



**PETER PAZMANY
CATHOLIC UNIVERSITY**



**SEMMELWEIS
UNIVERSITY**



Development of Complex Curricula for Molecular Bionics and Infobionics Programs within a consortial* framework**

Consortium leader

PETER PAZMANY CATHOLIC UNIVERSITY

Consortium members

SEMMELWEIS UNIVERSITY, DIALOG CAMPUS PUBLISHER

The Project has been realised with the support of the European Union and has been co-financed by the European Social Fund ***

****Molekuláris bionika és Infobionika Szakok tananyagának komplex fejlesztése konzorciumi keretben**

*****A projekt az Európai Unió támogatásával, az Európai Szociális Alap társfinanszírozásával valósul meg.**



Nemzeti Fejlesztési Ügynökség

ÚMFT infóvonal: 06 40 638 638

nfu@nfu.gov.hu • www.nfu.hu

TÁMOP – 4.1.2-08/2/A/KMR-2009-0006



BEVEZETÉS A FUNKCIONÁLIS NEUROBIOLÓGIÁBA

INTRODUCTION TO FUNCTIONAL NEUROBIOLOGY

By Imre Kalló

Contributed by: Tamás Freund, Zsolt Liposits, Zoltán Nusser, László Acsády, Szabolcs Káli, József Haller, Zsófia Maglóczky, Nórbert Hájos, Emilia Madarász, György Karmos, Miklós Palkovits, Anita Kamondi, Lóránd Eröss, Róbert Gábel, Zoltán Kisvárdai, Zoltán Vidnyánszky

Cerebellum: its structure and neuronal network

Imre Kalló & Miklós Palkovits

Pázmány Péter Catholic University, Faculty of Information Technology

- I. Macroscopic and microscopic structure
- II. Functional characterization of afferent and efferent connections
- III. Cerebellar neuronal network.

Role of the cerebellum in the central organisation of movement

It occupies a determinative site in the hierarchy of movement regulation

Its basic function:

- initiation, coordination, execution, learning of movement
- ongoing control of posture

It is in close relationship with the sensory and motor systems

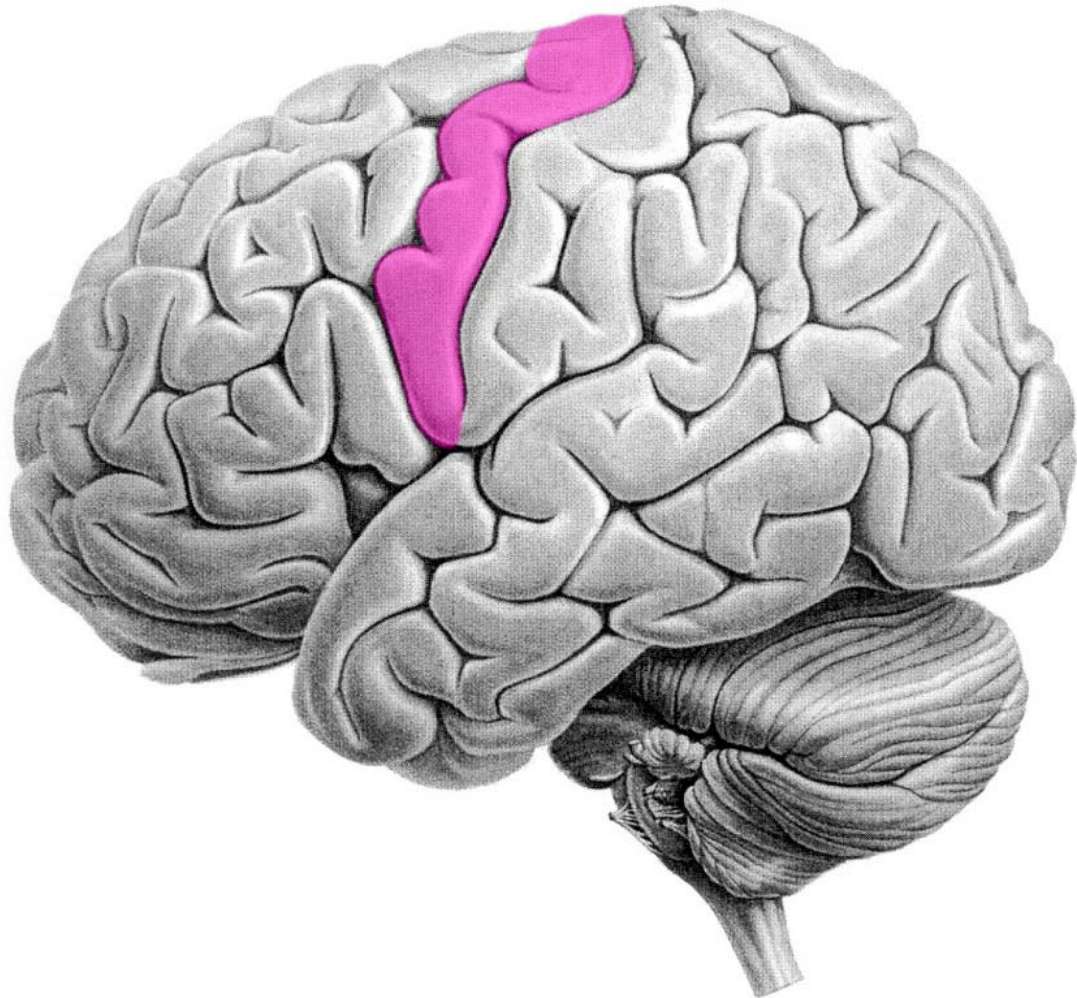
it receives information from

- muscles and joints through the spinal cord
- special neurons of the spinal cord
- motor areas of the cerebral cortex
- neurons of the brainstem (oliva inferior, formatio reticularis)
- vestibular system
- visual- and auditory system
- associative cortical areas

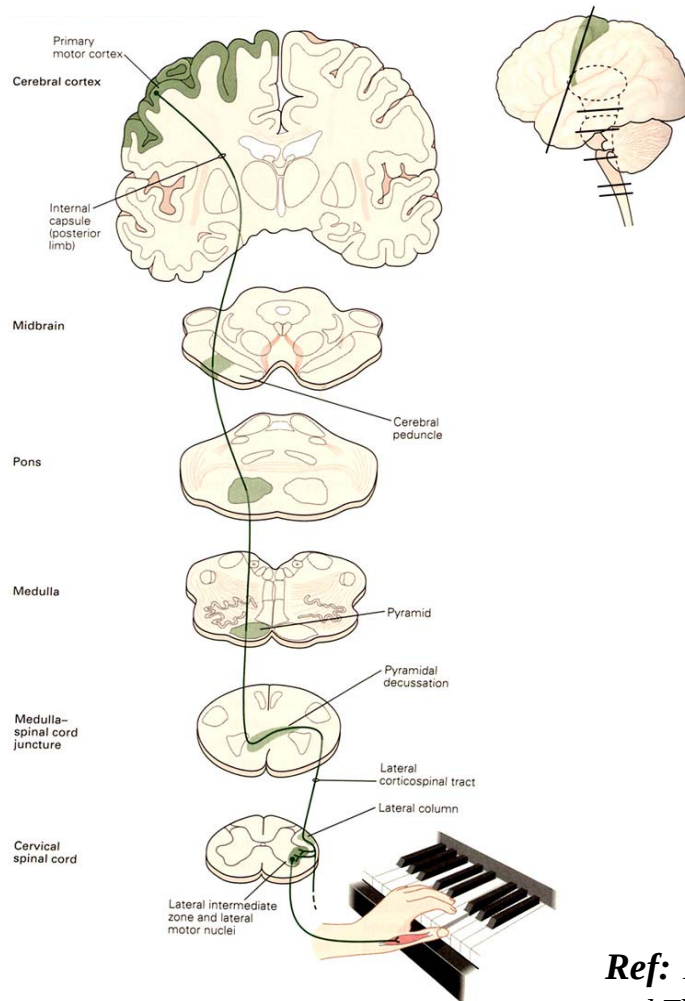
it provides information to

- the ascending and descending motor systems

Primary motor cortex



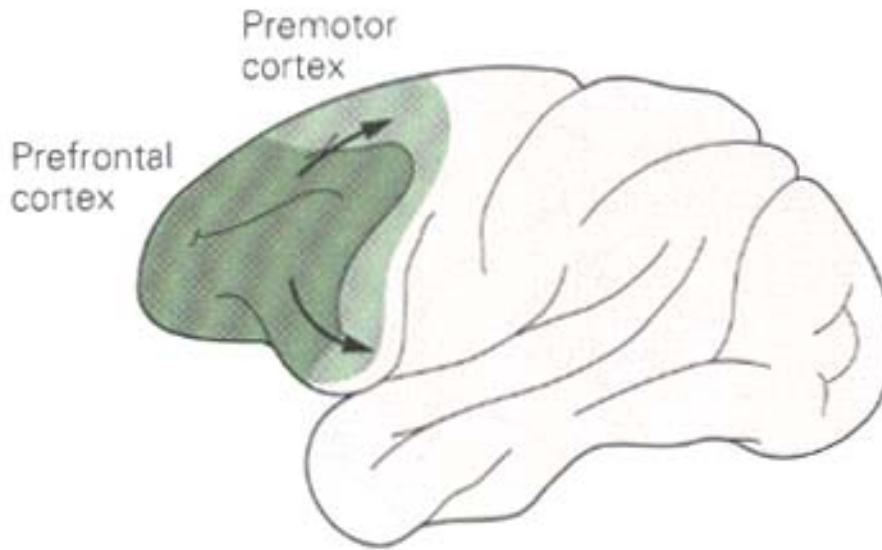
Descending lateral corticospinal pathway



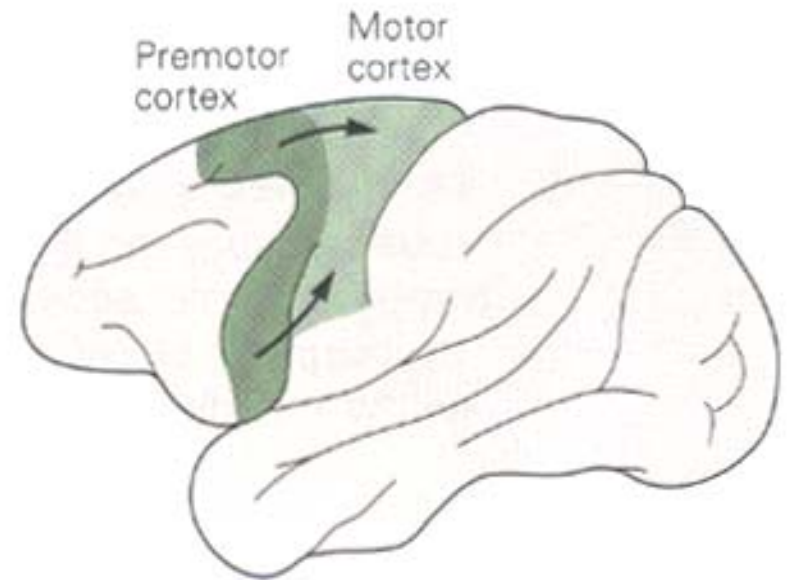
Ref: *Principles of Neural Science, 4th ed.* Edited by Eric R. Kandel, James H. Schwartz, and Thomas M. Jessell. New York, McGraw-Hill Professional Publishing, 2000

Site of motor planning and generation of motor programs

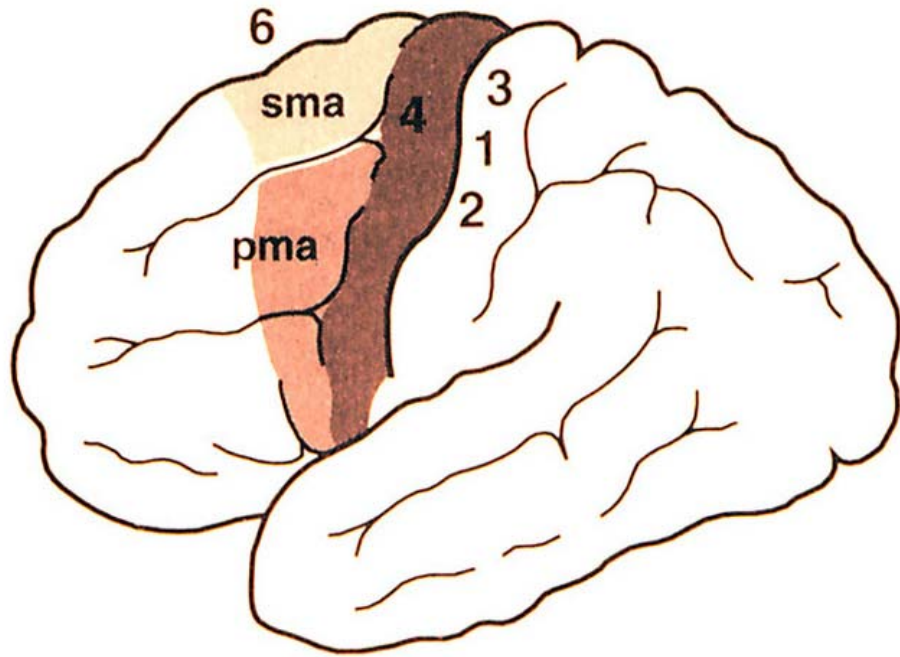
A Motor planning



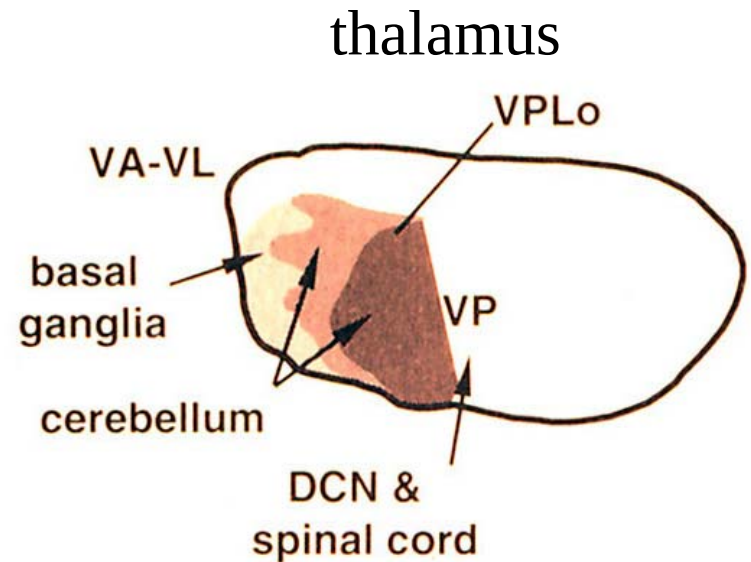
B Motor programs



Ref: *Principles of Neural Science, 4th ed.* Edited by Eric R. Kandel, James H. Schwartz, and Thomas M. Jessell. New York, McGraw-Hill Professional Publishing, 2000



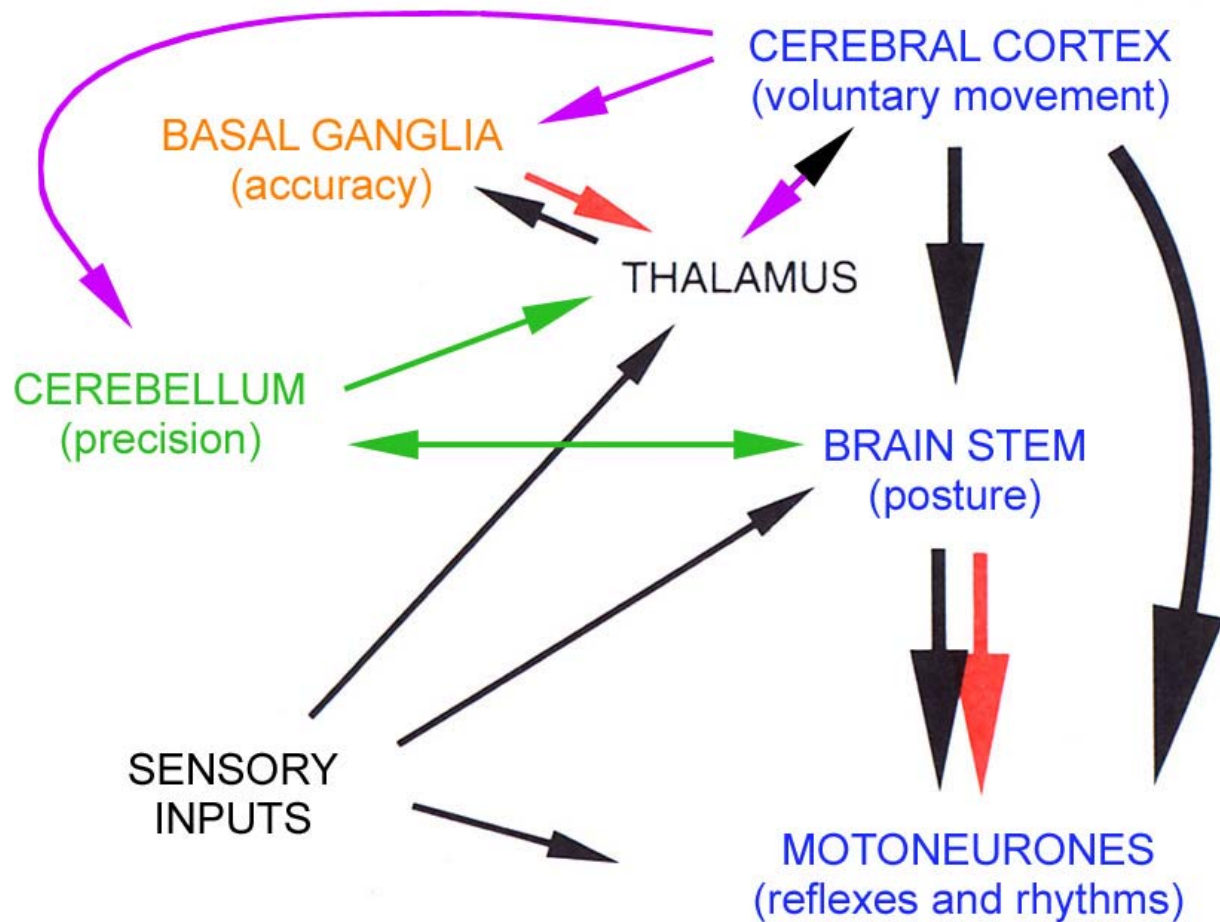
Subdivisions of thalamus with motor functions



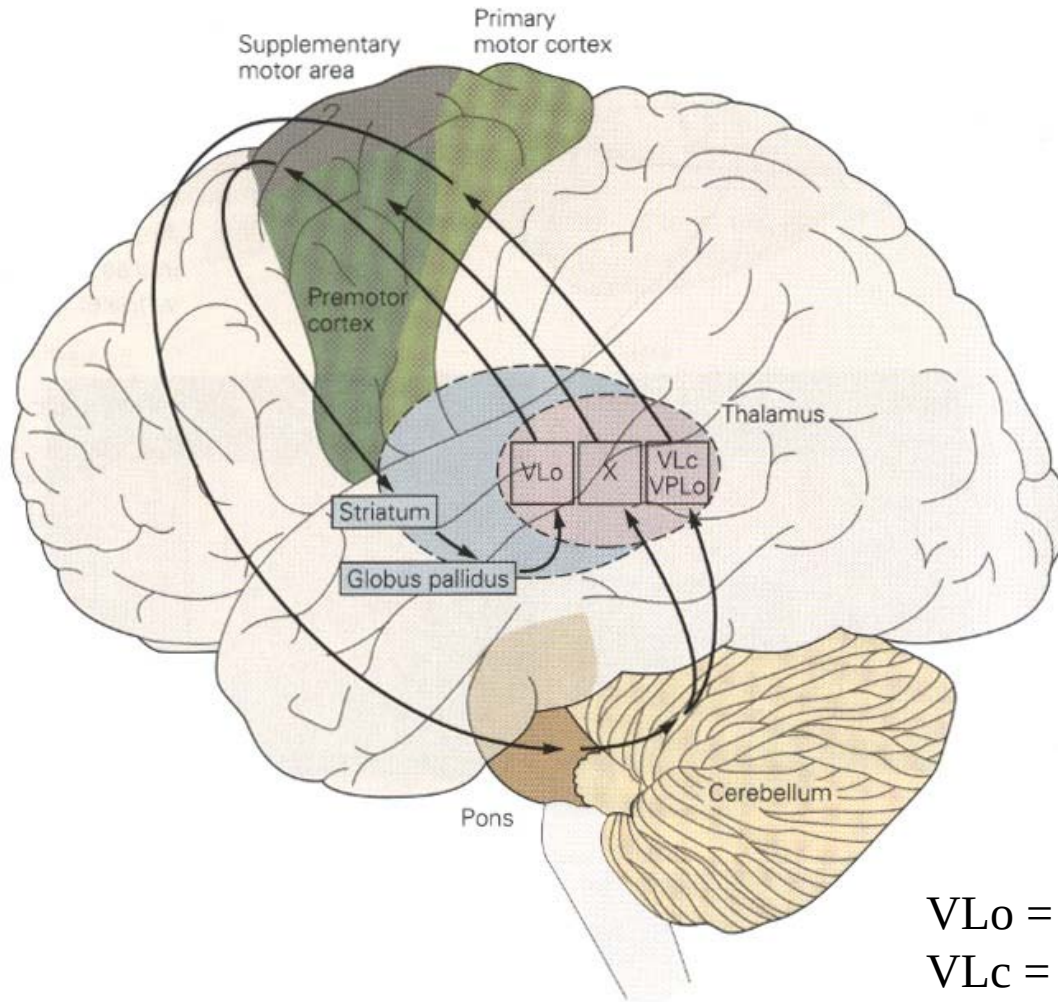
sma = supplementer motor area
pma = premotor area

VA-VL = Ventral anterior and lateral nuclei
VP = Ventral posterior complex
VPLo = Ventral posterolateral nucleus, pars oralis

Basic neuronal connections

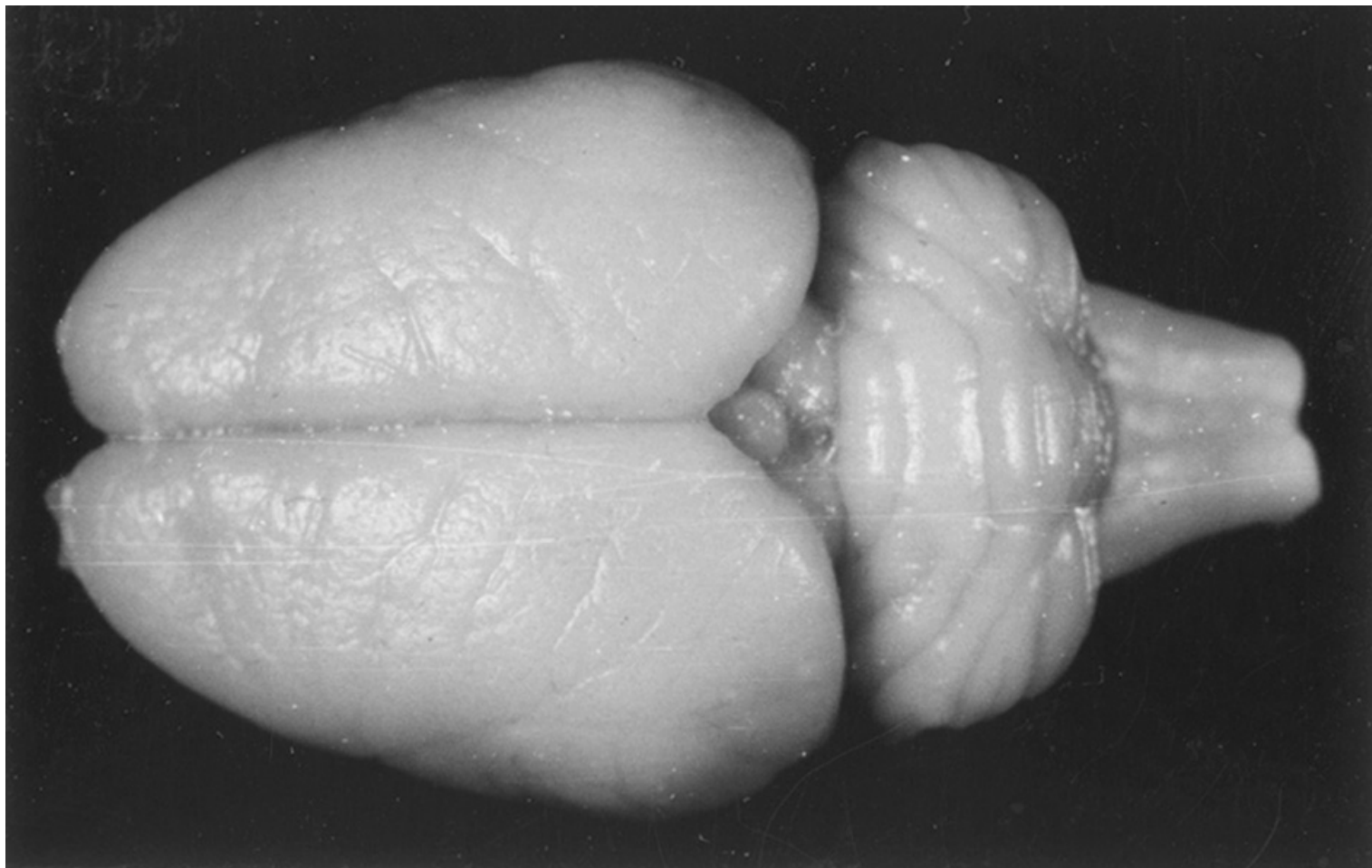


Regulatory circuits

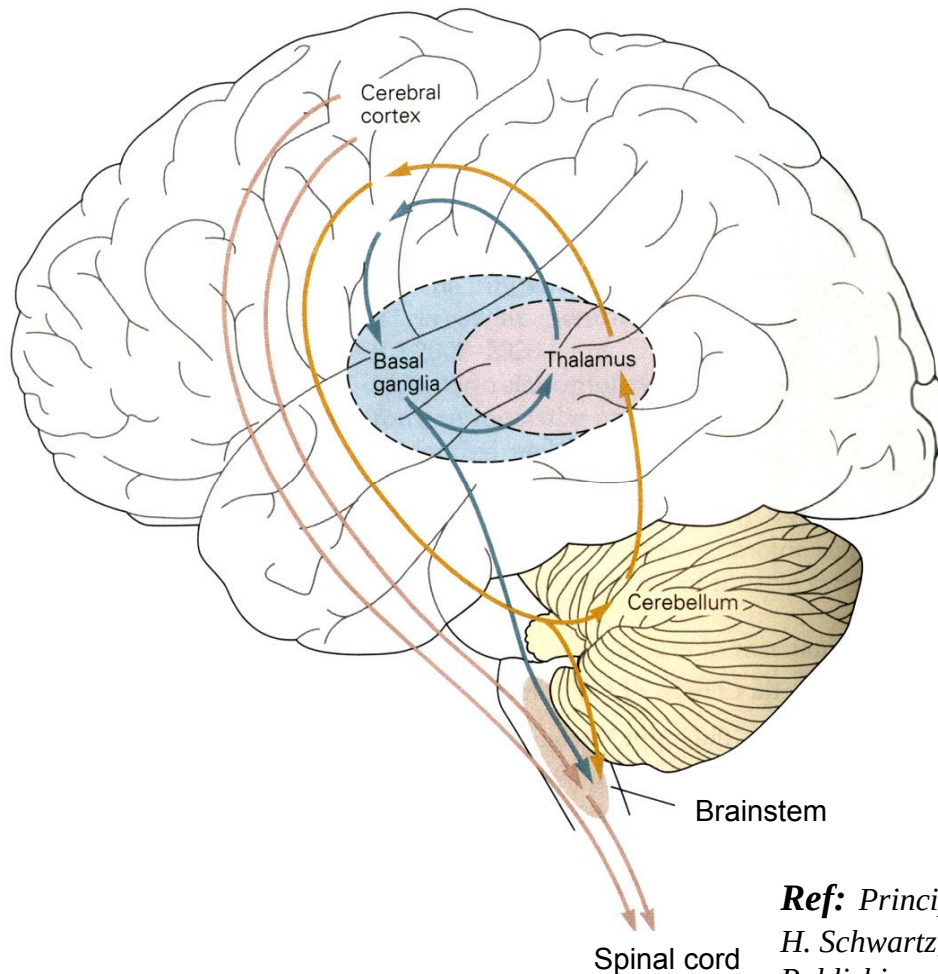


VLo = Ventral lateral nucleus, pars oralis
VLc = Ventral lateral nucleus, pars caudalis

