TOPOLOGICAL COMMUNITIES IN COMPLEX NETWORKS

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Most complex systems can be captured by graphs or networks. Networks connect nodes (e.g. neurons) through edges (synapses), thus summarizing the system's structure. A popular way of interrogating graphs is community detection, which uncovers sets of geometrically related nodes. *Geometric communities* consist of nodes "closer" to each other than to others in the graph. Some network features do not depend on node proximity–rather, on them playing similar roles (e.g. building bridges) even if located far apart. These features can thus escape proximity-based analyses. We lack a general framework to uncover such features. We introduce *topological communities*, an alternative perspective to decomposing graphs [1]. By segregating topological properties of all nodes in a graph (panel **a**), we find clusters (panels **b-c**) that describe a network as much as classical communities (panel **d**), yet are missed by current techniques. In our framework, each graph guides us to its relevant features, whether geometric or topological. Our analysis complements existing ones, and could be a default method to study networks confronted without prior knowledge. Classical community detection has bolstered our understanding of biological, neural, or social systems; yet it is only half the story. Topological communities promise deep insights on a wealth of available data. We will illustrate this for relevant graphs across complex systems. Most complex systems can be represented as networks connecting nodes through edges, capturing the system's structure. Traditional community detection methods focus on identifying geometrically related nodes - those that are closer to each other than to the rest of the network. However, this approach may overlook important features that depend not on proximity but on nodes playing similar functional roles within the network, such as serving as bridges between different parts of the graph. We present a novel framework for identifying *topological communities* that captures these role-based relationships. Unlike conventional methods, our approach segregates nodes based on their topological properties rather than their geometric arrangement. This reveals clusters of nodes that perform similar functions within the network, even when they are not physically close to each other. These topological communities provide complementary information to traditional geometric communities, offering a more complete picture of a network's organization. The significance of this approach lies in its ability to automatically identify the most relevant features of a network without prior assumptions about what to look for. This makes it particularly valuable for exploring complex systems where we may not know in advance what patterns or relationships are important. We demonstrate the power of topological communities through applications to various real-world networks, showing how they reveal structural features that would otherwise remain hidden.

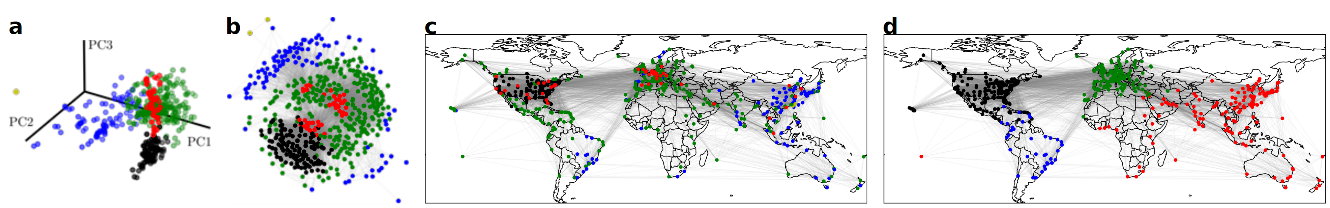

FIG. 1. (a) Topological properties of nodes in a sample network. (b-c) Identified topological communities. (d) Classical geometric communities for comparison.

[1] L.F. Seoane, *Topological communities in complex networks*, https://arxiv.org/abs/2409.02317 a b c d brigan@gmail.com 1, 2024).

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