BIEN 500- fall 2023
Lecture 15

- Dr.DeCoster:

- The nervous system: General principles and sensory physiology: Part 2

- Chaps 47 and 48, Guyton and Hall

Part II: Organization of the vertebrate nervous system

- Neurons that carry information about the external or internal environment to the brain or spinal cord are called **afferent neurons.**
- Neurons that carry commands from the brain or spinal cord to various parts of the body (e.g., muscles or glands) are called **efferent neurons**.
- Some neurons (**interneurons**) participate only in local ciruits; their cell bodies and their nerve terminals are in the same location.

Nerves

- **Nerves** are essentially bundles of axons covered with connective tissue.
- A nerve may carry only sensory fibers (a **sensory nerve**), only motor fibers (a **motor nerve**), or a mixture of the two (a **mixed nerve**).
- Neuronal cell bodies often cluster together; these groups are called **ganglia** in the periphery and **nuclei** in the brain.

Organization of the Nervous System

- The nervous system is divided into two major systems—
- The central nervous system (CNS) and
- The peripheral nervous system (PNS)

CNS

- The CNS consists of the brain and the spinal cord
- Brain: can be split into: forebrain, midbrain, and hindbrain.
- Forebrain: includes the cerebral cortex
- Midbrain: relay center for visual and auditory impulses and motor control
- Hindbrain: includes the cerebellum

CNS-spinal cord

- Spinal cord: elongated structure that is continuous with the brainstem, that extends down the dorsal side of vertebrates.
- Sensory information enters the spinal cord dorsally: the cell bodies of these sensory neurons are located in the **dorsal root ganglia**.
- All motor information exits the spinal cord ventrally.
- Nerve branches entering and leaving the cord are called roots.
- The spinal cord is divided into four regions: in order from brainstem to tail: cervical, thoracic, lumbar and sacral.

Peripheral Nervous System (PNS)

- PNS consists of 12 pairs of cranial nerves, which primarily innervate the head and shoulders, and 31 pairs of spinal nerves, which innervate the rest of the body.
- Cranial nerves exit from the brainstem and spinal nerves exit from the spinal cord.
- The PNS has two primary divisions: the somatic and the autonomic nervous systems, each of which has both motor and sensory components.

Sensory components

- In these lectures, we will focus on sensory components, including tactile and position sensors, and somatic sensations including pain, headache, and thermal sensations.
- Position sensors would be an example of proprioceptors, which transmit information regarding the position of the body in space, these receptors are located in muscles and tendons to tell the brain where the limbs are in space, and are also located in the inner ear to tell the brain where the head is in space.
- Pain and thermal sensations would include exteroceptors,which sense changes in the external environment.

