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A model for simultaneous encoding of "where" and "what" information in prefrontal cortex

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Introduction

In contrast to the classical theory of segregated cortical representation of information regarding the identity ("what") and location ("where") of a visual object, recent experimental results indicate that neurons in the primate prefrontal cortex convey combined information about both [1]. Moreover, this information was found to be maintained after stimulus removal, suggesting that these neurons contribute to working memory. To date, the mechanisms that underlie this integrated representation are unknown. In this study, we propose a model of a cortical network with biologically realistic properties that demonstrates a combined representation of stimulus identity and location.

Methods

The network is comprised of neurons embedded in a two-dimensional surface and involves two types of connections. The first, memory-related connections, have weights that are modified using Hebbian learning to store a set of memory patterns in the network. Based on experimental evidence related to the locality and sparseness of cortical connectivity [2], the probability of creating these connections is assumed to be a narrow Gaussian function of distance. Secondly, lateral inhibition is implemented through a Mexican hat type of interaction [3]; accordingly, each neuron projects inhibitory synapses on neurons that are located on a ring that is close, but not adjacent, to it.

Results

When the network is given a localized cue in the form of a short-time injected current, the attractor dynamics of the memory-related connections drive it to a state that retrieves the cued pattern, which codes the stimulus identity. At the same time, the lateral inhibition mechanism restricts the activity to a small area around the stimulated location, so the network exhibits an activity "bump" that codes the stimulus location [4]. Notably, our model behavior points to the existence of a tradeoff between the accuracy of the two types of information. When the radius of the lateral inhibition ring is small, high localization is achieved but the pattern retrieval is degraded. In contrast, when this radius is increased, the retrieval is improved but the activity spreads, so the "where" information is diminished.

Interestingly, we also find that the combined representation of stimulus identity and position can be obtained in networks with small world topology, in which a small fraction of the memory-related local connections is replaced by random, long-term connections [5]. This connectivity scheme, which was observed experimentally in brain networks [6], is considered more realistic than the fully local one. Furthermore, results of large-scale simulations indicate that the integrated representation is robust with regard to the signal-to-noise ratio of the cue.

Discussion

In our model, the combination of associative memory and lateral inhibition mechanisms enables the network to exhibit an activity profile that reflects both the "where" and "what" properties of a visual stimulus. The interplay between these mechanisms results in a tradeoff between the conveyed information qualities. Such tradeoffs are common in biological systems, and they reflect a constraint imposed by the universal principle of uncertainty.

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