Sensory Maps

Authored by
mohammad looti

November 19, 2022

Sensory maps are areas of the brain which respond to sensory stimulation, and are spatially organized according to some feature of the sensory stimulation. In some cases the sensory map is simply a topographic representation of a sensory surface such as the skin, cochlea, or retina. In other cases it represents other stimulus properties resulting from neuronal computation and is generally ordered in a manner that reflects the periphery. An example is the somatosensory map which is a projection of the skin's surface in the brain that arranges the processing of tactile sensation. This type of somatotopic map is the most common, possibly because it allows for physically neighboring areas of the brain to react to physically similar stimuli in the periphery or because it allows for greater motor control.

The somatosensory cortex is adjacent to the primary motor cortex which is similarly mapped. Sensory maps may play an important role in facilitating motor responses. Other examples of sensory map organization may be that adjacent brain regions are related through proximity of the receptors that they process as in the map of the cochlea in the brain, or that similar features are processed as in the map of the feature detectors or the retinotopic map, or that time codes are used in organization as in the maps of an owl's sense of direction via interaural time difference between ears. These examples exist in contrast to non-mapped or randomly distributed patterns of processing. An example of a non-mapped sensory processing system is the olfactory system where unrelated odorants are processed side-by-side in the olfactory bulb. In addition to non-mapped and mapped processing, stimuli may be processed under multiple maps as in the human visual system.

Functions

Mapped sensory processing areas are a complex phenomenon and must therefore serve an adaptive advantage as it is highly unlikely for complex phenomena to appear otherwise. Sensory maps are also very old in evolutionary history as they are nearly ubiquitous in all species of animals and are found for nearly all sensory systems. Some advantages of sensory maps have been elucidated by scientific exploration:

Filling In: When sensory stimulation is organized in the brain in some form of topographic pattern, then the animal might be able to "fill in" information that is missing using neighboring regions of the map since they will usually be activated together when all information is present. Loss of signal from one area can be filled in from adjacent areas of the brain if those areas are for physically related parts of the periphery. This is evident in animal studies where the neurons bordering a lesioned, or damaged, brain area (which used to process the sense of touch in a hand) to recover processing of that sensory region because they process information from adjacent hand areas.

Lateral Inhibition: Lateral inhibition is an organizing principle, it allows contrast in many systems from the visual to the somatosensory. This means that if adjacent areas inhibit one another then stimulation which activates one brain region can simultaneously inhibit the adjoining brain regions to create a sharper resolution between stimuli. This is evident in the visual system of humans where sharp lines can be detected between bright and dark regions because of simple cells which inhibit their neighbors.

Summation: Organization also allows related stimuli to be summed in the neural assessment of sensory information. Examples of this are found in the summation of tactile inputs neurally or visual inputs under low light.

Types

Topographic Maps

These maps may be thought of as a mapping of the surface of the body onto the brain structure. Phrased another way, topographic maps are organized in the neural system in a manner that is a projection of the sensory surface onto the brain. This means that the organization in the periphery mirrors the order of the information processing in the brain. This organization can be somatotopic, as in the tactile sense of touch, or tonotopic, as in the ear, and the retinotopic map which is laid out in the brain as the cells are arranged on the retina.

Examples

Wilder Penfield discovered the original topographic map in the form of the internal somatosensory Homunculus. His work on human neural systems showed that the brain areas that processed tactile sensations are mapped in the same fashion that the body is laid out. This sensory map exaggerates certain regions that have many peripheral sense cells like the lips and hands while reduces the relative space for processing areas with few receptors like the back.

Hair cells in the auditory system display tonotopic organization. This tonotopic arrangement means that cells are laid out to range from low frequency to high frequency and processed in that same organization within the brain.

Computational Maps

These maps are organized entirely in the neural system or organized in a manner not present in the periphery. This can be any map that is constructed by neural computation which is the brain relating two or more bits of information in order to obtain some new information from them. Often these maps involve comparing, as in performing subtraction to get a time delay, two stimuli, like incoming sound information from different ears, in order to produce a valuable new bit of information about those stimuli, as in where they originated. The process just described takes place in the owl's neural system very rapidly.

Examples

The Jeffres Map was a theory of how the brain might compute interaural time differences (ITD), or differences in time of stimulus arrival between the two ears. Jeffres was famous for producing a theoretical mechanism for making a place map out of timing information, this explained how some animals could appear to have a "look-up map" for where a sound came from. The neural system computes this ITD in the Owl Auditory System and the real neural system was found to almost exactly match the Jeffres Map theory. The Jeffres Map shows how ITD signals are used to determine distance and direction in the owl.

Feature Detectors in a visual system are another example of computational maps. No part of the physical system in the eyes actually analyzes for features like simple cells in the brain do. This system is well studied in frogs. It is known that frogs detect specific "worm-like" features in their environment and, controlled entirely by the neural system, will lunge at them even if they are a series of white squares in a line imitating a basic worm.

There is also an Frequency Modulation to Frequency Modulation Comparison in the Bat Auditory System which is used in echolocation. This FM-FM comparison determines flutter of their target and was made famous in work by Suga.