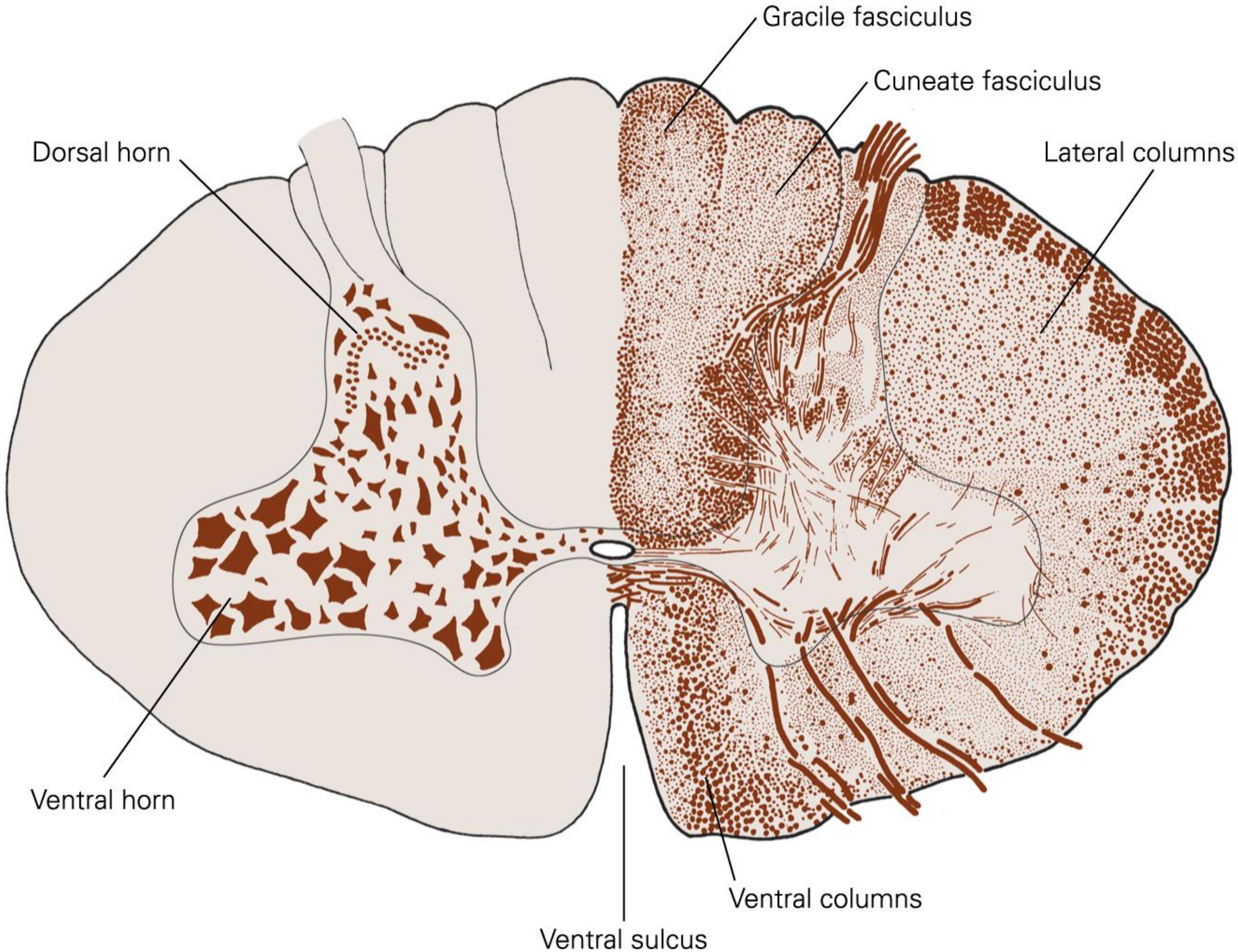
Sensory Components

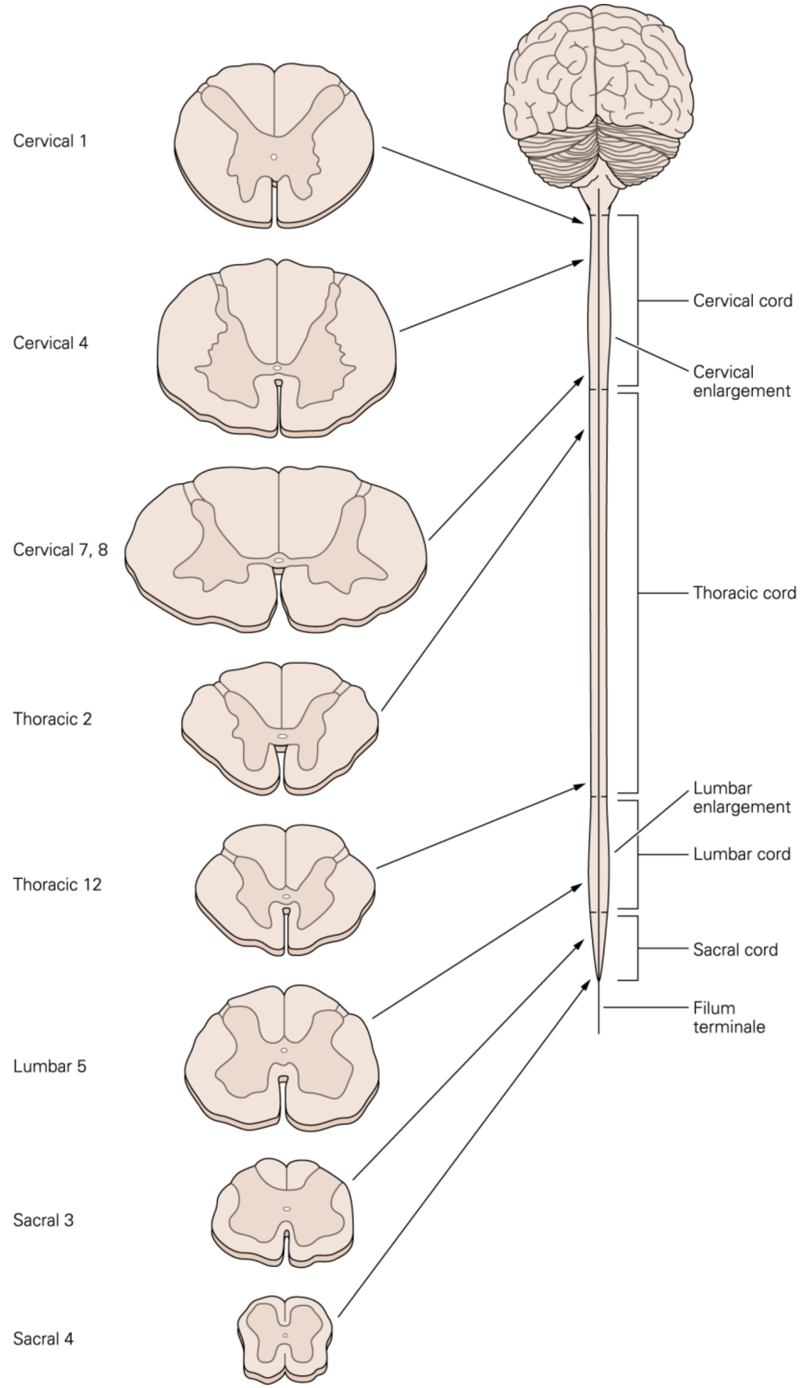
- Sensory information processing is illustrated in the somatosensory system
- Complex behaviors such as tactile perception generally require the integrated action of several nuclei and cortical regions.
- Brain information processing often occurs in a hierarchical fashion: stimulus information is conveyed through a succession of subcortical and then cortical regions.
- To increase the computational capacity of the brain, information processing, even within a single sensory modality, is often carried out simultaneously in several anatomically distinct pathways.
- For example, in the somatosensory system a light touch and a painful stimulus to the *same area* of skin are mediated by *different pathways* in the brain.

