Basic Neuroscience 2013

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.*

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 cosequences 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 with 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**.

- In gustatory, visual, auditory and vestibulary 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

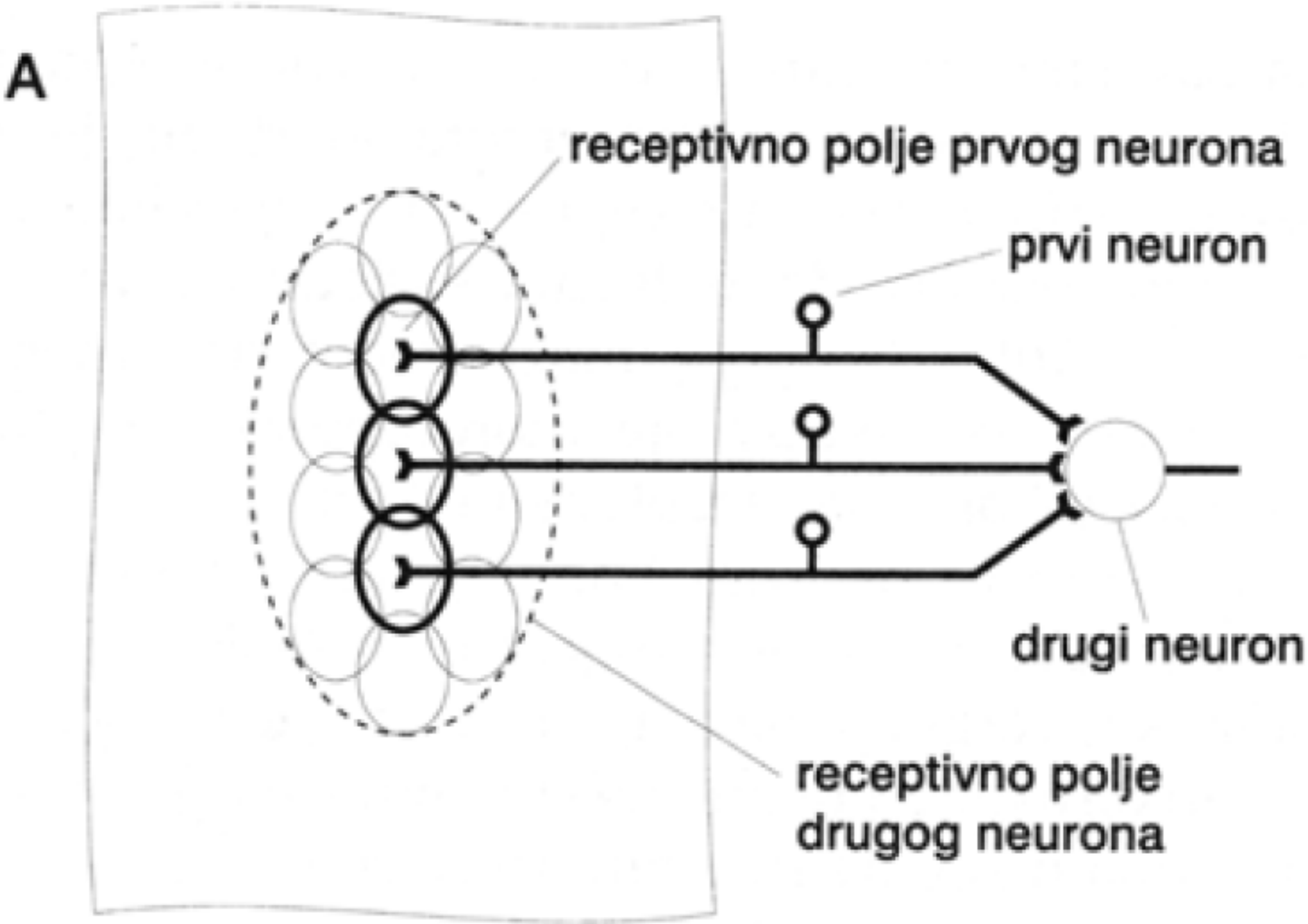
- Sensory areas in cerebral cortex have key roles in perception,
- It is the most obvious on example of primary visual cortex:
- When this cortical area is injured/damaged the patient is blind.

