

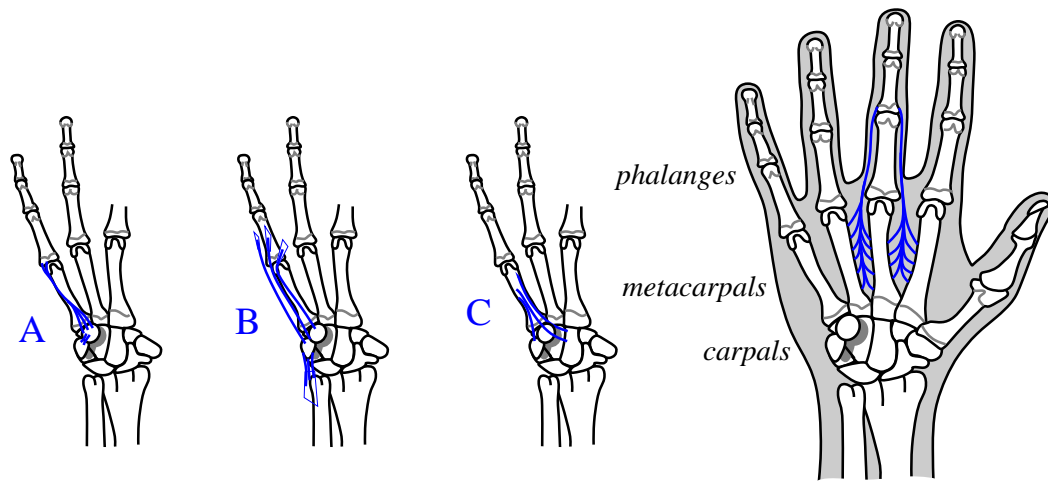
Haptics

...concerns the sense of touch—in particular, the perception and manipulation of objects using tactile and proprioceptive feedback

...a variety of central and peripheral neural systems that measure forces, heat flux, pain, accelerations, the degree of stretch in muscle fibers and tendons.

contact and movement, sense of shape, texture, temperature, grasp stability, and a variety of other subjective sensations associated with contact phenomena

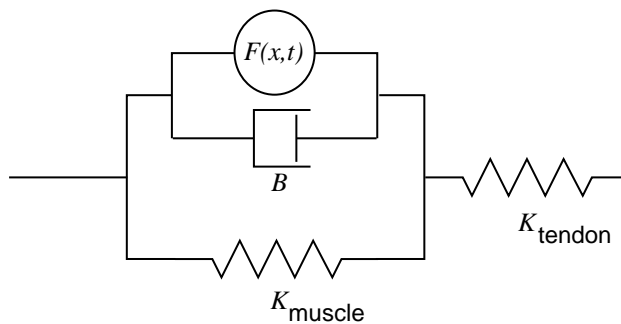
The Human Hand



- enhanced wrist mobility from brachiation
- improved lateral movement in little finger for opposition
- as many as 120 muscle spindles per gram of tissue, while large muscles (the calf, for instance) may have as few as 5 per gram of tissue.

Muscle

- 100 msec after action potential - a striated skeletal muscle contracts
- Muscle cell membranes propagate waves of activation at approximately 30 – 40 m/sec. a steady state contractile force with a periodic ripple at the frequency of the stimulus. constant contractile force - at about 50 and 60 impulses per second.