Somatosensory information from the trunk and limbs is conveyed to the spinal cord

- Sensory information from the trunk and limbs enters the spinal cord, through the dorsal horn, which contains the sensory nuclei.
- Interneurons of various types in the gray matter modulate information flowing from the sensory neurons towards the brain, as well as information incoming from the brain.
- The white matter surrounding the gray matter is divided into dorsal, lateral, and ventral columns. Each of these columns includes a variety of bundles of ascending or descending axons. Figs. 18-1, 18-2

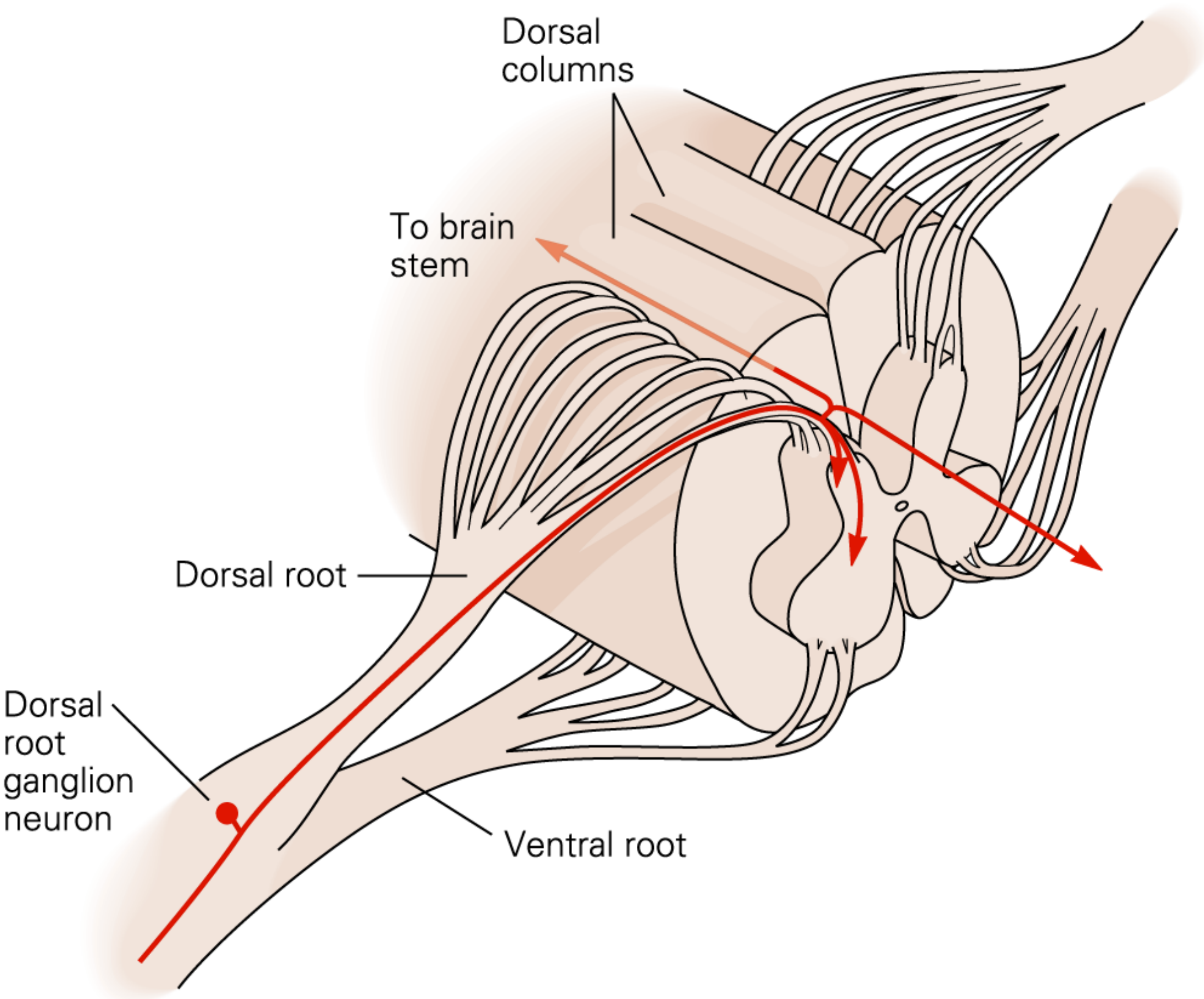
Spinal Cord in cross-section




Cervical 1
Cervical 4
Cervical 7, 8
Thoracic 2
Thoracic 12
Lumbar 5
Sacral 3
Sacral 4
Cervical cord
Cervical enlargement
Thoracic cord
Lumbar enlargement
Lumbar cord
Sacral cord
Filum terminale

The primary sensory neurons of the trunk and limbs are clustered in the dorsal root ganglia (DRG)

- The sensory neurons that convey information from the skin, muscles, and joints of the limbs and trunk to the spinal cord are clustered together in dorsal root ganglia within the vertebral column immediately adjacent to the spinal cord (Fig. 18-3).


