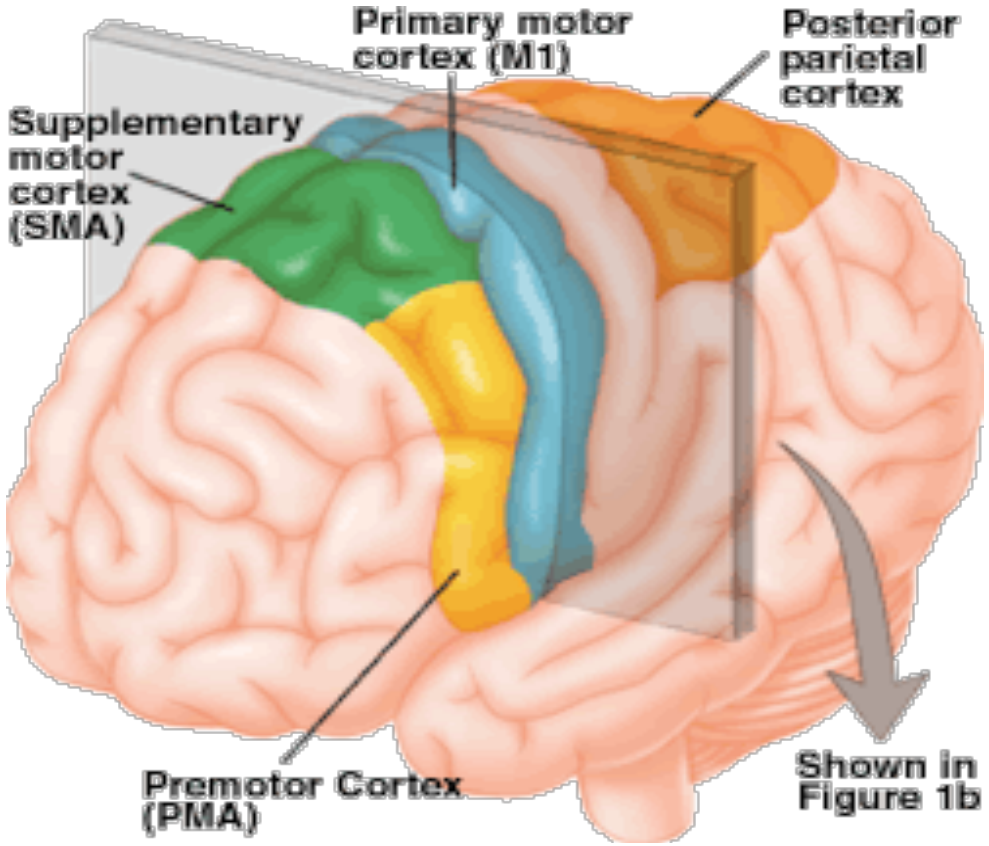
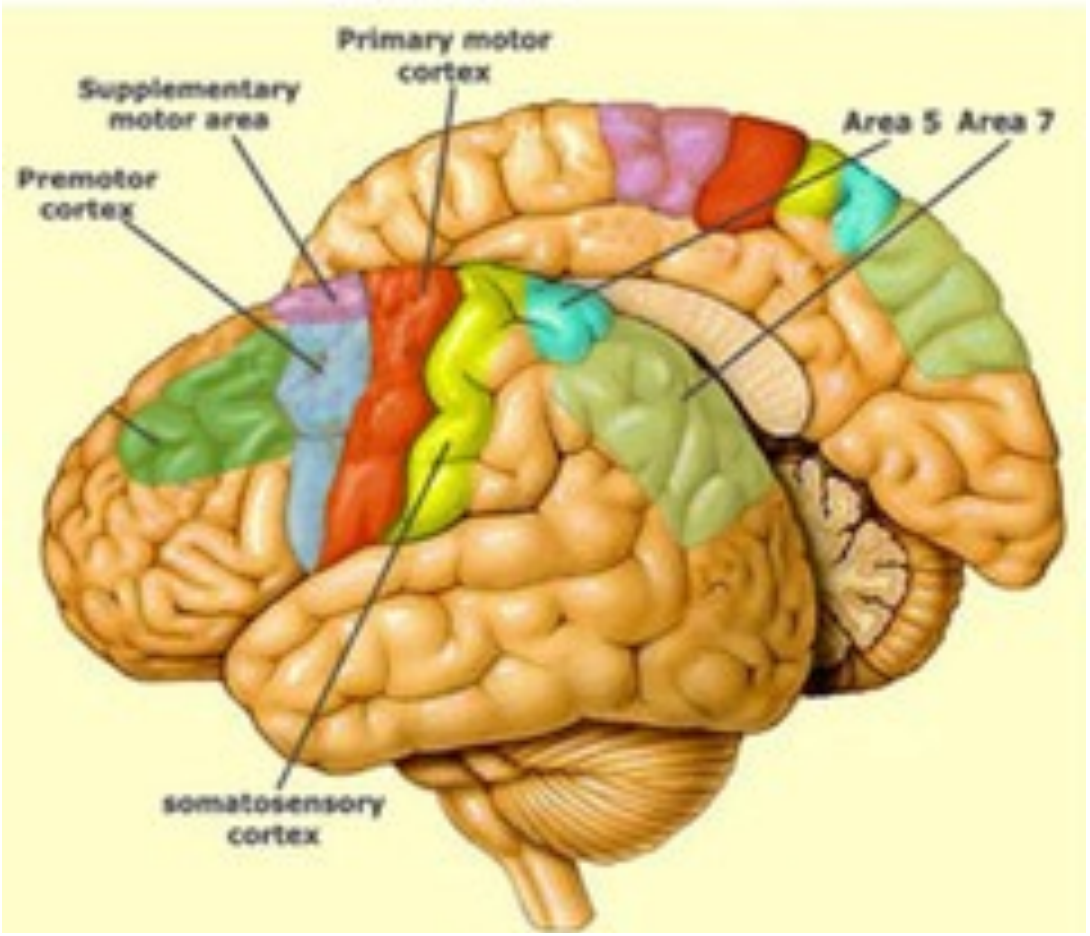
Steps involved in sensory perception:

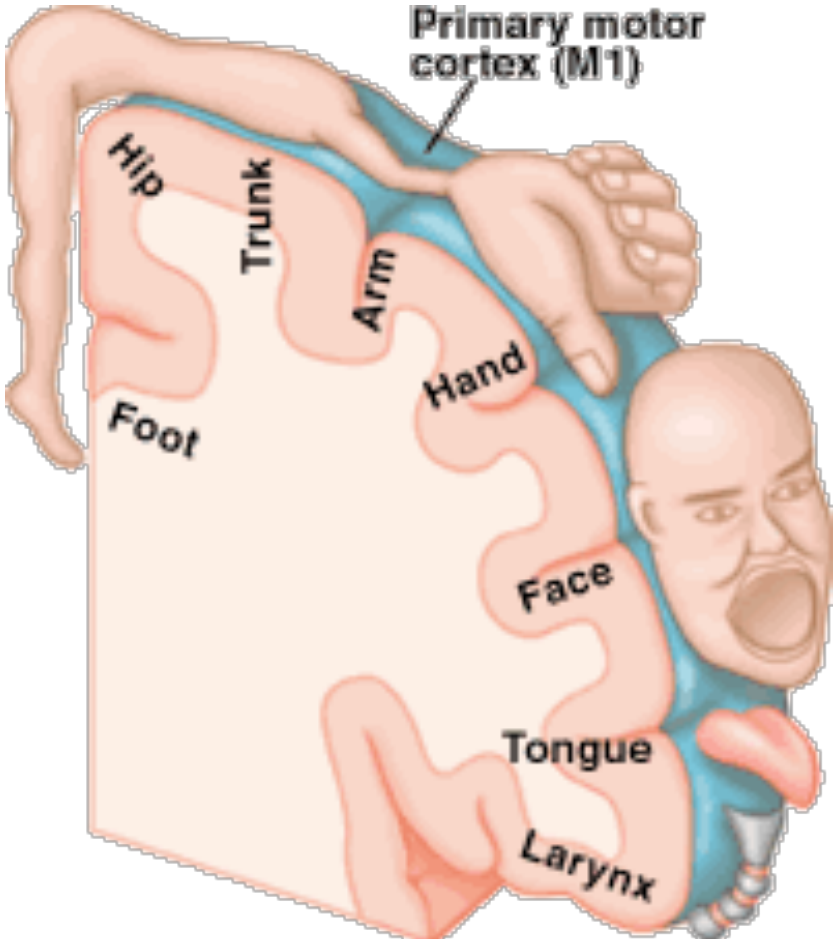
- activate sensory / receptor neurons with external stimulus
- propagate (via action potentials) info through afferent pathways
  - anatomical path (labeled line) with topographical organization tells us “what / where”
  - rate coding / population coding tells us “how much”
- very basic info is determined by primary sensory cortex
- parsed out to higher order areas for more advanced “abstraction”

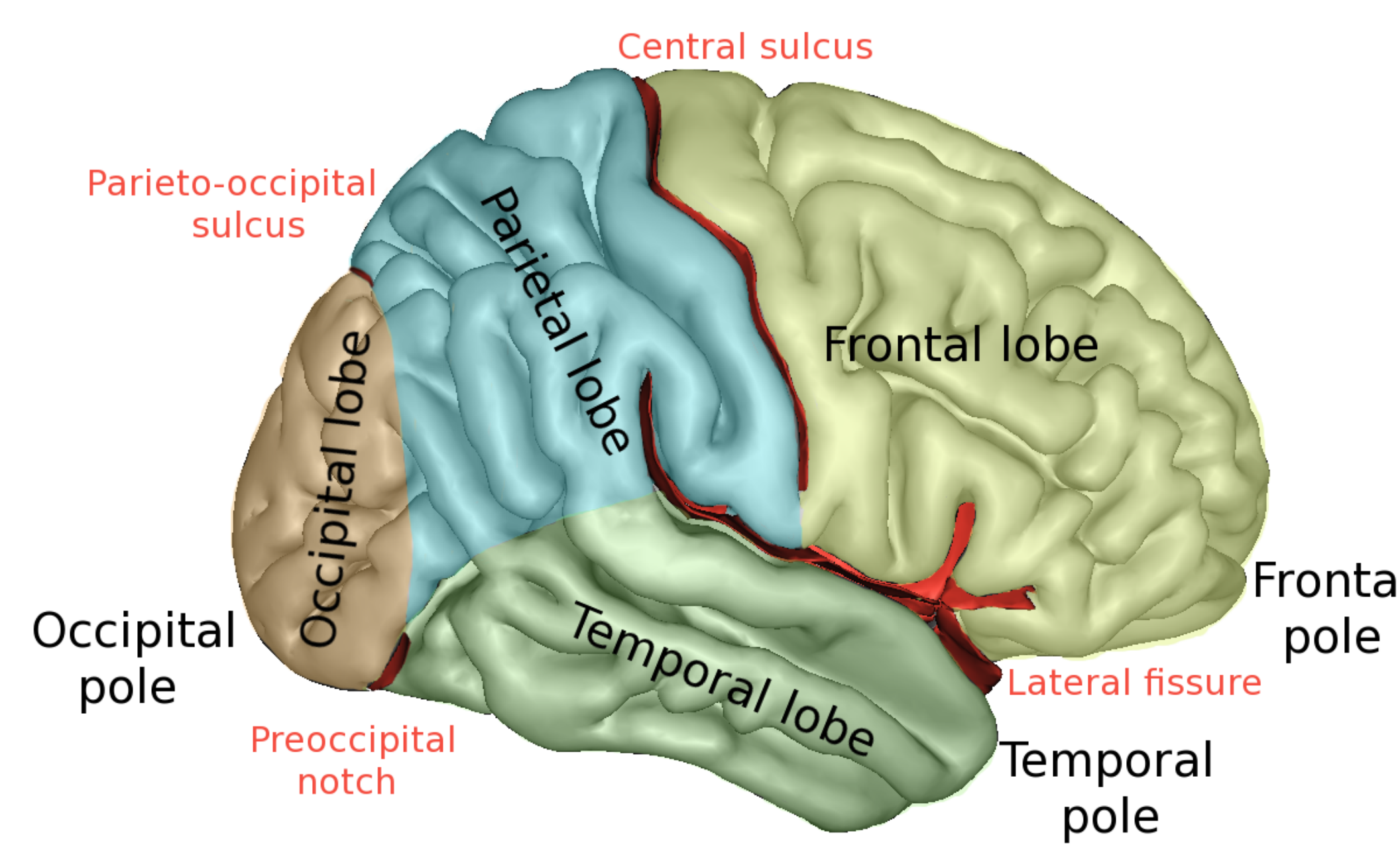


organization of nervous systems's motor "output" is mirror of somatosensory system:

- heavily dependent on sensory systems
  - needs precise info about body position / movements
    - from proprioceptive, visual, auditory, vestibular sensory systems

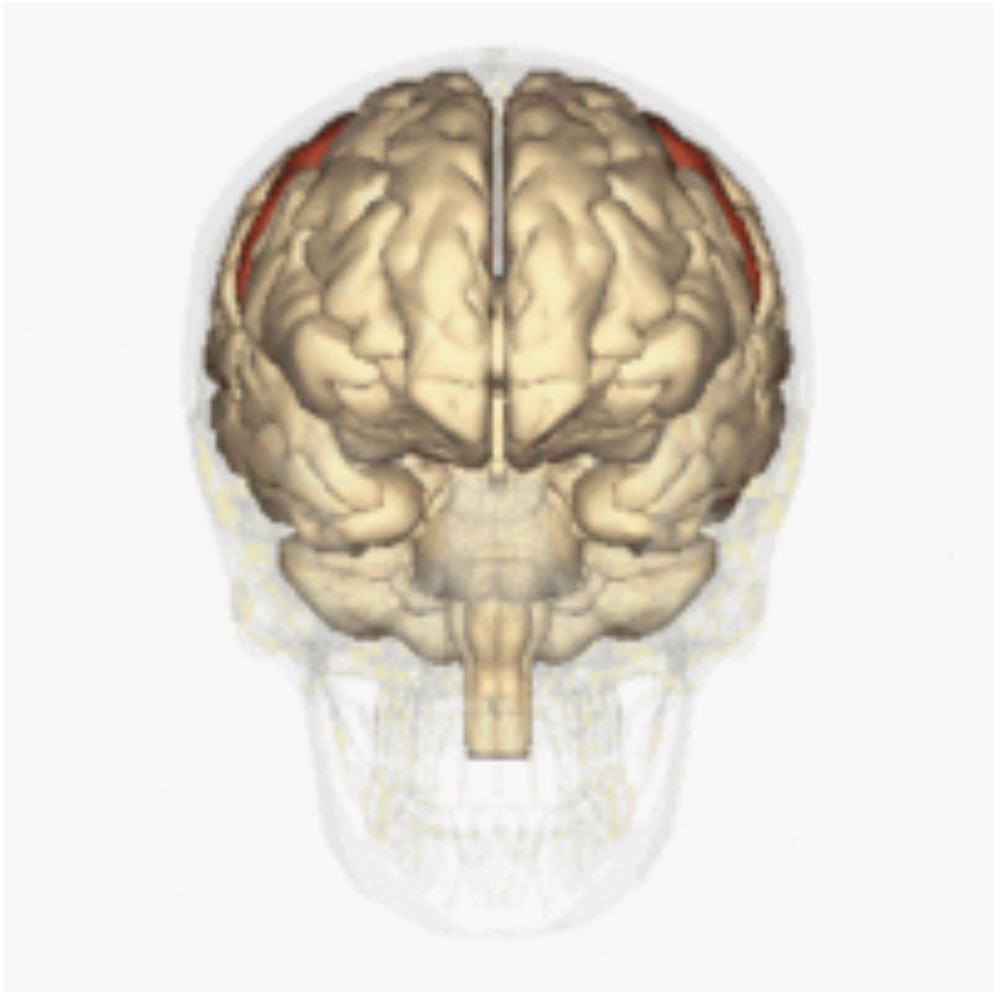





Central sulcus
Parieto-occipital sulcus
Parietal lobe
Occipital lobe
Frontal lobe
Fronta
pole
Occipital
pole
Temporal lobe
Lateral fissure
Preoccipital
notch
Temporal
pole

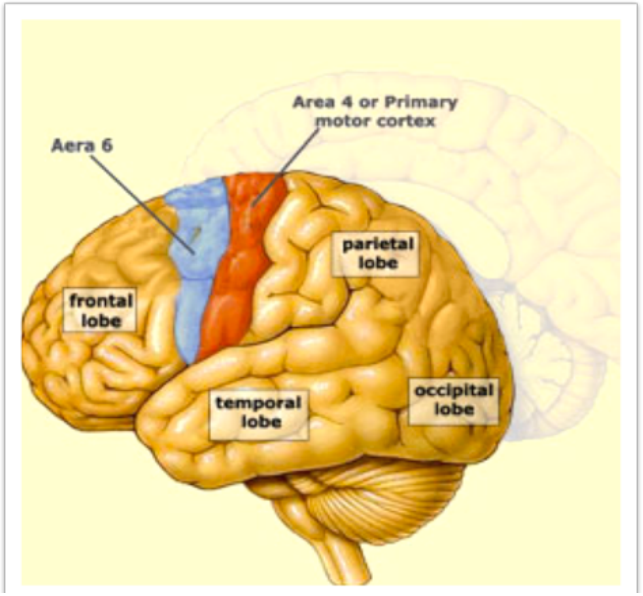
Primary somatosensory cortex
“post-central gyrus”

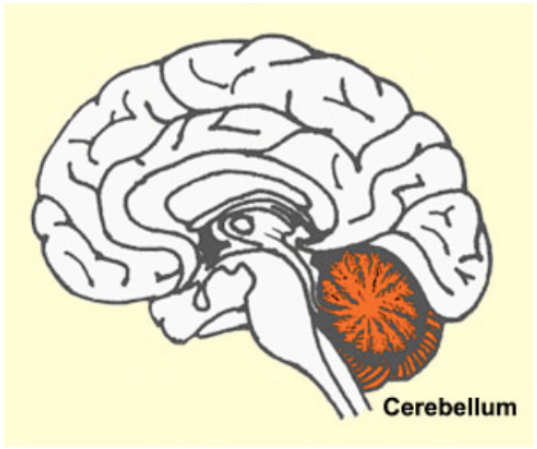
Primary motor cortex
“pre-central gyrus”

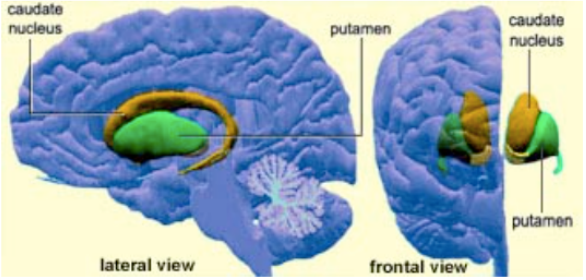


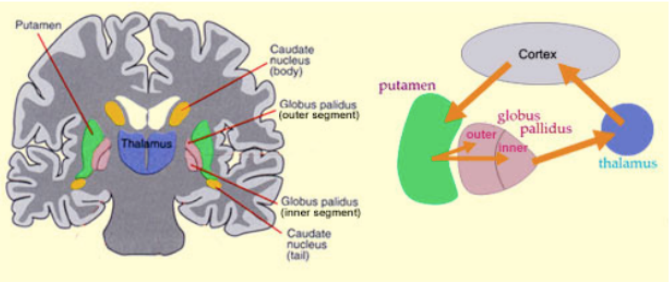
Steps involved in voluntary movement:

- "abstract" thought about what you want to do
  - association cortex, sensory / perceptual systems
- info funneled down to "*premotor*" areas to develop a motor program
  - how to accomplish goal (multiple ways)
    - modulated by *basal ganglia / cerebellum*
- motor program funneled down to primary motor cortex (M1) for execution
  - must indicate *sequence of muscle contractions* and *force* for coordination of body parts
    - anatomical pathway (labeled line) with topographical organization tells us "what / where"
    - rate coding / recruitment coding tells us "how much"