Location and gross anatomy of the cerebellum (rat)



The cerebro-cerebellar circuit



Ref: *Principles of Neural Science, 4th ed.* Edited by Eric R. Kandel, James H. Schwartz, and Thomas M. Jessell. New York, McGraw-Hill Professional Publishing, 2000



Location and gross anatomy of the cerebellum (human)

Phylogenetic subdivisions of the cerebellum

ARCHICEREBELLUM	- posture
PALEOCEREBELLUM	- muscle tone
NEOCEREBELLUM	- regulated movement

Functional anatomical subdivisions of the cerebellum

VESTIBULOCEREBELLUM = archicerebellum

FLOCCULO-NODULAR LOBE

(balance, eyemovement)

SPINOCEREBELLUM = paleocerebellum

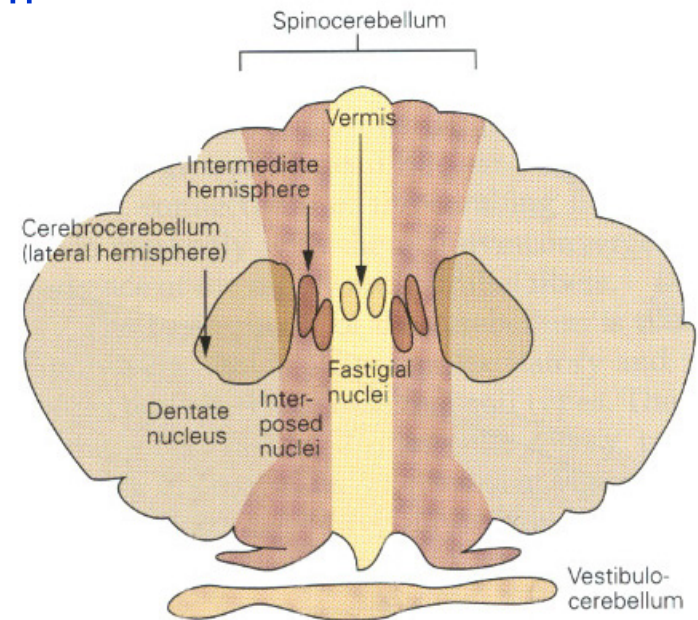
**MEDIAL (VERMIS) + INTERMEDIATE
CORTEX**

(execution of movement)

CEREBROCEREBELLUM = neocerebellum

LATERAL CORTEX

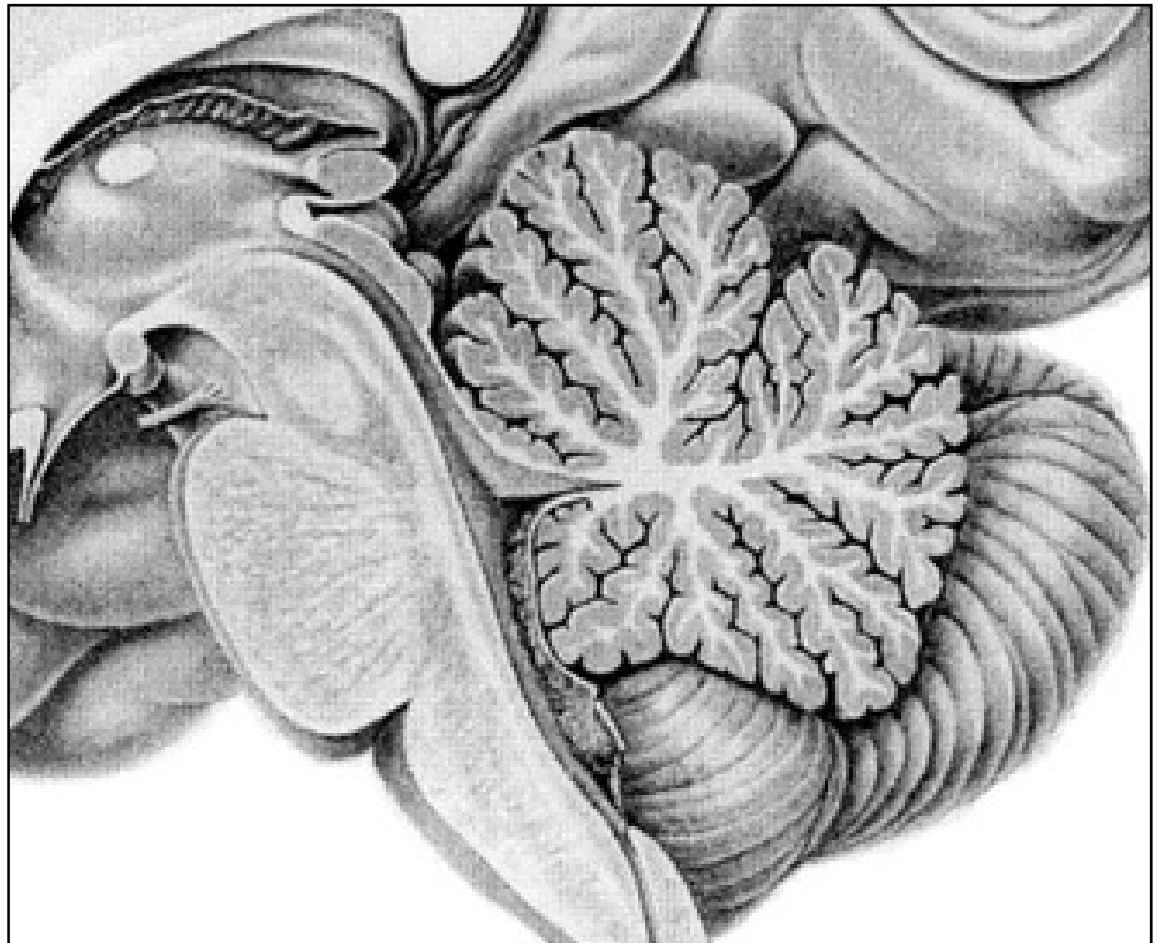
(planning and control of
movement)

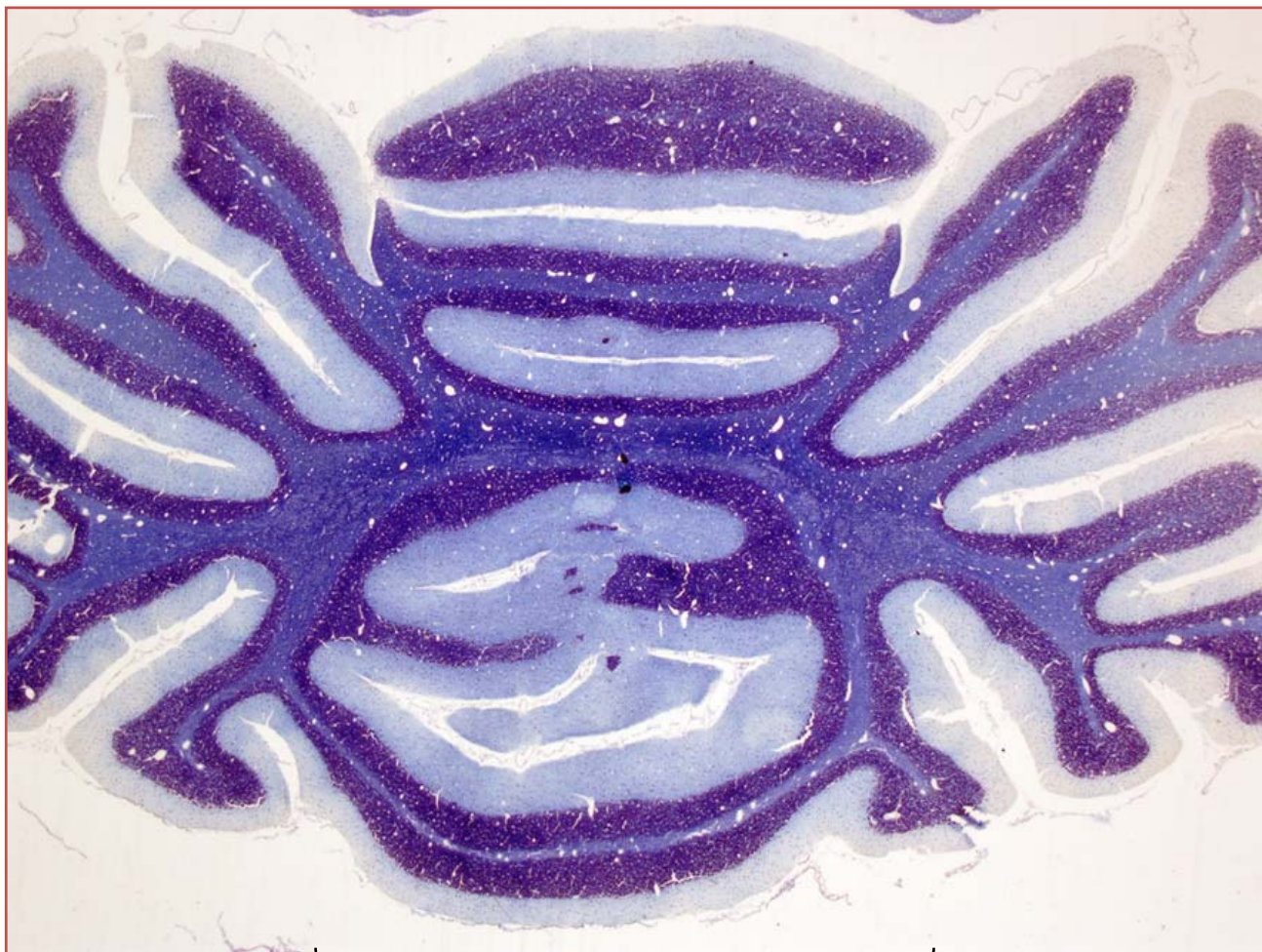


Structure of the cerebellum

Macroscopic structure

- vermis, hemispheres, lobes, folia
- peduncles
- nuclei

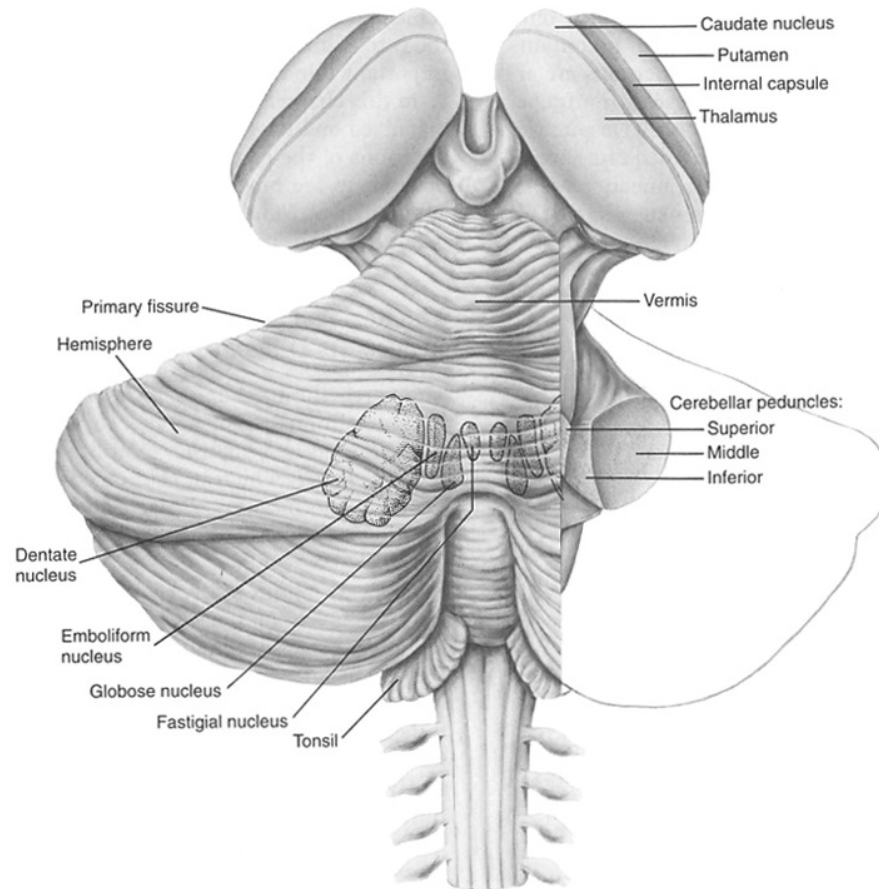
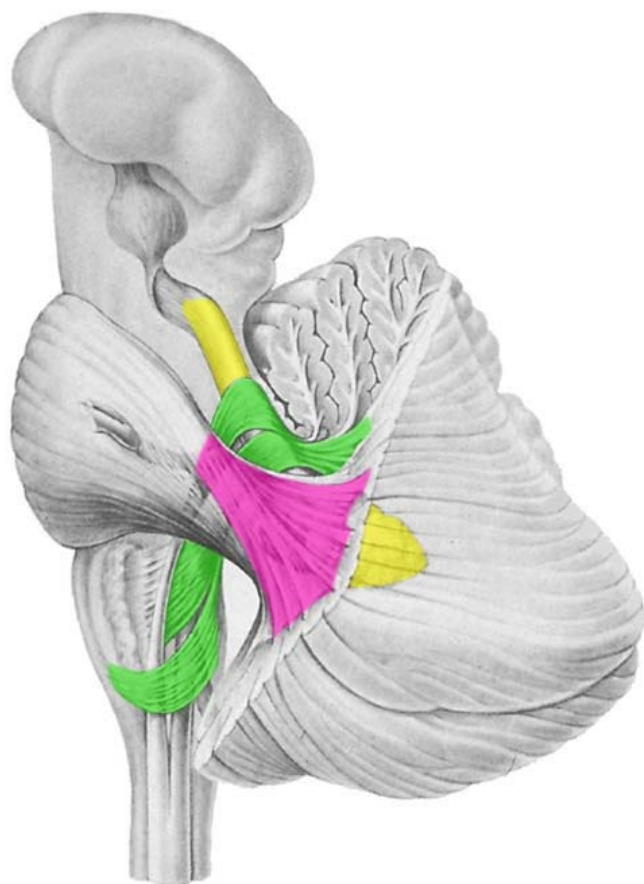


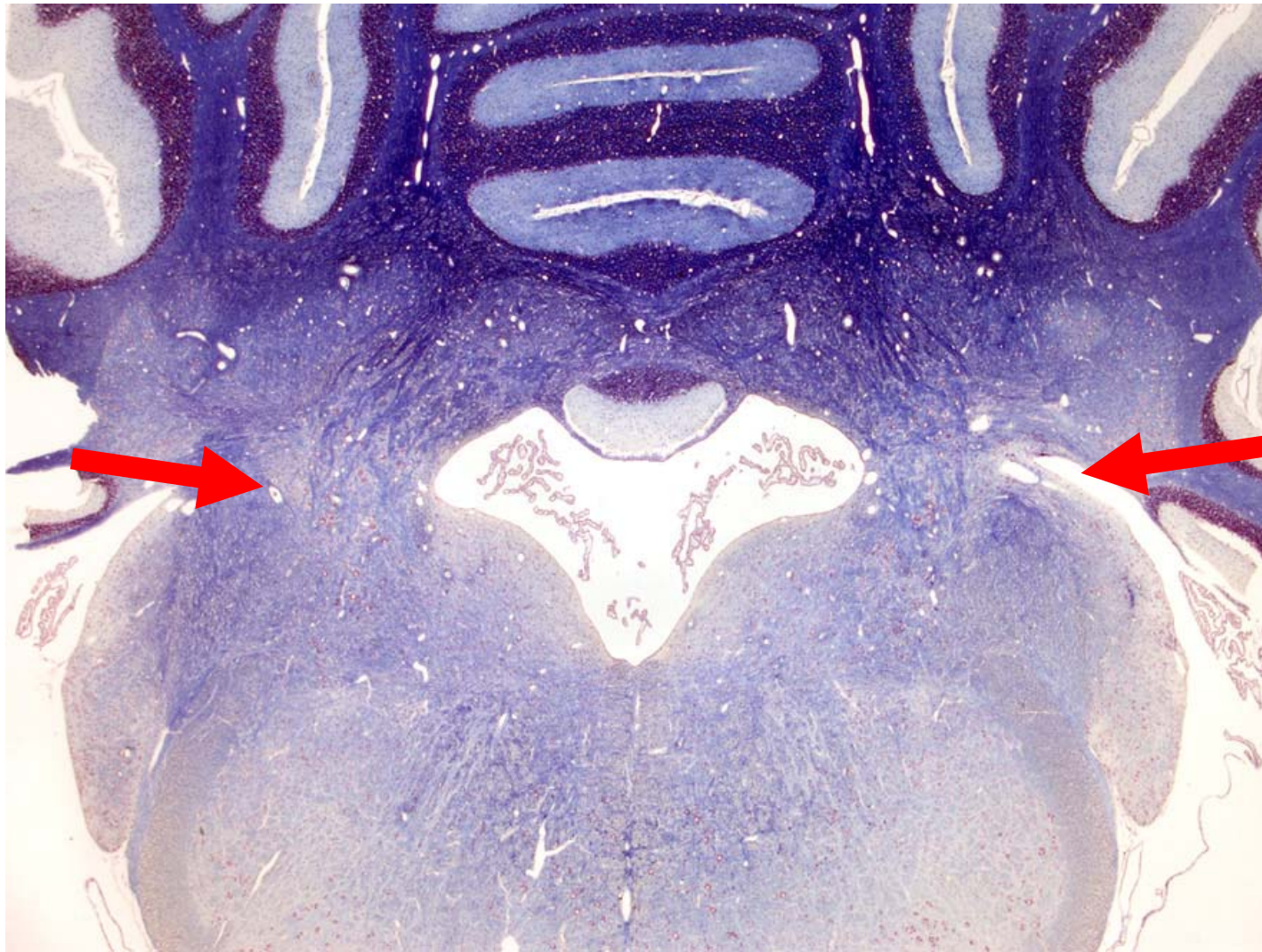


Microscopic
anatomy of the
cerebellum:
structure of the
vermis and the
cerebellar lobes
are similar

vermis

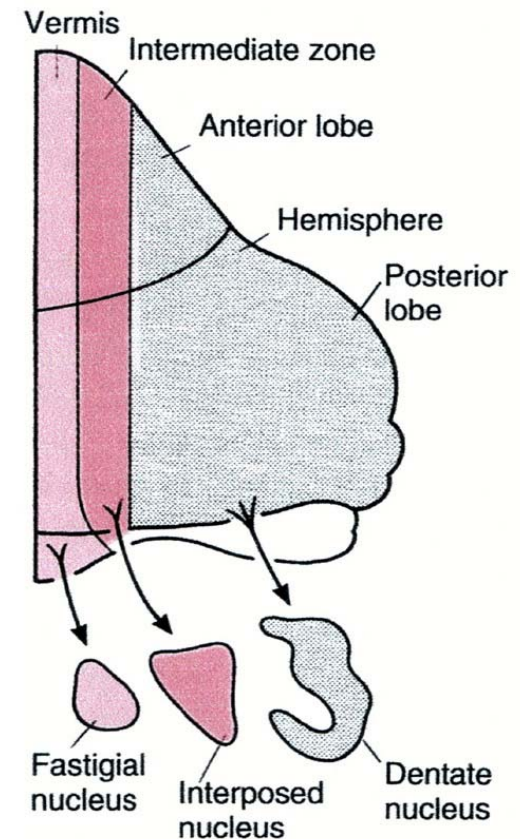
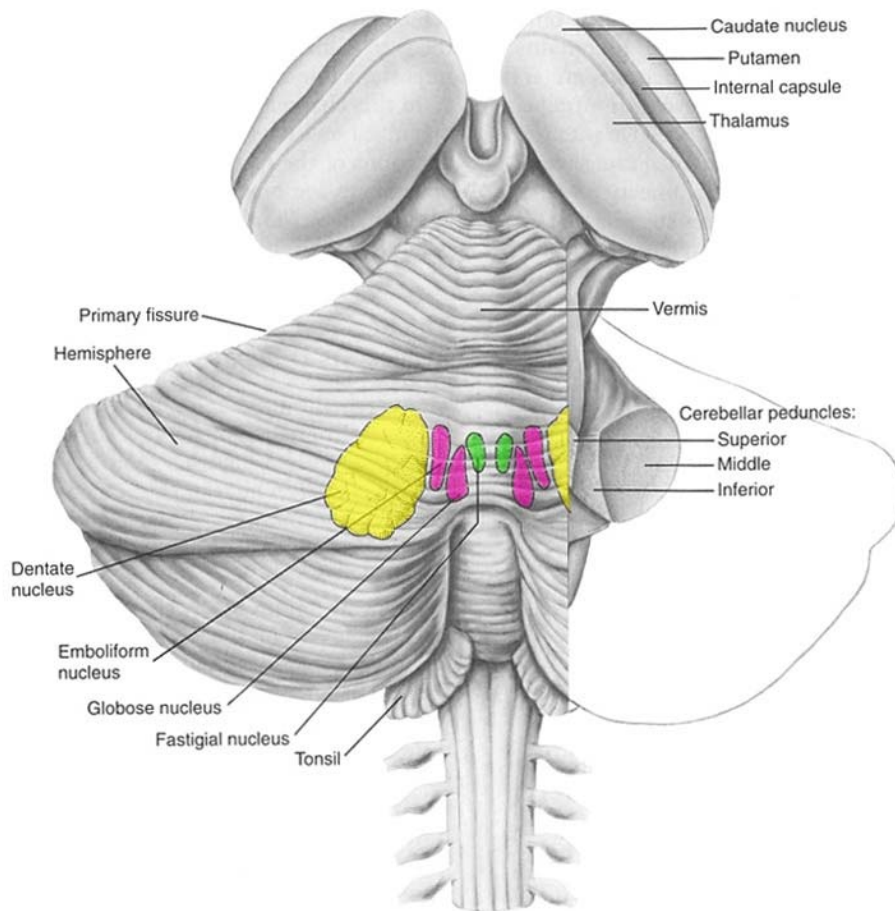
Cerebellar lobes, peduncles and deep nuclei

