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Neural networks with small-world topology are optimal for encoding based on spatiotemporal patterns of spikes

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Despite a wealth of knowledge at the micro- and macroscopic scales in neuroscience, the way information is encoded at the mesoscopic level of a few thousand neurons is still not understood. Polychronization is a newly proposed [1] mechanism of neuronal encoding that attempts to bridge this gap and that has been suggested to underlie a wide range of cognitive phenomena, from associative memory to attention and cross-modal binding. This encoding is based on millisecond-precision spatiotemporal firing patterns, corresponding to so-called polychronous groups, that have been shown to emerge spontaneously in networks of spiking neurons with axonal conduction delays and spike-timing-dependent plasticity.

Here, we investigate the effect of network topology on the ease and reliability with which input stimuli can be distinguished by such a network based on their encoding in the form of polychronous groups. We find that, while scale-free networks are unreliable in their performance, small-world and modular architectures perform an order of magnitude better than random networks at such discrimination tasks in a variety of situations. Furthermore, we find that these topologies introduce biologically realistic constraints on the optimal input stimuli for the system, performing best with inputs consistent with the topographic organization known to exist in many cortical areas. Finally, we investigate the capacity of such networks to distinguish between signals involving overlapping sets of input neurons and suggest that, for optimal performance, the network should be locally as well as globally small-world but should only show large-scale modularity.

These topological constraints on both networks and stimuli seem consistent with the first experimental findings on the cortical network architecture (see review [2] and references therein), suggesting that these are optimal for information processing through polychronization.

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References
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