Dorsal columns
To brain stem
Dorsal root
Dorsal root ganglion neuron
Ventral root

Primary sensory neurons

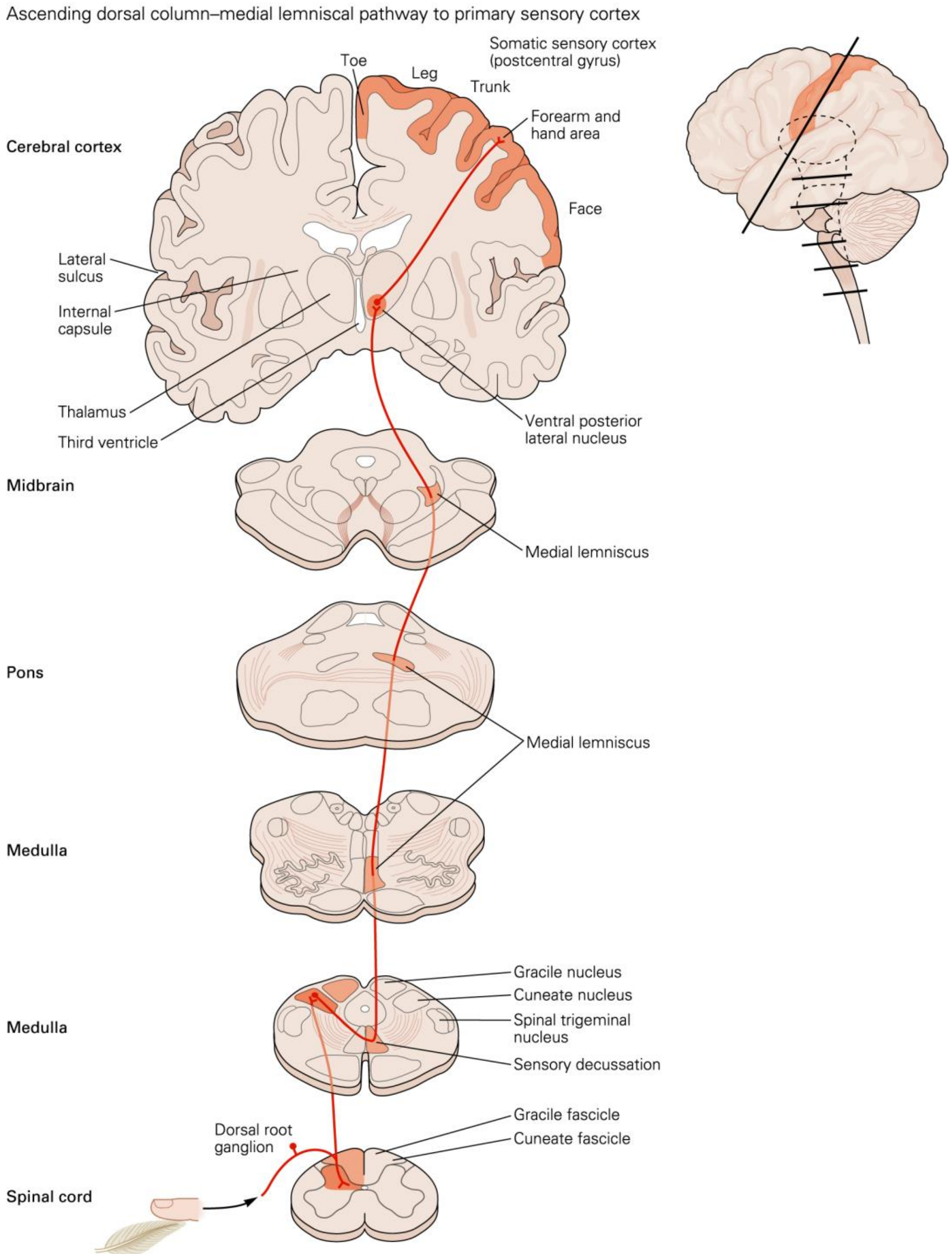
- These neurons have a bifurcated axon with central and peripheral branches. The peripheral branch terminates in skin, muscle, or other tissue as a *free nerve ending* or in association with specialized receptors.
- The central process enters the spinal cord close to the tip of the dorsal horn. Upon entry the axon forms branches that either terminate within the spinal cord gray matter or ascend to nuclei located at the junction of the spinal cord with the medulla.
- These local and ascending branches provide two functional pathways for somatosensory information entering the spinal cord from dorsal root ganglion cells: the local branches can activate local reflex circuits while the ascending branches carry information into the brain, where this information becomes the basis for perception of touch, position sense, or pain.

The central axons of DRG neurons are arranged to produce a map of the body surface

- The central axons of the DRG cells form a neural map of the body surface when they terminate in the spinal cord.
- This orderly distribution of inputs from different portions of the body surface is called *somatotopy* and is maintained throughout the entire ascending somatosensory pathway.

