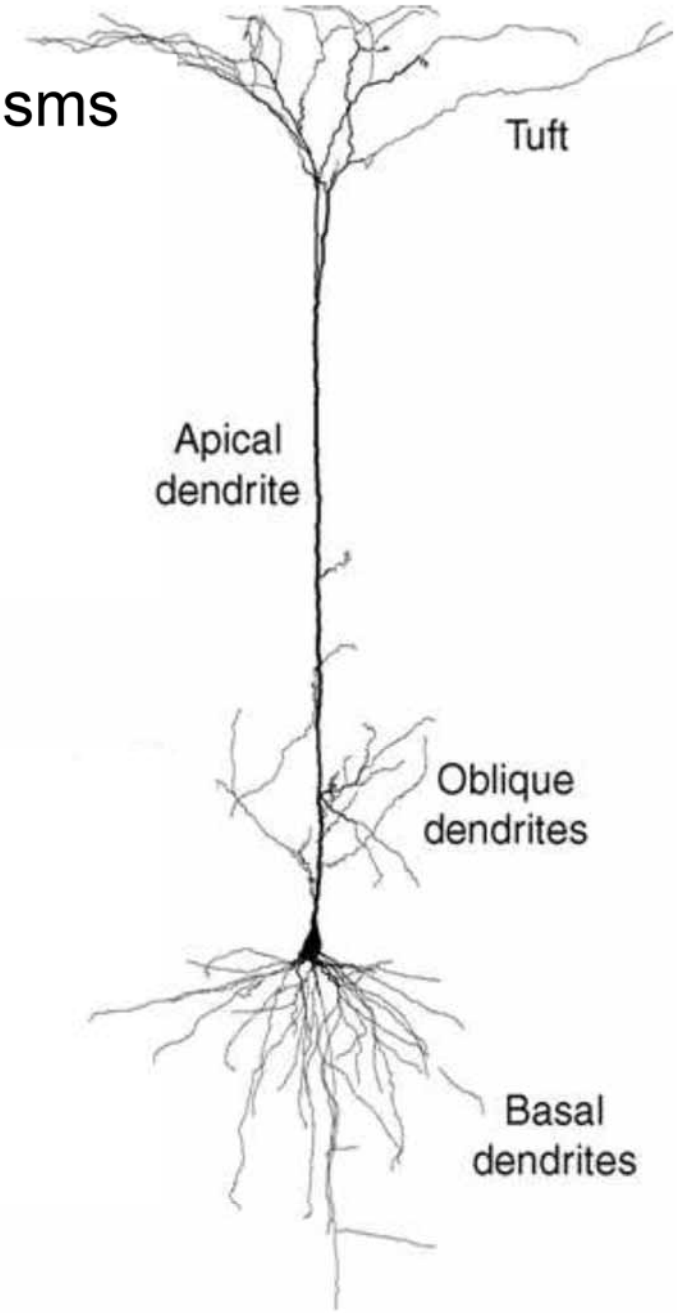
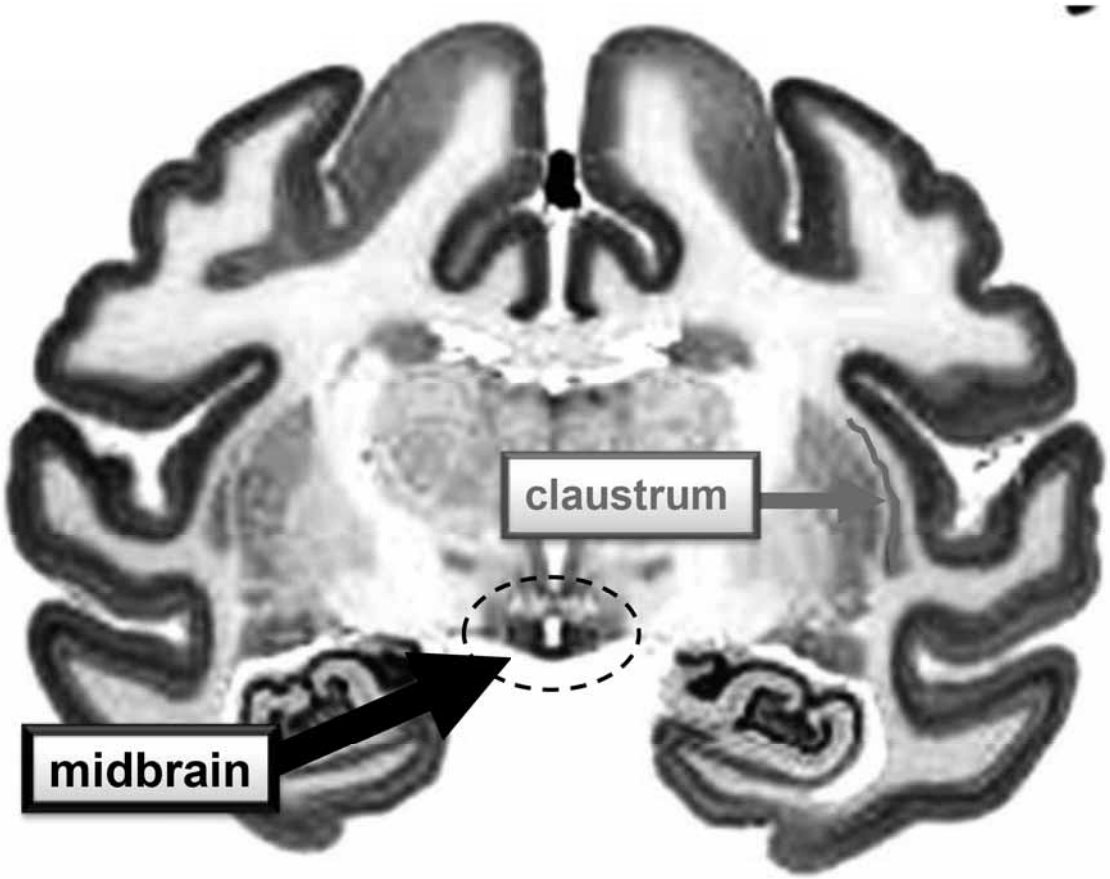
Cerebral Cortex – Cellular Mechanisms

TOP DOWN APPROACH

1 Cortical Functions
2 Cortical Areas
3 Cortical Flow of Information

4 Cortical Layers
5 Cellular Elements
6 Synaptic Connections
7 Synaptic Integration
8 Membrane Receptors





Consciousness

subjectivity

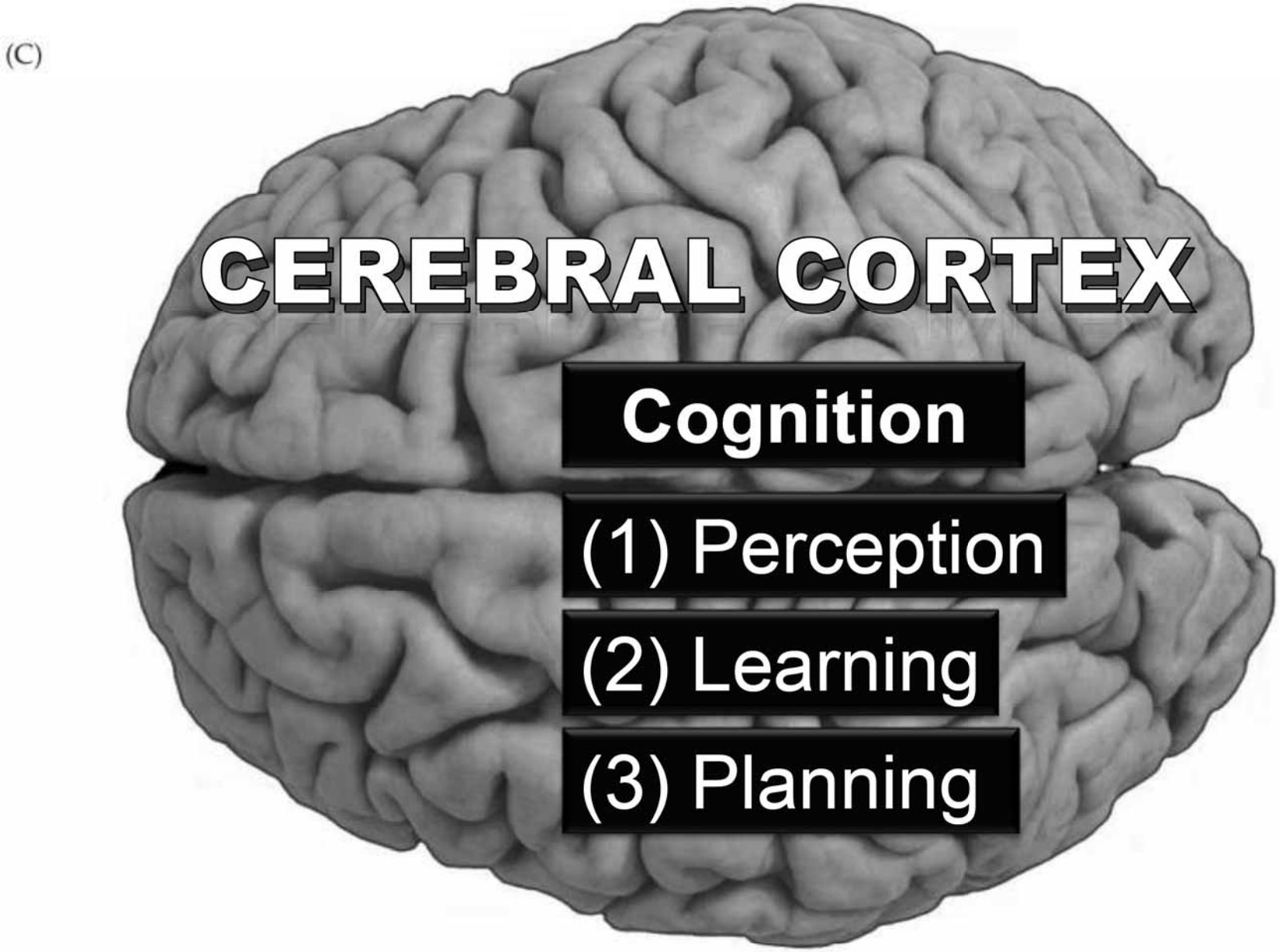
unity

intentionality

Watson and Crick - DNA – 1962 Nobel – Consciousness – Cell Mech

***The Mystery of the Mind : A Critical Study of Consciousness and the Human Brain*. Penfield, Wilder. Princeton University Press, 1975.**

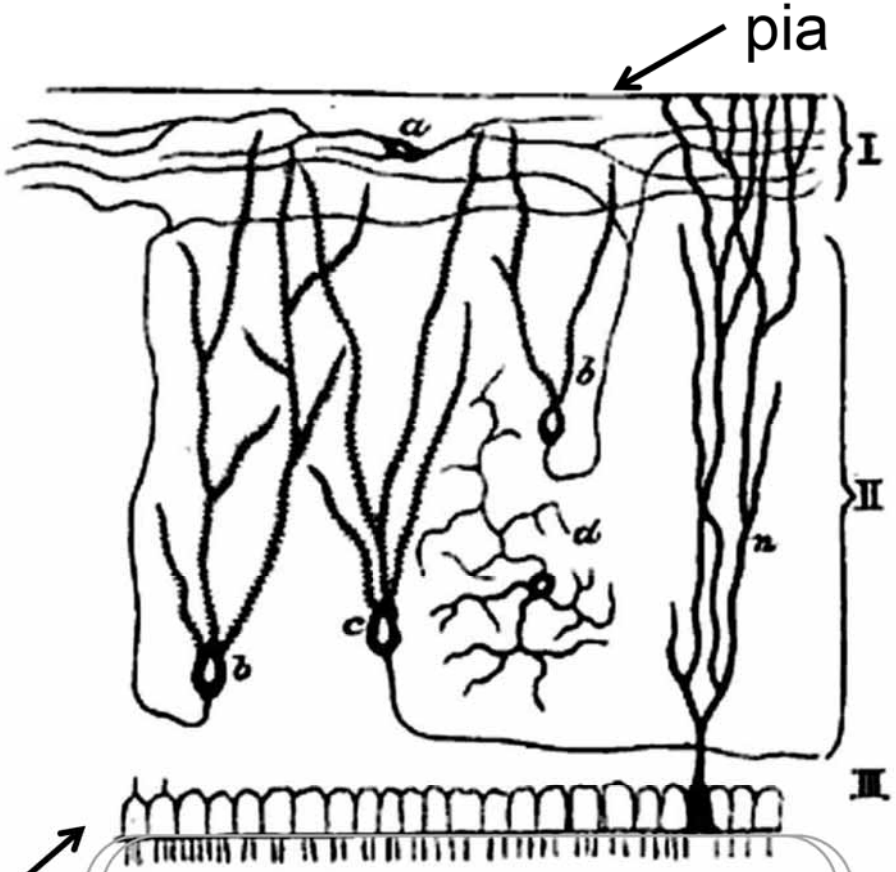
Surface features of a human brain specimen



