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Re-interpretation based on the IPL mechanism

Current studies in neuroscience are carried out by examining neuronal firing as a unitary property of the nervous system. Patterns of neuronal firing called neural population codes are used to make correlations with different brain functions. It is also used to make representations of sensory perception using animal behavior in response to sensory stimuli. By analyzing neuronal firing in response to a specific stimulus over different timescales, it is found that variations of elements (neurons that fire) occur within each set of neurons that fire (Rumyantsev et al., 2020; Driscoll et al., 2017; Montijn et al., 2016). A recent study (Ebrahimi et al., 2022) shows occurrence of a) sensory coding redundancy near the beginning of perception of a sensory stimulus, and b) shared co-fluctuations of neuronal firing in different areas of brain.

To decode behavioral response and to progress from representation to causation, it is necessary to understand a mechanistic explanation how first-person property of sensory perception is generated and how it is associated with firing of different sets of neurons. Since sensory perception occurs in a conscious mind, it is necessary to examine how first-person properties occur within the nervous system and how this mechanism is correlated with third person observation such as firing of neurons. Studies have shown that oscillating extracellular potentials need to be maintained in a narrow range for conscious perception. Oscillating extracellular potentials is a reflection of ionic changes occurring across neuronal cellular membranes that in turn reflect the nature of propagation of potentials across the neuronal processes. Since oscillations across three-dimensional space of extracellular matrix (ECM) can only be explained by the occurrence of vector components that contribute to these oscillations, it is necessary to find mechanisms that lead to generation of these vector components. Since there are oscillations of potentials with different amplitudes and frequencies in space, it is also necessary to explain how and where the vector components contributing to these oscillations occur. This also provides an opportunity to hypothesize mechanism/s that can lead towards a solution for the system that can explain how first-person properties are formed within the system.

Since inner sensations of memories are first-person properties, it is possible to ask, “What type of a change should occur within the system during associative learning that can be used to generate first-person inner sensations of retrieved memories?” Once it becomes possible to generate a hypothesis for such a mechanism, it allows us to test for the occurrence of a change during learning. With this aim, semblance hypothesis synthesized a general framework of a mechanism (Vadakkan, 2007). When attempts are made to generate artificial intelligence by transferring the mechanism of natural intelligence to engineered systems, it becomes necessary to understand how first-person properties are generated within the system. Towards this attempt, memories were viewed as hallucinations (inner sensation of a sensory stimulus in its absence) and a framework for a mechanism was developed (Minsky, 1980). When semblance hypothesis was further examined in line with K-lines proposed by Marvin Minsky, it was possible to derive formation of inter-postsynaptic functional LINK (IPL) as linchpin change occurring during learning whose reactivation is expected to generate internal sensation of memory (Vadakkan, 2013). Accordingly, reactivation of IPLs from a lateral direction by a specific cue stimulus is capable of generating units of inner sensations. Propagation of potentials through established IPLs provides one of the vector components to oscillating extracellular potentials at the locations where postsynaptic terminals of the same neuronal order interact with each other in their orthogonal organization with respect to linear orientation of neurons in the consecutive neuronal orders. Synaptic transmission between linearly-oriented neurons of different neuronal orders provide the second vector component perpendicular to that occur through the IPLs.

Many neurons are held at subthreshold activation states. Background subthreshold activation of a neuron depends on natural environmental stimuli (for example, gravity), phase of oscillation of oscillating extracellular potentials and spatial and temporal summations of potentials. Using propagation of potentials that contribute vector components, it is possible to explain both generation of oscillating extracellular potentials and addition of potentials to several neurons that are held at subthreshold activation levels. In other words, stimulus under investigation provides additional EPSPs to different sets of neurons that are being held at subthreshold activation states and allows them to fire action potentials. This is demonstrated in **Fig.1**.