Characteristics of sensory systems

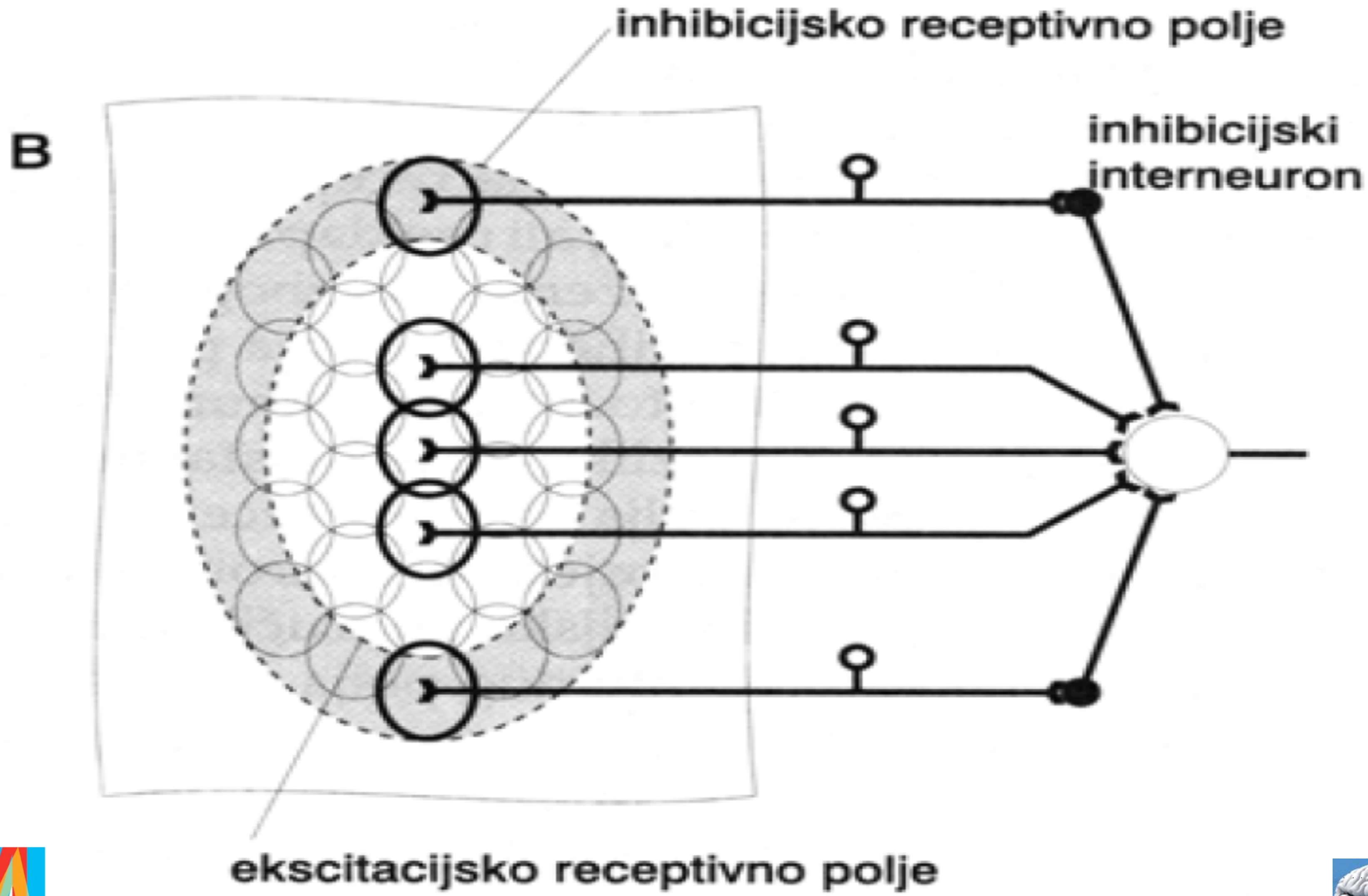
- Sensory receptors from physical stimulus “draw” 4 key characteristics:
  1) modality (quality, type),
  2) intensity (strength),
  3) duration,
  4) location (in space or in our body).

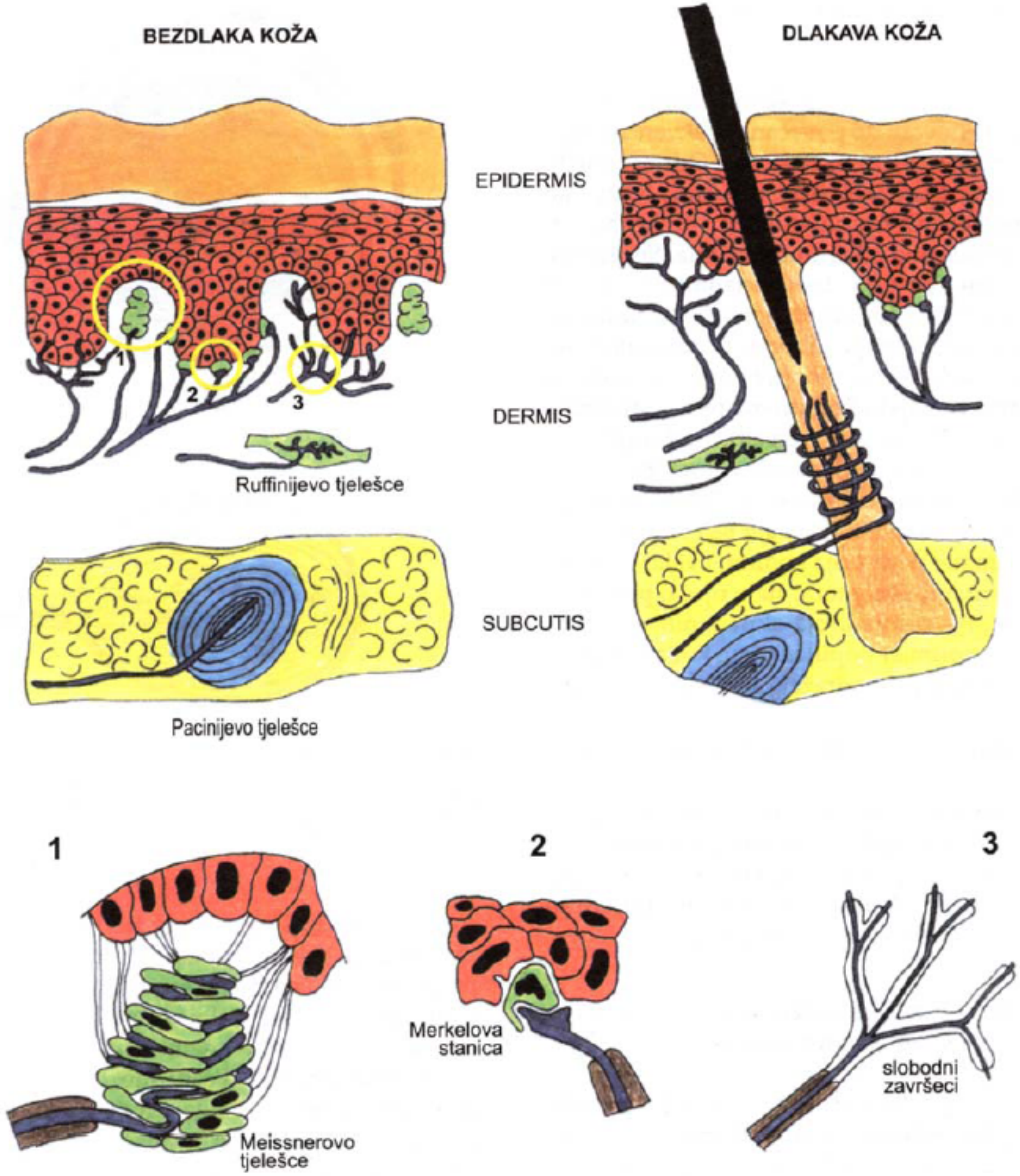
- CNS is combining them into senses (sensatio);
- When we are aware of these senses, then we say it was our conscious **notion** (perception) – **sensation is converted into perception by our brains**.

