Does the brain do retrograde extrapolation?

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Good questions bring progress in science. The title question raised by different readers belong to this category. From a neurophysiological point of view, depolarization does not cross a synapse in the opposite direction (i. e from the postsynaptic side towards the presynaptic side of a synapse). Semblance hypothesis has used artificial retrograde extrapolation from the inter-LINKed spine (postsynaptic terminal) towards the sensory receptors across many synapses (Explained this later. Also see **Fig.1**). Readers may confuse this artificial retrograde extrapolation as backpropagation of depolarization. However, it is reasonable to ask the question, “Since semblance hypothesis derives sensory qualia of internal sensations by retrograde extrapolation across the synapses in a backward direction, does the brain do similar retrograde extrapolation towards the sensory receptors to induce semblance?”

Before answering the last question, let me set the background. We are trying to understand how the nervous system works. It is not simple and it requires some procedures that are not routinely used by us. Since the system has the property to generate memory and perception as first-person inner sensations that we call as the “mind”, we are forced to replicate whatever mechanism that we claim to have discovered in an engineered system as the gold standard test. This inevitably forces us to explain its operational mechanism very clearly that makes sense theoretically. What is required to achieve this? Where do we go from here?

In the case of the nervous system, we need to overcome two hurdles at the same time. First, we have to understand how first-person inner sensations are generated at physiological time-scales of milliseconds that cannot be sensed by third-person experimenters and can take place either independently or concurrent with behavioral motor actions. Secondly, we have to examine whether a derived mechanism allows interconnection of different observations from different levels of the system. Whenever we reach such crossroads, it is an indication that we need to do something new that we haven’t done in the past.

Physics has developed methods to understand particles, fields and general principles that are not sensible to our nervous system. Basic examples include a) Rutherford's gold foil experiment that showed the existence of a massive center of atoms called the nucleus, b) specific distribution of ion filings on a horizontal sheet of hardboard allowed physicists to understand the direction of the generated magnetic field, and c) double slit experiment gave physicists information regarding the probabilities involved that led to the studies in quantum mechanics. However, when they face with the challenge of interconnecting disparate properties such as relativity and quantum mechanics, they continue to try to invent principles at a deeper level that can interconnect those disparate features.

Physicists often solve a system that exhibits properties that cannot be interconnected by taking help from the deep guiding principles used in mathematics. For example, when we solve a system of linear equations having a unique solution, the relationships between the variables within the equations of the system guide us towards the solution. If this principle can guide to reach a solution for the nervous system, then we can accept that as a solution and the properties that solution will become a first-principle for the nervous system. We can then try to replicate the derived mechanism in engineered systems with the expectation that it will lead to the generation of true artificial intelligence. This is a bonus for solving the nervous system!

The derived operational mechanism matches with a mechanism capable of evolving through multiple simple steps (Vadakkan, 2018) that provided it with survival advantages. Nervous system is a system having different sensory systems that respond to sensory stimuli that travels at different velocities - light at nearly $3x10^8$m/s, sound at nearly $3x10^2$m/s, smell at nearly 3m/s (a rough guess!). Now, in a predator-prey environment, both the predator and the prey receive the visual stimulus first (vision) from a remotely located prey or predator and then take motor action either for its survival for obtaining food or for escaping from being killed. In this context, when the visual stimulus can generate inner sensations of the remaining physical properties of the item that is being seen, it helps the animal to survive. This means that the nervous system has acquired certain changes during associative learning between visual and other stimuli when the item was close to the animal that allows the visual stimulus alone to generate inner sensations of the remaining sensory stimuli in their absence. This generation of a sensory stimulus in its absence is hallucination. Marvin Minsky, who was the founding director of MIT's Artificial Intelligence laboratory was interested in seeking a mechanism that can generate "hallucinations" within the nervous system responsible for memories (Minsky, 1980).

In the above contexts, we are forced to identify a structure-function change occurring during learning using which hallucinations can be generated at the time of memory retrieval. It is here that we have to use a novel strategy to identify this mechanism. **Ultimately, we want to know what critical step in the organization of neuronal processes between synaptically-connected neurons and what specific feature at those interaction sites enabled generation of hallucinations that provided survival advantage and got selected during evolution.** We must be prepared to accept a simple mechanism. Semblance hypothesis (Vadakkan, 2013) has arrived a learning mechanism that has the capabilities to retrieve memory as hallucinations. Several attributes of this operational mechanism provides properties that allow explaining large number of features of the system in an inter-connected manner.

