Introduction to Cognitive Neuroscience

Sensory Coding

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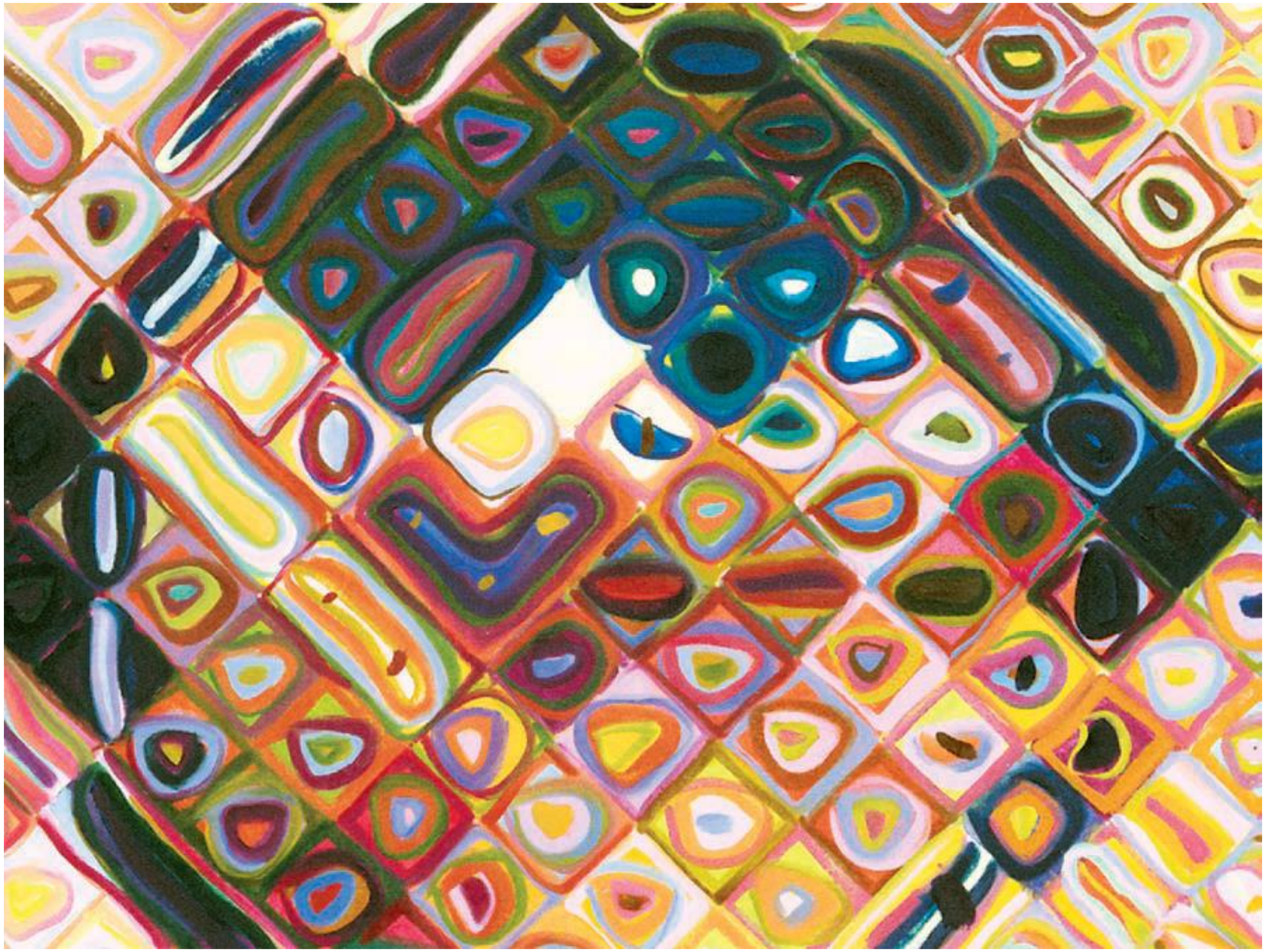
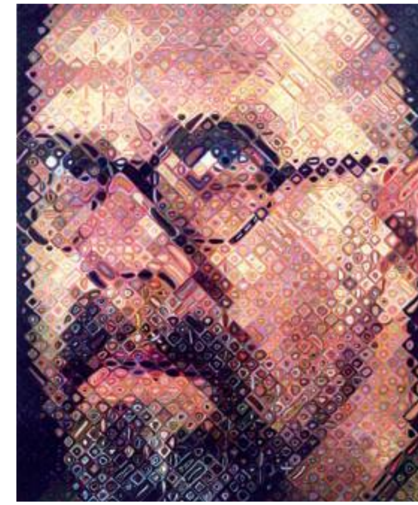


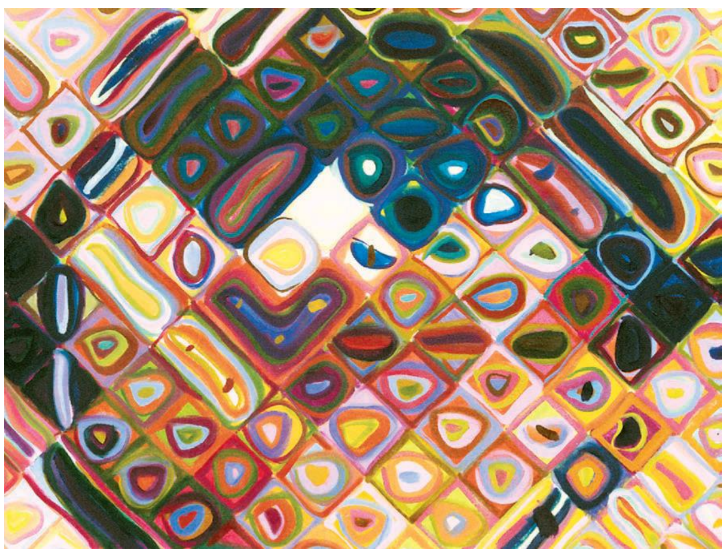
Detail of a self-portrait by Chuck Close:

- Viewed from a short distance: the painting appears to be and abstract grid of vividly colored squares and ovals (local feature)

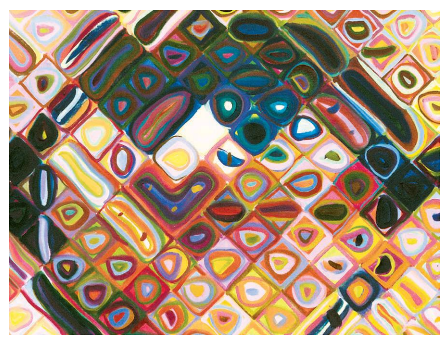
- Viewed from farther away: the local color blend and we begin to perceive a framed-eye (global feature)

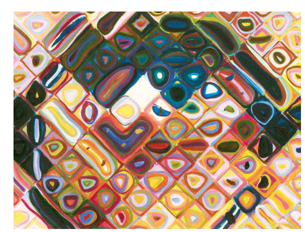
- **Chuck Close** has prosopagnosia, or difficulty in recognizing faces; his technique of flattening and subdividing an image into manageable elements enhances his ability to both perceive and portray the face.

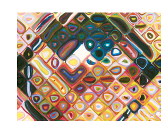




The **interplay between these local and global features**, which are **conveyed by discrete visual pathways**, gives the portrait its **particular dynamism**.







Perception

Objective methods for studding perception:

- How the **quantitative aspects** of physical stimuli correlate with the sensations they evoke is the subject of **psychophysics**.
- Studding the various **sensory receptors**
- Studding the **sensory pathway** that carry information from receptors to the cerebral cortex
- Two different coding approach:
  - Certain **critical attributes of sensation**, such as **location** and **intensity**, are encoded in **specific cells** of sensory system, both **peripheral** receptors and **central** neurons.
  - **Other attributes** of sensation are represented by the **pattern of activity** in a population of sensory neurons (**differentiation of sounds** depends on large part of **pattern coding**)

- **Major task** of current research in **sensory and system neuroscience**:
  - Determining the extent to which the single neurons and receptors specifically and pattern of neural activity are used in neural system to **encode information**.

Sensory pathway

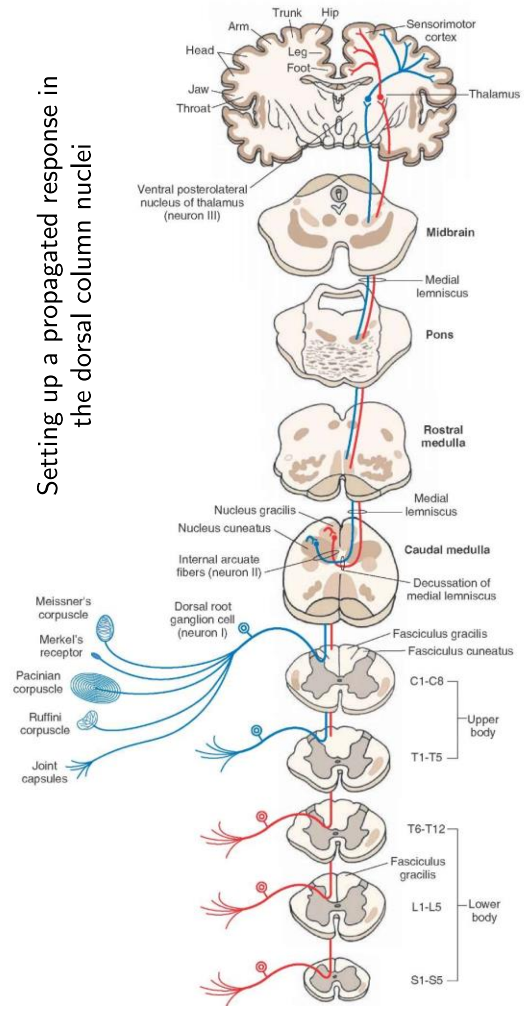
- Sensory pathway include neurons that:
  - **Link** the receptors at periphery with the spinal cord, brain stem, thalamus, and cerebral cortex.

- The cortical representation of sensory information is **closely correlated with our conscious perception**.

- By direct cortex electrical stimulation, the illusion of sensation will be created (casual study)

Setting up a propagated response in the dorsal column nuclei

cutaneous mechanoreceptors



From thalamus, sensory information flows to several areas of cerebral cortex.

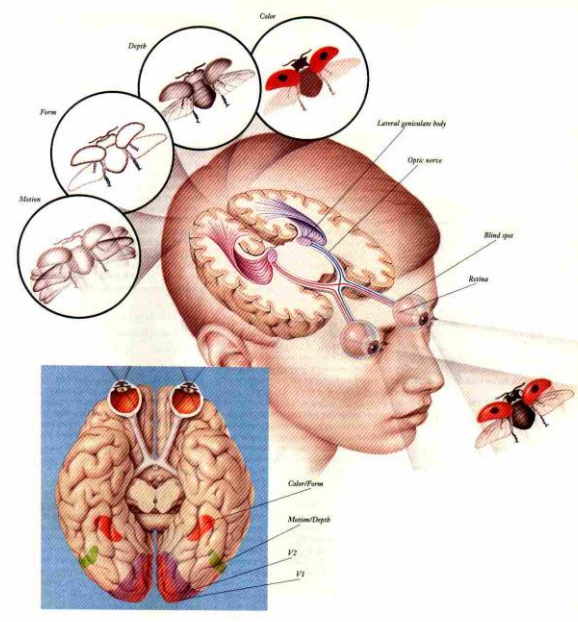
Each part of neural system analyzes **specific aspects** of the original stimulus

How perception occurs in the brain

- Contrary to our intuitive :
  - Perception are not **direct copies** of the world around us
  - The information available to sensory system and any instant in time is **imperfect and incomplete**
  - Perceptual systems are not **built like physical devices** for making measurements, but instead are build to **perform inferences** about the world.
  - Sensory data should not be thought of as giving answer, but as **providing clues**.

Sensory perception is creation of the brain

- For example, the brain is where seeing happens.
- Brain figures out what the clues mean.
- In visual system:



❖what is seen in the "**mind's eye**" goes far beyond what is presented in the input.

❖The brain uses information **it has extracted previously as the basis for educated guesses**—perceptual inferences about the state of the world.

Transformation in visual system

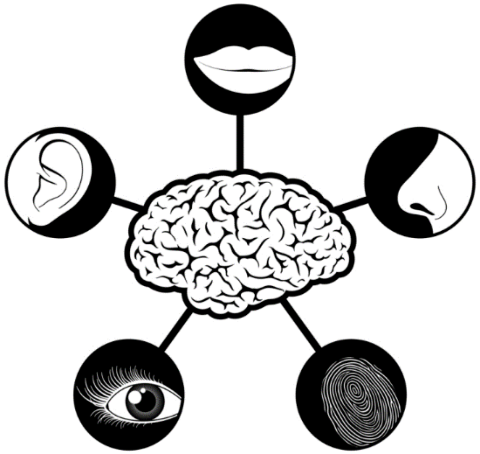
1. Visual system transform the stimulus energy that the retinal receptors receive into a **neural codes of action potential**
2. Action potential neuron codes is a binary neural code, like the dots and dashes of a Morse code.
3. Brain solve the problem of computation by:
   1. Performing relatively simple operation
   2. In parallel
   3. In massive number of neurons
   4. Repeating these operation at multiple hierarchical stages

A major goal of cognitive neural science

- To determine how the information that reaches the cerebral cortex by means of parallel afferent pathways is bound together to form a **unified conscious perception**.
- One of the hopes driving cognitive neural science is that:
  - progress in understanding the **binding problem** will yield our first insights into the **biological basis of attention and ultimately consciousness**.

Our sense

- The Greek philosopher Aristotle defined five senses:
  - Vision, hearing, touch, taste, and smell—each linked to specific sense organs in the body: the eyes, ears, skin, tongue, and nose
- **Pain** was considered as a affliction of soul (not to be specific sensory modality)
- Colloquially intuition refer as "sixth sense" . This view is beyond the experience of classic sensory. Today intuition usually consider as a **result of cognitive process** that is inference derived from previous experience rather than sensory process.



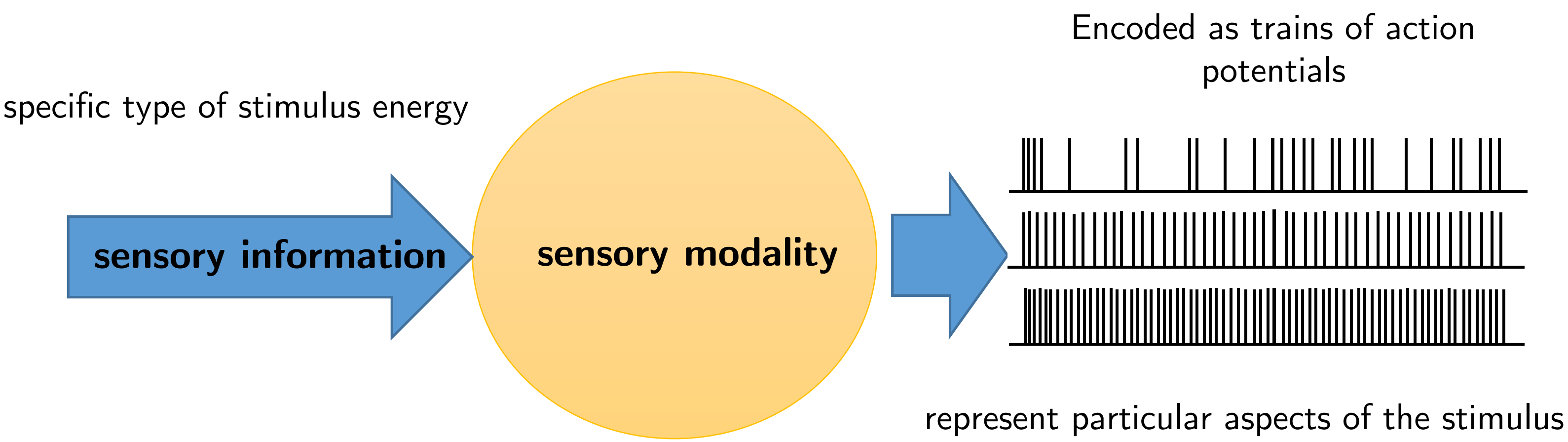
Universal coding mechanisms to all sensory systems

- ***Sensory* information**:
  - Neural activity **originating** from stimulation of receptor cells in specific parts of the body.
- These sense include the classic five sense **plus**:
  - The *somatic* sensations of proprioception (posture and movement of our own body), pain, itch, and temperature;
  - *Visceral* sensations (both conscious and unconscious) necessary for homeostasis
  - *Vestibular* senses of balance (the position of the body in the gravitational field) and head movement.

