

Principles of Organization of Sensory Systems

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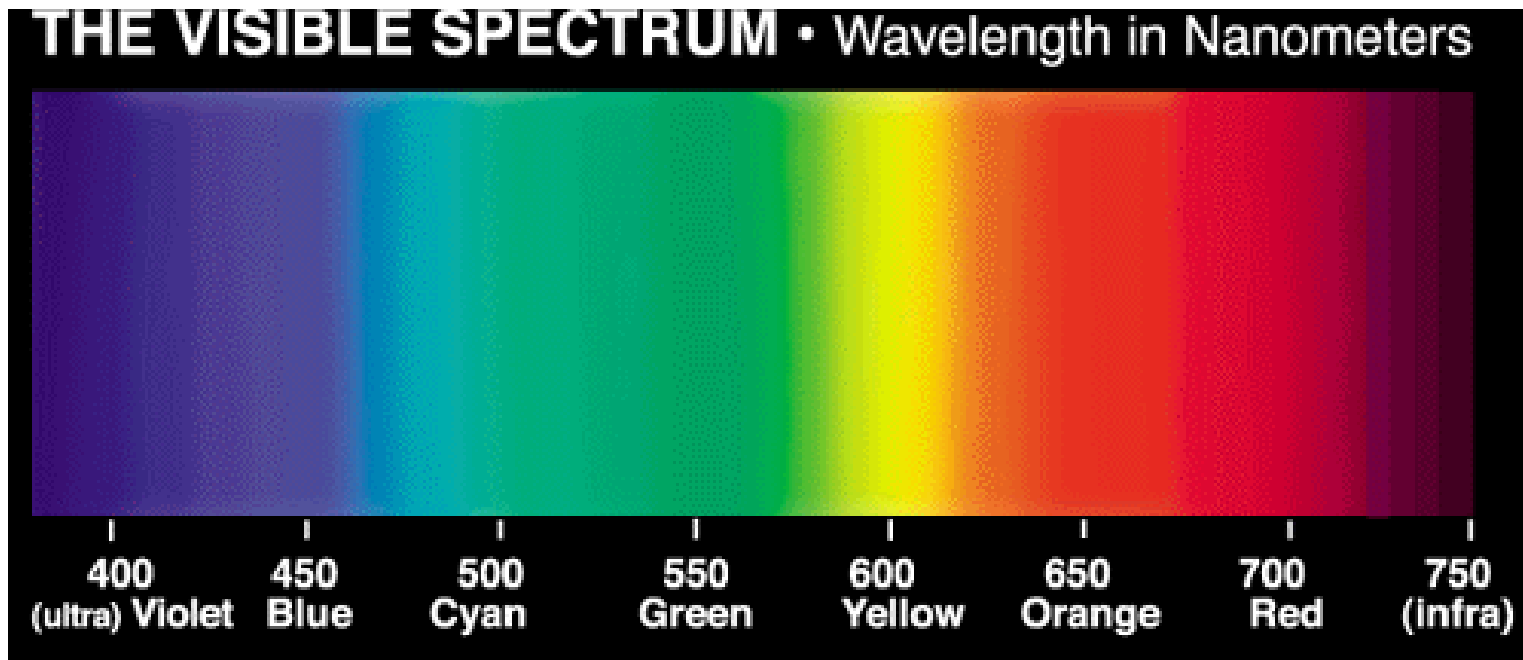
Sensory systems, Conscious senses (perceptions)

- All sensory information are not inherent characteristics of the world around us,
- but: *mental constructions created by the central nervous system of living beings based on their sensory experience,*
- *and this is created by “retrieving” of selected (and limited) number of information from physical stimuli.*



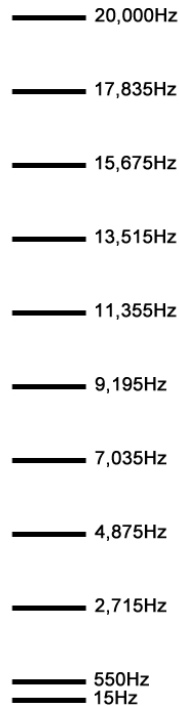
Color Vision

- Color is subjective experience tied to the spectral composition of the light

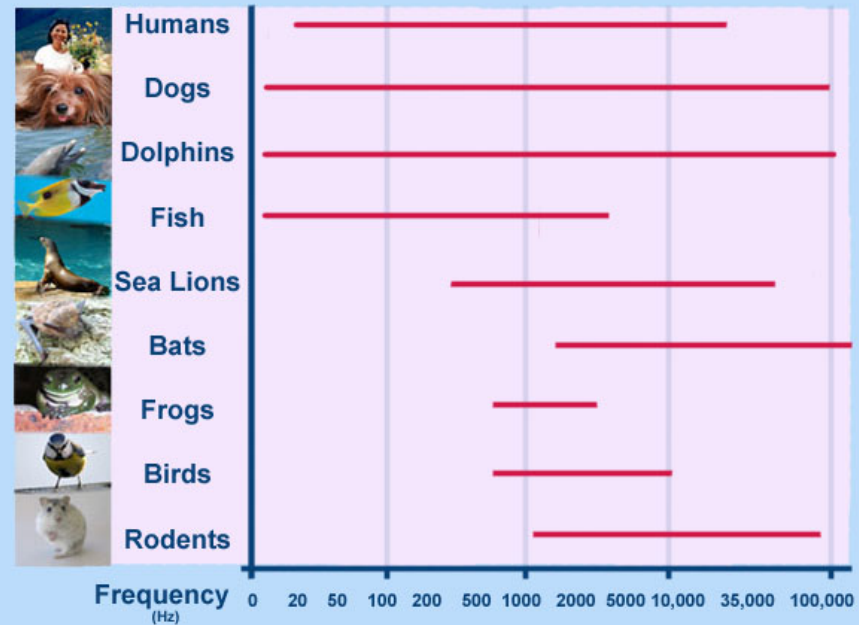


Hearing

Human Hearing
Frequency Range: 15Hz - 20,000Hz



Hearing Ranges of Various Species



Sensory processes

Three events are common characteristics of all sensory processes:

- 1) apparence of adequate **physical stimulus**,
- 2) processes that **convert** information contained in physical stimulus into information encoded by **neural signals**,
- 3) apparence of specific **body response** to the message as conscious sense (**perception**).



Sensory processes

- **Psychophysics**

Studying quantitative **characteristics** of physical stimuli and their relationships with **psychologic** characteristics of sensory experience.

- **Physiology of the senses**

Studying the **neural** consequences of stimuli, or the way how the stimulus is **converted** into neural signals and the mechanisms of further **processing** of those signals **in the brain**.



All sensory systems are organized by the same general plan

- Sensory receptors convert the energy of physical stimulus into **neural impulses**, which travel to the brain as **action potentials** of primary afferent fibers.
- All sensory systems have similar organization: initial touch with physical world is enabled by **sensory receptors**, and each receptor is sensitive to special forms of physical energy:
 - (mechanical, termical, chemical, electromagnetic).



All sensory systems are organized by the same general plan

- Receptor is translating the energy of stimuli in electrochemical energy of ***receptor and action potentials***.
- All sensory systems “*speak using the same language*”.
- This process is called stimulus transduction.



Action potential

- When amplitude of the receptor potential reaches the threshold of that cell, the action potential is generated.
- Action potentials are encoding information about those stimuli and then travel to the central nervous system.
- Therefore, stimulus information is represented by **series of action potentials**:

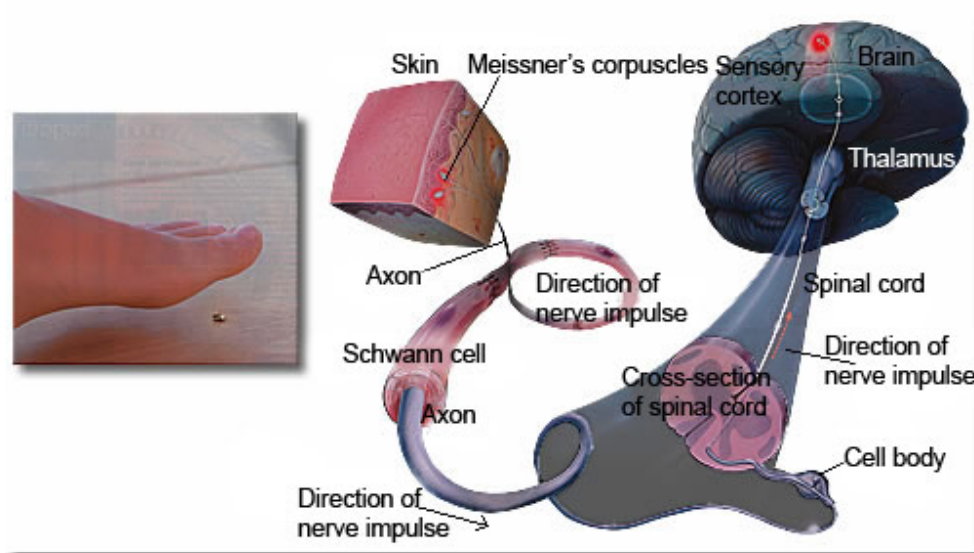
Process of **neural encoding**



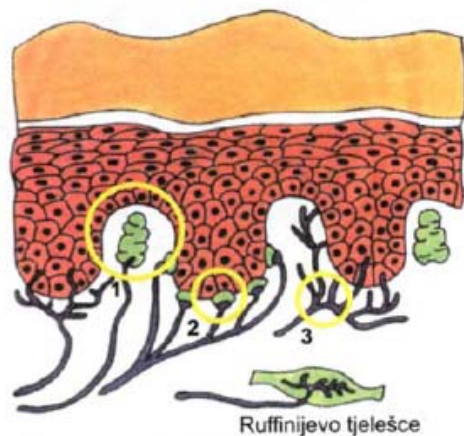
Different sensory systems

- In somatosensory and olfactory systems, the receptor cell is a neuron in which axon the action potentials are generated.

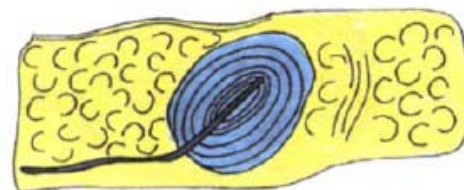
Somatosensory and olfactory receptors have double functions: **stimulus translation** and **neural encoding**.



BEZDLAKA KOŽA



Ruffinijevo tjelešće



Pacinijevo tjelešće

DLAKAVA KOŽA

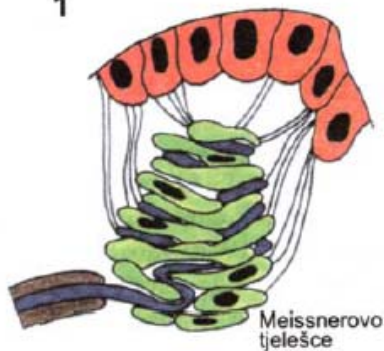


EPIDERMIS

DERMIS

SUBCUTIS

1



2

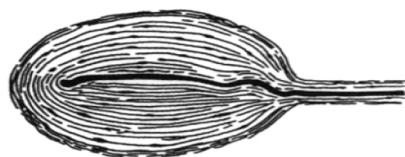


3



Slika 22-4. Glavne vrste kožnih mehanoreceptora i razlika slobodnih živčanih završetaka i učajurenih završetaka. Ti su receptori potanko opisani u 23. i 24. poglavlju. Termoreceptori i nociceptori su slobodni živčani završeci, a glavne vrste učajurenih mehanoreceptora su Pacinijeva, Meissnerova i Ruffinijeva tjelešća, te Merkelove stanice i Merkelove ploče. Posebna vrsta mehanoreceptora su receptori oko folikula dlake. Uočite da bezdlaka i dlakava koža nemaju jednake vrste mehanoreceptora. Nacrtno, uz izmjene, prema Brodal (1992).