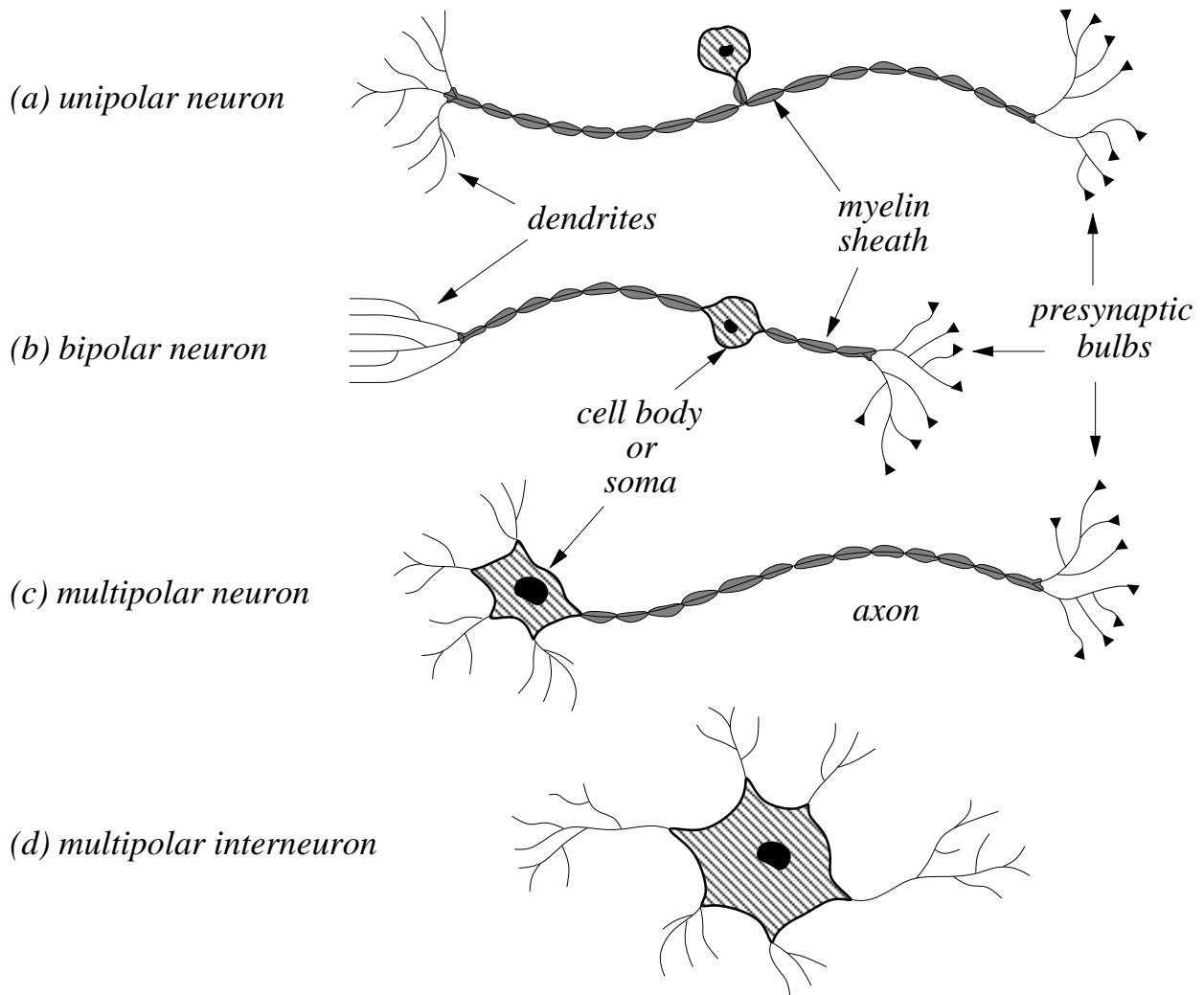
onset of force approximately 100 msec after stimulation and the rise to maximum tension about 3 – 5 msec later

pure force source, $F(x, t)$ - myosin and actin

- the bulbous head of long myosin proteins attach to sites on an adjacent actin protein and pulls muscle filaments 50 and 100 angstroms, then myosin protein detaches and repeats this cycle. distributed ratcheting mechanism that ultimately pulls on tendons and bones to accomplish mechanical work.
- ancient slime molds (and soil amoeba) employ a pure form of actin human muscle is the descendent of mobility mechanisms we have inherited from the oldest organisms.

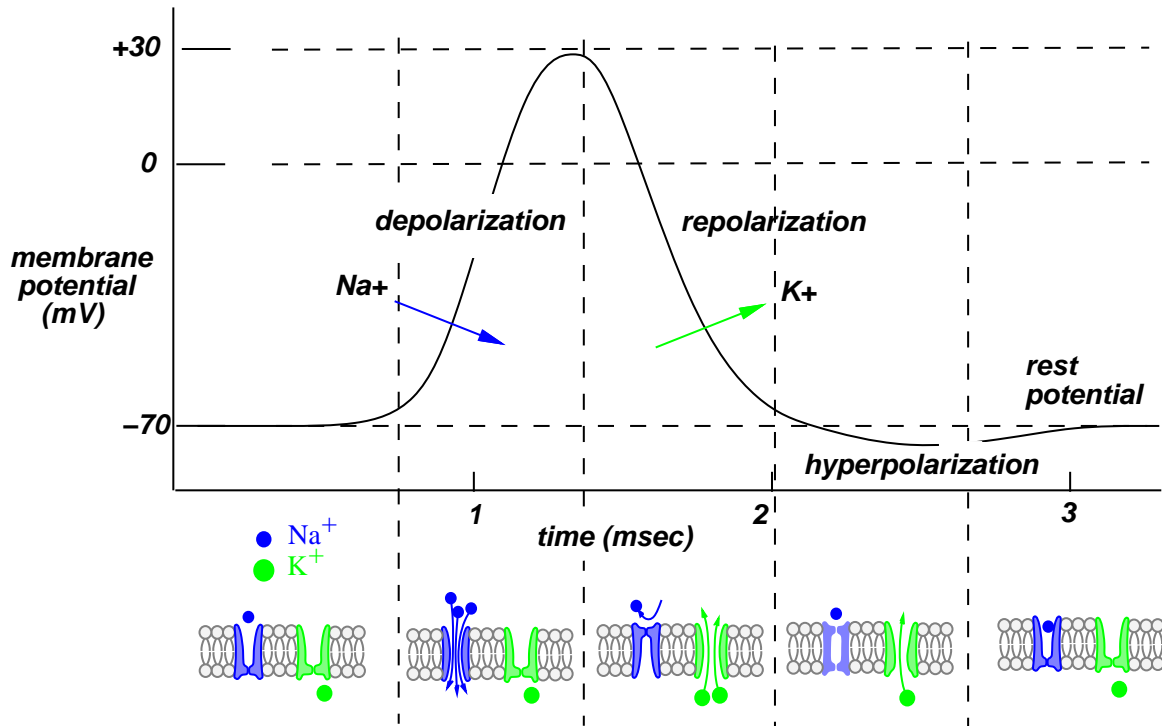
Multi-Polar Neuron

...the ancient Greeks observed that muscles could be permanently disabled by severing a thin white cord called a (peripheral) *nerve* that began and ended at the spinal cord