Percepts are shaped by internal as well as environmental factors

- **Receptors** provide the first neural representation of the **external words** and flow to the **brain regions** involved in cognition
- The **sensory pathway** contain:
  - Both **serial** and **parallel** components
  - Consisting of **fibers** tracts with thousands or millions of axons interrupted by synaptic **relay**
  - Each **relay** comprising **millions of neurons**
  - Information transform **from simple forms to complex forms** that are the **basis** of cognition
- Sensory pathways are also **recursive**: (feedback connections)
  - The higher centers in the brain **modify and structure the incoming flow** of sensory signals **by feeding information back to earlier stages of processing**

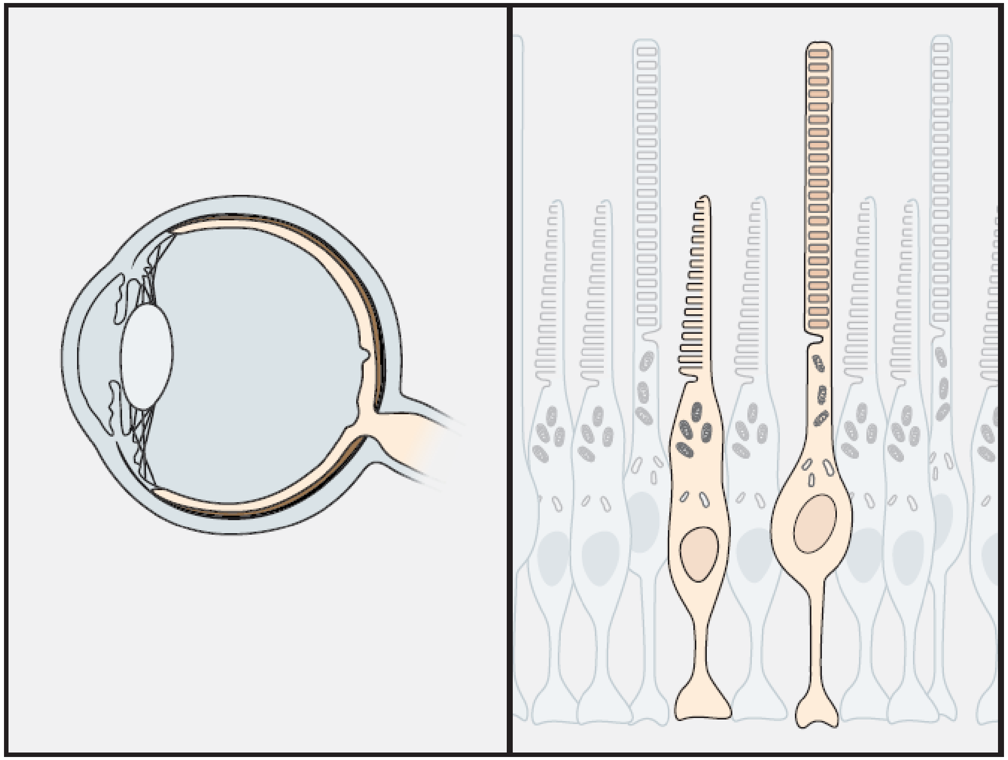
A specific type of stimulus energy is transformed into electrical signals by specialized receptors



The major sensory modalities in humans are mediated by distinct classes of receptor neurons located in specific sense organs.