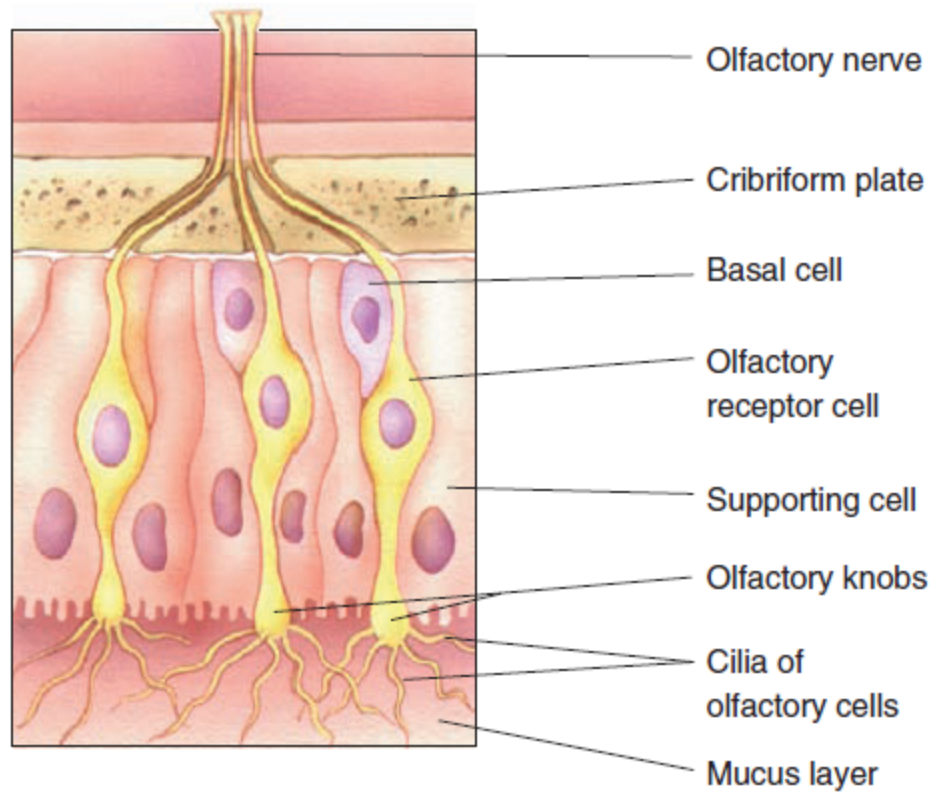


Slika 22-5. Pacinijevo tjelešce je najpoznatiji primjer ućahurenog osjetnog završetka. Periferni završetak primarnog osjetnog aksona završava usred ćahure sastavljene od niza koncentričnih slojeva posebnih epitelnih stanica.

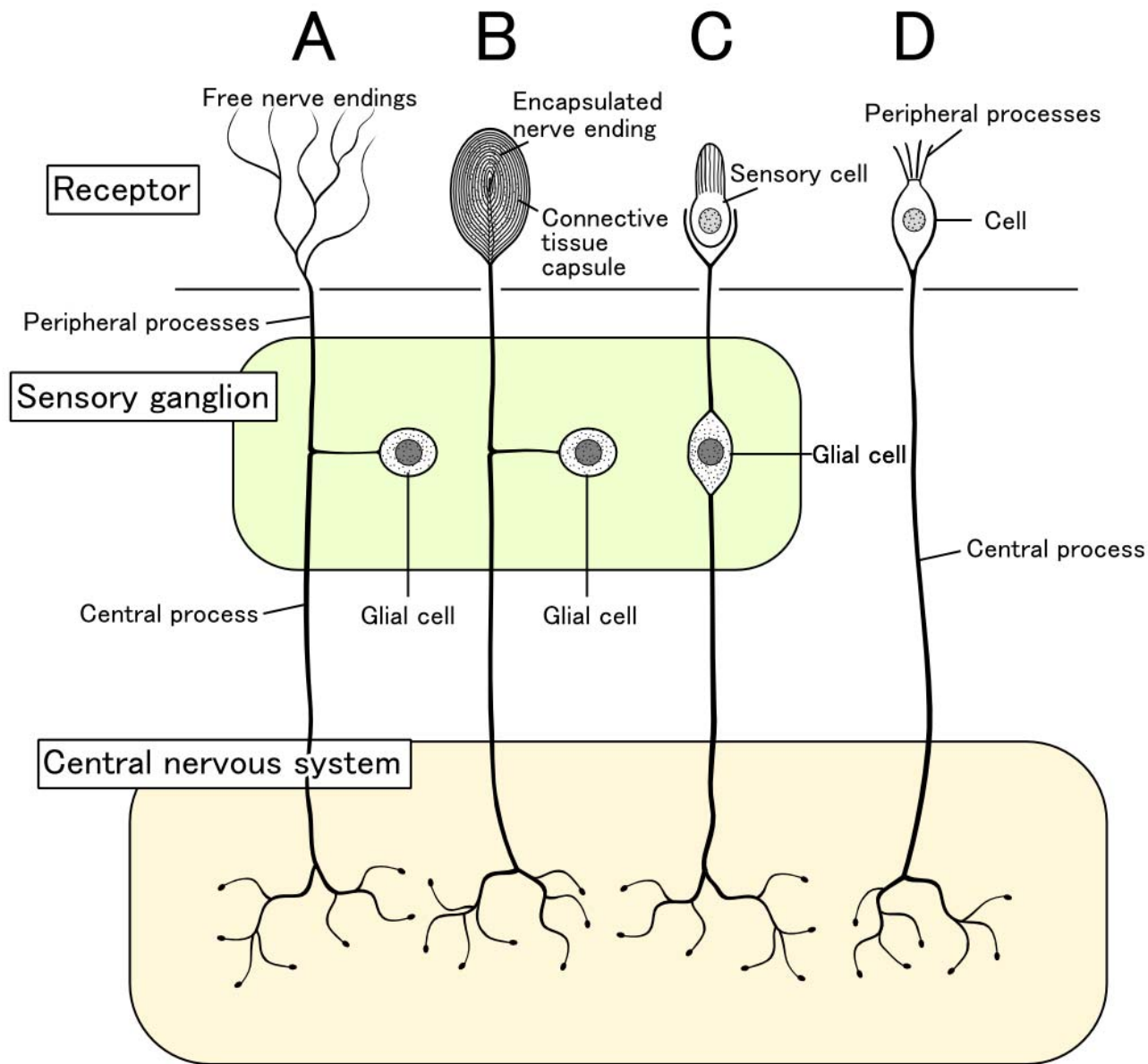
TABLE 15–2 Mechanoreceptors

Mechanoreceptor Type Receptor	Function	
Cutaneous and subcutaneous: involved in touch, pressure, and vibration	Meissner's corpuscle (low-threshold, rapidly adapting); found in glabrous skin	Touch, vibration below 100 Hz
	Merkel's receptor (low-threshold, slowly adapting); found in glabrous skin	Pressure
	Pacinian corpuscle* (low-threshold, rapidly adapting); found in both hairy and glabrous skin	Rapid indentation of skin, e.g., the sensation caused by a high frequency vibration (100–400 Hz)
	Ruffini's corpuscle (low-threshold, slowly adapting); found in both hairy and glabrous skin	Magnitude and direction of stretch
Muscle mechanoreceptors	Muscle spindles	Limb proprioception
	Golgi tendon organ	Limb proprioception

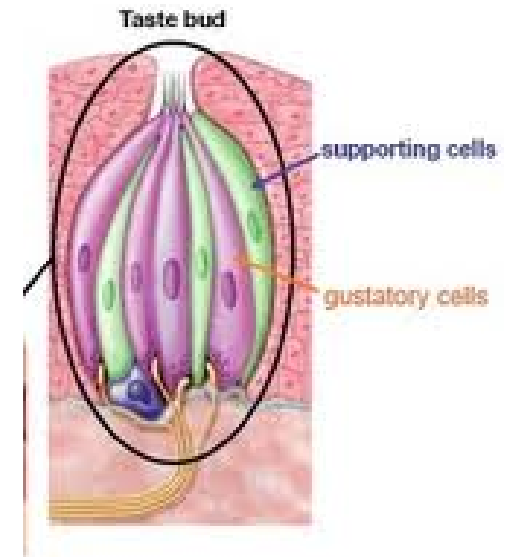
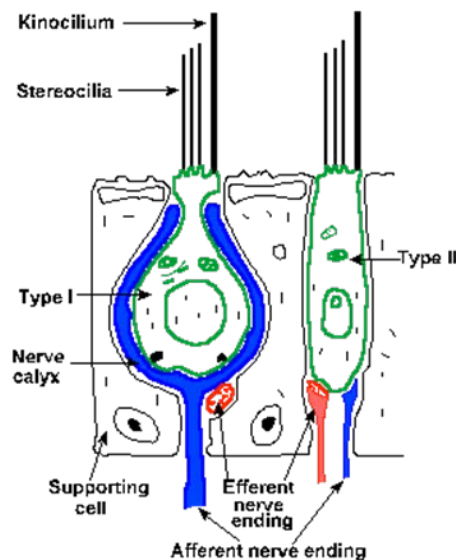
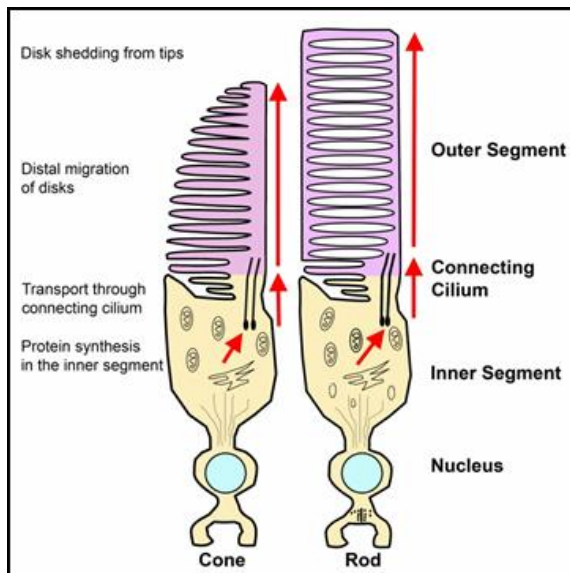
*Pacinian corpuscle is also present in the mesentery.



B

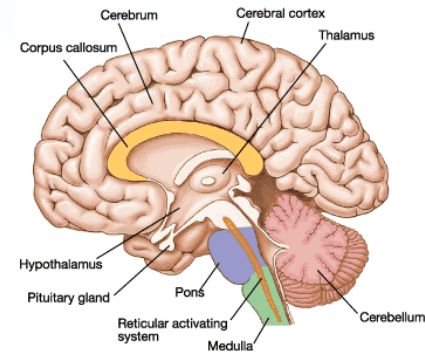


- In gustatory, visual, auditory and vestibular systems, those functions are performed by separate cells:
 - stimulus translation is done by sensory receptors, and
 - neural encoding is done by primary sensory neurons which are in direct touch with receptor cells.