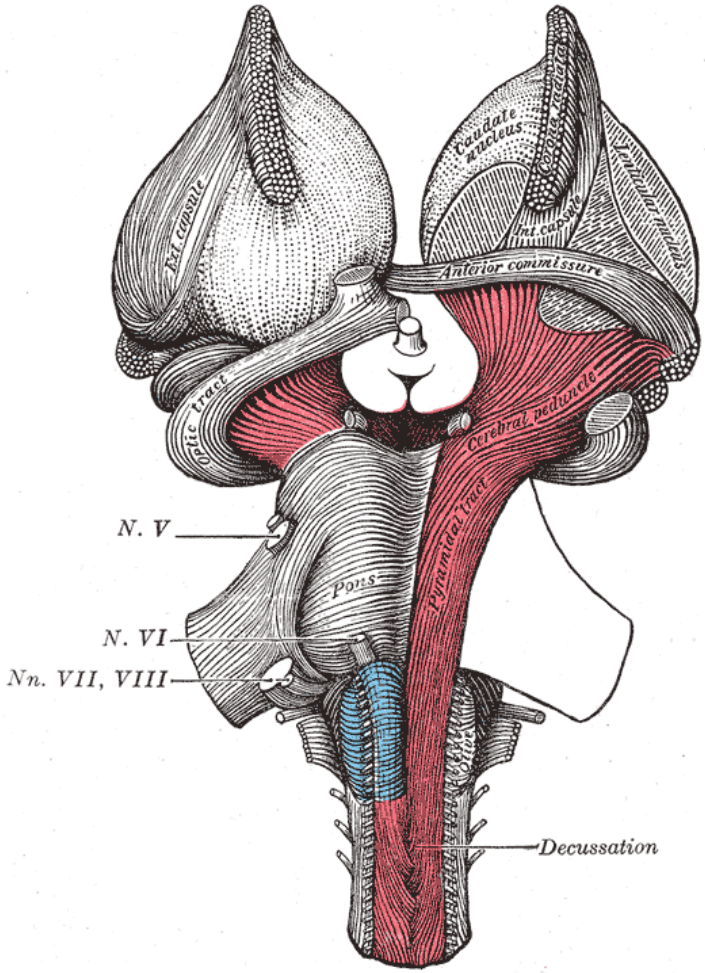


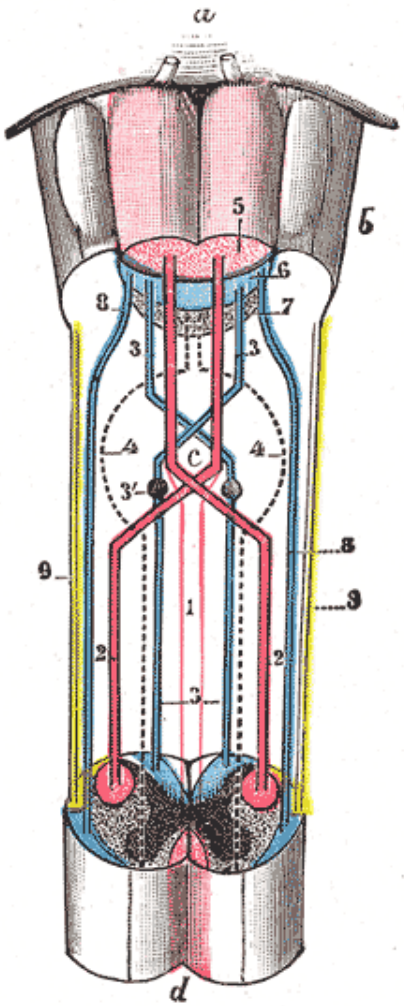


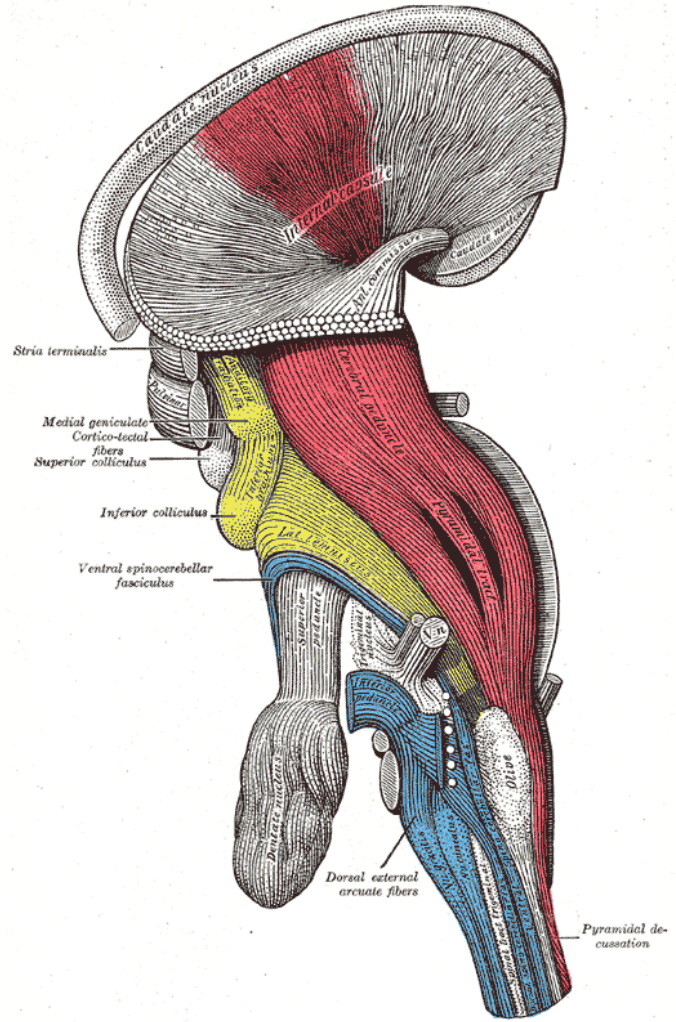




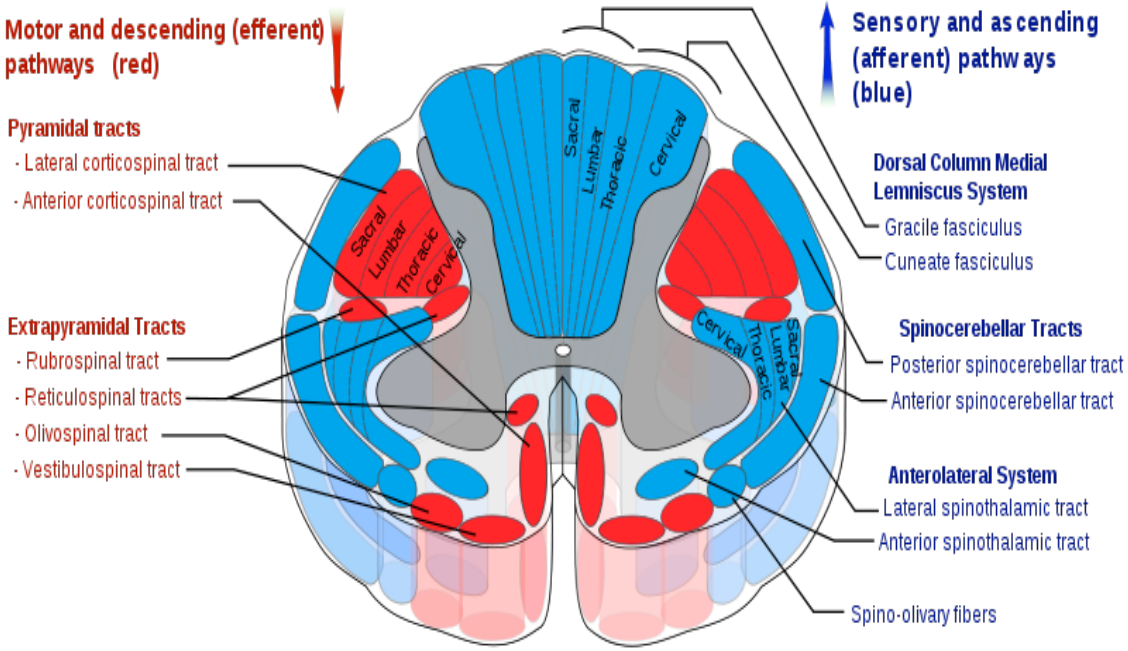
- M1 neurons send axons through descending fiber tracts to synapse with alpha (“true” / “lower”) motor neurons (on contralateral side)
  - in brainstem (cranial motor nuclei) - axial / proximal parts of body
  - in spinal cord (ventral horn) - distal extremities
- muscles contract with desired sequence and force to accomplish goal