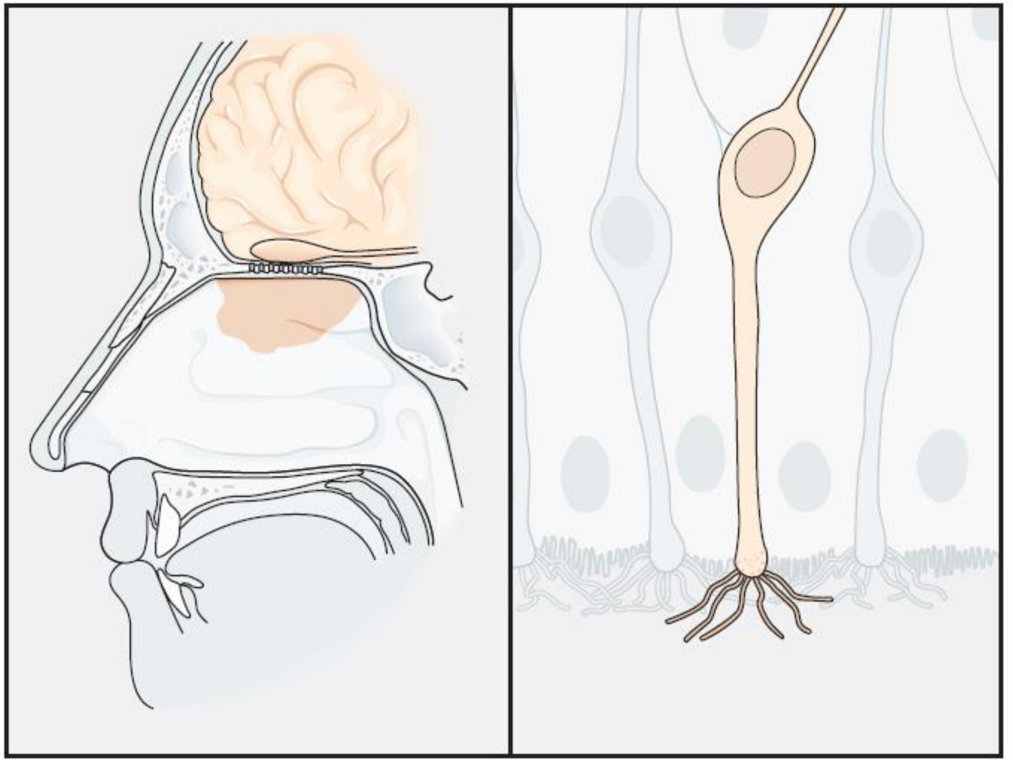
Photoreceptors

Vision



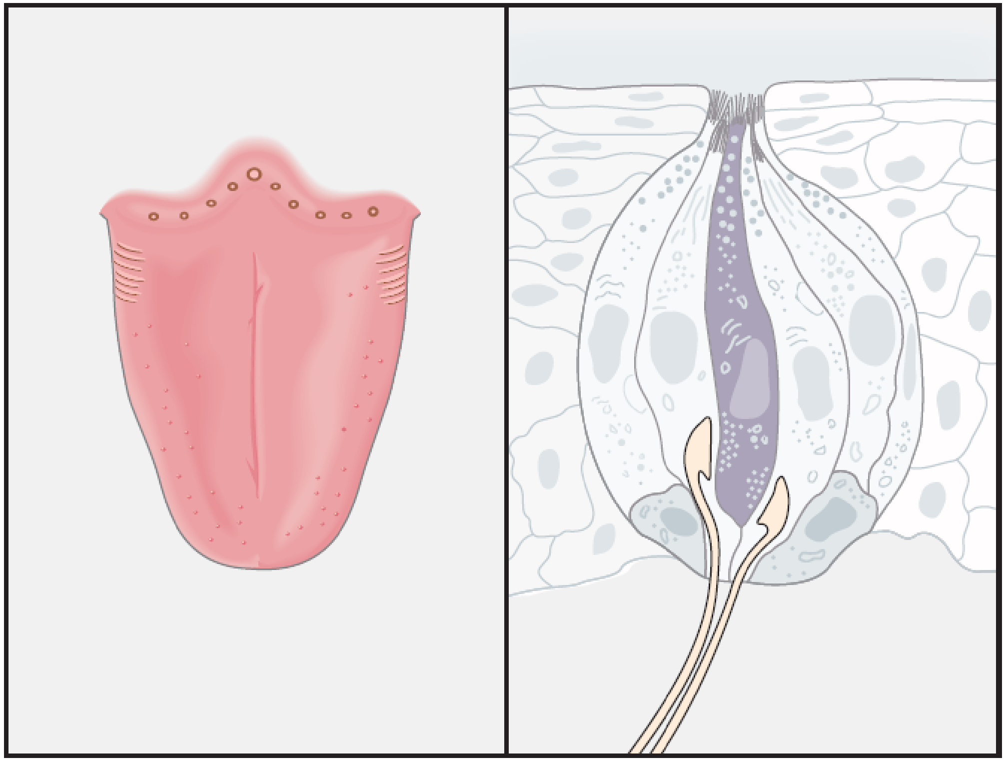
Chemoreceptors

Smell



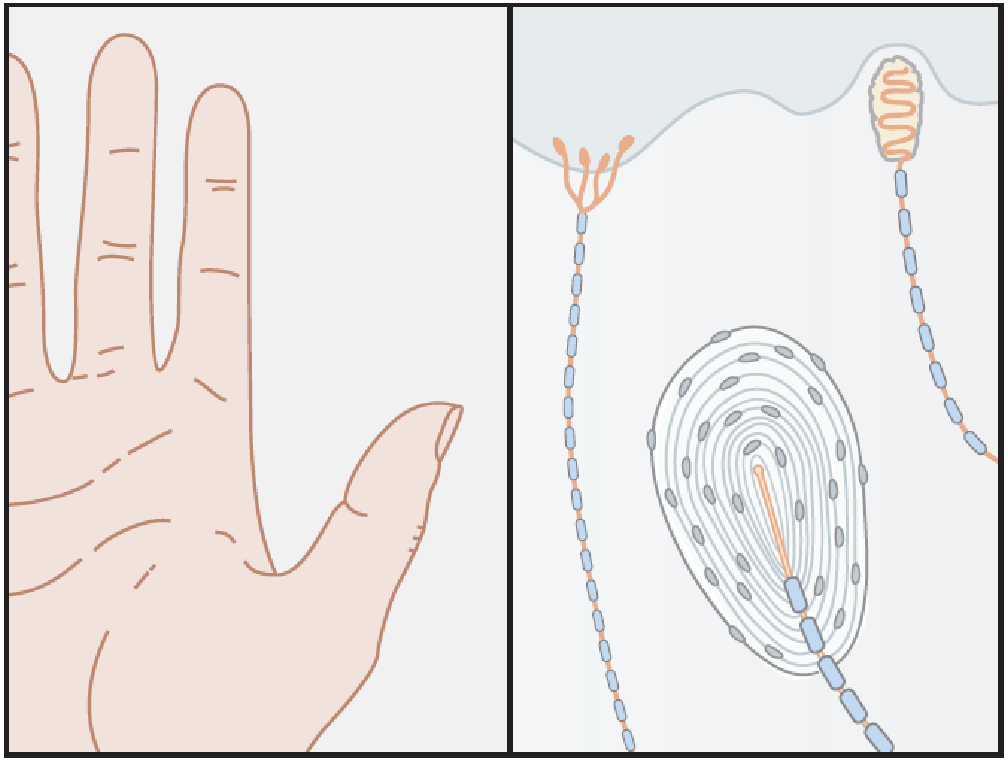
Chemoreceptors

Taste



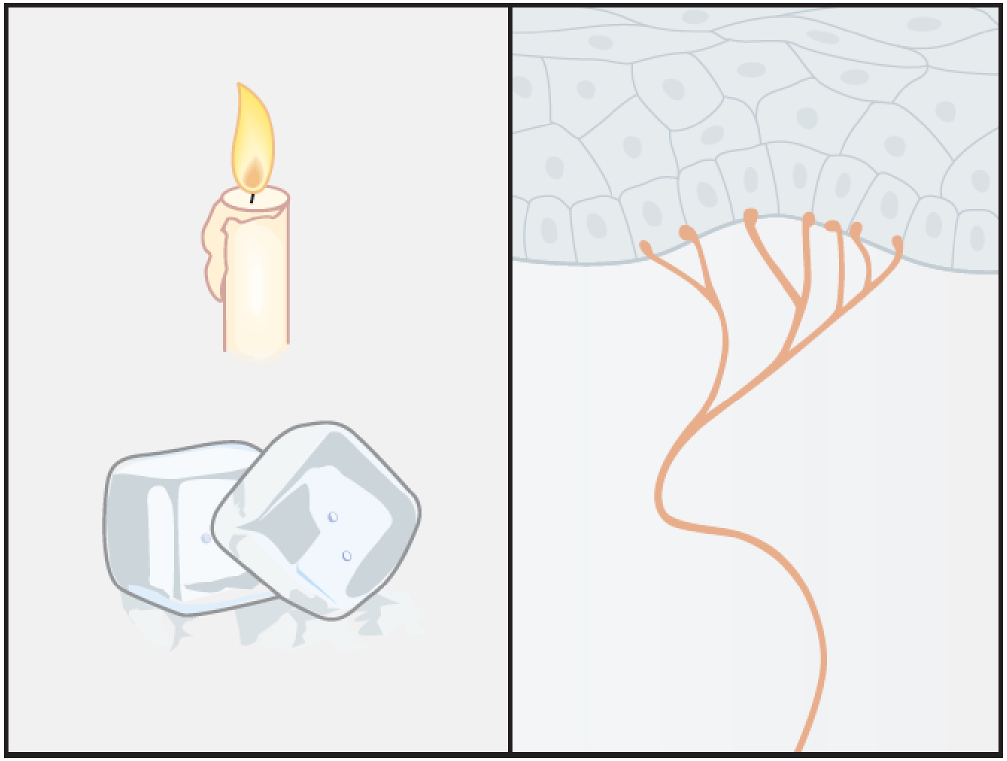
Mechanoreceptors

Touch



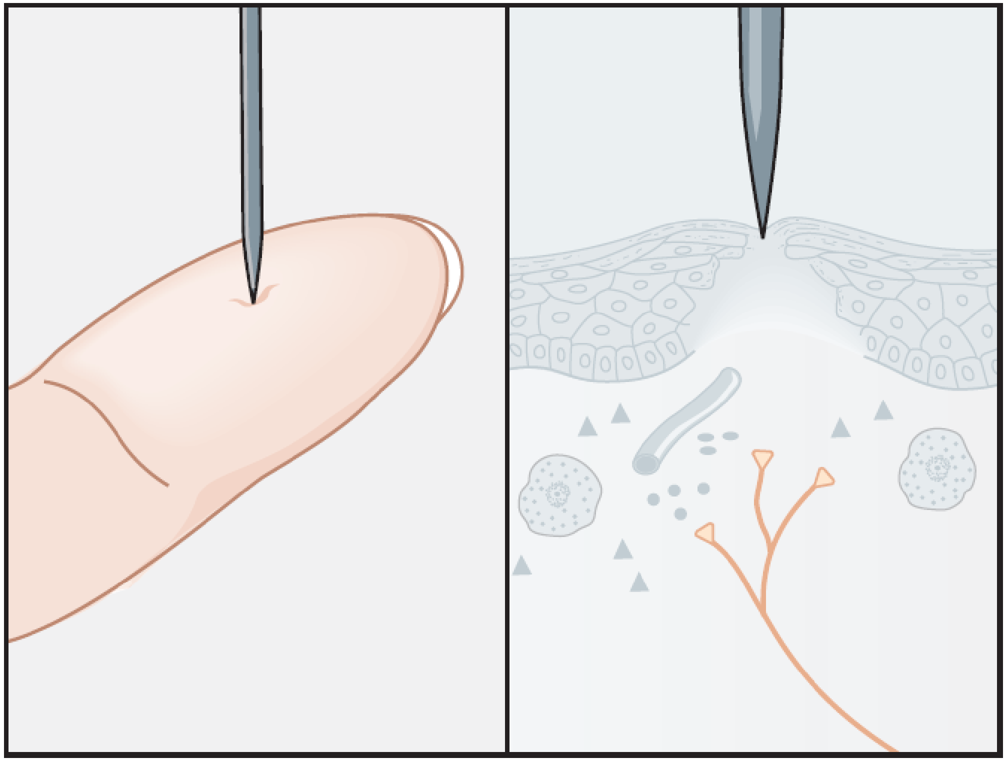
Thermal receptors

Thermal senses



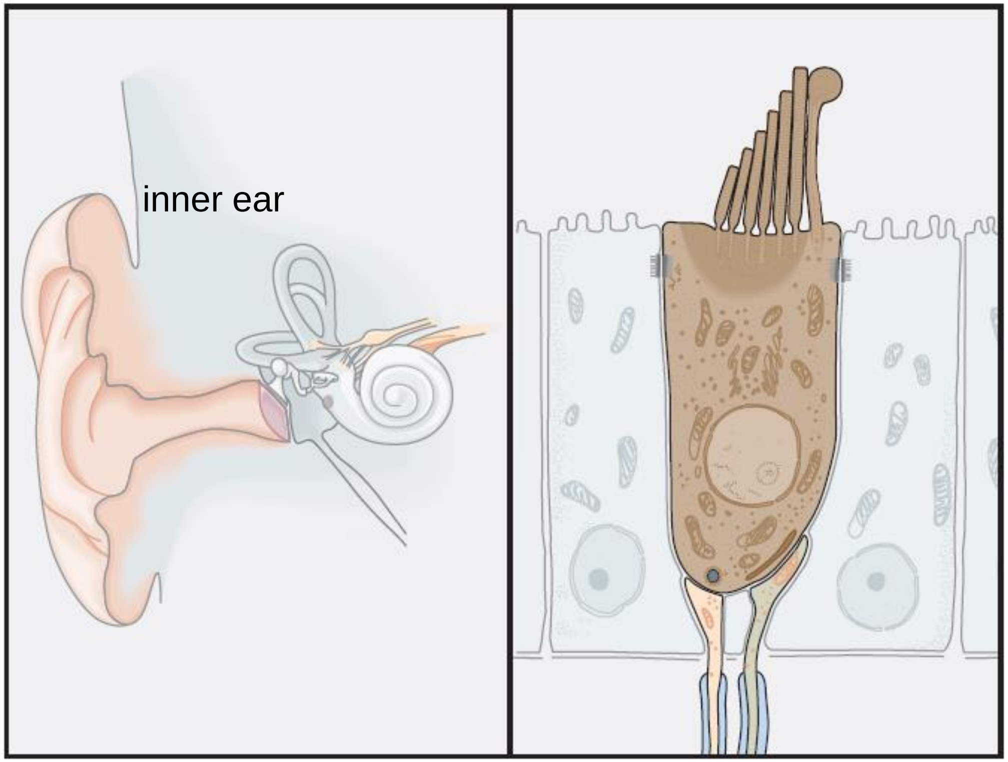
Chemoreceptors

Pain



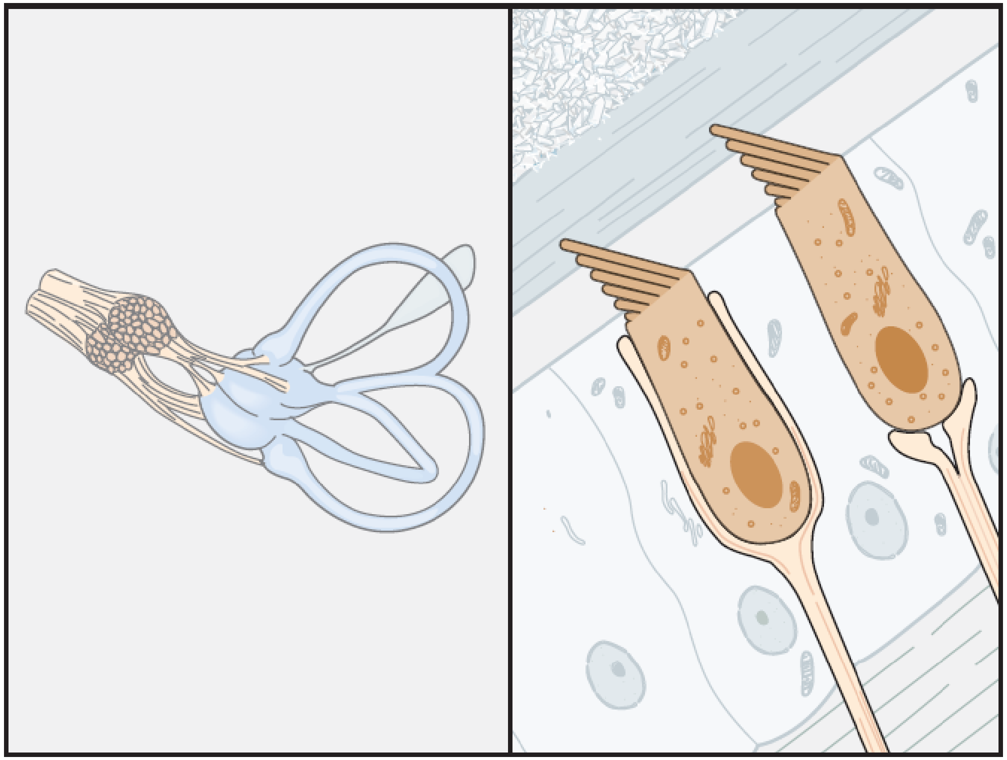
Mechanoreceptors

Hearing



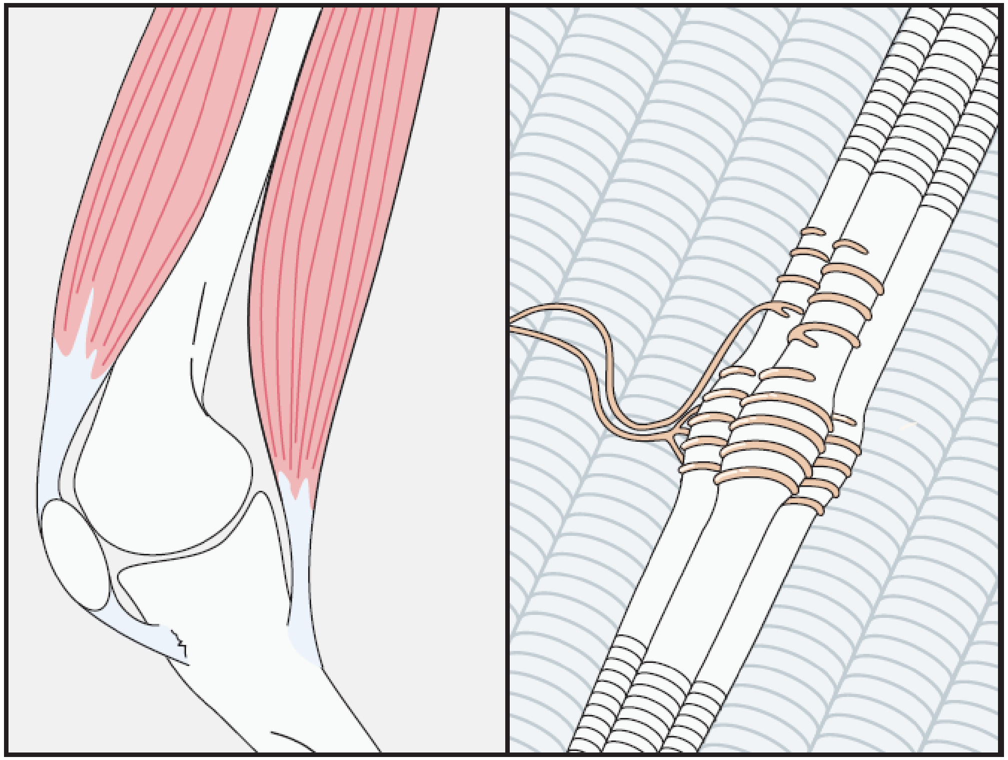
Mechanoreceptors

Balance



Mechanoreceptors

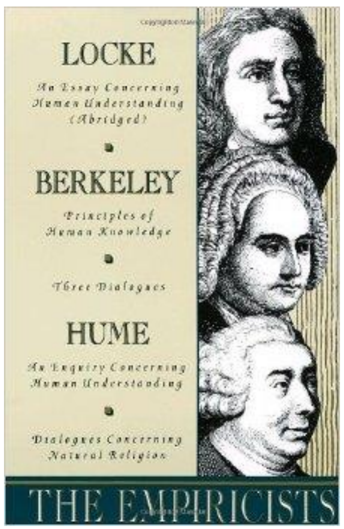
Proprioception



Sensation and perception was related to the question of **human nature** itself.

Empiricists: John Locke, George Berkeley, and David Hume

mind at birth is a blank slate, or ***tabula rasa***, void of any ideas



Berkeley questioned **whether there was any sensory reality** beyond the experiences and knowledge acquired through the senses.
"Does a falling tree make a sound if no one is near enough to hear it?"

Idealists: René Descartes, Immanuel Kant, and Georg Wilhelm Friedrich Hegel

human mind possesses certain innate abilities, including logical reasoning itself

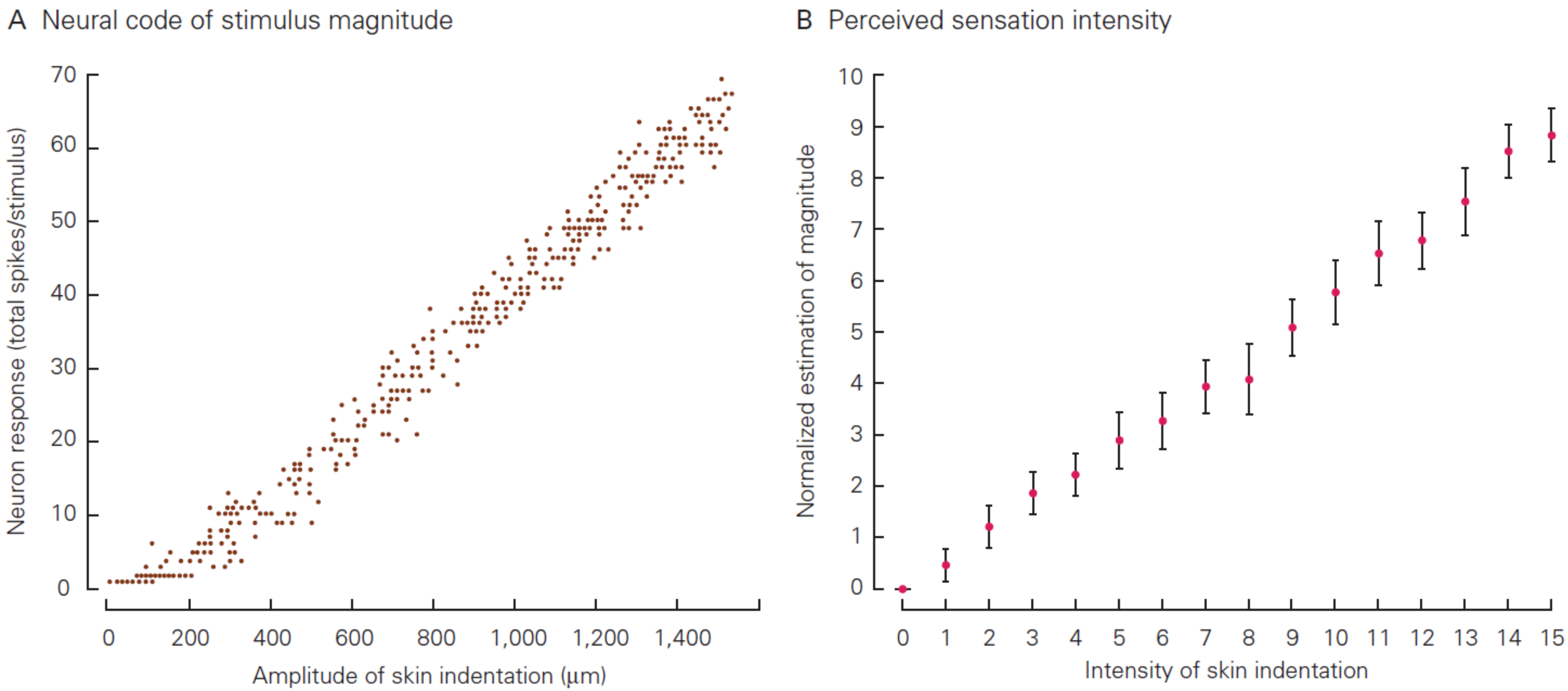


- Kant classified five sense as categories of human understanding.

- He argued that perception is not a direct record of the world around us rather were products of brain (depend on the nervous system)→ he referred to this brain properties as ***a priori***
- *Mind is not a passive receiver of sense impression*. So it had evolved to confirm certain universal condition such as ***space, time, and causality***. These conditions are *independent* of any physical stimuli detected by the body.

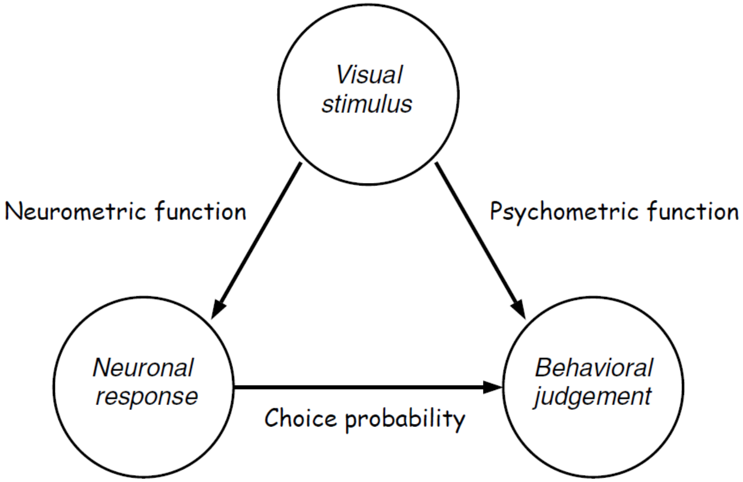
The firing rates of sensory nerves encode the stimulus magnitude reported by subjects

The relation between a subject's estimate of the intensity of the stimulus and its physical strength resembles the relation between the discharge frequency of the sensory neuron and the stimulus amplitude.

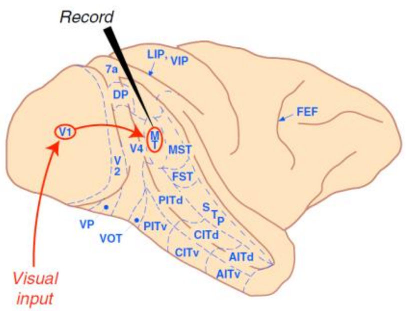


Decision theory in neural data

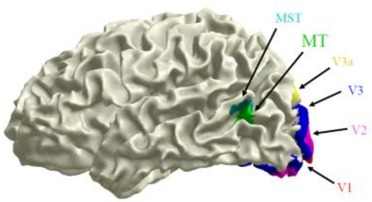
- Such techniques probe the sensory capabilities of animal subjects as the discrimination tasks become more difficult
- To investigate the **underlying neural mechanisms** when **electrophysiological** and **behavioral** studies are **combined** in the same experiment
- The **neurometric** function, plotting **neural discriminability** as a function of stimulus differences, corresponds closely to the **psychometric function**
- The **neurometric** function providing a physiological basis for the observed behavioral responses.