Intercellular Communication

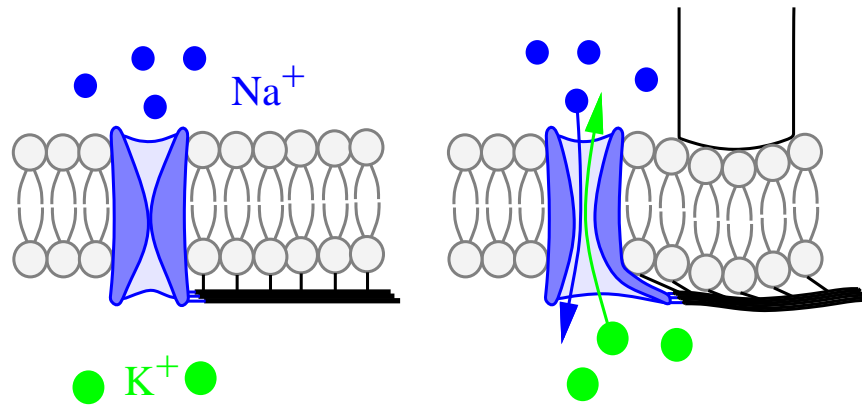
indirect electrical coupling
refractory period
sodium and potassium pumps



direct ion exchange
retina and substantia nigra

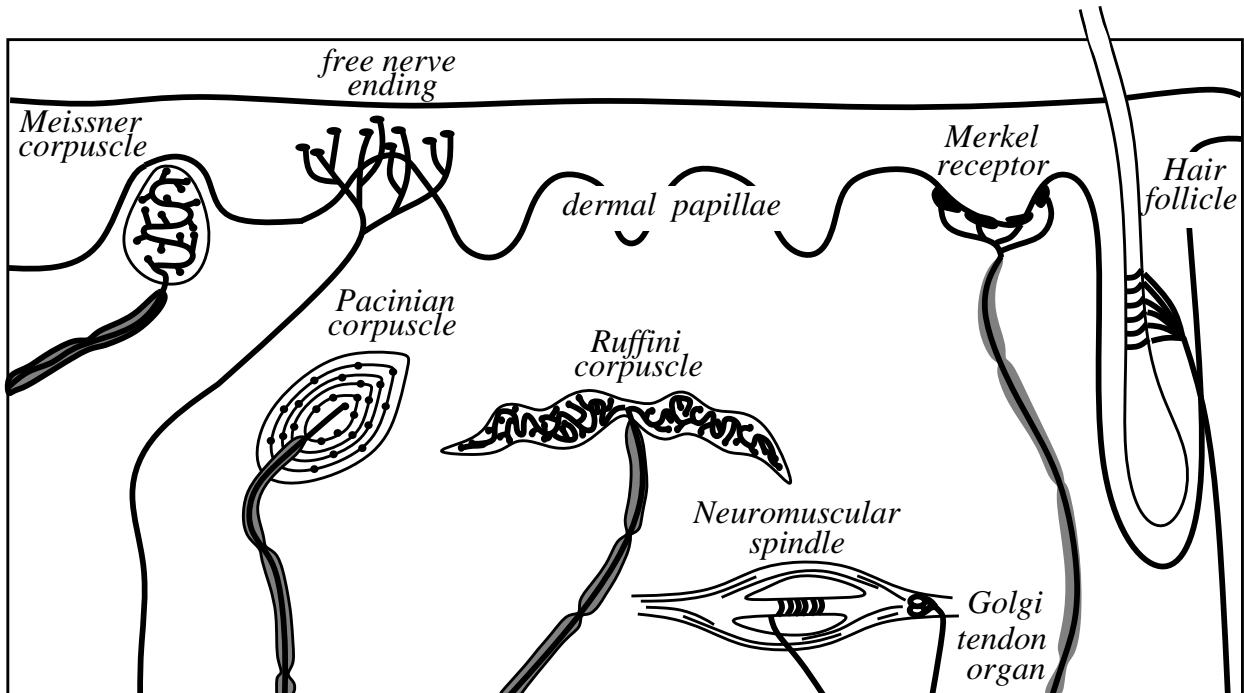
Mechanoreceptors

...combination of electrical (depolarization) dynamics and mechanical affects...