Now let us examine our question, "Does the brain do retrograde extrapolation?" Let us first examine how the derived structure-function mechanism of inter-postsynaptic (spine) functional LINK (IPL) formed during learning can generate units of internal sensations (**Fig.1)**. In short, interaction between the postsynaptic terminals at the locations of convergence of two pathways through which sensory inputs arrive led to the formation of IPLs by an accidental coincidence. After its formation, arrival of one of the sensory stimuli at the location of convergence led to the reactivation of the IPL and activated the inter-LINKed spine (spine D in **Fig.1**). This incidental lateral activation generates the cellular hallucination of receiving sensory inputs from the latter's sensory receptors, through its presynaptic terminal, as a systems property. The derivation was carried out by different methods ((see FAQ section of www.semblancehypothesis.org) and the solution can explain large number of findings of the system from different levels (see the publications). The learning mechanism can last for different time intervals following learning to explain working, short and long-term memories.

Back to the question, "Does the brain do retrograde extrapolation?" In figure 1, we are artificially making an extrapolation from postsynaptic terminal D towards the sensory receptors to estimate the sensory qualia of the units of internal sensation induced at the inter-LINKed postsynaptic terminal D. How does the nervous system do this during memory retrieval? Lateral activation of inter-LINKed postsynaptic terminal D allows the system to get tricked to hallucinate that it is receiving sensory stimuli from the sensory receptors. Does the nervous system have to perform retrograde extrapolation to achieve memory retrieval?

To know the answer, let us examine the events that occur in the nervous system during the background state. 1) There is continuous quantal release of neurotransmitter molecules from single vesicles sufficient enough to depolarize the spine head region. 2) In a stimuli-rich environment, the nervous system continuously receive different sensory stimuli that will lead to unidirectional activation of large number of synapses. 3) This will also lead to the reactivation of several IPLs. 4) Both the synaptic transmission and the propagation of potentials across the IPLs in perpendicular directions provide vector components to the background oscillating extracellular potentials. 5) The induction of units of internal sensations occurs only at a narrow frequency of these oscillating extracellular potentials. In these contexts, an incidental lateral activation of the inter-LINKed

