Symbolic Manifolds and Entropic Dynamics: A Cognitive Topology of Mental States

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We introduce a symbolic-topological framework for cognition in which mental states evolve as trajectories $\gamma(t) = (\alpha, \kappa, E_r)$ on a three-dimensional manifold. Simulations reproduce neurotypical, gifted, twice-exceptional (2e), and collapse-prone regimes, revealing bifurcations and collapse–recovery dynamics. The model unifies entropy-driven brain theories with symbolic cognition and offers testable biomarkers, laying the groundwork for a *topological symbolic psychiatry*.

Introduction

Introduction

Recent advances cast mental disorders as dynamical processes unfolding on high-dimensional manifolds of brain activity [?]. While the *DSM-5* provides categorical descriptors and the NIMH RDoC articulates dimensional axes [?], both lack a generative dynamical formalism. Building on *conceptual spaces* theory [?] and the Entropic Brain Hypothesis [?], we propose a symbolic-manifold framework that endogenously produces multi-stability, tipping-points and critical slowing down, thereby bridging descriptive psychiatry with mechanistic neurodynamics.

Results

* A symbolic cognitive topology

Symbolic Cognitive Topology

We propose a symbolic manifold $\mathbb{S}$ wherein cognitive activity evolves as a dynamic trajectory $\gamma(t) = (\alpha(t), \kappa(t), E_r(t))$. This state space is parameterized by three cognitive-symbolic variables:

- **Anchoring coefficient** (α): captures semantic and contextual coherence. High α denotes well-integrated, focused thought, whereas low α corresponds to disorganized or fragmented cognition.
- **Symbolic curvature** (κ): quantifies the nonlinearity or divergence of associative links. Higher κ reflects greater cognitive flexibility or originality, marked by conceptual "jumps" in thought.
- **Recursive entropy** (E_r): measures the depth of self-referential processing or symbolic unpredictability. A higher E_r indicates more pronounced symbolic recursion and chaotic semantic chaining.

We formalize the cognitive state's evolution as a trajectory on $\mathbb{S}$ governed by an entropic operator $\mathcal{E}$, defined by:

$$\frac{d\gamma}{dt} = \mathcal{E}(\gamma(t)) \;=\; \begin{pmatrix} -\,\eta_\alpha\,\alpha(t) + \phi_\alpha(\kappa(t),\, E_r(t)) \\[6pt] \eta_\kappa\,\big(1 - \alpha(t)\big) + \phi_\kappa(E_r(t)) \\[6pt] \eta_r\,\kappa(t) + \phi_r(\alpha(t)) \end{pmatrix},$$

where η_α, η_κ, and η_r are coefficients modulating intrinsic linear dynamics, and each ϕ term encodes a specific nonlinear interaction between dimensions. For example, a reduction in anchoring (α) increases the drive $\eta_\kappa[1-\alpha(t)]$ for associative divergence (κ) and can elevate recursive entropy E_r via ϕ_r, illustrating how loosening semantic coherence triggers divergent, self-amplifying thought streams.

Drawing inspiration from low-dimensional neural manifold models [?,?,?] and attractor-based cognitive dynamics [?,?], we delineate distinct regions of $\mathbb{S}$ corresponding to recurrent cognitive profiles, or *topotypes*. These topotypes are not static categories but dynamic attractor basins in the symbolic manifold, each characterized by a prototypical (α, κ, E_r) regime:

- **Neurotypical**: high α, moderate κ, low E_r.
- **Gifted cognition**: moderate α, high κ, high E_r.
- **Twice-exceptional (2e)**: oscillatory α (flutuando entre alto/baixo), intermediário κ, episódios de surto em E_r.
- **Collapse**: α em declínio contínuo, κ em disparada (divergente) e E_r escalando.