The Peripheral Nervous System

Cutaneous Mechanoreceptors



- variable response and sensitivity, massive redundancy
- *touch blend* interpretation over multi-sensory signals temperature, pressure, and vibration ... distinguish wet, slimy, greasy, syrupy, mushy, doughy, gummy, spongy or dry, hardness, texture, compliance, size, shape, and curvature.
- movement is critical to the formation of haptic images leading to active tactile exploratory strategies

Biological Sensor Frequency Response

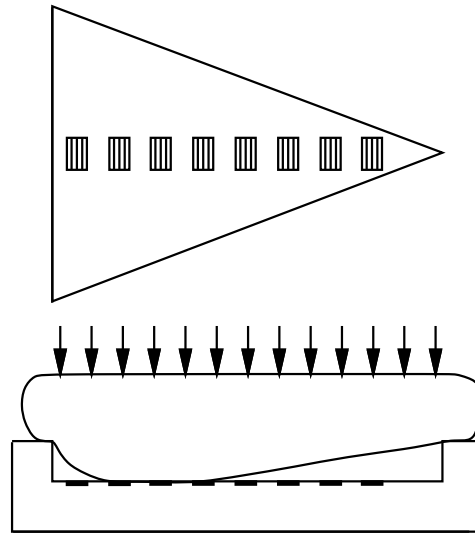
frequency response	0 to 400 <i>Hz</i> (+ very high freq)
response range	0 to 100 <i>grams/mm²</i>
sensitivity	approx. 0.2 <i>grams/mm²</i>
spatial resolution	1.8 <i>mm</i>
signal propagation	motor neurons 100 <i>m/sec</i> sensory neurons 2 to 80 <i>m/sec</i> autonomic neurons 0.5 to 15 <i>m/sec</i>

Robot Tactile Sensors

contour sensing, force sensing, spatial resolution (1 – 2 *mm*) sensitivity, dynamic range, hysteresis, frequency response (slip detection), addressing, number of wires

Binary Contact Switch

on/off contact switch, can be augmented easily to improve resolution...

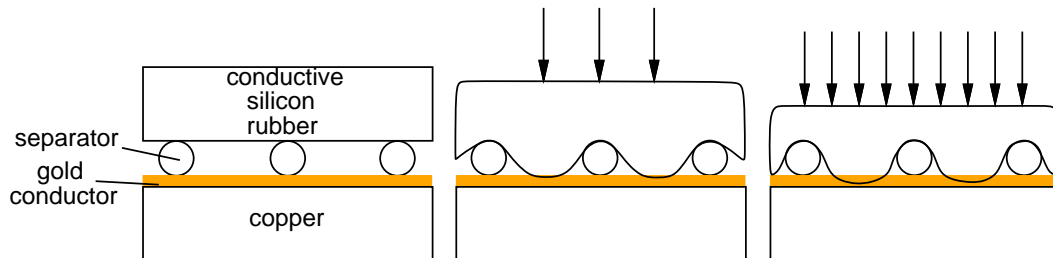


Raibert (1984) increasing contact force threshold for each successive switch a prototype was constructed to produce 4 bits of pressure output per cell, serialized I/O, 200 tactile cells with a 1 *mm* spacing driven by 5 wires: power, ground, clock, data-in, and data-out.

Load Cells

Conductive Elastomers

Hillis (1984)



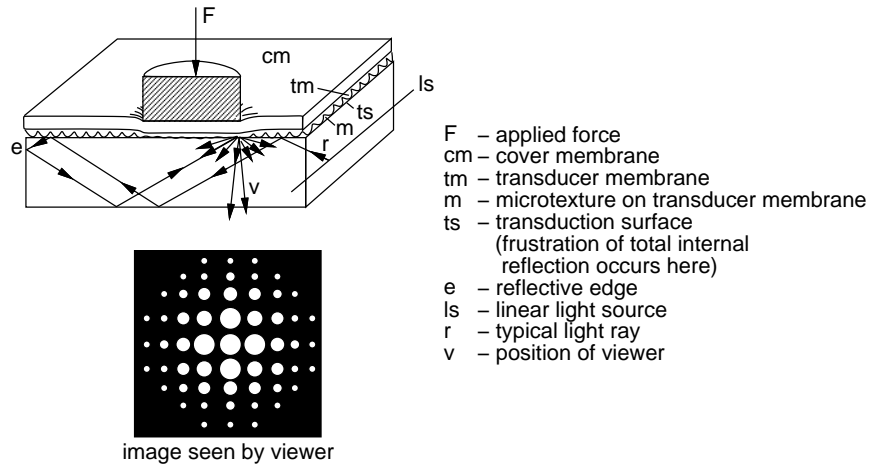
a conductive silicone rubber deforms around the separator and contacts an electrode under an applied pressure...increased pressure causes increased surface contact between the silicone and the electrode influencing contact resistance.

the separator is designed to produce the correct sensitivity, resolution and dynamic range for the specific application.

prototype with 256 tactile sensors with a spatial resolution of about 1 *mm*, addressing rows and columns as in a keyboard used 32 wires resulting in a cable diameter of less than 3 *mm*.