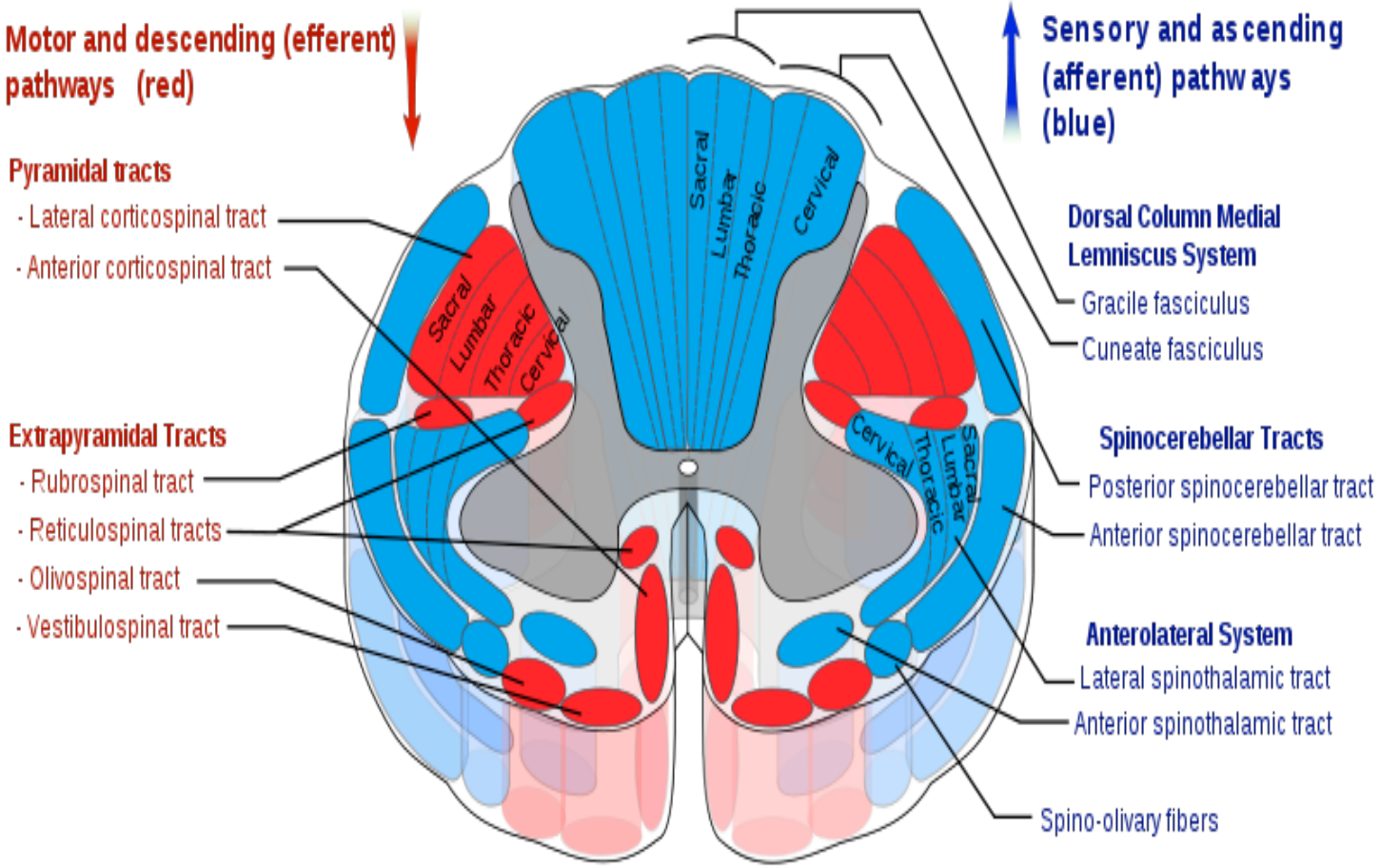


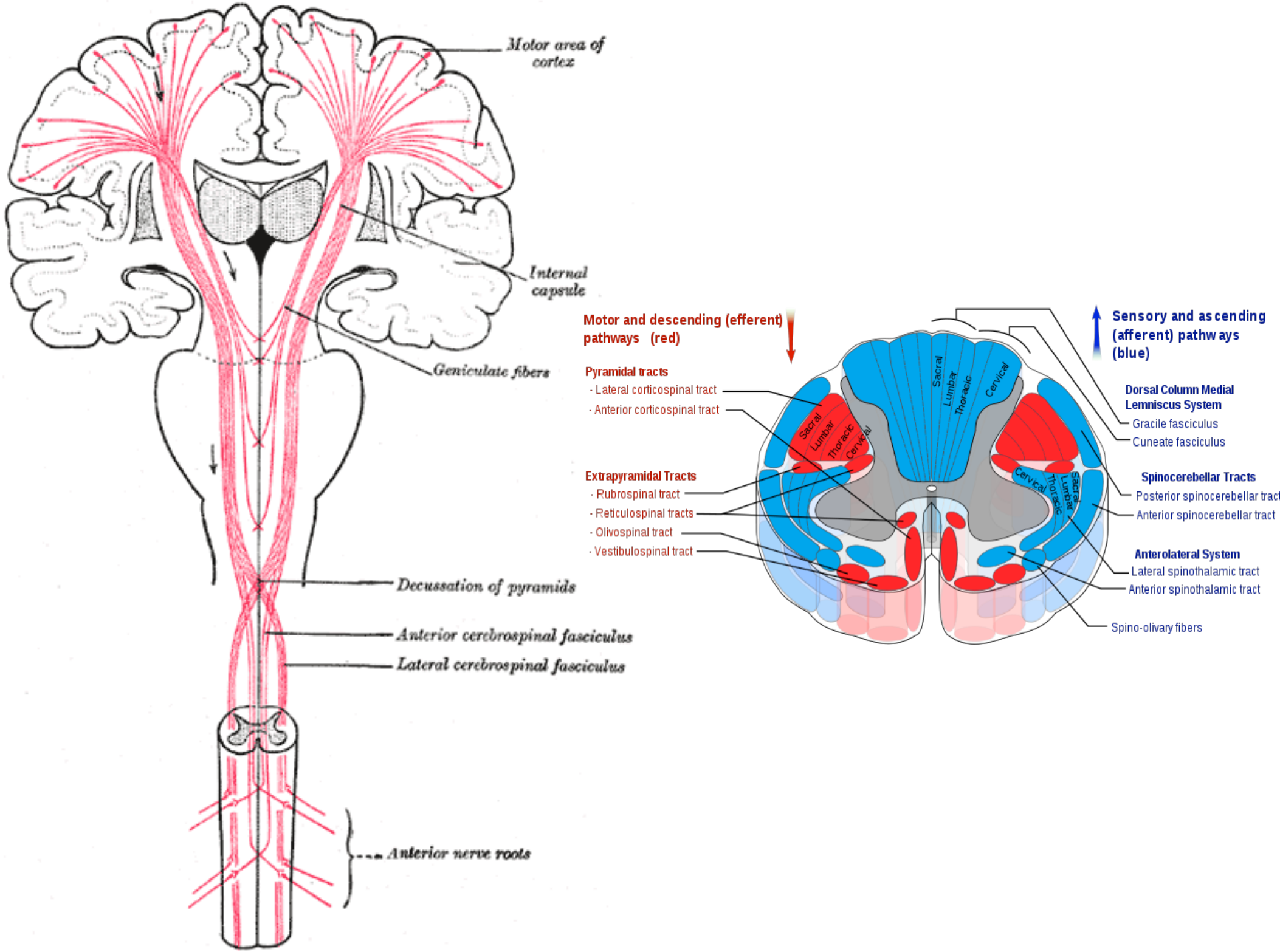


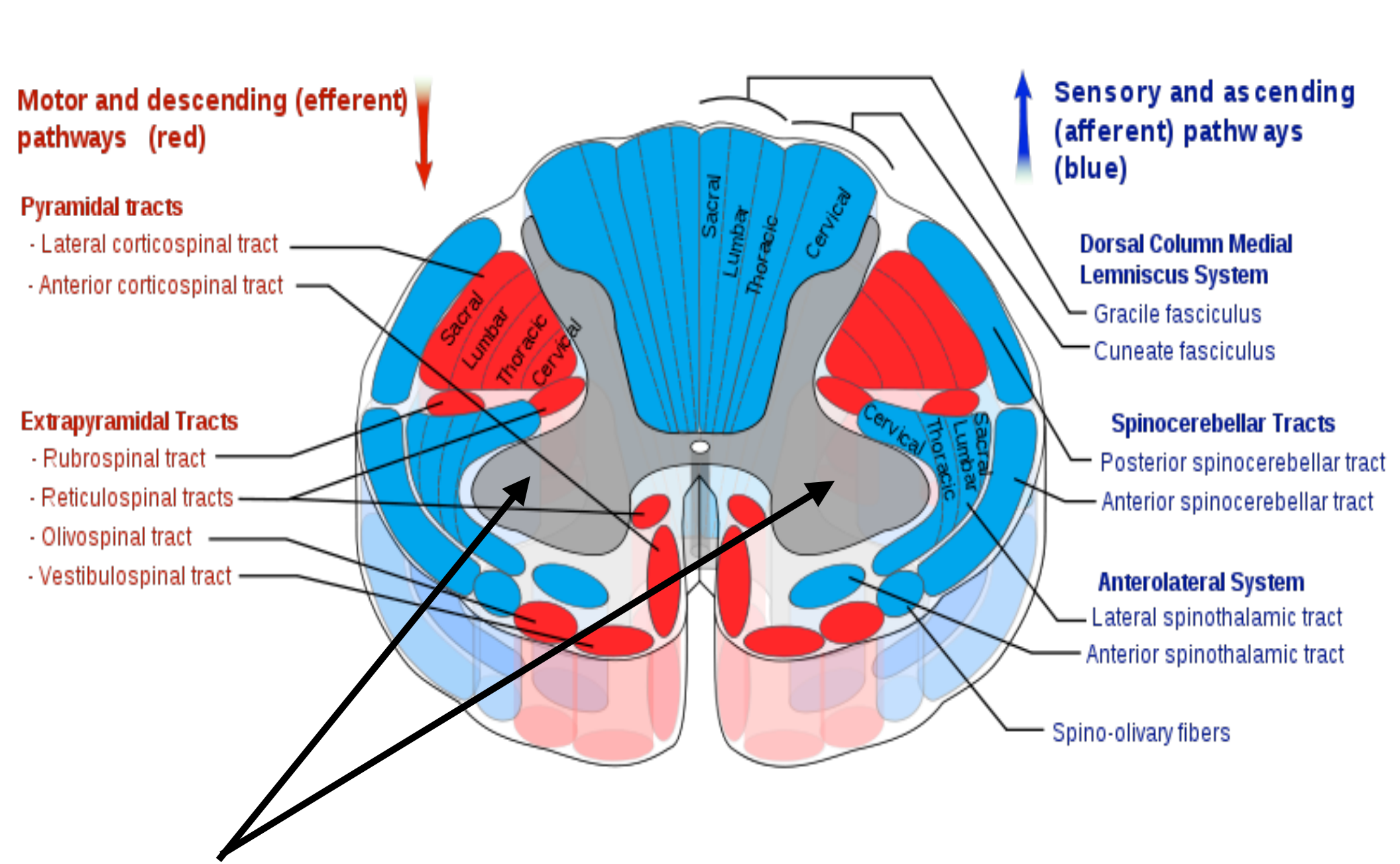
- Upper Motor Neurons <u>do not synapse with muscles</u>
  - premotor / supplementary motor cortex - planning
  - basal ganglia - initiation
  - cerebellum - error detection / correction
  - primary M1 motor cortex in frontal lobe - send info to Lower Motor Neurons for execution
    - descending axons form <u>pyramidal (corticospinal) tracts</u>
      - lateral / anterior



- subcortical motor areas - axons form <u>extrapyramidal tracts</u>
  - rubrospinal tract
  - reticulospinal tract
  - olivospinal tract
  - vestibulospinal tract

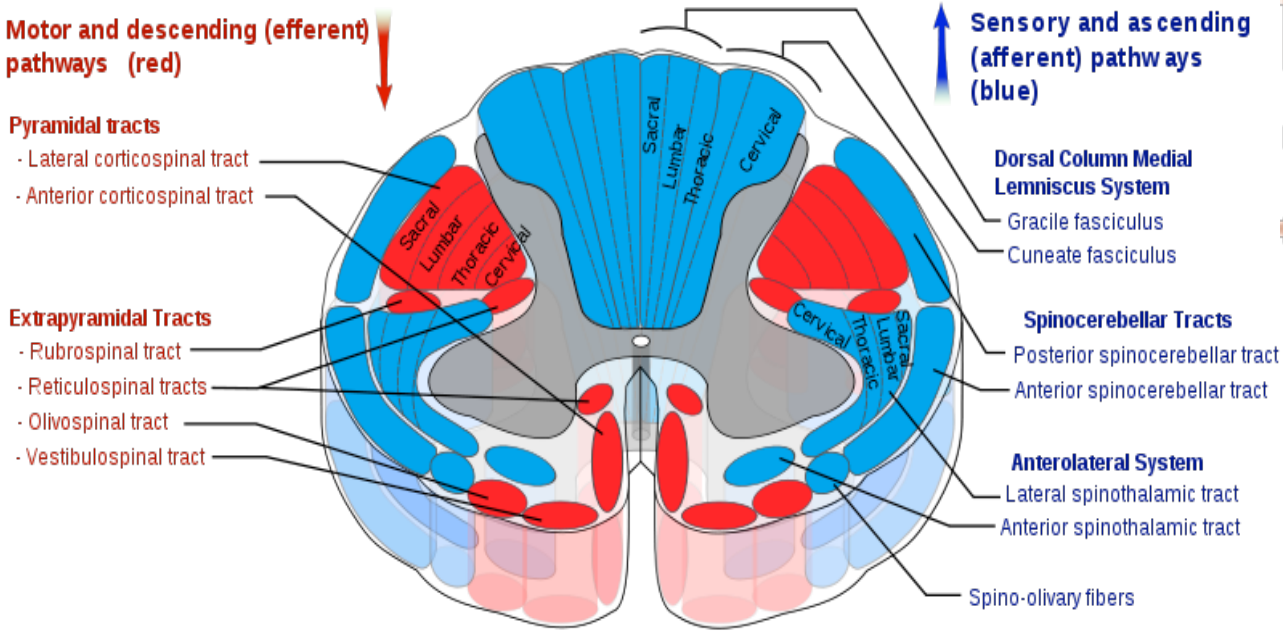


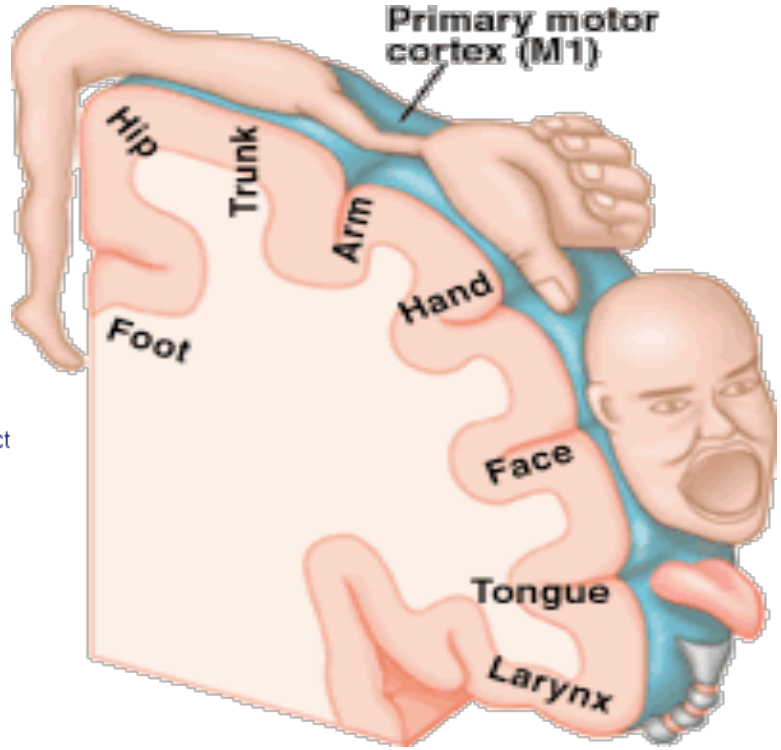

Motor area of cortex
Internal capsule
Geniculate fibers
Decussation of pyramids
Anterior cerebrospinal fasciculus
Lateral cerebrospinal fasciculus
Anterior nerve roots
Motor and descending (efferent) pathways (red)
Pyramidal tracts
- Lateral corticospinal tract
- Anterior corticospinal tract
Extrapyramidal Tracts
- Rubrospinal tract
- Reticulospinal tracts
- Olivospinal tract
- Vestibulospinal tract
Sensory and ascending (afferent) pathways (blue)
Dorsal Column Medial Lemniscus System
Gracile fasciculus
Cuneate fasciculus
Spinocerebellar Tracts
Posterior spinocerebellar tract
Anterior spinocerebellar tract
Anterolateral System
Lateral spinothalamic tract
Anterior spinothalamic tract
Spino-olivary fibers
Sacral
Lumbar
Thoracic
Cervical