Somatotopy-2

- Axons that enter the cord in the sacral region ascend in the dorsal column near the midline, while those at progressively higher levels ascend at more lateral positions within the dorsal columns.
- Thus, in the cervical cord, where axons from all portions of the body have already entered the cord, sensory fibers from the lower body are carried medially in the dorsal column; fibers from the trunk, the arm and shoulder, and finally the neck occupy progressively more lateral areas—(think about how spinal cord injury reflects this)-Figure 18-4


Ascending dorsal column–medial lemniscal pathway to primary sensory cortex
Somatic sensory cortex (postcentral gyrus)
Toe
Leg
Trunk
Forearm and hand area
Face
Cerebral cortex
Lateral sulcus
Internal capsule
Thalamus
Third ventricle
Ventral posterior lateral nucleus
Midbrain
Medial lemniscus
Pons
Medial lemniscus
Medulla
Medulla
Gracile nucleus
Cuneate nucleus
Spinal trigeminal nucleus
Sensory decussation
Gracile fascicle
Cuneate fascicle
Dorsal root ganglion
Spinal cord

Each somatic submodality is processed in a distinct subsystem from the periphery to the brain

- The submodalities of somatic sensation: touch, pain, and position sense, are processed in the brain through different pathways that end in different brain regions.
- As in the dorsal columns of the spinal cord, the fibers of the medial lemniscus (in the midbrain), are arranged somatotopically.
- Sensory fibers cross the midline to the other side of the brain, thus the right side of the brain receives sensory information from the left side of the body, and vice versa.
- The fibers of the medial lemniscus end in the thalamus of the brain

The thalamus is an essential link between sensory receptors and cerebral cortex for all modalities *except olfaction*

- The thalamus conveys sensory input to the primary sensory areas of the cerebral cortex but is more than simply a relay.
- It acts as a gatekeeper for information to the cerebral cortex, preventing or enhancing the passage of specific information depending on the behavioral state of the animal.

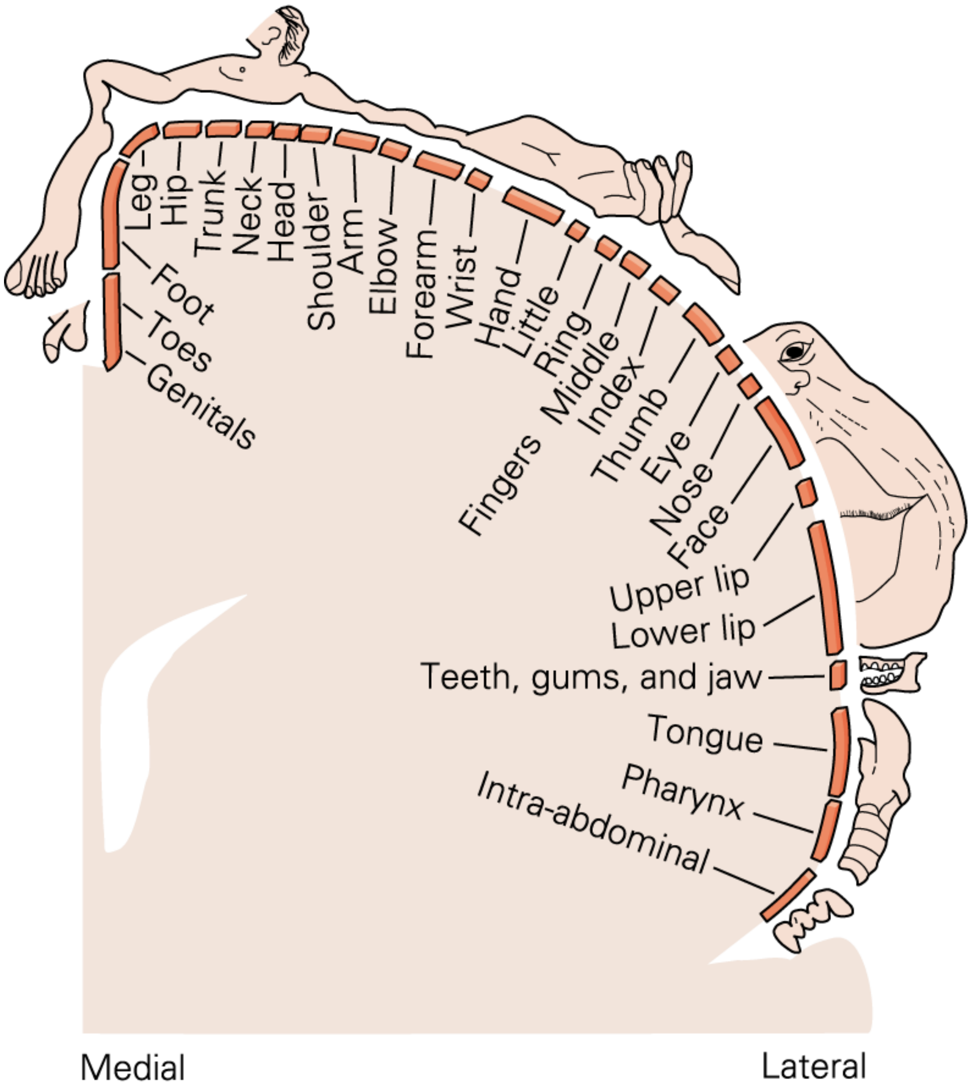
Sensory information processing culminates in the cerebral cortex

- After the thalamus,what is the next relay in the processing of somatic sensory information?–
- Axons of cells in the thalamus responsible for somatosensory processing terminate primarily in the primary somatosensory cortex. The neurons here are exquisitely sensitive to tactile stimulation of the skin surface.
- As in other processing organs of the somatosensory system, the neurons in different parts of the cortex are somatotopically organized.