Optical Sensors

“frustration” of total internal reflection (Begej 1984)

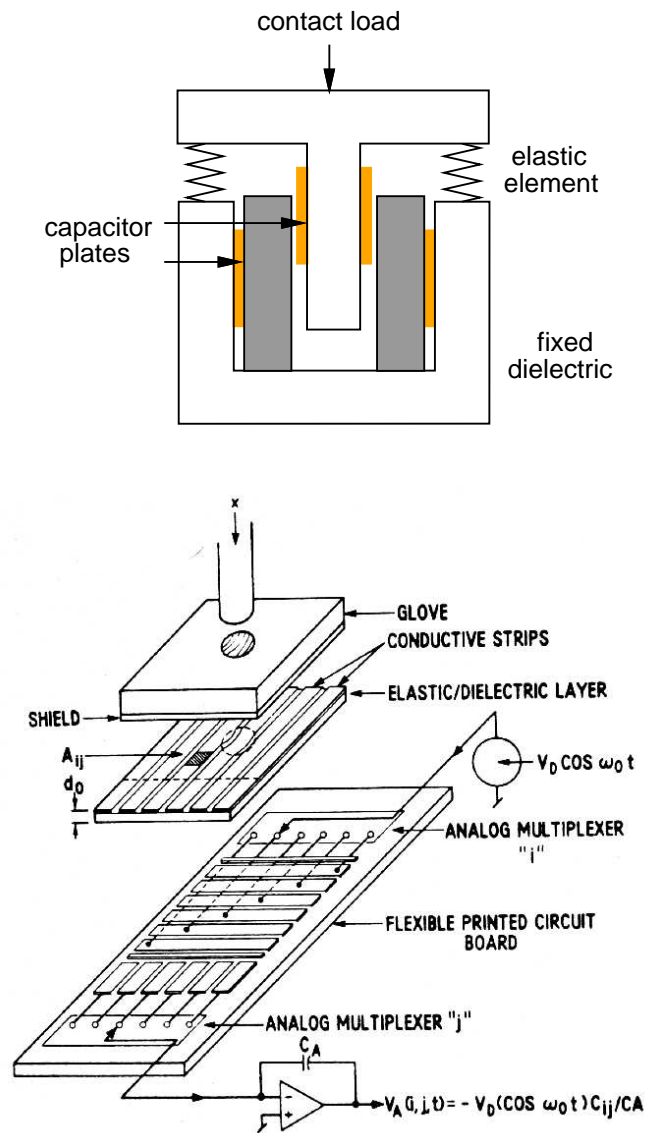


the tactile *image* is conducted away using optical fibers and then subject to image processing

Birefringence

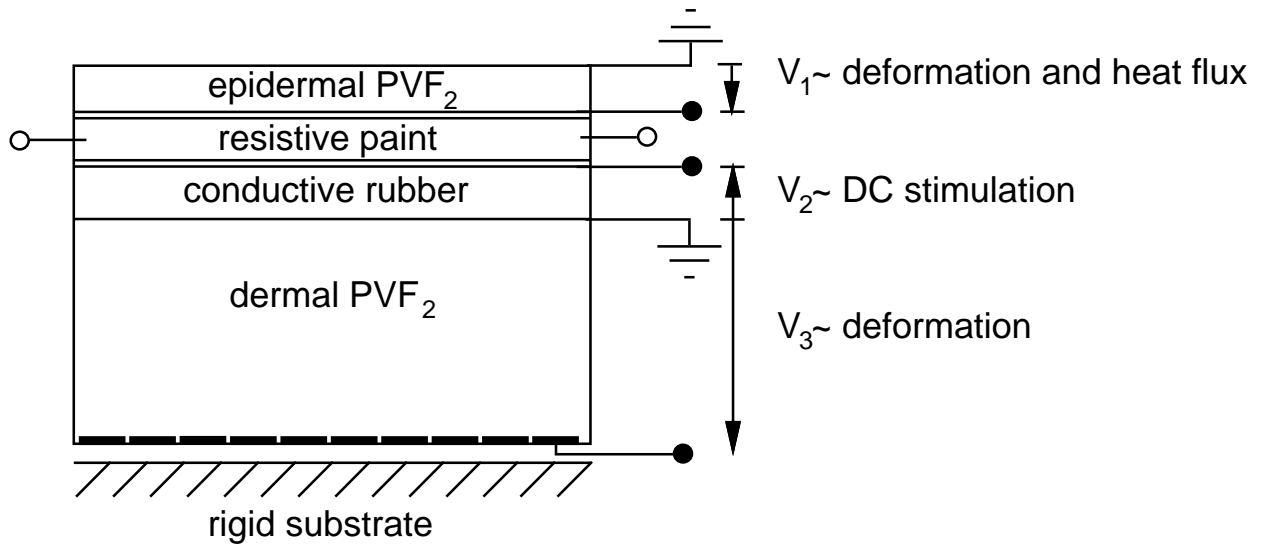
Capacitive Sensors

Capacitive Shutter



Piezo- and Pyroelectric Effects

PVF_2 (polyvinylidene fluoride)