Thalamus – relay nuclei

- Key relay structure in processing of sensory information is thalamus:
- Practically all sensory pathways which convey sensory information to cortex first switch in thalamus.
- Thalamic neurons of all sensory systems project in a specific primary sensory area in cortex.
- An exception: olfactory system (smell)



Cerebral cortex

- Sensory areas in cerebral cortex have key roles in perception,
- It is the most obvious on example of primary visual cortex:
- When this cortical area is injured/damaged the patient is blind.



Characteristics of sensory systems

- Sensory receptors from physical stimulus “draw” 4 key characteristics:
 - 1) modality (quality, type),
 - 2) intensity (strength),
 - 3) duration,
 - 4) location (in space or in our body).
- CNS is combining them into senses (sensatio);
- When we are aware of these senses, then we say it was our conscious **notion** (perception) – **sensation is converted into perception by our brains.**

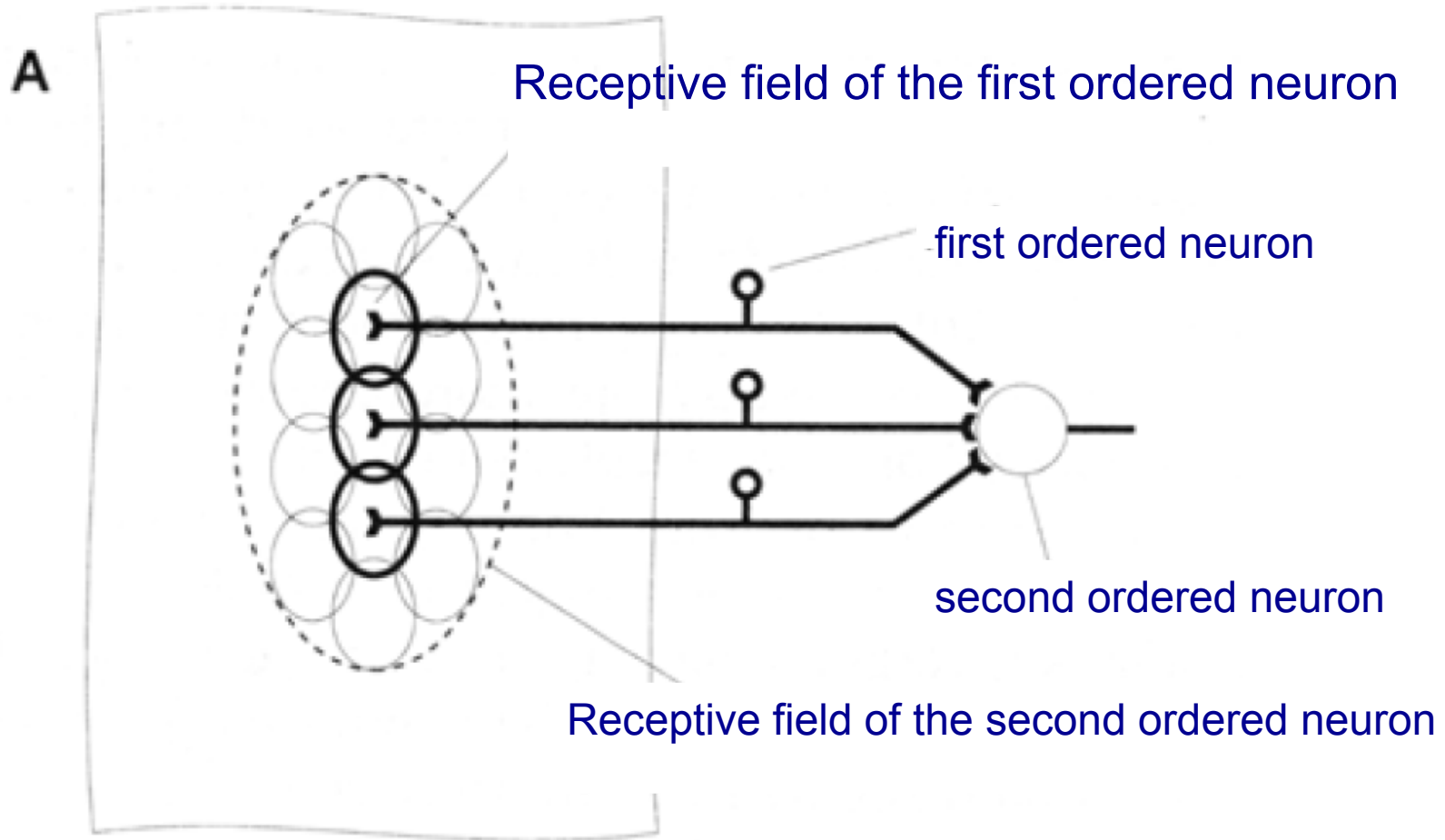




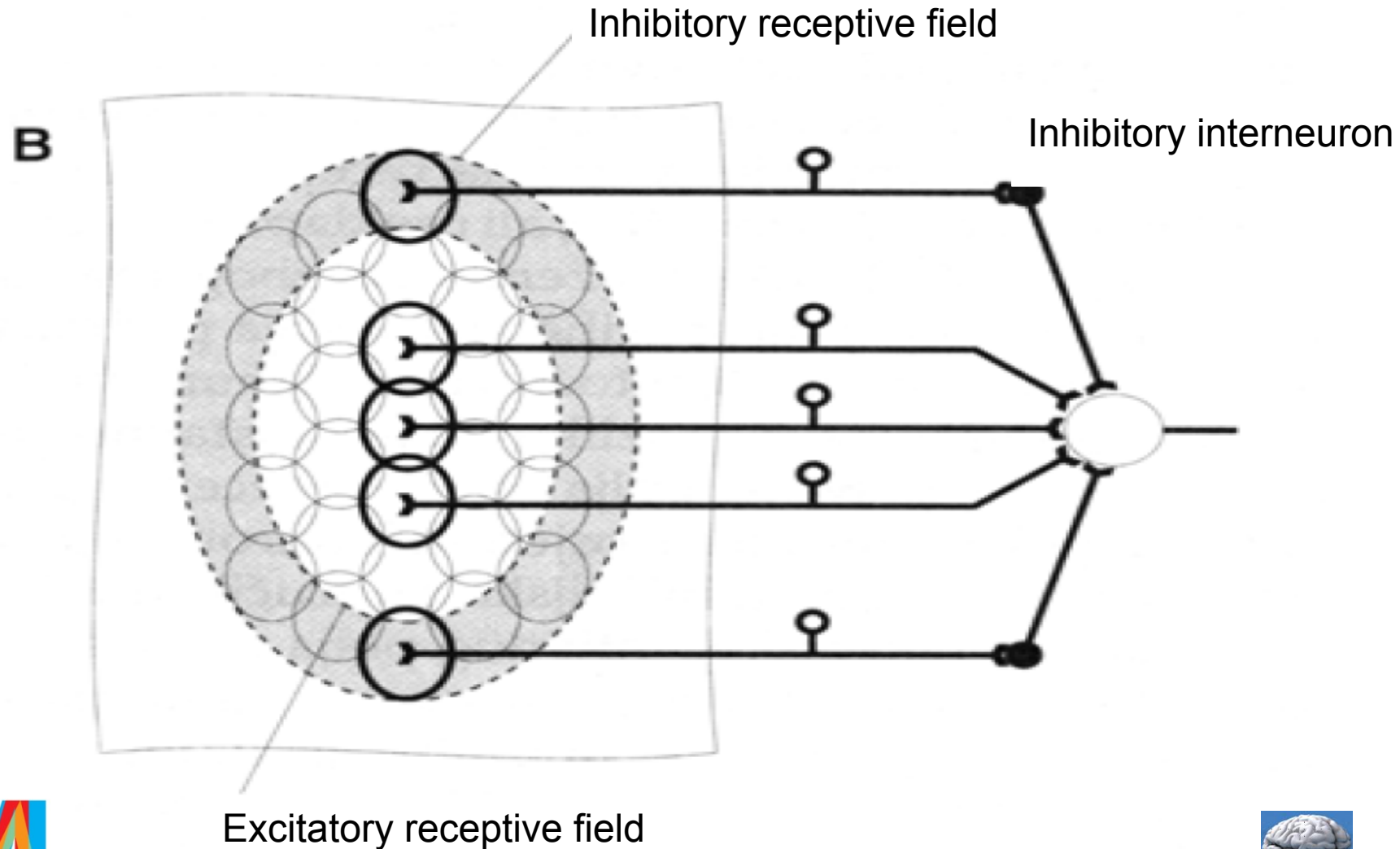
Receptive Field

The space in which the sensory receptor is located and where it produces the transduction of the stimuli is called the **receptive field** of the receptor.

Receptive field



Receptive field



Smell and Taste

Chemical Senses



Filogenetically very old:

- Many lower animals rely only on those two senses
- Perform many vital functions
 - e.g., feeding,
 - mating,
 - avoiding predators.
- Smell and Taste systems have very few common characteristics
- But both start with *chemoreceptors*



Olfaction in different animals

Macrosmatic - animals with powerfully developed sense of smell (dogs, cats, rats)

Microsmatic - animals with poorly developed sense of smell (dolphins, whales, human)



Olfactory system - Smell

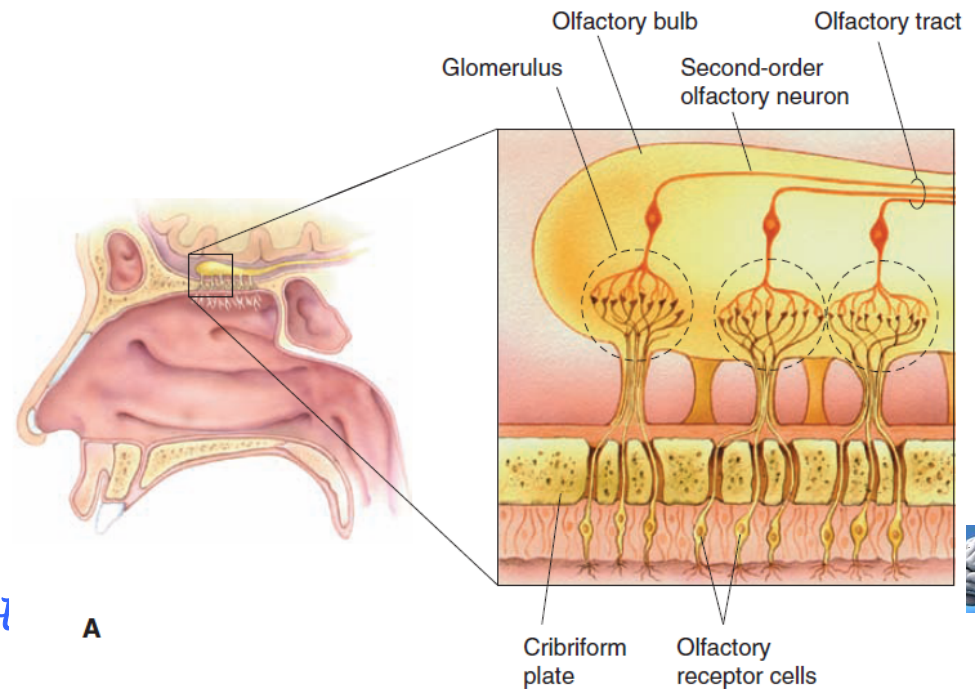
The olfactory system includes:


- olfactory part of nasal mucosa,
- olfactory nerves, and
- olfactory areas of the central nervous system.