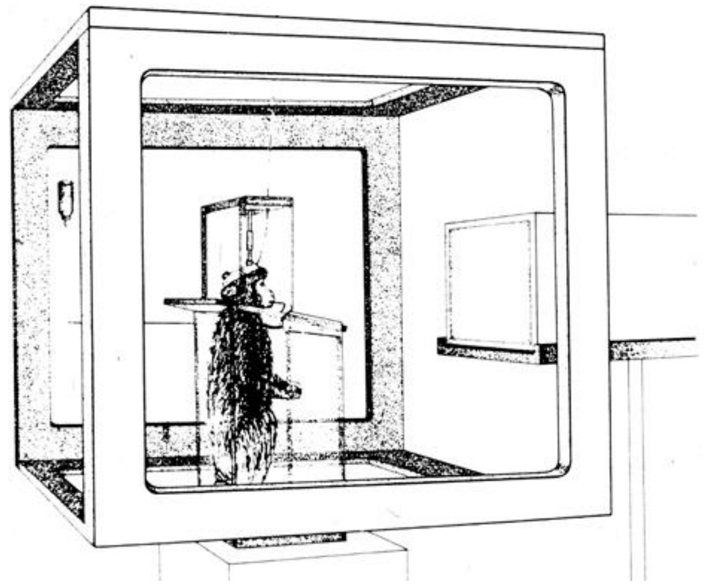


Newsome, Movshon, Britten, Shadlen, Salzman famous work



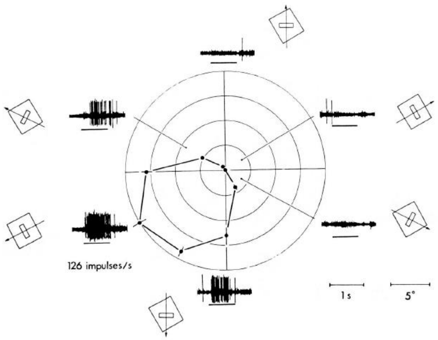
Record neuron that prefers downward motion while monkeys make up/down motion judgments for stimuli that are barely discriminable.

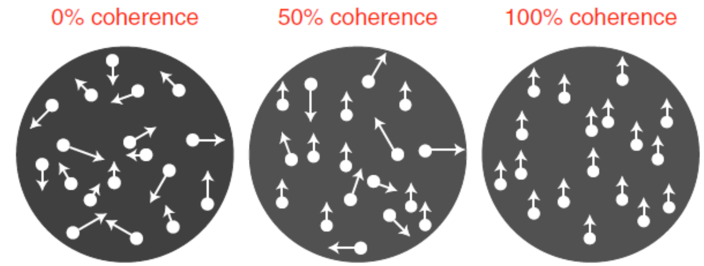




Britten, Kenneth H., et al. "The analysis of visual motion: a comparison of neuronal and psychophysical performance." *The Journal of Neuroscience* 12.12 (1992): 4745-4765.

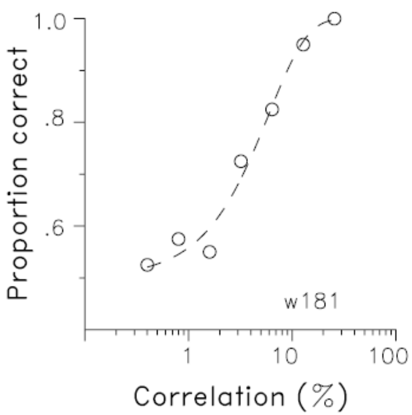
MT neurons are direction-selective

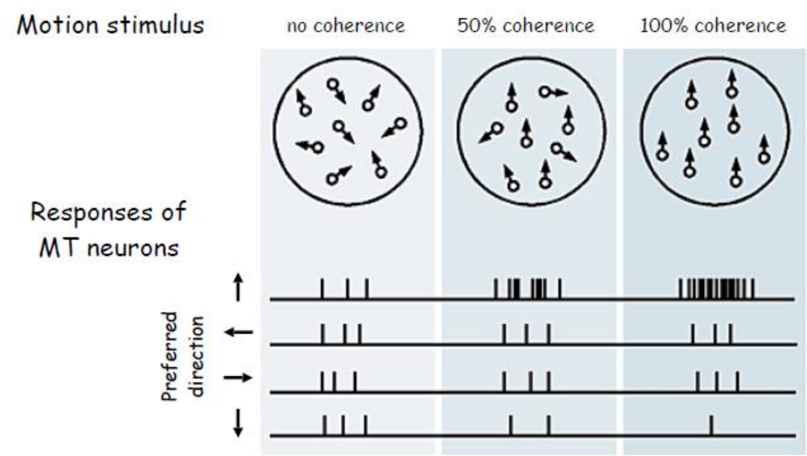




Motion coherence and MT neurons

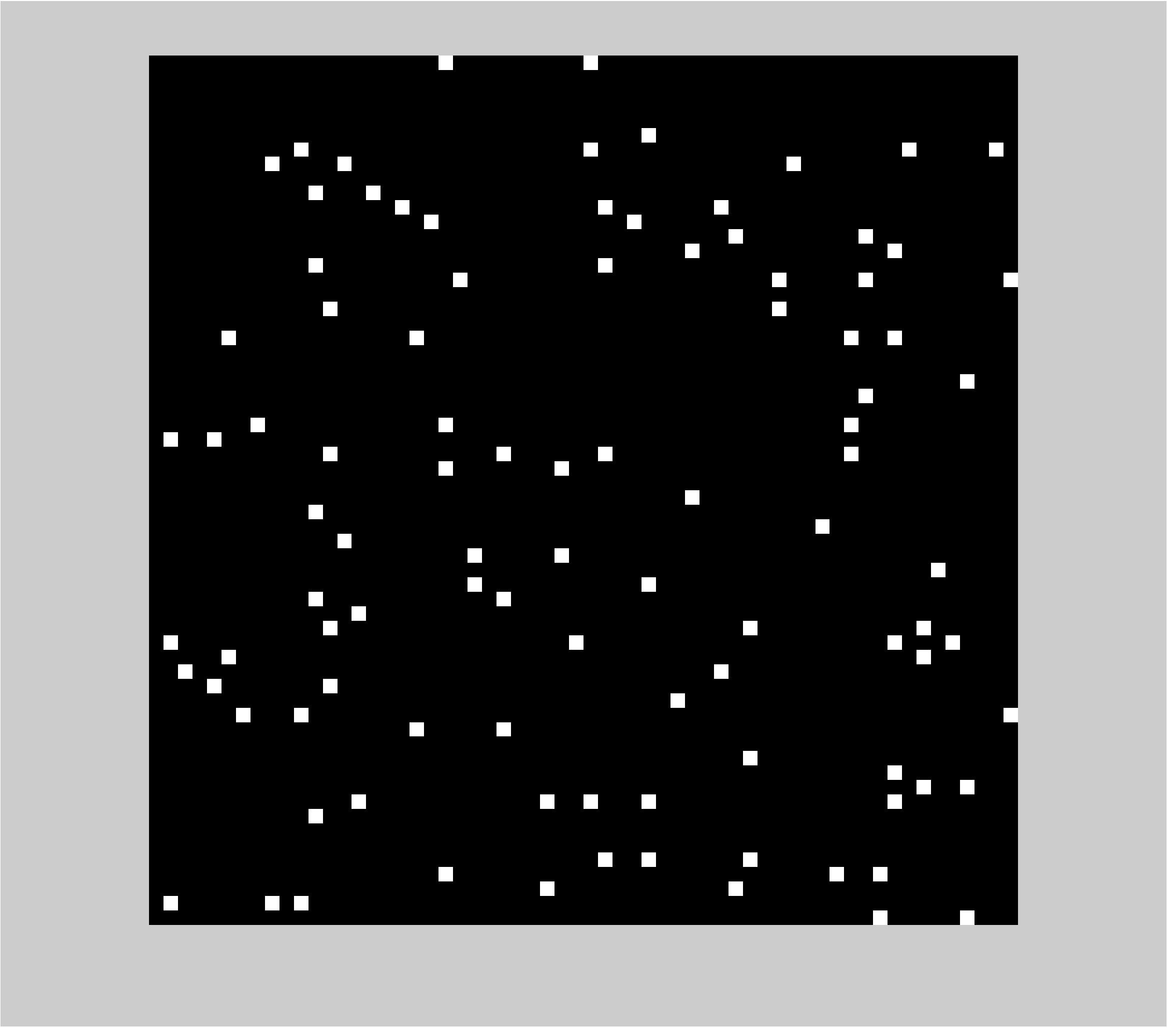
Psychometric function





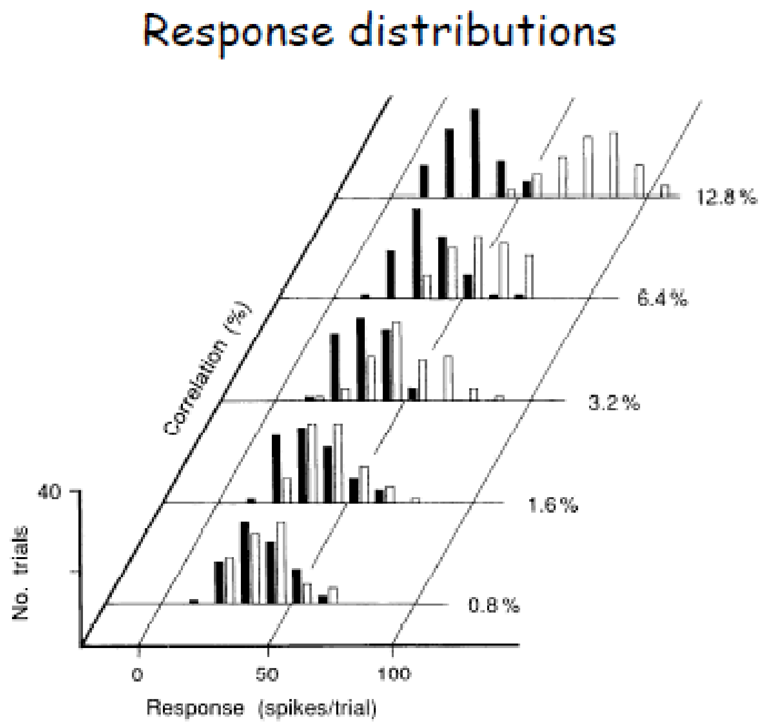
Maunsell and Van Essen, 1983

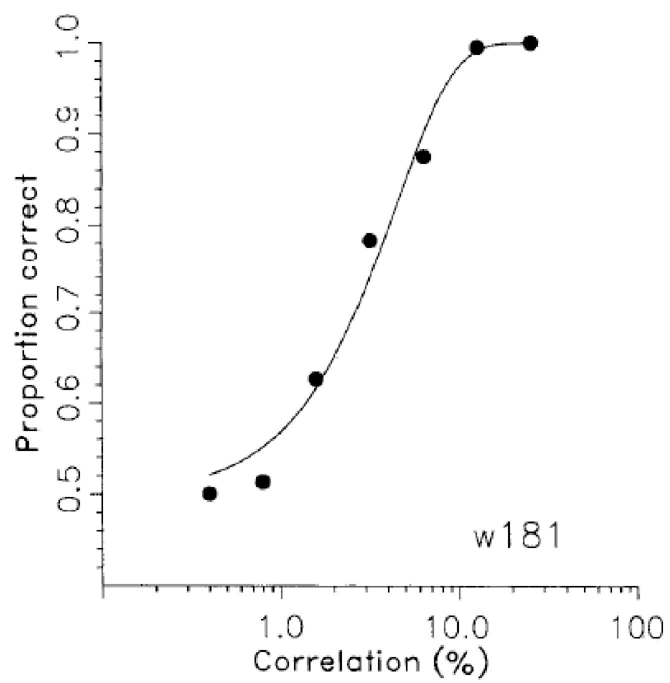
6.4% coherence (right direction) **random dot motion** stimulus presented at 60 Hz with 3 frame interleaving.



http://techlab.bu.edu/resources/demo/mode_demo_for_medium_coherence_case.html

Neurometric function

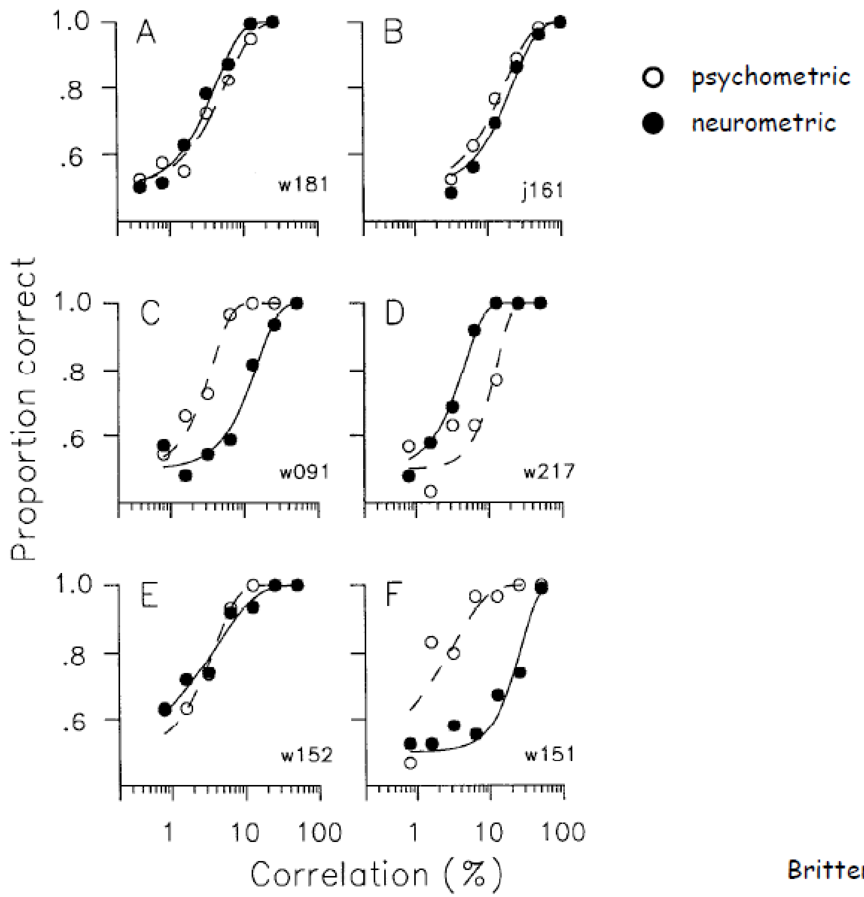




Black is response to **non-preferred**
Whit is response to **preferred**

Britten, Shadlen, Newsome & Movshon, 1992

Neurometric vs. psychometric functions



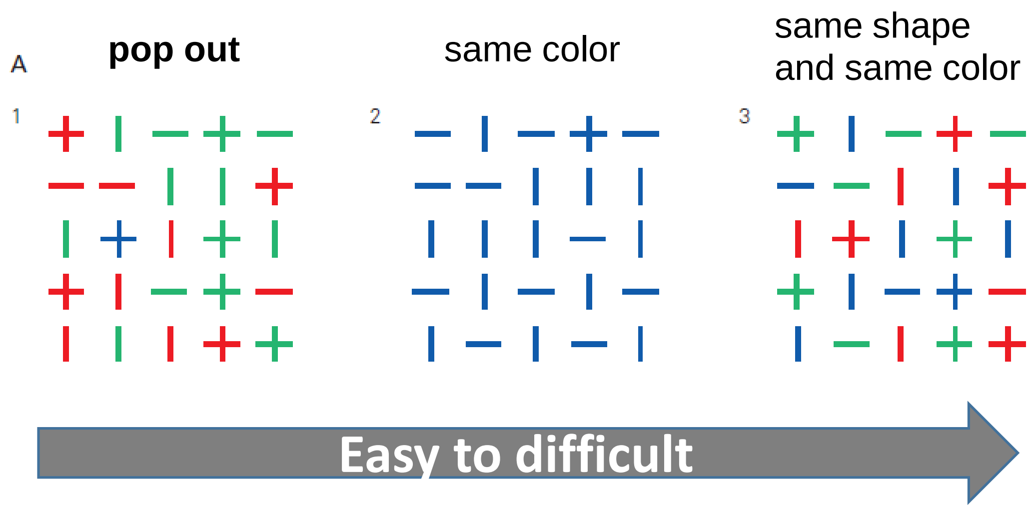
Britten, Shadlen, Newsome & Movshon, 1992