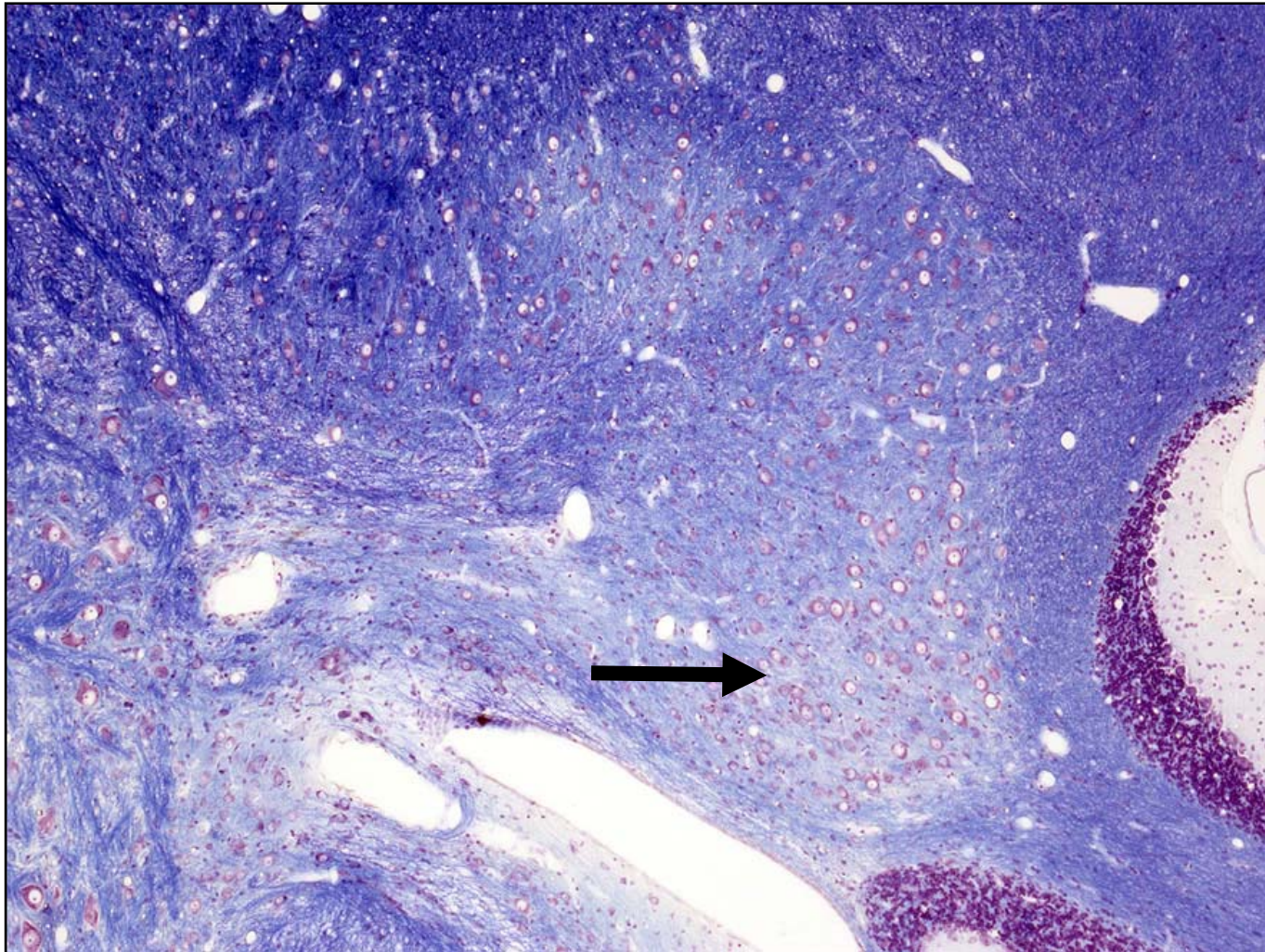




Microscopic
anatomy of
the
cerebellum:
middle
cerebellar
peduncle

Deep cerebellar nuclei





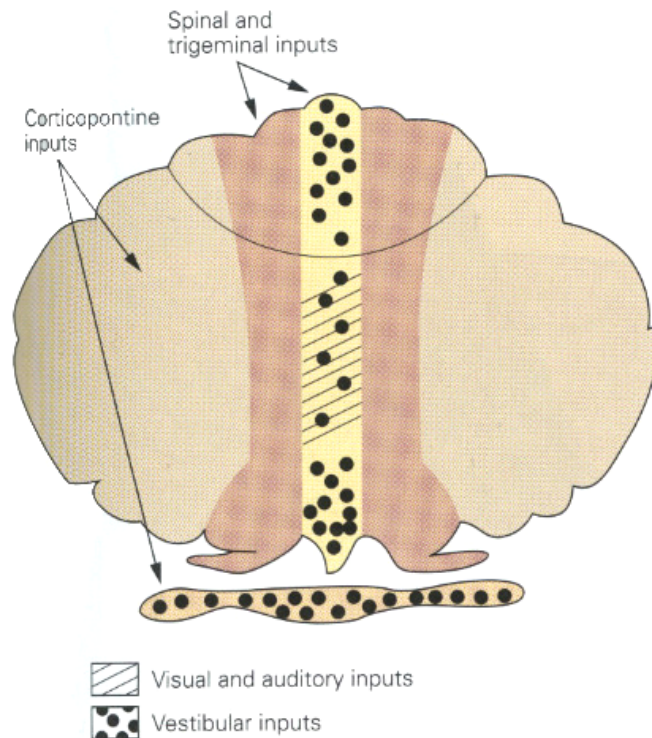
Microscopic
anatomy of
the
cerebellum:
Deep
cerebellar
nuclei

Cerebellar nuclei

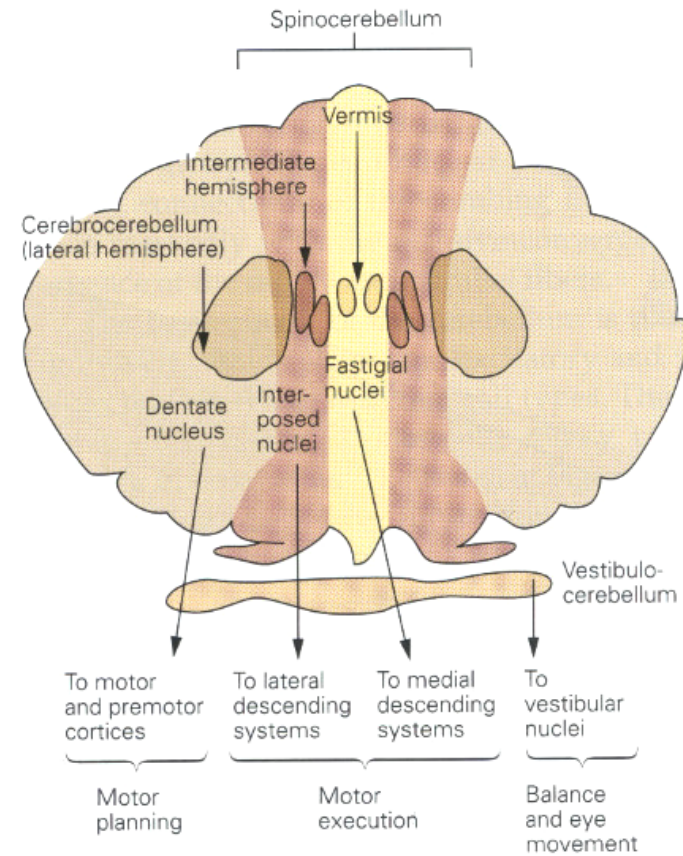
FASTIGIUS	(MEDIALIS)
EMBOLIFORMIS	(ANTERIOR INTERPOSITUS)
GLOBOSUS	(POSTERIOR INTERPOSITUS)
LATERALIS	(DENTATUS)

Functional anatomical subdivisions of cerebellum

A Inputs



B Outputs



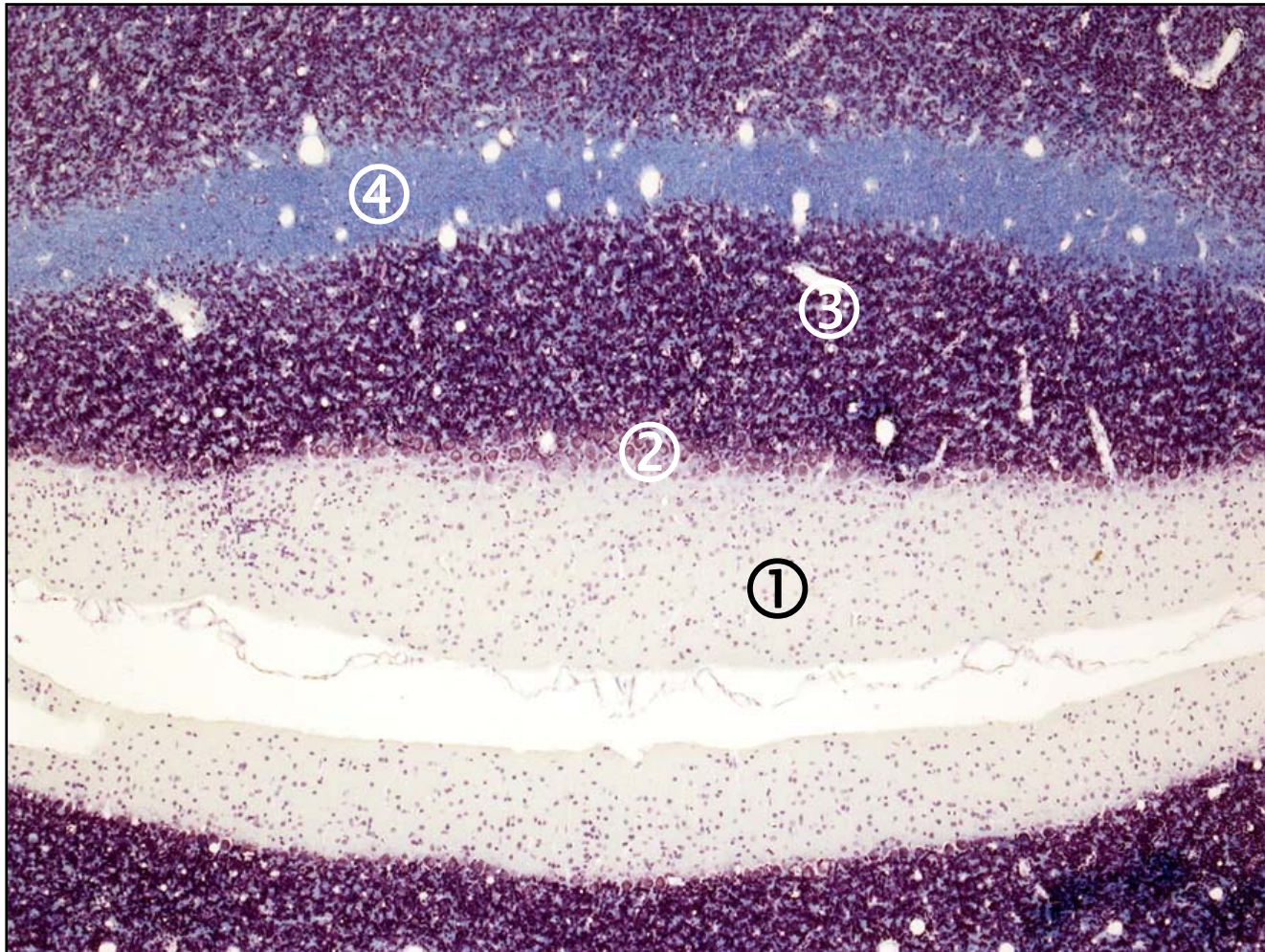
Structure of the cerebellum

MACROSCOPIC STRUCTURE

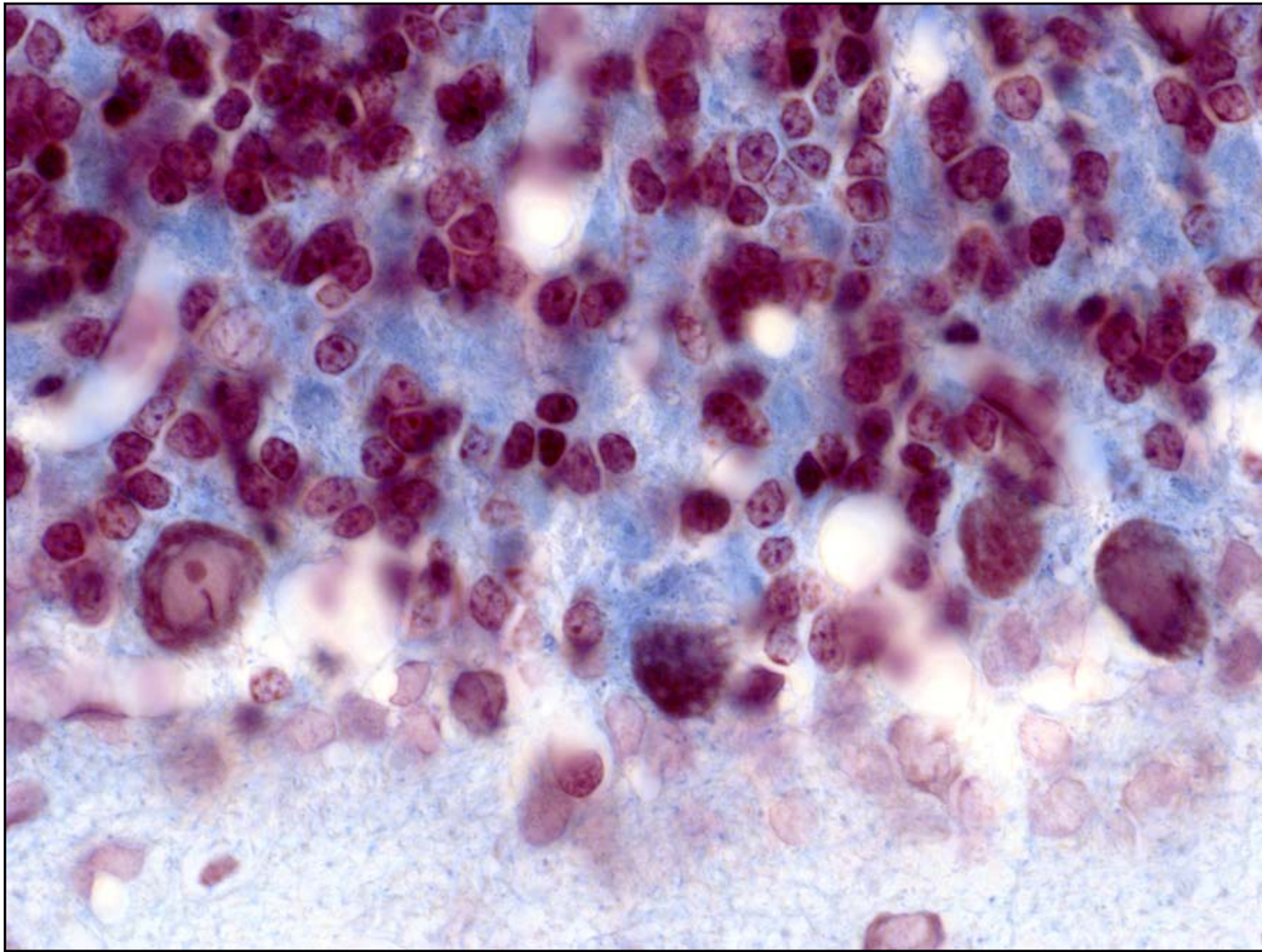
- vermis, hemispheres, lobes, folia
- pedunculi
- nuclei

MICROSCOPIC STRUCTURE

- cerebellar cortex
 - layers
 - cell types



Layers of the
cerebellar cortex:
1-3
Medulla: 4



Cell types of
the cerebellar
cortex:
Note the size,
and the
number of
cells in the
different
layers

CELL TYPES

Cerebellar cortex

Purkinje cell	⊖
granule cell	⊕
basket cell	⊖
Golgi cell	⊖
stellate cell	⊖
glial cells	

White matter

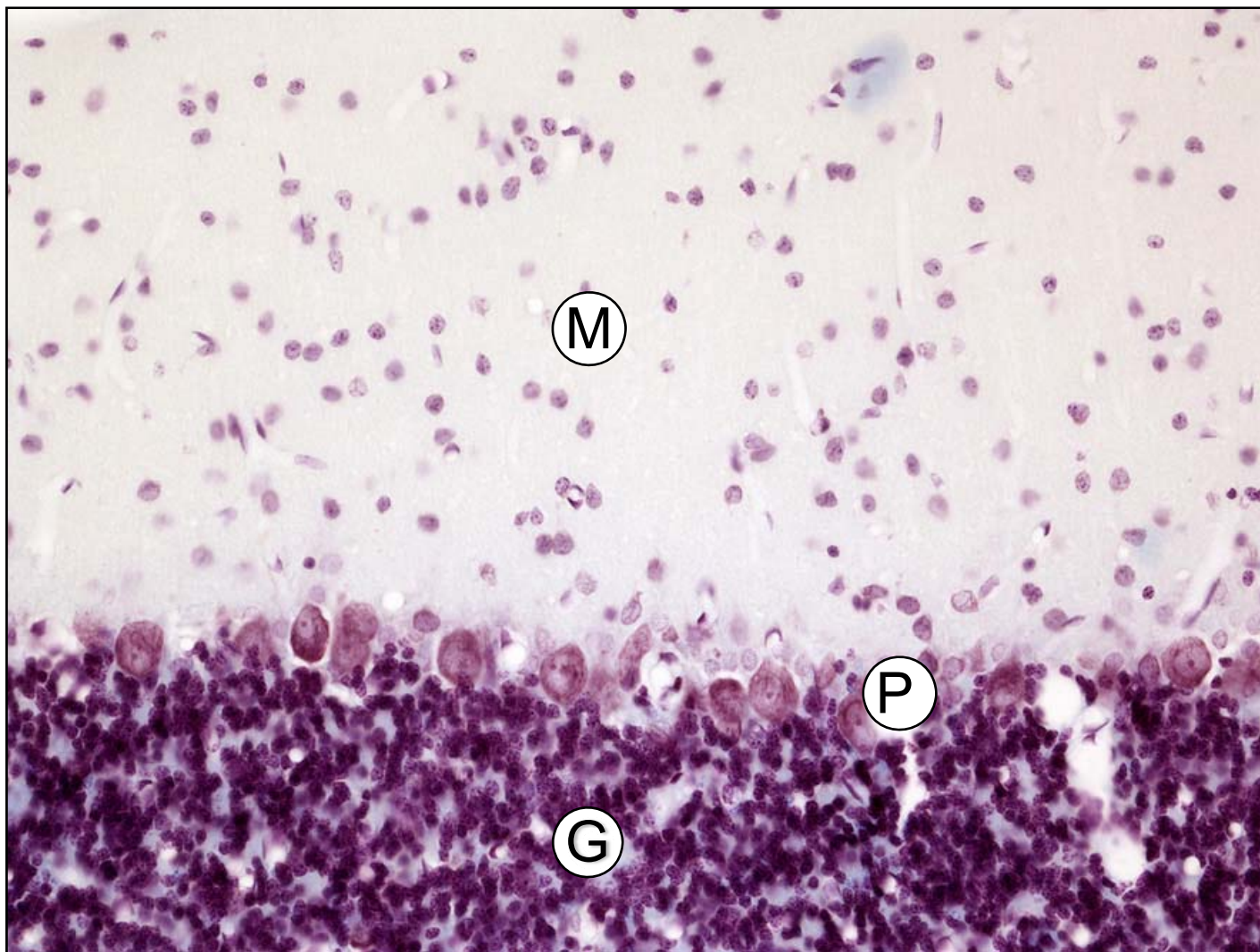
glial cells

Cerebellar nuclei

neuron	⊕
glial cells	

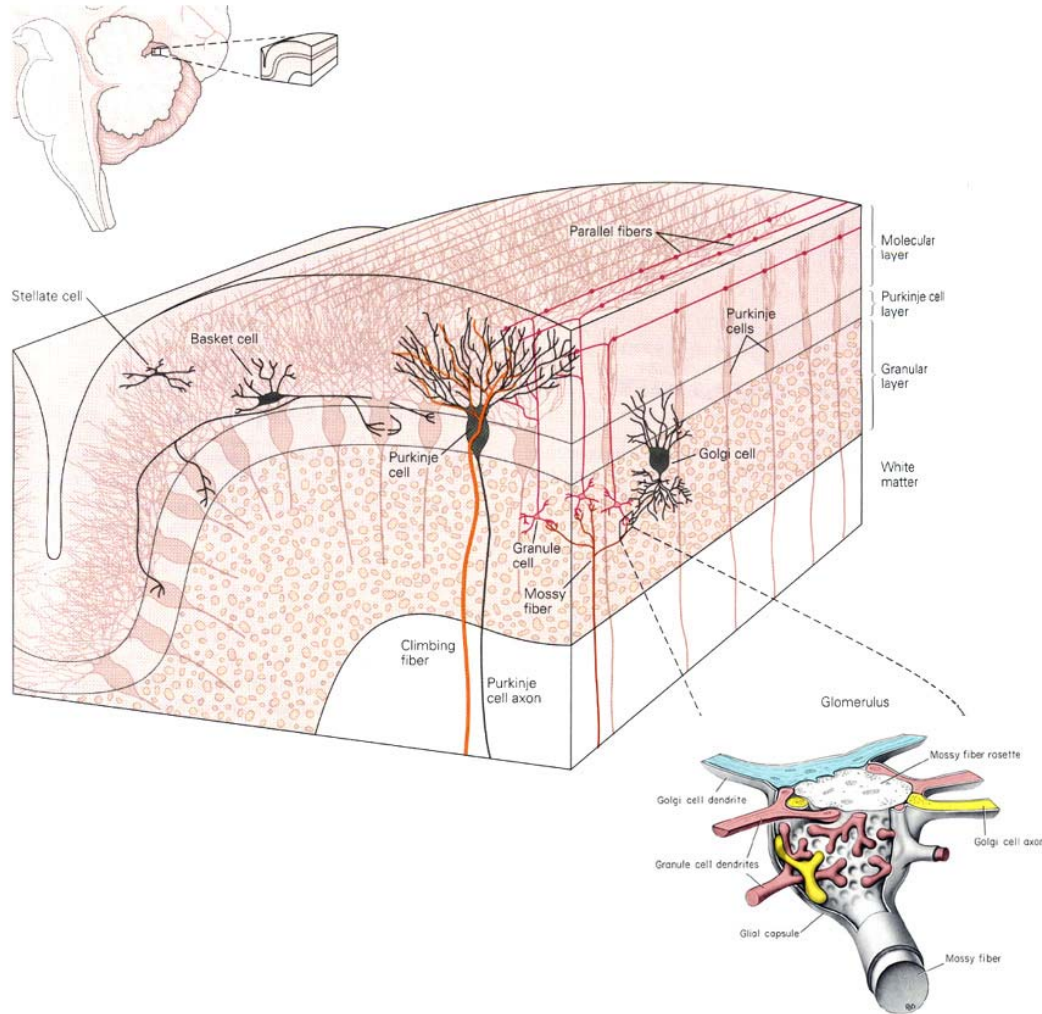
Characteristics of the cerebellar neurons

Cell types	Layers	Function	Innervated neurons
<u>Projection neuron</u>			
Purkinje cells	Purkinje	inhibitory	Deep cerebellar and vestibular nuclei
<u>Interneurons</u>			
Granule cells	Granule cell	excitatory	Purkinje-, stellate- basket and Golgi cells
Basket cells	Molecular	inhibitory	Purkinje cells
Stellate cells	Molecular	inhibitory	Purkinje cells
Golgi cells	Granule cell	inhibitory	Granule cells



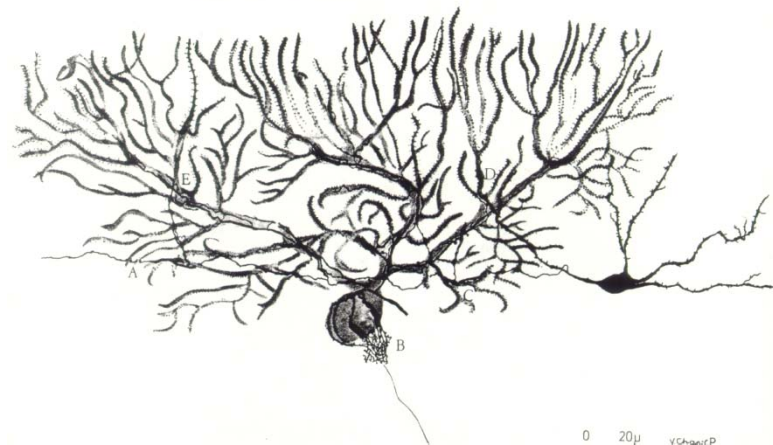
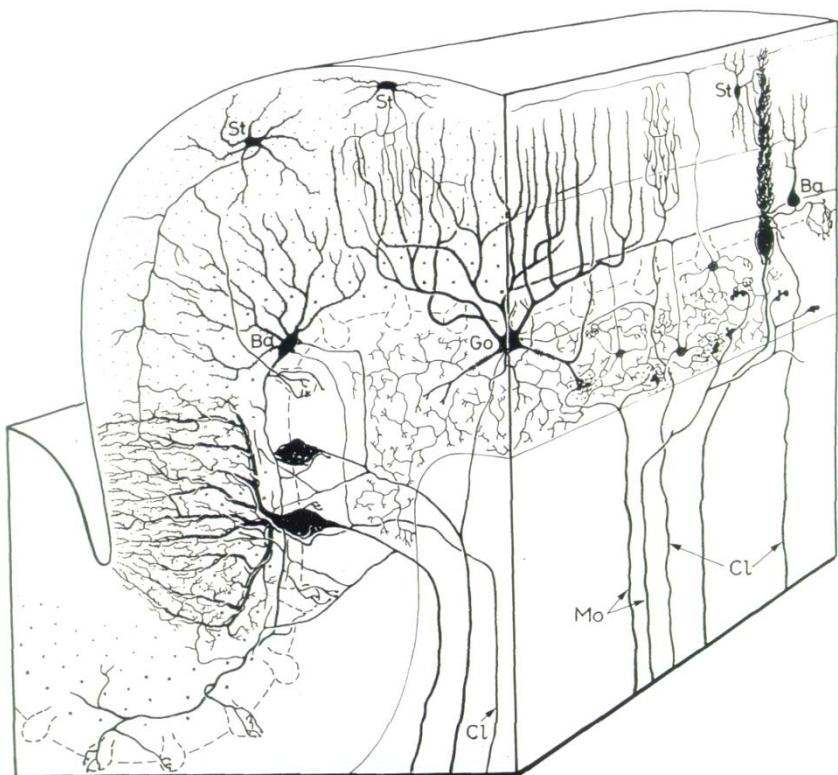
Cell types of
the cerebellar
cortex:
location of
different cell
types

