VECTOR CODING AND NEURONAL MAPS

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A model of vector coding is proposed. An excitation vector is generated in an ensemble of neurons, which has simultaneous actions on the map of selective detectors (selectors), creating a local excitation maximum which represents the input stimulus. Vector coding is also proposed as an explanation for associative learning and memory. Responses to the input in this model are determined by the excitation vectors triggered by command neurons in ensembles of premotor neurons.

The problem of encoding information in neural networks includes: the sensory coding of stimuli, the coding of stimuli in short-term and long-term memory, semantic coding, and coding of responses [1, 2].

The principle of mapping can be applied to the question of encoding of stimuli in the nervous system. The essence of this is that, by means of a multiplicity of parallel channels, a receptor surface is imaged on a screen consisting of neural elements of the cerebral cortex. Movement of a stimulus relative to the receptor surface produces a shift in the focus of excitation on the screen formed by the neural elements. Specific examples of this type of mapping are provided by the retinotopic, somatotopic, and tonotopic projections. While the retinotopic and somatotopic projections have direct relevance to the spatial relationship of the stimulus and the point of excitation, analysis of the tonotopic projection reveals a different type of selective sensitivity to the frequency of sound vibrations of hair cells along the organ of Corti. Thus, the tonotopic projection consists of a special case of the somatotopic projection.

Each element in a map representing the image of a stimulus responds only when the signal is located on a specific part of the receptor surface. Such an element can be described as a local selective detector. The screen upon which the image of the spatial position of the stimuli is represented consists of a map of the selective detectors. This approach combines the mapping concept with detector theory. However, this can only be applied to signals which are discriminated in terms of their position on a receptor surface.

This raises the questions of how stimuli which act on a local region of a receptor surface without changing their position are encoded, and whether it is possible to apply the mapping concept to such stimuli, i.e., whether they can be imaged on a map of selective detectors. These questions can be answered in the affirmative, in that local regions of a receptor surface have different types of receptors, which form receptor ensembles for which the nervous system has corresponding ensembles of neurons. When the signal changes in a local region of the receptor surface, the levels of excitation of different receptors change to different extents, which produces corresponding changes in the excitation of the neurons forming the neuronal ensemble associated with these receptors. The combination of excitations of the neurons in the ensemble acts simultaneously on neurons forming the selective detector map, thus creating within the map a defined focus of excitation. On changes in the input stimulus, the combination of excitations in the receptor ensemble changes. This leads to corresponding changes in the combination of excitations in the neuronal ensemble, and the focus of excitation shifts on the selective detector map in a similar way as occurs in the case of a moving stimulus relative to the receptor surface. The ensemble of receptors detecting the signal in a local region of the receptor surface sends the signal to the neuronal ensemble, which creates the necessary conditions for subsequent imaging of the signal on the selective detector map. Thus, the concepts of mapping, neuronal ensembles, and selective detectors form different aspects of the general mechanism of sensory coding.

Excitation of the neurons forming the ensemble generates component vectors of the excitation. Thus, the neuronal ensemble transforms the external signal into an excitation vector. All subsequent processing within the nervous system acts on the excitation vector. This vector acts simultaneously on the map formed by the selective detectors of properties.

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Fig. 1. Schematic representation of the arrival of information at a selective detector (a) and a geometrical model of the synaptic organization of a selective detector (b). For further explanation see text.

Each selective detector is characterized by its own specific set of synapses connecting the selector with elements of the neuronal ensemble. These synapses differ in terms of their efficiency or weighting. The set of synapses with different weightings for a given selective detector forms its vector of synaptic connection or, more succinctly, its connection vector. It can be proposed that the excitation vector and the connection vector of each selective detector have the same length. This means that stimuli acting on a neuronal ensemble create excitation vectors of different orientations but equal length. Correspondingly, the different selective detectors making up the map have synaptic connection vectors of different orientations but identical length. Each selective detector sums the paired products of the incoming excitation, with weightings determined by the corresponding synapses. The sum of these paired products is a scalar derivative of the excitation vector with respect to the connection vector of a given selective detector (Fig. 1).

Stimulus $S$ (Fig. 1, a) acts on a group of receptors $r$, making up a receptor ensemble. The receptors are in turn connected to neurons $f_1, f_2,$ and $f_3$, making up a neuron ensemble. Excitation of elements of the neuronal ensemble forms an excitation vector. Neuronal excitation is passed to the selective detector via synaptic contacts with weightings $c_1, c_2,$ and $c_3$. The incoming excitations are multiplied in the synapse by the weighting of the synaptic contact. The selective detector sums these paired products, to determine the formally scalar derivative of the excitation vector and the connection vector.

The synaptic organization of the selective detector can be represented (Fig. 1, b) as a geometrical model incorporating all excitation coordinates $f_1, f_2,$ and $f_3$ (the components of excitation vector $F$) and the weightings of the connections $c_1, c_2,$ and $c_3$ (the connection vector $C$). The response of the detector is determined by the scalar product of vectors $F$ and $C$, which is equal to the product of the lengths of these vectors and the cosine of the angle between them.

Each detector is characterized by its own set of synapses (its connection vectors $C_1, C_2, C_3,$ and $C_4$). The response of the detector is determined by the extent to which the active excitation vector coincides with the direction of the connection vector of the detector concerned. The stimulus is coded by the position of the excitation peak on the selective detector map. The excitation peak appears in the detector whose connection vector agrees in direction with the excitation vector elicited in the neuron ensemble by the stimulus.

The detector map can be represented as a geometrical model of the group of connection vectors $C_1, C_2, C_3,$ and $C_4$ and the excitation vector $F$. Plotting the projection of the excitation vector $F$ on each of the connection vectors $C_1, C_2, C_3,$ and $C_4$ shows that the excitation vector $F$ is closest in direction to vector $C_1$, which corresponds to a maximal level of excitation for this vector.

Stimulus $S$ (Fig. 2, a) acts on an ensemble of receptors connected to an ensemble of neurons; the neuron ensemble acts simultaneously on the entire field of selective detectors.