Decision Times Are Correlated with Cognitive Processes

- Franciscus Donders was the first, in 1865
- He and others found that reaction times elicited by **strong** stimuli are **shorter** than those elicited by **weak** stimuli
- Reaction times are widely used as measures of **certainty of responses** in humans and animals.
- Reaction times are often **correlated with neural activity in sensory areas** of the brain and in studies of sensory-triggered motor behaviors

Reaction times are used to evaluate cognitive function

- Mechanisms of pattern recognition

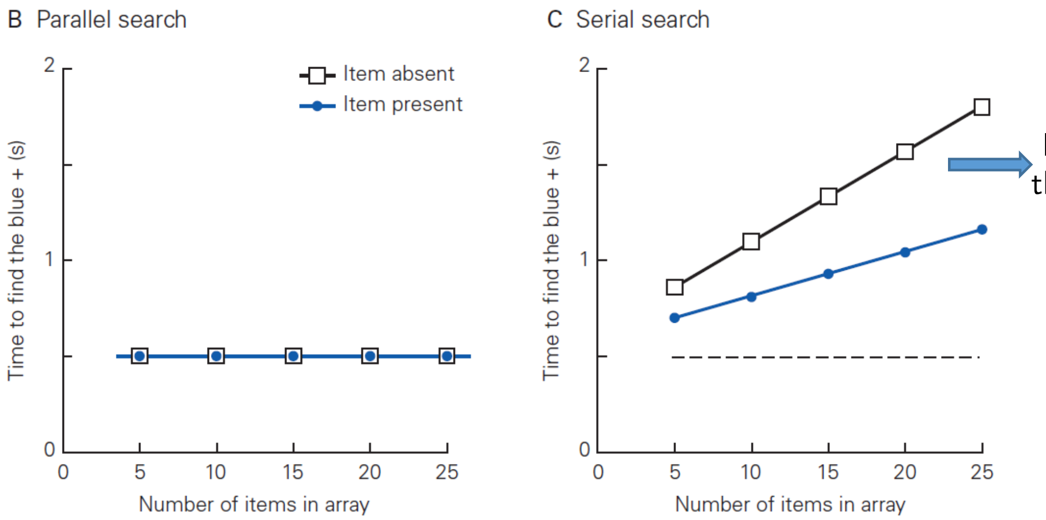


Task of human subjects: Subjects are asked to find the blue cross in each array.

Two alternative mechanism: serial vs. parallel search.

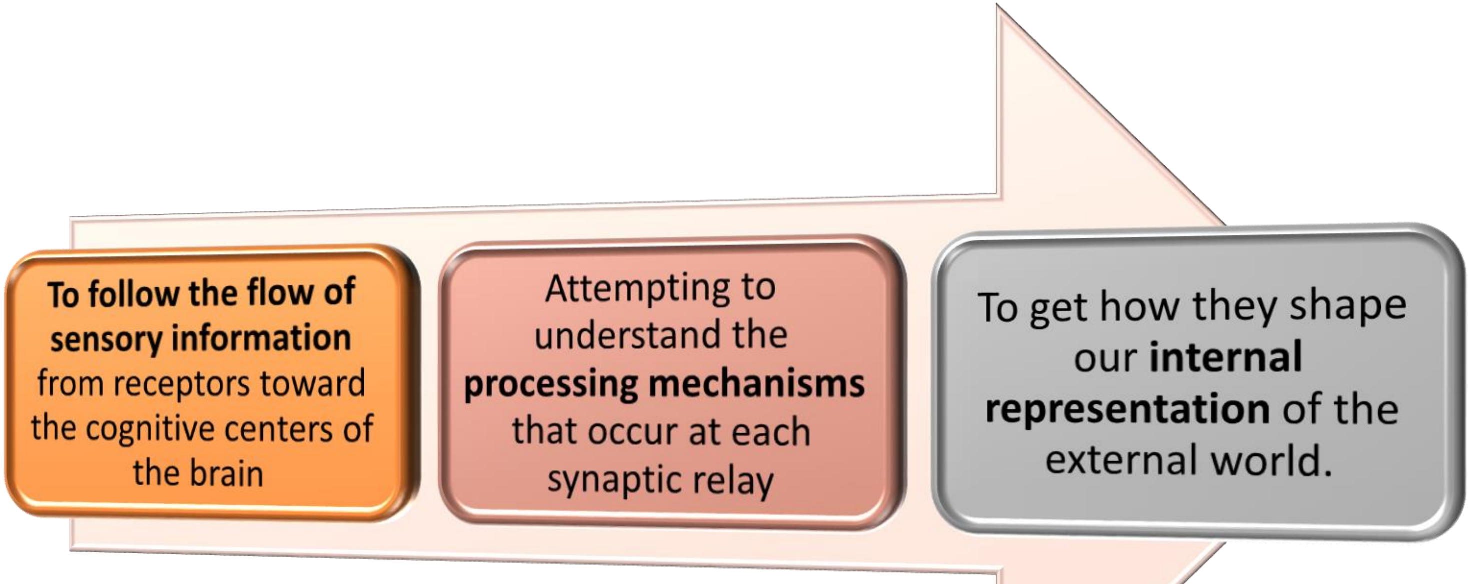
detect the blue cross in arrays 1 and 2 is independent of the total number of objects

in array 3 increases in proportion to the number of items



It takes twice as long to determine that an item is absent because all of the objects must be examined

The dominant research strategy in sensory neuroscience



The neural coding of sensory information is better understood at the early stages of processing than at later stages

Brain power

If we understand a muscle cell, we essentially understand how a whole muscle works.

The **power of the brain**

lies in the **parallel action** of millions of cells,

each doing **something different**

we need to understand how **its tasks are organized** and how individual neurons carry out those tasks

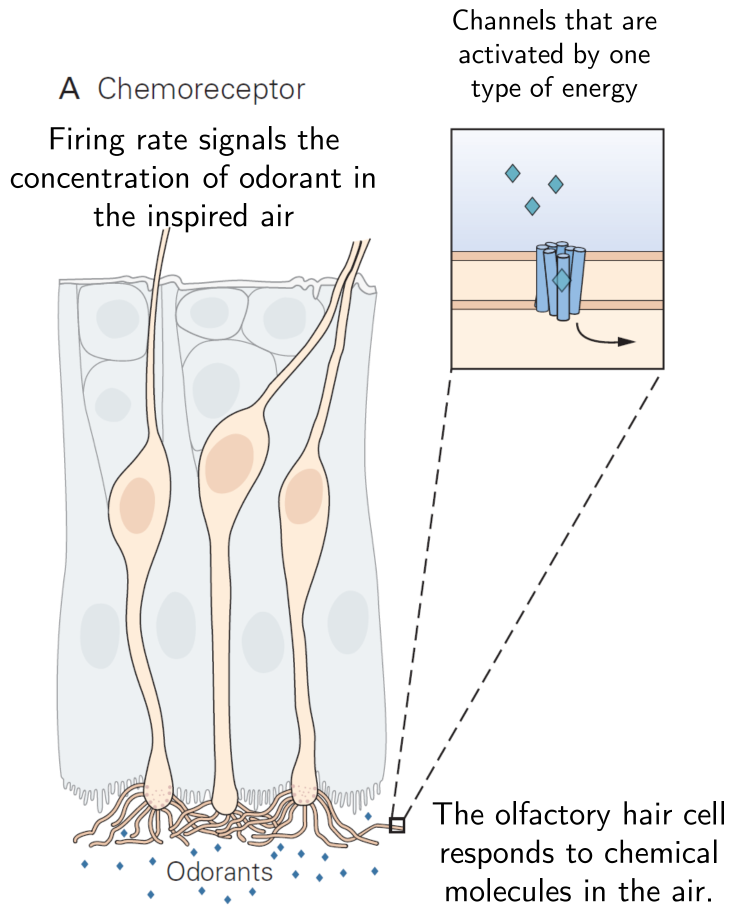
Sensory Receptors Are Responsive to a Single Type of Stimulus Energy

- Each receptor responds to a **specific kind of energy** at **specific locations** on the body and sometimes only to energy with a **particular temporal or spatial pattern**.
- ***Receptor potential***:
  - The amplitude and duration of the electrical signal produced by the receptor are related to the intensity and time course of stimulation of the receptor
- ***Stimulus transduction***:
  - The process by which specific stimulus energy is converted into an electrical signal
- Sensory receptors are **morphologically** specialized
- *Receptor specificity*:
  - Most receptors are optimally selective for a **single type of stimulus** energy

Table 21-1 Classification of Sensory Receptors

Sensory system	Modality	Stimulus	Receptor class	Receptor cells
Visual	Vision	Light (photons)	Photoreceptor	Rods and cones
Auditory	Hearing	Sound (pressure waves)	Mechanoreceptor	Hair cells in cochlea
Vestibular	Head motion	Gravity, acceleration, and head motion	Mechanoreceptor	Hair cells in vestibular labyrinths
Somatosensory				Cranial and dorsal root ganglion cells with receptors in:
	Touch	Skin deformation and motion	Mechanoreceptor	Skin
	Proprioception	Muscle length, muscle force, and joint angle	Mechanoreceptor	Muscle spindles and joint capsules
	Pain	Noxious stimuli (thermal, mechanical, and chemical stimuli)	Thermoreceptor, mechanoreceptor, and chemoreceptor	All tissues except central nervous system
	Itch	Histamine	Chemoreceptor	Skin
	Visceral (not painful)	Wide range (thermal, mechanical, and chemical stimuli)	Thermoreceptor, mechanoreceptor, and chemoreceptor	Gastrointestinal tract, urinary bladder, and lungs
Gustatory	Taste	Chemicals	Chemoreceptor	Taste buds
Olfactory	Smell	Odorants	Chemoreceptor	Olfactory sensory neurons

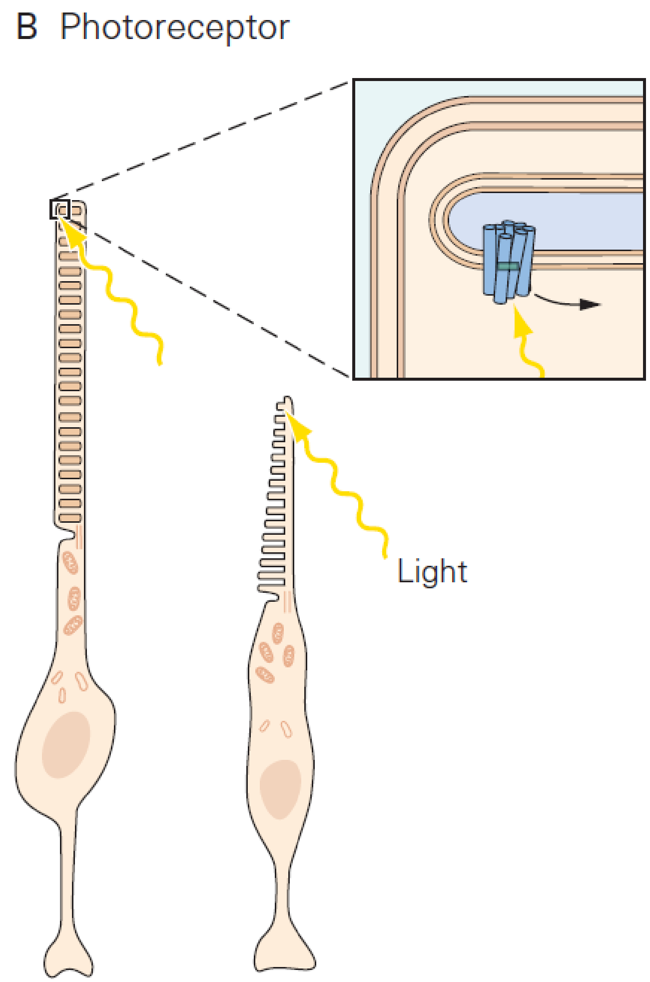
Chemoreceptors



The **olfactory cilia** on the mucosal surface bind specific odorant molecules and depolarize the sensory nerve through a **second-messenger system**.

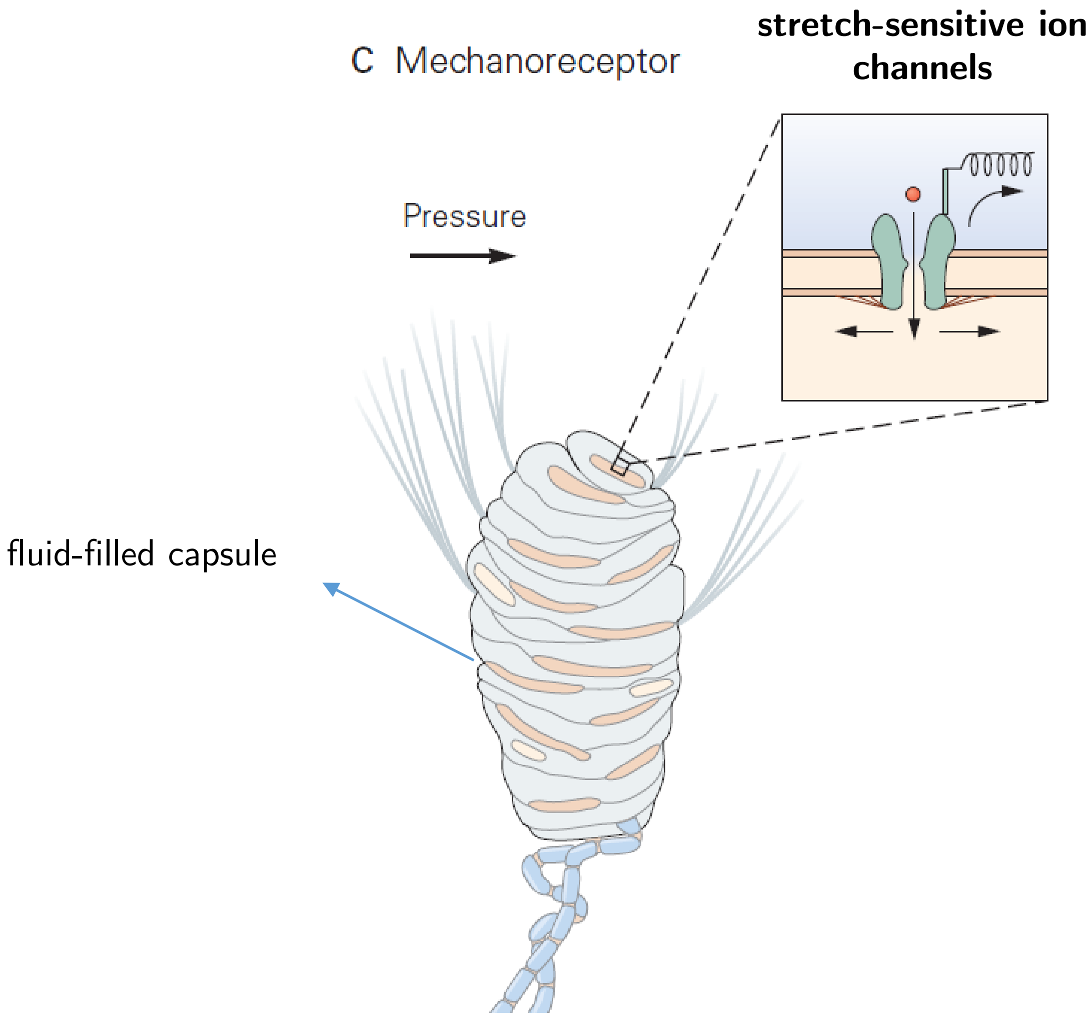
Photoreceptor

The outer segment contains the **photopigment rhodopsin**, which changes configuration when it absorbs light of particular wavelengths