***NEUROSCIENCE, Fourth Edition*, Atlas, Plate 1 (Part 3)**

Frog Cortex – Only 2 Layers

Frog Cerebral Cortex



Ependymal Epithelium

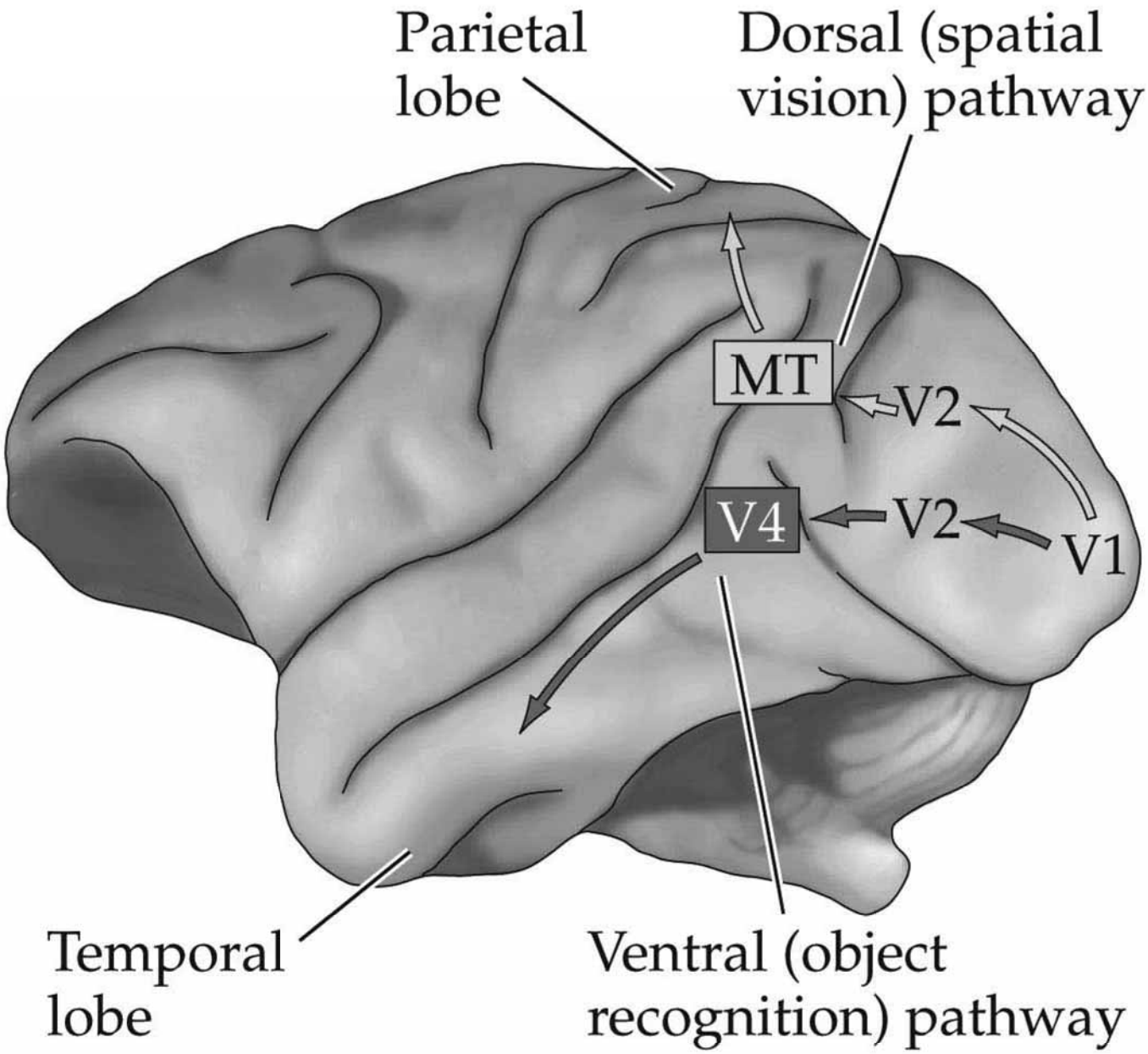
Frog Cerebral Ventricle

Cerebrospinal Fluid

Frog – 2 Layers

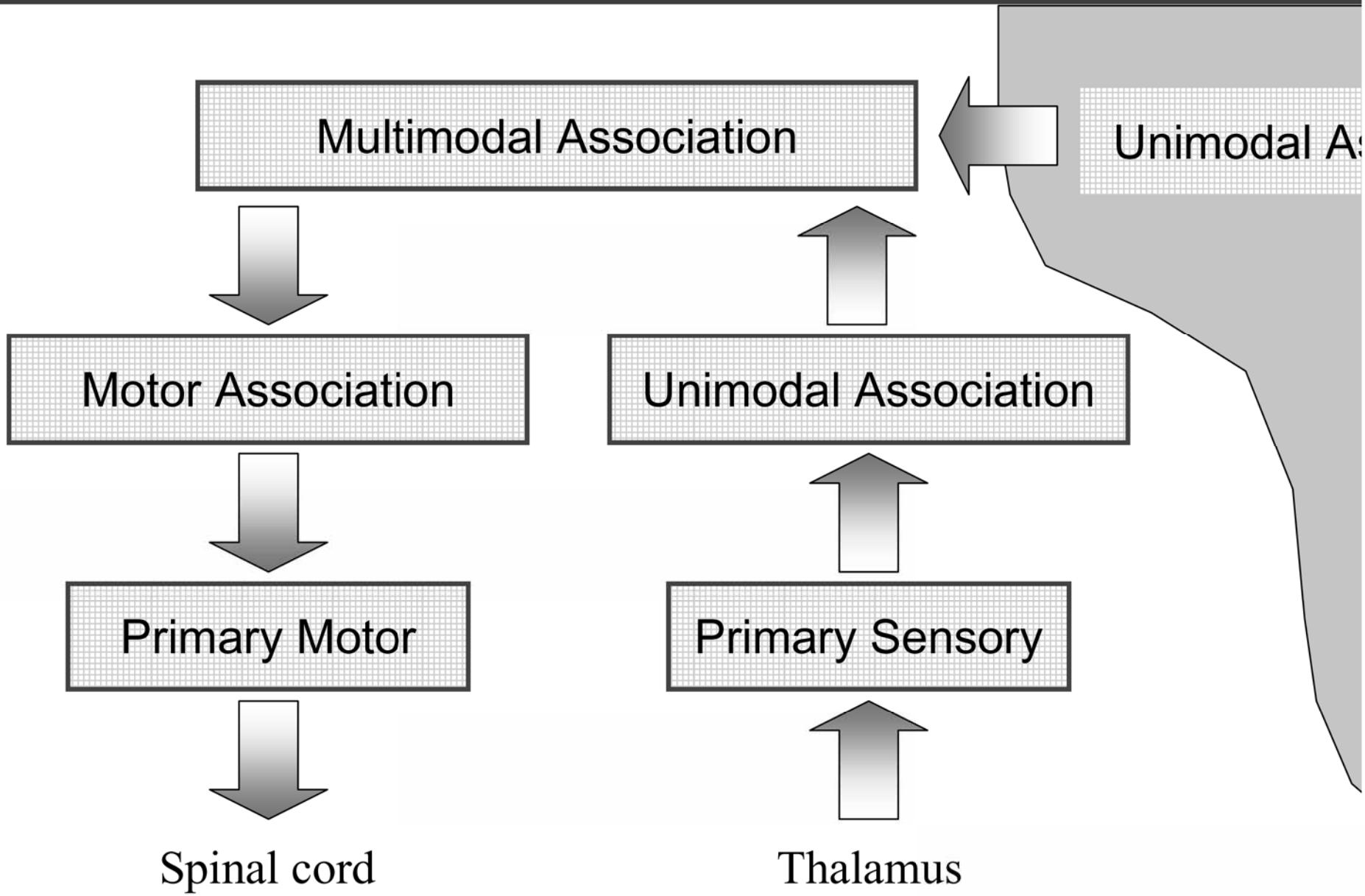
Human – 6 Layers

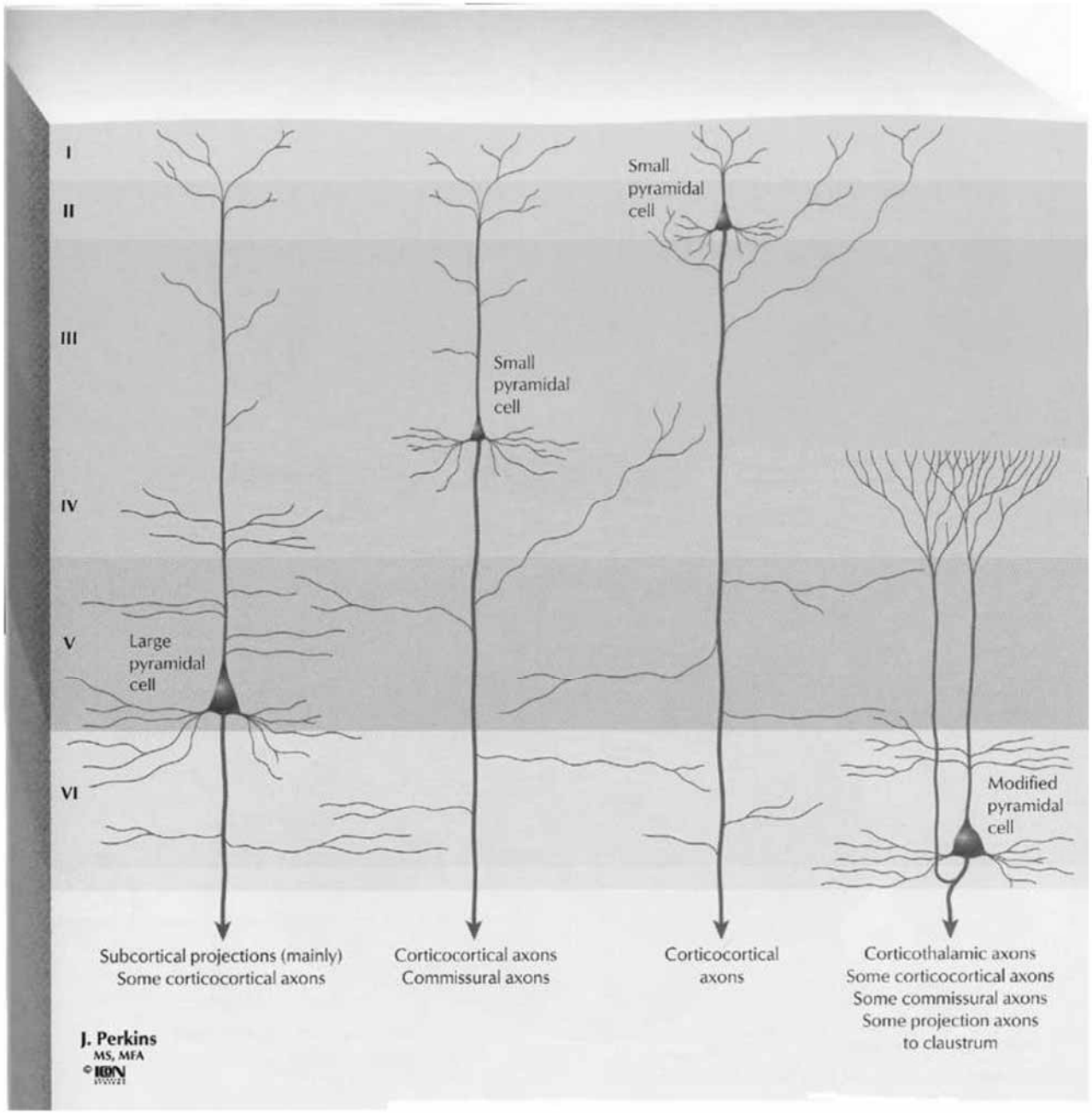
Figure 12.18 The visual areas beyond the striate cortex are broadly organized into two pathways



***NEUROSCIENCE, Fourth Edition*, Figure 12.18**

Flow Chart Summary of the FEEDFORWARD connectivity in the human cerebral cortex





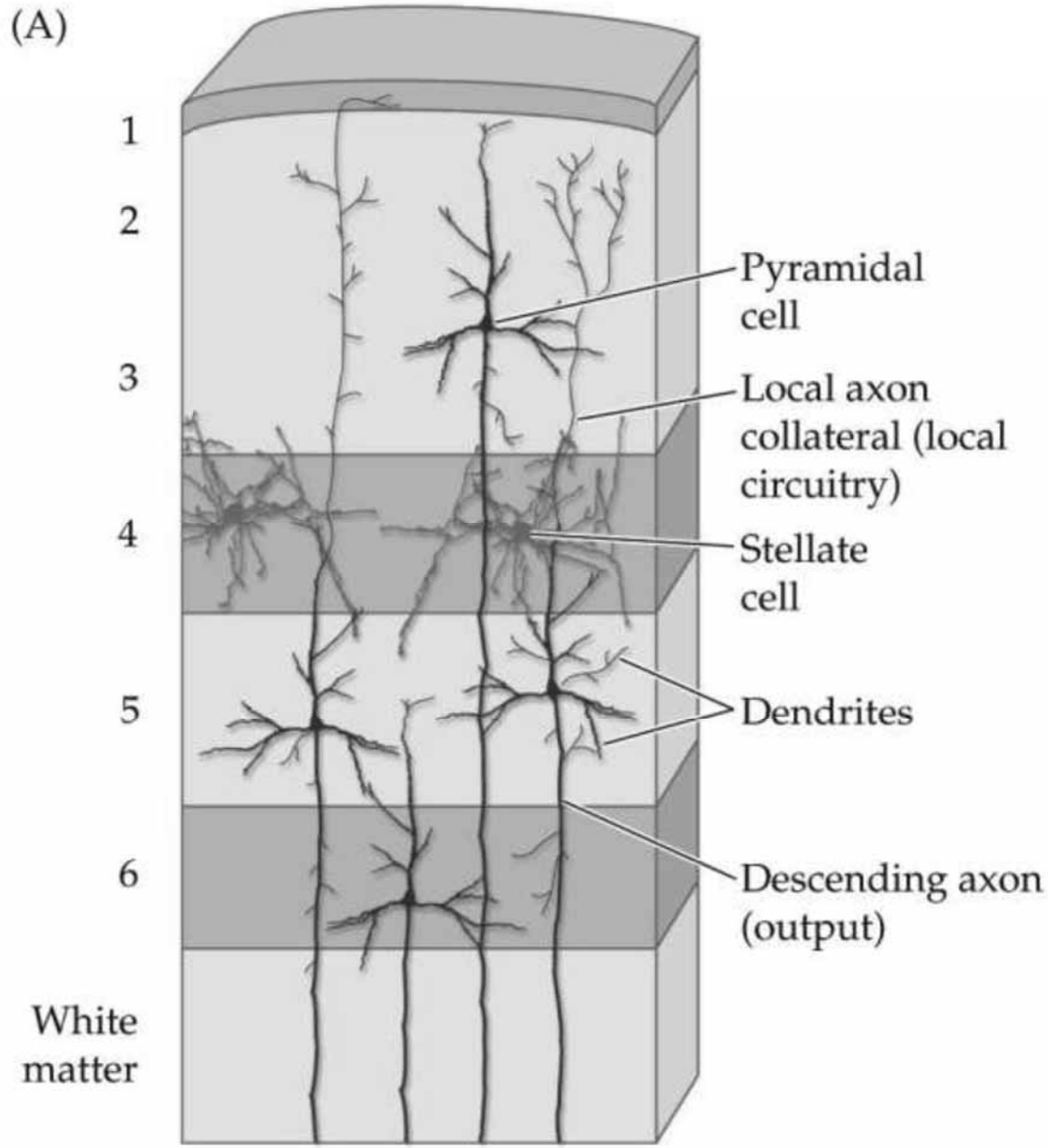
Cortex:

- **Why cortex layered is?**
- **Why are different cortical regions so similar?**

Pyramidal neurons:

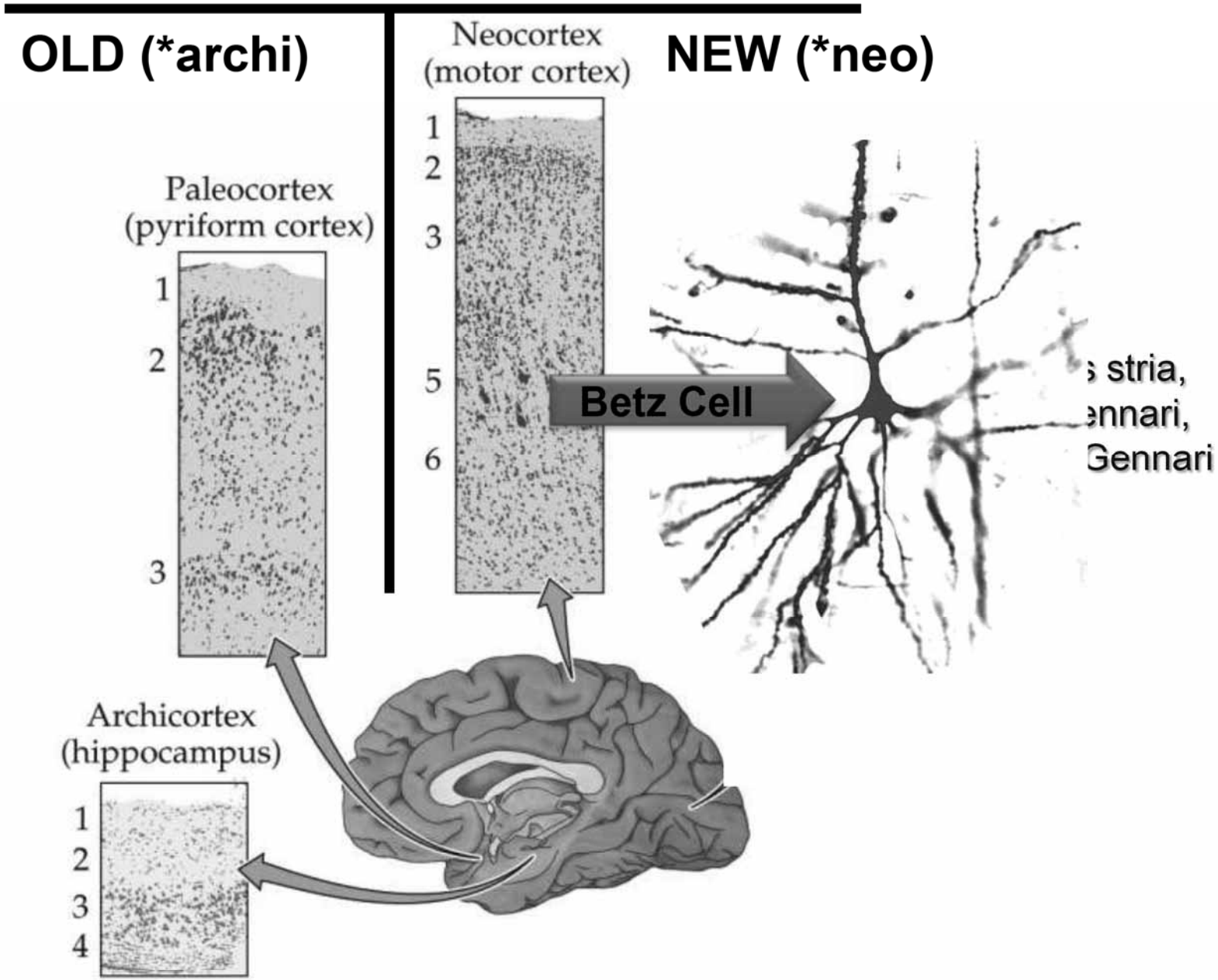
- **Why are they the predominant cortical neuronal type?**
- **Why have such distal synapses?**

Figure 26.2 The layered structure of the human neocortex (Part 1)



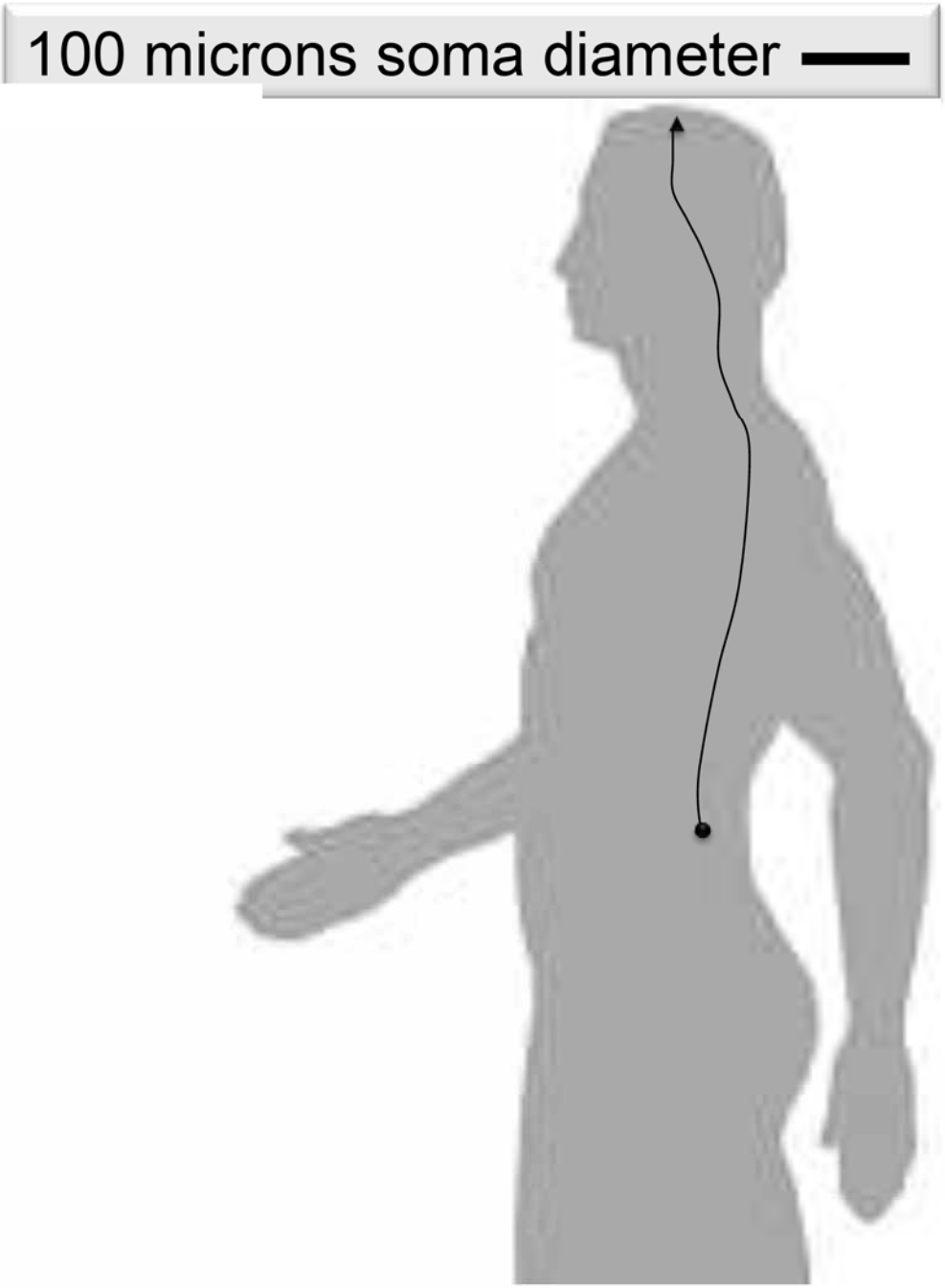
***NEUROSCIENCE, Fourth Edition*, Figure 26.2 (Part 1)**