Two types of cerebellar afferents: mossy fibers and climbing fibers

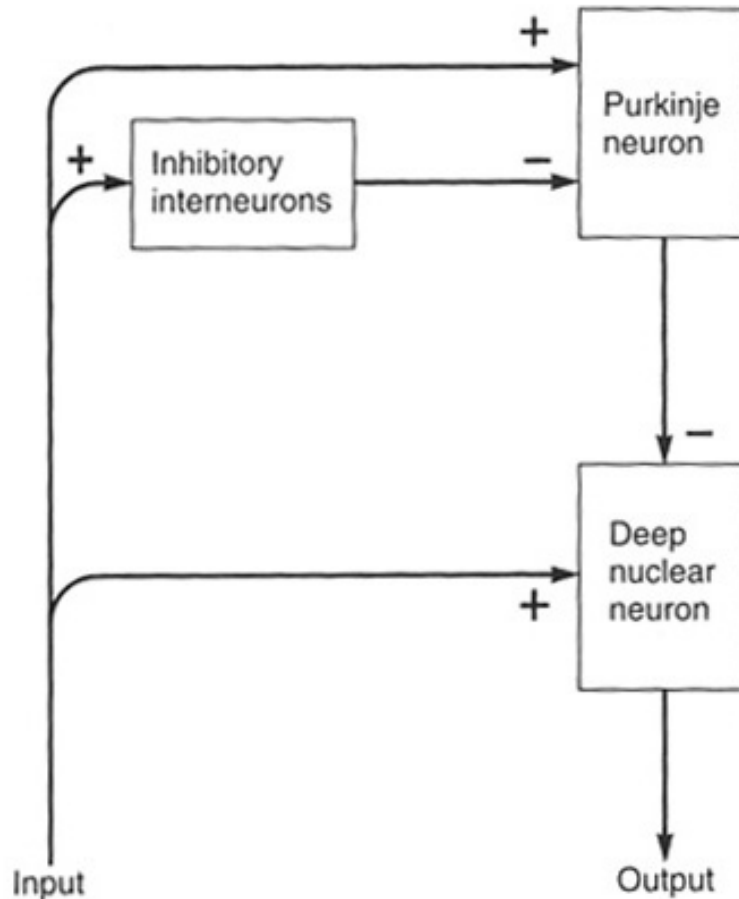


Cerebellar glomerulus

Purkinje cells



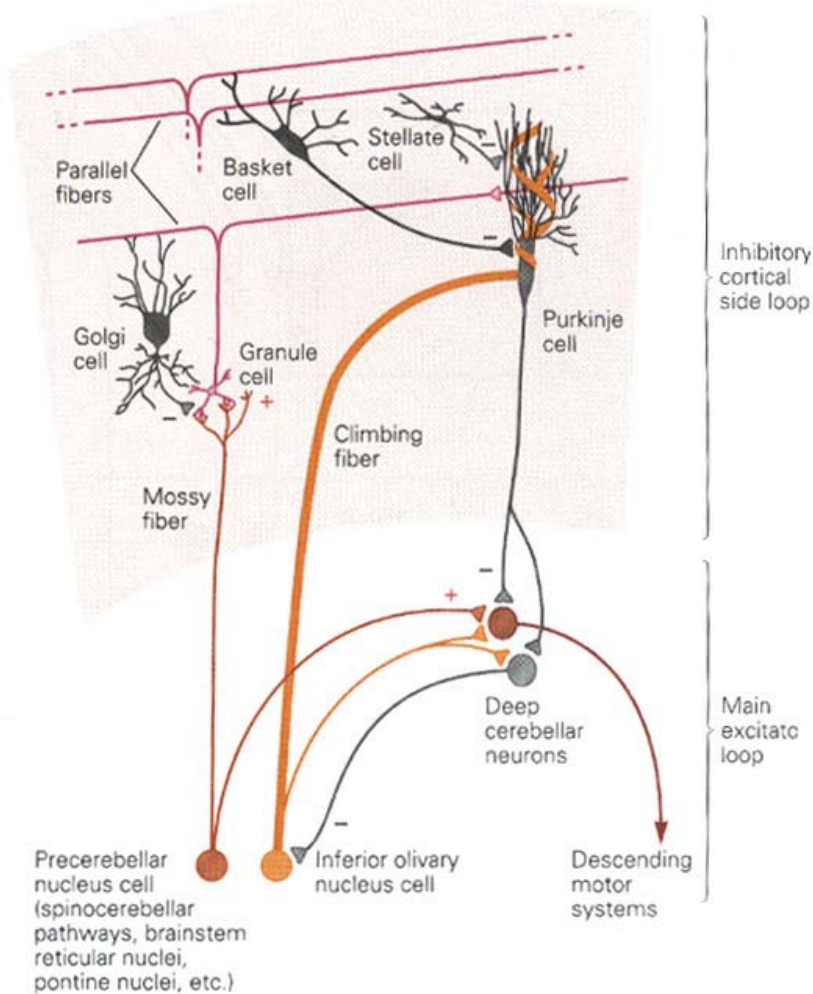
Neuronal connections of the Purkinje cells



afferents

efferents

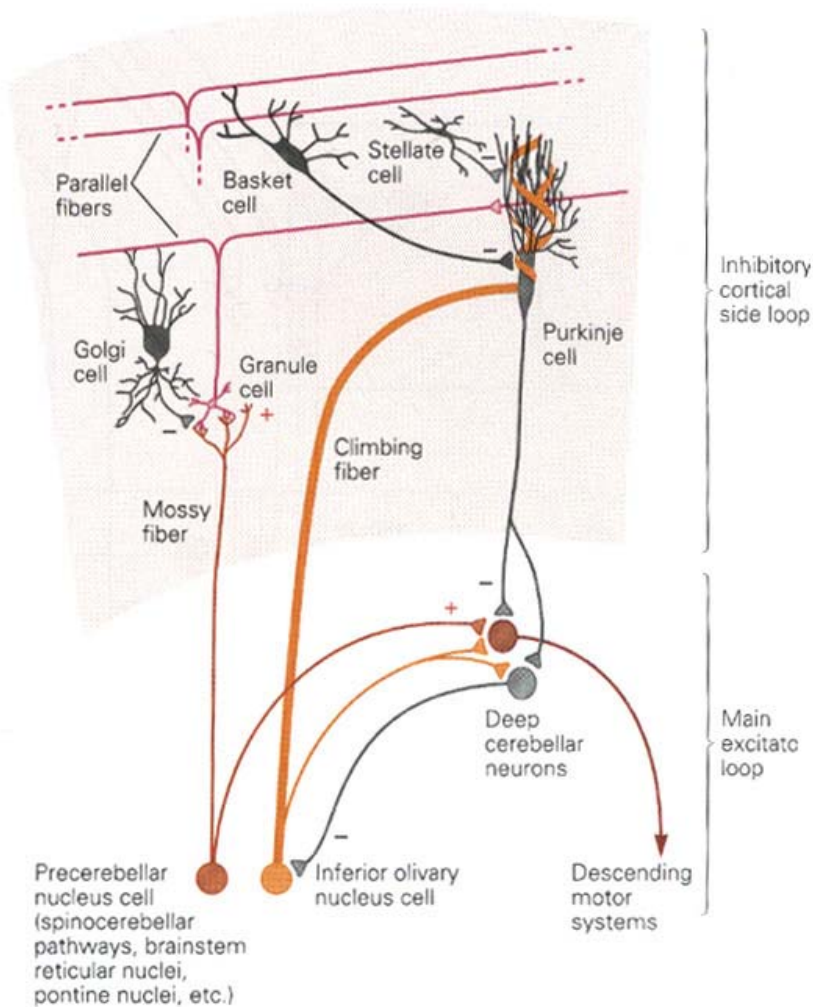
Neuronal connections of the Purkinje cells

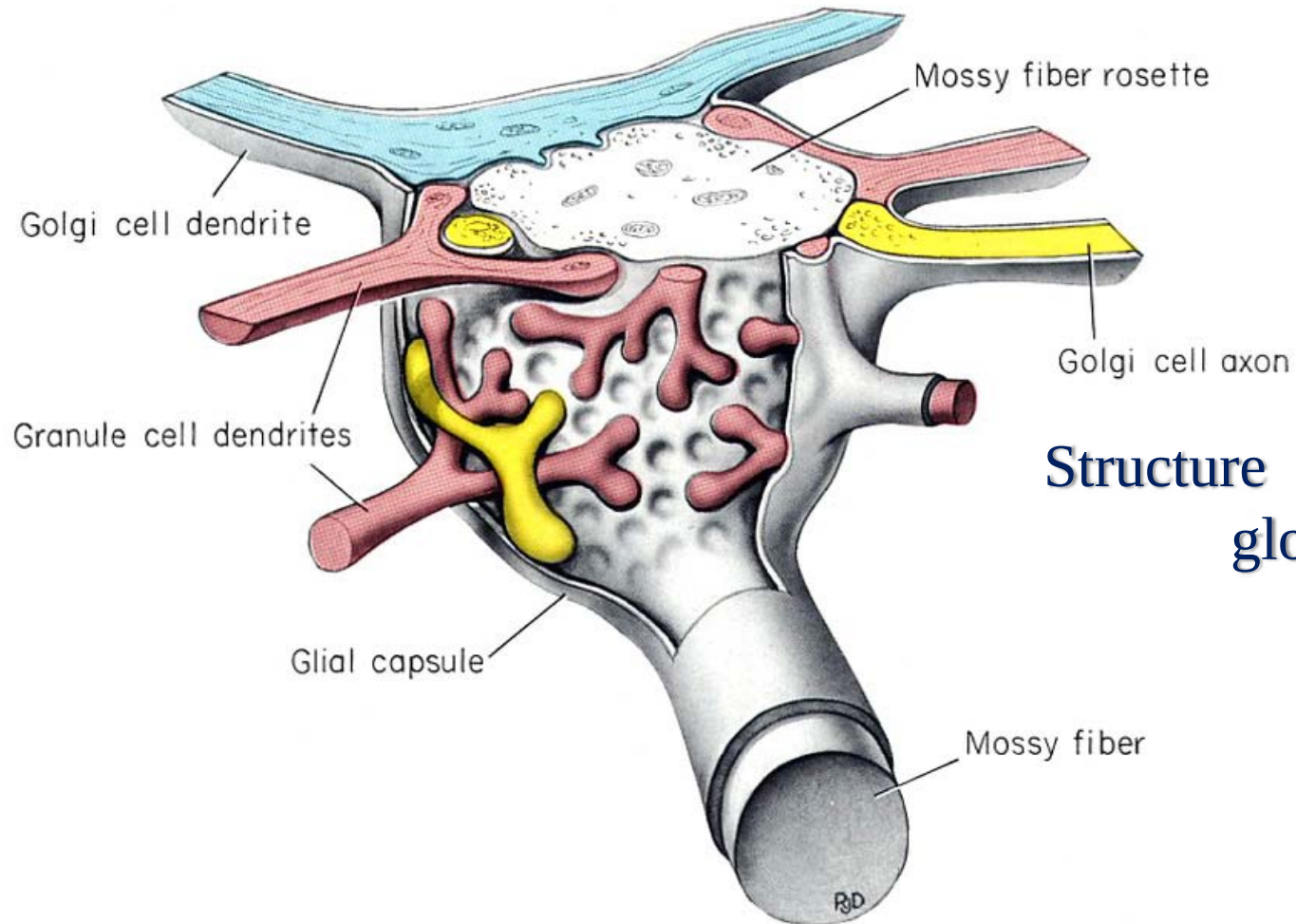


Characteristics of the cerebellar neurons

Cell types	Layers	Function	Innervated neurons
<u>Projection neuron</u>			
Purkinje cells	Purkinje	inhibitory	Deep cerebellar and vestibular nuclei
<u>Interneurons</u>			
Granule cells	Granule cell	excitatory	Purkinje-, stellate- basket and Golgi cells
Basket cells	Molecular	inhibitory	Purkinje cells
Stellate cells	Molecular	inhibitory	Purkinje cells
Golgi cells	Granule cell	inhibitory	Granule cells

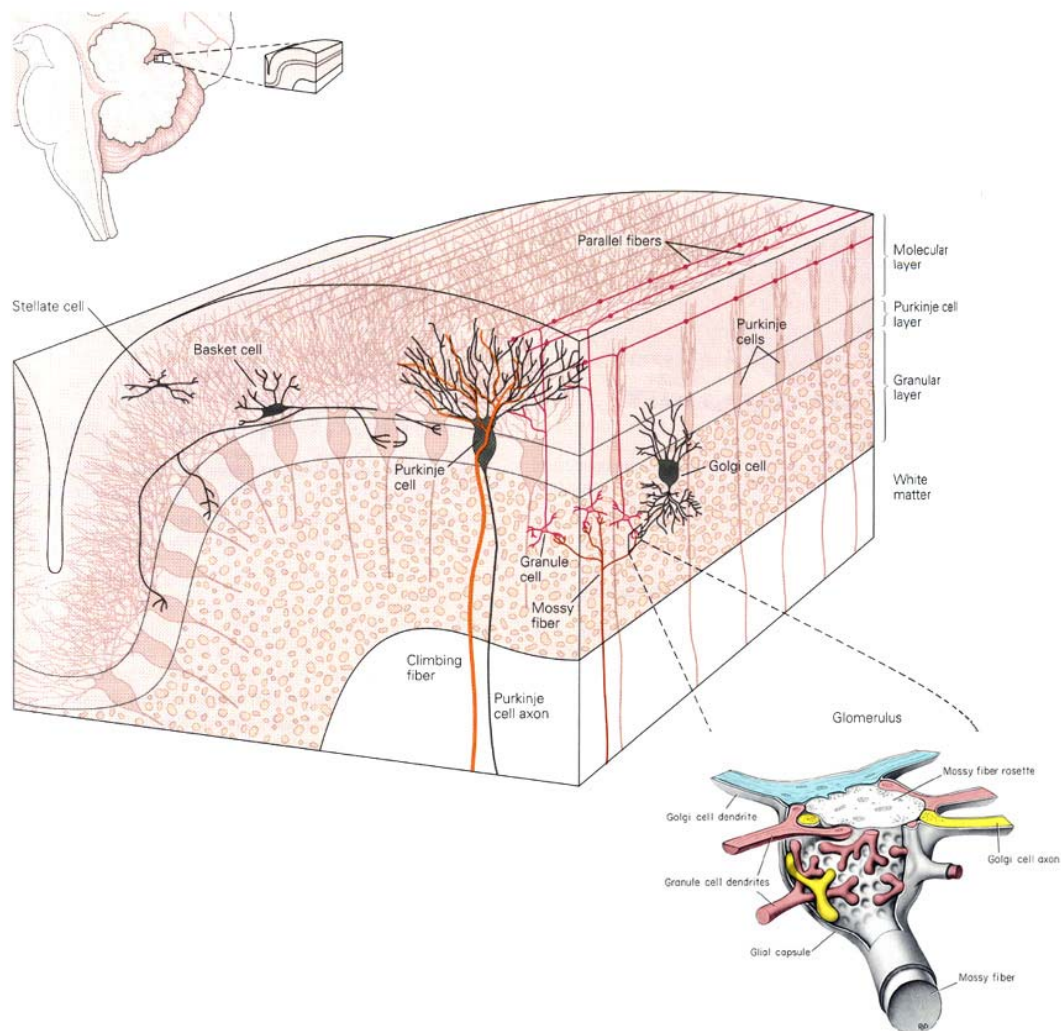
Neuronal connections of the granule cells

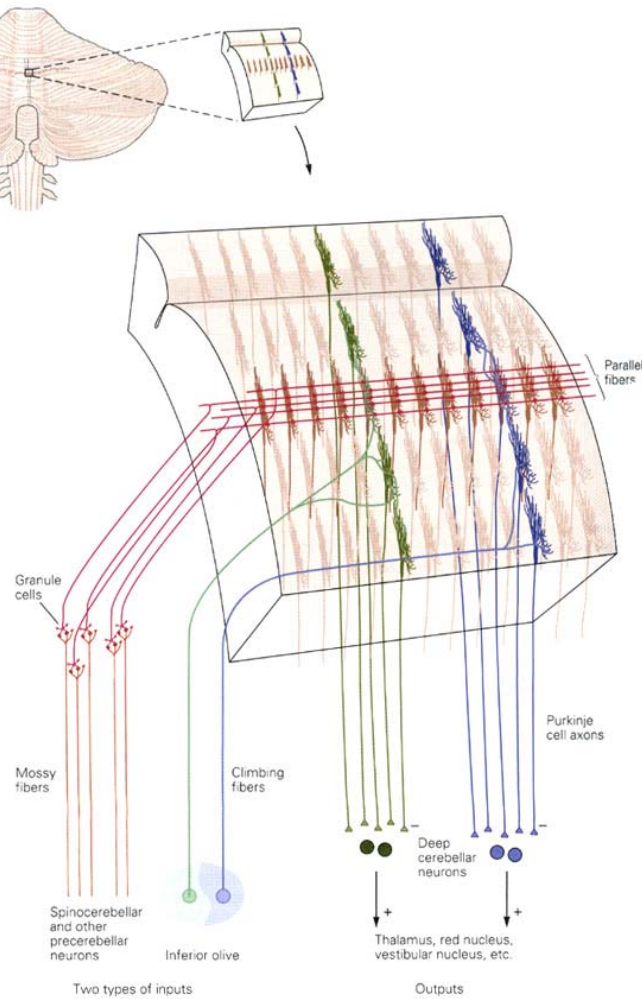




Structure of the cerebellar glomerulus

Neuronal connections of the granule cells





Activation of Purkinje cells by the axons of granule cells (parallel fibers)

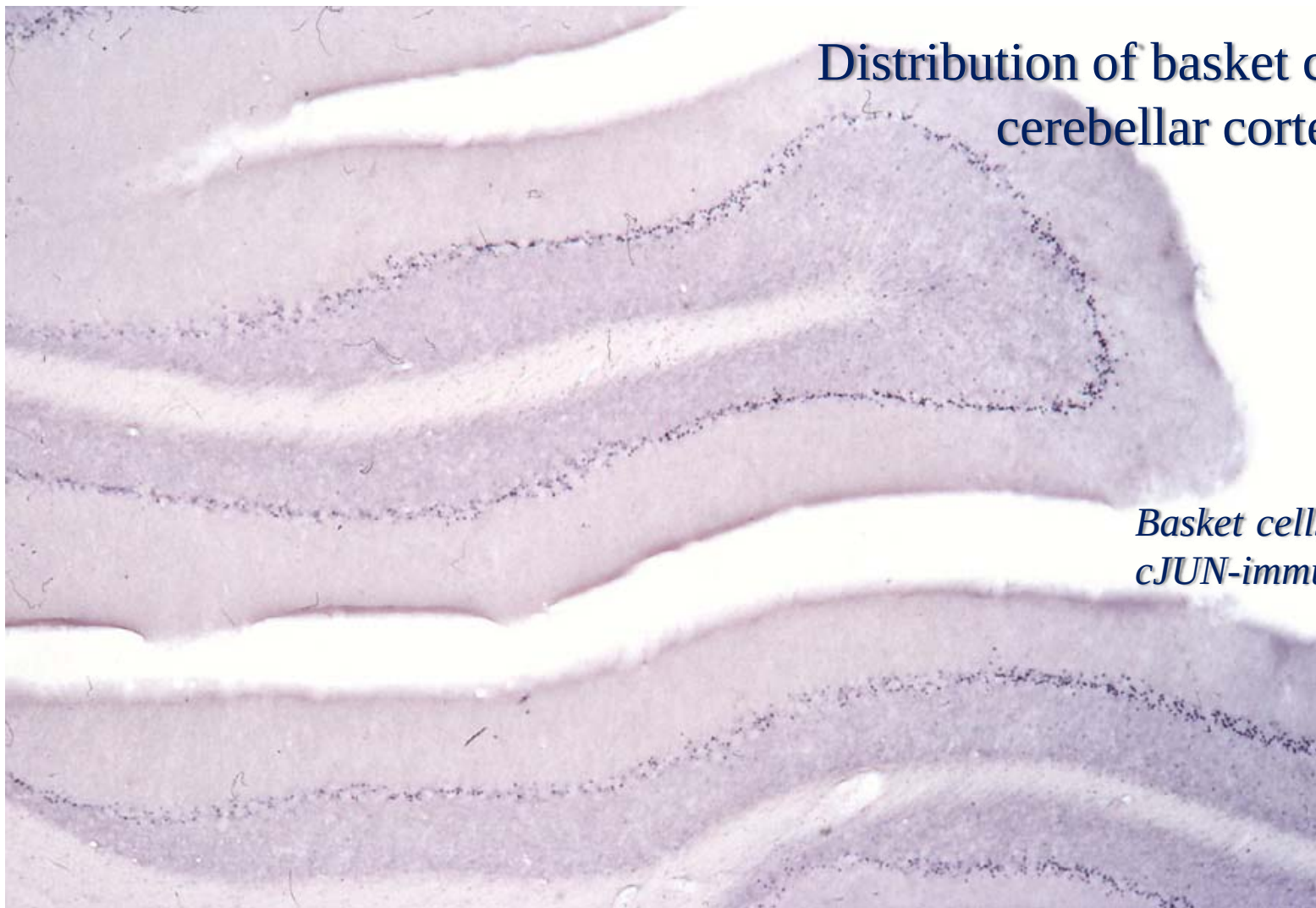
Red: Dendritic trees of Purkinje cells innervated by granule cells

Green and **Blue:** Dendritic trees of Purkinje cells innervated by inferior olive neurons located in different subdivisions of the nucleus

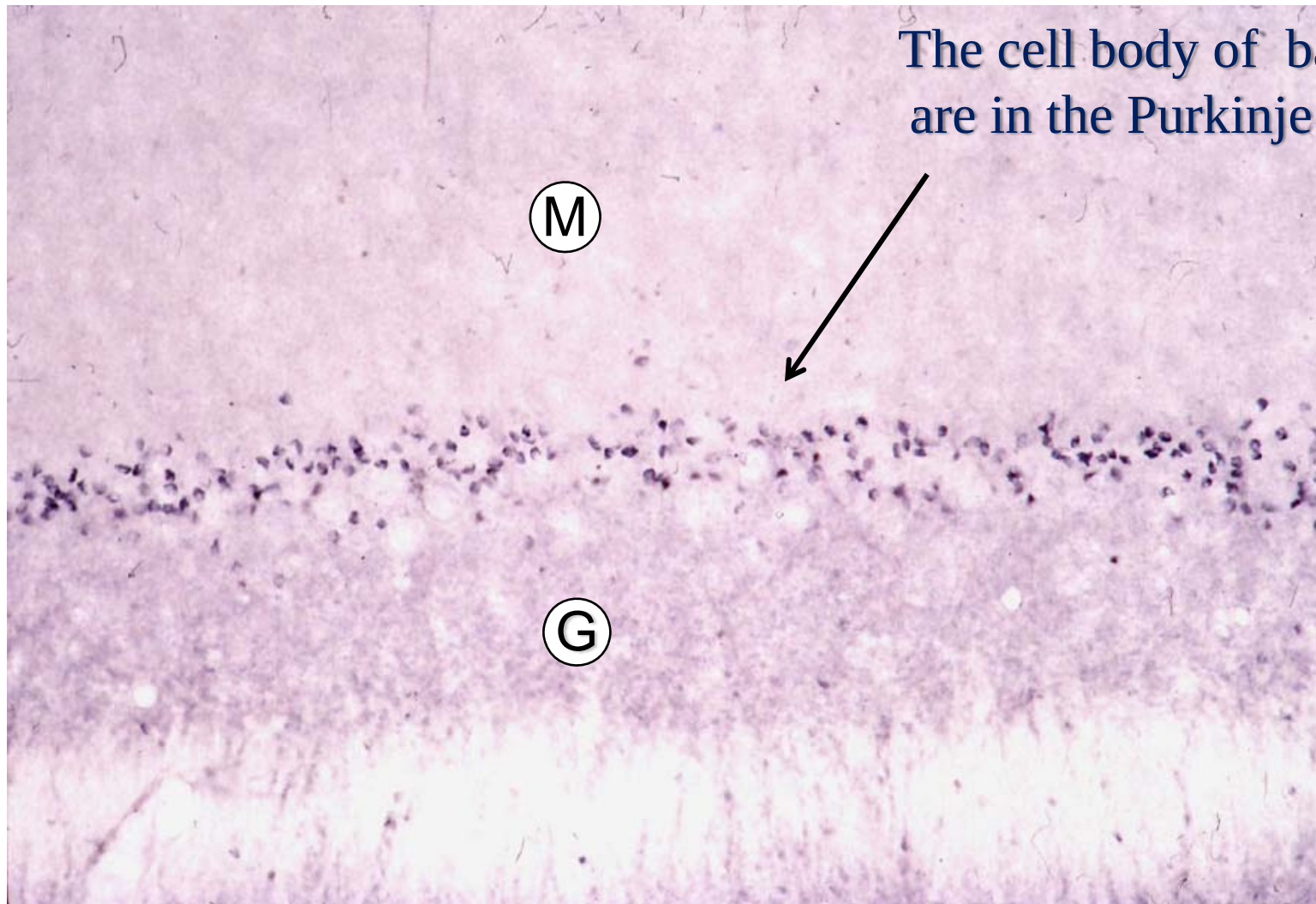
Characteristics of the cerebellar neurons