Olfactory system – 4 unique characteristics

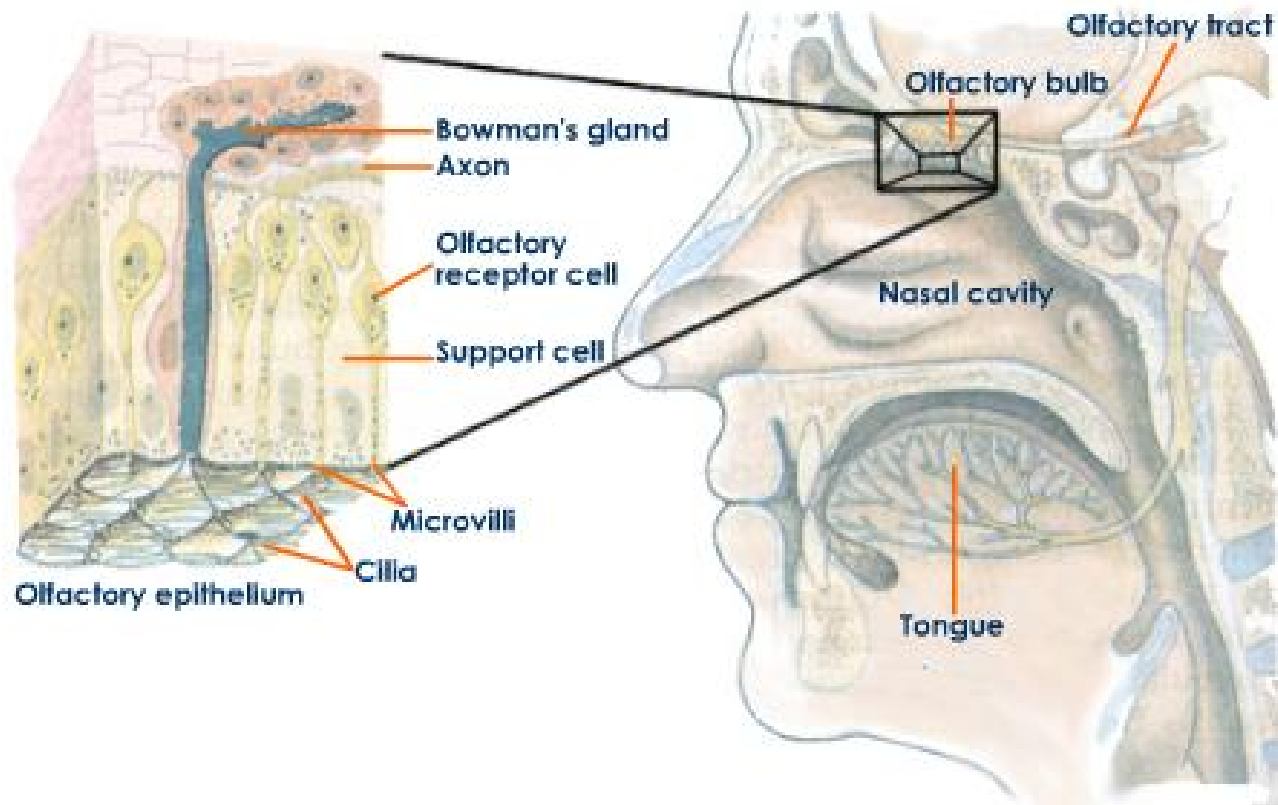
1. Bodies of primary afferent neurons are *NOT* in a sensory ganglion, but *in sensory epithelium* of specific parts of nasal mucosa of the nasal cavity just below a thin sheet of bone called the **cribriform plate of the ethmoid bone of the skull**.



- 
- 2. Axons of primary afferent neurons *directly* enter the primitive brain cortex (olfactory bulb); there are no subcortical secondary sensory neurons;
 - 3. Primary afferent neurons constantly *die*, being replaced by new primary neurons;
 - 4. Whole olfactory pathway (up to associative olfactory areas of the frontal cortex) is completely *ipsilateral*.

Olfactory epithelium

Upper one fifth of lateral and septal wall of nasal cavity



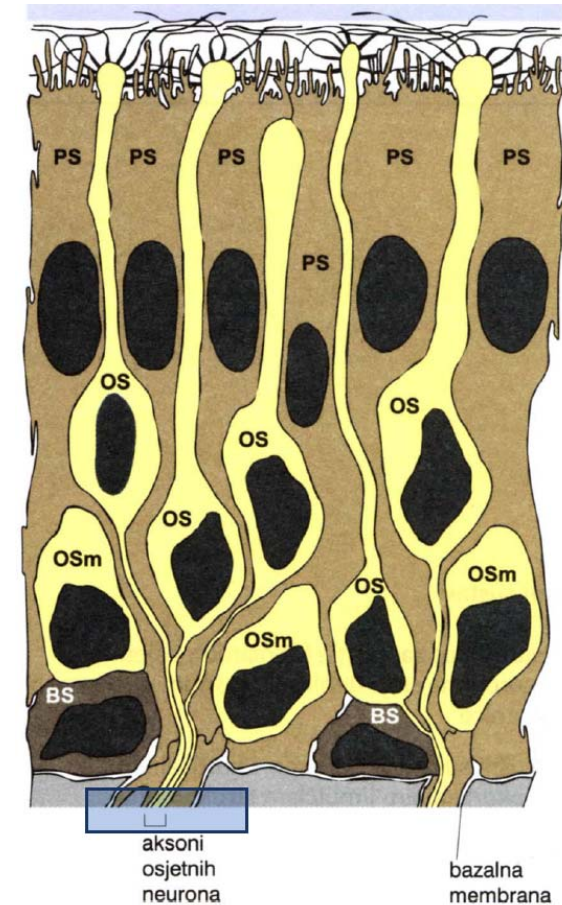
Olfactory epithelium

Contains three types of cells:

- Sensory cells, primary afferent olfactory neurons,
- Supporting cells,
- Basal cells,
- (Brush cells).

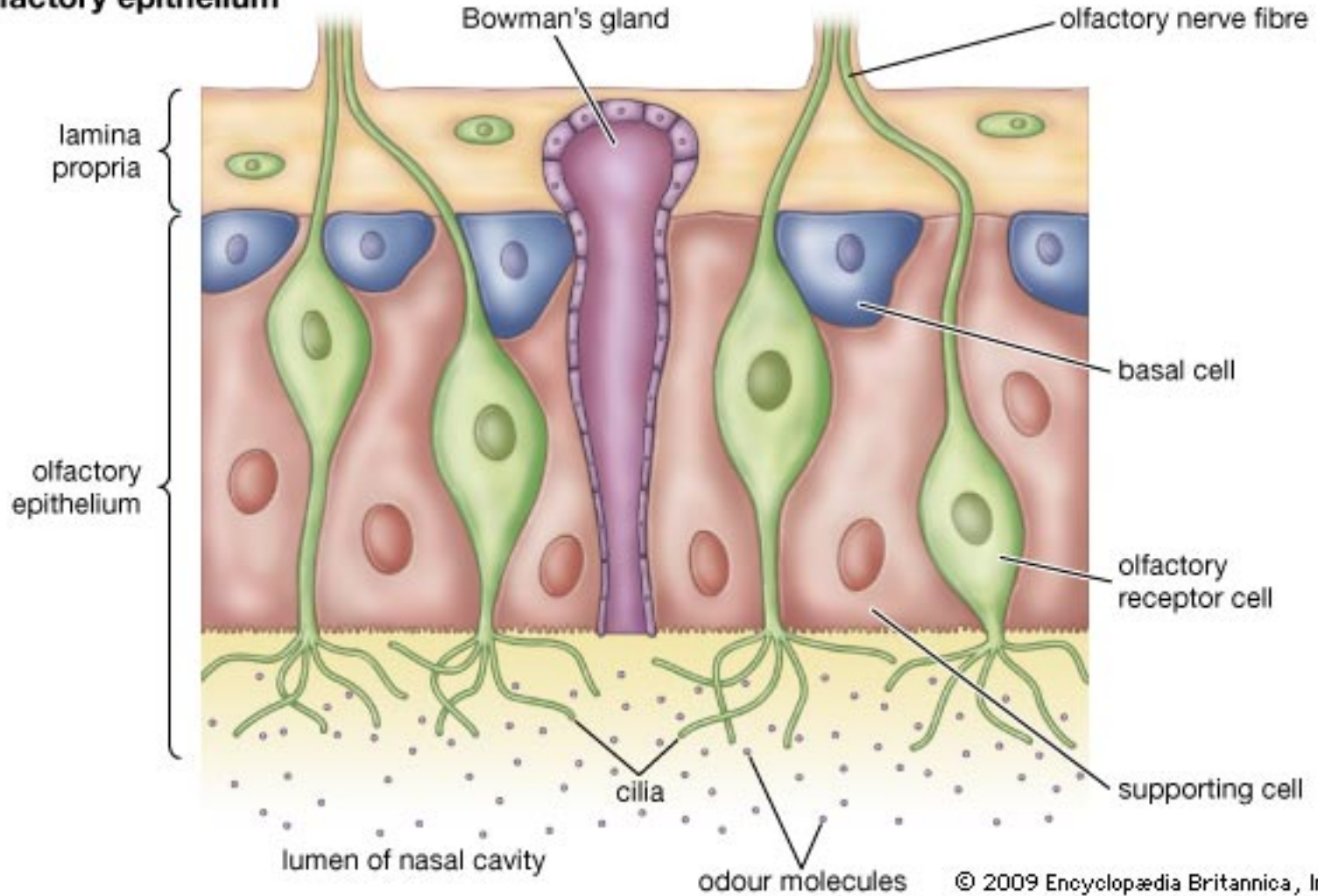
Surface of olfactory mucosa in man: 2-5 cm², in dogs: 100 cm²

