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Does network analysis provide a novel kind of topological explanations in life and brain sciences?

In this talk I argue that network analysis provides a new topological style explanation as opposed to a mere new way to describe complex systems. I discuss the examples in which this mathematical tool is used to explain how synchronicity is achieved, i.e. flashing of the fireflies and neural synchronous firing.

In the last ten years network analysis has permeated special sciences like biology, ecology and neuroscience. Especially after the publication of several groundbreaking papers, some of which make very explicit proposals on how this mathematical tool can be used in special sciences, especially in biology and in medicine (Barabasi and Oltvai, 2004; Barabasi et al, 2011). The topological approach, as it will be labeled in this talk, studies structural and network properties of a complex system and their features of connectedness by using network analysis.

Network analysis is used to describe real-world systems, their elements and their interactions as graphs and then analyze them using various topological metrics (clustering, betweeness algorithms) to discover new elements of the system, to analyze and explain its dynamics or to explain some of its emergent properties, e.g. stability, resilience, robustness, functional features. A graph is defined simply as a set of nodes (vertices) linked by connections (edges) (Newman 2010; Fortunato 2010).

Topological explanations play a key role in explaining similarities in macroscopic behavior of complex systems that are fundamentally different in their microscopic workings and elements (Bullmore and Sporns 2009, p. 190). For example, the World Wide Web exhibits the same topology as the brain or transportation systems, or social networks, they are all small-world scale-free networks. But each one of these complex systems contains very different elements, i.e. brain regions, roads, web pages, which are completely independent from each other outside of network analysis. Can very different mechanisms inherent to each of these complex systems explain the similarity of their macroscopic behavior without reference to their topology?

The question that I want to focus on is whether network analysis in neuroscience and biology provides a novel kind of explanations which are based on certain properties of graphs that could be considered topological. Huneman (2010) argues persuasively that topological explanations complement or constrain mechanistic ones, especially in biology and ecology and provides clear-cut examples, especially the one with the stability of ecological communities (Huneman, 2010, pp. 219-222). On the other hand, Craver (manuscript) thinks there aren't genuinely novel topological explanations, or at the very least there aren't such explanations in neuroscience. He maintains that network analysis only provides descriptions which allow us to discover a new part of a causal structure of a system. He provides examples that corroborate this claim, but these examples do not undermine or prevent the claim that there are genuine topological explanations in neuroscience. I claim that network analysis can provide a novel topological kind of explanations, that can help us better understand the target phenomenon in the ways the more traditional approaches can't.

I analyze a variety of cases, such as explanation of synchronous neuronal firing that enables communication between various regions of the brain. One can appeal to Hodgkins/Huxley theory of action potential and ion channels, more generally one can appeal to a mechanism to explain how the communication between the neurons is established. But that does not explain how the synchronicity is achieved. What explains it are certain features of the network, e.g. small-world and scale-free features that explain the synchronous flashing of the fireflies in the jungle in the same way the neural synchronicity is explained.

I start from the claim that topological explanations explain without reference to causality but in reference to network properties of a system. Obviously, causal relations can be represented as edges in a graph, and that's a direct reference to causality. That is not what is meant here. What I actually mean to say is that whatever new description, analysis or an explanation of a system we get by using network analysis we get it from analyzing the properties of a graph representing that system and its interactions. We wouldn't be able to find them just by observing the complex system without any descriptive or analytic tools such as network analysis. Some neuroscientists even explicitly claim that structure determines the function and that just by describing the topology of a system (describing the metrics of a graph in network analysis) we can explain its function, dynamics and behavior (Bullmore and Sporns, 2009; Honey et al, 2010). To that effect, it would seem wrong to say that networks cause some higher order property of a system (stability, resilience, synchronicity, metabolic economy). Rather, the structural information embedded in the network's topology (various metrics of graphs) suffices to explain the phenomenon.

The question immediately arises: if all real networks have properties that are intrinsic to a graph representing their interactions, then can these mathematical features of graphs tell us something about target phenomena that cannot be described or discovered with more traditional representational tools? I argue that it does and that constitutes a truly novel way to understand certain phenomena rather than just to describe them.

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