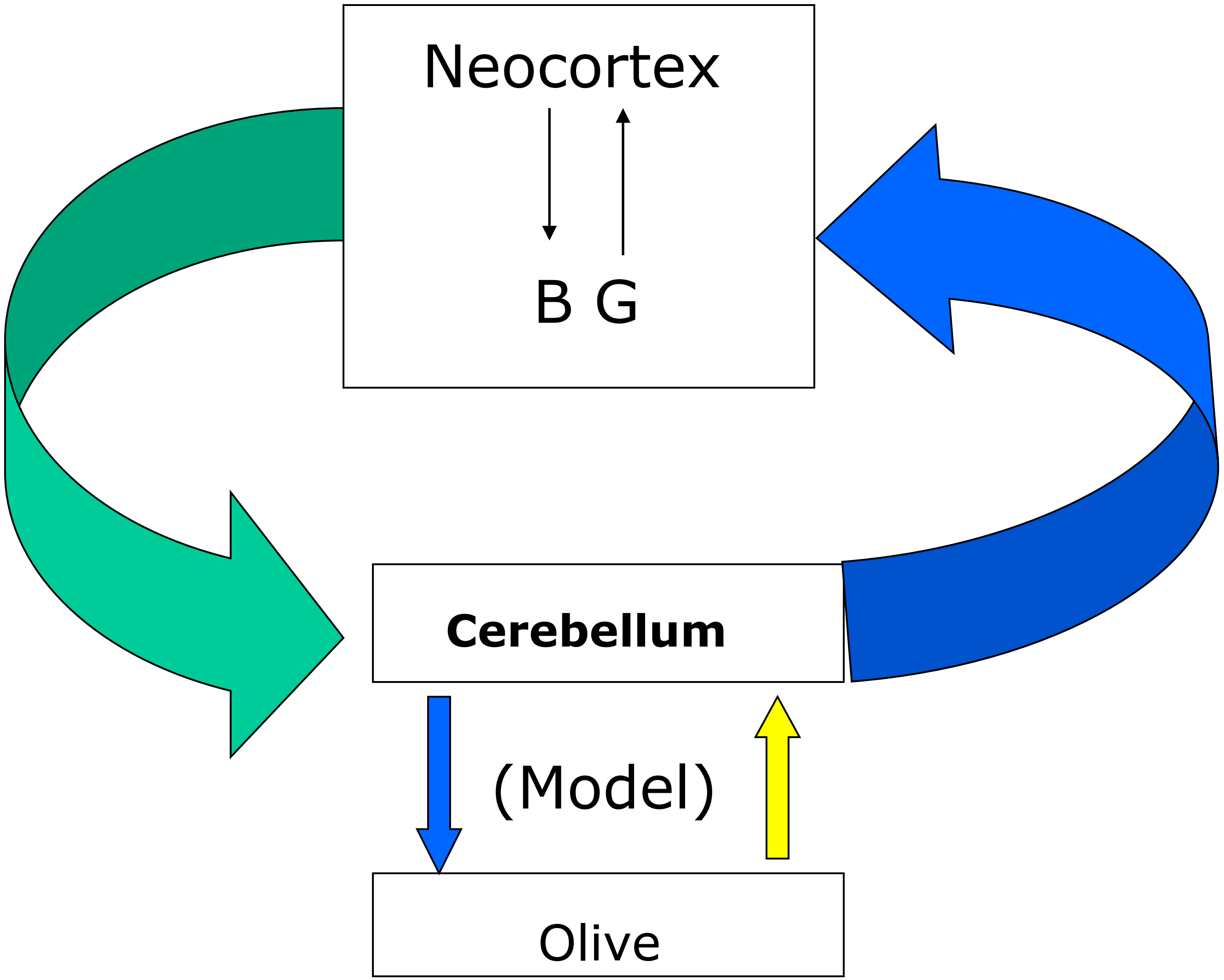
Inverse Models

- Cerebellar models allow behavior to become independent of cortical control/cortical working memory input and to rely less and less on sensory feedback from the moving limbs for accuracy.
- With successful repetition, behaviors governed consciously by cerebellar feedforward models become automated

- As automaticity develops, it reflects the development of cerebellar inverse models
- Inverse models permit rapid, coordinated, highly skilled movement (and thought) to occur at an unconscious level, outside of the awareness of cortically based working memory

The Cerebellum: Two Fundamental Principles

- The cerebellum plays a critical in the initial acquisition and automation of new behaviors
- The cerebellum plays a critical role in adapting these learned, automated behaviors across various environmental settings
- These principles and dynamics appear to be at the heart of the UCT



Koziol, 2007

Examples

- Neurodevelopment – “learning” to walk
- Playing sports – basketball, as the game unfolds in “real time”
- Football – the well prepared quarterback
- Assembly work/moving furniture
- Cognition – problem-solving
- Motor and cognitive procedural learning

More Examples

- First responder professions
- US Airways flight landing in the Hudson River
- Simple, daily routine tasks
- Approaches towards interpreting NP test data
- The surgeon, etc., etc., etc…

Pathology: The Cerebellar Motor Syndrome

- Dysmetria of the extremities – movements become erratic in amplitude and size; overshooting/undershooting
- Gait ataxia
- Eye movement abnormalities
- Speech
- Dysphagia

Cerebellum as a Modulator

- Possessing a normal cerebellum and disrupting function
- Never possessing much of a functional cerebellum
- Possessing a cerebellum with focal abnormality.
- Cerebellar pathologies can look different at various ages/stages of neurodevelopment

The Dual Tiered Model

- All domains of behavior can be conceptualized within a dual tiered model of brain function
- Neuroanatomic data support this conclusion in each and every domain that has been studied
- Without dual tiered systems, the vertebrate, and human, cannot function autonomously!
- If you cannot "automate," you are as good as "dead."
- All cognitive/behavioral pathology can be explained by a dual tiered model

A Simple Practical Framework

- Cortex – devises strategies and develops programs
- Basal Ganglia – selects and mobilizes procedures based upon context/links voluntary with automatic behavior (intention)
- Cerebellum – adapts cognition and behavior to the situation (rate, rhythm/timing,and force/amplification)
- This has implications for neuropsychological testing