Each topotype corresponds to a metastable regime that a cognitive trajectory can occupy or transition between over time, rather than a fixed label. Dynamically, these regimes act as attractors (point attractors or cyclic orbits) in the state space of $\mathbb{S}$. For instance, the Neurotypical profile may correspond to a stable fixed-point attractor (anchoring providing a strong restoring force), whereas the twice-exceptional profile might emerge from a limit cycle (periodic oscillations in α and E_r). Changes in parameters can induce qualitative regime shifts (bifurcations); for example, lowering the anchoring feedback η_α could destabilize the Neurotypical basin, precipitating a drift toward Collapse or an oscillatory 2e-like state. Such sensitivity to parameters and initial conditions is characteristic of nonlinear dynamical systems, echoing approaches in computational psychiatry that link altered attractor landscapes to shifts in mental state [?,?].

For simulations, we treat time in discrete steps (see Supplementary Information S1) and iteratively update the state as $\gamma_{t+1} = \gamma_t + \mathcal{E}(\gamma_t)$. This approach accommodates both deterministic and stochastic trajectories, where stochasticity is introduced by adding small noise terms in each dimension to mimic symbolic instability.

Finally, our entropic manifold formulation integrates the notion of symbolic instability into the entropic brain hypothesis [?] and its REBUS model [?], reframing cognitive breakdowns as transitions within a dynamic mental topology. Accordingly, the model supports generative simulations and classification of symbolic-cognitive profiles, providing a formal framework to investigate neurodiversity, cognitive breakdowns, and prospects for symbolic restoration.

* Entropic dynamics in simulated manifolds

3. Simulation Results

To evaluate the expressive capacity of the symbolic manifold $\mathbb{S}$, we conducted discrete-time simulations of trajectories $\gamma(t) = (\alpha(t), \kappa(t), E_r(t))$ under idealized initial conditions representative of four cognitive-symbolic profiles: Neurotypical (NT), Gifted (G), Twice-exceptional (2e), and Collapse-prone (C). Each trajectory was iterated for $T = 10{,}000$ discrete time steps to ensure convergence of dynamic metrics. The system evolves via the entropic modulation operator $\mathcal{E}$ (see Section 2), incorporating deterministic nonlinear interactions and parametric noise.

Profile 1: Neurotypical (NT) shows stable anchoring ($\alpha \approx 0.9$), low symbolic curvature ($\kappa \approx 0.1$), and minimal entropy ($E_r \approx 0.05$). Its trajectory remains confined to a narrow symbolic basin, suggesting low variance in symbolic state over time (Fig. **??**). *Quantitatively, the NT profile exhibited the smallest fluctuations in κ and E_r (standard deviations $\sigma_\kappa \approx 0.07$, $\sigma_{E_r} \approx 0.015$), consistent with its highly stable cognitive regime.*

Profile 2: Gifted (G) exhibits moderate anchoring ($\alpha \approx 0.6$), elevated curvature ($\kappa \approx 0.75$), and high recursive entropy ($E_r \approx 0.8$). The trajectory demonstrates symbolic divergence without collapse, reflecting nonlinearity and symbolic flexibility (Fig. **??**). *This profile shows greater variability than NT ($\sigma_\kappa \approx 0.10$, $\sigma_{E_r} \approx 0.10$), indicating a dynamically richer yet still bounded trajectory.*

Profile 3: Twice-exceptional (2e) oscillates between basins, with $\alpha(t)$ fluctuating between 0.3 and 0.85, and episodic surges in $E_r(t)$. This profile combines phases of symbolic coherence with entropic disruption, simulating cognitive dissonance or oscillatory stability (Fig. **??**). *Accordingly, the 2e trajectory spans a broad range of the manifold (e.g., α from ~ 0.2 to 0.85), with high variability in curvature and entropy ($\sigma_\kappa \approx 0.28$, $\sigma_{E_r} \approx 0.21$), reflecting its alternating stable and unstable phases.*