Sensory information processing culminates in the cerebral cortex-2

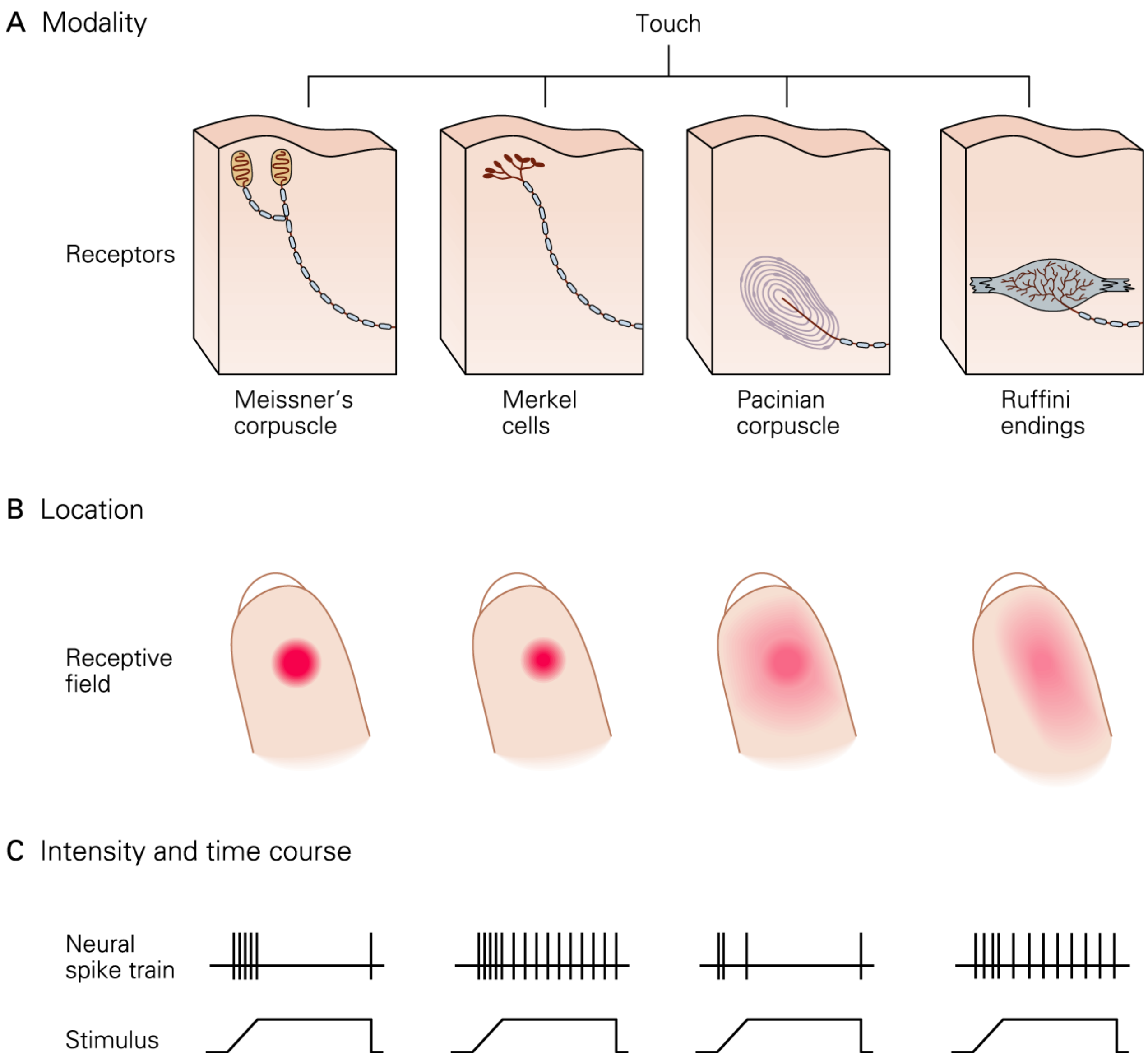
- All portions of the body are represented in the cortex somatotopically,**<u>but not in proportion to body mass</u>**.
- Instead, each part of the body is represented in the cortex **<u>in proportion to its degree of innervation</u>**.
- Thus, the area of cortex devoted to the fingers is larger than that for the arms; lips and tongue occupy more cortical space than the rest of the face.
- Because the cerebral cortex is organized functionally into columns of cells extending from the white matter to the surface of the cortex, the larger the area of cortex dedicated to a function, the greater the number of computational columns that are involved in that function.
- Our highly discriminative sense of touch in the fingers is thus due to the large area of cortex dedicated to the processing of somatosensory information from this part of the body. (Fig. 18-6)