Ventral horn of spinal cord - alpha / true / lower motor neurons
axons leave through ventral root to synapse with muscle fibers

- Motor system is topographically organized
  - Lower motor neurons in ventral “horn” of spinal cord (gray matter)
    - medial = medial (axial) muscles (gross movements)
    - lateral = lateral (distal) muscles (fine movements)
    - dorsal = flexor muscles
    - ventral = extensor muscles

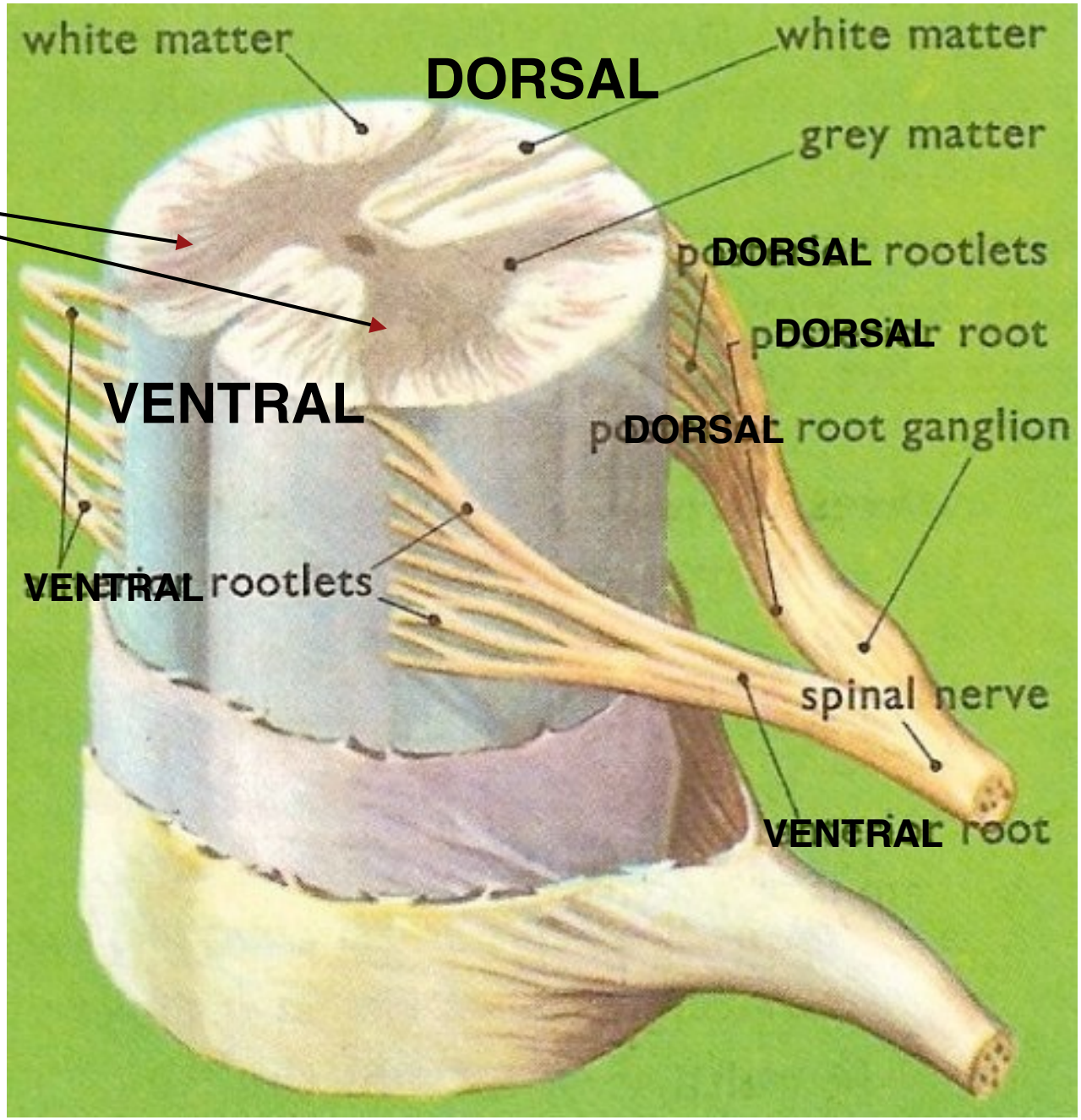




cell bodies of Lower Motor Neurons in ventral horns:

- alpha (α) motor neurons innervate skeletal (extrafusal / contracting) fibers

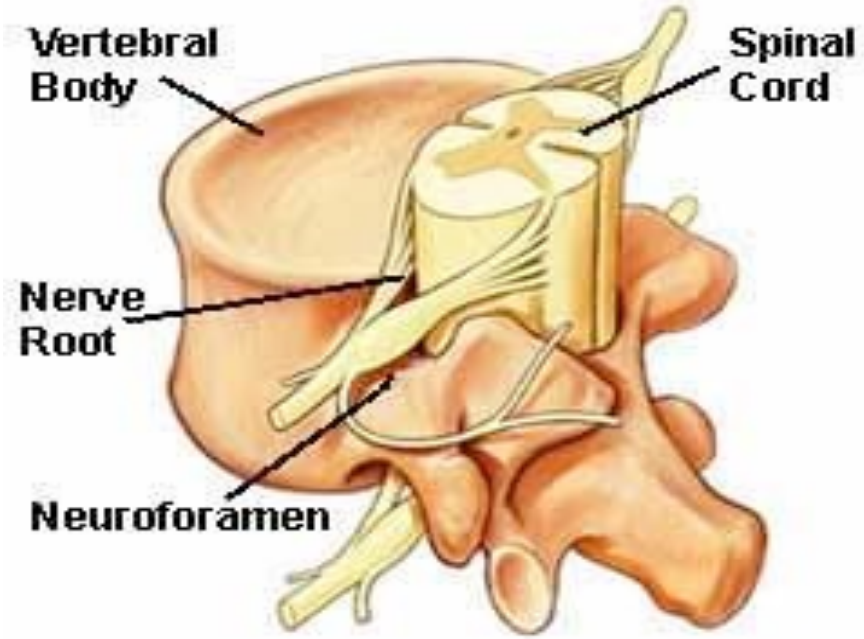
- gamma (y) motor neurons adjust tension of muscles' sensory receptors

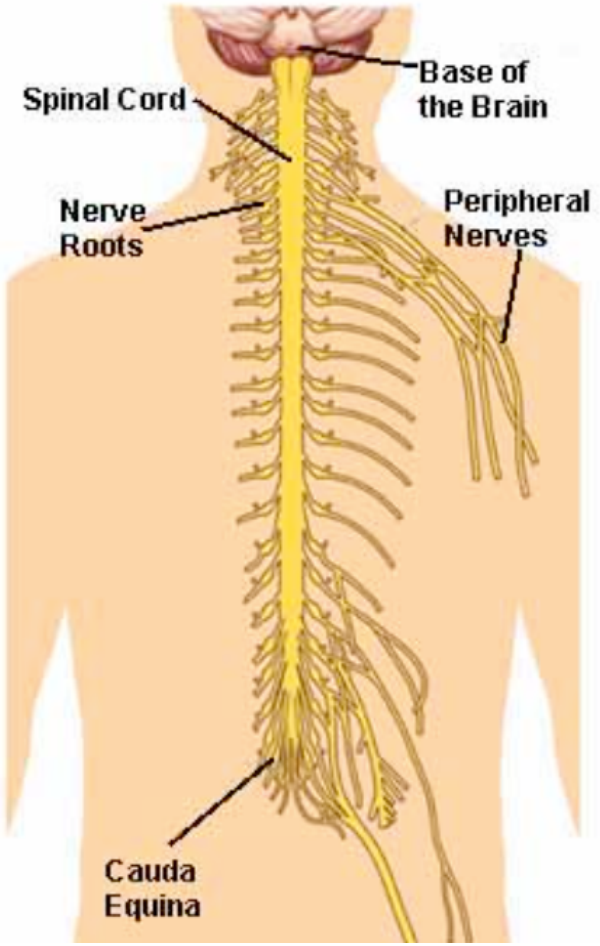


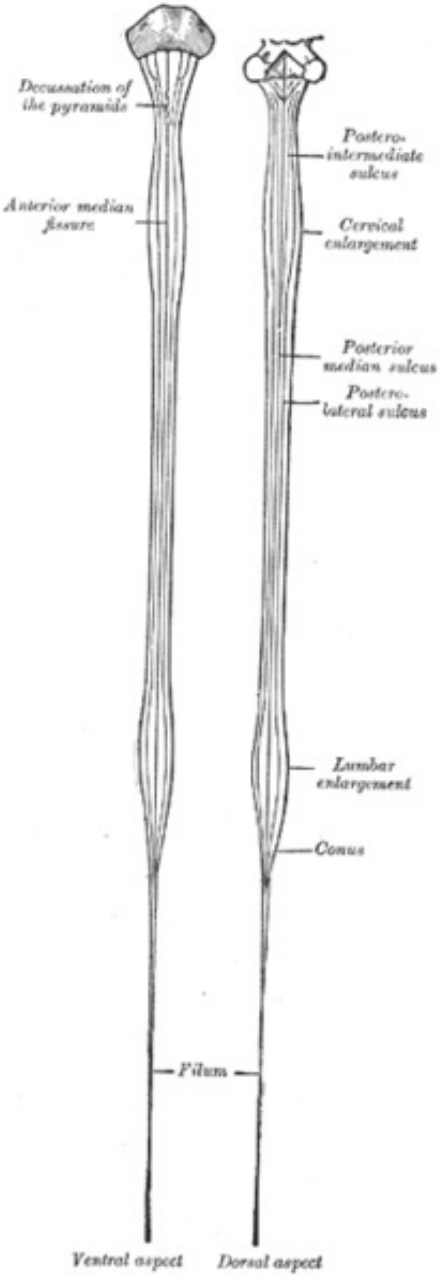
- **Spinal Cord contains all the local circuits required for every movement**
  - voluntary movements: efferents from cortex turn circuits on / off
  - non-voluntary movements:
    - *autogenic movement - spontaneous activity of α-motor neurons (non-reflexive / non-voluntary)*
    - *reflex - stereotyped responses to a specific stimulus*
      - *graded response - intensity directly proportional to stimulus intensity*
      - *local sign - fixed relationship between site stimulated and reflex produced (e.g., knee = kick)*
        - *every reflex can be suppressed voluntarily*
    - *autometisms - stereotyped response*
      - *reflexogenic - elicited by stimulation, but continues over time following stimulus (e.g., walking)*

- “lower motor neurons” in brain stem innervate medial / axial muscles
  - face / neck
  - posture
  - gross motor movements
  - equilibrium