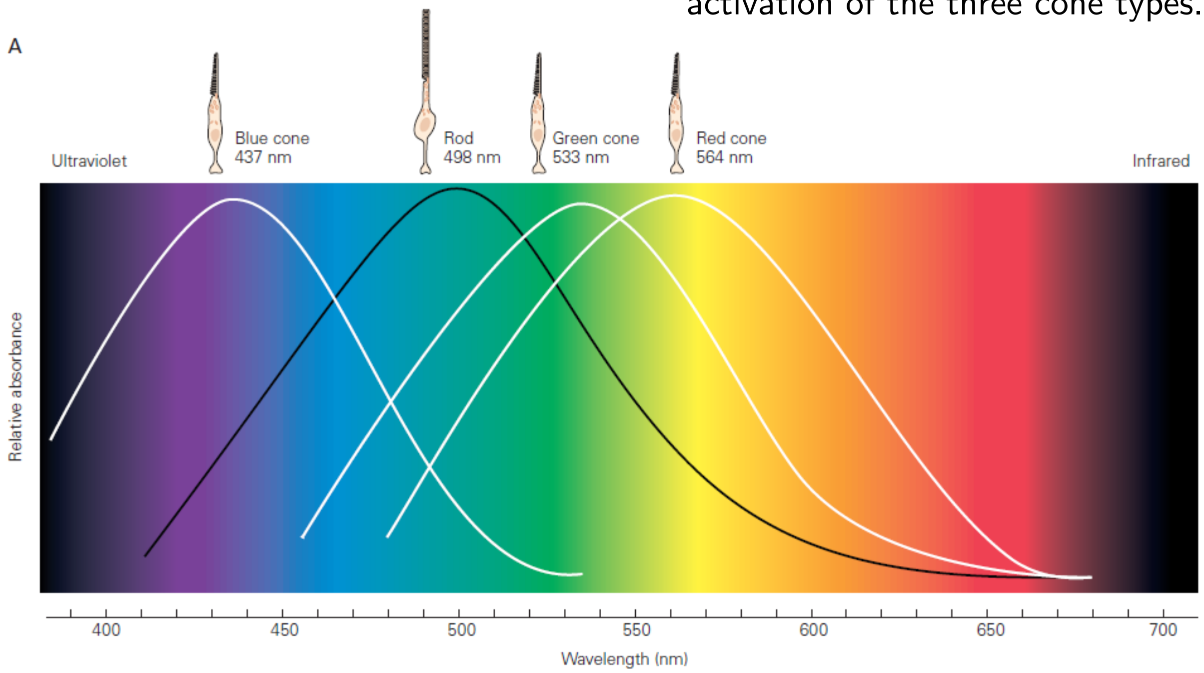
Mechanoreceptor

Meissner's corpuscles



Human perception of colors results from the simultaneous activation of three different classes of photoreceptors in the retina.

The **specific colors perceived** result from the relative activation of the three cone types.



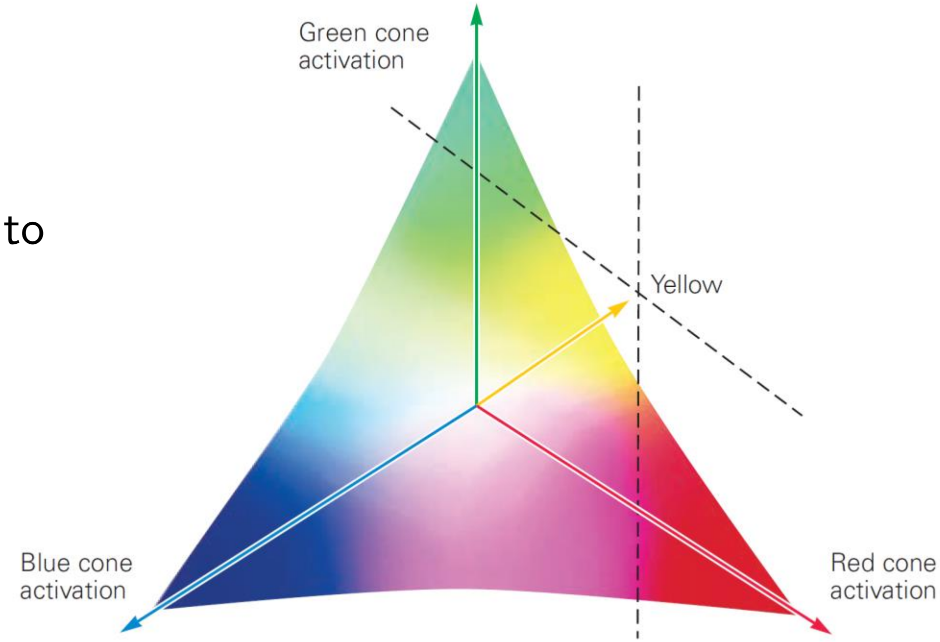
visible spectrum of light

The neural coding of color and brightness in the retina

It can be portrayed as a **three-dimensional** vector in which the strength of activation of each cone type is plotted along one of the three axes

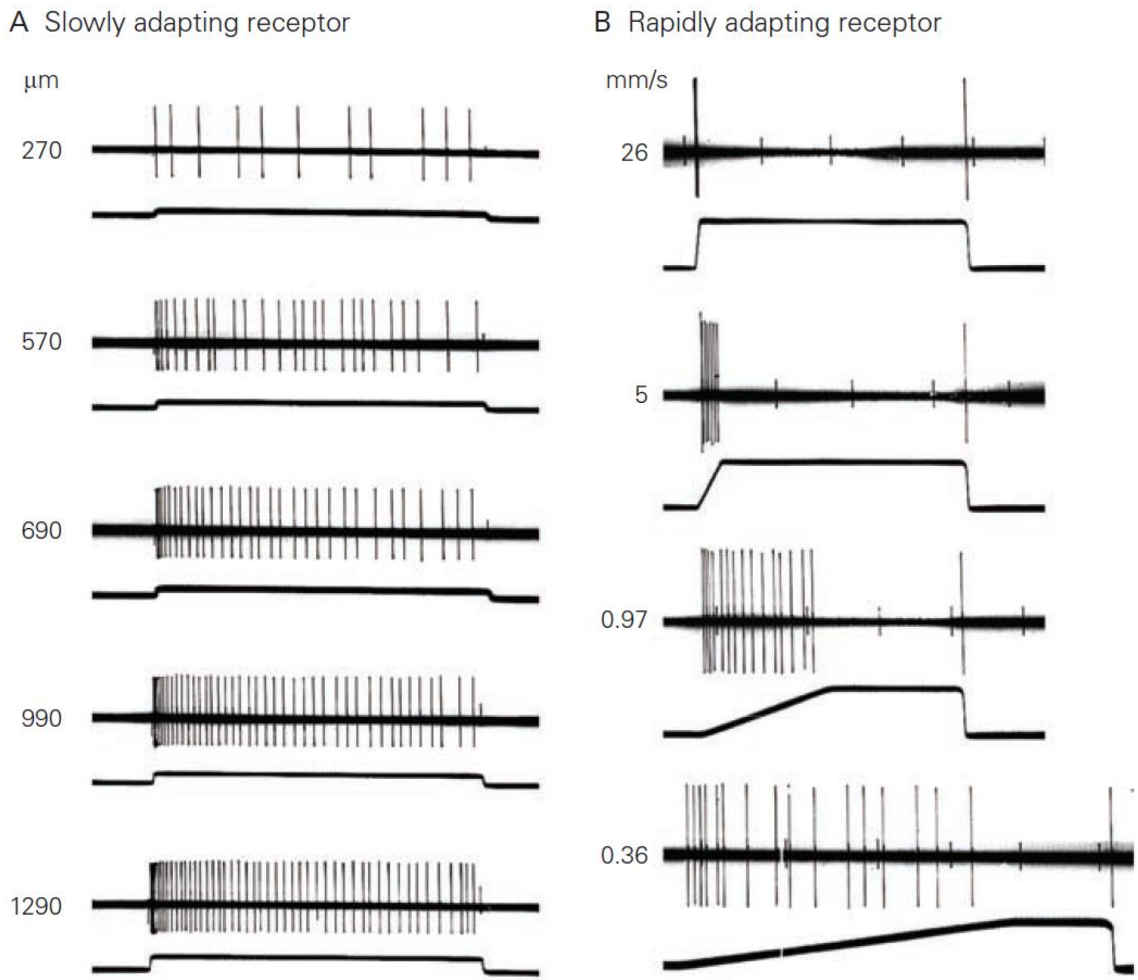
The length of the vector from the origin to the point represents the intensity or brightness of light in that region **of the retina**.

In the **higher order**, the mechanism of color perception is **different**



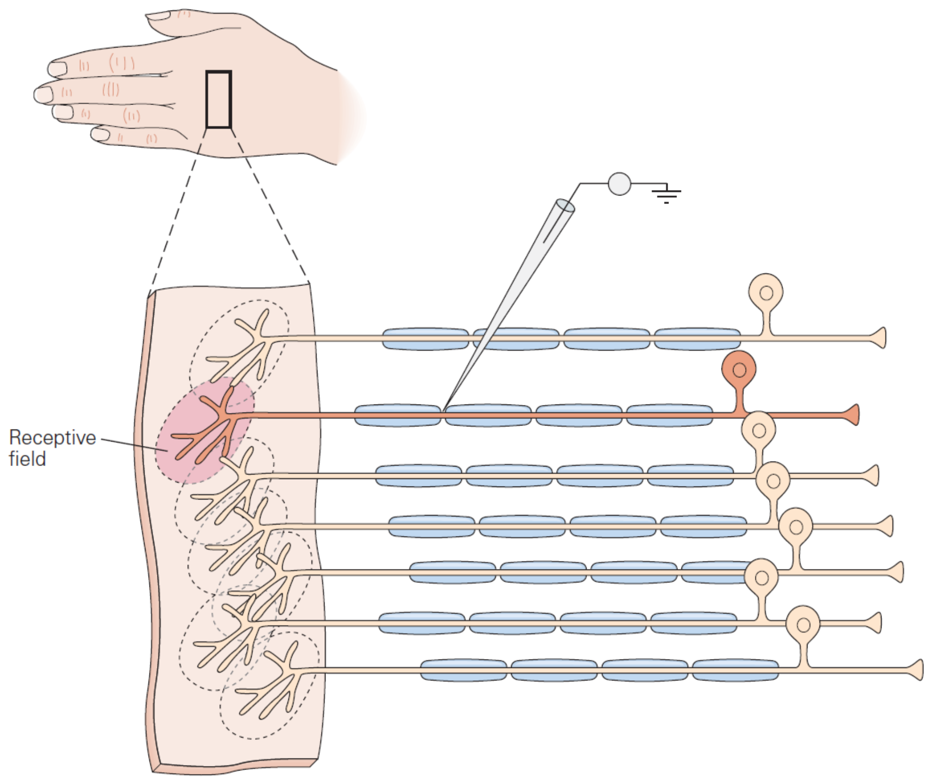
Firing rates of sensory neurons convey information about the stimulus **intensity** and **time** course

Responses of two different classes of touch receptors to a probe pressed into the skin



The **receptive field** of a sensory neuron is the **spatial domain** in the sense organ where stimulation excites or inhibits the neuron.

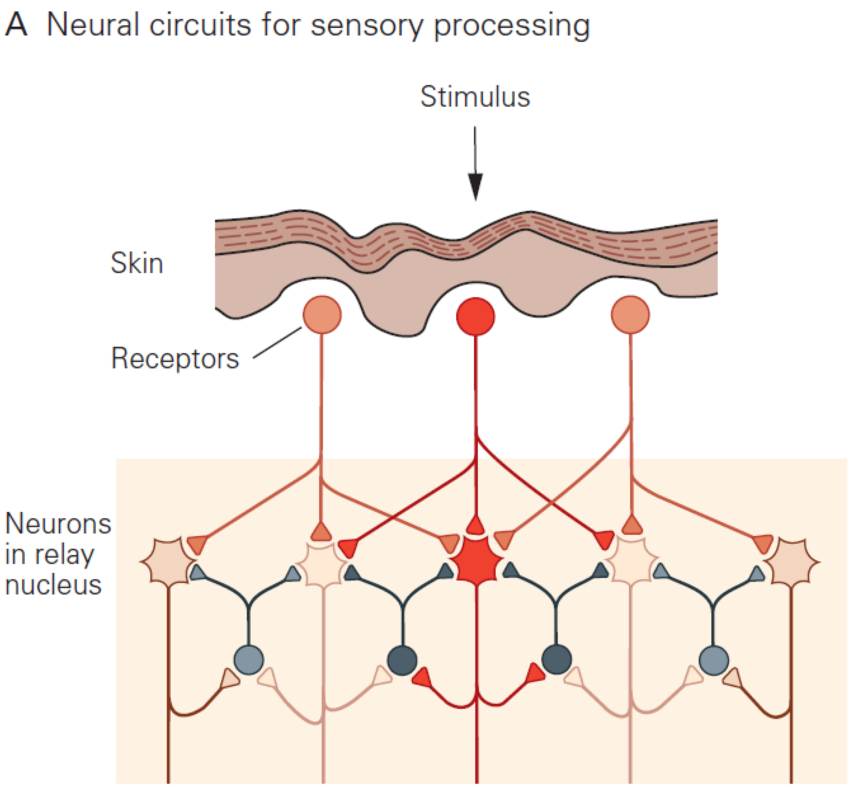
If the fiber is stimulated electrically with a microelectrode, the subject experiences touch localized to the receptive field



A patch of skin contains many overlapping receptive Fields, **allowing sensations to shift** smoothly from one sensory neuron to the next in a continuous sweep

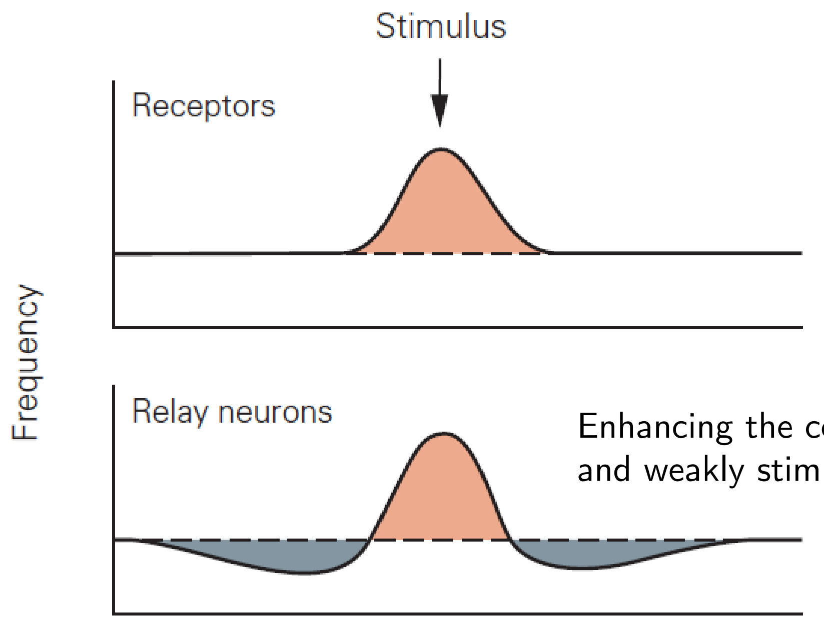
Coding by a large group of neurons

A stimulus to the skin is registered by a **large group of postsynaptic neurons** in relay nuclei in the brain stem and thalamus, but most strongly by neurons in the **center of the array**



Spatial distribution of excitation and inhibition

Inhibition (gray areas) mediated by local interneurons confines excitation (orange area)



Enhancing the contrast between strongly and weakly stimulated relay

Types of inhibition in relay nuclei

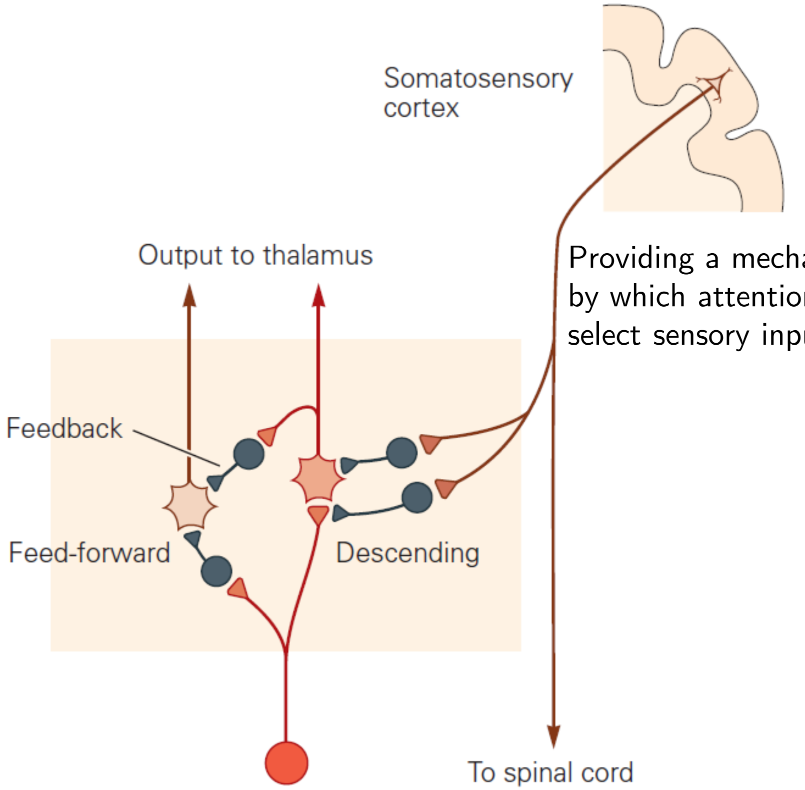
Winner-take-all strategy that ensures that only one of two or more competing responses is expressed

Inhibitory interneurons in a relay nucleus are activated by three distinct excitatory pathways:

1- **Feed-forward** inhibition: by the afferent fibers of receptors that terminate on the inhibitory interneurons.