Cell types	Layers	Function	Innervated neurons
<u>Projection neuron</u>			
Purkinje cells	Purkinje	inhibitory	Deep cerebellar and vestibular nuclei
<u>Interneurons</u>			
Granule cells	Granule cell	excitatory	Purkinje-, stellate- basket and Golgi cells
Basket cells	Molecular	inhibitory	Purkinje cells
Stellate cells	Molecular	inhibitory	Purkinje cells
Golgi cells	Granule cell	inhibitory	Granule cells

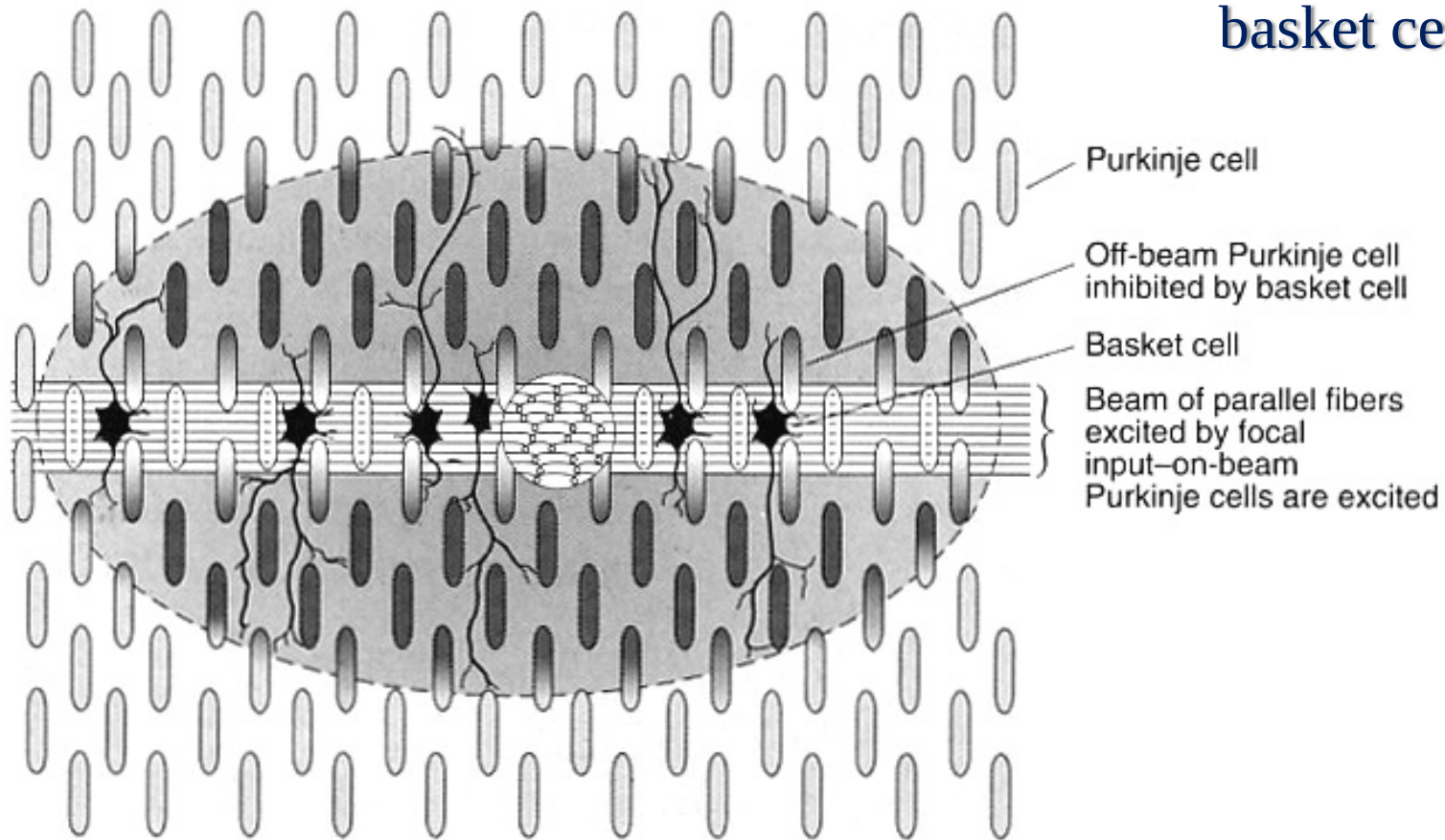
Distribution of basket cells in the cerebellar cortex



*Basket cells are marked by
cJUN-immunoreactivity*



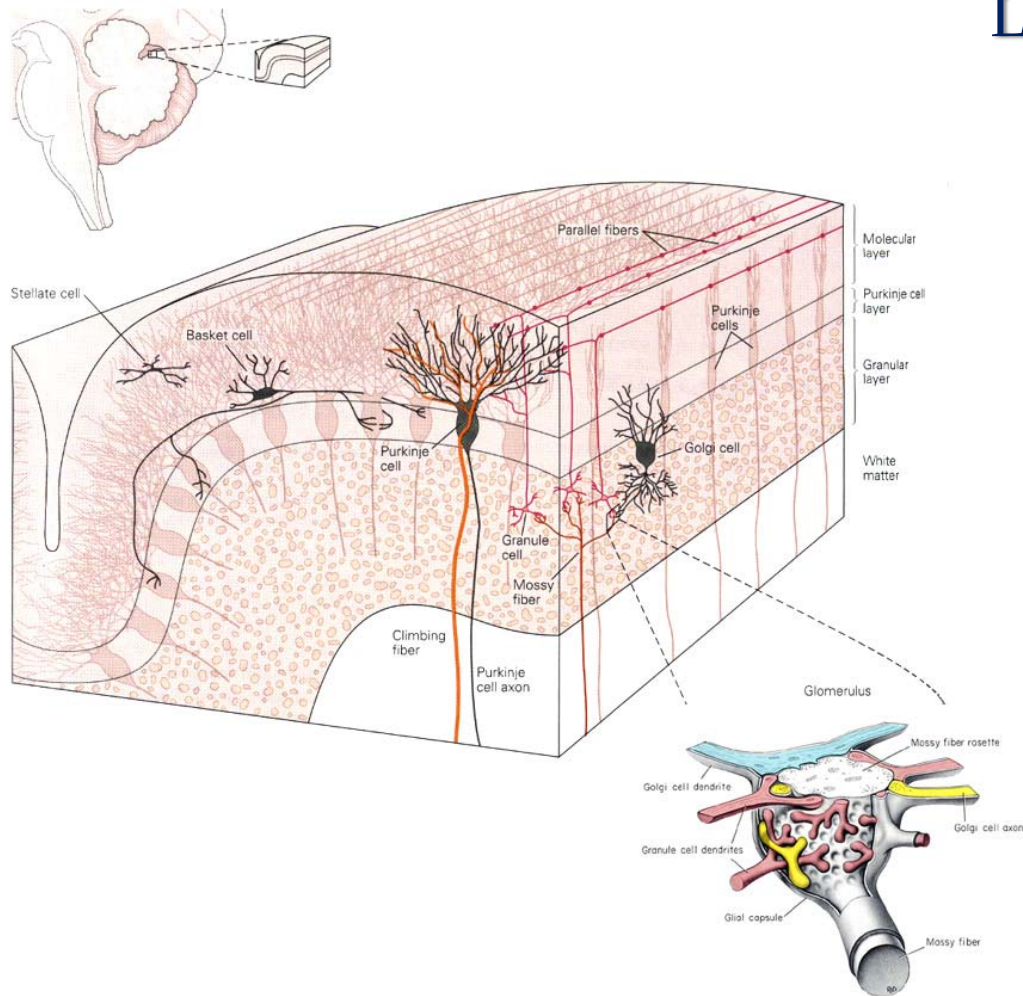
Lateral inhibition by basket cells



Characteristics of the cerebellar neurons

Cell types	Layers	Function	Innervated neurons
<u>Projection neuron</u>			
Purkinje cells	Purkinje	inhibitory	Deep cerebellar and vestibular nuclei
<u>Interneurons</u>			
Granule cells	Granule cell	excitatory	Purkinje-, stellate- basket and Golgi cells
Basket cells	Molecular	inhibitory	Purkinje cells
Stellate cells	Molecular	inhibitory	Purkinje cells
Golgi cells	Granule cell	inhibitory	Granule cells

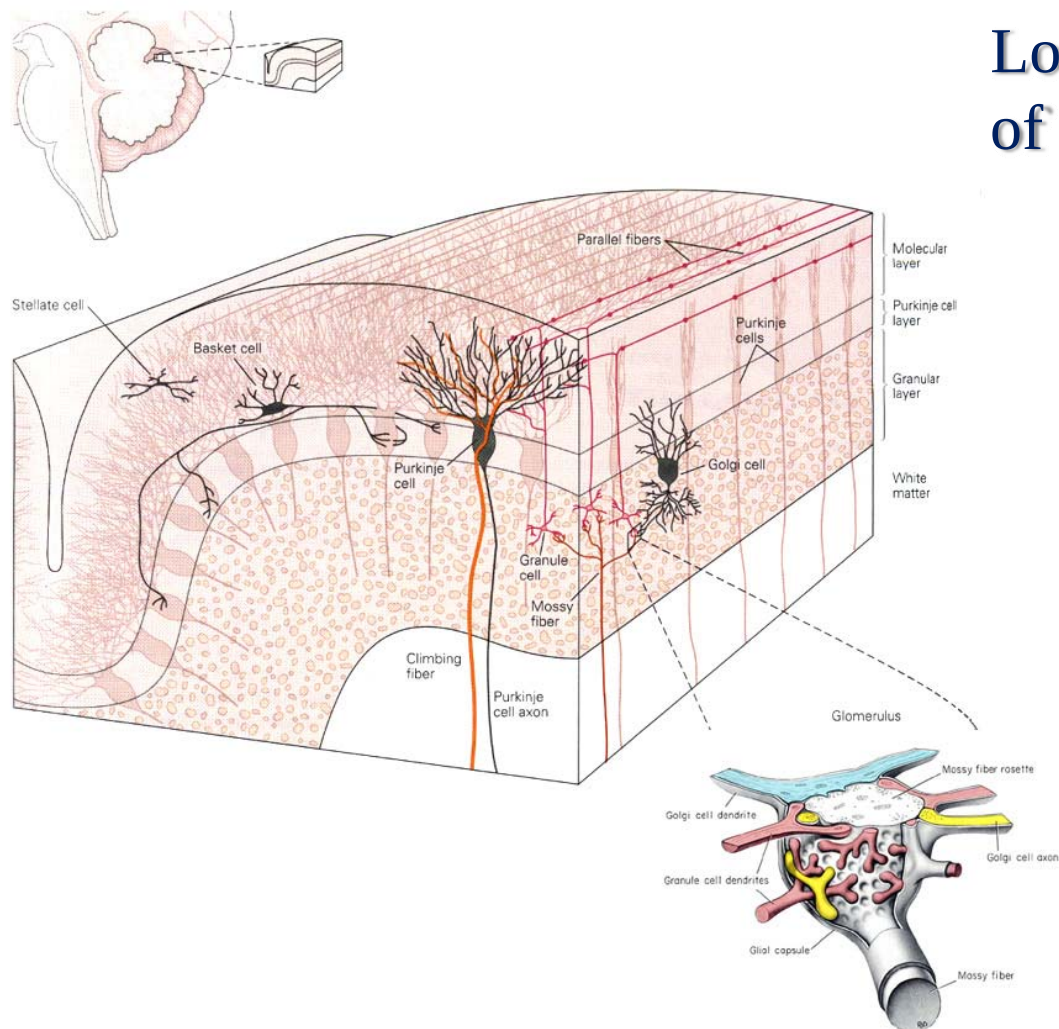
Localization and connectivity of stellate cells in the cerebellar cortex



Characteristics of the cerebellar neurons

Cell types	Layers	Function	Innervated neurons
<u>Projection neuron</u>			
Purkinje cells	Purkinje	inhibitory	Deep cerebellar and vestibular nuclei
<u>Interneurons</u>			
Granule cells	Granule cell	excitatory	Purkinje-, stellate- basket and Golgi cells
Basket cells	Molecular	inhibitory	Purkinje cells
Stellate cells	Molecular	inhibitory	Purkinje cells
Golgi cells	Granule cell	inhibitory	Granule cells

Localization and connectivity of Golgi cells in the cerebellar cortex

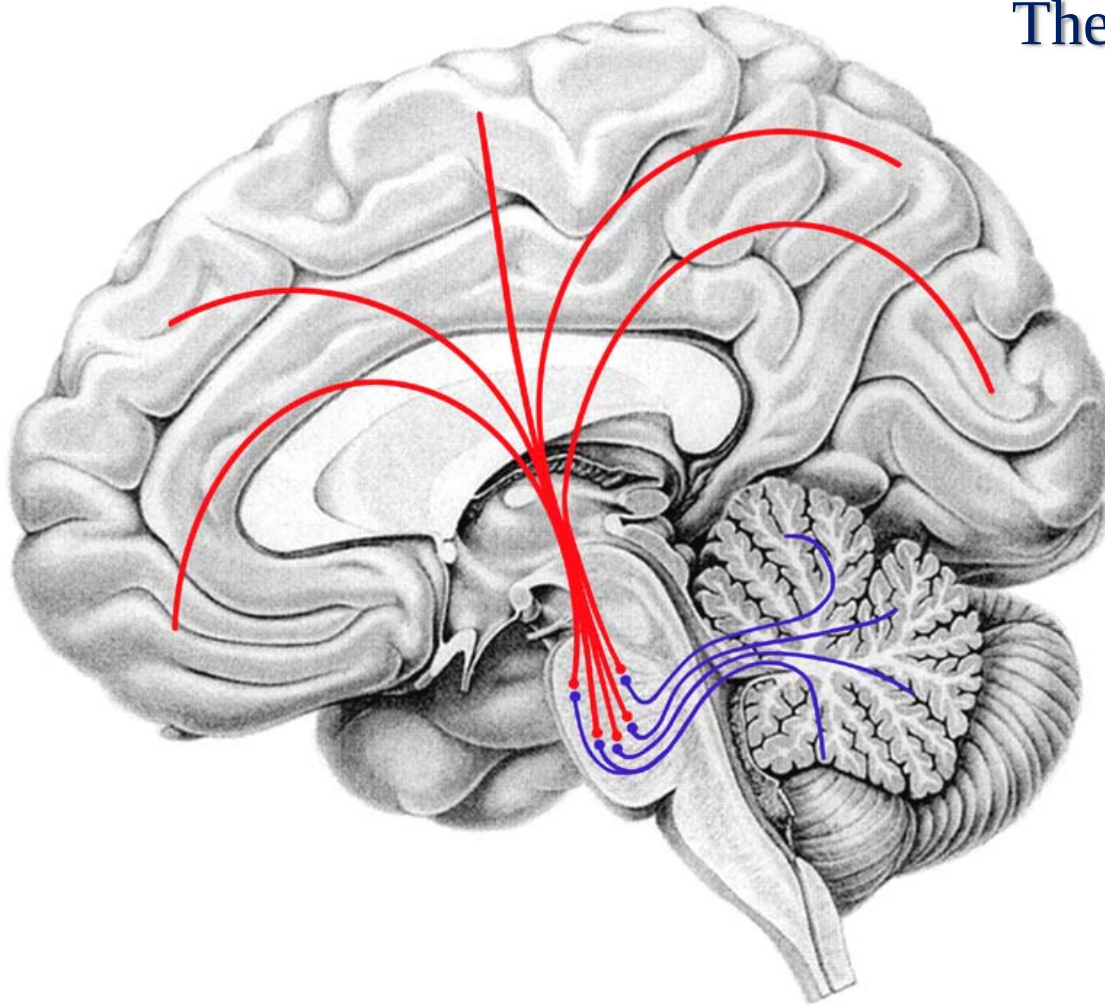


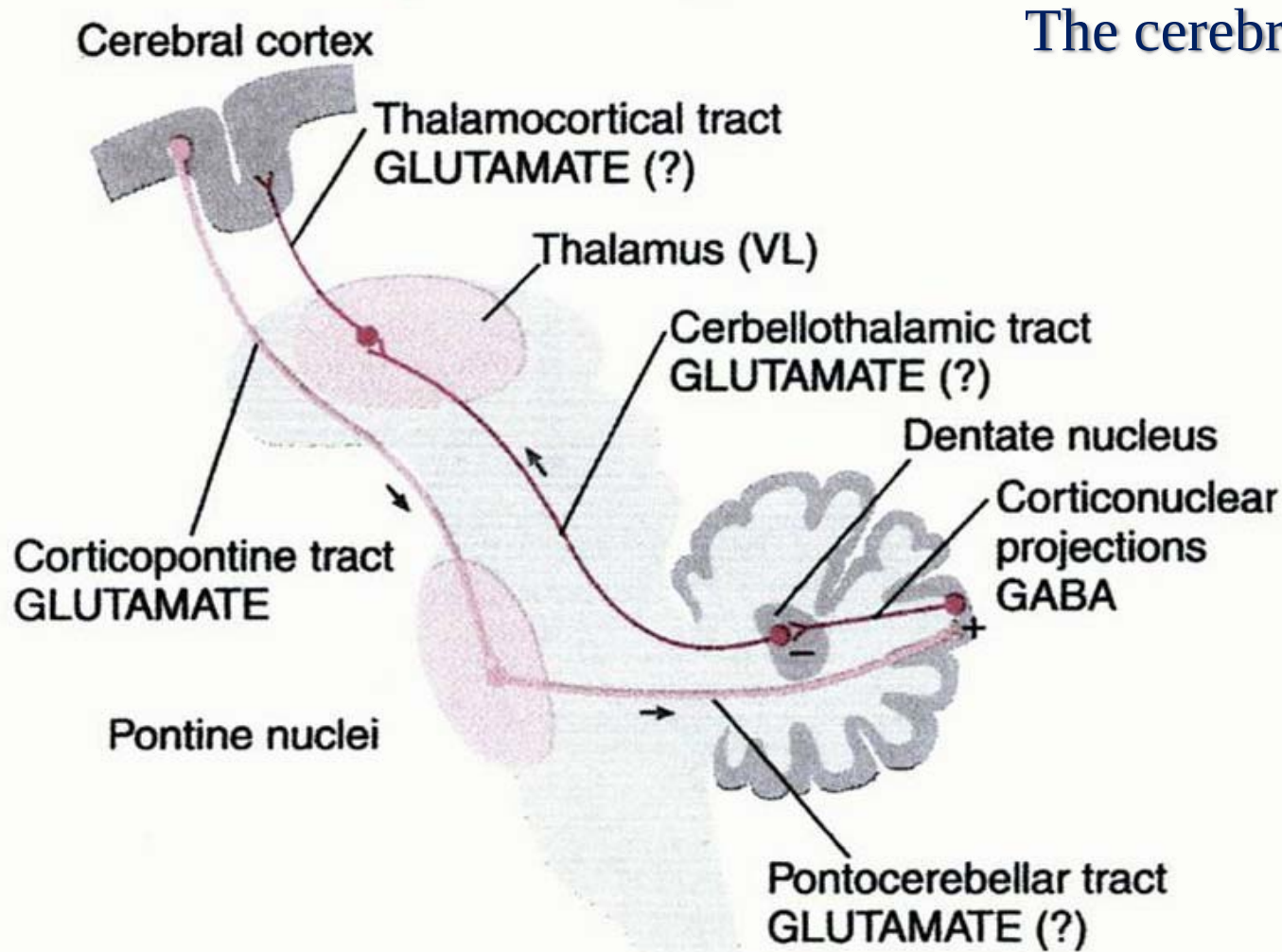
Pathways of the cerebellum: the afferent connections

Pathways:

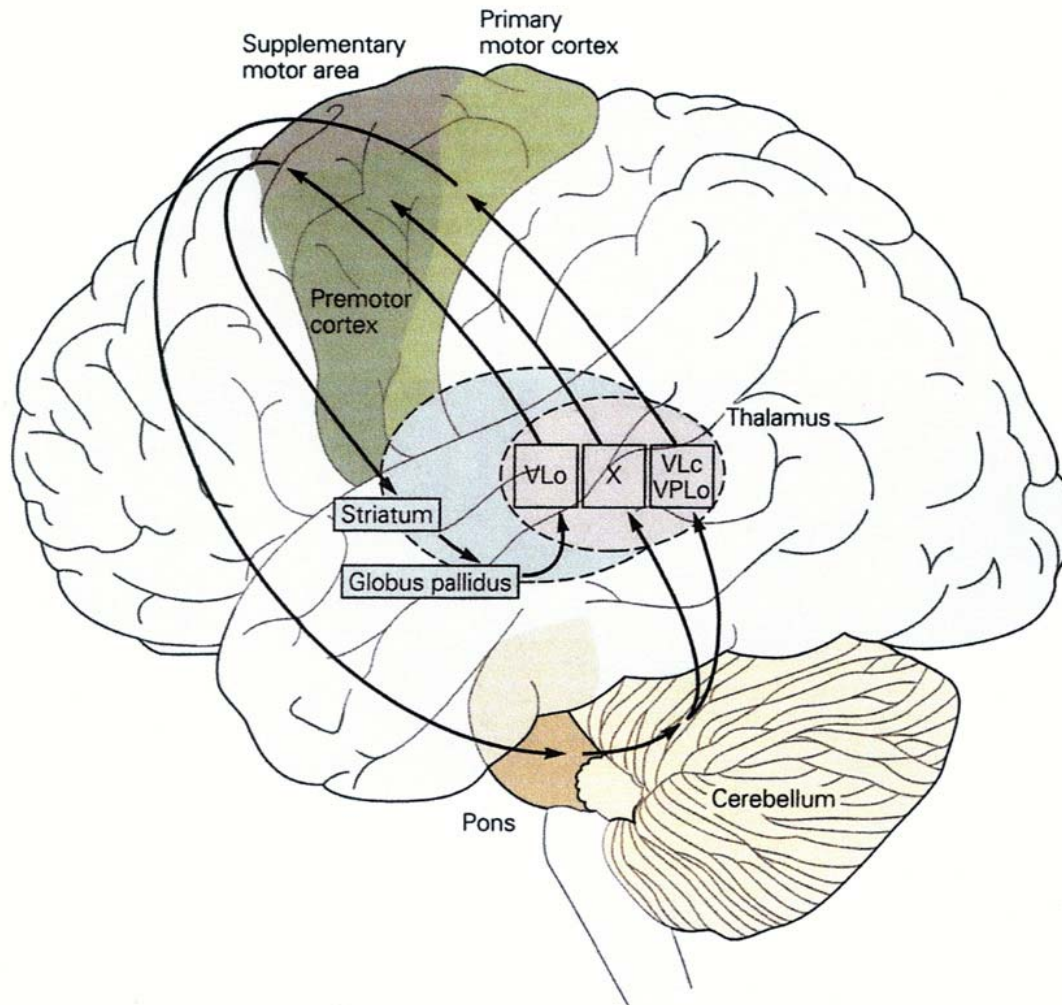
cerebrum (cortico-ponto-cerebellar)	—————→	mossy fibers
spinal cord (spino-cerebellar)	—————→	mossy fibers
oliva inferior (olivo-cerebellar)	—————→	climbing fibers
formatio reticularis (reticulo-cerebellar)	—————→	mossy fibers
vestibular system (vestibulo-cerebellar)	—————→	mossy fibers

