Cliques of Neurons Bound into Cavities Provide a Missing Link between Structure and Function

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The lack of a formal link between neural network structure and its emergent function has hampered our understanding of how the brain processes information. We have now come closer to describing such a link by taking the direction of synaptic transmission into account, constructing graphs of a network that reflect the direction of information flow, and analyzing these directed graphs using algebraic topology. Applying this approach to a local network of neurons in the neocortex revealed a remarkably intricate and previously unseen topology of synaptic connectivity. The synaptic network contains an abundance of cliques of neurons bound into cavities that guide the emergence of correlated activity. In response to stimuli, correlated activity binds synaptically connected neurons into functional cliques and cavities that evolve in a stereotypical sequence toward peak complexity. We propose that the brain processes stimuli by forming increasingly complex functional cliques and cavities.

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1. INTRODUCTION

How the structure of a network determines its function is not well understood. For neural networks specifically, we lack a unifying mathematical framework to unambiguously describe the emergent behavior of the network in terms of its underlying structure (Bassett and Sporns, 2017). While graph theory has been used to analyze network topology with some success (Bullmore and Sporns, 2009), current methods are usually constrained to analyzing how local connectivity influences local activity (Pajevic and Plenz, 2012; Chambers and MacLean, 2016) or global network dynamics (Hu et al., 2014), or how global network properties like connectivity and balance of excitatory and inhibitory neurons influence network dynamics (Renart et al., 2010; Rosenbaum et al., 2017). One such global network property is small-worldness. While it has been shown that small-worldness optimizes information exchange (Latora and Marchiori, 2001), and that adaptive rewiring during chaotic activity leads to small world networks (Gong and Leeuwen, 2004), the degree of small-worldness cannot describe most local network properties, such as the different roles of individual neurons.

Algebraic topology (Munkres, 1984) offers the unique advantage of providing methods to describe quantitatively both local network properties and the global network properties that