Box 26A Cortical Lamination

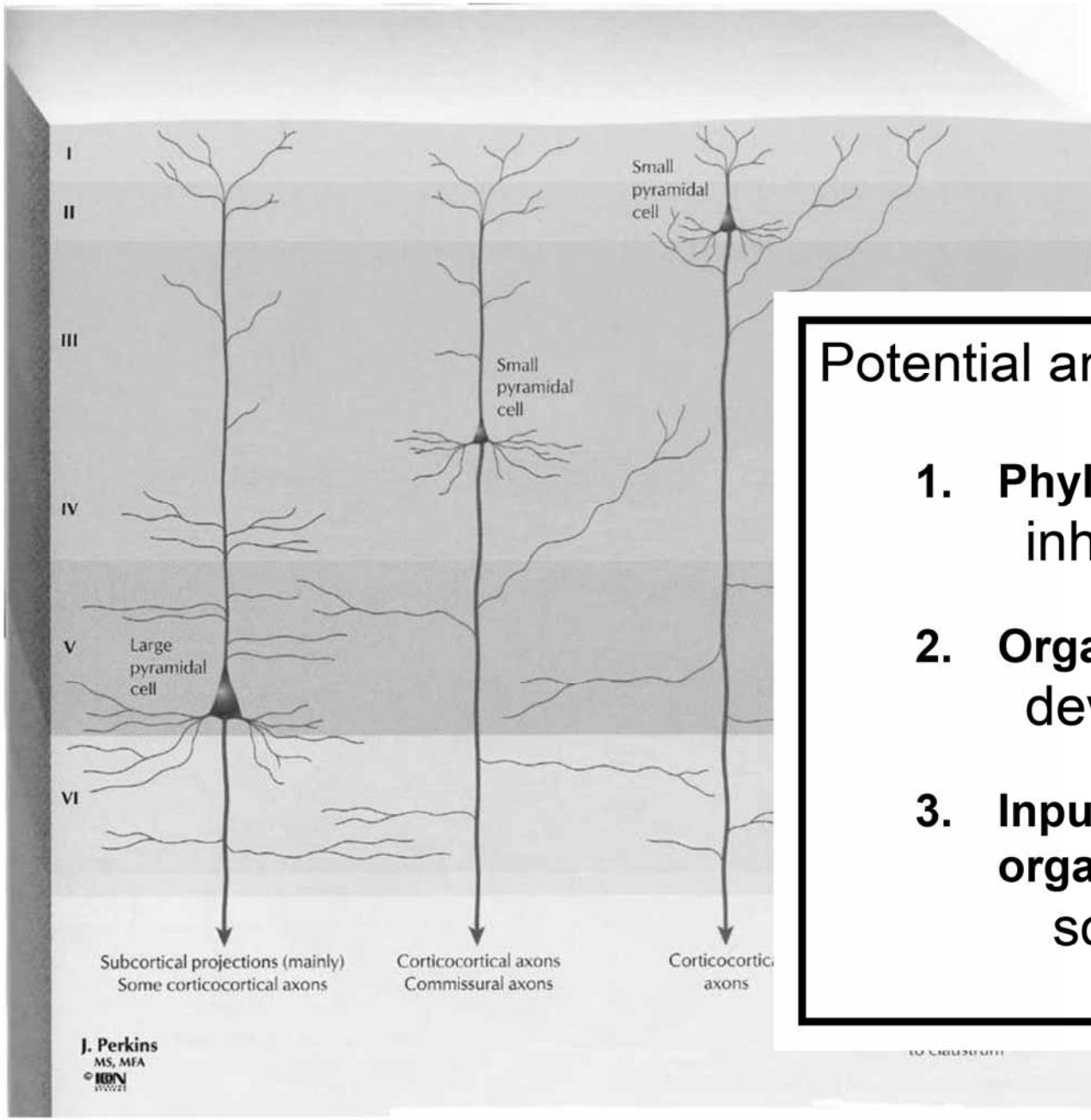


NEUROSCIENCE, Fourth Edition, Box 26A

Betz Cells



- 5th (Vb) layer of the primary motor cortex. 10% of the total pyramidal cell population in layer Vb of the human primary motor cortex.
- Send their axons down the corticospinal tracts to the anterior horn cells of the spinal cord.
- One apical dendrite.
- Many primary dendritic shafts, that branch out of the soma and proxymal apical trunk. These perisomatic (basal) dendrites project into all cortical layers, some reaching down into the white matter.
- Betz cells are affected in motor neuron disease, such as Amyotrophic lateral sclerosis.



Cortex:

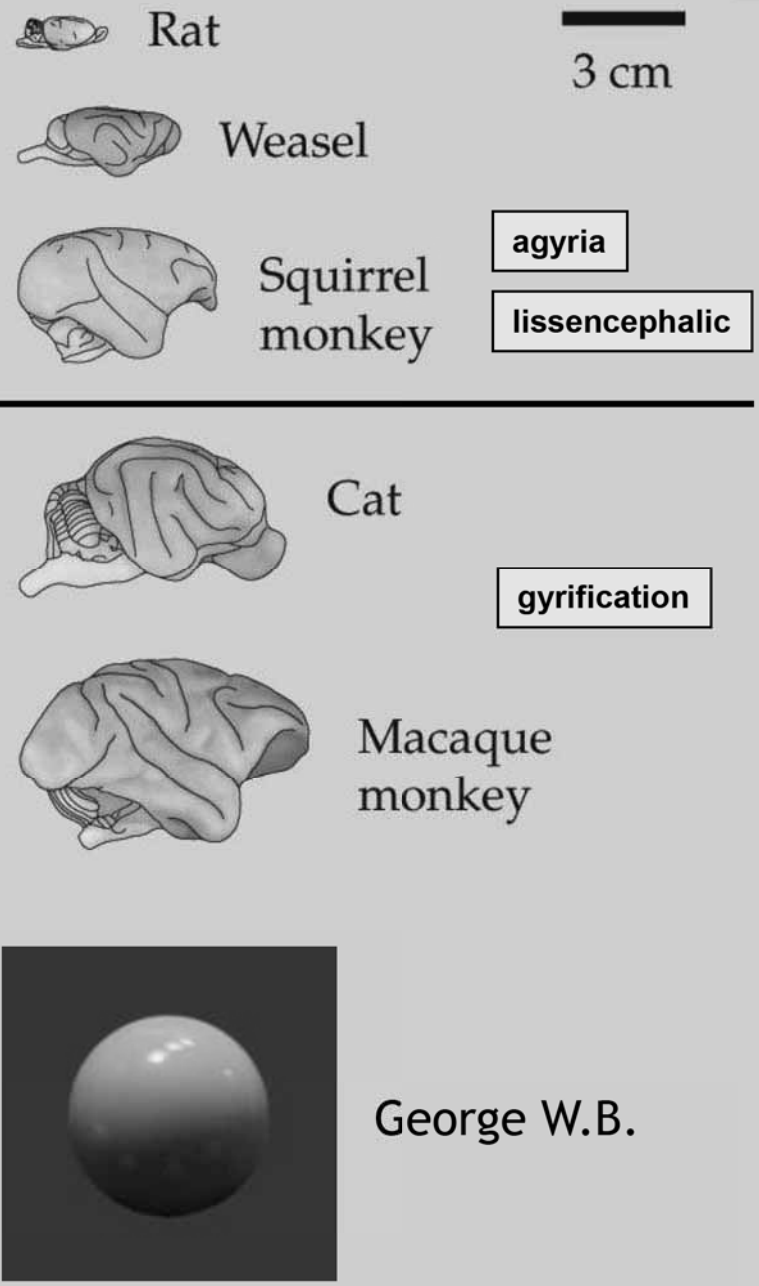
- **Why is the cortex layered?**

Potential answers:

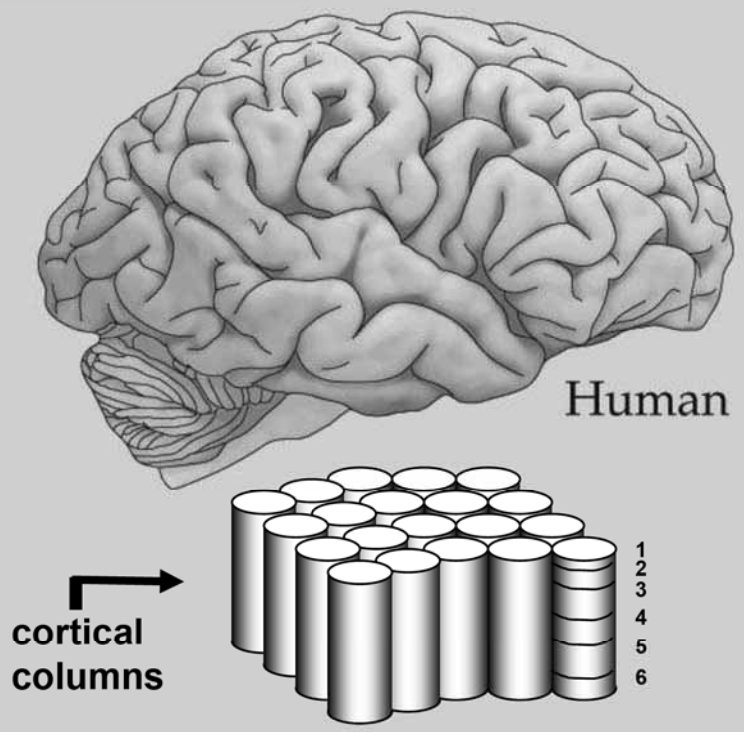
1. **Phylogenesis**
   inheritance
2. **Organogenesis**
   development
3. **Input-Output organization**
   sorting

Box 26D Brain Size and Intelligence

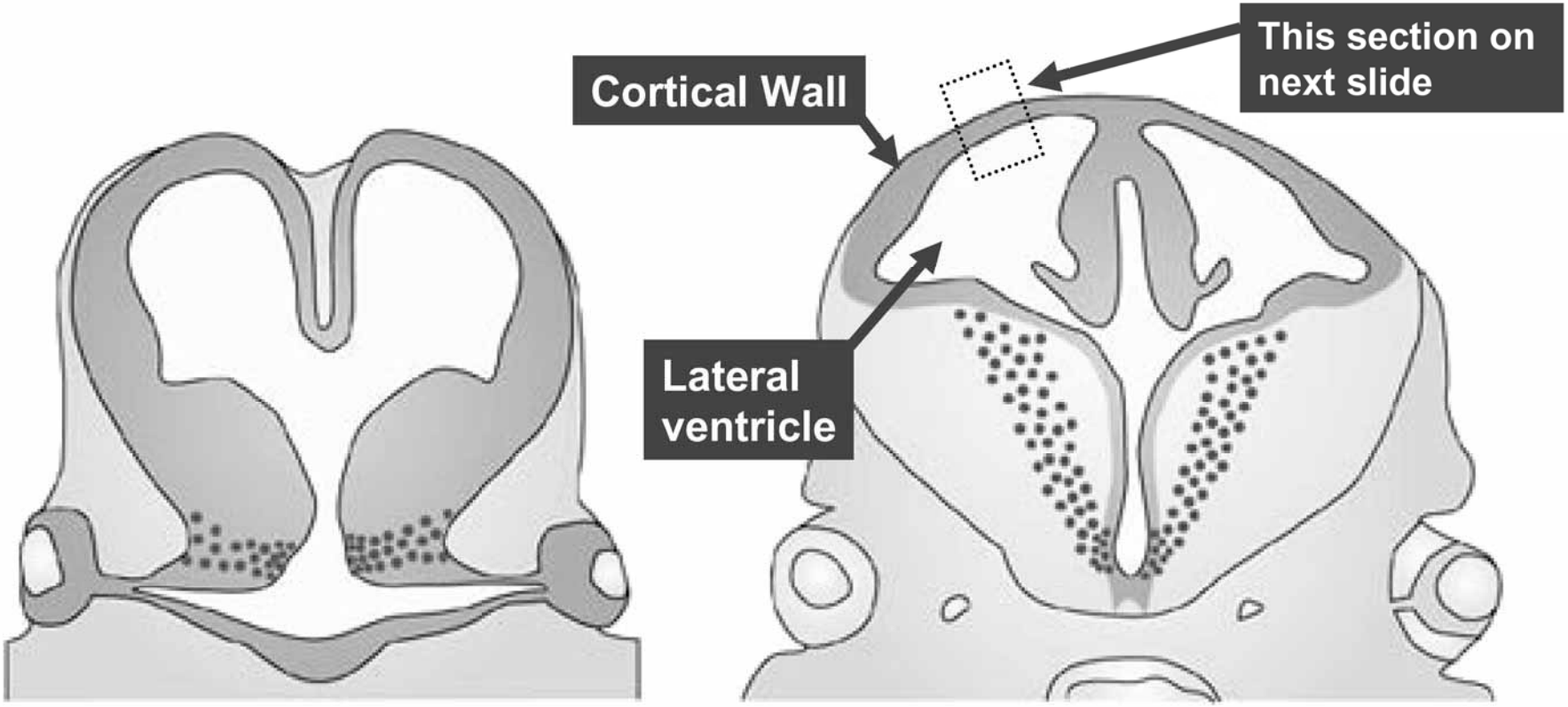
1. Phylogenesis - Inheritance



The increase in brain size is largely due to the expansion of neocortex and its connections. The massive and rapid changes in the size of neocortex are paralleled in the phylogenetic differences we see in contemporary mammalian brains.



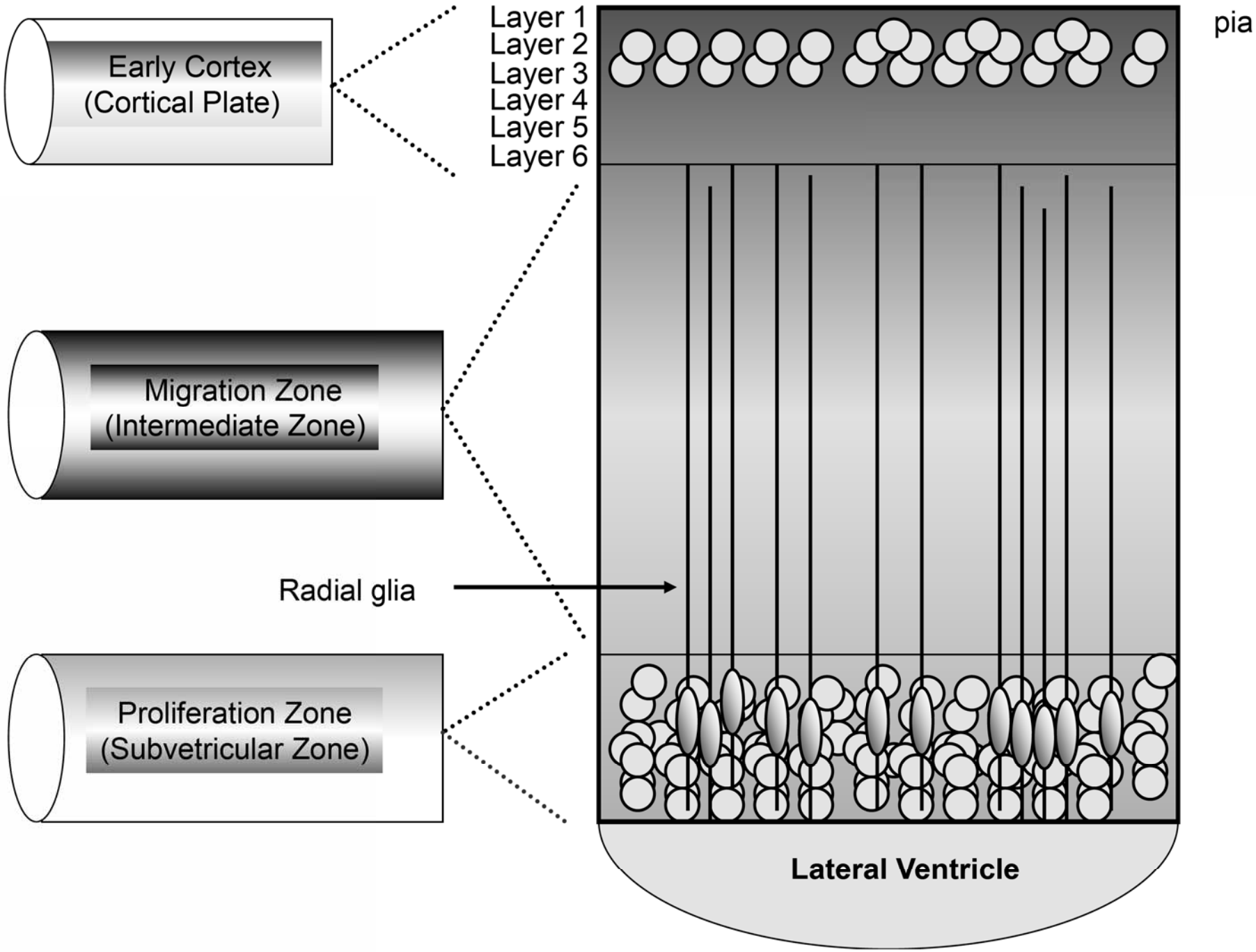
Embryonal / Fetal Development / In Utero



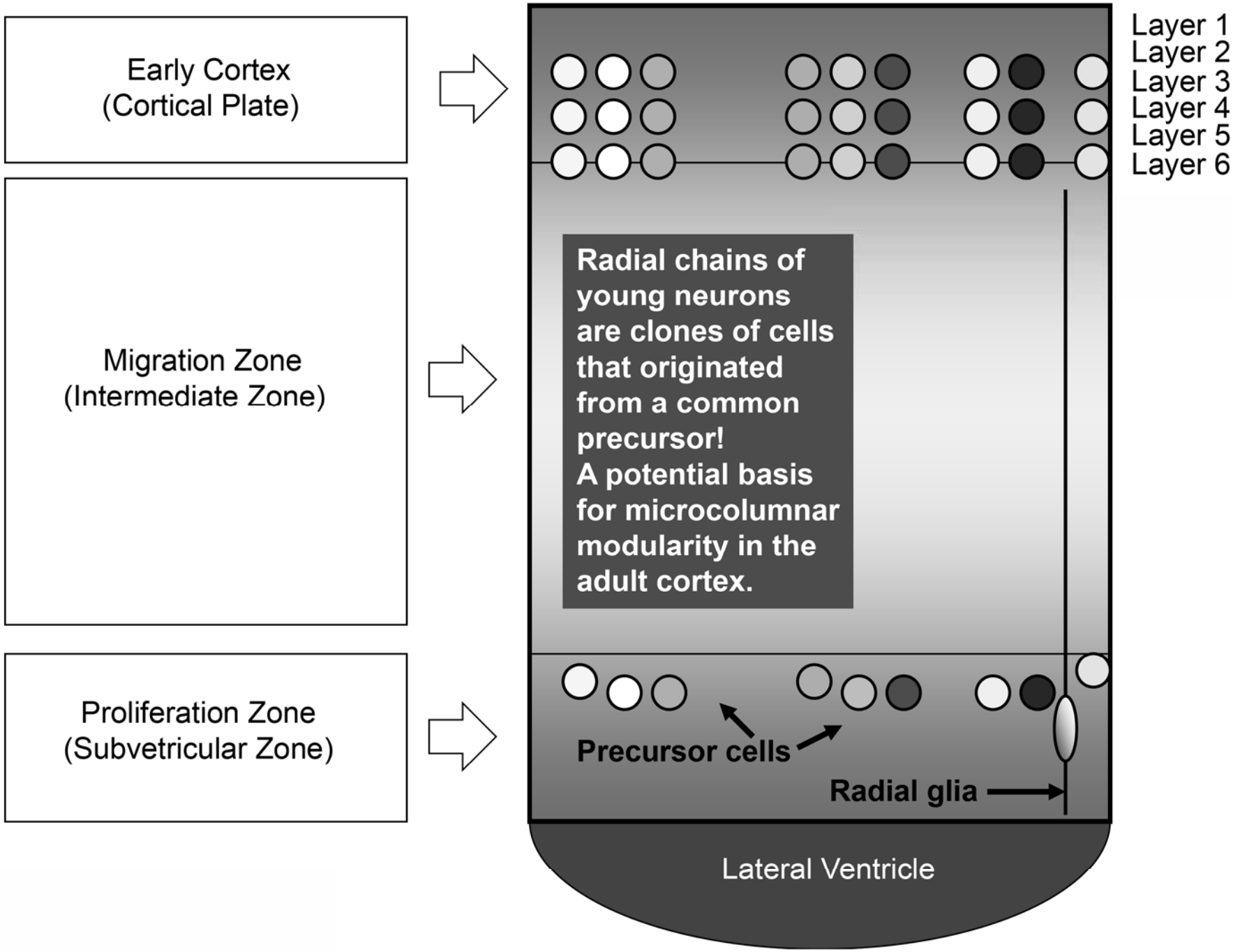
Fetus – coronal sections through the Forebrain