Receptive field

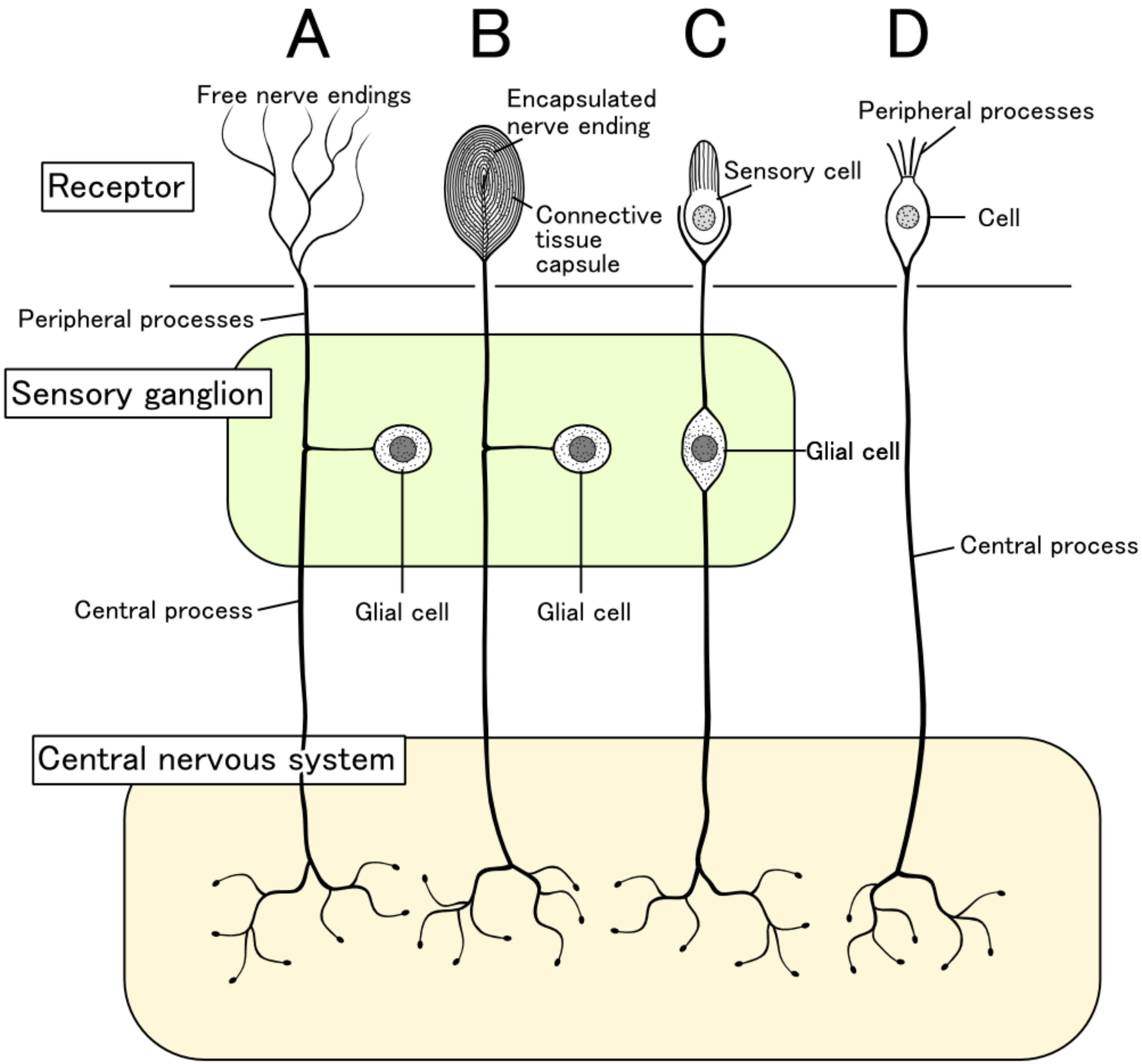


Receptive field





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


A
B
C
D
Free nerve endings
Encapsulated nerve ending
Peripheral processes
Receptor
Sensory cell
Cell
Connective tissue capsule
Peripheral processes
Sensory ganglion
Glial cell
Central process
Central process
Glial cell
Glial cell
Central nervous system

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Smell and Taste
Chemical Senses

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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*

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

a) Bodies of primary afferent neurons are *NOT* in a sensory ganglion, but *in sensory epithelium of* specific parts of nasal mucosa;

b) Axons of primary afferent neurons *directly* enter the primitive brain cortex (olfactory bulb); there are no subcortical secundary sensory neurons;

c) Primary afferent neurons constantly *die*, being replaced by new primary neurons;

d) Whole olfactory pathway (up to associative olfactory areas of the frontal cortex) is completely *ipsilateral*.