What Human Neuroanatomy says about the Design of Intelligent Robots

Synergy/Symbiosis in Multicellular Organization

⇒ specialization

⇒ communication

1. Margulis: anaerobic
 bacteria
 +
 mitochondria } → modern eukaryotes

2. cellular specialization

muscle - bone - sensory receptors - neurons

3. complex organization

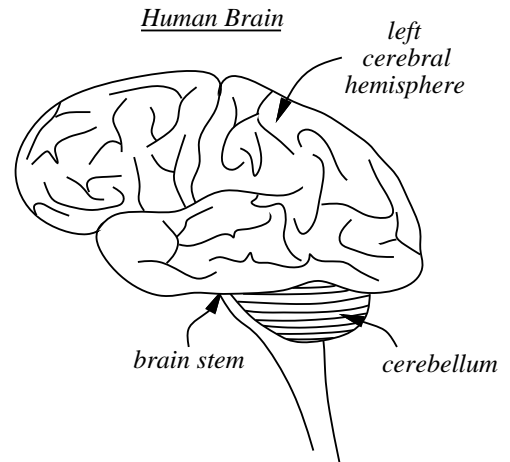
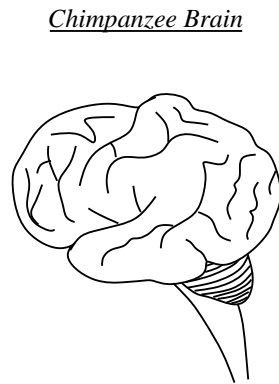
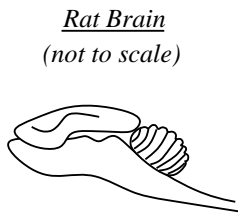
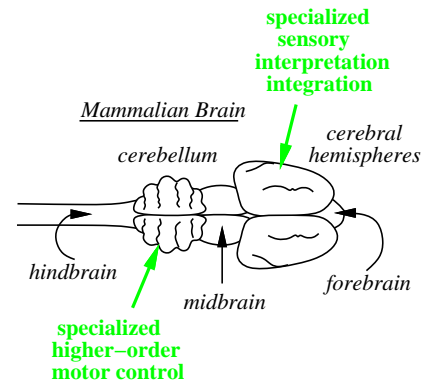
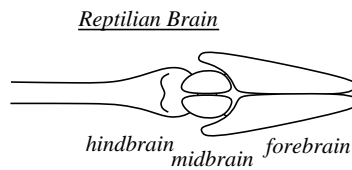
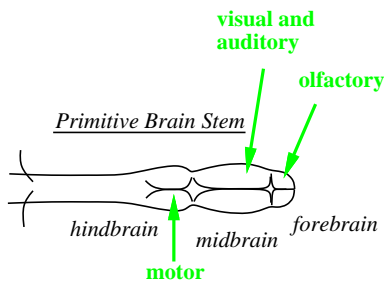
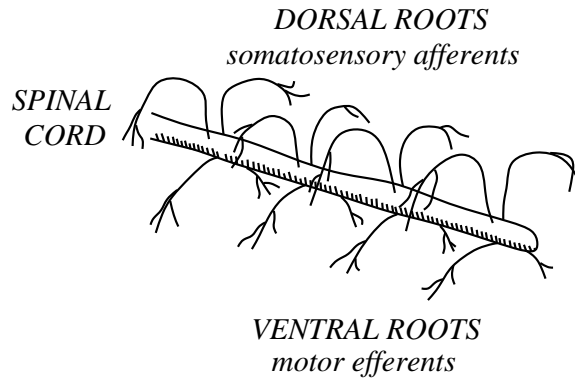
evolution of central and peripheral nervous system

spinal - brainstem - cerebellum - midbrain - cortex **hierarchy**

HYPOTHESIS:

cognitive processes exploit similar relationships between perceptual affordances, musculoskeletal structure, and neurological commitment

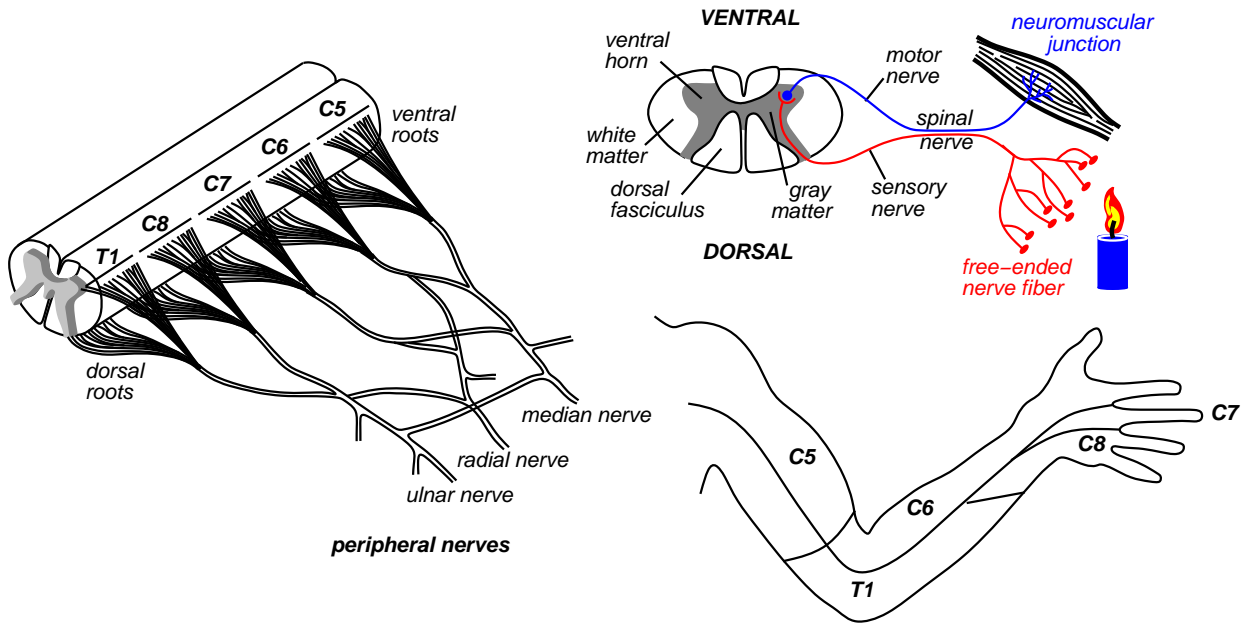
The Evolution of the Central Nervous System