Nature Reviews | Neuroscience

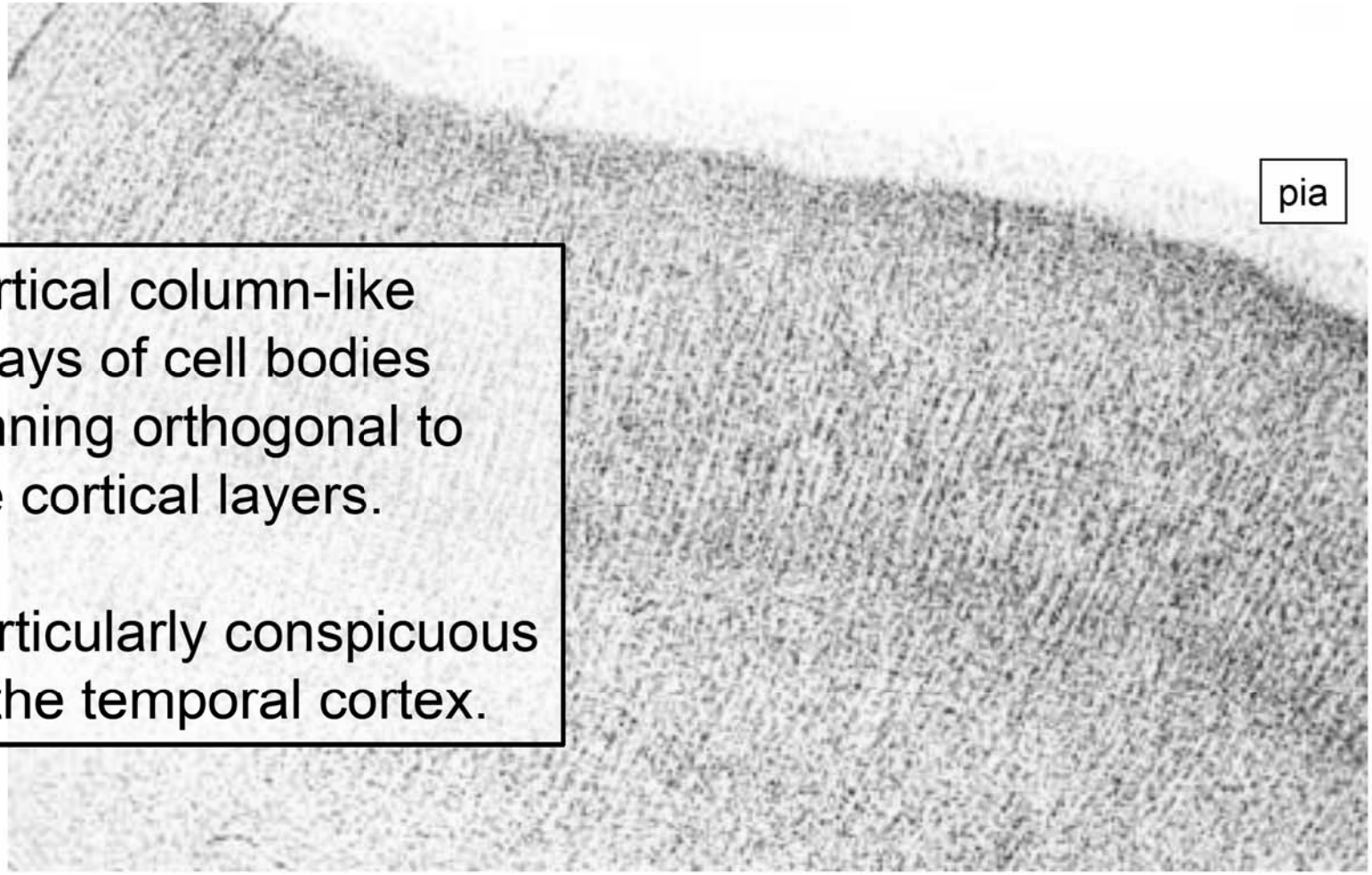
Development of the Human Cerebral Cortex



Development of the Human Cerebral Cortex



Cortical Microcolumns



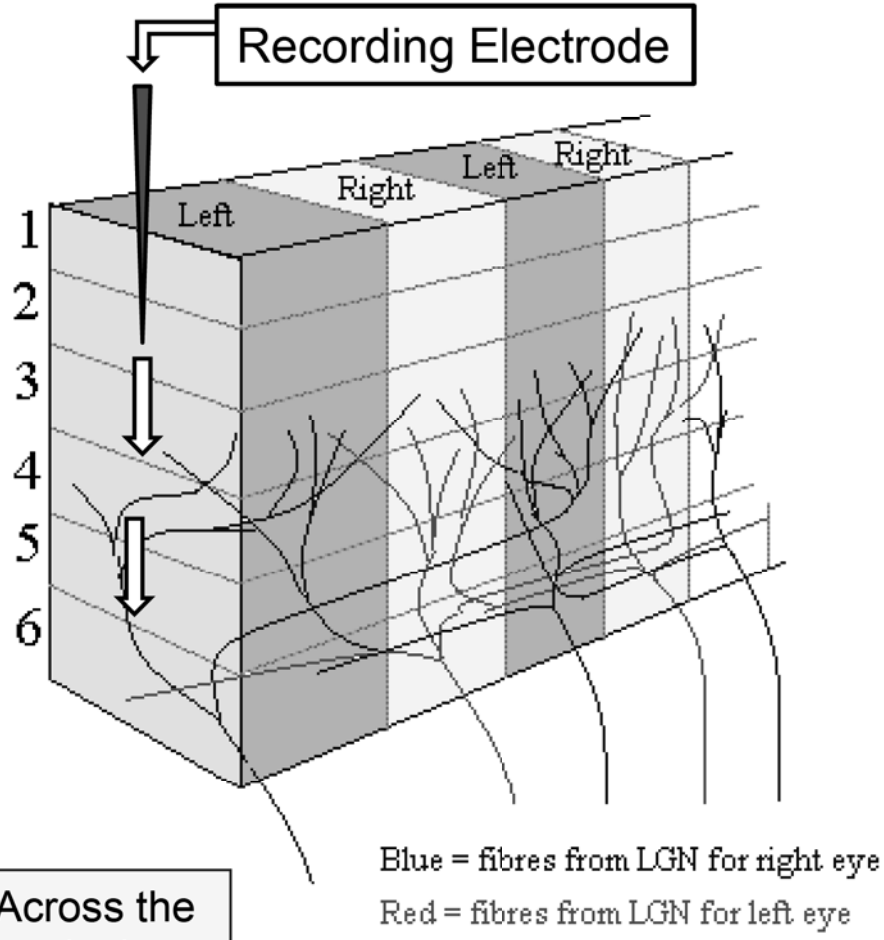
Vertical column-like arrays of cell bodies running orthogonal to the cortical layers.

Particularly conspicuous in the temporal cortex.

Cerebral cortex of human brain.
Nissl-stain shows microcolumns of nerve cells.

Edward G. Jones, 2009

Cortical Columns

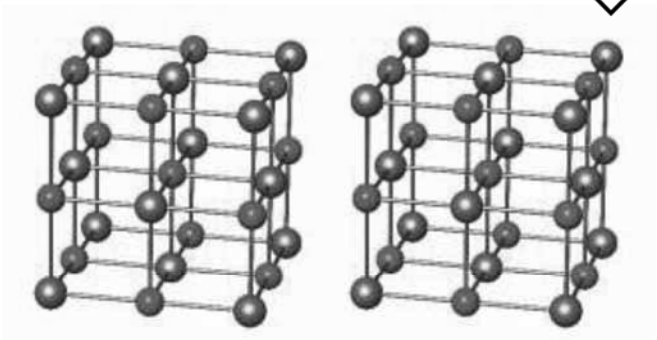


Mountcastle used micro-electrode measurements to show that activity of small cylinders of cortex about 0.1 to 1 mm in diameter corresponded to particular points in the receptive field. These functional columns of cortical tissue are called **cortical columns**.

Nerve cells in middle layers of the cortex, in which thalamic afferents terminate, are joined by narrow vertical connections to cells in layers lying **superficial** and **deep** to them, so that all cells in the column are excited by incoming stimuli with only small latency differences. The columns form a series of repeating units across the horizontal extent of the cortex.

Across the cortical surface, cortical columns differ in diameter.

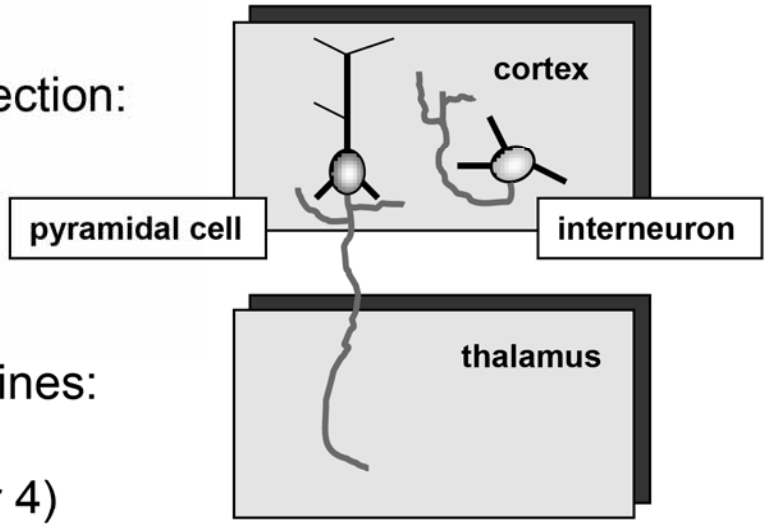
Column is an elemental processing unit that characterizes cortex, independent of its areal specializations (Crystal structure of cortex).



5. Cellular Elements

Golgi's method can identify more than 40 types of cortical neurons based on distribution of their dendrites and axons.

Classification based on axonal projection:

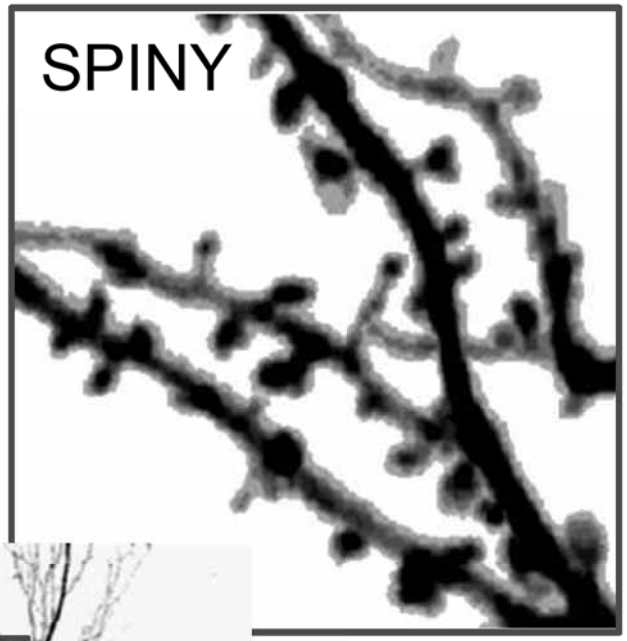


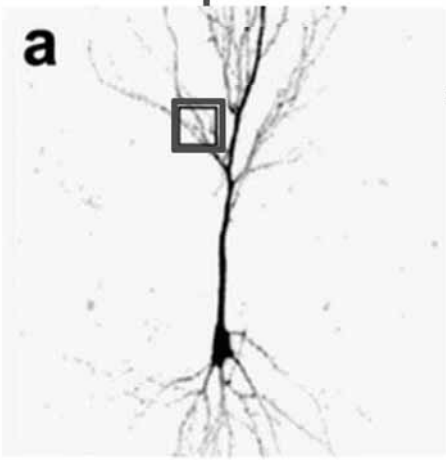
PROJECTION neurons:
INTERNEURONS

Classification based on dendritic spines:

SPINY (pyramidal cells, stellate cells of layer 4)
SMOOTH (GABA-ergic inhibitory interneurons of all layers)

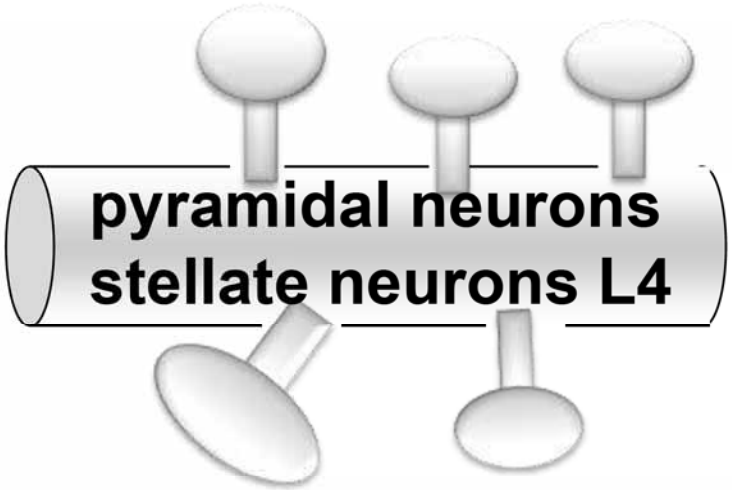
SPINY NEURONS





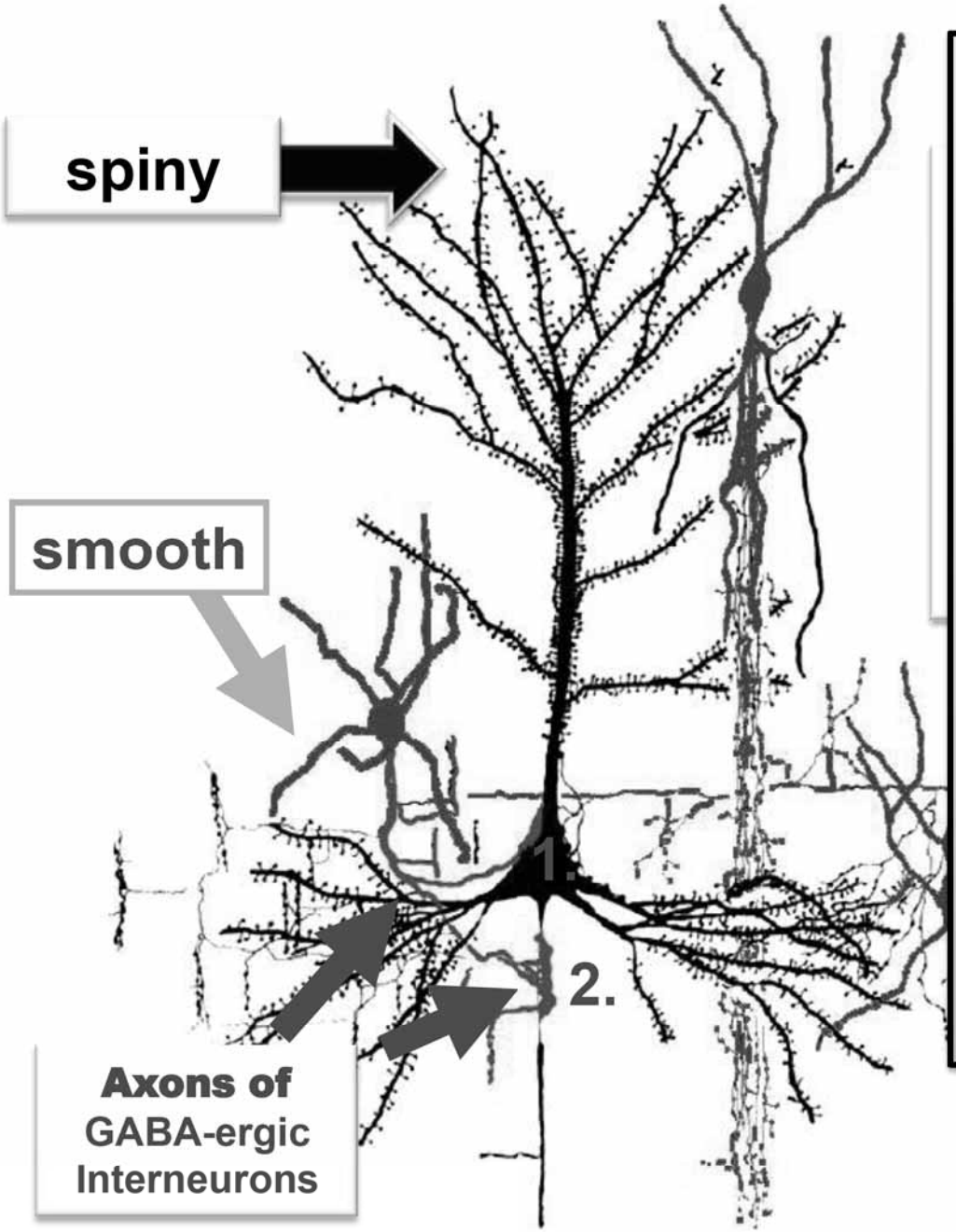
pyramidal

SPINY



SMOOTH

ASPINY (SMOOTH) NEURONS make inhibitory GABA-ergic synapses near pyramidal cell body



An Non-Exclusive List Of GABA interneuron Morphologies:

1. Large Basket Cells
2. Small Basket Cells (*Clutch Cells*)
3. Chandelier Cells
4. Double Bouquet Cells (*Bitufted Cells*)
5. Neuroglialform Cells
6. Martinotti Cells
7. Cajal Retzius Cells
8. …..