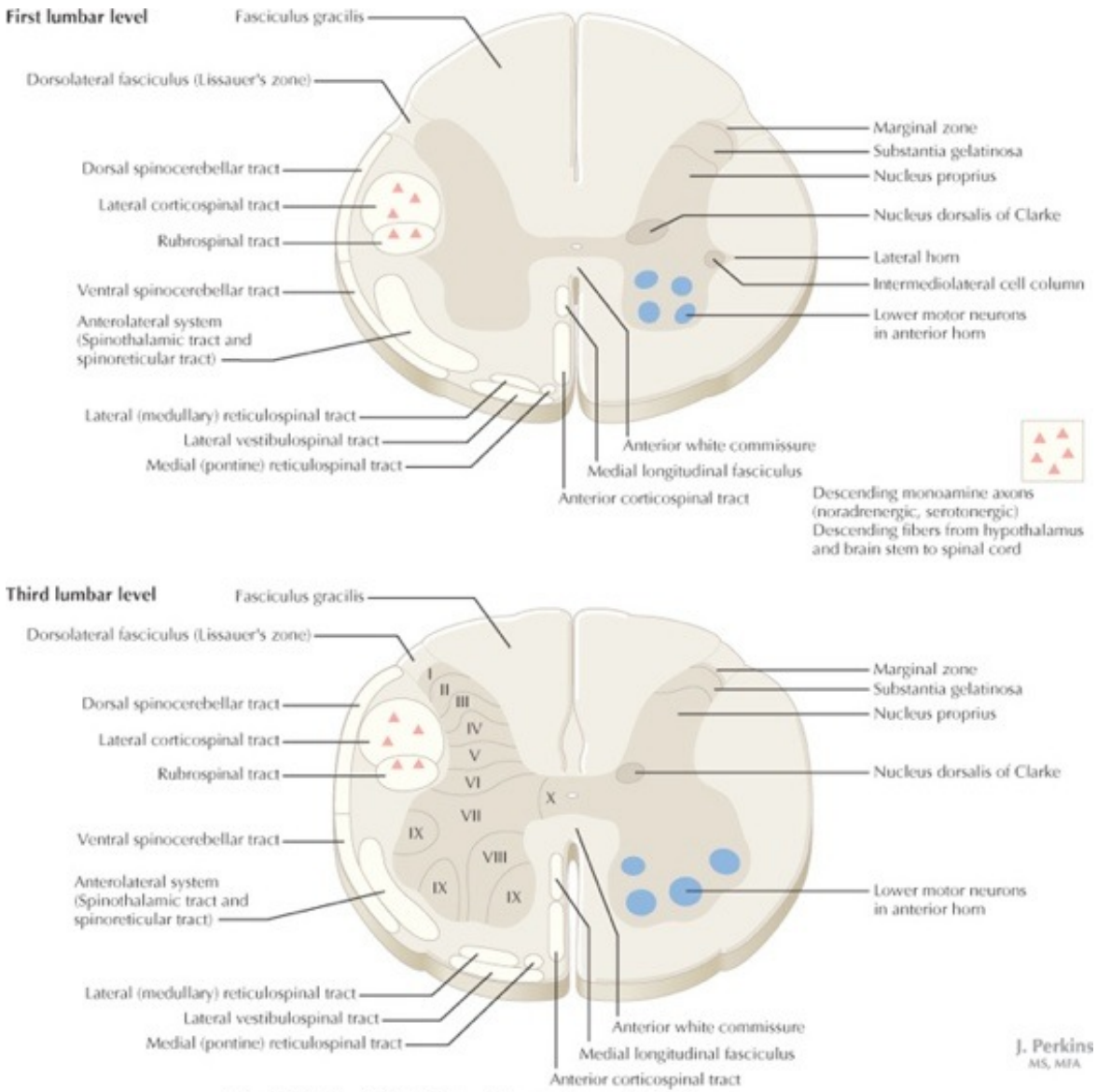
- “lower motor neurons” in spinal cord innervate distal limbs etc.
  - cervical & lumbar enlargements - contain more cells
    - for arms and legs, respectively
  - autogenic movements / reflexes





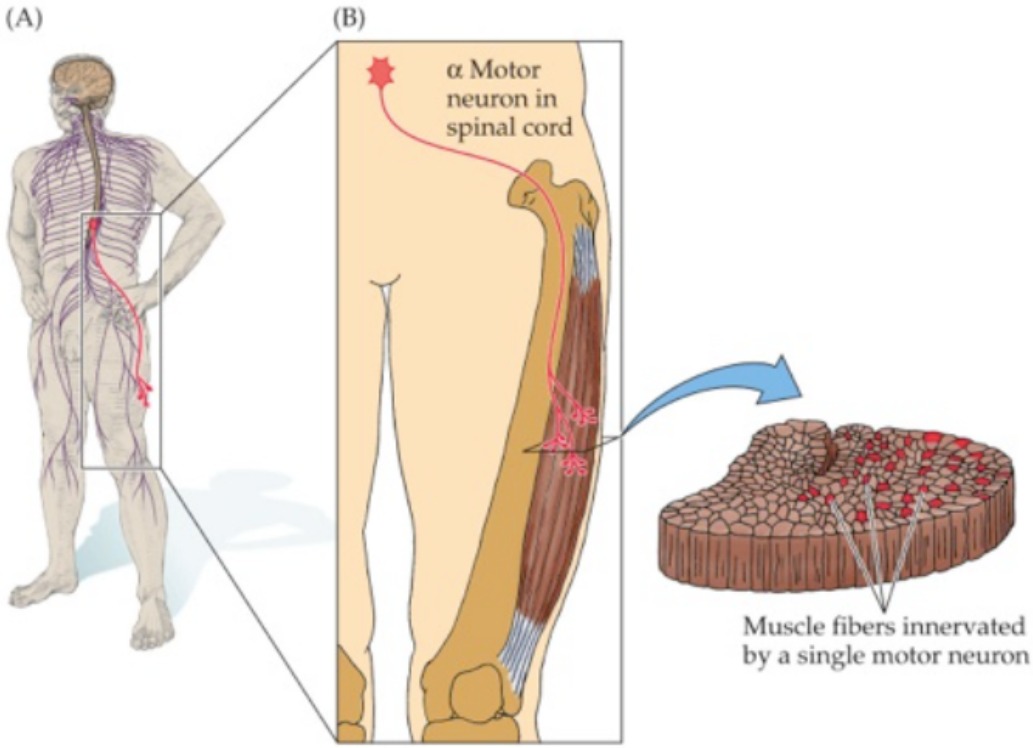


Lower motor neuron – ipsilateral / single muscle
Upper motor neuron - contralateral / groups of muscles



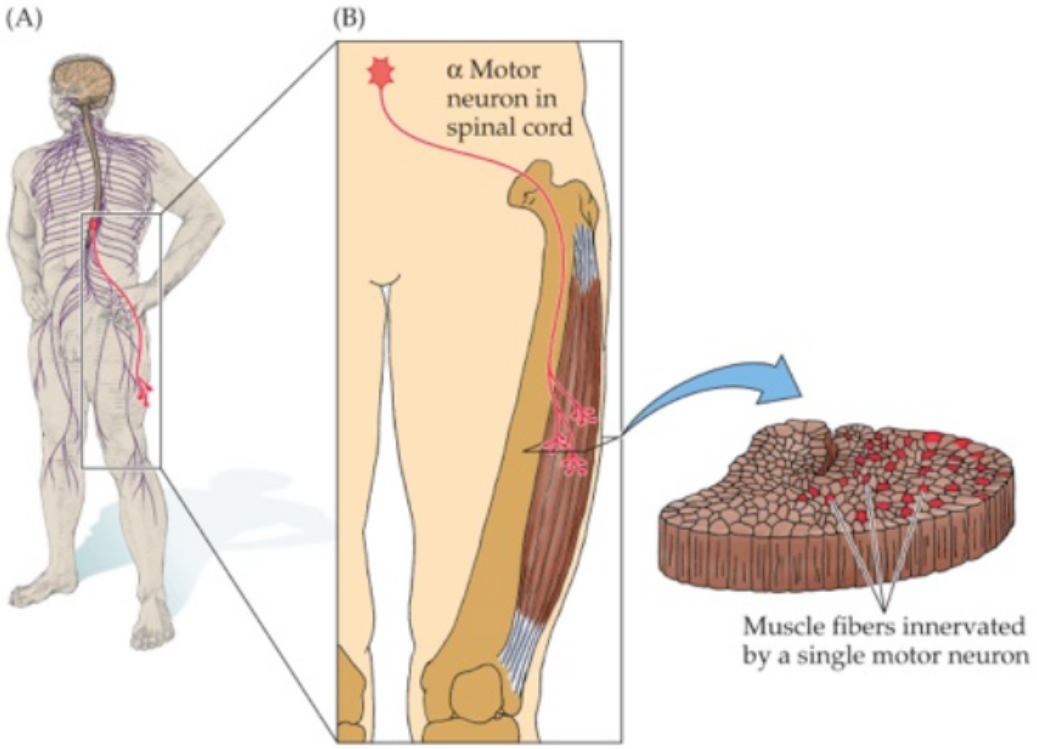
Felten & Shetty: Netter's Atlas of Neuroscience, 2nd Edition.

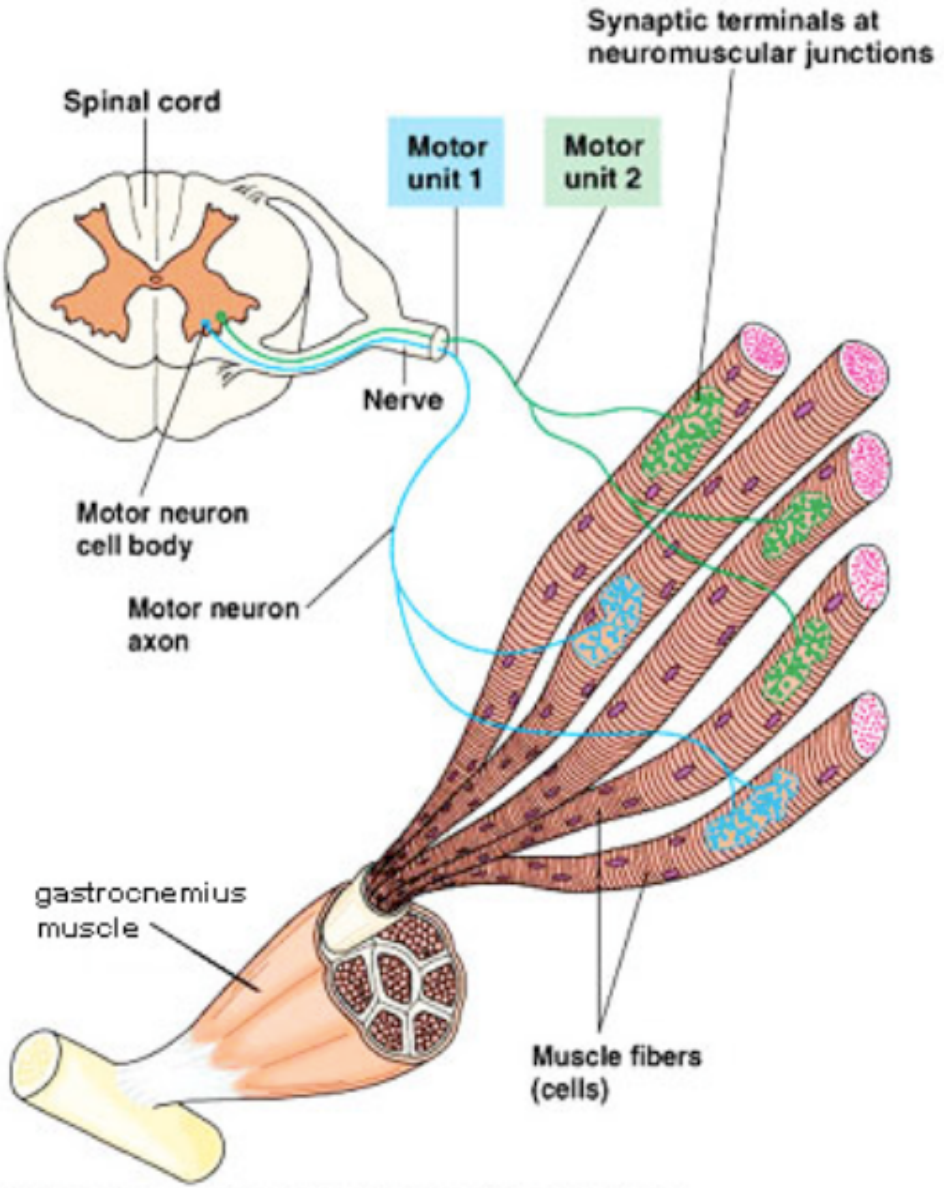
- “final common pathway” - α-motor neurons output to muscles
  - opposite of sensory systems
  - **All** movement is related to the output of spinal and cranial <u>lower motor neurons</u>
  - muscle contractions AND MUSCLE TONE mediated thru muscle’s sensory receptors
    - muscle spindles (detect muscle stretch)
    - Golgi tendon organs (detect muscle contraction)
      - <u>sensory</u> input feeds back to spinal cord in a reflexive loop