purposeful behavior: long term objectives

The Central Nervous System - Spinal Processing

spinal cord: about 1 *cm* in diameter and protected within the bony vertebral column - cervical, thoracic, lumbar, sacral, and coccygeal.



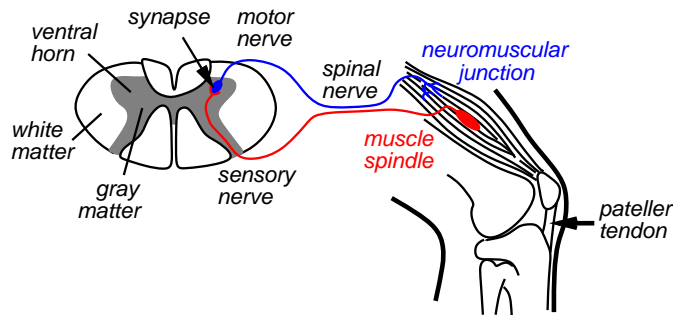
gray matter spinal sensory and motor cells and **white matter** ascending and descending tracts - gets its color from neuroglial cells that act as insulators for the ascending and descending pathways.

thirty one pairs of spinal nerves

Muscle Stretch Reflex

in response to muscle stretch - signals from muscle spindles transmit neural impulses (at about 100 m/sec) to synapses on the α -motor neurons that innervate muscle tissue via the efferent fibers of the spinal nerve - act to diminishes the perceived stretch.

response is expressed in a single synapse and cannot be inhibited by higher-level motor processes.



knee - L2-L4, bicep - C5-C6, tricep - C6-C7, ankle - S1

Related Segmental and Intersegmental Reflexes

withdrawl reflex movement is initiated by the free-ended nerve fiber in response to painful stimuli rather than the muscle spindle. The number of body parts enlisted by the reflex is proportional to the strength of the painful stimulus. Two synapses are involved in this reflex that can be inhibited cortically via an interneuron.

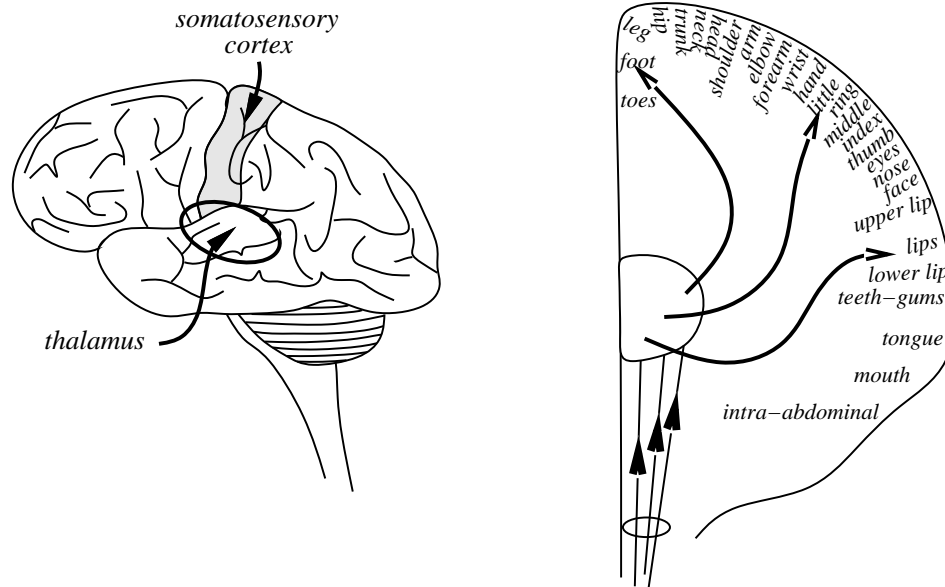


Descarte - the *animal spirit* expressed in the form of a reflex

intersegmental extensor reflex the flexor (withdrawl) reflex on one arm, for instance is accompanied about 0.5 *seconds* later by a contralateral extensor response.