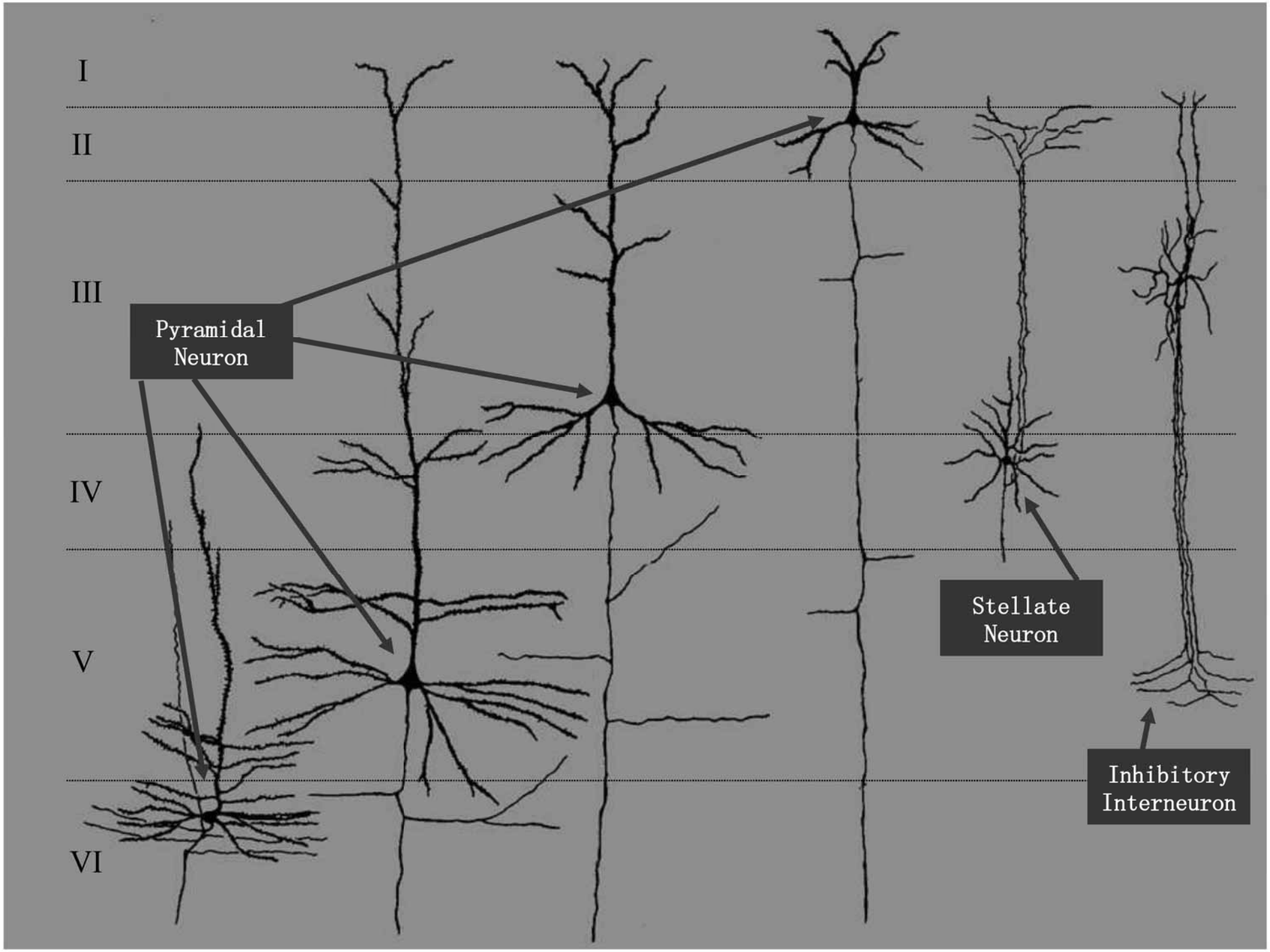
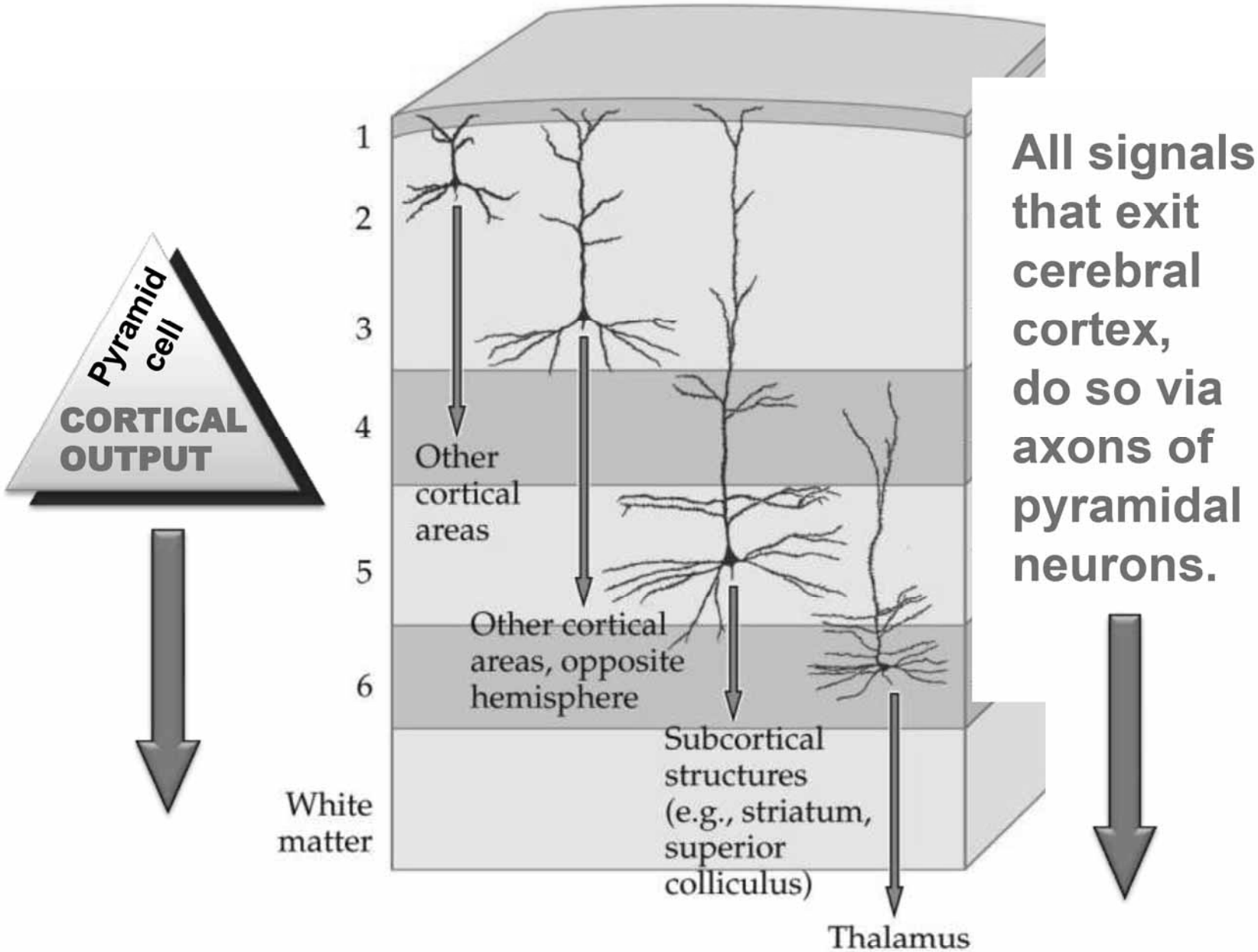
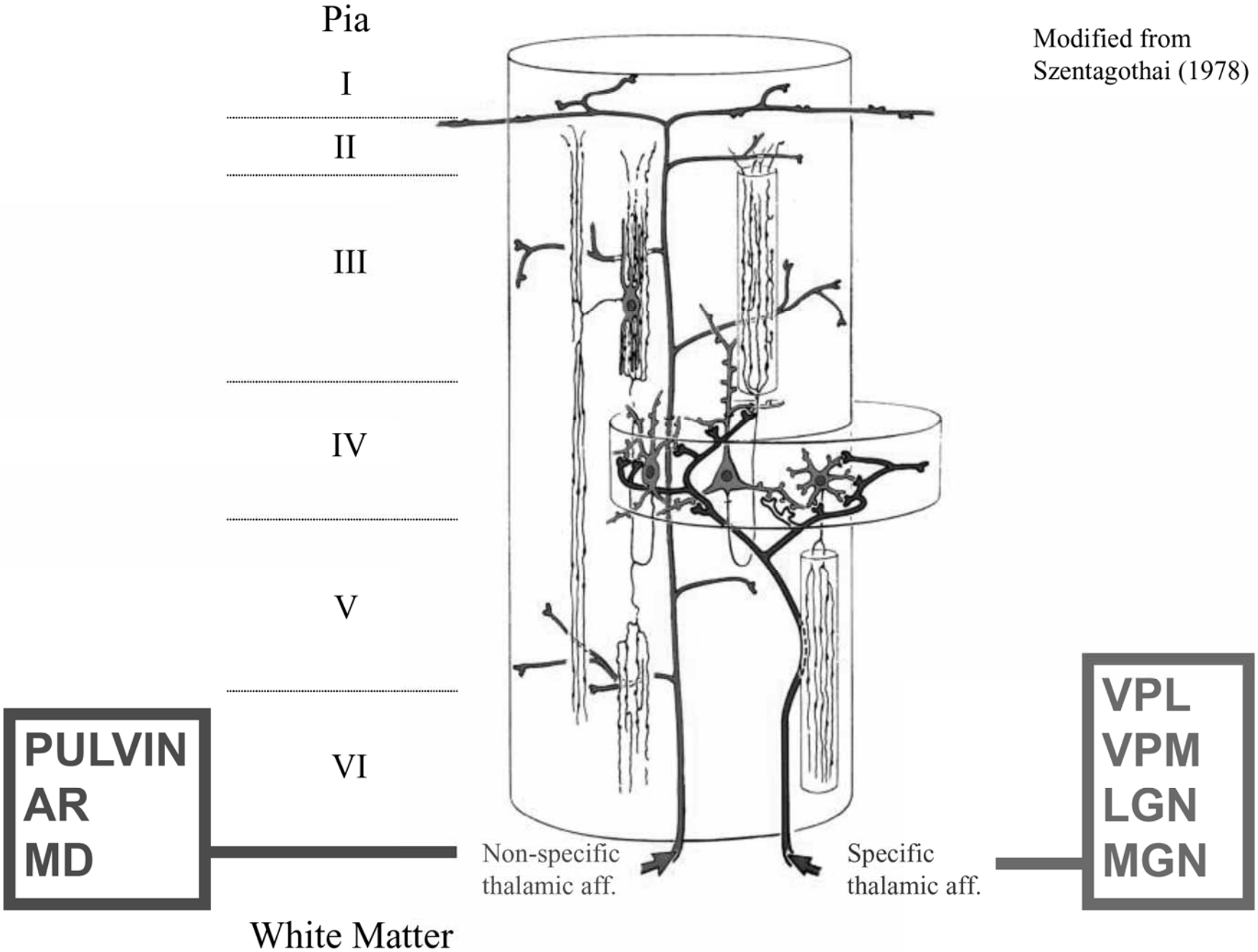

I
II
III
IV
V
VI
Pyramidal Neuron
Stellate Neuron
Inhibitory Interneuron

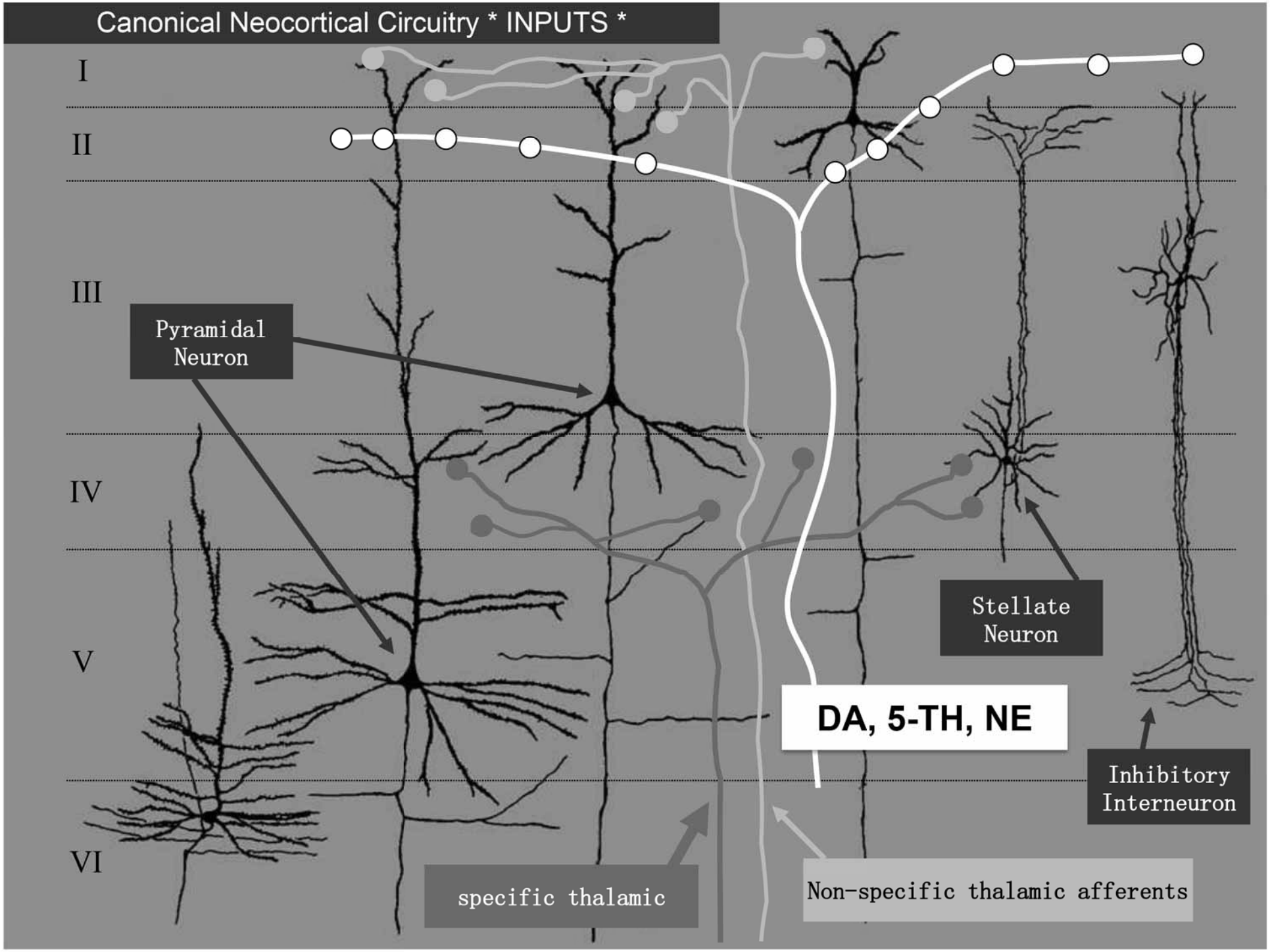
Figure 26.3 Canonical neocortical circuitry ********* OUTPUTS *********