A Sensory homunculus



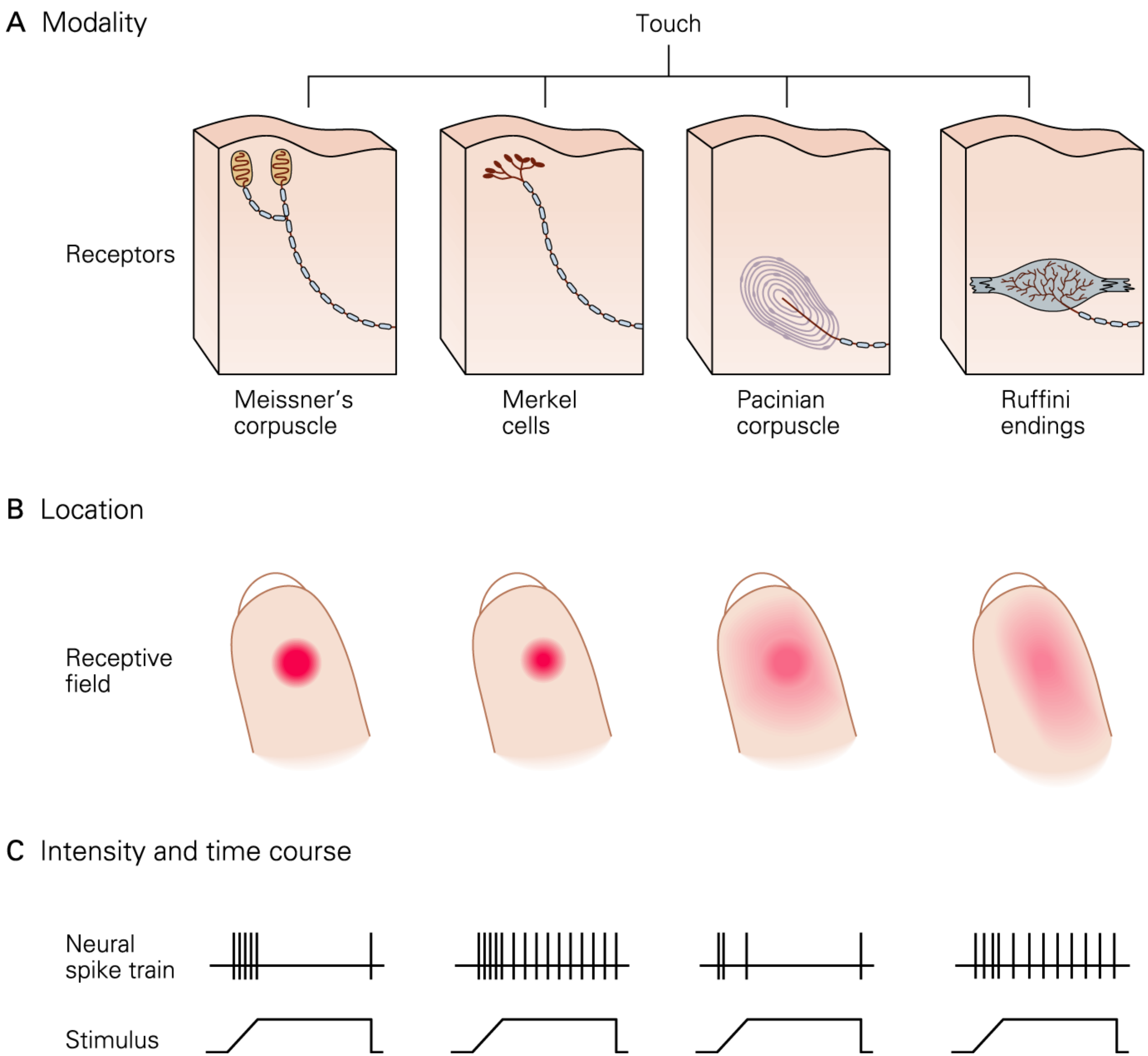
Coding of Sensory Information

- Sensory systems mediate 4 attributes of a stimulus that can be correlated quantitatively with a sensation:
- 1) **Modality**: Sensory modality is determined by stimulus energy
- 2) **Location**: The spatial distribution of sensory neurons activated by a stimulus conveys information about the stimulus location
- 3) **Intensity**: Intensity of sensation is determined by the stimulus amplitude
- 4) **Timing**: The duration of a sensation is determined in part by the adaptation rates of a receptor


A Modality
Touch
Receptors
Meissner's corpuscle
Merkel cells
Pacinian corpuscle
Ruffini endings
B Location
Receptive field
C Intensity and time course
Neural spike train
Stimulus

Encoding Touch

- 21-1A—In the human hand the submodalities of touch are sensed by four types of mechanoreceptors. Specific tactile sensations occur when distinct types of receptors are activated.
- Firing of all four receptor types produces the sensation of *contact* with the object.