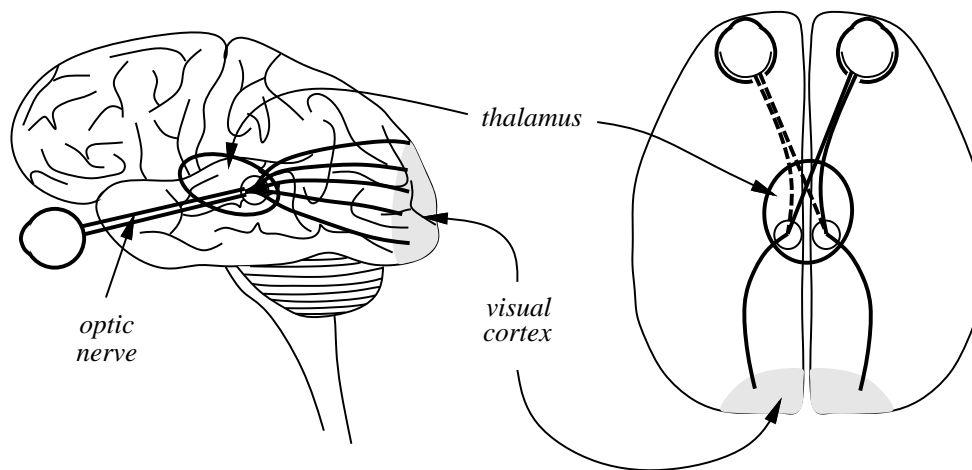
reciprocal inhibition keeps antagonistic pairs from fighting each other. It is especially important in walking as contact with the ground causes reaction loads.

The Somatosensory Homunculus



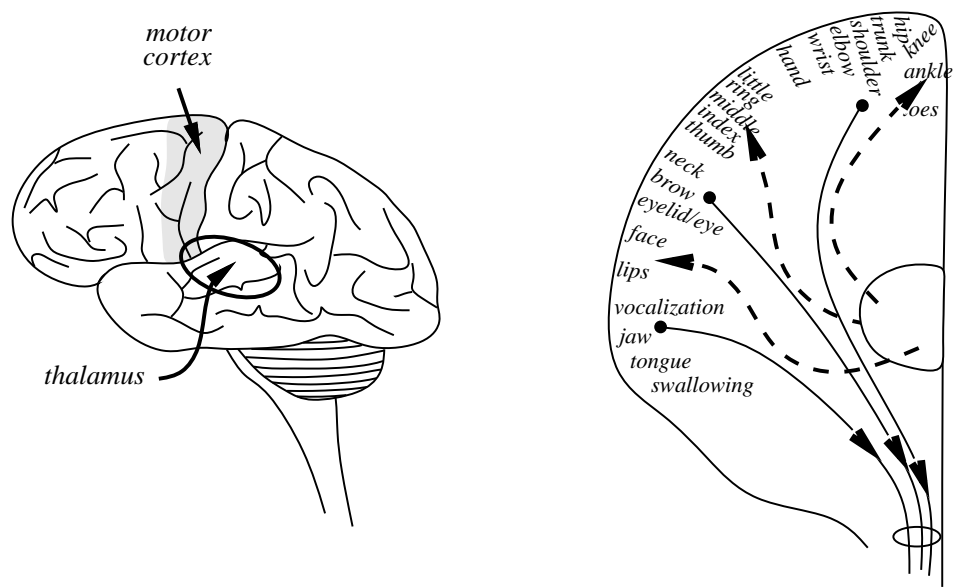
- proprioceptive feedback
- feature focus
- somatotopic organization

The Visual Cortex



- distributed processing
- up to 60 different somatotopic maps of visual information
- low-, intermediate-, and high-level sensorimotor relationships
- low-, intermediate- and high-level feature focus

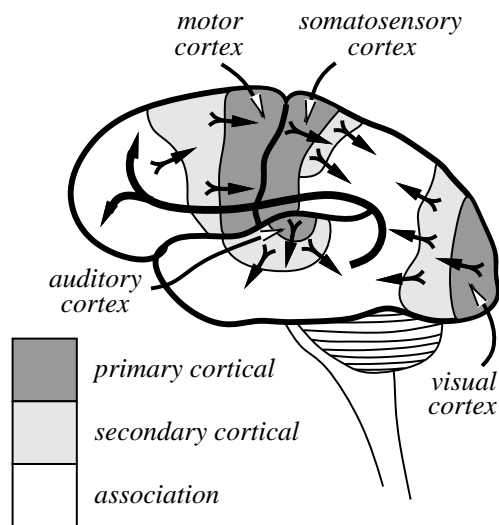
The Motor Cortex



...a high level of a hierarchical motor organization ranging from reflex arcs to complex sequences of motor activity...

The Neuroscience of Behavior

Sensorimotor Projections in the Brain



- strategically focuses and compresses sensory information
- context of activity includes world, organism, and task
- *fan-out* of motor strategies into large scale synergies within the musculoskeletal system

Hierarchy