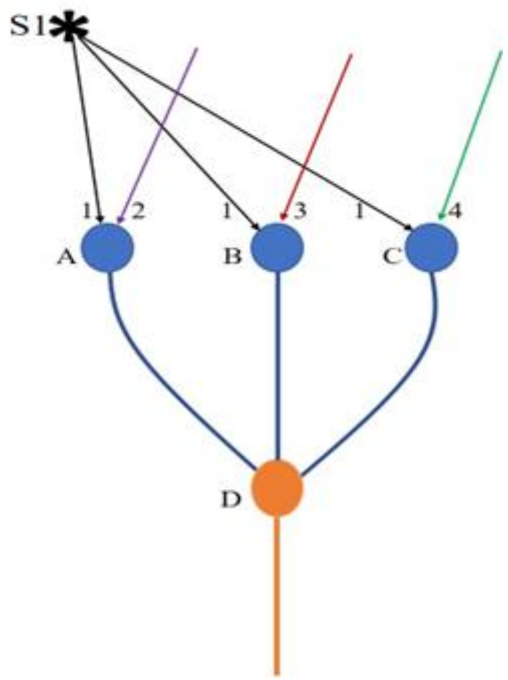

Figure.1. Sensory coding redundancy explained using an example. When a stimulus arrives, it will provide sufficient stimulus to several first order neurons that leads to their firing. Action potential triggered by an excitatory neuron will lead to synaptic transmission at the synapses on all its axonal terminals. The EPSP generated at a postsynaptic terminal gets spatially or temporally summated with the rest of the ESPSs arriving at the axonal hillock. Depending on whether the net summated EPSP crosses the threshold for firing, the postsynaptic neuron either fires or does not fire. This is pictorially depicted by the example of three neurons A, B and C that receive sub-threshold activations short of two EPSPs at their baseline resting states. A specific stimulus under investigation is marked “S1”. It provides EPSPS to all three neurons A, B and C. EPSPs 2, 3 and 4 reaching neurons A, B

and C respectively arrive from either internal or external stimulus at the same time. If neuron A receives EPSP 1 and 2 simultaneously, it will lead to its firing. If neuron B receives EPSP 1 and 3 simultaneously, it will lead to its firing. If neuron C receives EPSP 1 and 4 simultaneously, it will lead to its firing. Hence, when EPSP1 arrives, firing of neurons A, B and C depends on whether they are receiving additional EPSPs concurrently or temporally so that these neurons fire. If D is a neuron of the second order of neurons and if it is being held at subthreshold state short of one EPSP and if it has inputs from neurons A, B, and C, then firing of either one of the neurons A or B or C will cause its firing. Hence, a stimulus under examination can cause firing of sets of A and D or A, B and D or A, B, C and D or B and D or B, C, and D or C and D, or A, C and D simultaneously.

Second explanation is needed for the observation of sensory coding redundancy at the start of perception (Ebrahimi et al., 2022). Redundancy of inputs is expected to minimize the effect of variations in the sets of neurons that fire. But the stochastic nature informs that something new is taking place within the circuitry. This provides a unique opportunity to examine any proposed hypothesis of brain functions for its explanatory capabilities. Since any set of nearly 140 input signals arriving through nearly tens of thousands of input terminals of a pyramidal neuron in the cortex can fire a neuron (Palmer et al. 2014; Eyal et al., 2018), there is presence of extreme degeneracy of input signals in firing a neuron (Vadakkan, 2019). Since many neurons are being held at subthreshold activation levels in the background state, and since there is presence of continuously varying internal stimuli originating from within the system, arrival of different combinations of input signals can lead to firing of the same neuron. By extension, it I possible to infer that stimulus from a sensory stimulus under examination can generate potentials that can reach neurons where they get summated with potentials from a) input signals generated either internally or externally, and b) reactivation of IPLs that also contribute to oscillating extracellular potentials. As the interval between testing increases, occurrence of different associative learning events will add more IPLs to the system. In addition, some IPLs will get reversed back over time. These can lead to changes in the net EPSPs arriving at the axonal hillocks of neurons that are held at subthreshold activation states. This can explain variations of neuronal sets that fire in response to a specific stimulus over different timescales (Rumyantsev et al., 2020; Driscoll et al., 2017; Montijn et al., 2016).

Thirdly, it is necessary to explain how different areas of brain show shared co-fluctuations of neuronal firing. As explained in the previous paragraph, addition and deletion of IPLs over time will lead to changes in the sets of neurons that fire. Both propagation of potentials along projection neurons between different brain areas, and maintenance of both frequency and amplitude of waveforms of oscillating extracellular potentials are expected to allow maintenance of correlated subthreshold states of sets of neurons at two locations. When a stimulus arrives, this can provide inputs to subthreshold-activated neurons at those two locations and allow them to cross thresholds for firing.

Both correlated fluctuations and visual coding redundancy that are time-varying throughout stimulus presentation rise within 100ms and peak around 200ms after sensory stimulus onset (Ebrahimi et al., 2022). This time delay matches with the time needed for expansion of several spines that eventually leads to the formation of more IPLs. These late-forming IPLs have no role in early perception. However, their physiological utility is in maintaining continuity of perception of a stimulus. The inference made in the work that some neurons have greater intrinsic variability in the fidelity of stimulus encoding than others can be explained by 1) Different combinations of inputs add potentials that will allow the summated EPSPs to cross the threshold to fire a neuron, and 2) IPLs are formed in excess such that same semblance can be generated from different combinations of units of semblance generated at those IPLs. Inference from all the observations tempted the authors to speculate for presence of “non-interfering communication channels” in the neocortex, which can be explained in terms of the IPL mechanism.

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