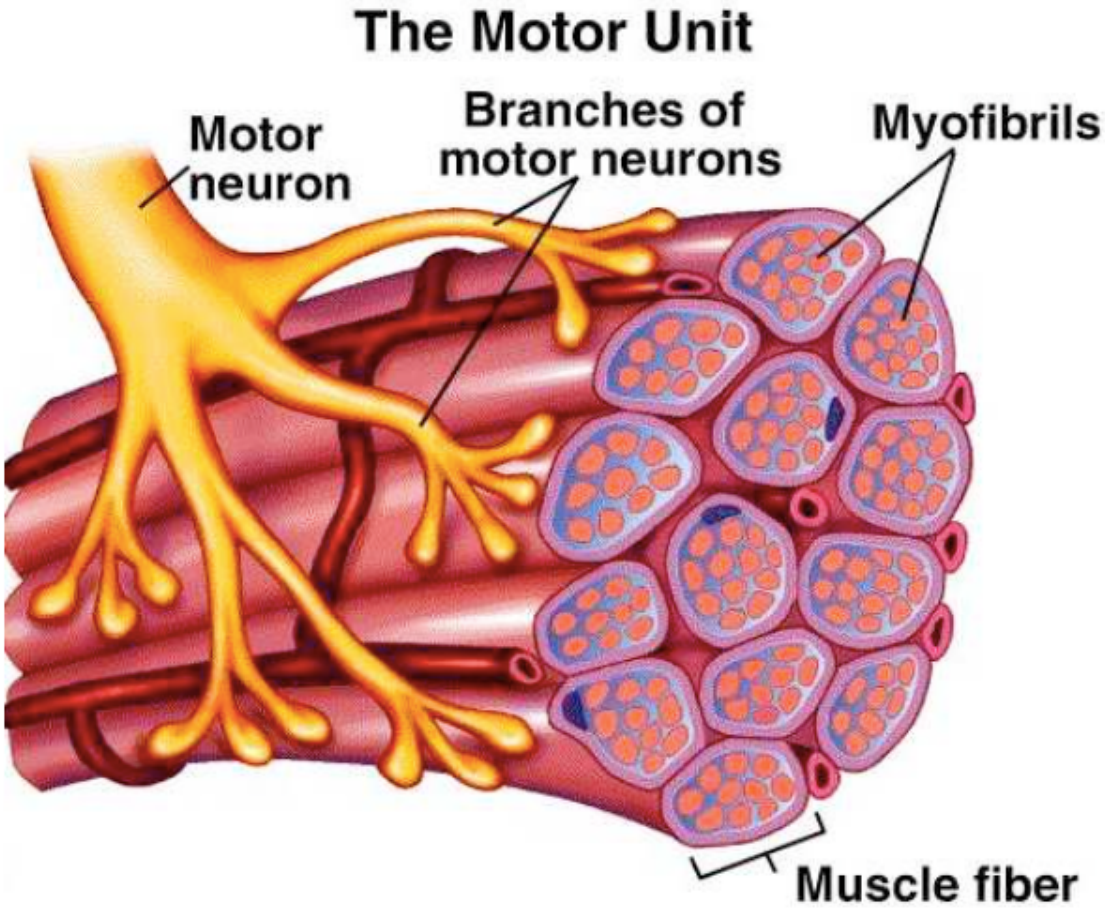


- Neuromuscular junction:
  - each individual muscle fiber is innervated by 1 α-motor neuron
    - ACh released from axon terminal, activates muscle fiber (contraction)
  - each α-motor neuron, however, can innervate several fibers (150 ave)

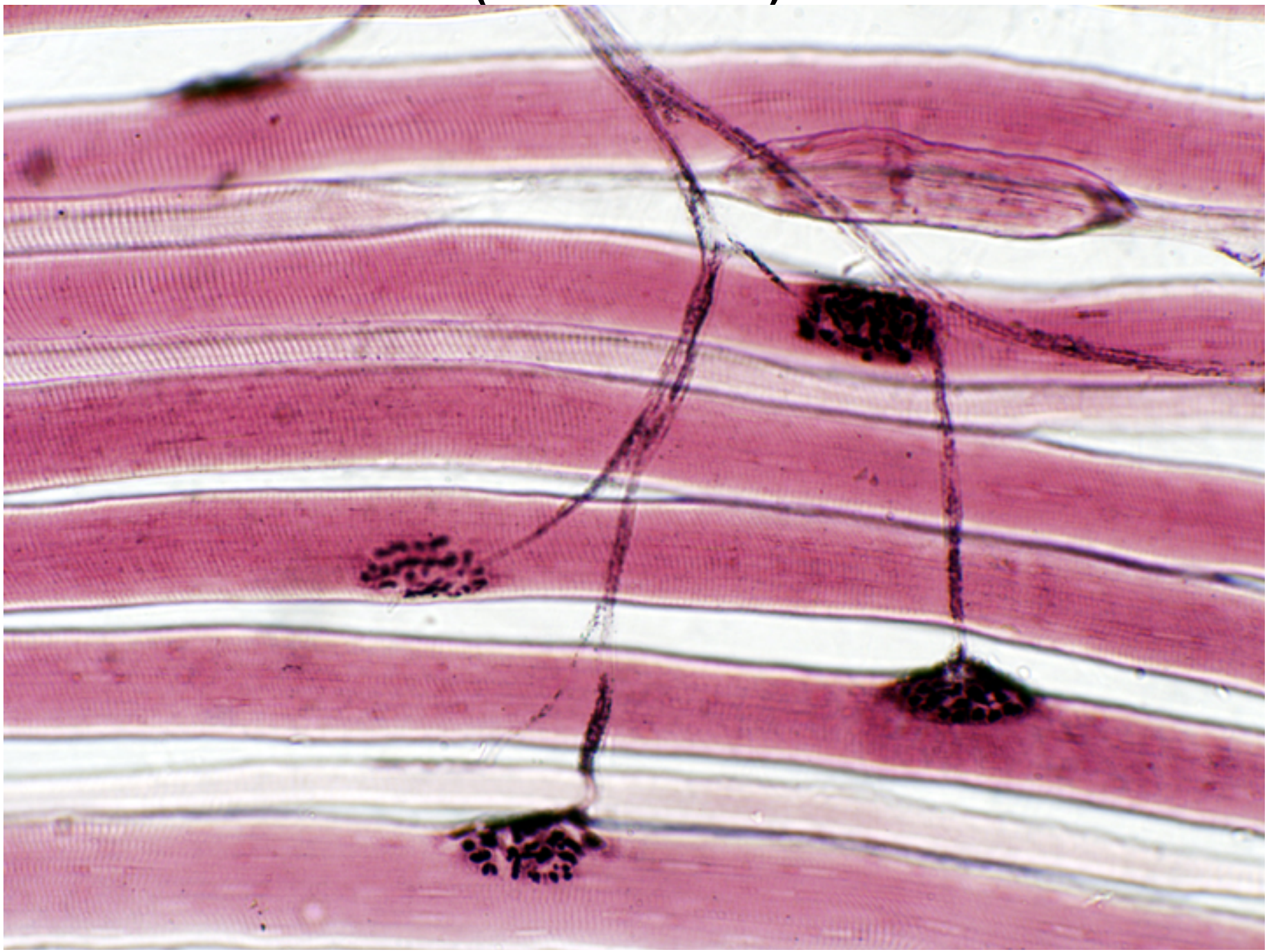
  - motor unit - 1 α-motor neuron and all of its innervated muscle fibers
    - smallest functional unit
    - smaller innervation ratio for distal musculature (fractionation of movement)
  - motor pool - all of the α-motor neurons innervating a whole muscle




Synaptic terminals at
neuromuscular junctions
Spinal cord
Motor
unit 1
Motor
unit 2
Nerve
Motor neuron
cell body
Motor neuron
axon
gastrocnemius
muscle
Muscle fibers
(cells)


The Motor Unit
Motor
neuron
Branches of
motor neurons
Myofibrils
Muscle fiber

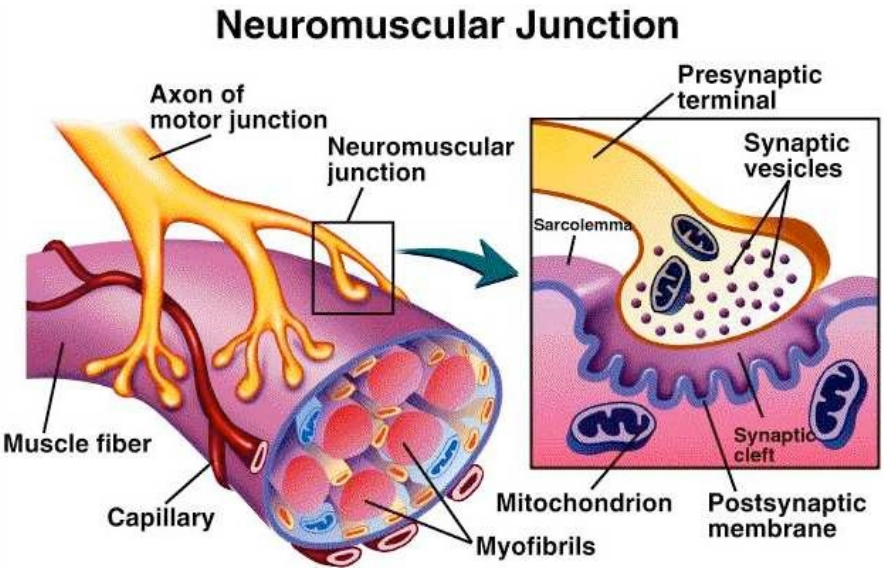
Neuromuscular Junction
(1 motor unit)

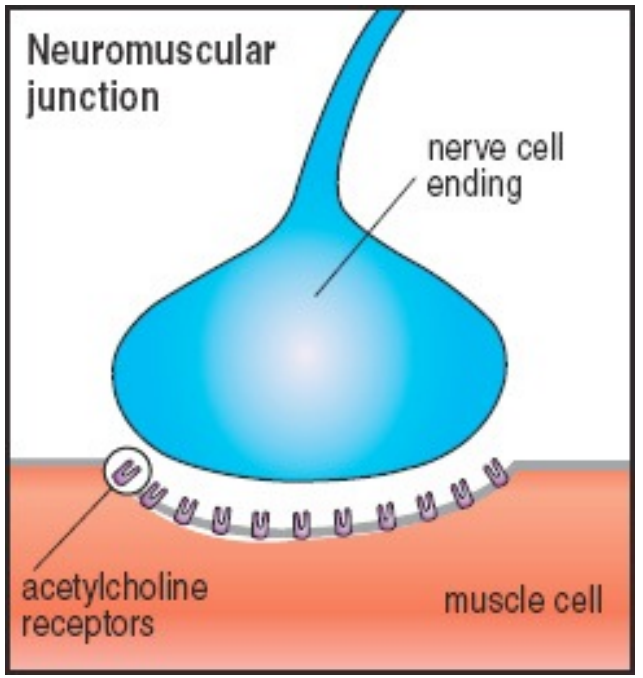


Neuromuscular Junction

- muscle fibers produce ion-dependent “action potential”
  - results in muscle contraction / twitch