man - microsmatic, dog - macrosmatic



Olfactory epithelium

Olfactory epithelium



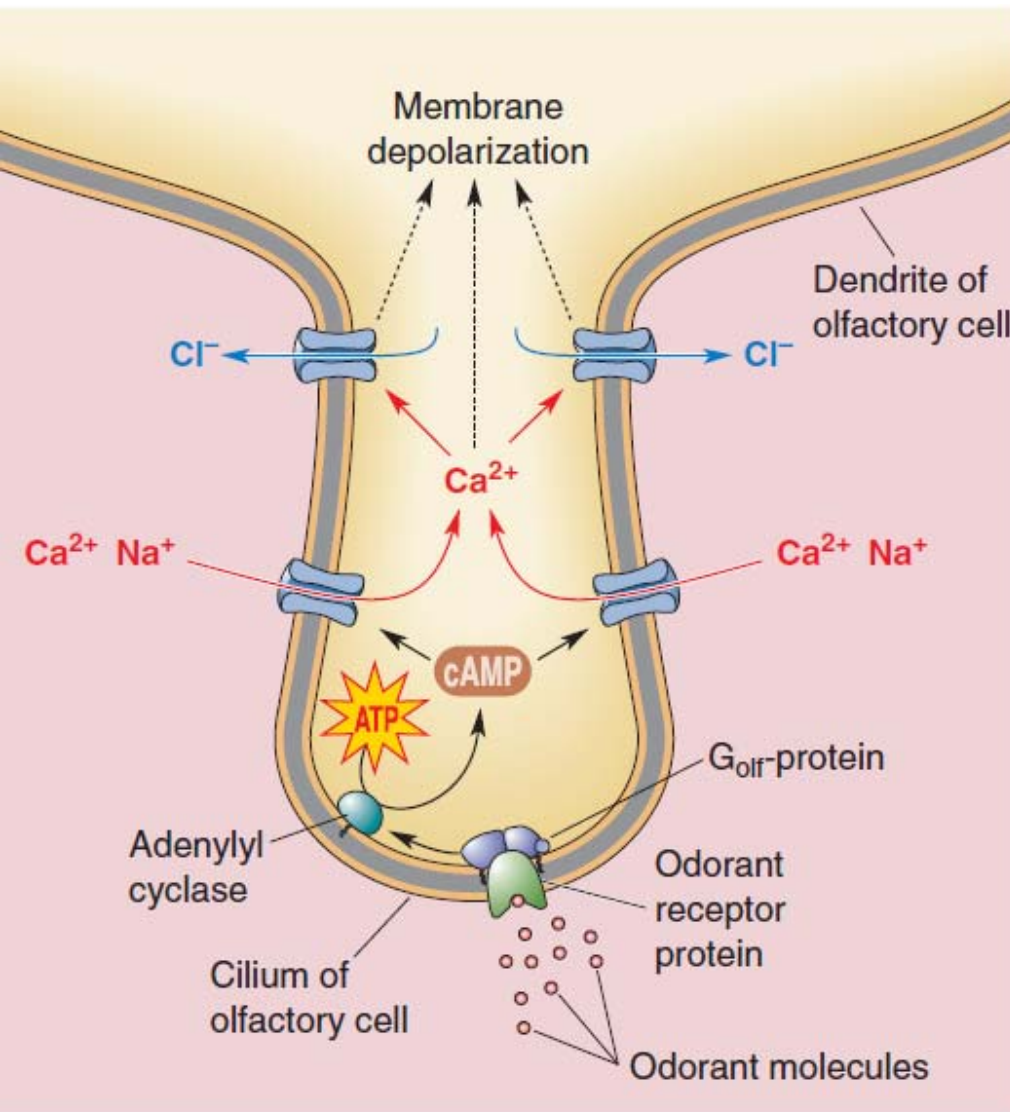
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Sensory Transduction

1. A protein, called **olfactory binding protein**, is **secreted by the Bowman's glands**
2. it carries and/or concentrates the odorant (a substance that stimulates olfactory receptors) around the cilia.
- 3. At least two second- messenger systems—cAMP and IP3—are involved in the **transduction** of olfactory signals.



- When an odorant molecule binds to the receptor protein on the cilia, a receptor-odorant complex is formed, which activates a G protein.
- G protein (G_{olf}) combines with GTP
- The GTP-G_{olf} complex activates adenylyl cyclase, leading to the generation of cAMP
- cAMP opens Na⁺ and Ca²⁺ channels
- depolarizing generator potential occurs
- Ca²⁺-gated Cl⁻ channels (efflux)

Primary afferent olfactory neurons

Bipolar

In mucosa, not in a ganglion

Around 6 millions (3 millions per side)

Axons form more than 100 fibers (*fila olfactoria*)

They pass via lamina cribrosa of ethmoidal bone into skull

Make synapses in the olfactory bulb

All *fila olfactoria* together make *nervus olfactorius*, the only peripheral nerve directly connected to telencephalon.



Dendrites of primary olfactory neurons

They reach surface of olfactory epithelium.

On top of each dendrite:

Around 10 do 20 imobile and long *cilia*

Cilia contain olfactory receptor molecules.

They are intermingled throughout the superficial layer of the epithelium.



Cilia contain olfactory receptor molecules

Special olfactory protein, OBP (engl. odorant binding protein = protein that binds odorant molecules)

High affinity for binding odorant molecules

OBP is secreted by Bowman's glands which deliver a proteinaceous secretion via ducts onto the surface of the mucosa. The role of the secretions are to trap and dissolve odiferous substances for the bipolar neurons).



Function of OBP is not well understood.

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Olfactory epithelium

Supporting cells are located around sensory bipolar neurons and create olfactory mucosa with them.

Basal cells serve as a replacement or to create new sensory neurons.

In monkey (probably in man, as well), sensory bipolar neurons live for about a month and then die.

They are replaced by the new neurons developed from the basal cells.



Olfactory receptors

We better understand the intracellular mechanisms than receptors themselves.

Olfactory receptors work as metabotropic receptors.

Key role for the special trimer G-protein, Golf

Activation of adenilil cyclase (AC) and increased synthesis of cAMP in cilia of sensory neurons

Some odorant molecules activate system of inositol phosphate (IP3 and DAG).

Depolarisation of bipolar olf neurons and APs

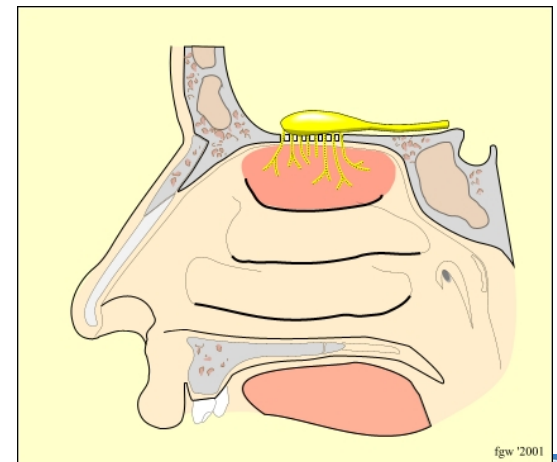
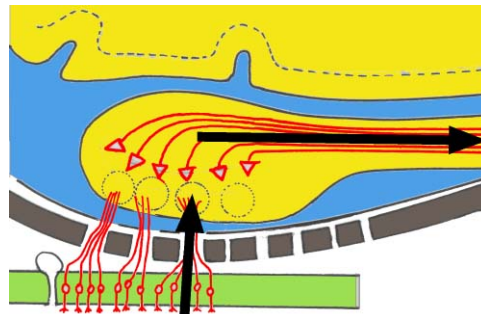


Brain olfactory system

Central part of the brain olfactory system (*rhinencephalon*) is located exclusively in telencephalon.

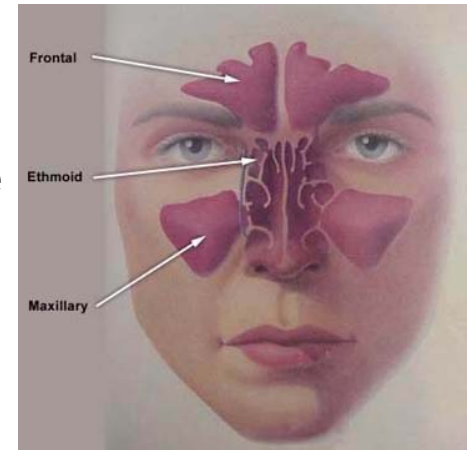
It is composed of: *bulbus olfactorius*, *tractus olfactorius*, *area olfactoria basalis*.

Olfactory bulb (*bulbus olfactorius*) is egg-like structure lying on *lamina cribriformis* of ethmoid bone.

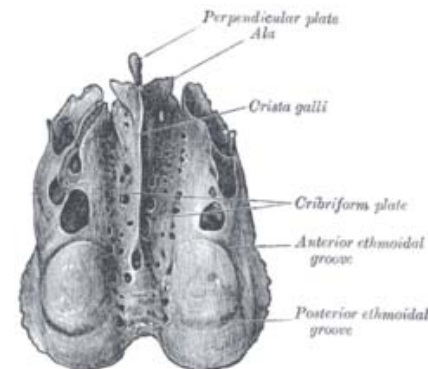
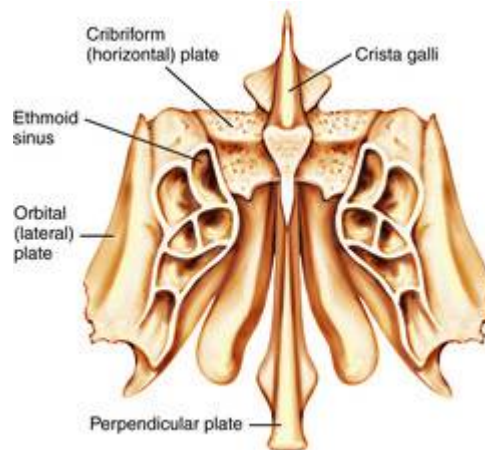


Brain olfactory system

Olfactory bulb (*bulbus olfactorius*) is egg-like structure lying on *lamina cribriformis* of ethmoid bone.



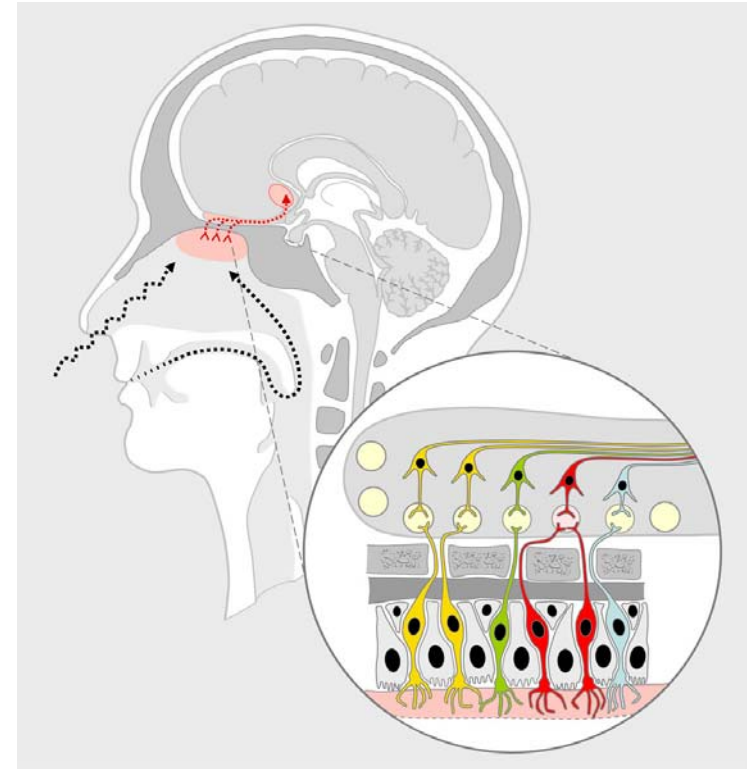
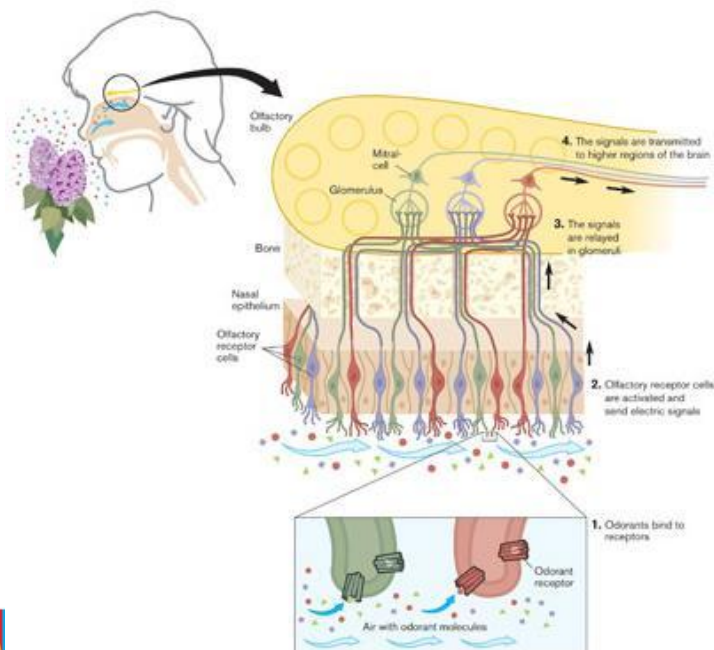
From the nasal cavity, via bone openings in lamina cribriformis, central parts of bipolar olfactory neurons (*fila olfactoria*) enter the skull.