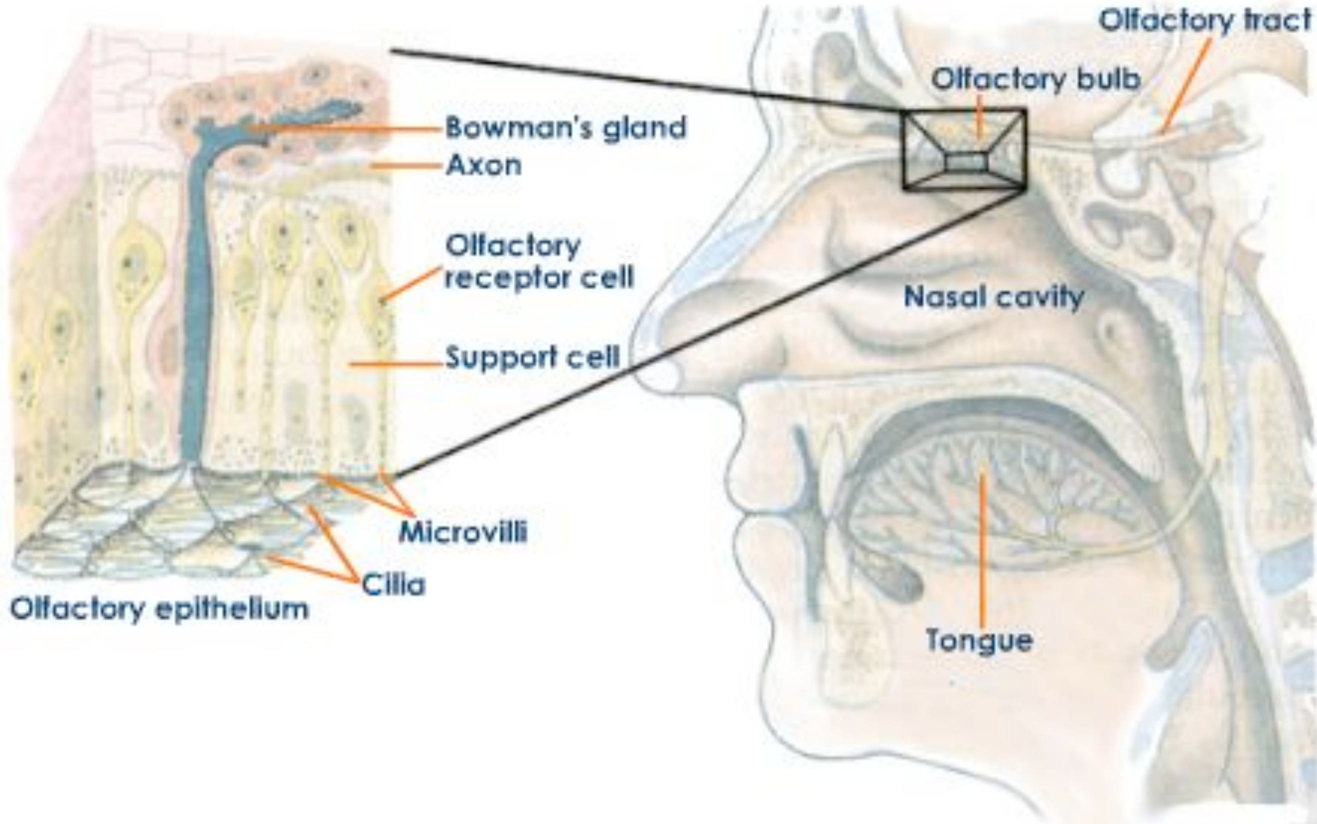
Olfaction in different animals

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

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

Olfactory epithelium

Upper one fifth of lateral and septal wall of nasal cavity



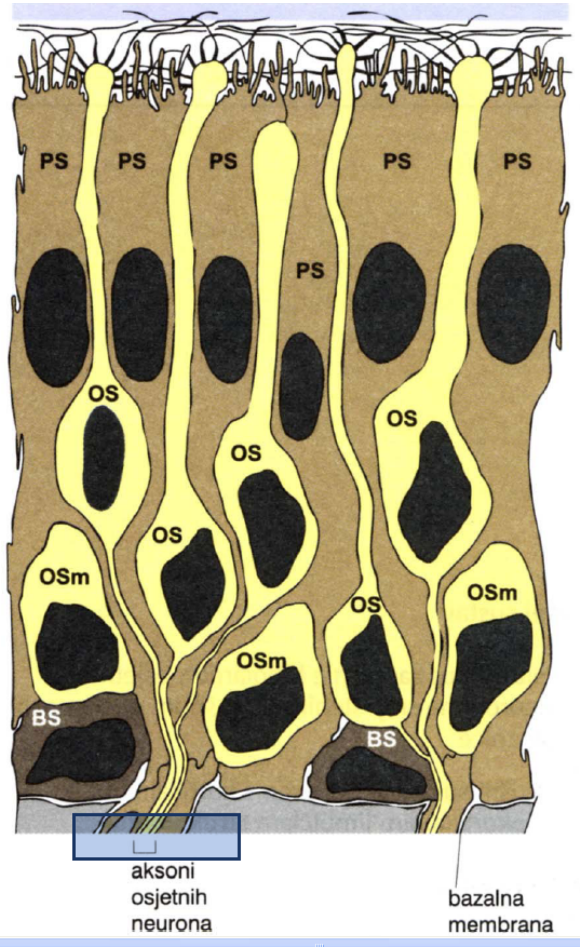
Olfactory epithelium

Contains three types of cells:

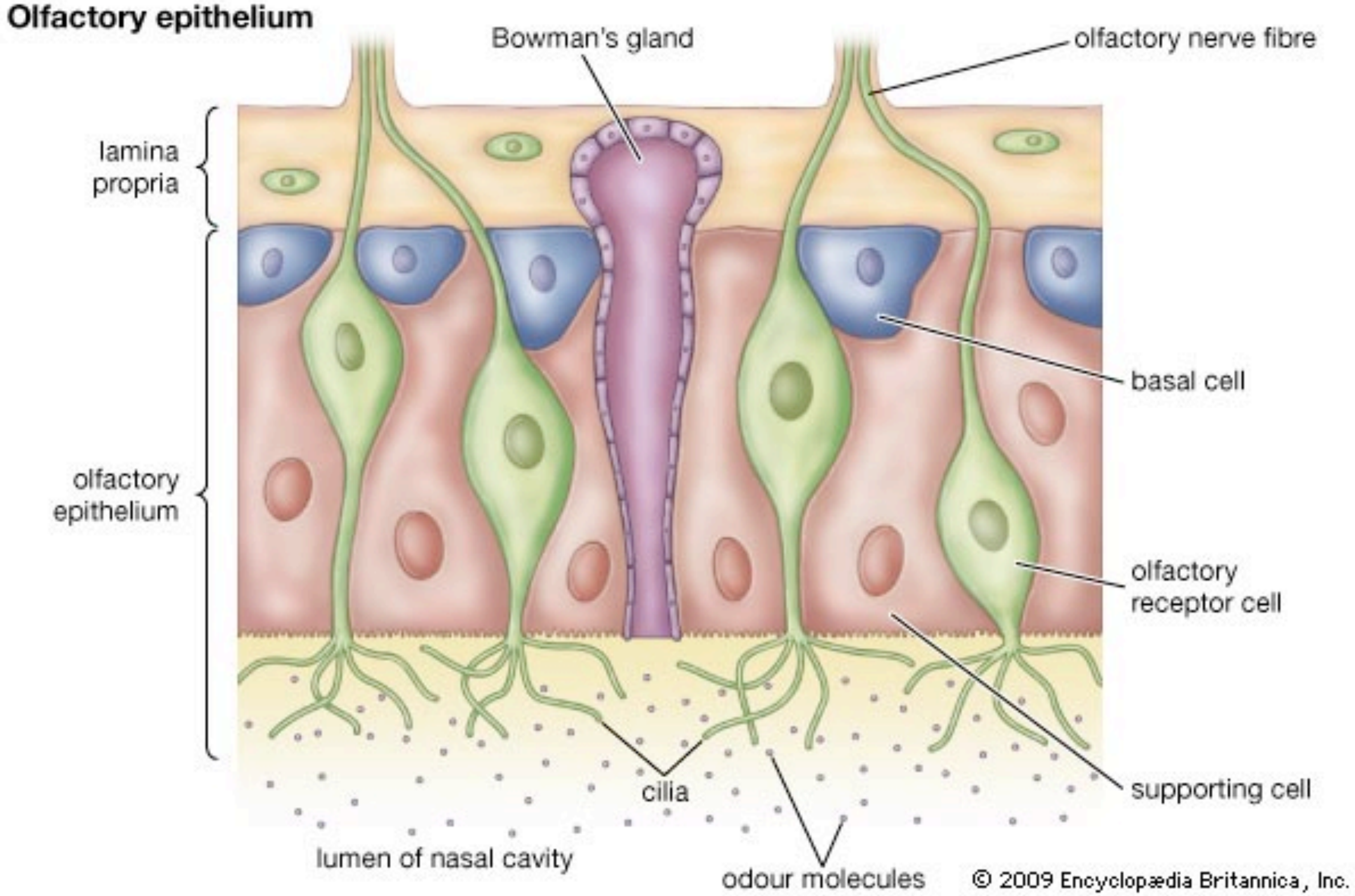
- •Sensory cells, primary afferent olfactory neurons,
- •Supporting cells,
- •Basal cells,
- •Brush cells.

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

man - microsmatic, dog - macrosmatic



Olfactory epithelium



Primary afferent olfactory neurons

Bipolar
In mucosa, not in a ganglion
Around 6 millions (3 millions per side)
Axons form 100 or more 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 affinitety 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.

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).

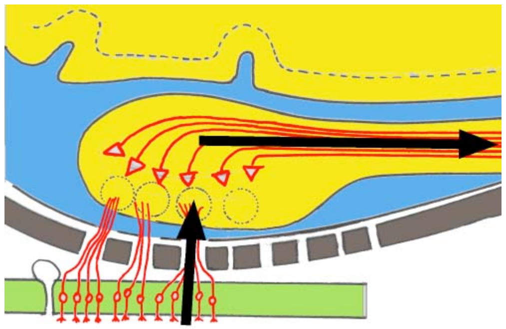
Depolarisation of bipolar olf neurons and APs

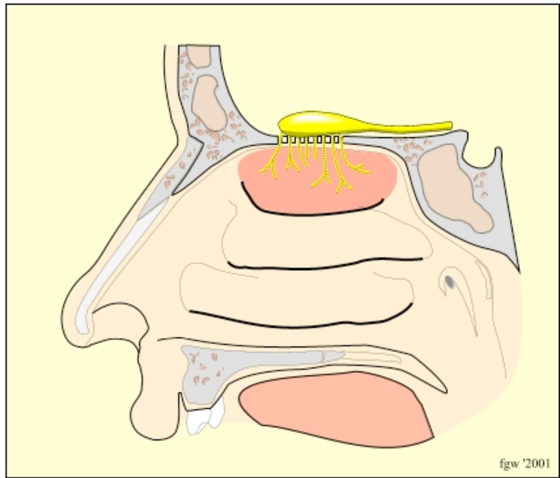
Brain olfactory system

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

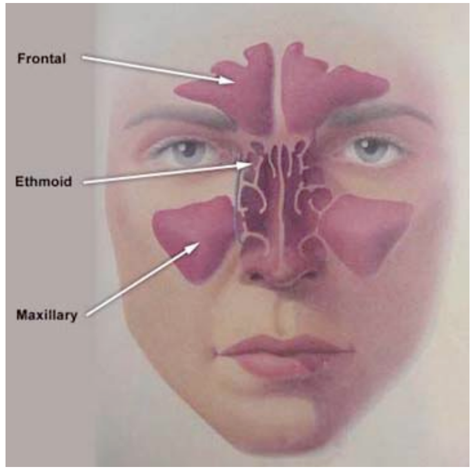
It is composed of: *bulbus olfactorius, tractus olfactorius, area olfactoria basalis*.