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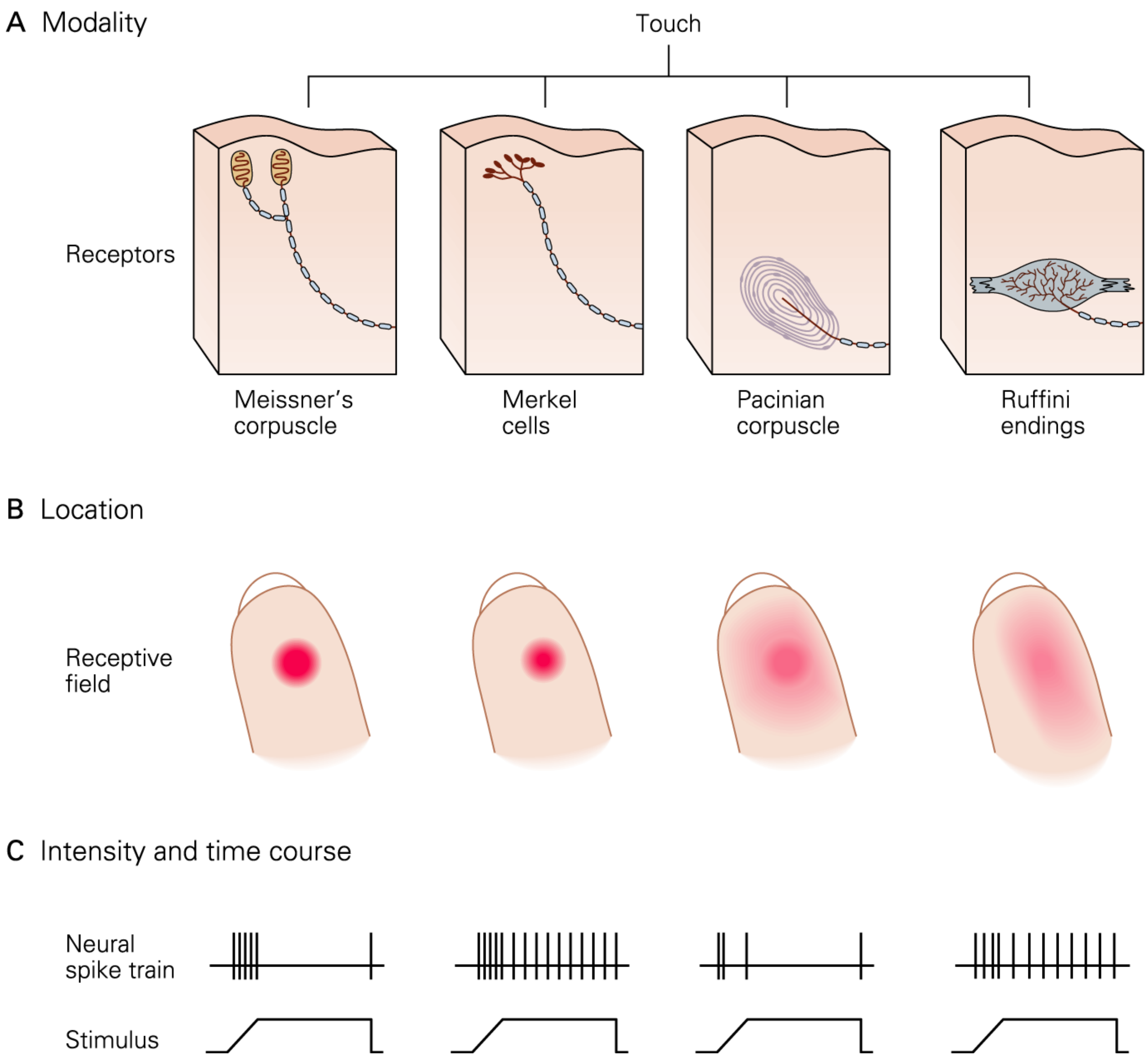
Encoding Touch-2

- 21-1B:
- Location and other spatial properties of a stimulus are encoded by the spatial distribution of the population of activated receptors.
- Each receptor fires action potentials only when the skin close to its sensory terminals is touched, ie, when a stimulus impinges on the receptor's *receptive field*
- The receptive fields of different mechanoreceptors- shown as red areas on the finger tip, differ in size and response to touch.
- Merkel cells and Meissner's corpuscles provide the most precise localization of touch, as they have the smallest receptive fields and are also more sensitive to pressure applied by a small probe.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Encoding Touch-2

- 21-1C
- The intensity of stimulation is signaled by the firing rates of individual receptors, and the duration of stimulation is signaled by the time course of firing.
- The spike trains below each finger indicate the action potentials evoked by pressure from a small probe at the center of the receptive field.
- Two of these receptors (Meissner’s and Pacinian corpuscles) adapt rapidly to constant stimulation, while the other two adapt slowly.

Sensory Systems and Modalities

Sensory System	Modality	Stimulus Energy	Receptor Class	Receptor cell type
Somatosensory	Somatic Senses:			
	Touch	Pressure	Mechanoreceptor	Cutaneous Mechanoreceptor
	Proprioception	Displacement	Mechanoreceptor	Muscle and joint receptors
	Temperture sense	Thermal	Thermoreceptor	Cold and warm receptors
	Pain	Chemical, thermal, or mechanical	Chemo-, thermo- or mechanoreceptor	Polymodal, thermal, and mechanical nociceptors
	Itch	chemical	chemoreceptor	Chemical nociceptor

Sensory Modality is determined by the stimulus energy

- Receptors transduce specific types of energy into an electrical signal:
- Mechanoreceptors are sensitive to mechanical energy--the mechanoreceptors of the somatosensory system mediate the sense of touch, whereas the mechanoreceptors of the inner ear mediate hearing and a sense of balance.
- Chemoreceptors are sensitive to chemical energy and are involved in the senses of pain and itch, among others.
- Thermal energy is sensed by thermoreceptors in the skin which sense body temperature and also the temperature of the ambient air and the objects that we touch.

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