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How Activity Regulates Connectivity: A Self-Organizing Complex Neural Network

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Abstract— Our model demonstrates the possibility for a complex directed network to self-organize on the basis of a feedback loop between activity and connectivity. Connections are assigned continuous weight values between 0 ("removed") and 1 ("established"), which vary according to temporal correlations between the states of activity of the nodes. Conversely, nodes possess binary states of activity, 0 ("inactive") or 1 ("active"), which result from the sum of input neighbor nodes weighted by the connections, via a probabilistic function (in a neuronal fashion). We start with a fully connected or uniformly random graph of weak weight values (e.g., .1) and irregularly pulse synchronous activity into a few nodes. This triggers the network to incrementally reshape itself toward a regime of higher order characterized by regular chains of 1-valued connections, called "synfire chains", surrounded by connections that dropped to 0 and were pruned. In parallel, activities also transition from a stochastic mode to a regular, wave-like propagation mode. In the ordered regime, the chains sustain and guide the waves, which in turn create and reinforce the chains. (Metaphorically, the chain/wave mutual reinforcement mechanism could be compared to a river digging its own bed.) We interpret this process as the first step in a possible self-structuration of cortical areas toward a multilevel, hierarchical network of networks. After their initial growth, and under the influence of external stimuli, chain motifs can dynamically bind and form new structural combinations at a higher level, which are able to support more complex modes of activity propagation. By this preliminary model, we suggest that neocortex is another instance of a "self-made tapestry" exhibiting pattern formation, as is the vast majority of natural complex systems—physical, chemical, biological or social. In this case, the patterns are spatiotemporal configurations of activity and connectivity, which could implement the representations or "mental objects" entertained by the mind.