Olfactory bulb

Olfactory bulb (*bulbus olfactorius*) is egg-like structure lying on *lamina cribriformis* of ethmoid bone.

Odorant Receptors and the Organization of the Olfactory System

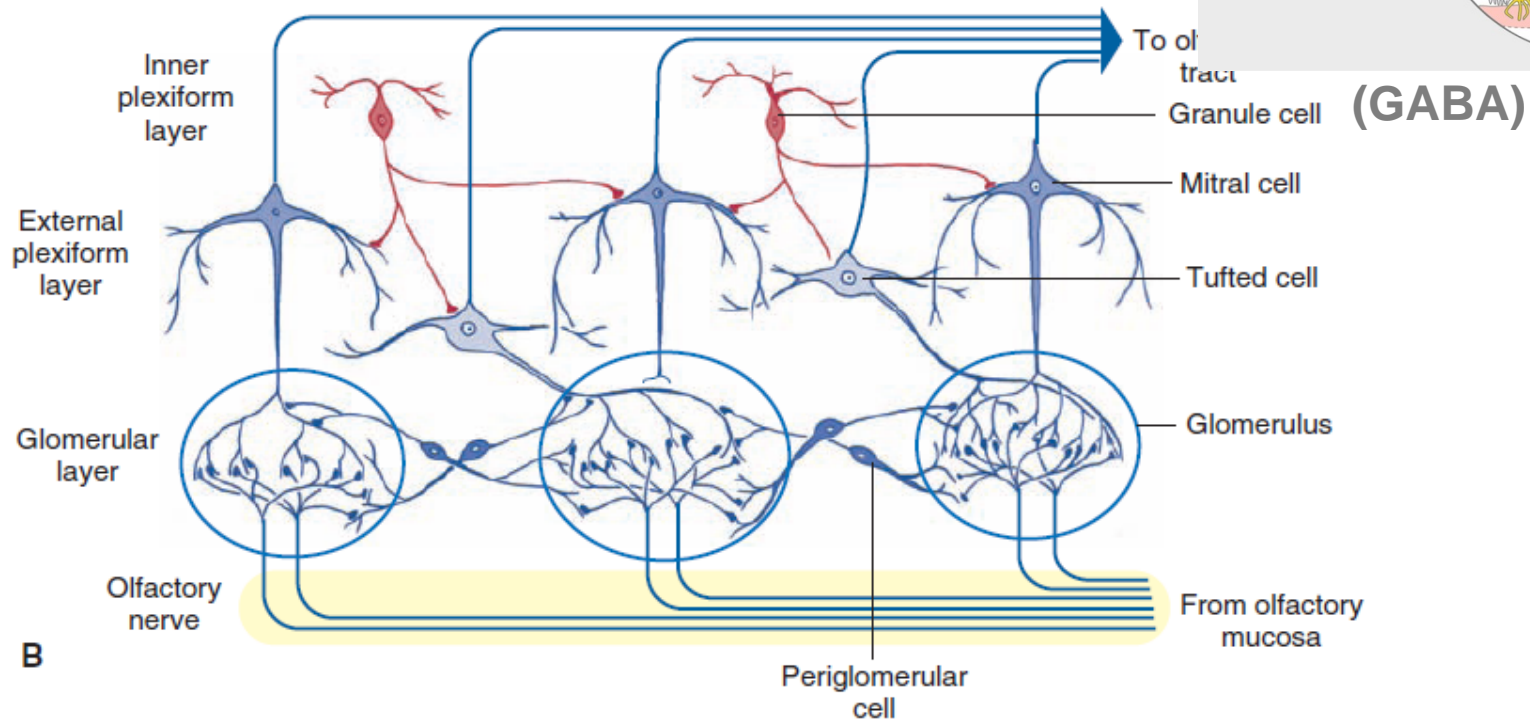
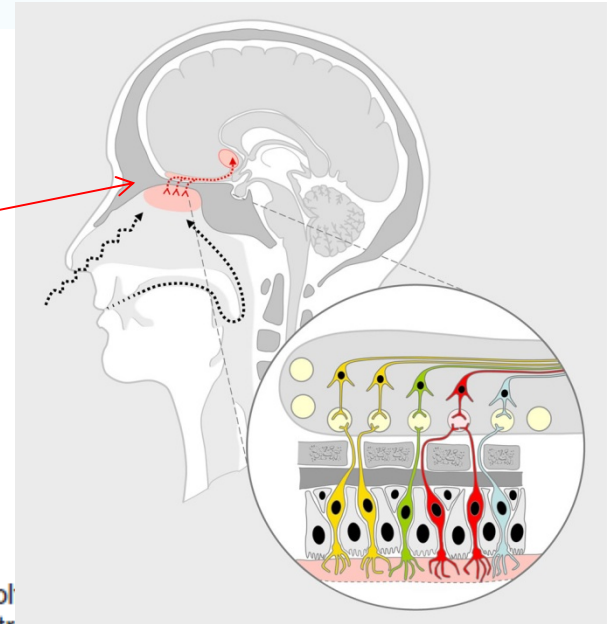


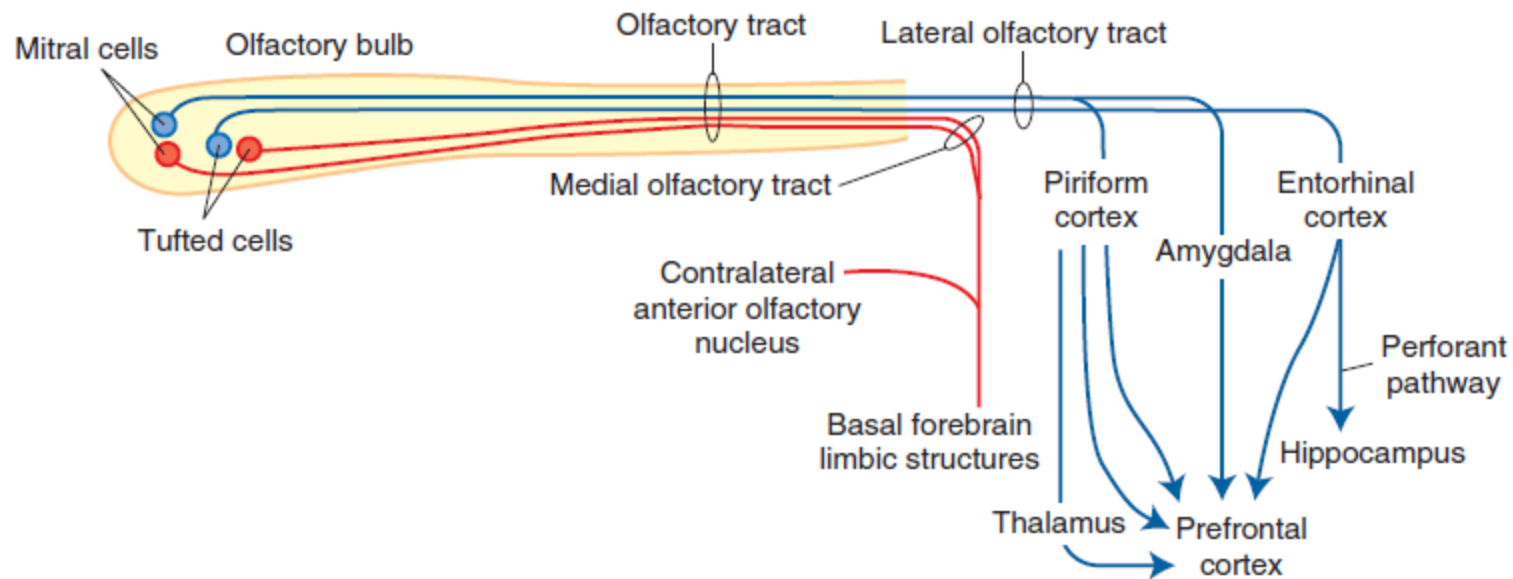
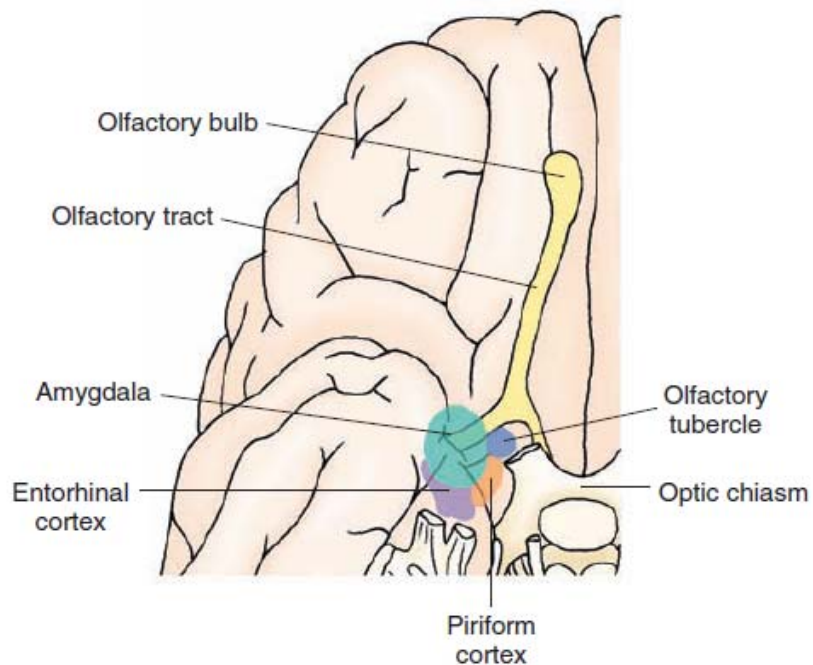
Secondary neurons:
Mitral cells
Tufted cells