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



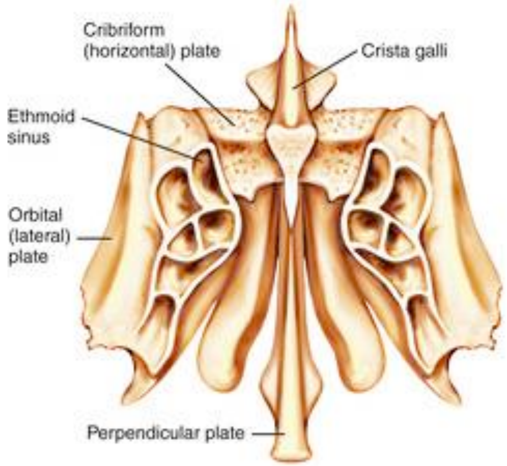


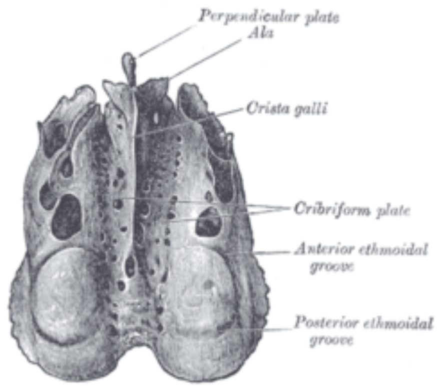
Brain olfactory system



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

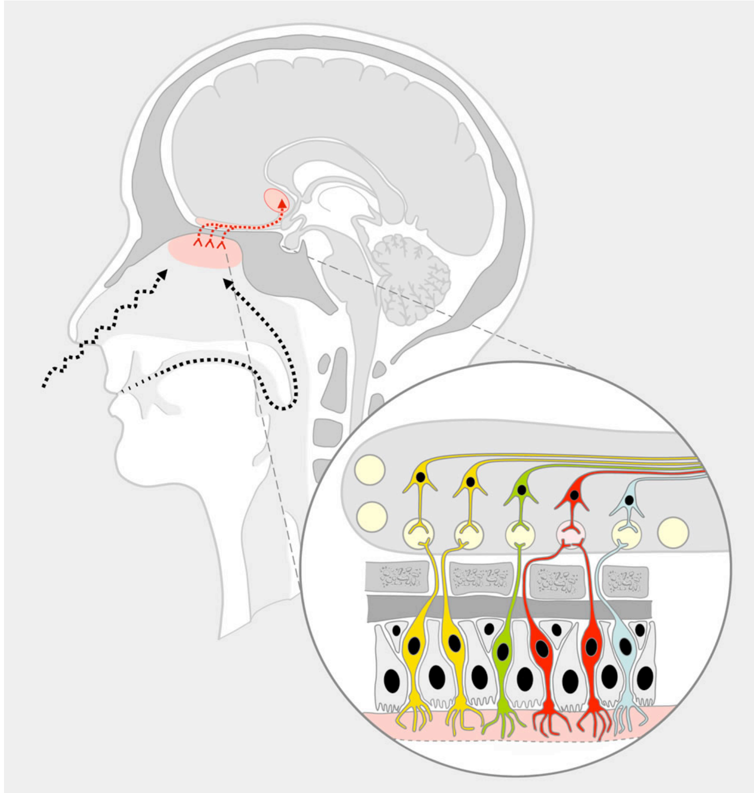
From the nasal cavity, via bone openings in lamina cribriformis, central parts of bipolar olfactory neurons (*fila olfactoria*) enter the skull.