The cerebro-ponto-cerebellar pathway





Information processing in the cerebro-cerebellar pathway

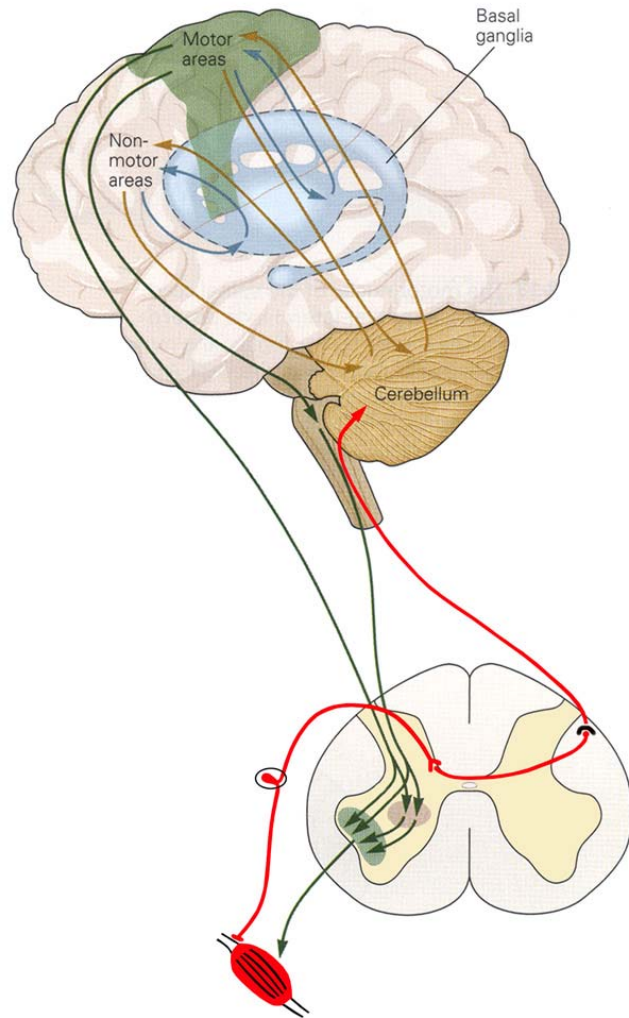


Pathways of the cerebellum: the afferent connections

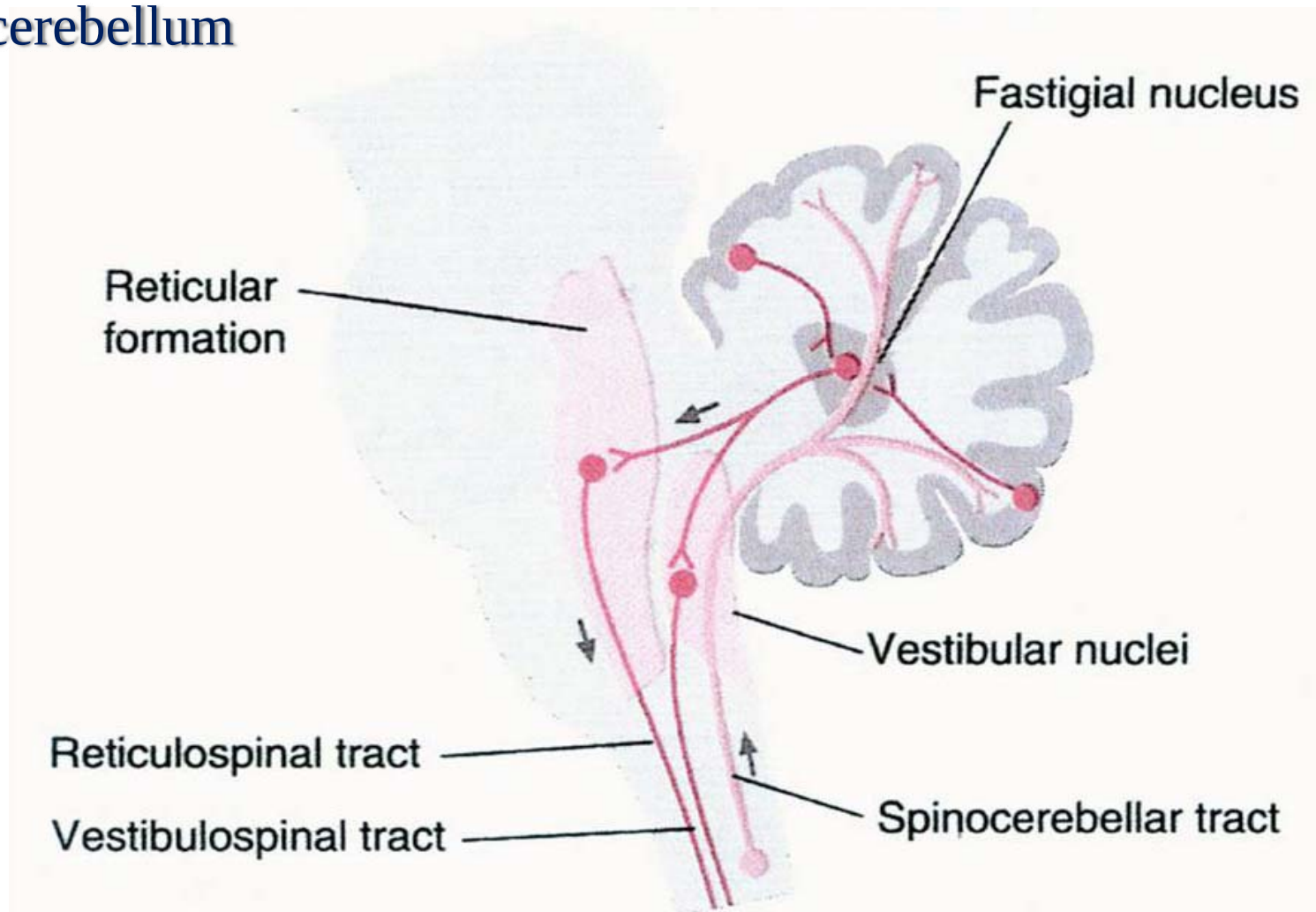
Pathways:

cerebrum (cortico-ponto-cerebellar)	—————→	mossy fibers
spinal cord (spino-cerebellar)	—————→	mossy fibers
oliva inferior (olivo-cerebellar)	—————→	climbing fibers
formatio reticularis (reticulo-cerebellar)	—————→	mossy fibers
vestibular system (vestibulo-cerebellar)	—————→	mossy fibers

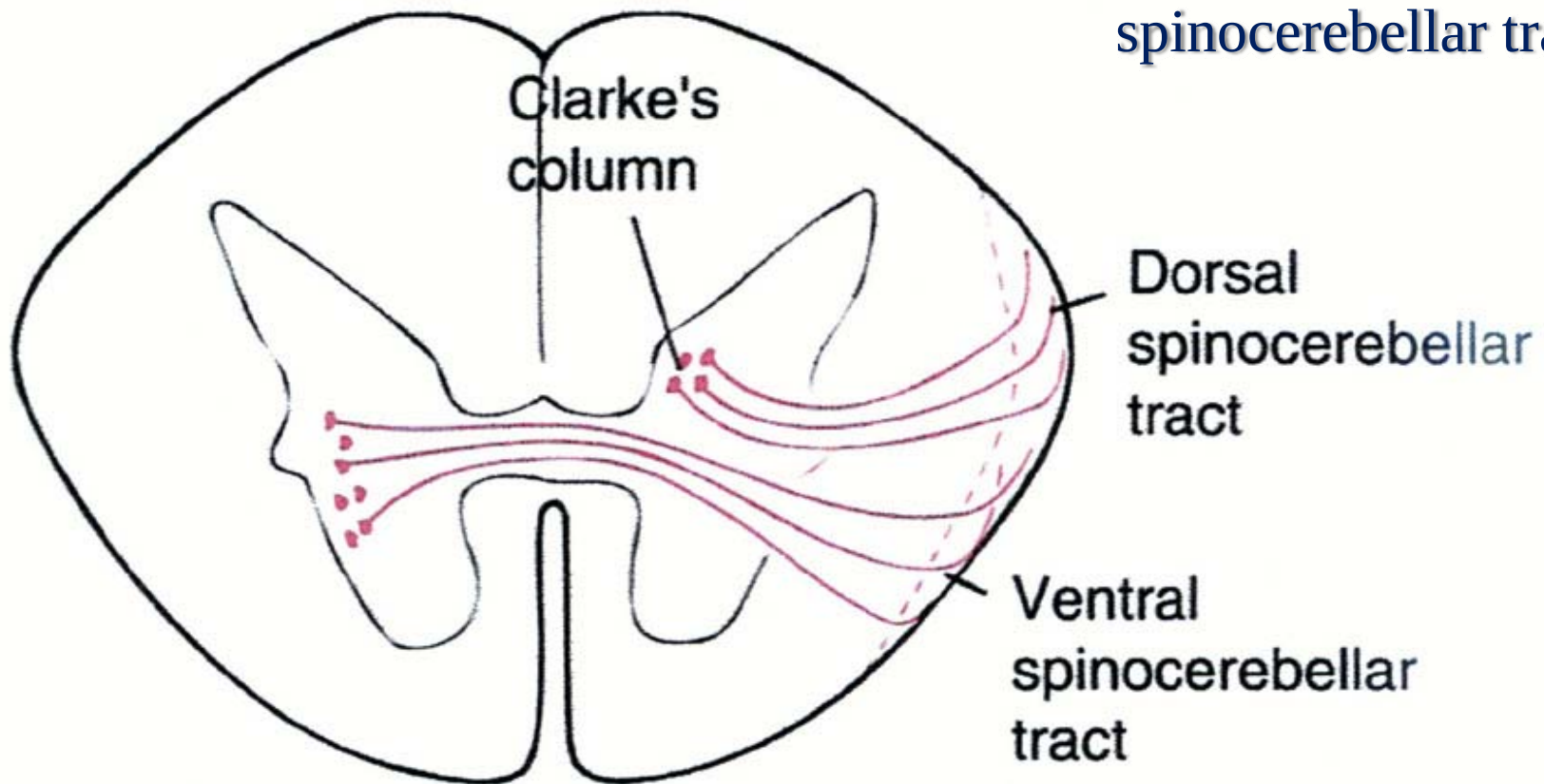
Structure, location and function of the spinocerebellar pathway



Spinocerebellum



Origin of spinocerebellar tracts

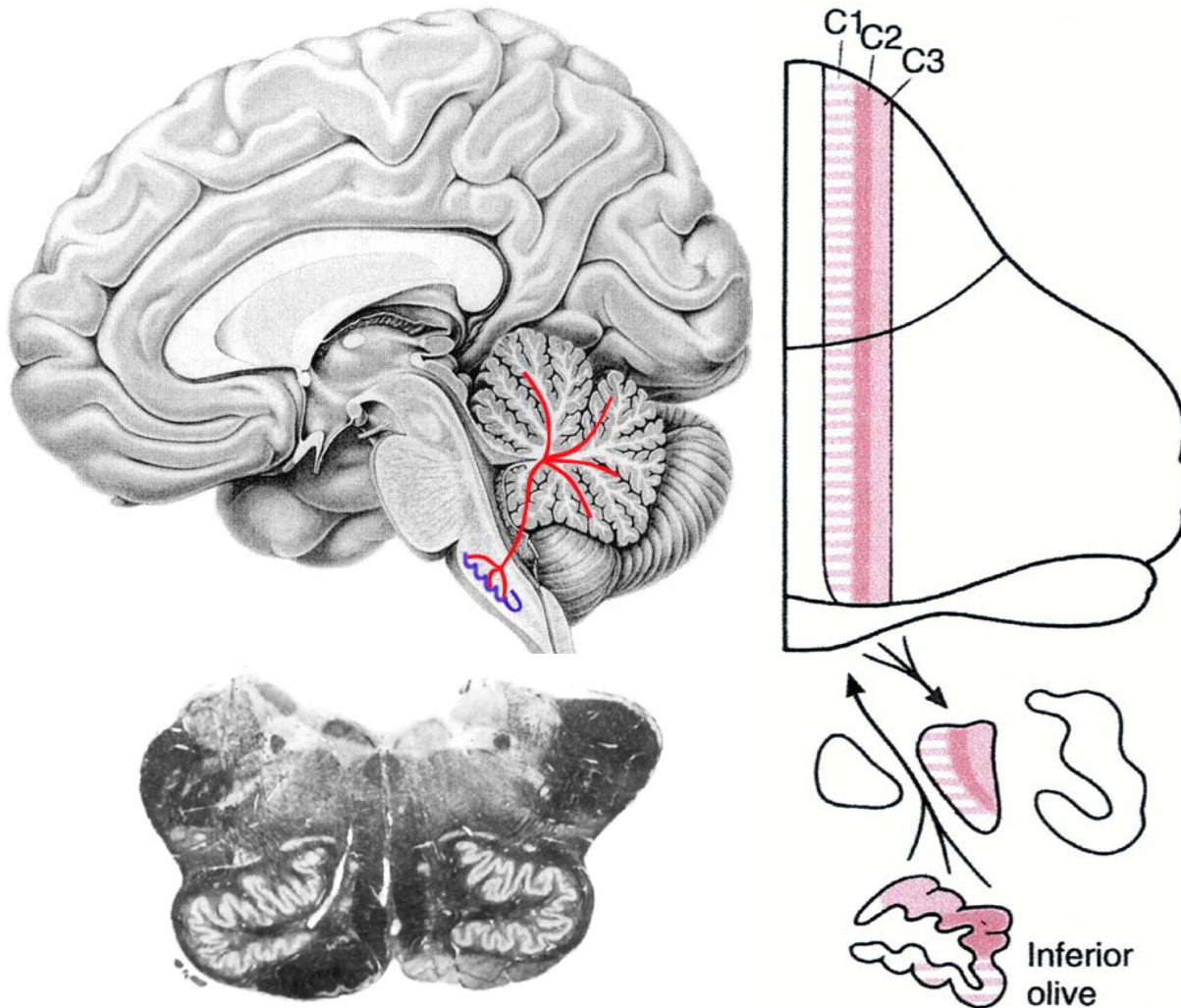


Pathways of the cerebellum: the afferent connections

Pathways:

cerebrum (cortico-ponto-cerebellar)	—————>	mossy fibers
spinal cord (spino-cerebellar)	—————>	mossy fibers
oliva inferior (olivo-cerebellar)	—————>	climbing fibers
formatio reticularis (reticulo-cerebellar)	—————>	mossy fibers
vestibular system (vestibulo-cerebellar)	—————>	mossy fibers

The olivo-cerebellar tract

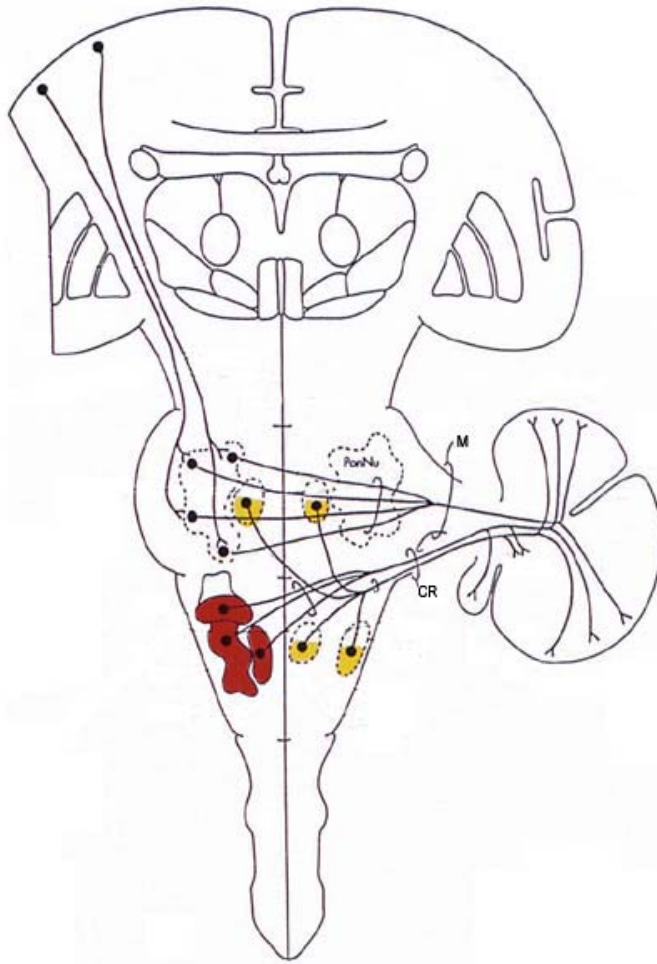


Pathways of the cerebellum: the afferent connections

Pathways:

cerebrum (cortico-ponto-cerebellar)	—————→	mossy fibers
spinal cord (spino-cerebellar)	—————→	mossy fibers
oliva inferior (olivo-cerebellar)	—————→	climbing fibers
formatio reticularis (reticulo-cerebellar)	—————→	mossy fibers
vestibular system (vestibulo-cerebellar)	—————→	mossy fibers

Reticulo-, and Olivocerebellar Fibers

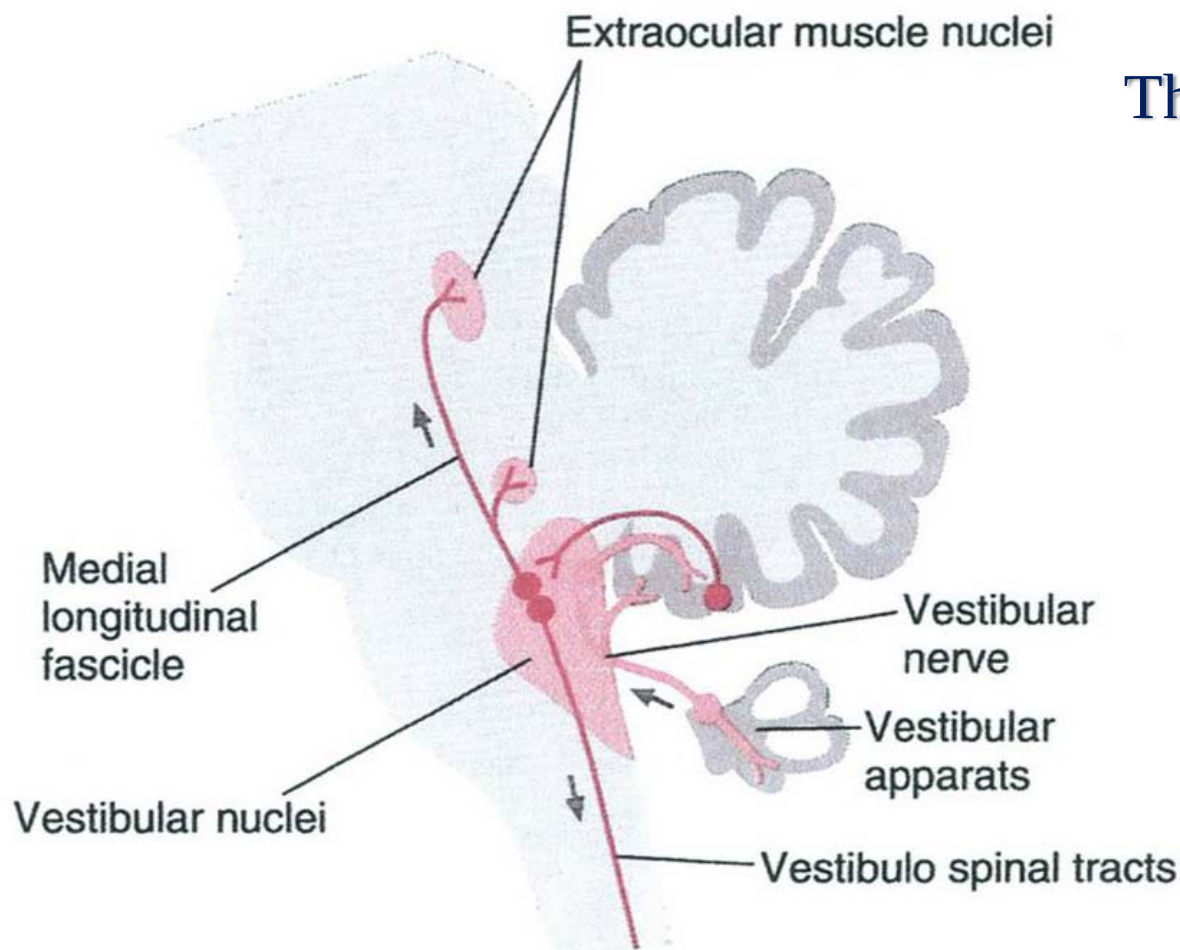


The reticulo-cerebellar tract

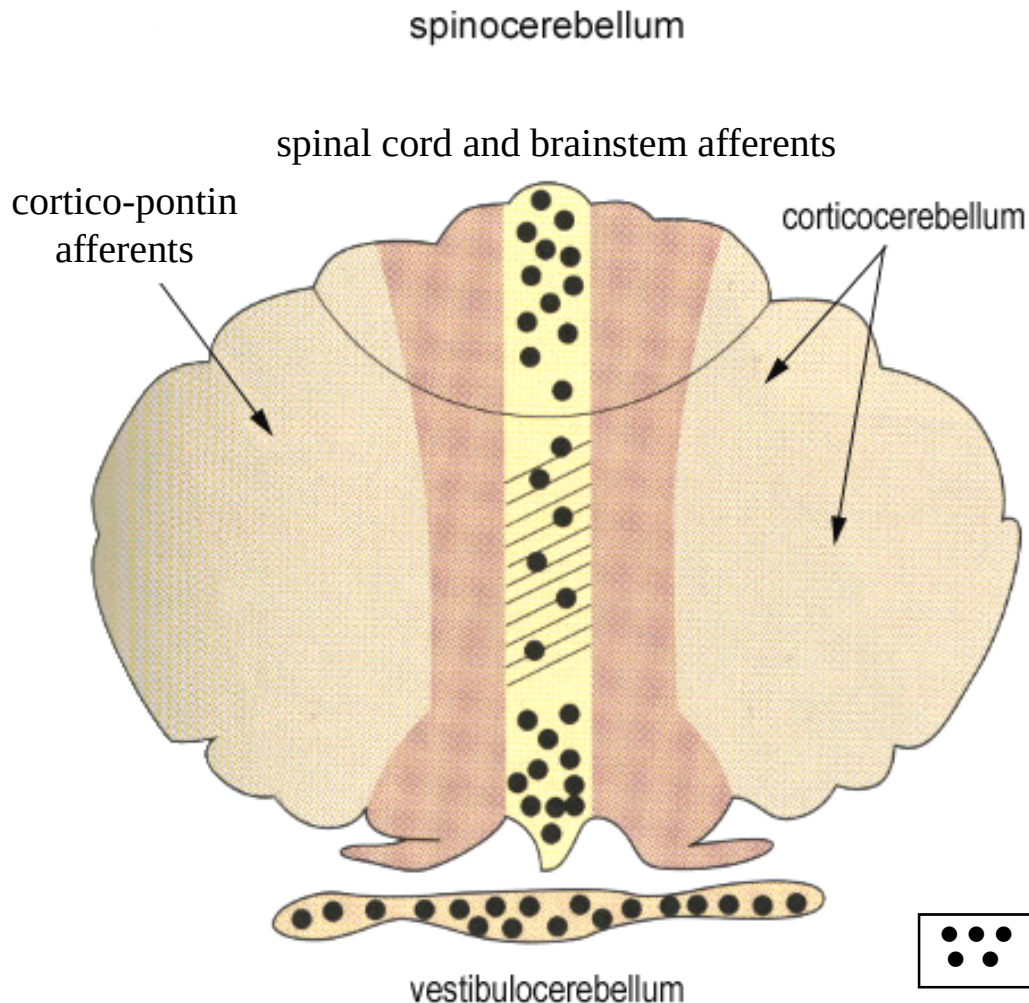
Pathways of the cerebellum: the afferent connections

Pathways:

cerebrum (cortico-ponto-cerebellar)	—————>	mossy fibers
spinal cord (spino-cerebellar)	—————>	mossy fibers
oliva inferior (olivo-cerebellar)	—————>	climbing fibers
formatio reticularis (reticulo-cerebellar)	—————>	mossy fibers
vestibular system (vestibulo-cerebellar)	—————>	mossy fibers



The vestibulocerebellum



Termination fields of the afferent pathways in the cerebellum

Pathways of the cerebellum: the efferent connections

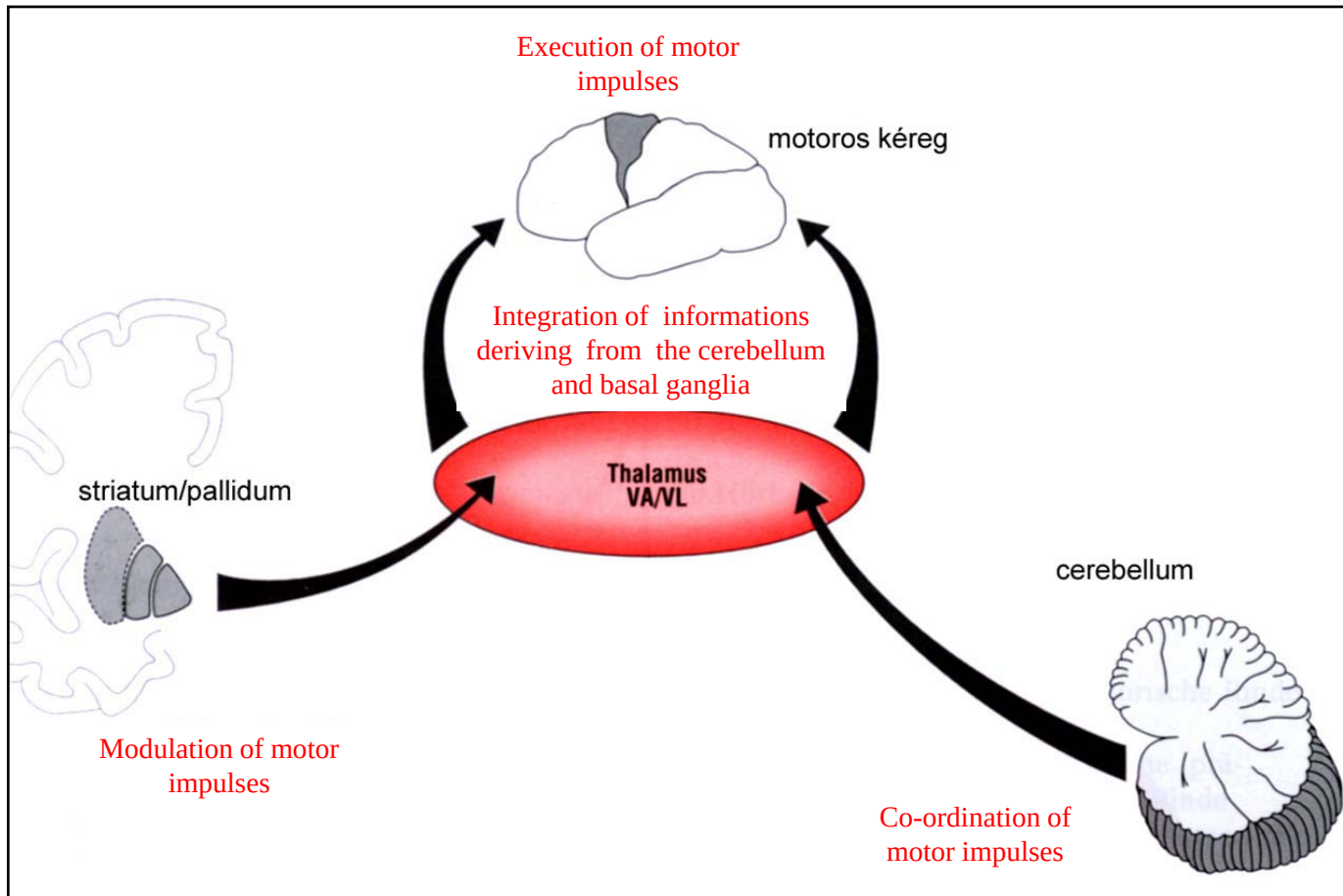
Cerebello-cerebral pathway:

Purkinje cell → cerebellar nuclei →
→ thalamo-cortical
→ rubro-spinal

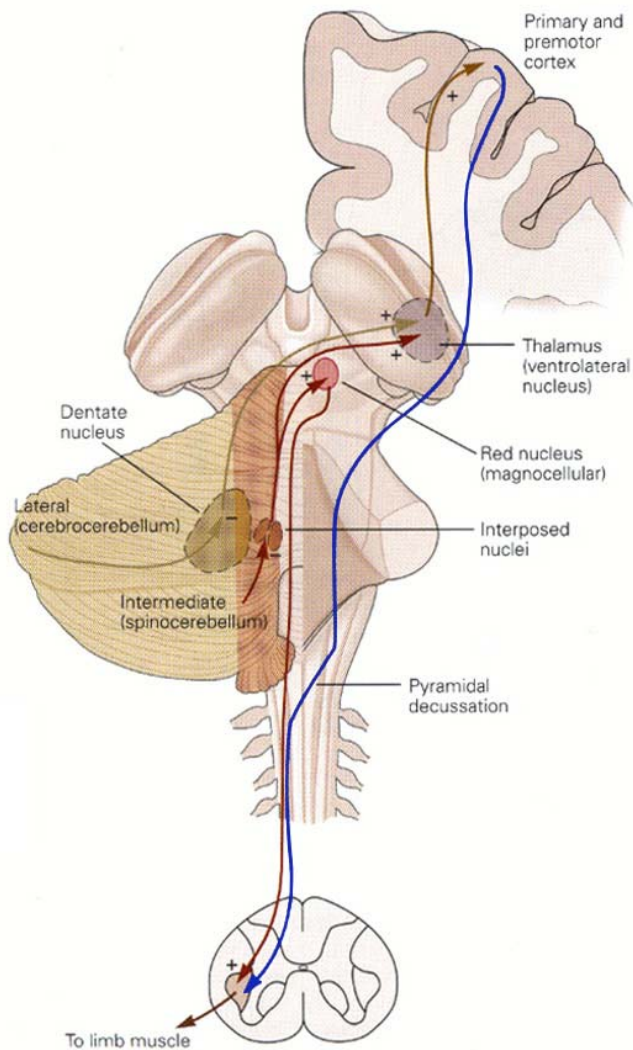
Cerebello-vestibular pathway:

→ Purkinje cell → vestibular nuclei → vestibulo-spinal

Ventral motor nuclei of the thalamus



Dentato-thalamic and dentato-rubral pathways



Pathways of the cerebellum: the efferent connections

Cerebello-cerebral pathway:

Purkinje cell → cerebellar nuclei →

→ thalamo-cortical

→ rubro-spinal

Cerebello-vestibular pathway:

→ Purkinje cell → vestibular nuclei → vestibulo-spinal

Pathways of the cerebellum: the efferent connections

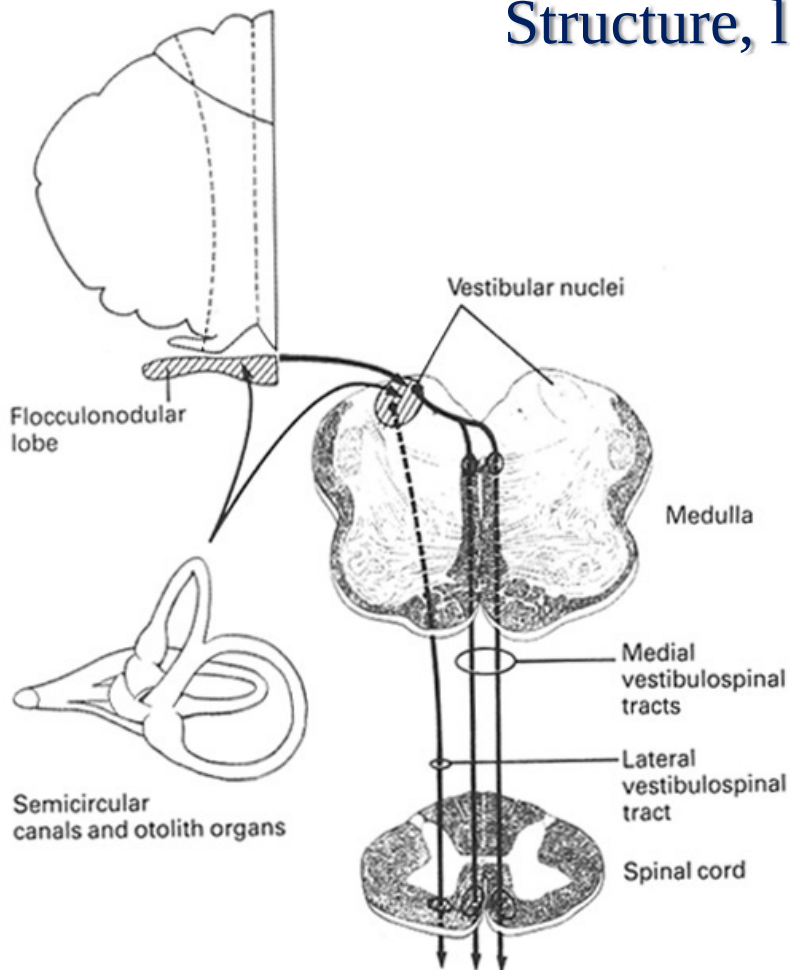
Cerebello-cerebral pathway:

Purkinje cell → cerebellar nuclei →
→ thalamo-cortical
→ rubro-spinal

Cerebello-vestibular pathway:

→ Purkinje cell → vestibular nuclei → vestibulo-spinal

Structure, location and function of the cerebello-vestibular pathway



Introduction to functional neurobiology: Cerebellum

www.itk.ppke.hu

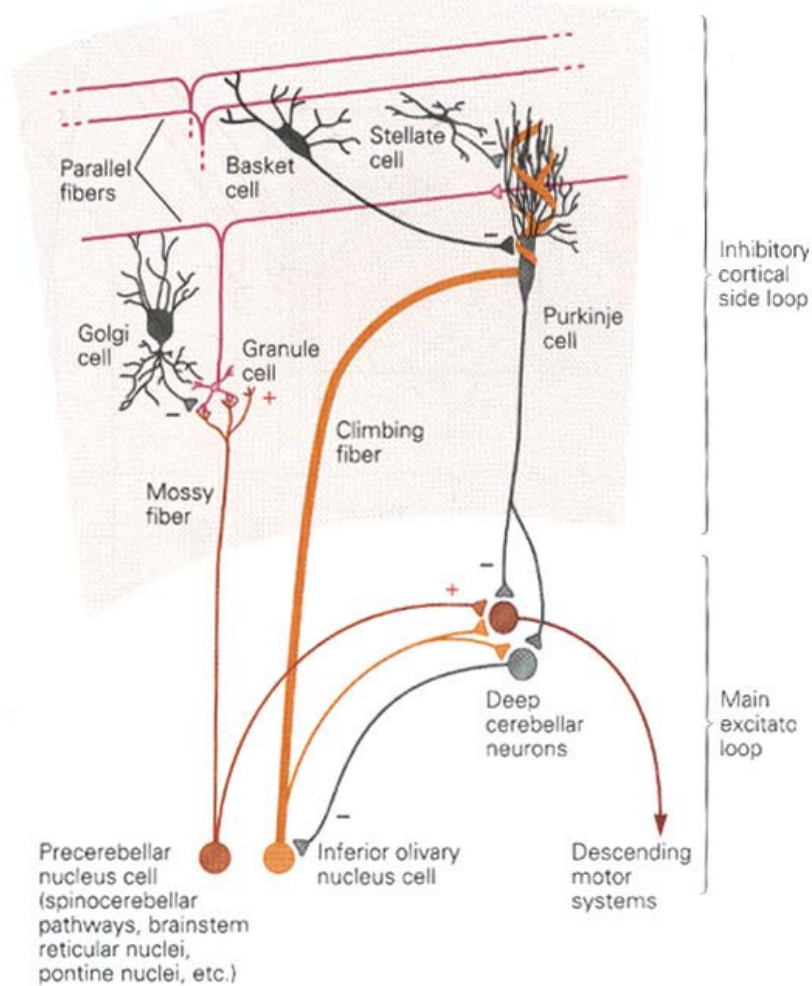
	Anatomical regions	Incoming informations	Relay nucleus	Termination field	Function
Spinocerebellum	vermis	vestibular labyrinth, spinal cord (upper part of the body) cranial nerves (head, neck)	fastigial	medial system: vestibularis nucleus, reticular formation, motor cortex	coordination of movements
	intermediate cortex	spinal cord (lower part of the body)	interpositus	lateral system: nucleus ruber (magnocellular), distal motor cortex	coordination of movements
Cerebrocerebellum	lateral cortex	cerebral cortex	dentate	integrative system: nucleus ruber (parvocellular), premotor cortex (area 6)	initiation of movements, planning and temporal-tuning of movements
Vestibulocerebellum	flocculonodular lobe	vestibular labyrinth	lateral vestibular	medial system: motoneurons	posture, vestibular reflexes

Cerebellar network model

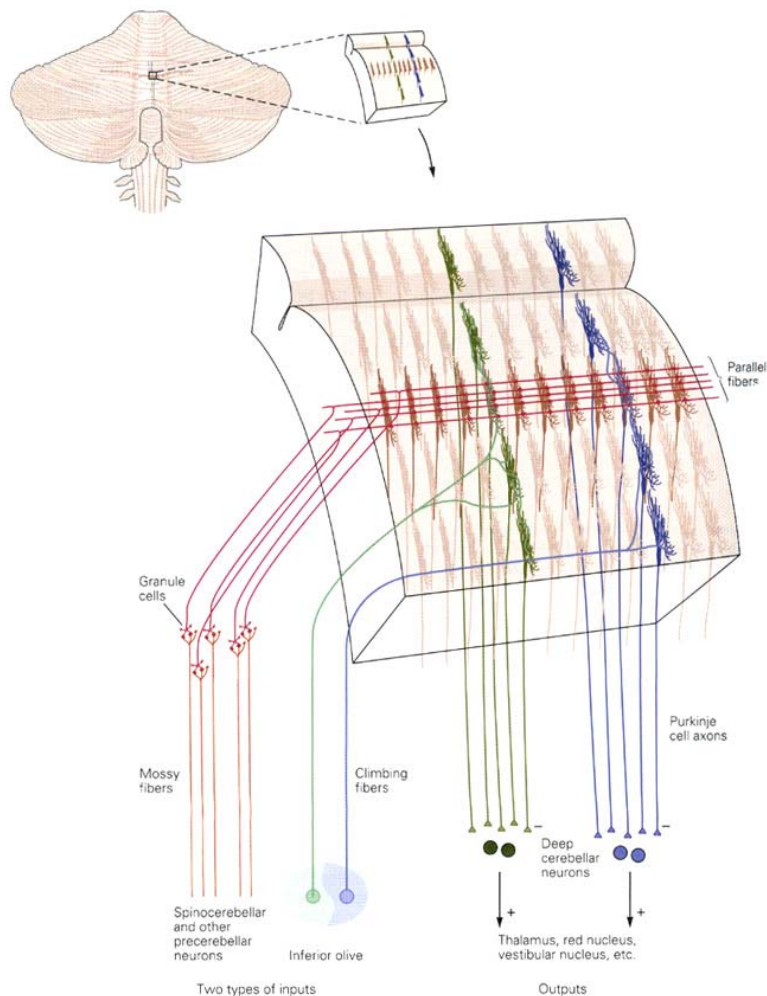
Activation of Purkinje cells

- climbing fibers
 - stimulation of single Purkinje cells
 - Golgi cell, inhibition by basket cells
- mossy fibers - glomerulus – activation by T-axons

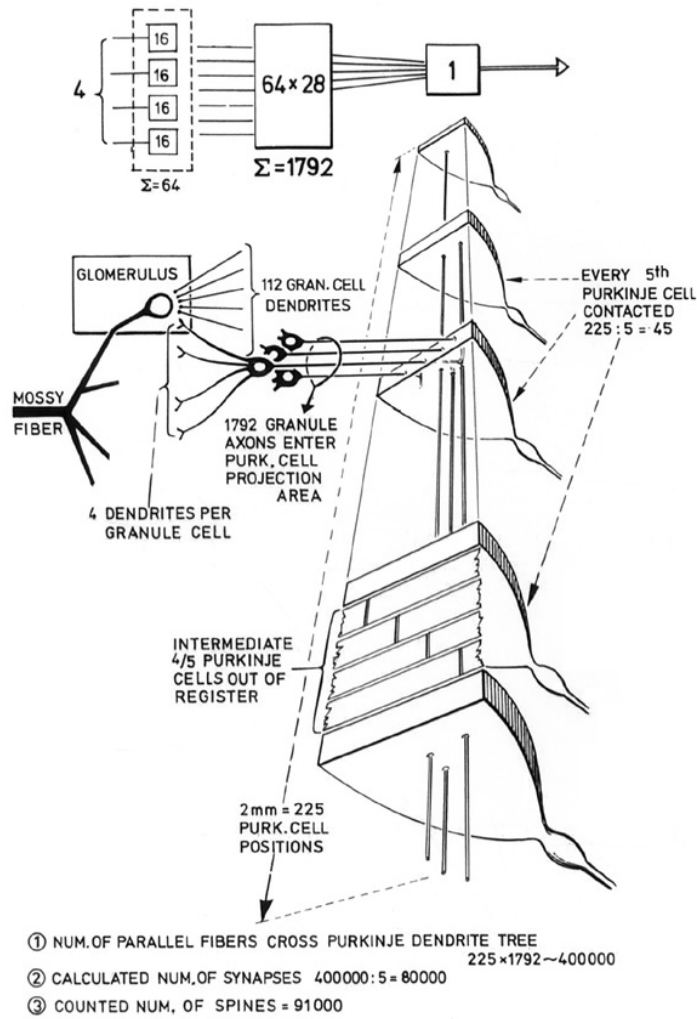
Cerebellar network model



Cerebellar network model



Cerebellar network model

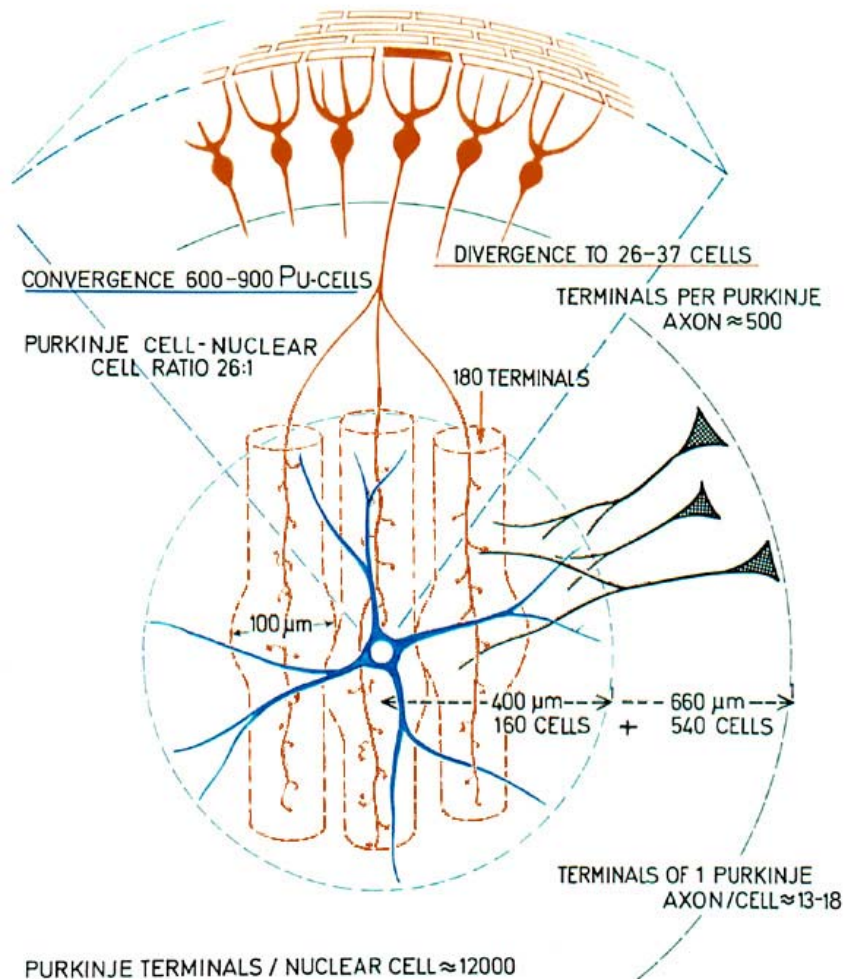


Cerebellar network model

Activation of Purkinje cells (signal divergence)

- climbing fibers
 - stimulation of single Purkinje cells
 - Golgi cell, inhibition by basket cells
- mossy fibers - glomerulus – activation by T-axons
- **Output – signal originating from Purkinje cells (signal convergence)**
 - cerebellar nuclei → efferent pathways