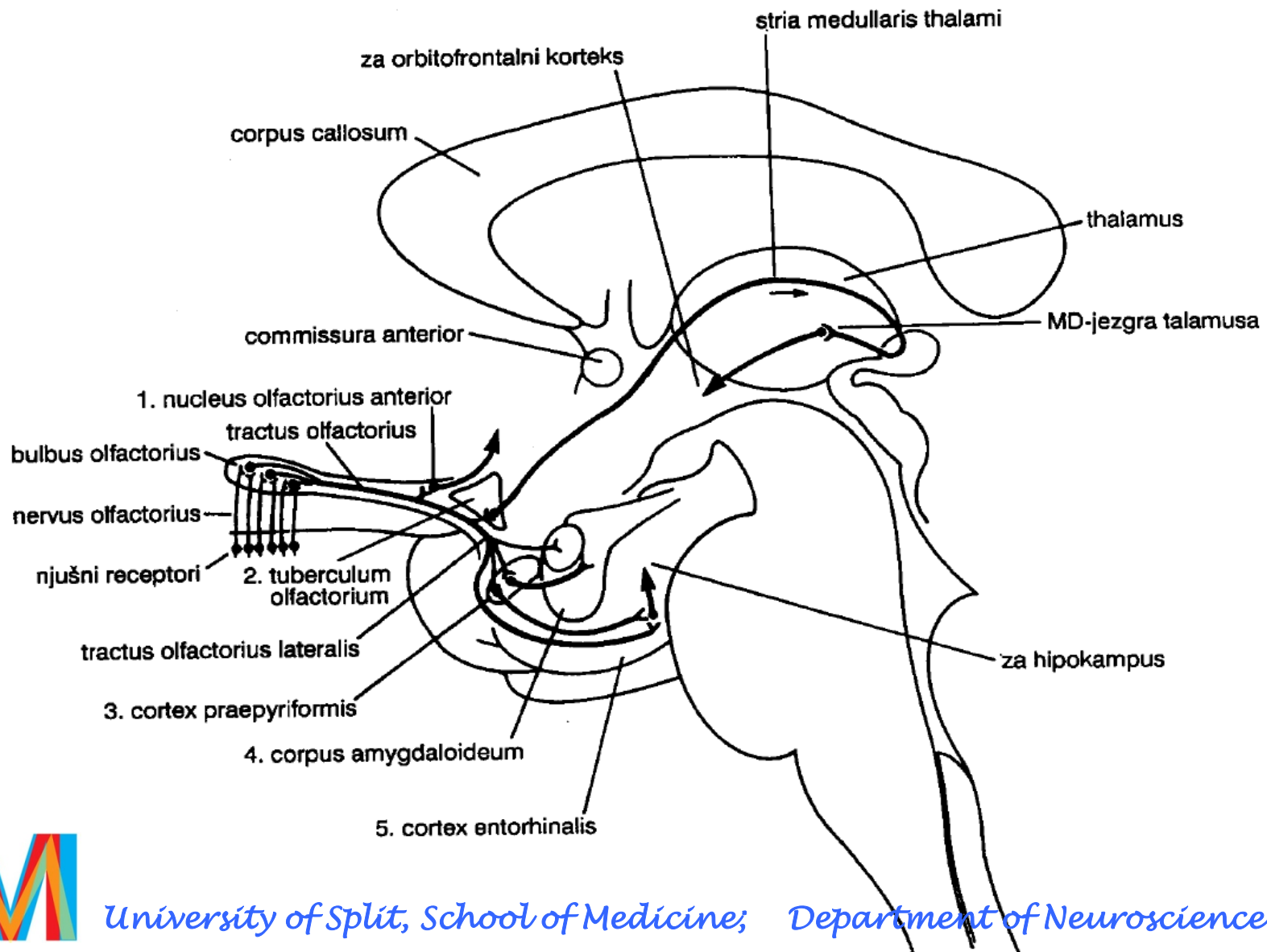
Central Pathways

Olfactory bulb





Olfactory pathway



Olfactory pathway

- Olfactory bulb contains two types of excitatory projection neurons = SECOND NEURONS OF OLFACTORY PATHWAY.
 - a) mitral cells
 - b) tufted cells
- Their axons form olfactory tract – TRACTUS OLFACTORIUS which connects olfactory bulb with the rest of the brain.
- Stria olfactoria is divided on medial and lateral part.



Olfactory pathway

- BASAL OLFACTORY FIELD (area olfactoria basalis) – all areas that receive direct projections from olfactory bulb
 - nucleus olfactorius anterior
 - tuberculum olfactorium
 - cortex praepyriformis
 - cortex periamygdaloideus (w/ nuclues corticalis amygdalae)



Olfactory pathway

From those areas, olfactory information via polysynaptic pathways can reach other brain areas:

- Orbitofrontal cortex
- Thalamus
- Lateral hypothalamus
- Septum
- Brain stem



Olfactory pathway

Orbitofrontal cortex has two fields linked with olfactory system:

centroposterior orbitofrontal cortex
(CPOF = field 13) and

lateroposterior orbitofrontal cortex
(LPOF = posterior part of field 12)



Olfactory pathway

Physiologic experiments showed that:

CPOF has a key role in olfactory (smell)
discrimination

(difference between two olfactory stimuli)



Olfactory pathway

- Olfactory bulb receives numerous **AFFERENT** fibers from:
 - nuclus olfactorius anterior
 - tuberculum olfactorium
 - cortex praepyriformis
 - nuclus diagonalis horizontalis
 - nucleus basalis Meynert, preoptic area, lateral part of hypothalamus
 - locus coeruleus, nucleus raphe dorsalis





Gustatory system - Taste

Four basic submodalities:

***sweet,
bitter,
sour and
salty.***

In everyday life “taste” of food and drink is often thought of as combination of taste and smell (aroma).



Gustatory system - Taste

Taste organs (taste buds) are located on three types of tongue papillas, in 4 distinctive tongue areas.



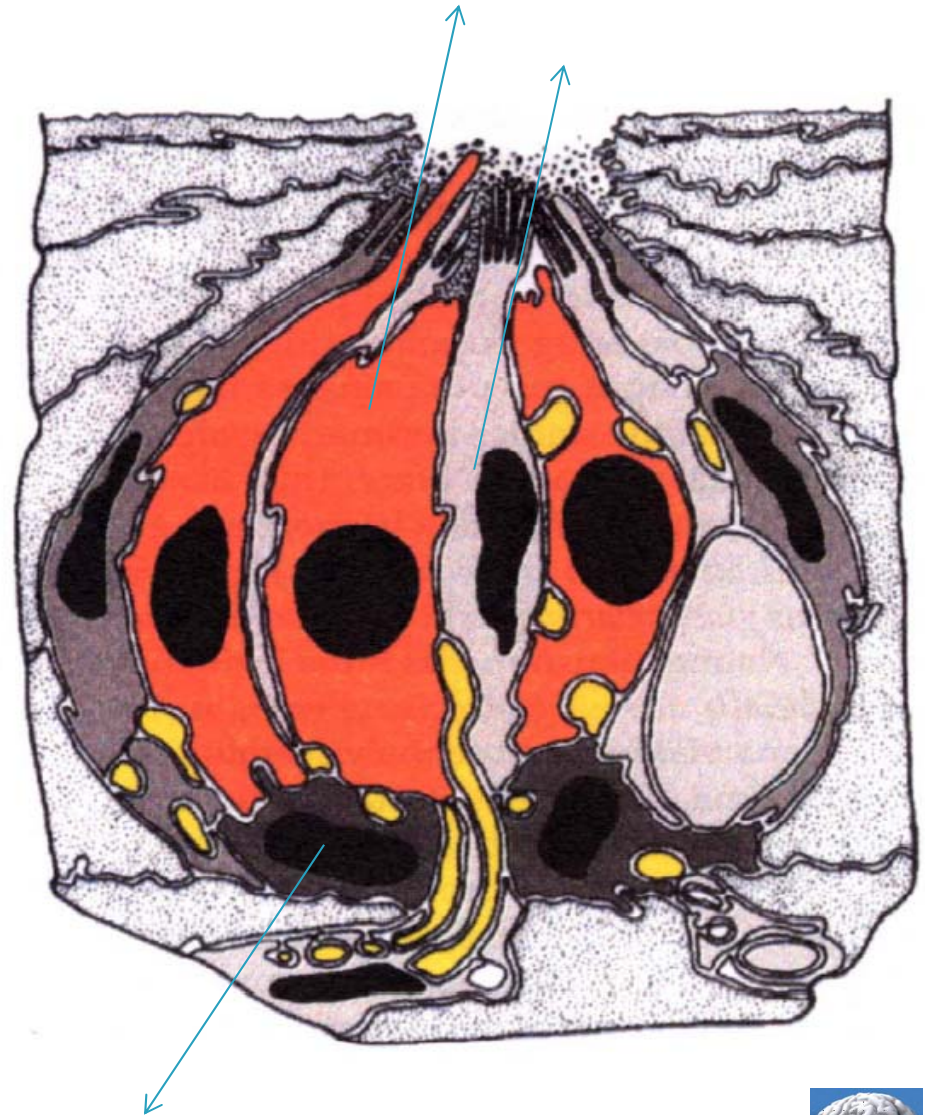
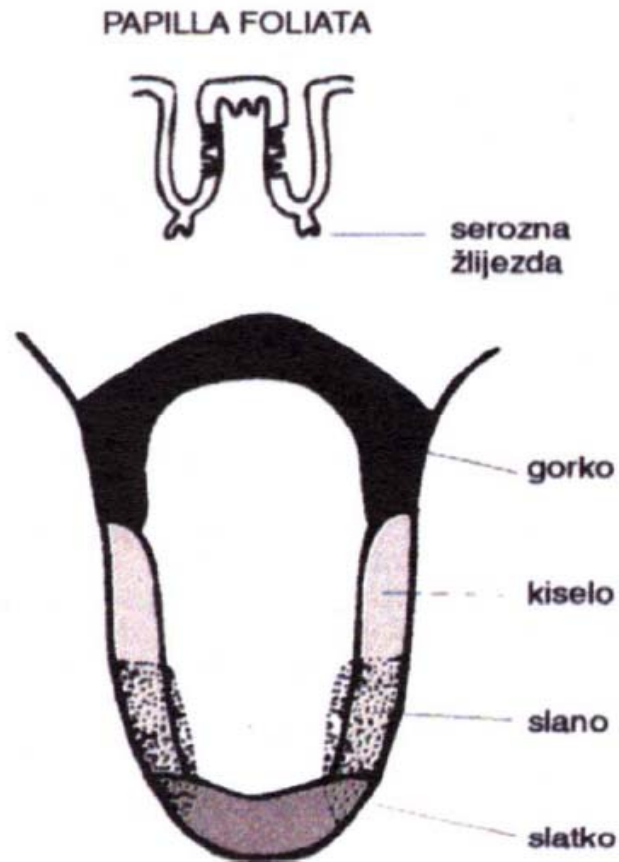
Gustatory system - Taste

Four types of papillas are:

- 1) *Papillae filiformes*
- 2) *Papillae circumvallatae*
- 3) *Papillae fungiformes*
- 4) *Papillae foliatae*