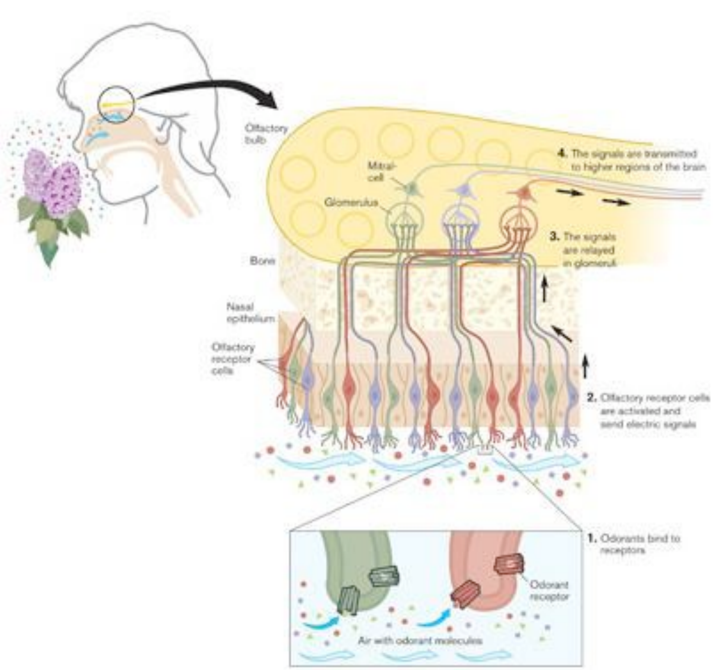


Olfactory bulb

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

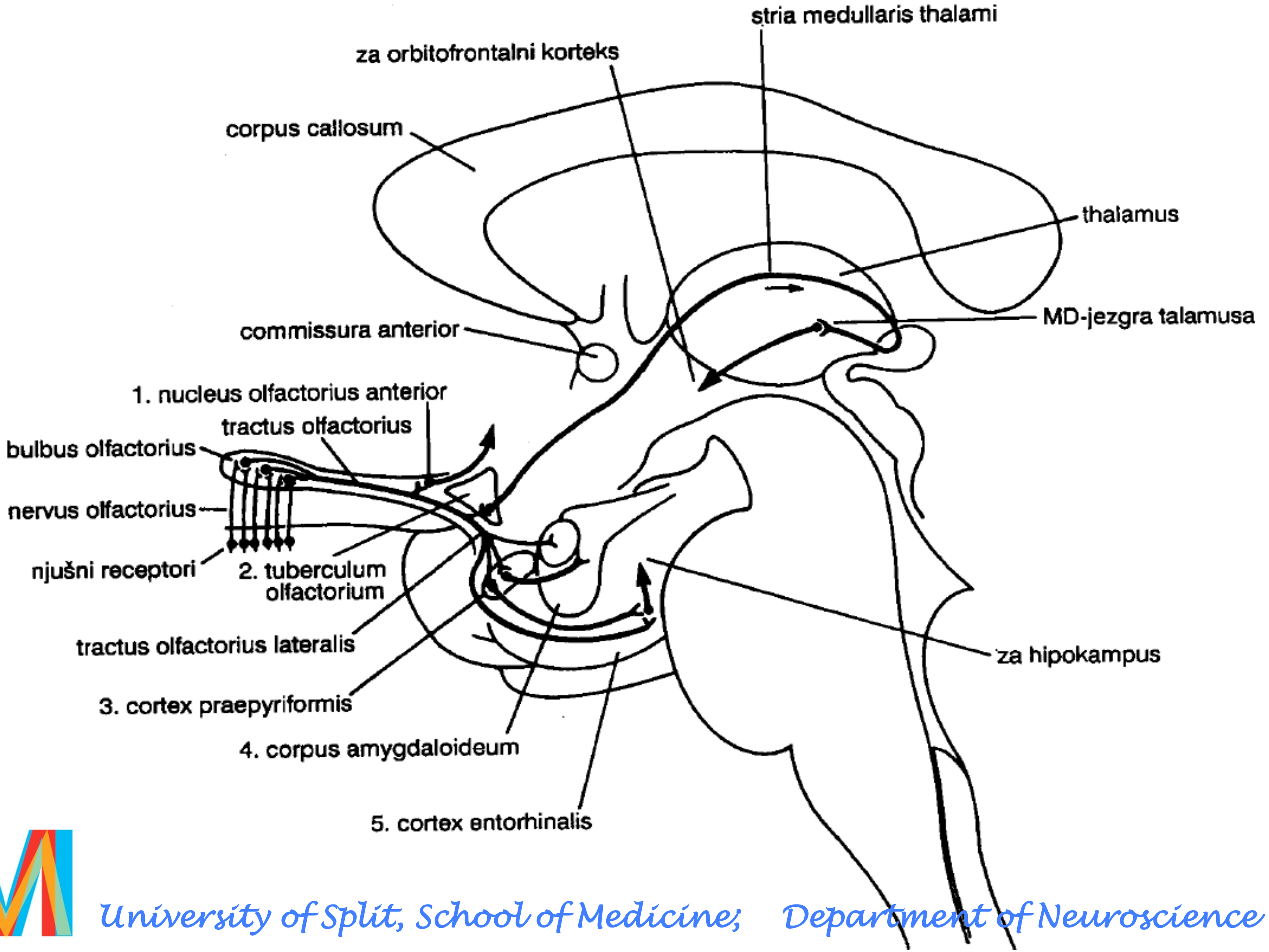


Odorant Receptors and the Organization of the Olfactory System



Secondary neurons:
Mitral cells
Tufted cells

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 everydays 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:

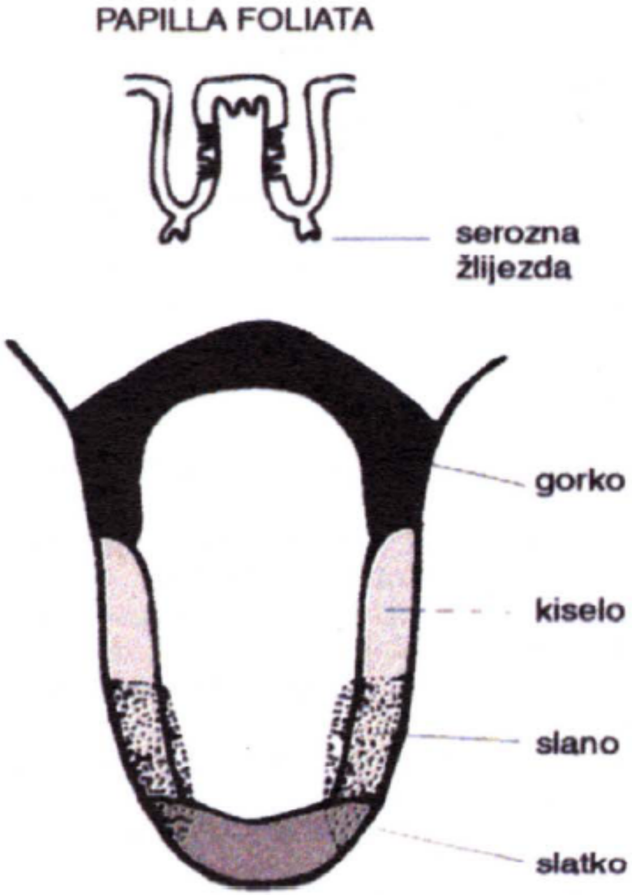
1) *Papillae filliformes*

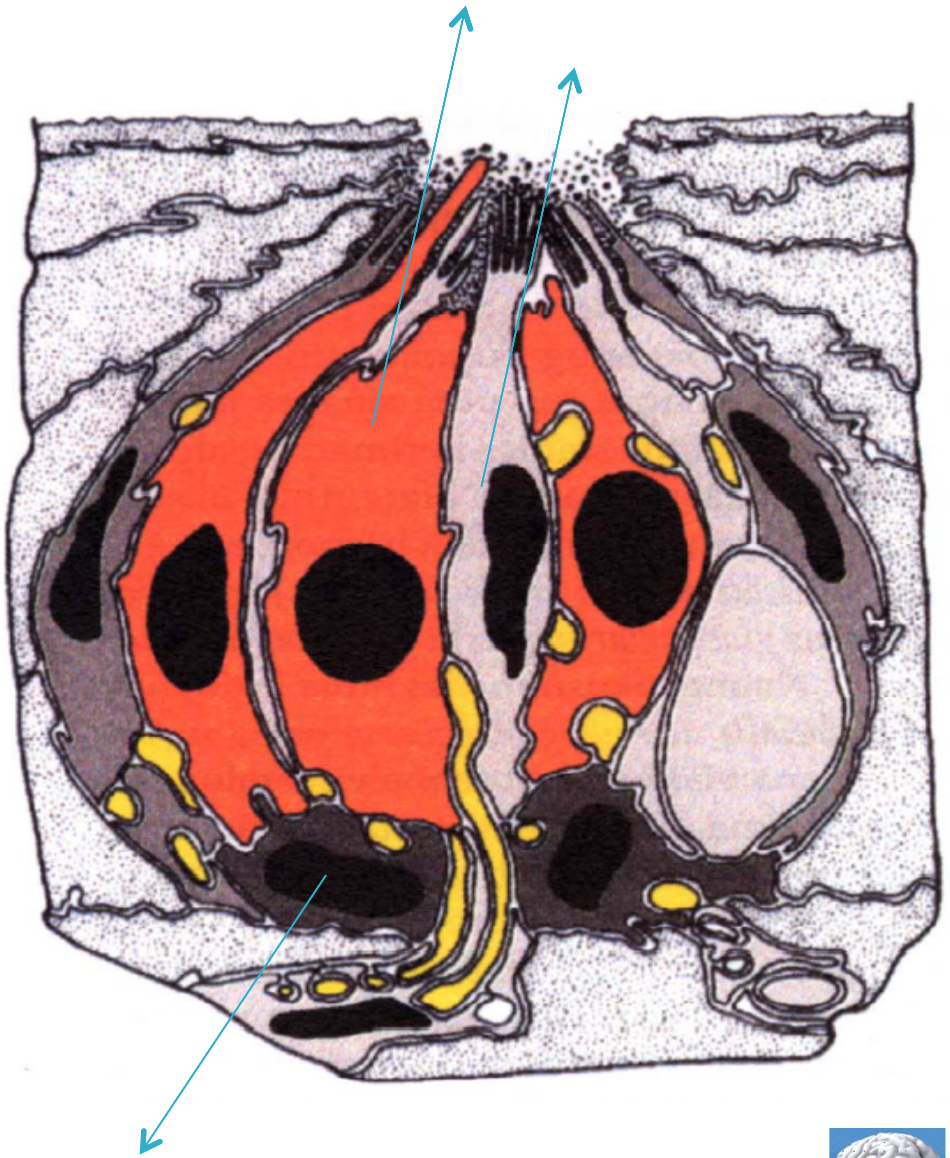
2) *Papillae circumvallatae*

3) *Papillae fungiformes*

4) *Papillae foliatae*

Taste bud


PAPILLA FOLIATA
serozna
žlijezda
gorko
kiselo
slano
slatko

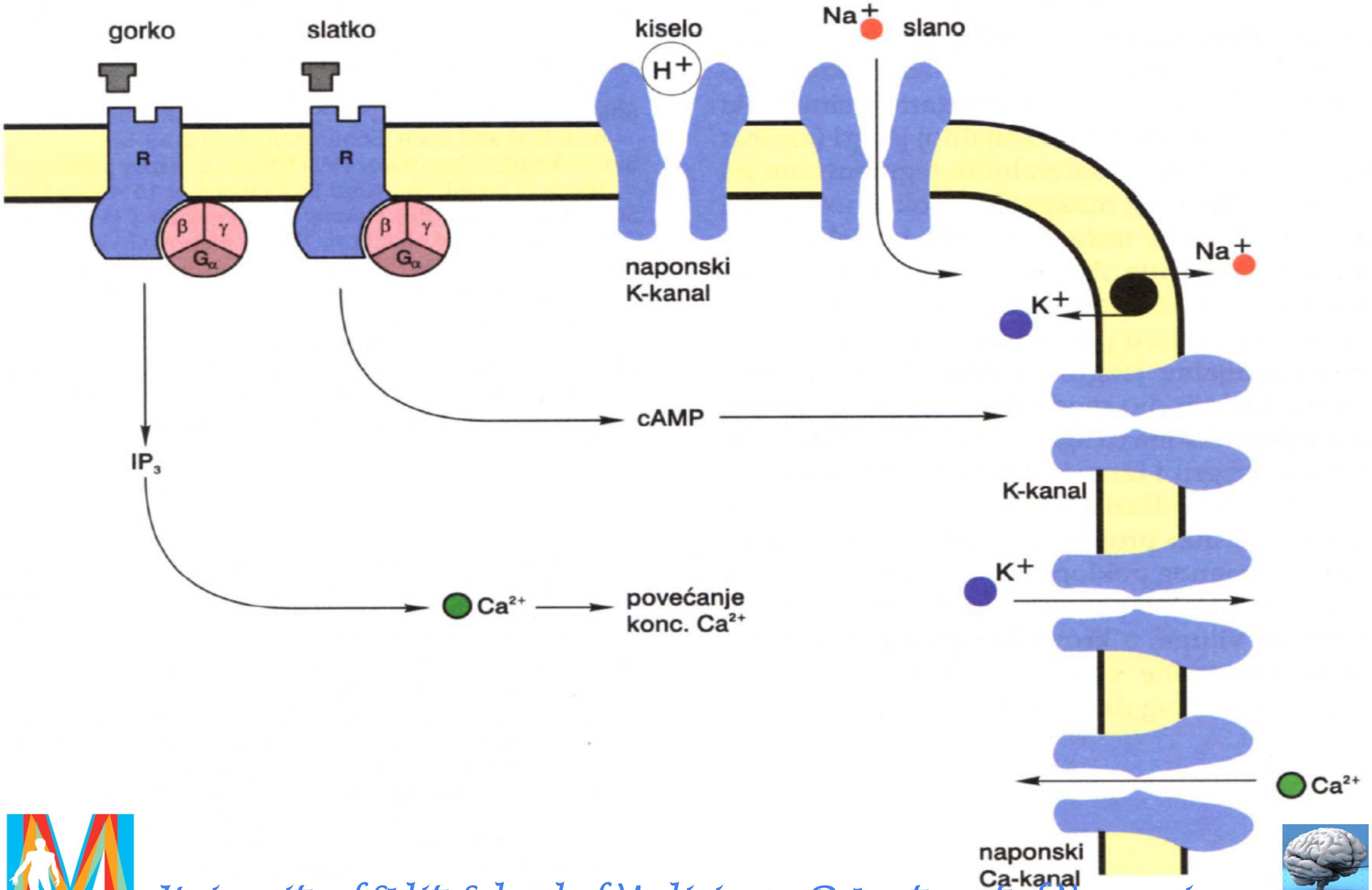


Gustatory system - Taste

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 iz 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 epiglotis.

Gustatory Pathway

- Central processses 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*.