A Mathematical Model for the Hippocampus — Toward the understanding of episodic memory

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ABSTRACT

How does the brain encode episode? Episodic memory has become interested in scientific society since finding of malfunction of formation of episodic memory caused by a damage of the hippocampus, especially, the part named CA1, which was clinically observed. On the other hand, simple memory has been explored in various contexts, especially, since Marr's theory for archecortex (incl. the hippocampus), where Marr considered the hippocampus, in particular, another hippocampal region named CA3 to be responsible for associative memory. However, a conventional mathematical model of associative memory guaranteed only a single association in case without any given rule for the order of successive association. We hypothesize that it stems from the lack of the consideration of inhibitory neuron. Actually, we obtain a successive association of stored patterns, which can be regulated by emergent chaotic activity of neural networks. A detailed observation of the architecture of CA3 ensures the presence of inhibitory neurons together with recurrent connections of excitatory neurons, the latter of which, together with a Hebbian learning algorithm, guarantees a single association. We also made a model for CA1 which has much less recurrent networks, but internal connections of excitatory and inhibitory neurons. We found a Cantor set in the output of CA1 neurons and clarified the functional significance of this set in relation to episodic memory. Our hypothesis is that CA1 is responsible for the formation of episodic memory in the form of Cantor coding of temporal patterns. Furthermore, to observe the Cantor set in real brain we conducted an experiment, using the rat hippocampal slice, collaborated with M. Tsukada and Y. Fukushima of Tamagawa university. We observed the Cantor-like sets and affine transformations in the data, which indicate the IFS-like mechanism can actually work in the process of episodic memory formation.

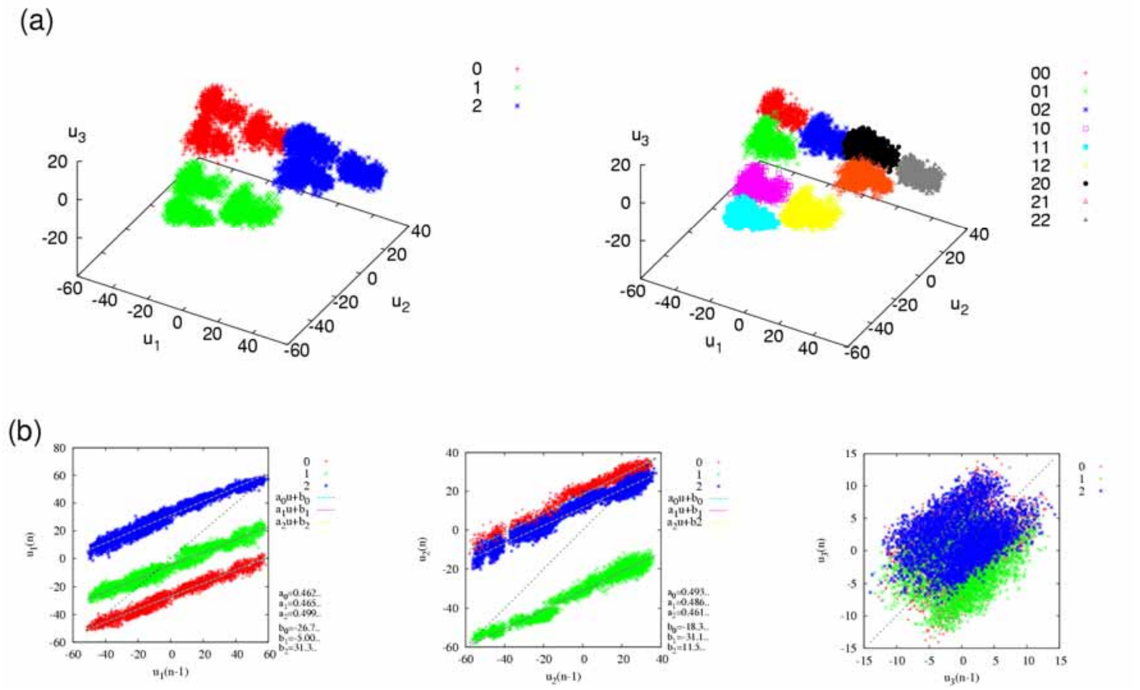

Figure 1 A cantor coding in the phase space constructed by membrane potentials of CA1 model neurons. Three different spatial patterns are repeatedly input from the CA3 to the CA1 neurons in a random order. (a) Self-similar structures are shown in the phase space. Each color indicates the input sequence of length one (left), and of length two (right). Principal Component Analysis is applied to the state vectors, and the principal components up to the third are shown. The states of the CA1 are hierarchically clustered in a self-similar manner according to the input sequences. (b) Return maps of each principal component. In each figure, return maps corresponding to different inputs are represented by different colors. In the first and second components, the maps are well described by contractive affine transformations, which indicates an appearance of the IFS-like dynamics producing fractal structure of the membrane potentials.

References

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