2- **Feedback inhibition**: by **recurrent collateral** axons of neurons in the output pathway

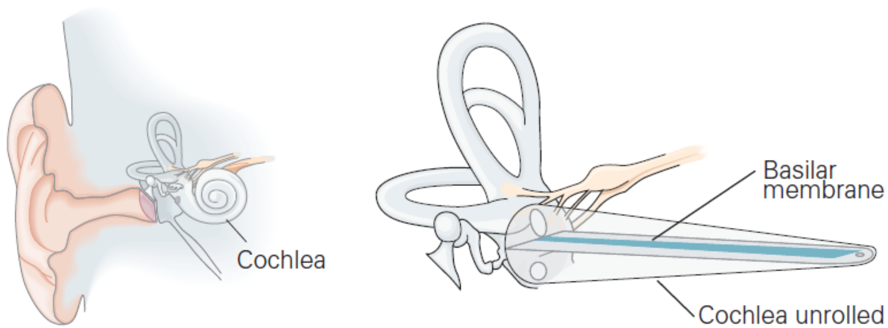
3- The **descending pathways** allow cortical neurons to **control the relay** of sensory information

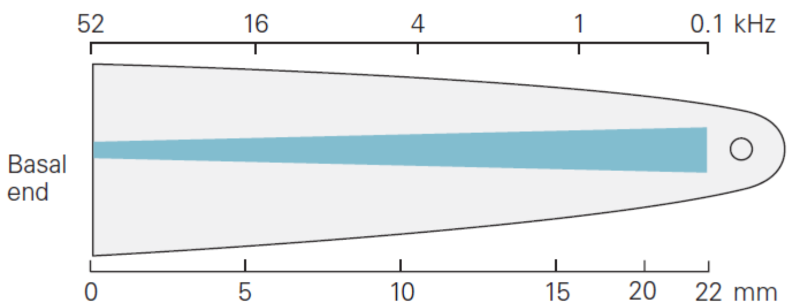


Providing a mechanism by which attention can select sensory inputs

Receptors in the cochlea, the sense organ of the inner ear, are arranged tonotopically

The **frequency selectivity** of hair cell receptors in the cochlea **is due in part to** the change in dimensions along the **length of the basilar** membrane where the hair cells are embedded

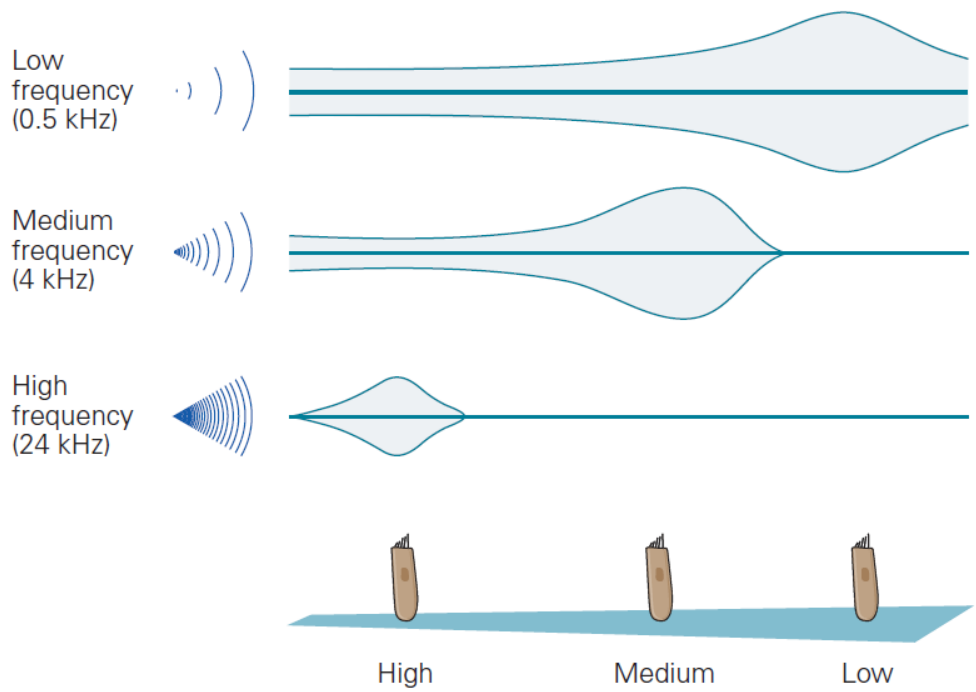




Sound coding

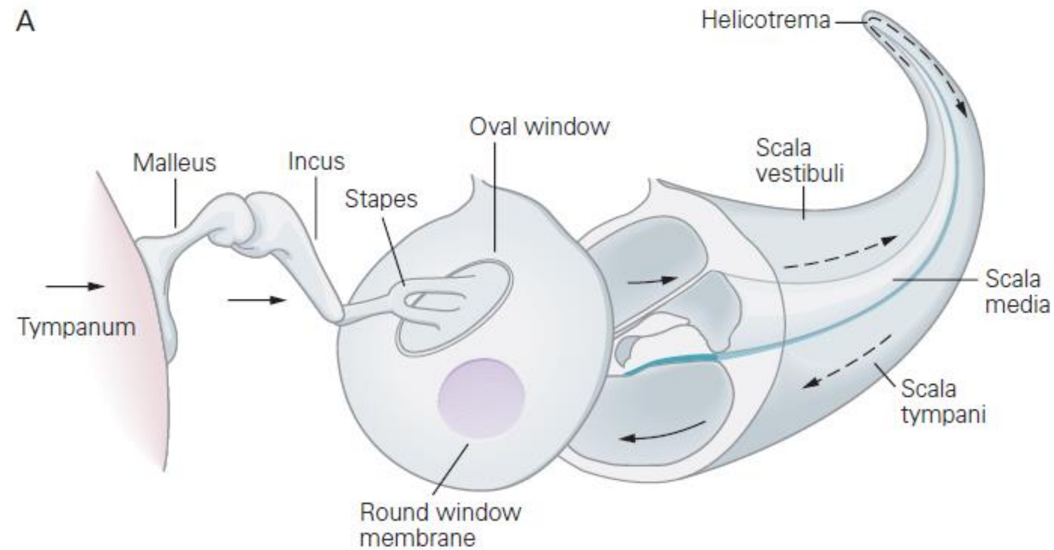
When sound is received at the cochlea, a traveling wave moves along the basilar membrane.

The increasing width of the basilar membrane alters the amplitude of vibration: high frequencies evoke the greatest displacement toward the basal end, whereas low frequencies are strongest at the apical end.

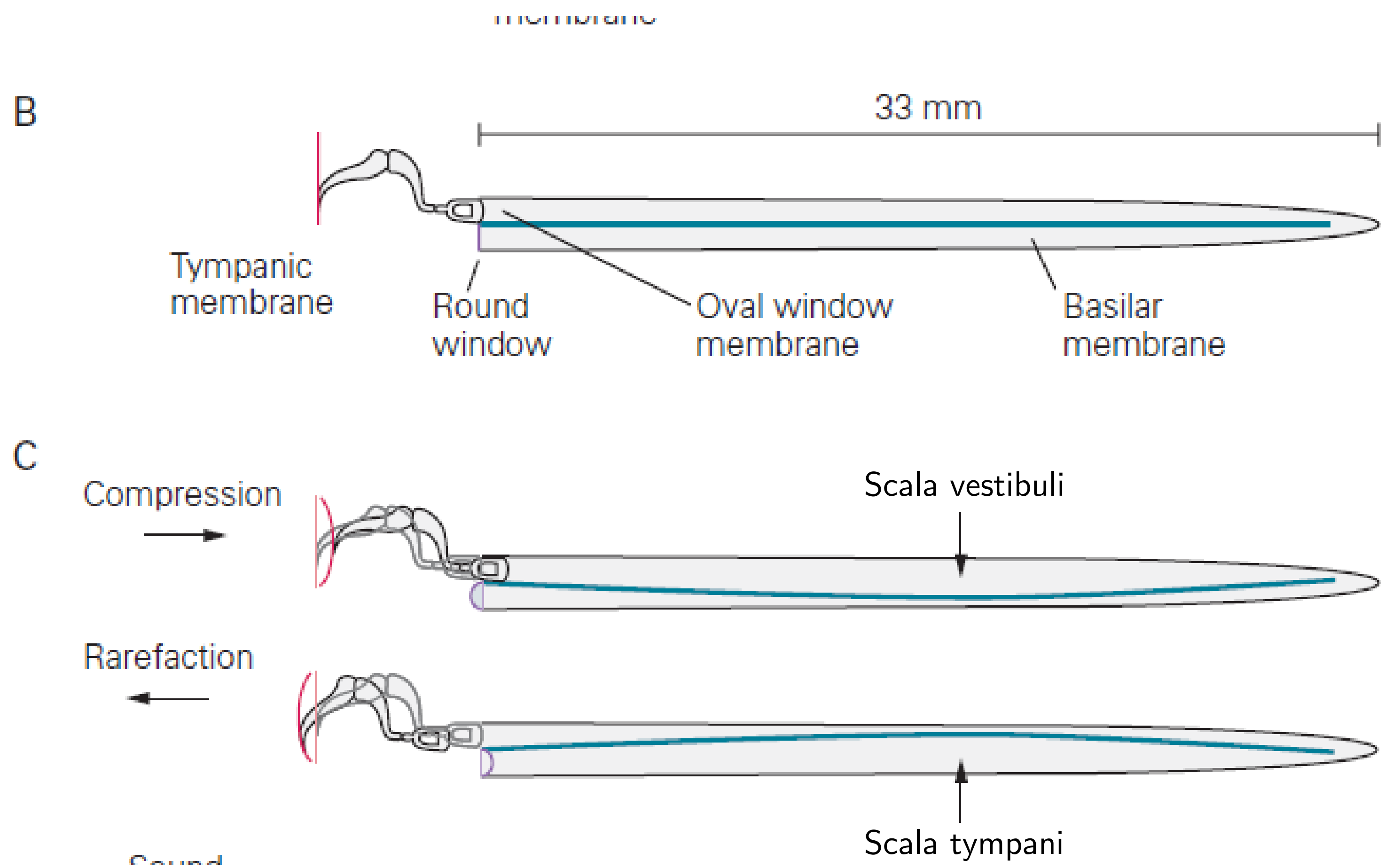


Motion of the basilar membrane

- An uncoiled cochlea
- Sound vibrates the tympanum
- The **piston-like** action of the stapes, a bone inserted partially into the **elastic** oval window, produces oscillatory pressure differences that rapidly propagate along the scala vestibuli and scala tympani.
- Low-frequency pressure differences are shunted through the helicotrema



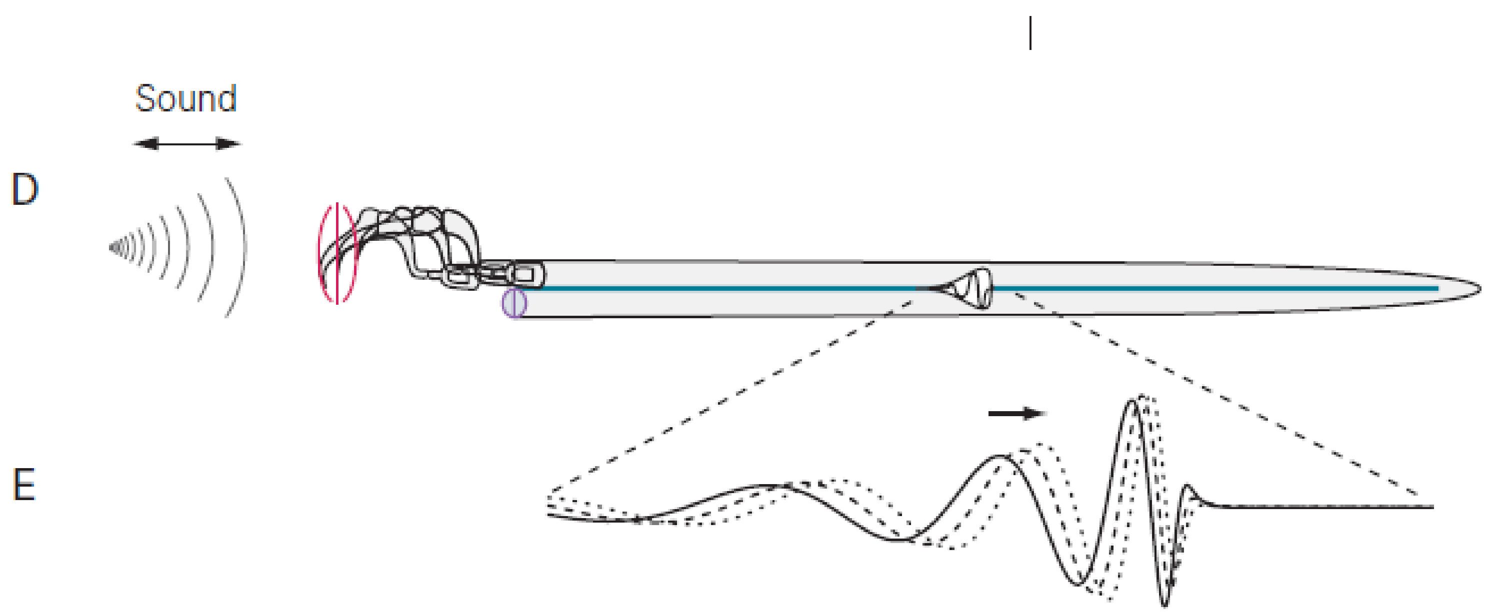
The functional properties of the cochlea are conceptually simplified if the cochlea is viewed as a **linear structure** with only two liquid-field compartments separated by the elastic basilar membrane.



The movements of the **tympanum**, ***ossicles***, and **basilar membrane** are greatly exaggerated.

Basilar membrane's mechanical properties

- In fact, the basilar membrane's mechanical properties vary continuously along its length.
- The oscillatory stimulation of a sound causes a traveling wave on the basilar membrane
- The loudest tolerable sounds move the basilar membrane by only ± 150 nm,.