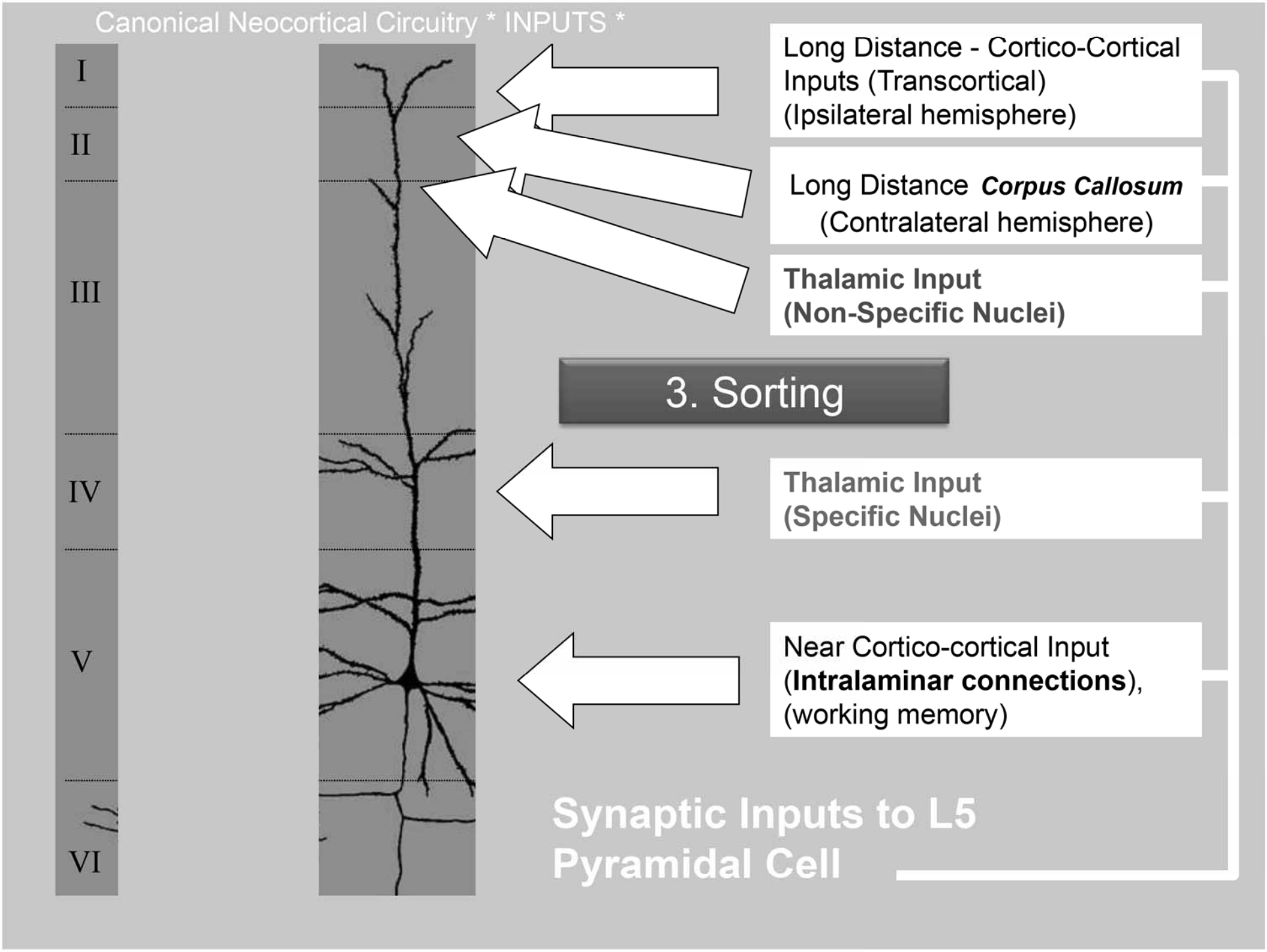


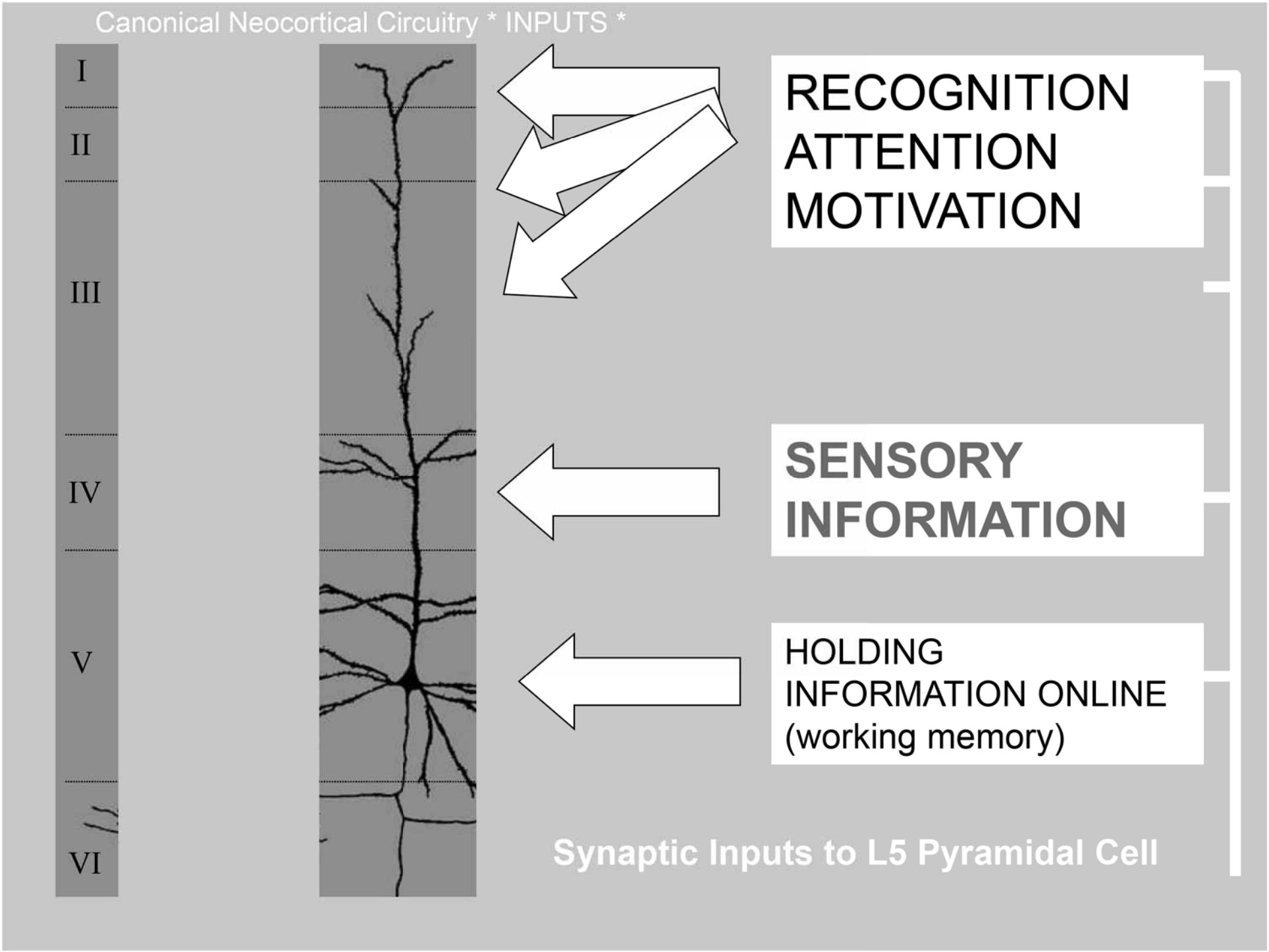
***NEUROSCIENCE, Fourth Edition*, Figure 26.3**

Canonical Neocortical Circuitry * INPUTS *



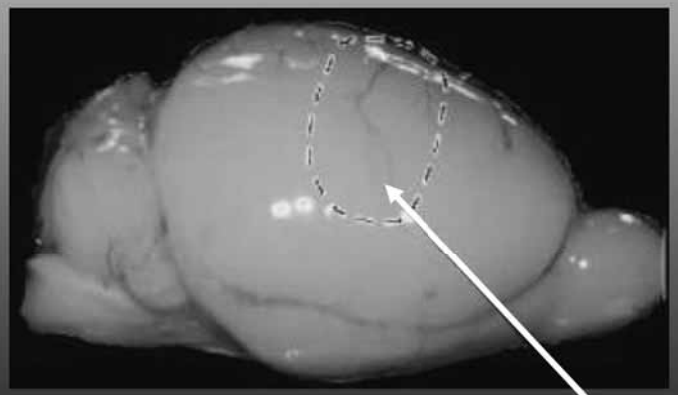

Canonical Neocortical Circuitry * INPUTS *
I
II
III
IV
V
VI
Pyramidal Neuron
Stellate Neuron
DA, 5-TH, NE
Inhibitory Interneuron
specific thalamic
Non-specific thalamic afferents


Canonical Neocortical Circuitry * INPUTS *
I
II
III
IV
V
VI
Long Distance - Cortico-Cortical Inputs (Transcortical) (Ipsilateral hemisphere)
Long Distance Corpus Callosum (Contralateral hemisphere)
Thalamic Input (Non-Specific Nuclei)
3. Sorting
Thalamic Input (Specific Nuclei)
Near Cortico-cortical Input (Intralaminar connections), (working memory)
Synaptic Inputs to L5 Pyramidal Cell

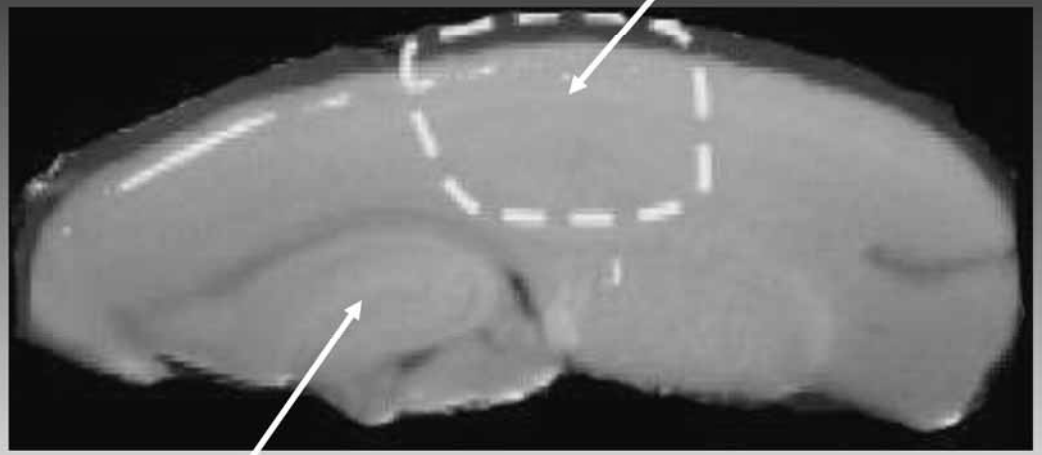

Canonical Neocortical Circuitry * INPUTS *
I
II
III
IV
V
VI
RECOGNITION
ATTENTION
MOTIVATION
SENSORY
INFORMATION
HOLDING
INFORMATION ONLINE
(working memory)
Synaptic Inputs to L5 Pyramidal Cell

Studying the Physiology of Pyramidal Neurons *In Vitro*

Slice preparation

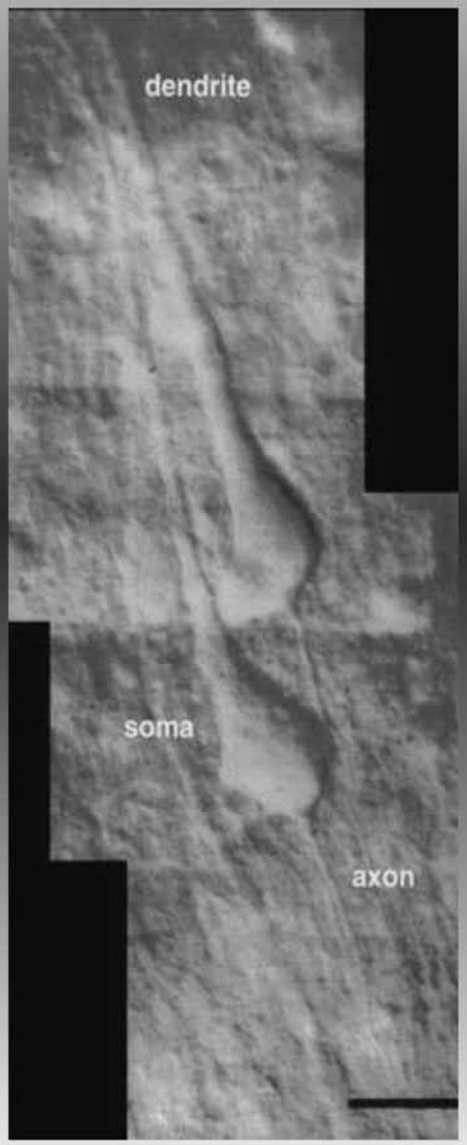


Somatosensory cortex

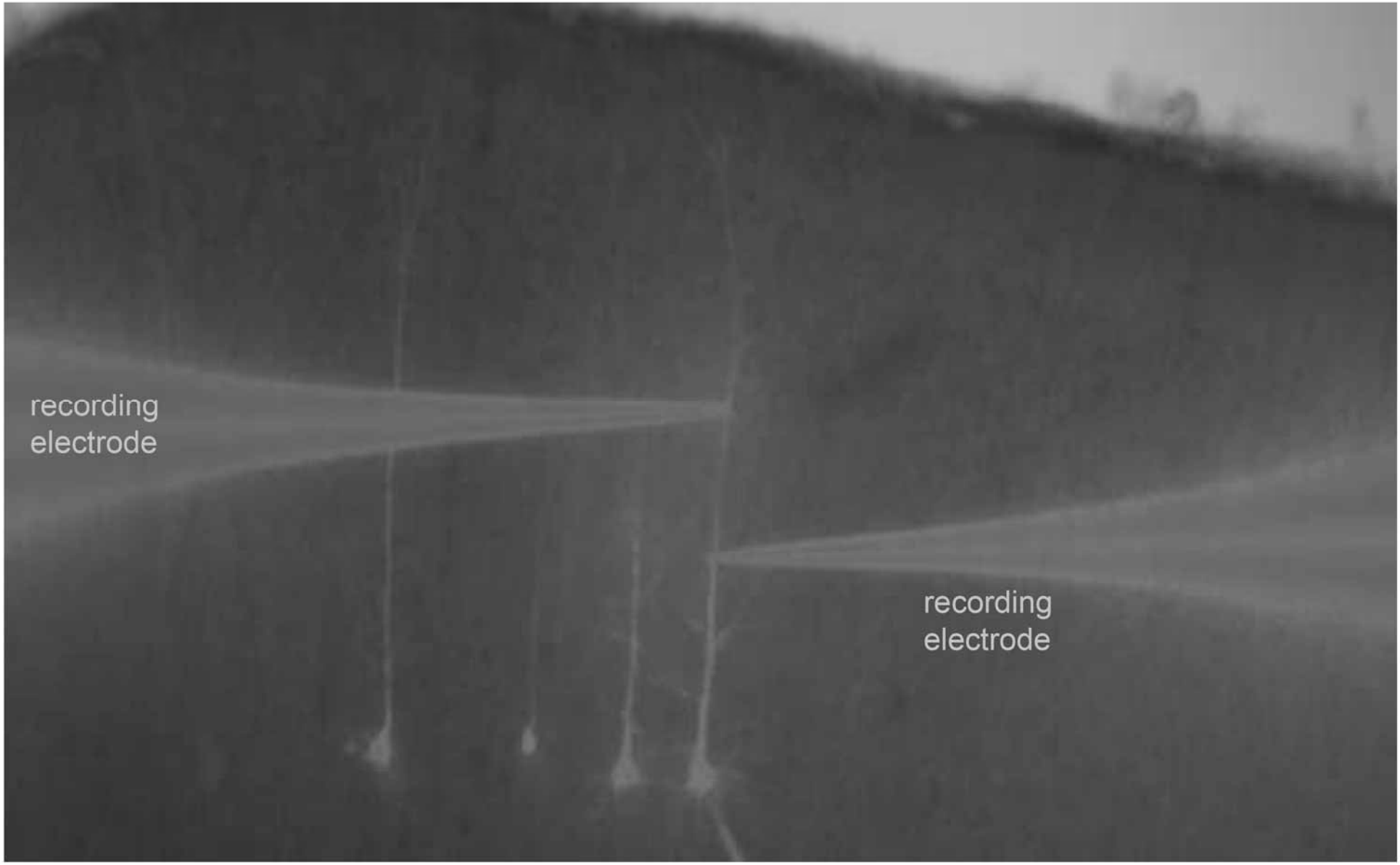


Hippocampus

DIC infrared image



Layer 5 pyramidal neurons are the output neuron of columns



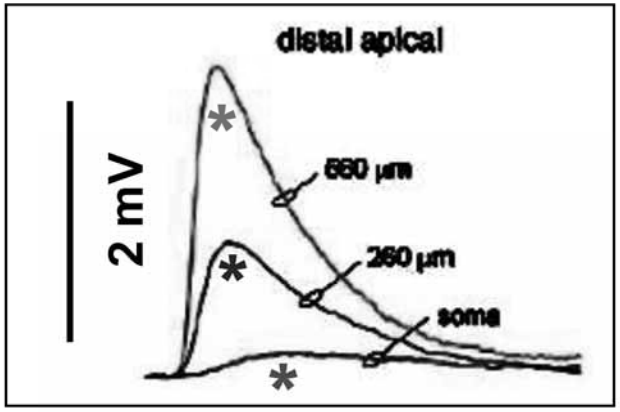
recording
electrode

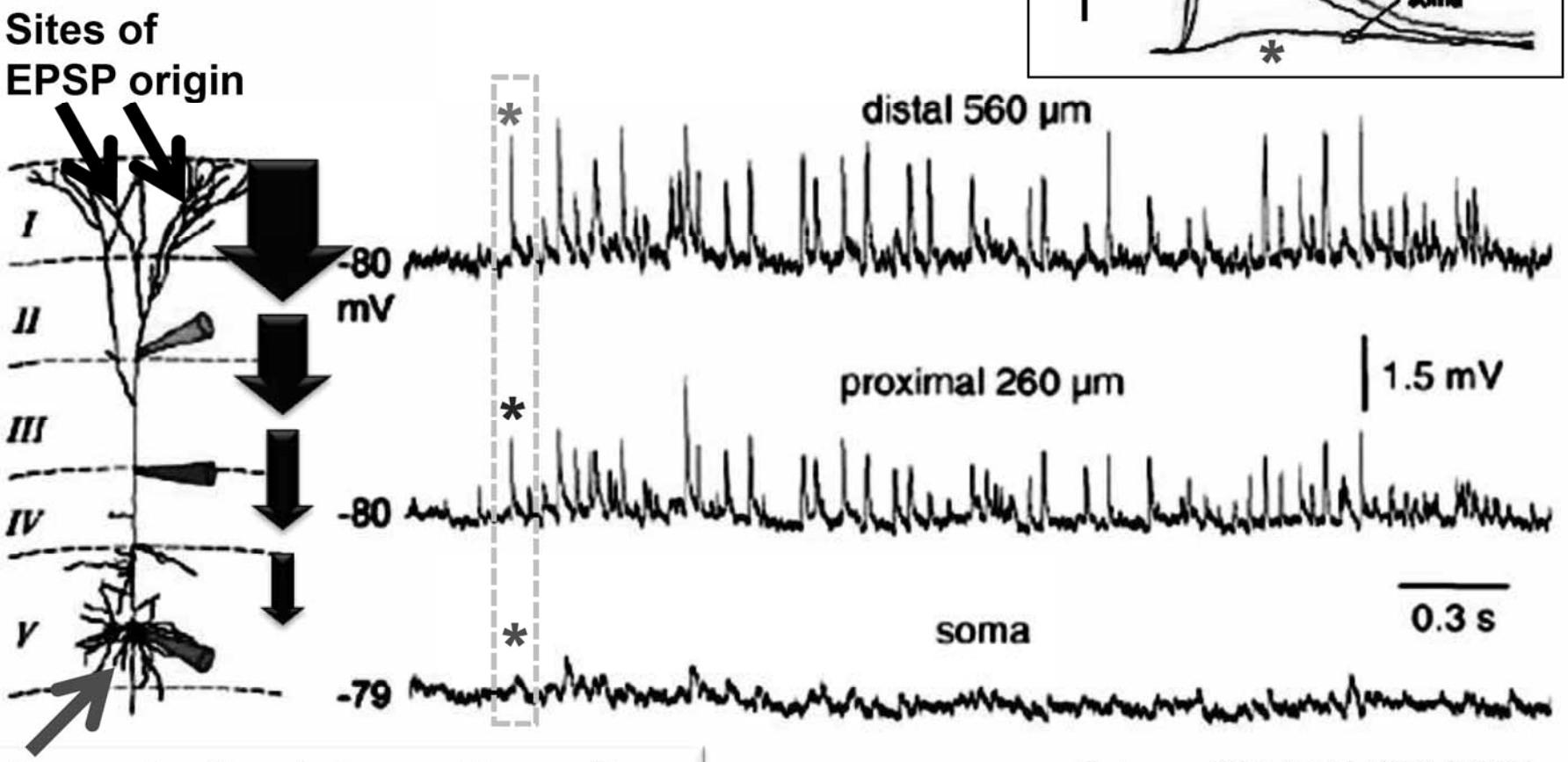
Peters et al., Cerebral Cortex, 7: 405-421, 1997