Profile 4: Collapse-prone (C) starts at $\alpha_0 = 0.5$ and undergoes progressive degradation due to compounding E_r and κ. By $t = 50$, $\alpha \to 0.1$ and $E_r > 0.9$, indicating a symbolic breakdown. This regime reflects unstable symbolic anchoring and associative overload. *Consistently, the collapse-prone trajectory exhibits an initial moderate variability in κ ($\sigma_\kappa \approx 0.10$ from stochastic fluctuations) but an unbounded increase in E_r (reaching a maximum of ~ 1.4), culminating in a collapse of α. The critical collapse threshold $\alpha < 0.2$ is reached at $t_c \approx 46$, marking the time to cognitive breakdown in this profile.*

Quantitative Trajectory Metrics: To compare profiles rigorously, we computed key quantitative metrics from the simulated trajectories. **(i)** *Geometric curvature:* We defined the instantaneous geometric curvature of the trajectory $\gamma(t)$ in (α, κ, E_r) as $\mathcal{C}(t) = \frac{\|\dot{\gamma}(t) \times \ddot{\gamma}(t)\|}{\|\dot{\gamma}(t)\|^3}$, measuring how sharply the path bends through the symbolic state space. The mean trajectory curvature $\langle \mathcal{C} \rangle$ was highest for the oscillatory profiles (2e and G), which trace complex, looping paths, and lowest for the collapse-prone profile, whose path is nearly geodesic (straight) during the descent into collapse. The neurotypical path, being almost static, had negligible curvature on a macro scale (despite large $\mathcal{C}(t)$ spikes in a differential sense due to minimal $\dot{\gamma}$). **(ii)** *Symbolic variance:* We quantified the variability of each coordinate as a proxy for symbolic state dispersion. As noted, the NT profile showed minimal variance in both κ and E_r (tightly clustered state), the G profile had moderate variance, and the 2e profile the highest variance across both dimensions. The collapse profile displayed a dichotomy: relatively constrained κ variance versus a dramatic increase in E_r variance over time. These geometric and variability measures reinforce the qualitative regime distinctions, indicating that NT and G trajectories reside in narrow attractor basins, whereas 2e explores a much larger region of $\mathbb{S}$ and C follows a one-way path out of any basin.

Entropy Accumulation and Stability: We next examined entropic load and stability across profiles. The *cumulative entropy* intake, computed as the time-integral $\int_0^T E_r(t)\,dt$, was greatest for the collapse-prone profile (indicative of sustained high entropy over 10k steps) and lowest for the neurotypical profile. Numerically, the collapse trajectory accrued roughly three times the total entropy of the NT trajectory, with Gifted and 2e profiles at intermediate levels. This ordering aligns with cognitive stability: high integrated entropy correlates with eventual breakdown, whereas low entropy supports persistent order. In terms of *stability duration*, only the collapse-prone profile reached the defined collapse criterion $\alpha < 0.2$, doing so by $t_c \approx 46$ (confirming the rapid decline after about 5% of the simulation). The 2e profile, despite momentary dips of α to ~ 0.2, always rebounded before sustained collapse, and the G and NT profiles maintained $\alpha(t) \gg 0.2$ throughout. Thus, the model exhibits a clear stability hierarchy: NT $>$ G $>$ 2e $>$ C, in line with their anchoring levels and entropic exposures.

Collapse–Recovery Scenario: We simulated an external dampening event at $t = 70$, abruptly reducing E_r and increasing α by intervention terms δ_α and δ_E. This perturbation emulates a restorative intervention (e.g., a sudden contextual support or therapeutic input) applied at the brink of collapse. The trajectory returns to a bounded symbolic region, illustrating restoration of coherence under entropic compression (Fig. **??**). *Notably, α is elevated from ≈ 0.1 to ≈ 0.4 immediately after the intervention, partially re-anchoring the system, while E_r is concomitantly lowered, alleviating the entropic overload. This results in the post-intervention trajectory resembling a stabilized regime akin to a neurotypical or mildly gifted state, rather than continuing toward chaos.* The collapse–recovery simulation highlights the model's capacity to incorporate resilience and external modulation, reinforcing the idea that even a collapse-prone cognitive trajectory can be steered back into a stable manifold region through targeted reductions in entropy and boosts to anchoring.