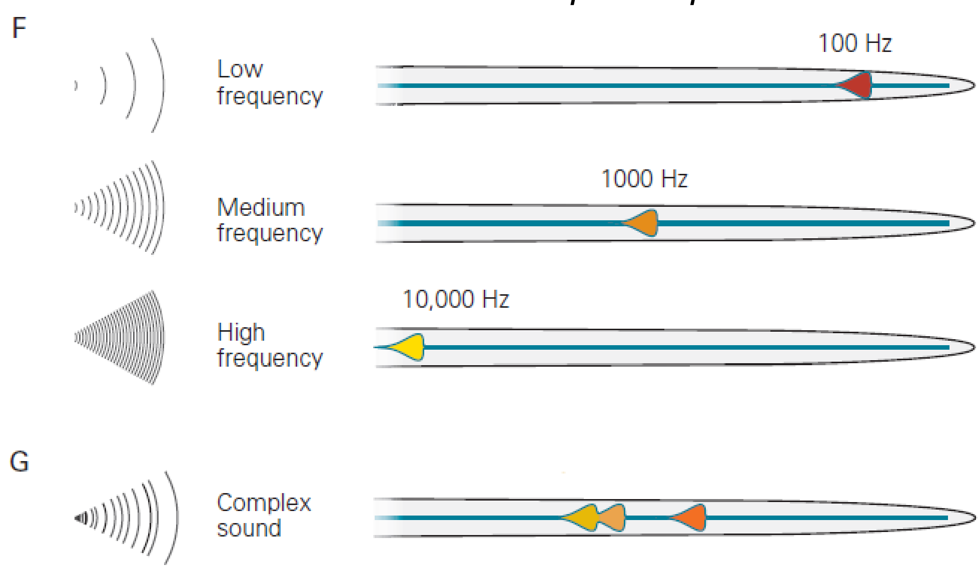


As the **wave approaches the characteristic place for the stimulus frequency**, it slows and
Grows in amplitude. The stimulus energy is then transferred to hair cells at the position of the wave's peak

Each frequency of stimulation excites maximal motion at a **particular position** along the basilar membrane.

The mapping of sound frequency onto the basilar membrane is approximately **logarithmic**.

Tonotopic map



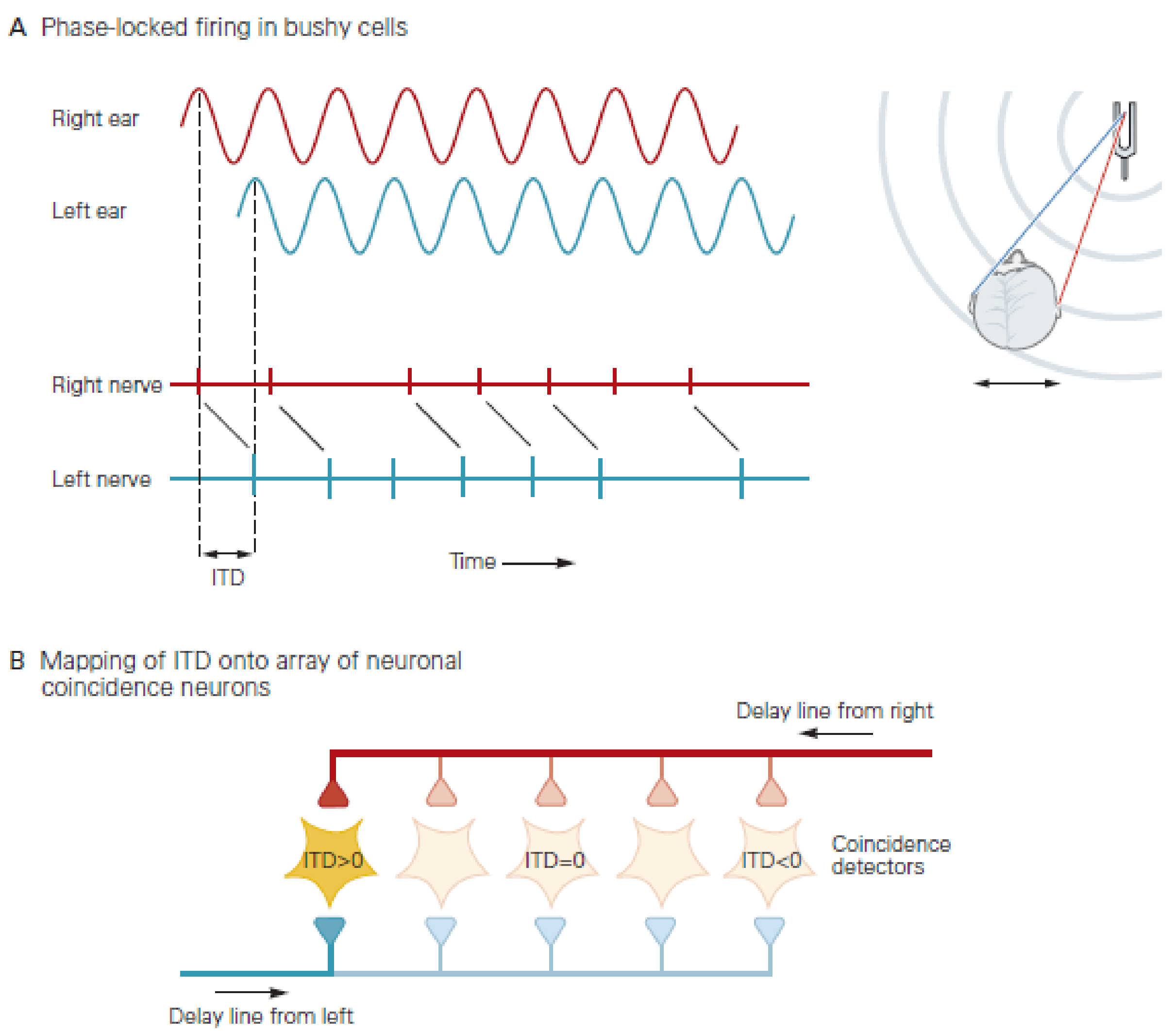
Membrane is relatively broad and flaccid

Narrow, taut base.

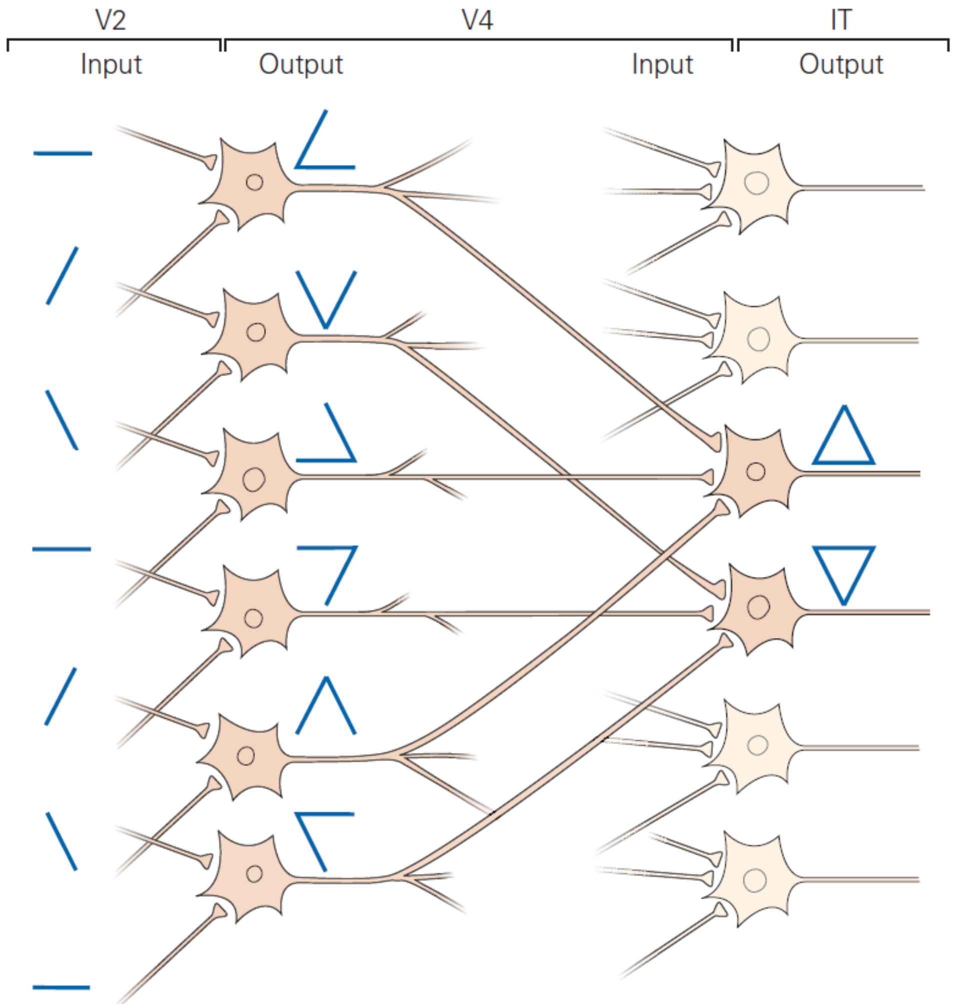
Basilar membrane performs **spectral analysis of complex sounds**

Basilar membrane thus acts as a **mechanical frequency analyzer** by distributing specific stimulus energies to hair cells arrayed along its length, and in doing so begins the **encoding of the frequencies and intensities in a sound**

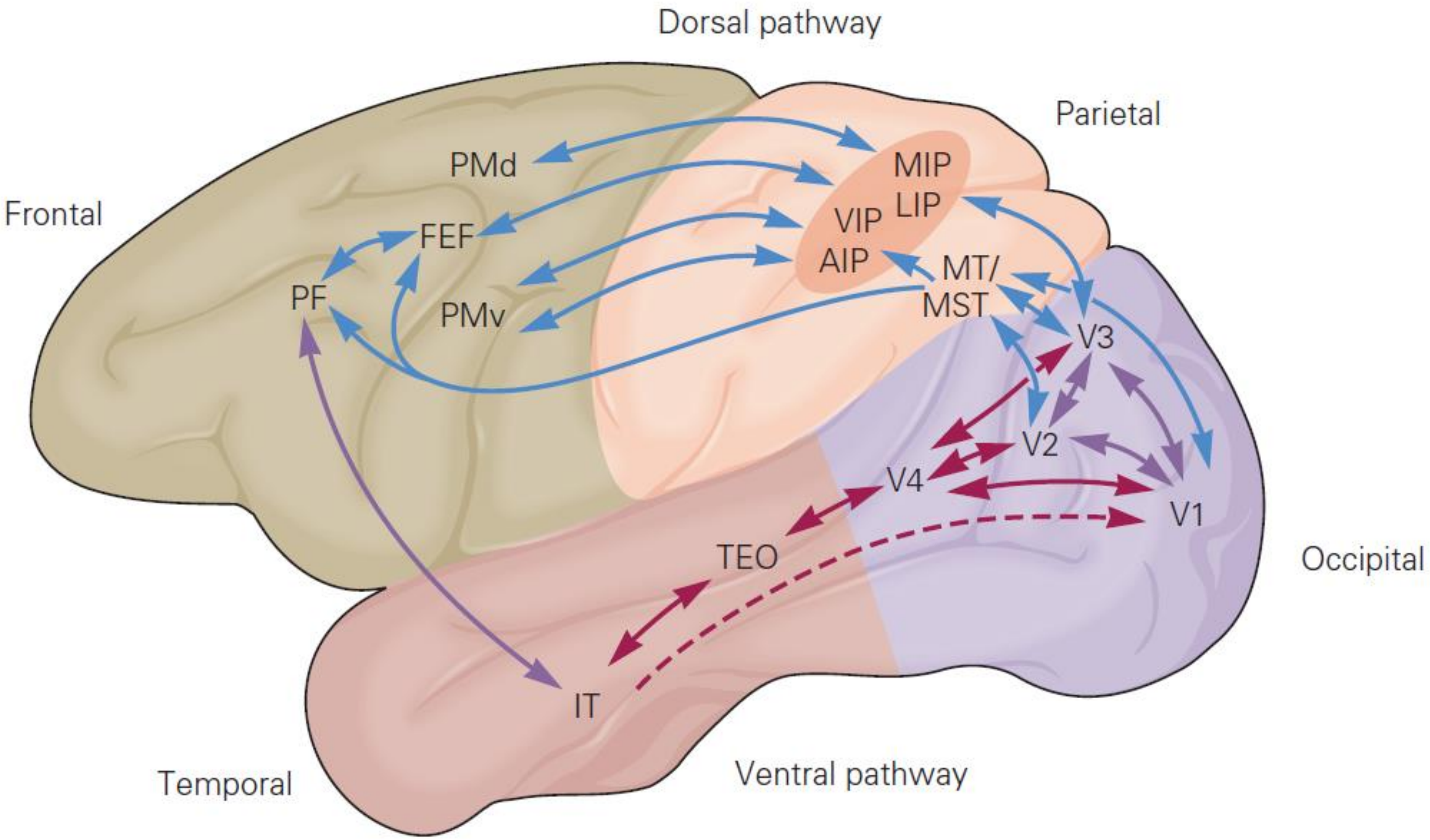
Interaural time differences **localize** sound sources in the horizontal plane.



Convergent connections allow cortical neurons to abstract complex information from simple patterns



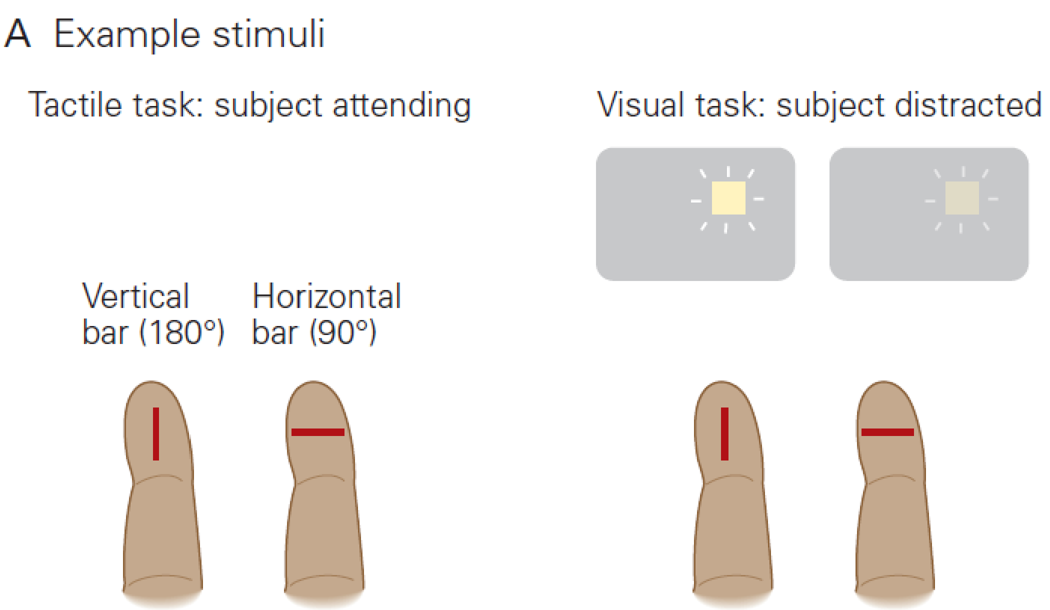
Visual stimuli are processed by serial and parallel networks in the cerebral cortex



Attention to a stimulus enhances the responses of a neuron in the **secondary somatosensory cortex**

When we pay attention to a stimulus we are **selecting certain sensory** inputs for cognitive processing, **and ignoring or suppressing other information**.

- The animal was required to indicate whether the **orientations** of the bars were the same or different.
- In the visual task the animal had to detect a change in the brightness of a square **while the bars were pressed** against its fingertips



Effect of attention