

Topological Communities in Complex Networks

A Novel Perspective Beyond Geometric Communities

Adapted from Luís F. Seoane's Work

Motivation

- Networks model complex systems (e.g., biology, transport, neural systems).
- Community detection traditionally focuses on proximity.
- **Blind spot:** Distributed roles missed by geometric approaches.

Key Concept: Topological Communities (TC)

- **Definition:** TC clusters nodes with similar roles, regardless of proximity.
- Complements Geometric Communities (GC).
- Captures non-local roles like bridging or core-periphery structures.

① Measure Topological Properties:

- Centralities (e.g., eigenvector, betweenness).
- Connectivity metrics (cliques, clustering).
- Cycles and local features.

② Dimensionality Reduction:

- Principal Component Analysis (PCA).
- Nodes projected into eigenspace.

③ Clustering in PCA Space:

- Hierarchical clustering to identify TC.

Application: Watts-Strogatz Network

- Minimal Example: Watts-Strogatz (WS) graph.
- **Results:** TCs highlight nodes near "shortcuts" created by rewiring.

Application: Global Airport Network

- Analysis of 500 busiest airports worldwide.
- **Key TCs:**
 - U.S. domestic cluster.
 - Global hub backbone.
 - Distributed regional clusters.

Application: Human Connectomes

- Analysis of brain networks.
- **Findings:**
 - TCs reveal cortical clusters (visual, sensory).
 - Show symmetry/asymmetry across hemispheres.

Comparison: TC vs. GC

Geometric Communities (GC):

- Identify contiguous clusters.
- Limited to local proximity.

Topological Communities (TC):

- Identify distributed clusters.
- Capture functional roles.

Implications for Network Science

- Broader insights into biological, social, and technical systems.
- Complements GC in network analysis.
- Potential for automated graph exploration.

Future Directions

- Extend TC framework to:
 - Weighted and directed networks.
 - Multiplex and simplicial networks.
 - Applications in AI and machine learning.

Conclusion

- Topological Communities uncover a new dimension in network analysis.
- Promising for understanding diverse systems and inspiring future research.