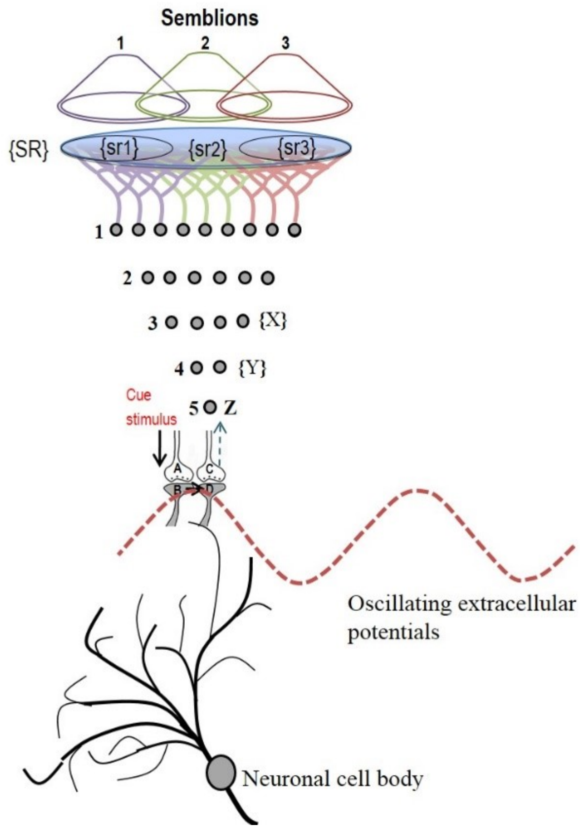

Figure 1. *Generation of units of internal sensations. During memory retrieval, a cue-stimulus reaching presynaptic terminal A depolarizes its postsynaptic membrane (dendritic spine or spine) B, which re-activates the functional LINK between postsynaptic terminals B and D and activates D. When postsynaptic membrane D is depolarized, it evokes cellular hallucination of arrival of a sensory stimulus at the sensory receptors capable of reaching presynaptic terminal C. This is called semblance. In order to understand the sensory qualia of hallucination induced at postsynaptic terminal D, we have to make an extrapolation from postsynaptic terminal D towards the sensory receptor level. Presynaptic terminal C belongs to the neuron Z, which gets activated when input reach from a set of neurons {Y}. Set of neurons {Y} is activated by activation of set of neurons {X}, which in turn is activated by a set of neurons in the neuronal order above it. (Functional LINKs between spines at lower orders, recurrent collaterals and projection neurons should also be included in this procedure. For simplicity these are not shown). This extrapolation identifies a set of sensory receptors {SR}. Stimulation of subsets of sensory receptor sets {sr1}, {sr2}, and {sr3} from the set {SR} may be capable of independently activating neuron Z. The dimensions of hypothetical packets of sensory stimuli capable of activating the sensory receptor sets {sr1}, {sr2}, and {sr3} are called semblions 1, 2 and 3 respectively. These semblions are viewed as the basic building blocks of the virtual internal sensations of memory generated by the cue stimulus. A cue stimulus can cause postsynaptic terminal D to hallucinate about any of the sembions 1, 2, 3 or an integral of them. The method of integrating different semblions generated at different inter-LINKed postsynaptic terminals can be understood by finding the algorithm that allows a match between the integral of internal sensations induced by the cue stimulus with that of the item whose memory is retrieved. Note that the potentials generated at the postsynaptic terminal and that propagate through the IPL contribute vector components to the oscillating extracellular potentials (marked by the waveform). Reader is asked to envision the whole system around the inter-LINKed spines bound by oscillating extracellular potentials. Gray circles represent neurons. The numbers on the left side of the neuronal orders denote their position from the sensory receptors (Modified from Vadakkan, 2013).*

postsynaptic terminal is expected to generate a hallucination that it is receiving sensory stimuli from the environment through its presynaptic terminal, as a systems property. This forms the building blocks (units) of internal sensations, namely semblions (see **Fig.1**). **A system of synaptically-connected neurons operating through IPLs having specific features (numbered 1-5 above) is expected to generate internal sensation of hallucination as a systems property by a passive (without needing energy) retrograde extrapolation.** Integral of all the units of internal sensations induced at large number of inter-LINKed spines in response to specific features of a cue stimulus generates memory of an item that was associated with it in the past within milliseconds. As experimenters, we can carry out this retrograde extrapolation (**Fig.1**) to estimate the sensory qualia. While the system properties of the nervous system allow generation of internal sensation of memory within milliseconds, a computer program may take very long time to complete such a huge computation. Furthermore, the increasing size of deep neural network designs of current artificial intelligence (AI) methods that use backpropagation needs high performing hardware platforms with very high energy efficiency of the memory needed. In summary, the natural intelligence (NI) is generated within milliseconds using a highly energy efficient mechanism.

At this point, one may ask, "How can we be sure that this is the operational mechanism whereby the system is generating internal sensations?" This question has been addressed since the derivation of this hypothesis by examining its ability to explain different features of the system. Use of this operational mechanism allowed explaining very large number of disparate findings from different levels of the system in an inter-connected manner (See **Table 2** on the first page of the website www.semblancehypothesis.org). This provides necessary confidence that induction of internal sensations in a system of neurons having specific features (numbered (1-5) in the above paragraph) is a first-principle of this system. **Generation of internal sensation can be viewed as an accidental coincidence that enabled animals to survive in a predator-prey environment. It got evolutionarily selected and is continuously being optimized.** Internal sensation can be viewed similar to any other first-principle, for example electromagnetism.

One may ask whether such passive retrograde extrapolation can occur when initial neuronal orders are lost, for example in phantom limb sensation. In a system having extreme degeneracy of inputs in firing a neuron (Vadakkan, 2019) and operating through IPL mechanism, reactivation of inter-LINKed spines within the remaining system is expected to generate internal sensation of a previous sensation that had sensory elements propagated through those IPLs present in the remaining system. It is necessary to maintain both a) narrow range of frequency of oscillating extracellular potentials, and b) normal state of consciousness for the system to induce specific semblances for accurate internal sensation. An explanation for internal sensation of consciousness and its tight association with the frequency of oscillating extracellular potentials is explained (Vadakkan, 2017).

Internal sensation occurs only in the context of a dominant state of continuous activation of the inter-LINKed postsynaptic terminal (D in **Fig.1**) from its presynaptic terminal. Therefore, the system has to shut down for at least one third of a day to update this dominant state so that it can continue to evoke hallucinations. This explains sleep (Vadakkan, 2016). As shown in the fifth paragraph, a derived mechanism that can explain all the properties of the system in an inter-connectable manner is the solution for the system. Where will this finding take us from here? The explanations that were possible (See **Table 2** on the first page of the website www.semblancehypothesis.org) provide necessary confidence to test its predictions. When verified, it provides us an opportunity to conduct the gold standard test to replicate the mechanism in an engineered system. Since memories were examined in its true nature as first-person internal sensations and since strict criteria were applied during different stages of its theoretical verification, it is reasonable to hope that it will stand all the tests. Until then, let us keep our scientific methods at the highest standards possible towards solving this system. It needs continuous questioning of the hypothesis at each and every stage.

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