Amplitude of an EPSP attenuates as the EPSP travel to the soma

Dependence of EPSP Efficacy on Synapse Location in Neocortical Pyramidal Neurons

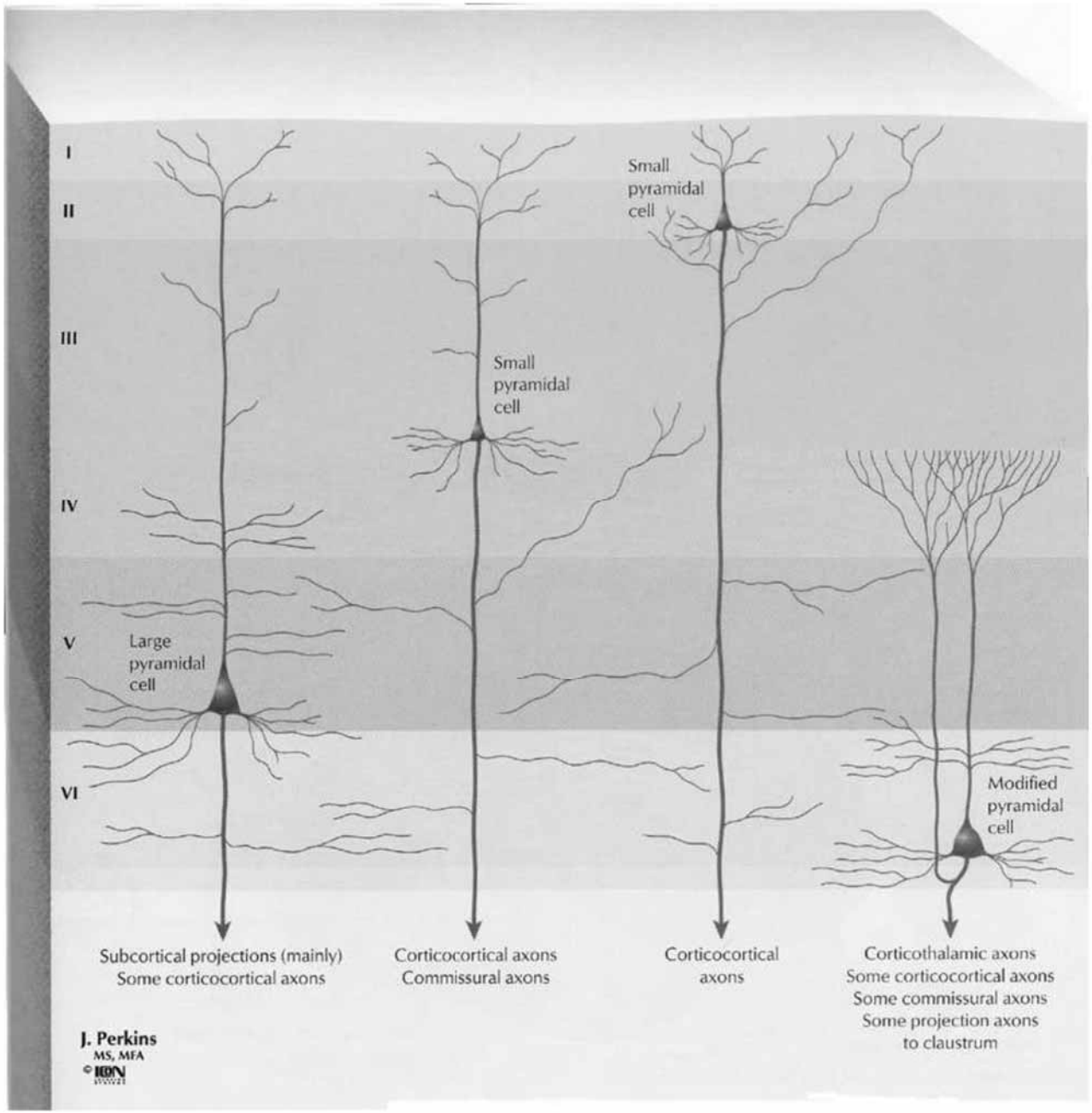
Stephen R. Williams and Greg J. Stuart*





Soma is the integration site

Science 295:1907-1910 (2002)

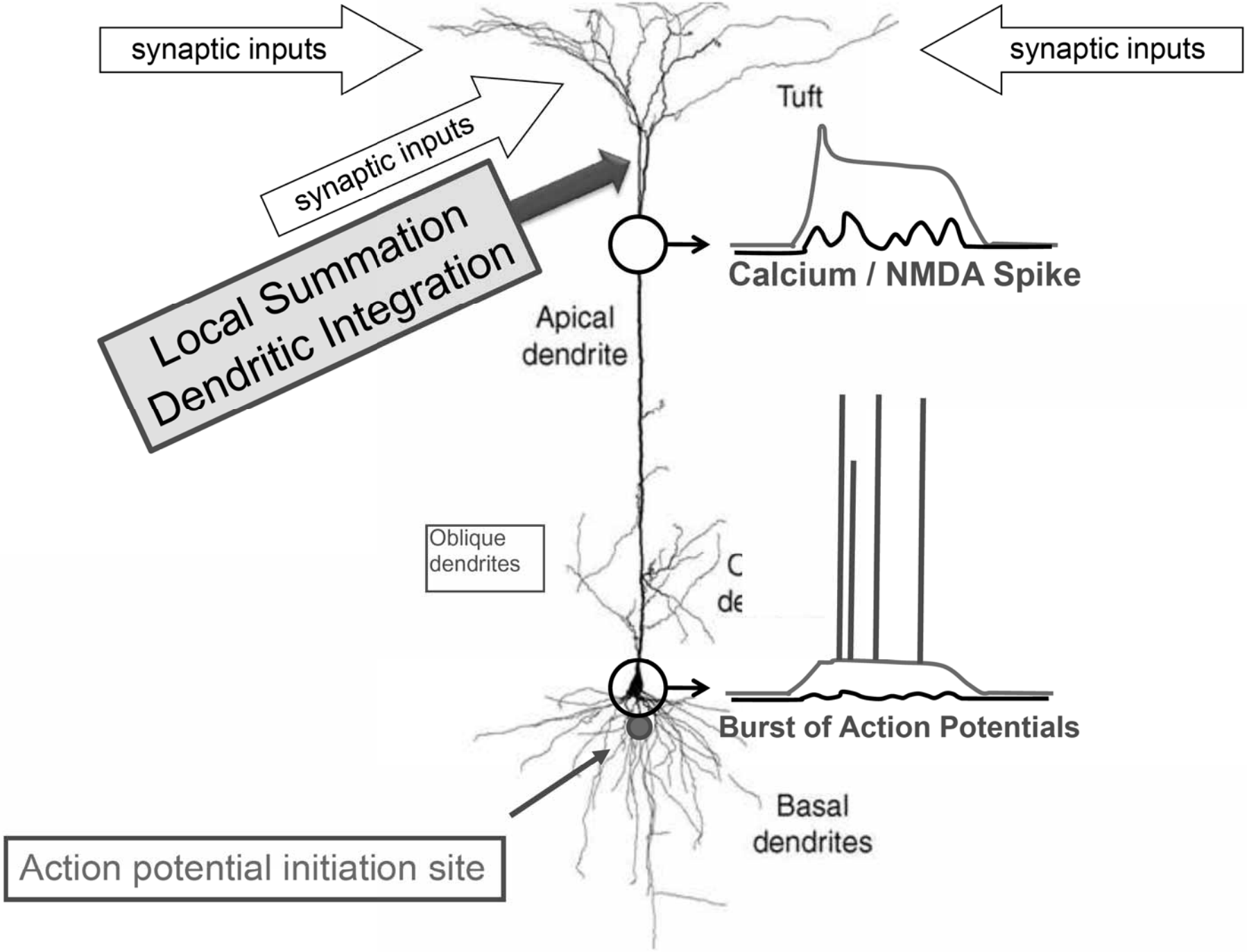


Cortex:

Pyramidal neurons:

- **Why have such distal synapses?**

SYNAPTIC INTEGRATION - Computational Task of the Neocortical Layer 5 Pyramidal Neuron



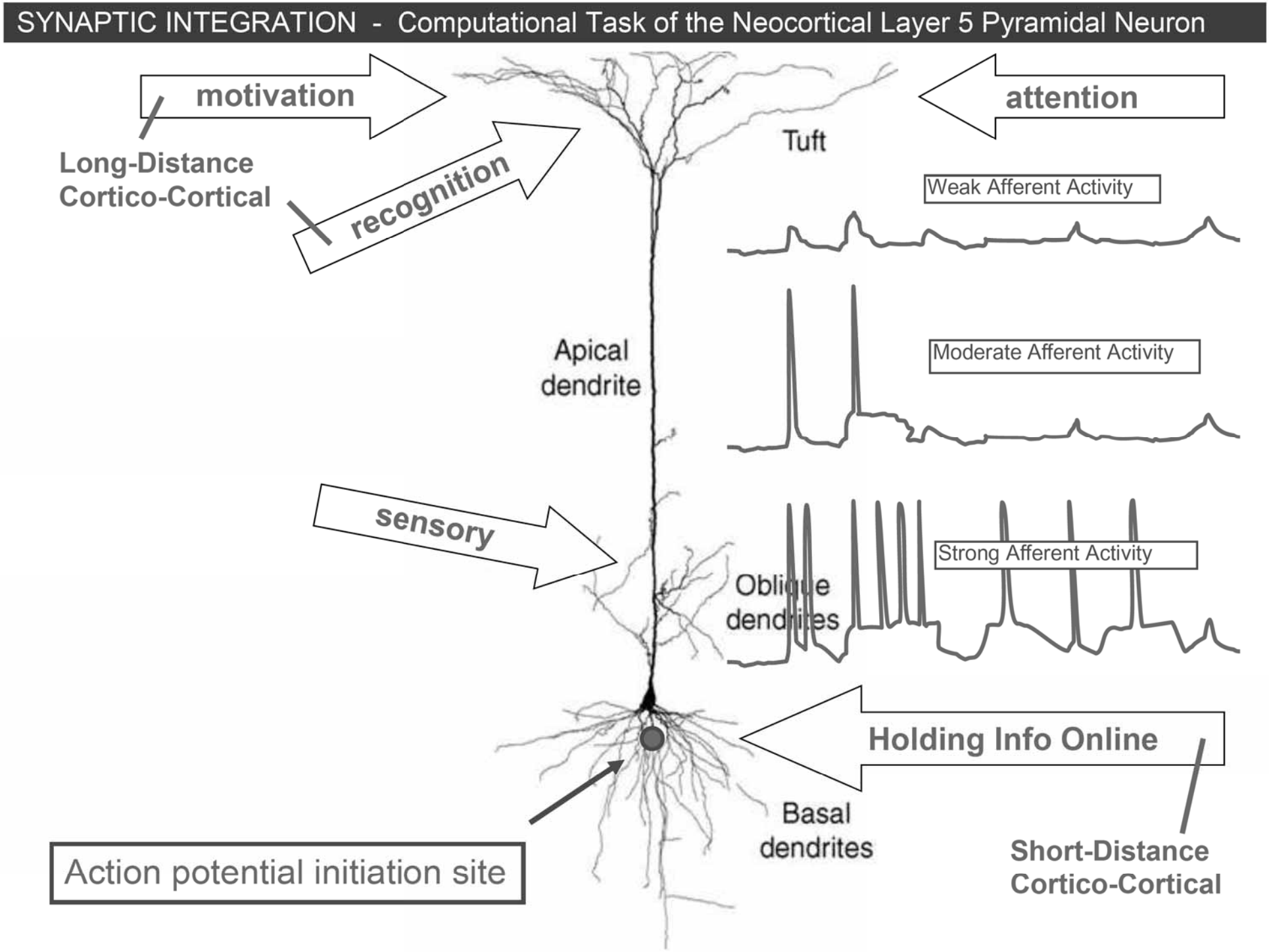
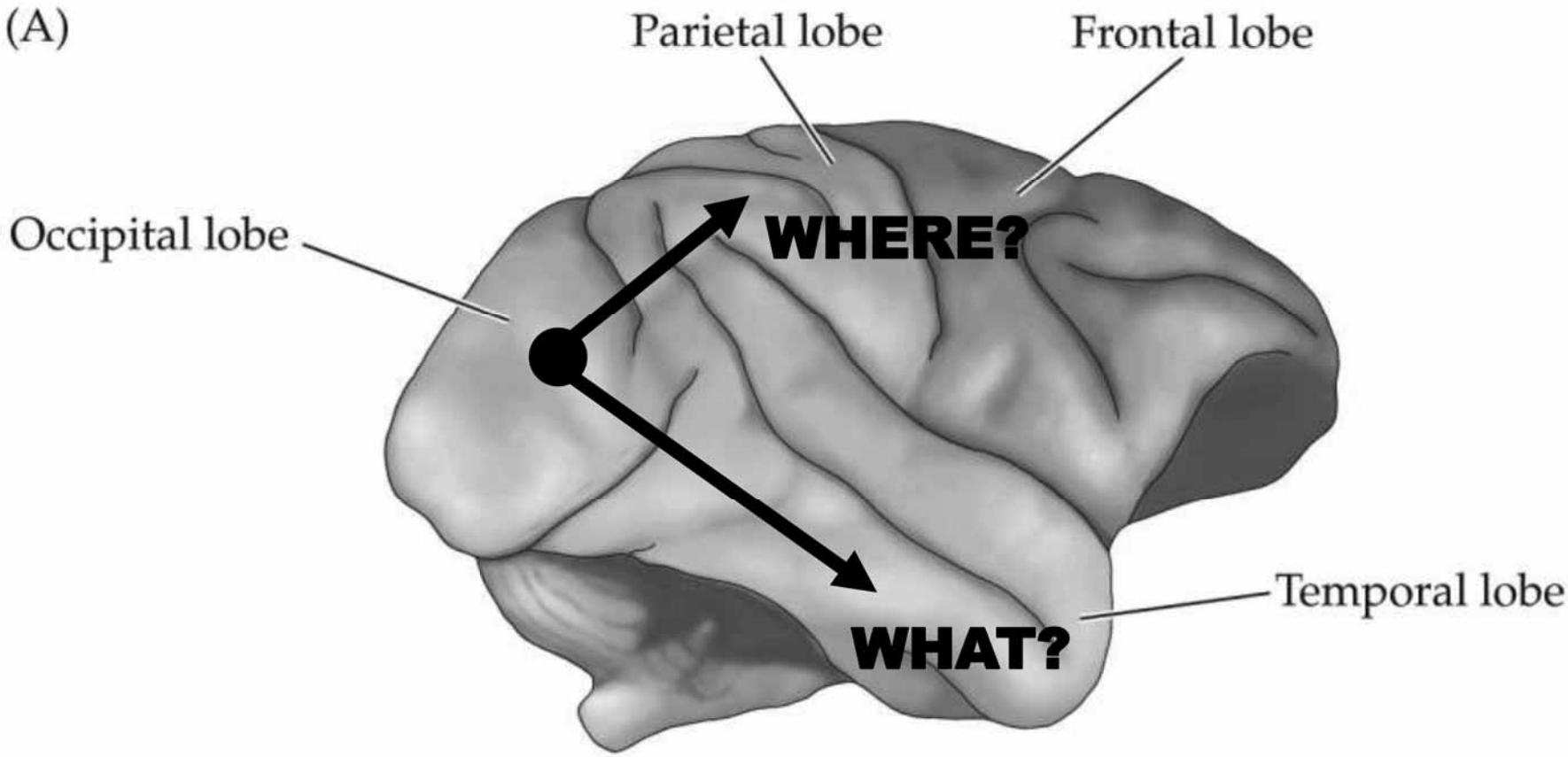
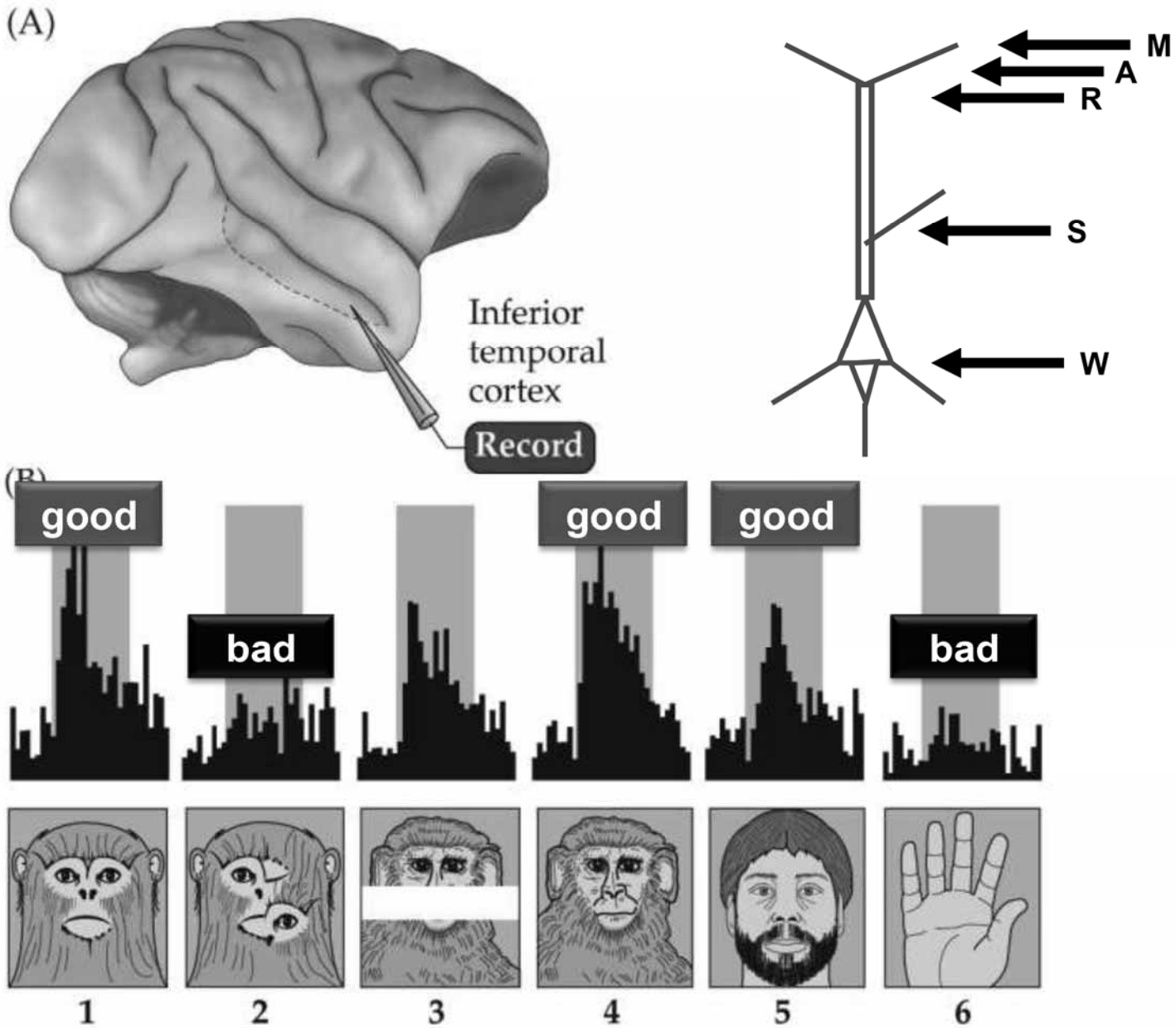

