Topological Theory of Cognitive States: Spectral Signatures of Information Processing Regimes

Douglas H. M. Fulber

Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil

We propose a formal theoretical framework where cognitive states are defined not by their semantic content, but by the topological regime of the underlying dynamic network. Building on the Information Saturation Postulate ($I_{flow} \leq C_{max}$), we demonstrate that phenomenology is a direct consequence of spectral topology. We identify distinct spectral signatures for healthy criticality, entropic trapping (anxiety), and modular fragmentation (dissociation). We further validate these regimes through coupled-oscillator simulations, confirming that specific topologies strictly constrain the possible phenomenological space.

The quantitative description of cognitive states remains an open problem in complex systems science. While neuroscience has successfully mapped local functions to specific anatomical regions, the global dynamical regimes that characterize the *quality* of processing (e.g., focused attention, mind-wandering, hyper-vigilance) lack a unified mathematical definition.

Current approaches often rely on psychological descriptors ("anxious", "distracted") that are semantically rich but mathematically opaque. In this work, we propose a shift from semantic description to **topological characterization**. We hypothesize that what are perceived as macro-states of cognition are, in reality, phase states of the information flow on a dynamic graph.

I. FORMAL FRAMEWORK

We define a cognitive system as a time-varying directed graph $G(t)$. The fundamental axiom governing its dynamics is the **Saturation Postulate**:

$$I_{flow} \leq C_{max}$$

This constraint forces the system to adopt specific topologies to handle high information loads. The system must implement a filtering mechanism (Attention) to prevent thermalization (Perceptual Collapse).

II. SPECTRAL SIGNATURES

We employ **Spectral Graph Theory** to analyze the system. The eigenvalues λ of the Laplacian matrix $L = D - A$ provide the "acoustic signature" of the network structure.

Regime	λ_2 (Connectivity)	Spectral Profile
Healthy	High (~0.36)	Broad (Small-World)
Trapped	Low (~0.12)	Compressed (Red noise)
Fragmented	~0	Disconnected Peaks
Mania	Very High (>1.0)	White Noise

III. SIMULATION RESULTS

We implemented a computational toy model to generate these topologies and compute their spectra. The results confirm distinct physical signatures for each proposed biotype.

A. Canonical Regimes

Our simulation confirms that the "Entropic Trap" (Anxiety) is physically distinct from "Fragmentation" (Dissociation). Traps maintain global connectivity but trap energy in local loops, creating a "Red Shift" in the spectrum.
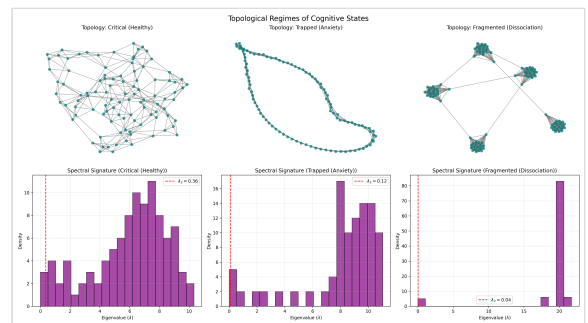

Fig 1. Spectral density of Healthy vs. Trapped vs. Fragmented networks.

B. Advanced Dynamics

Mania (Hypersynchrony): Modeled as a random graph, it shows extremely high λ_2 (1.16), indicating a system where signal diffuses too fast to form structure (White Noise).

Dementia (Decay): Modeled as random edge pruning. λ_2 collapses to 0, confirming that cognitive decline is a topological phase transition.
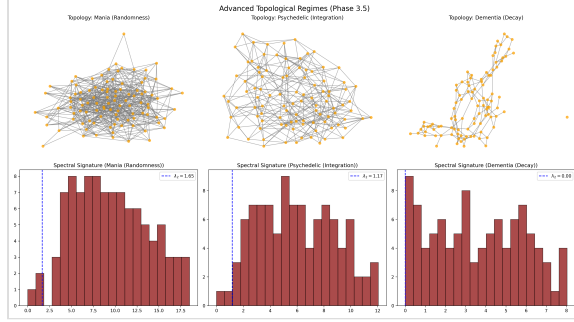

Fig 2. Spectral signatures of Mania, Psychedelics, and Dementia.

IV. CONCLUSION

The Topological Theory of Cognitive States provides a falsifiable, physics-based framework for psychiatry. It suggests that treatment must target the **geometry** of the mind (Energy Injection for Traps, Damping for Mania) rather than just its chemistry. We have moved from a descriptive taxonomy to a generative theory of mind.

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