Taste bud



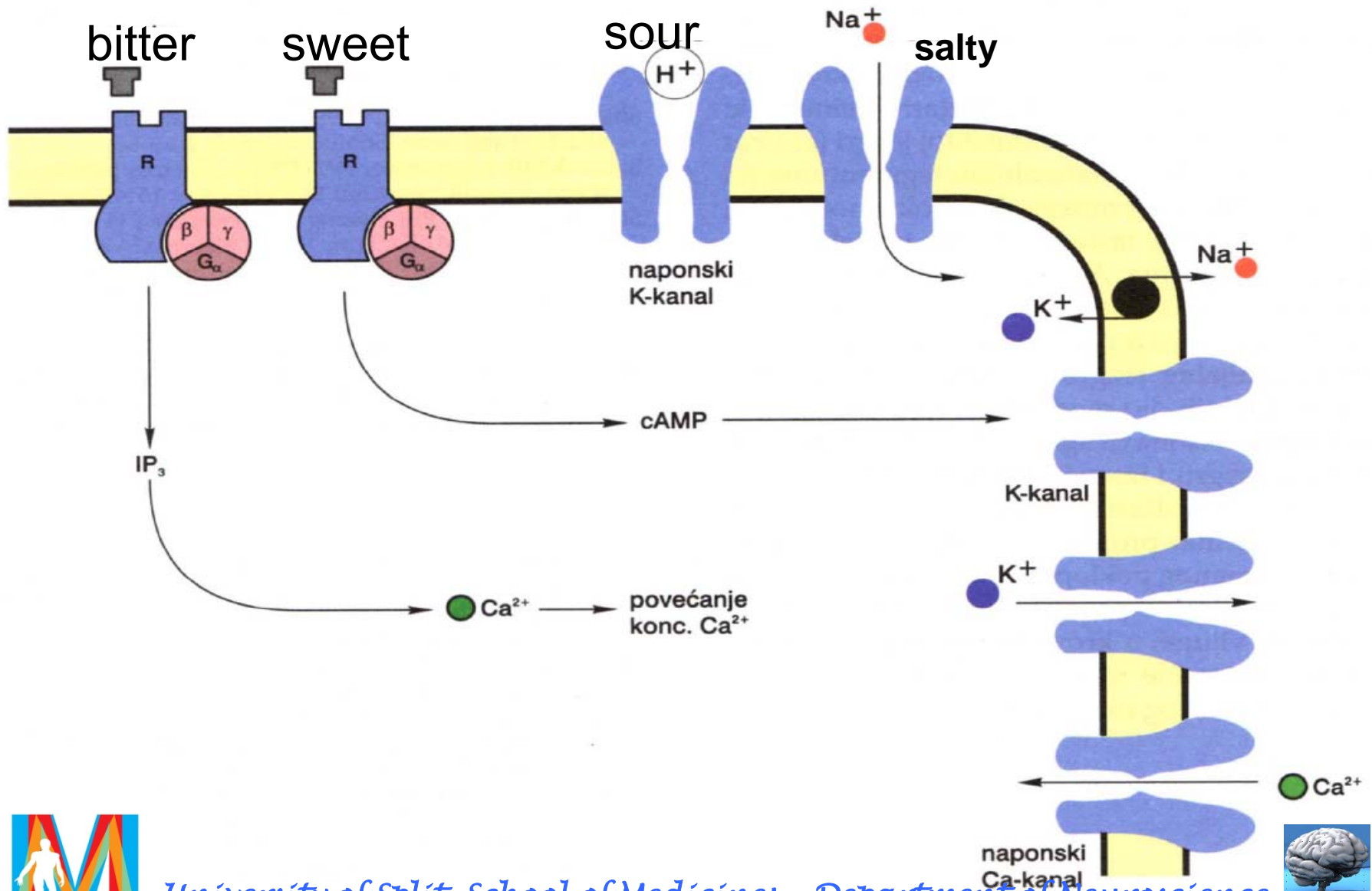
Gustatory system - Taste

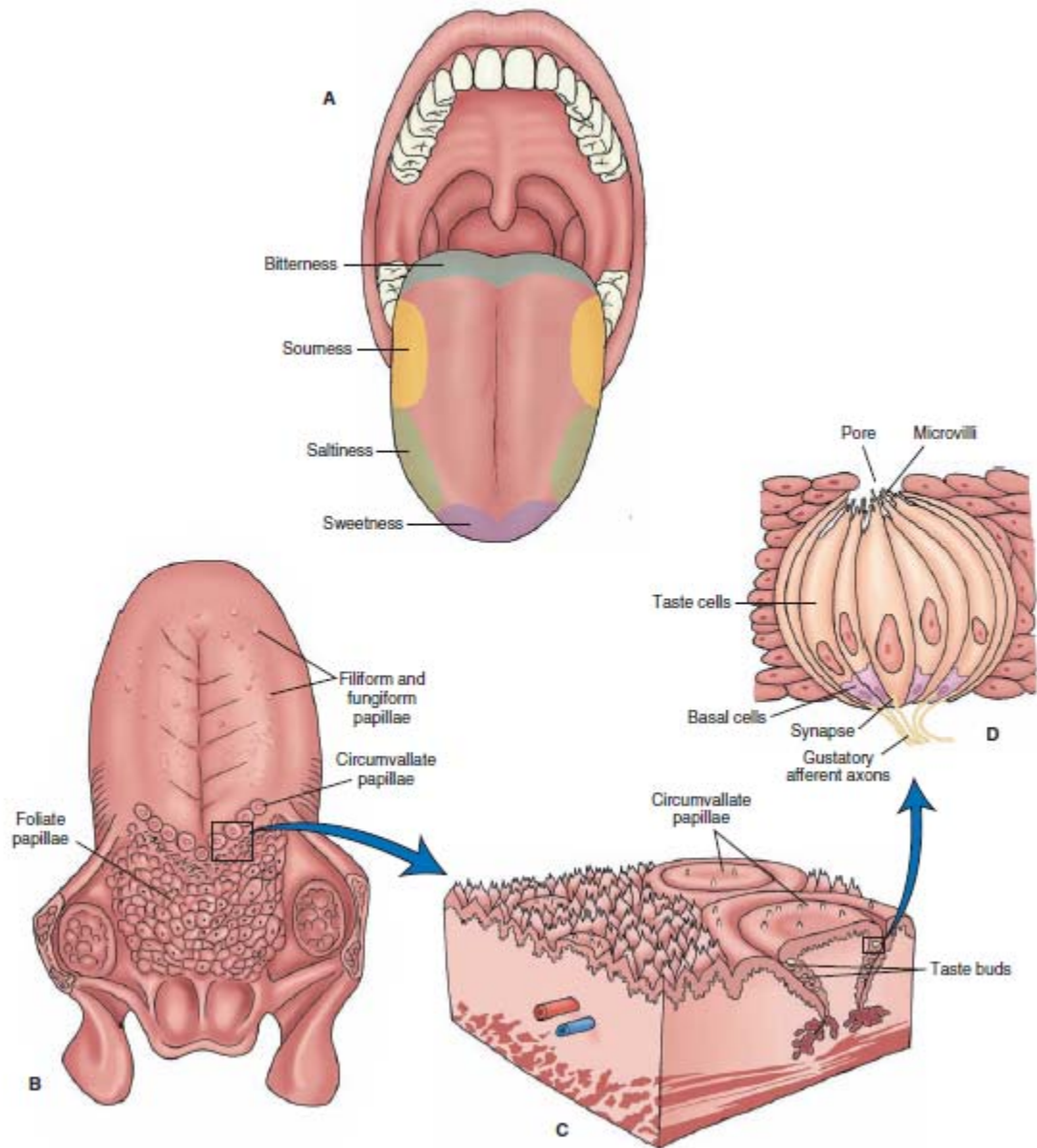
Sensory cells (on apical surface with microvillia) have both ***metabotropic and ionotropic receptors*** and different ionic channels.

It is believed that **bitter and sweet** work via ***metabotropic***,
and **sour and salty** via ***ionotropic*** receptors.



Taste receptors





Gustatory Pathway

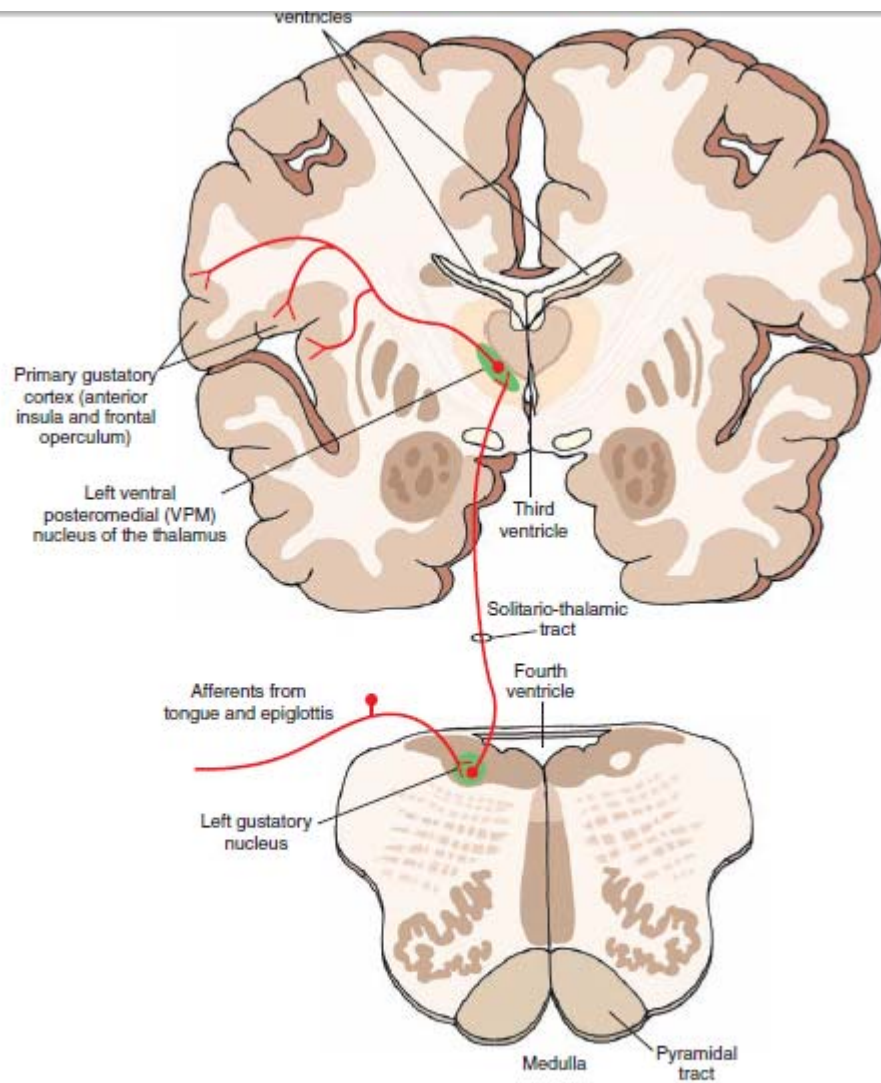
- It starts with sensory cells of the taste bud.
- First synapse is between basal surface of sensory cells and primary afferent neuron.
- Bodies of primary afferent neuron are in sensory ganglia of the three brain nerves.



Gustatory Pathway

- Ganglion geniculi externi (nervus facialis)
- Ganglion petrosum (nervus glossopharyngeus)
- Ganglion nodosum (nervus vagus)





Taste pathway

Three brain nerves:

n. facialis

anterior 2/3 of tongue,

n. glossopharyngeus

posterior 1/3 of tongue, and

n. vagus a few taste buds located on epiglottis.



Gustatory Pathway

- Central processes of all primary afferent taste neurons enter brain stem and end in the rostral (gustatory) part of solitary nucleus – *nucleus solitarius, polus gustatorius*
- *In nucleus solitarius, polus gustatorius* there is a body of the SECOND ORDER NEURON of the taste pathway.



Gustatory Pathway

- Axonal branches end in salivatory nuclei (secretion of saliva) and dorsal nucleus n. vagi (secretion of gastric content)
- In *nucleus parabrachialis medialis* there is a body of the third order neuron of taste pathway.
- Axons of the third order neuron go to thalamus and end in VPMpc nucleus.



Gustatory Pathway

- Talamocortical taste projection ends in cortex of fronto-parietal cover (*operculum frontoparietale*) and in cortex of anterior and ventral parts of *insula*.