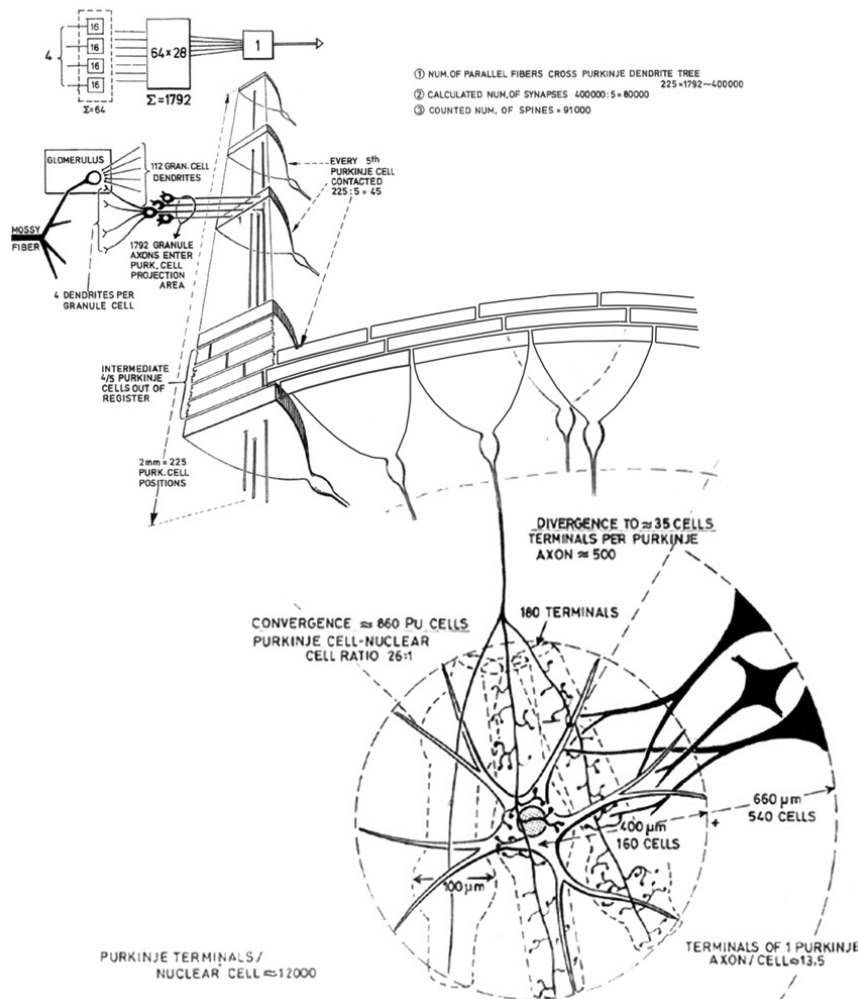
Cerebellar network model



26

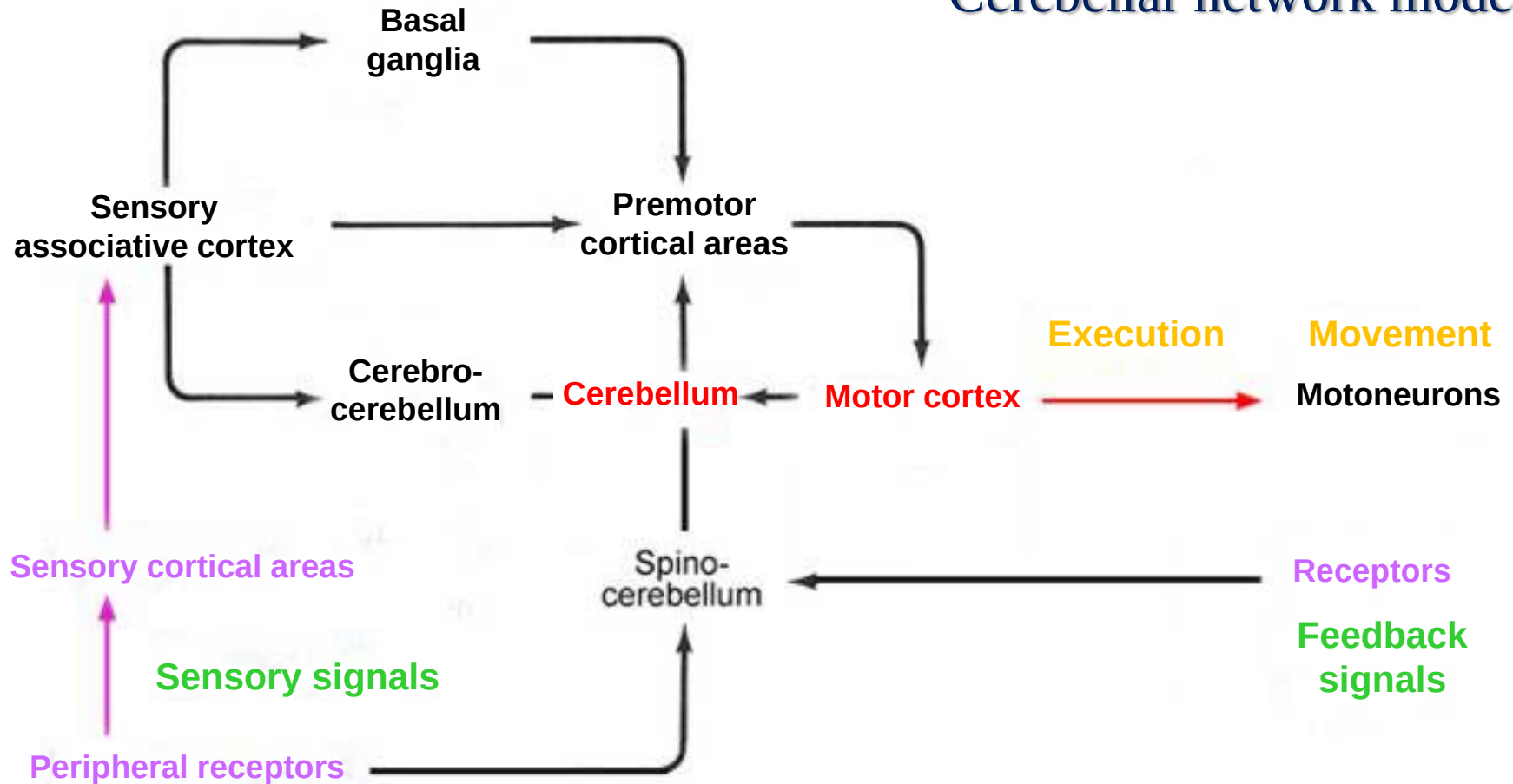
M. PALKOVITS *et al.*

Cerebellar network model

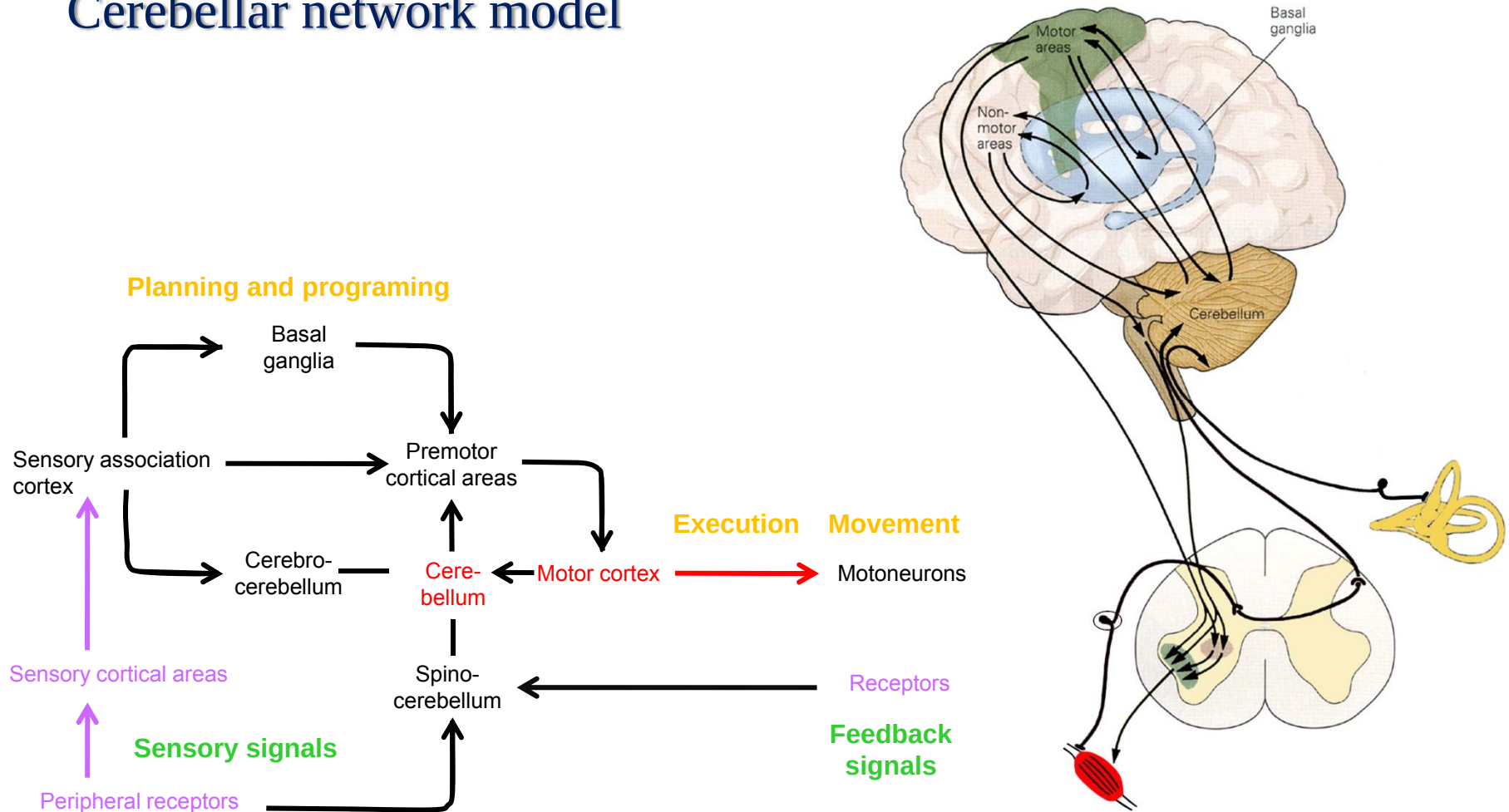


Planning and programing

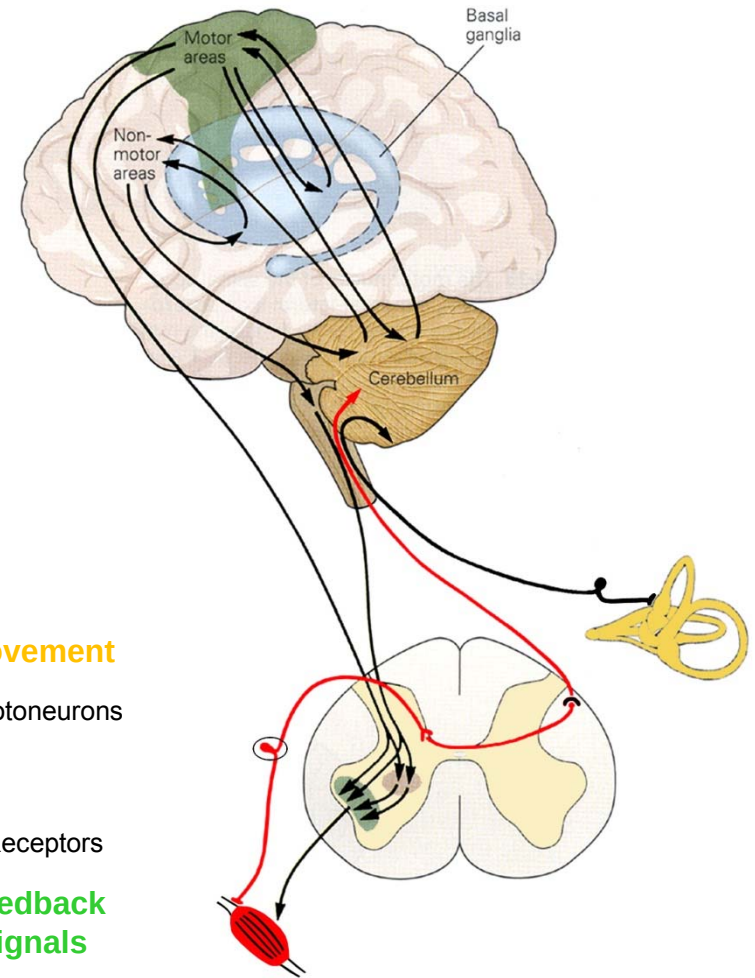
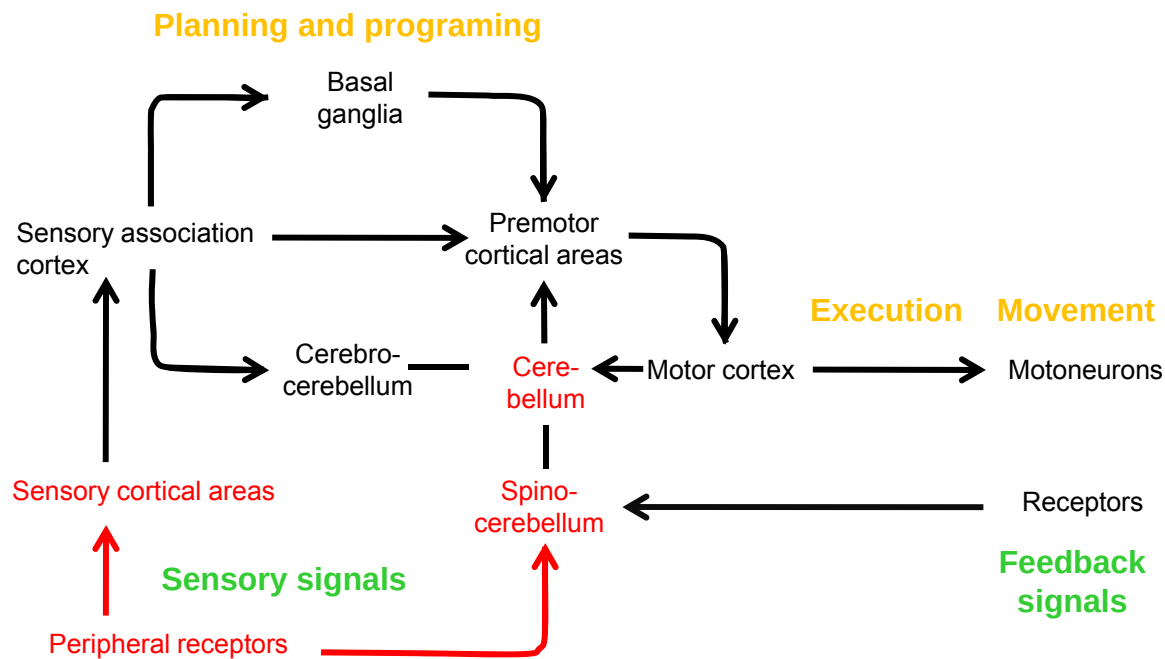
Cerebellar network model



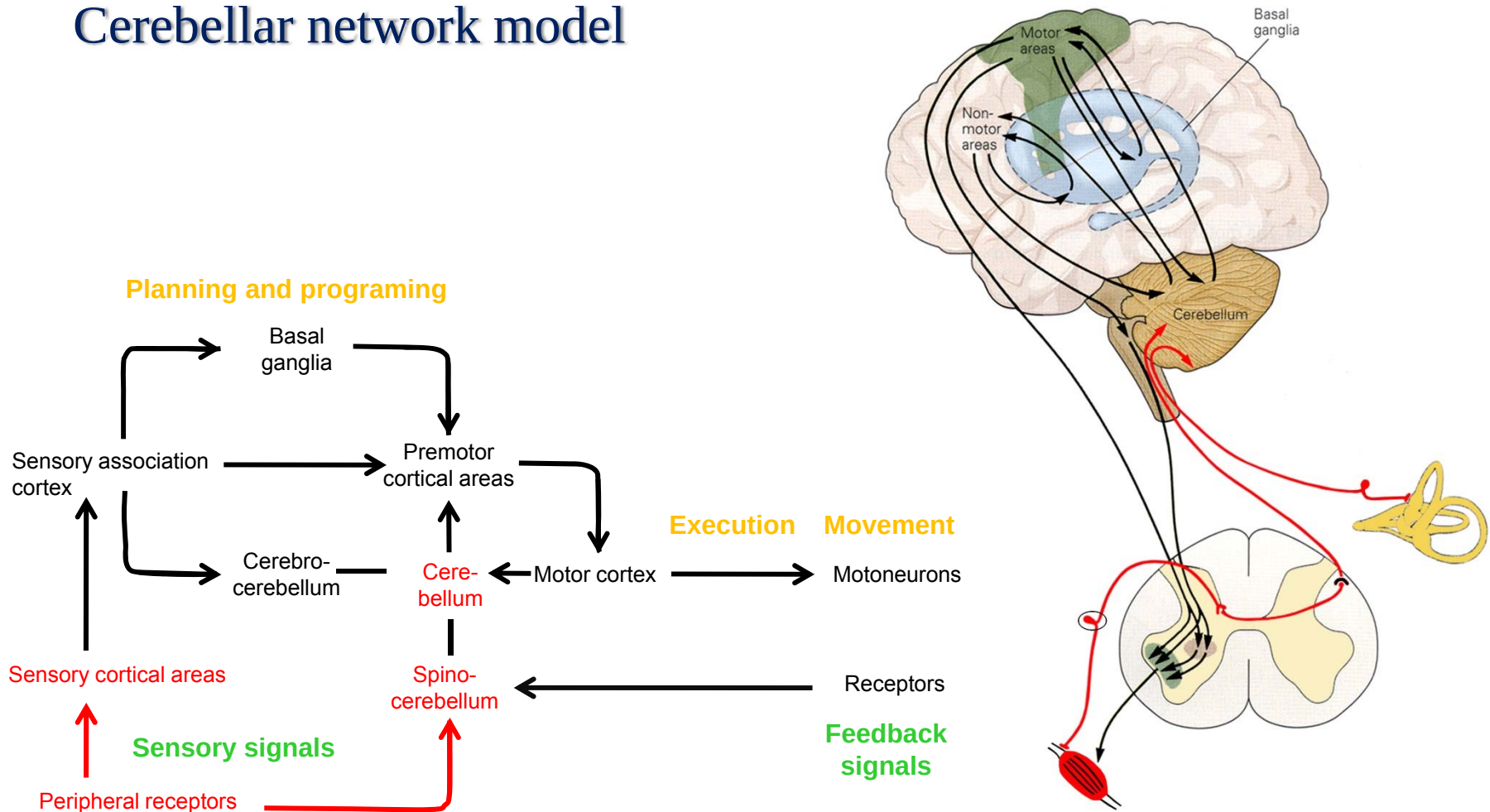
Cerebellar network model



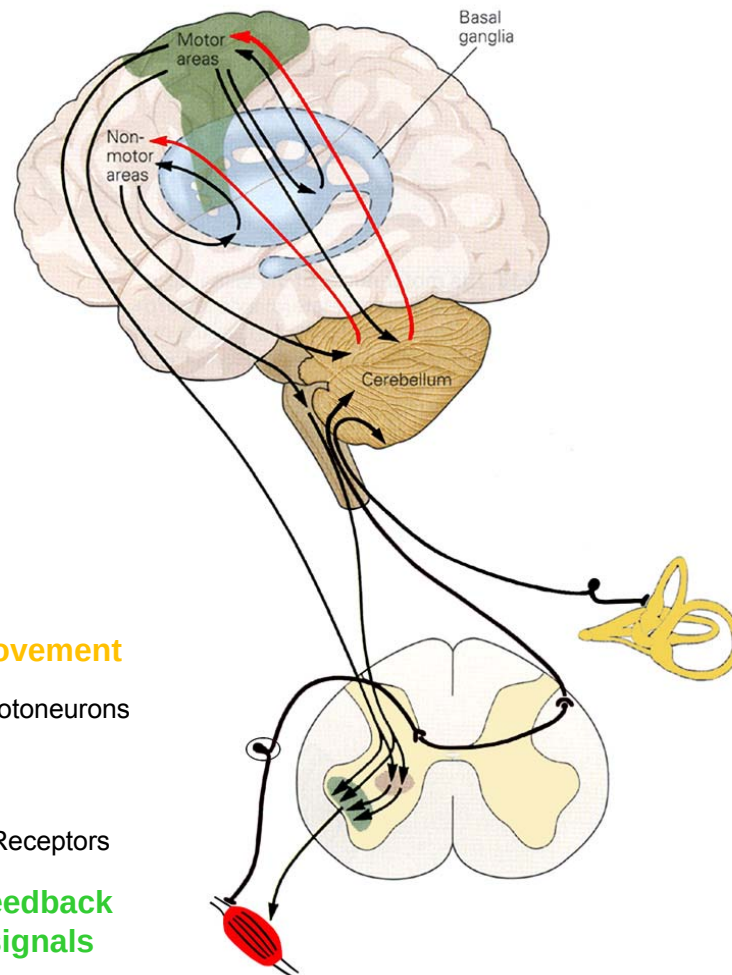
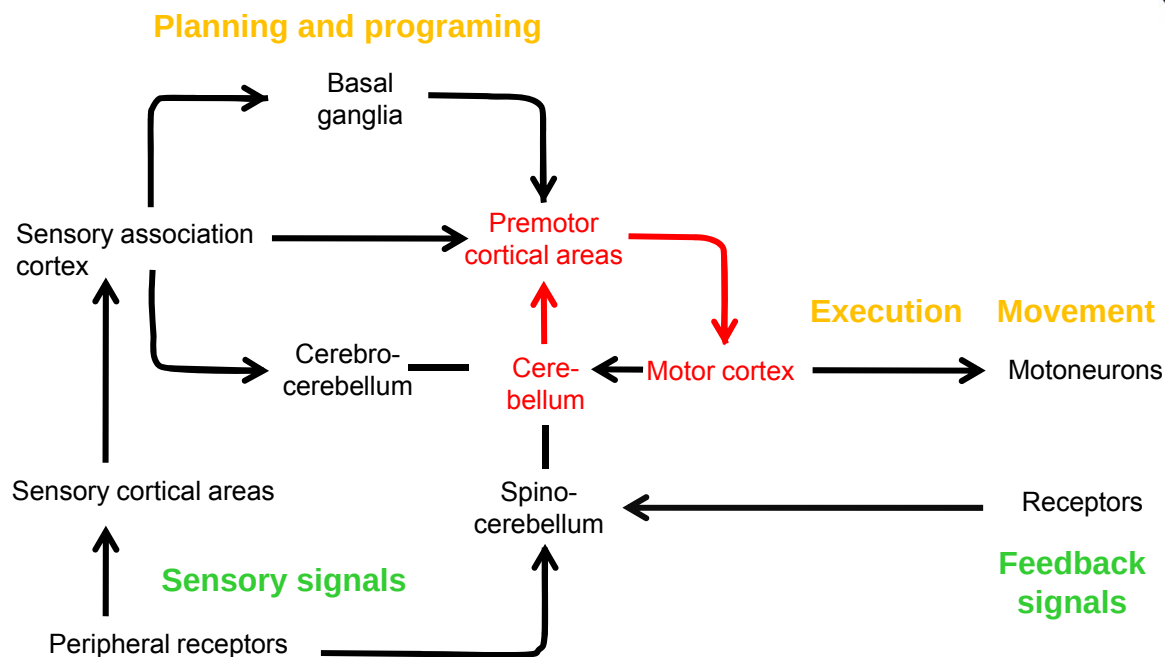
Cerebellar network model



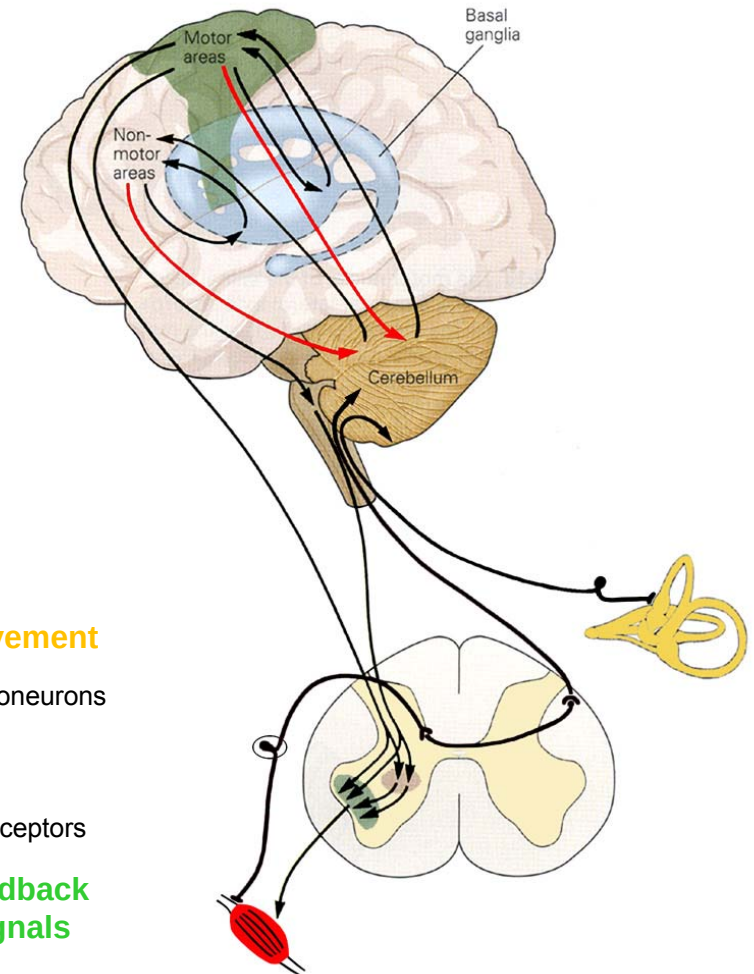
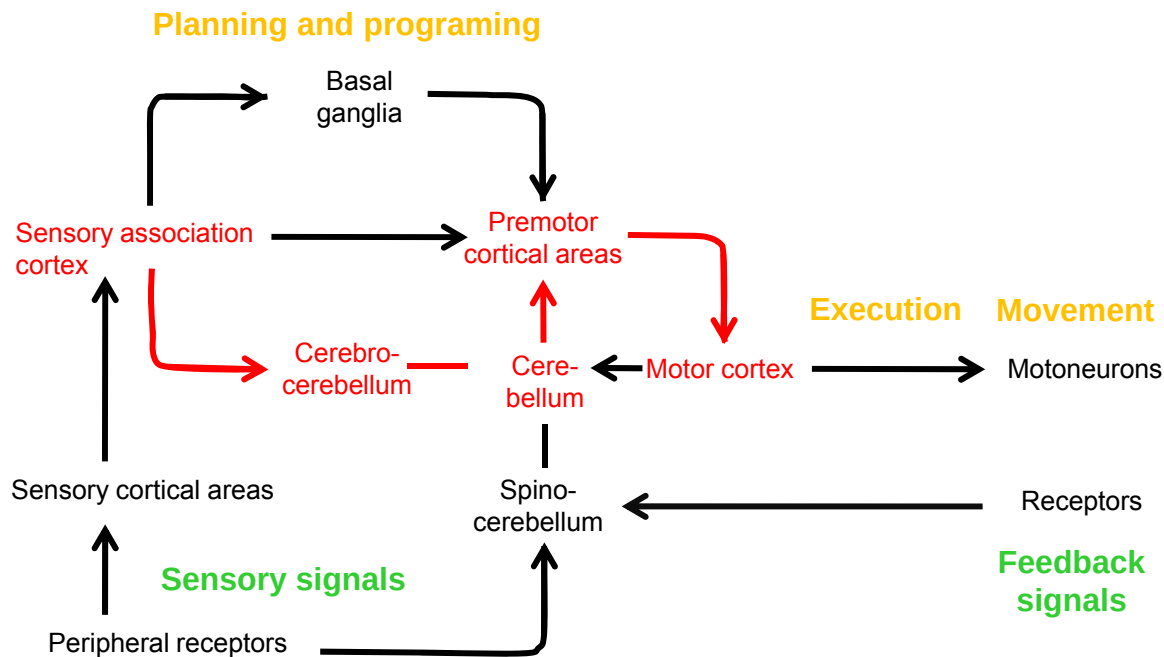
Cerebellar network model



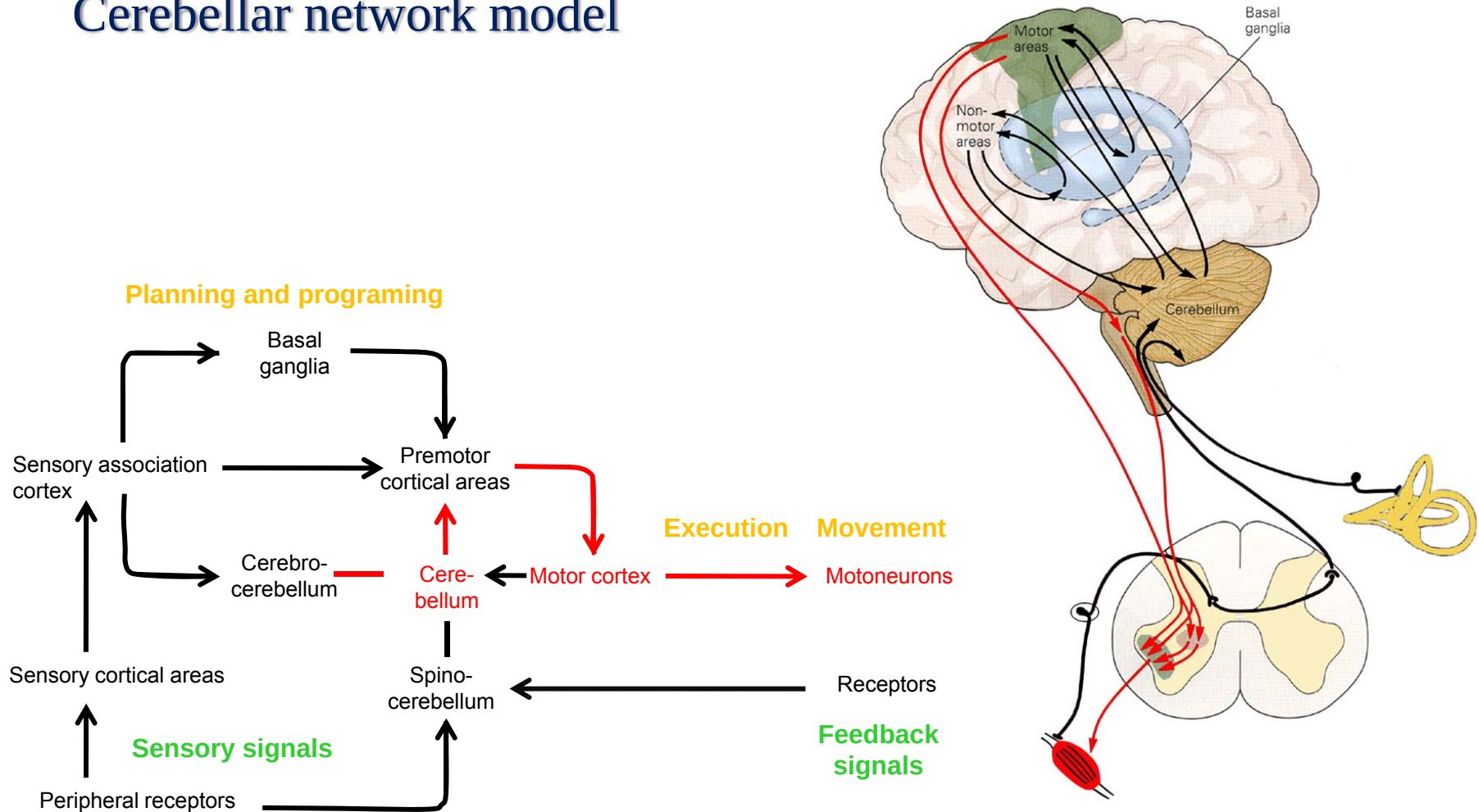
Cerebellar network model



Cerebellar network model



Cerebellar network model



Cerebellar network model