- *excitation-contraction coupling*:
  - 1 neuron produces a potential large enough so that <u>every</u> α-motor neuron AP produces a twitch
    - unlike summation of EPSPs to threshold



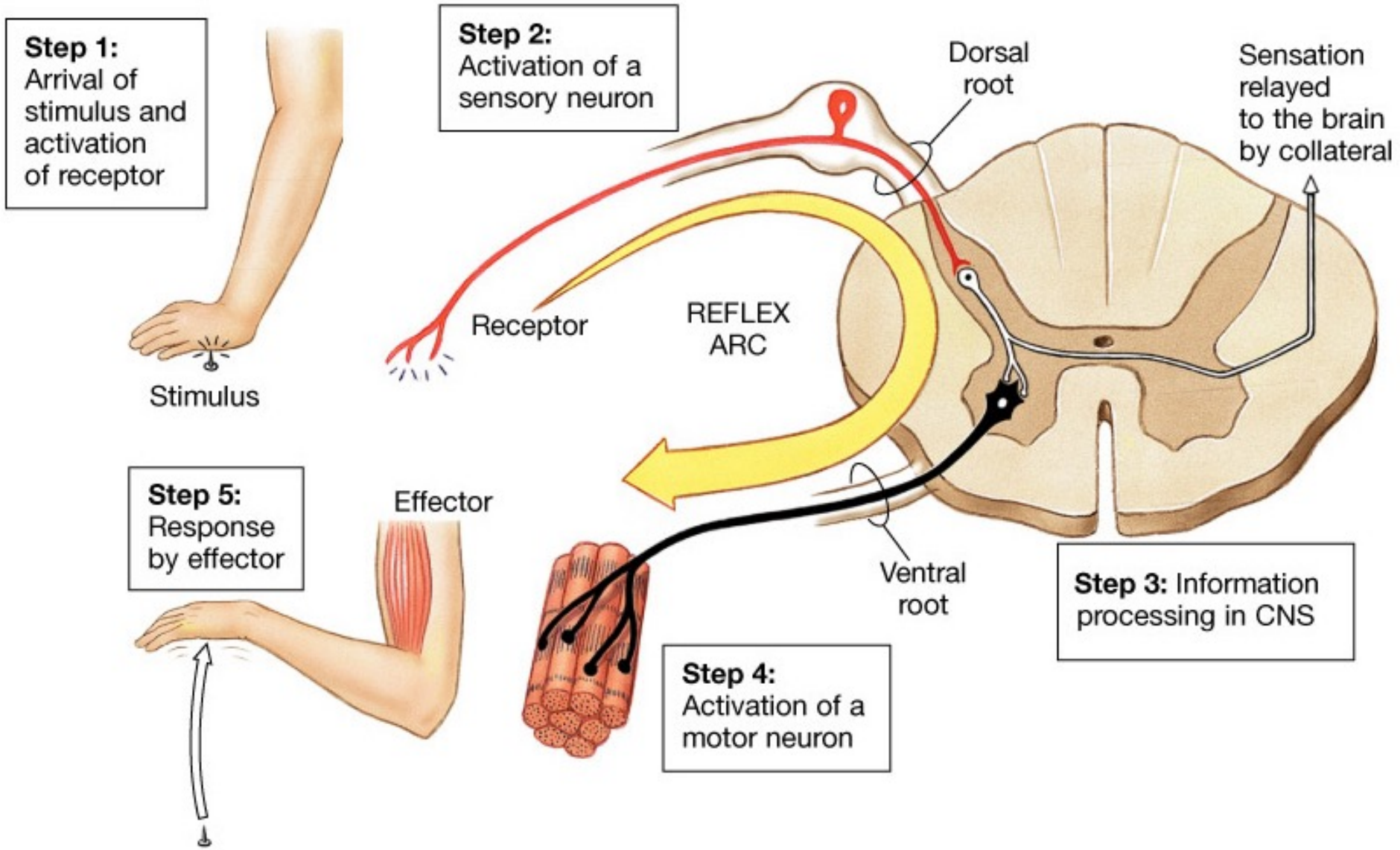


Motor Coding

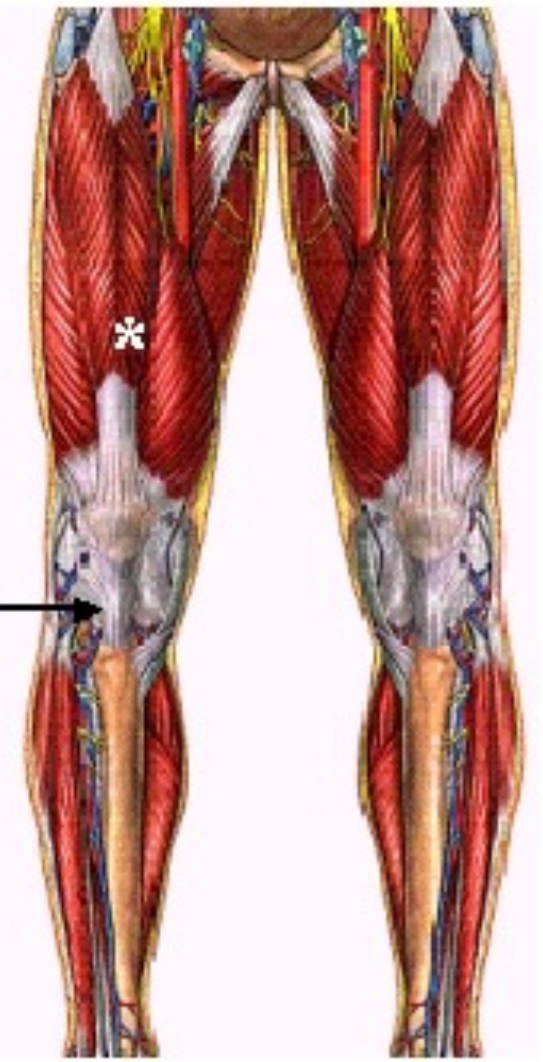
- *rate coding* - higher frequencies of AP = larger contraction
  - analogous to sensory system *frequency coding*

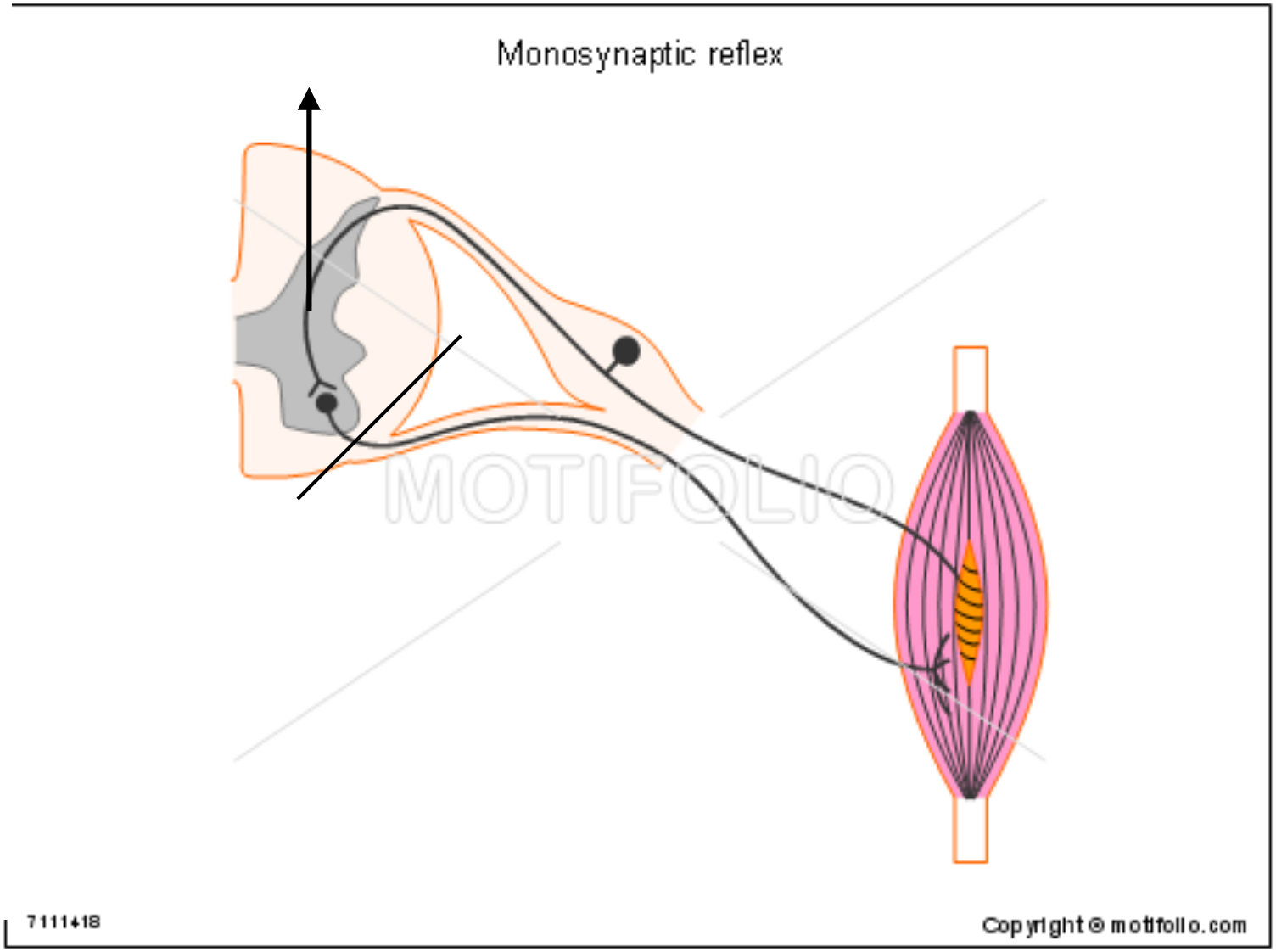
- *recruitment coding* - the more α-motor neurons in a motor pool that fire, the larger the resulting muscle contraction
  - analogous to sensory system *population coding*
  - fixed order, depending on conduction velocity / axon diameter
    - size principle - smallest / weakest first

Reflex Arc


Step 1:
Arrival of stimulus and activation of receptor
Stimulus
Step 2:
Activation of a sensory neuron
Receptor
REFLEX ARC
Dorsal root
Sensation relayed to the brain by collateral
Ventral root
Step 3: Information processing in CNS
Step 4:
Activation of a motor neuron
Effector
Step 5:
Response by effector

Monosynaptic Reflex





- Summary of Motor / Sensory Commonalities
  - (PERIPHERY) Sensory receptors > spinal cord / brainstem > primary sensory cortex > secondary sensory cortex > association cortex

  - Association cortex > “premotor” cortex (+ basal ganglia / cerebellum) > primary motor cortex > spinal cord / brainstem > muscles (PERIPHERY)