SYNAPTIC INTEGRATION - Computational Task of the Neocortical Layer 5 Pyramidal Neuron
motivation
Long-Distance
Cortico-Cortical
recognition
attention
Tuft
Weak Afferent Activity
Apical
dendrite
Moderate Afferent Activity
sensory
Strong Afferent Activity
Oblique
dendrites
Holding Info Online
Basal
dendrites
Short-Distance
Cortico-Cortical
Action potential initiation site

Figure 26.9 Recording from single neurons in the brain of a rhesus monkey (Part 1)



***NEUROSCIENCE, Fourth Edition*, Figure 26.9 (Part 1)**

Figure 26.12 Selective activation of face cells in inferior temporal cortex of rhesus monkey (Part 1)



NEUROSCIENCE, Fourth Edition, Figure 26.12 (Part 1)

Cerebral Cortex – Cellular Mechanisms

TOP DOWN APPROACH

1 Cortical Functions
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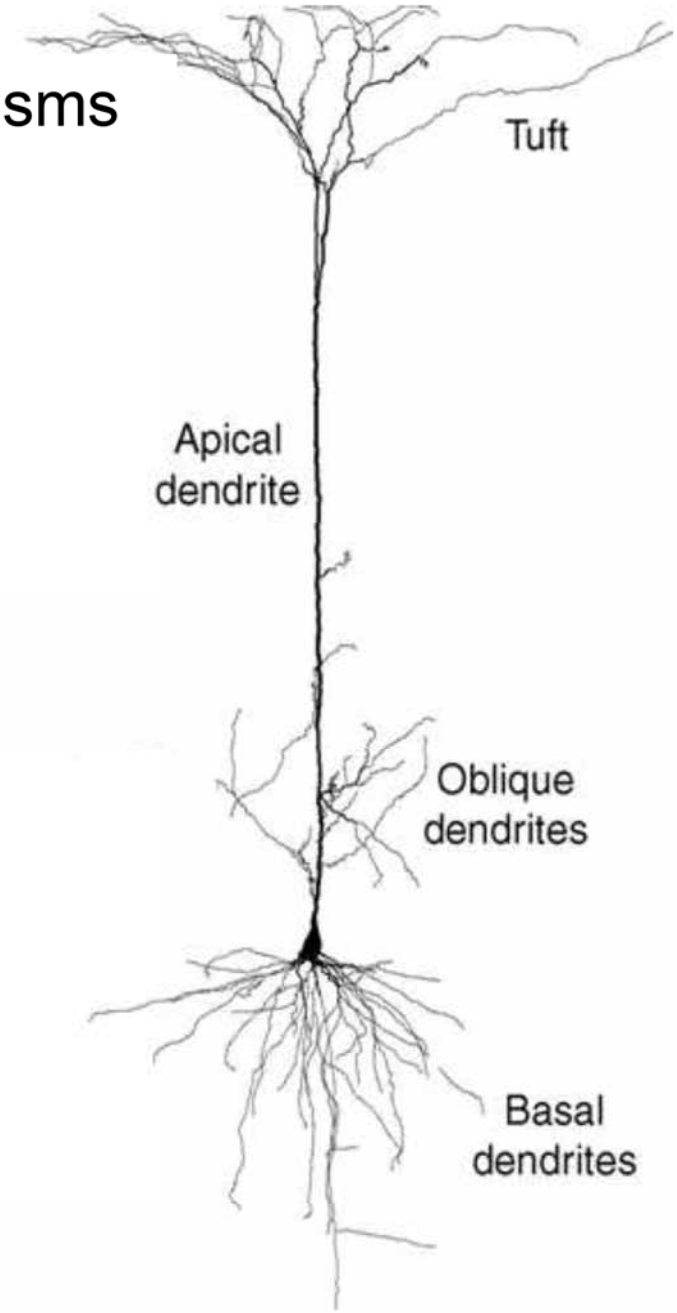
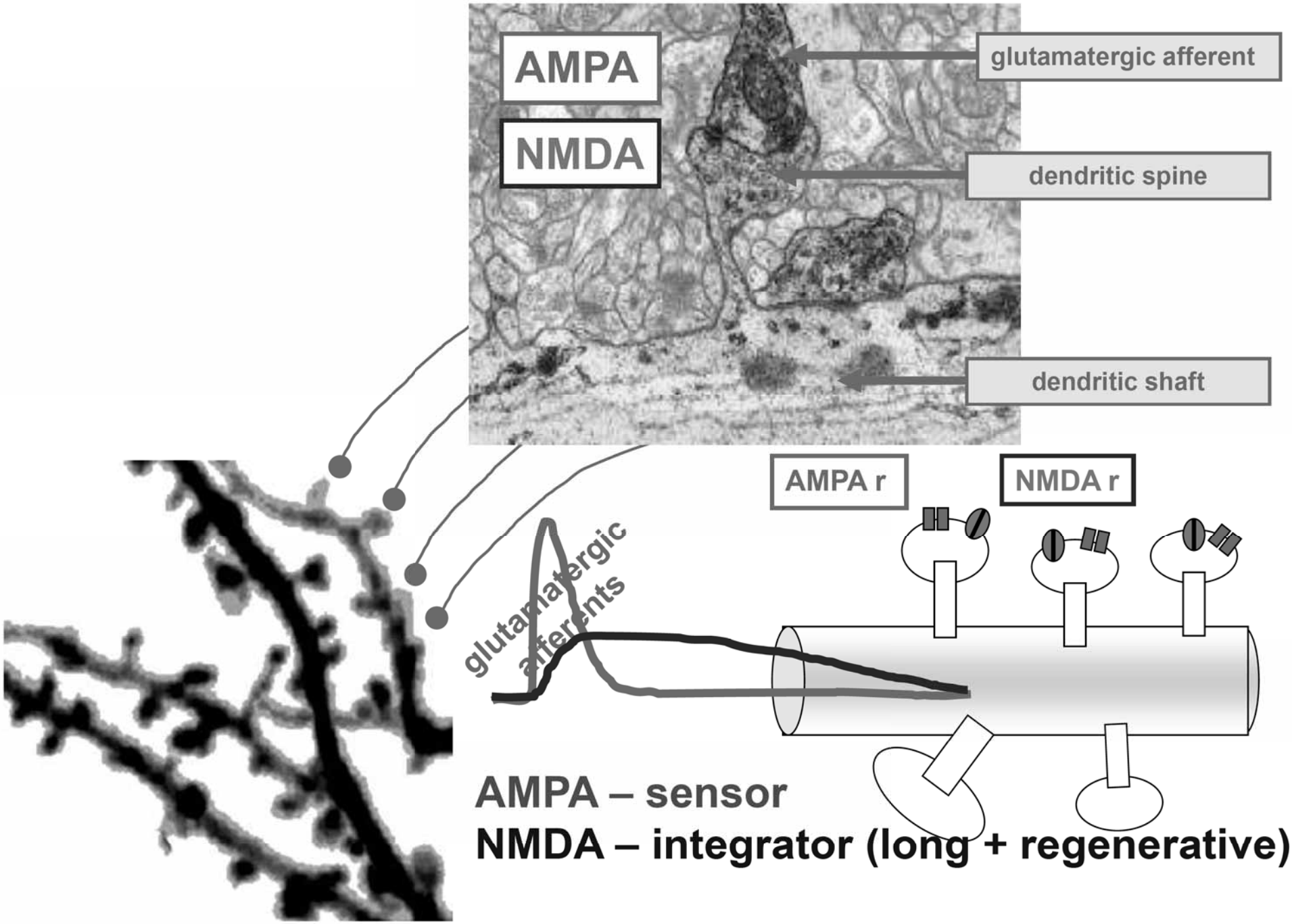
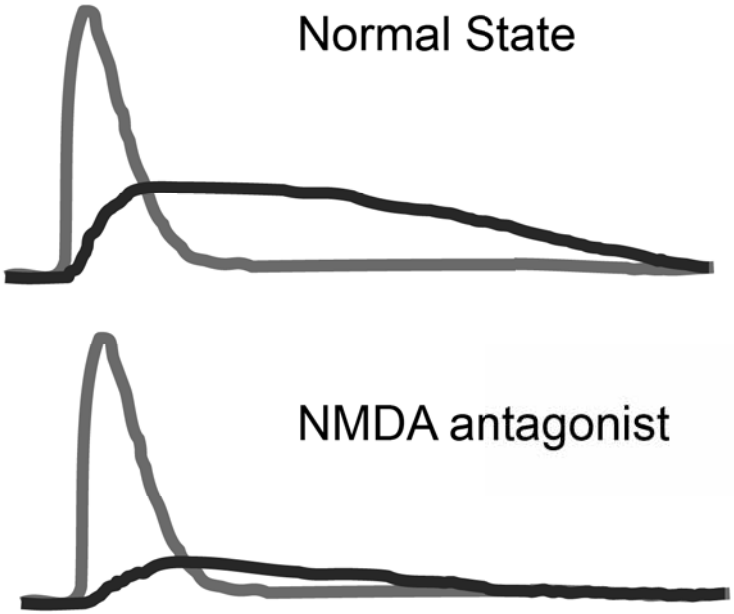
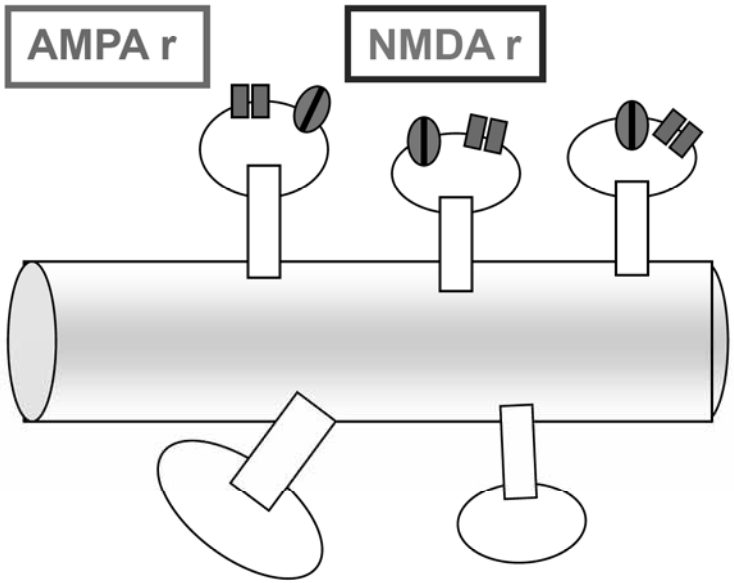


Glutamate Receptors



Glutamate Receptors

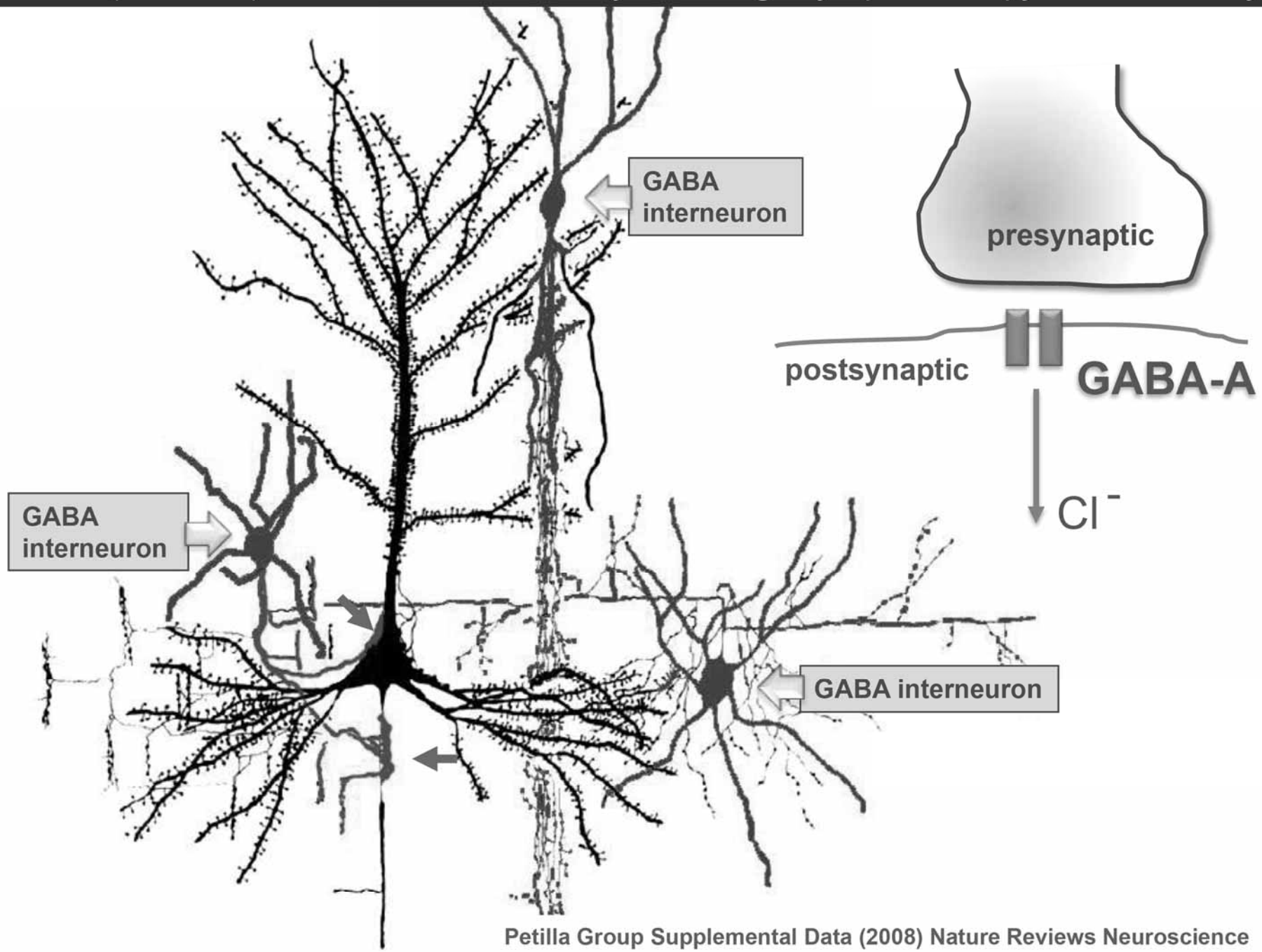




Ketamine – hallucinations, dissociative state, sedation and anesthesia.

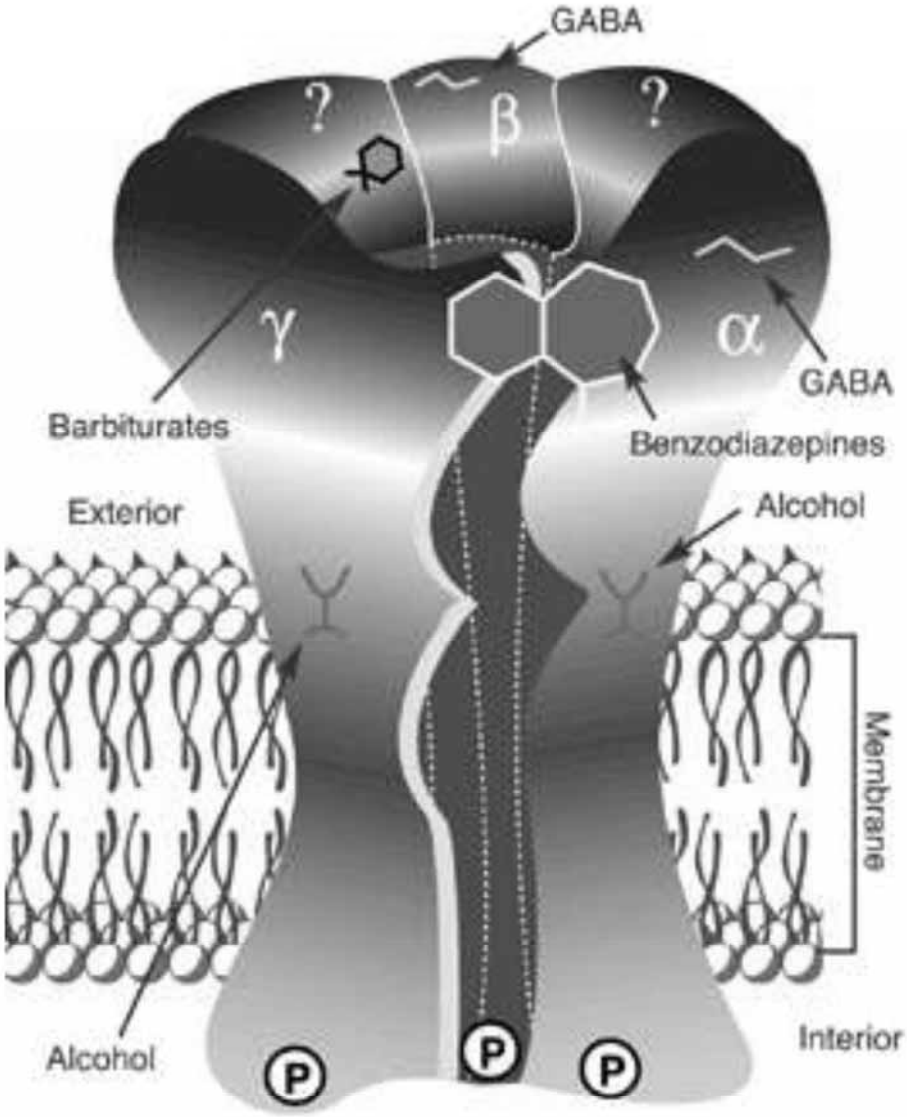
Phencyclidine – PCP - hallucinations, disorientation, mania, and delirium. Induces symptoms virtually indistinguishable from SCHphrenia.

ASPINY (SMOOTH) NEURONS make inhibitory GABA-ergic synapses near pyramidal cell body



Petilla Group Supplemental Data (2008) Nature Reviews Neuroscience

GABA-A RECEPTOR



Positive Modulation of **GABA-A** receptors by:

- ❑ Barbiturates
- ❑ Benzodiazepines
- ❑ Alcohols
- ❑ Volatile Anesthetics