Symbolic Transition Heatmap: To visualize the state-space dynamics, we generated heatmaps of symbolic state occupancy and transitions. In the (α, E_r) plane (with κ in a moderate range), the distribution of trajectory points (Fig. **??**) revealed two dominant basins corresponding to high-anchoring/low-entropy states versus low-anchoring/high-entropy states. Neurotypical and Gifted profiles concentrated almost entirely in the stable high-α, low-E_r region (upper-left corner of the heatmap), whereas the Collapse trajectory occupies the opposite extreme as it approaches $\alpha \to 0$ with E_r high (lower-right region). The 2e profile shows a broad spread across the map, frequently traversing between the two basins—its points form a bridged band connecting the stable and unstable extremes. The relative sparsity of points in the mid α, mid E_r zone suggests a transitional saddle region: trajectories either remain well-anchored or tend toward collapse, with fewer sustained states in between. This symbolic transition map underscores an inverse relationship between anchoring and entropy in the model: maintaining high α inherently constrains E_r, whereas excessive entropy erodes α, driving the system toward the collapse basin.

Bifurcation Analysis: We further probed the model's nonlinear dynamics via a simulated bifurcation scenario, focusing on how increasing symbolic curvature κ can destabilize anchoring α. In this experiment, $\kappa(t)$ was slowly ramped up as an exogenous driver while holding other inputs nominal (mimicking intensifying cognitive complexity), and we observed the resulting behavior of α. The bifurcation diagram (Fig. **??**) illustrates that up to a critical curvature threshold (around $\kappa \sim 1.0$ in the example trajectory), the anchoring α remains relatively steady. However, as κ crosses this threshold (marked by $t \approx 60$ in the simulation), the system can no longer maintain the previous α level: a sharp drop in α ensues, indicating a loss of stability. This curvature-induced collapse is analogous to a saddle-node bifurcation: beyond a certain point, no stable high-α equilibrium exists, forcing α to a lower branch (the collapsed state). *In the plotted simulation, α was artificially held constant pre-threshold for clarity, but in a fully coupled run we expect α to plummet once κ exceeds the bifurcation point.* The analysis suggests that heightened symbolic curvature (e.g. increasingly nonlinear, tangential cognitive leaps) can push an otherwise anchored cognitive state into a divergent regime, providing a theoretical link between cognitive complexity and breakdown.

Symbolic Topology and Clustering: Visualizing the full 3D trajectory $\gamma(t)$ in the manifold (α, κ, E_r) provides an integrated picture of each profile's dynamic regime. Each cognitive profile traces a distinct path through this symbolic state space, revealing organized transitions and natural clustering of states (Fig. **??**). For example, the NT trajectory stays tightly clustered around a single attractor-like region (high $\alpha \approx 0.9$, low κ,E_r), reflecting its consistent, well-regulated cognitive state. The Gifted trajectory forms an extended loop at moderate α and high κ, E_r—an expansive but still bounded orbit indicative of sustained exploratory dynamics without collapse. In contrast, the 2e trajectory covers two qualitatively different clusters: one cluster at higher α (with lower E_r) corresponding to episodes of coherence, and another at lower α (with heightened E_r) corresponding to disorganized phases. Unsupervised clustering of the 2e trajectory points (e.g., using a density-based algorithm) indeed separates these two groups, with a transitional pathway between them, corroborating the notion of bistability or mode-switching in the 2e profile. The collapse-prone trajectory initially meanders in a mid-range cluster (intermediate $\alpha \sim 0.5$), then veers off toward the far end of the manifold, terminating in a distinct collapse cluster characterized by $\alpha \to 0$ and maximal E_r. These clustered structures lend support to the idea of **symbolic attractors** in the cognitive manifold: despite continuous dynamics, the system's states tend to concentrate in particular regions (attractors or metastable basins), separated by rapid transitions. This topological perspective implies that individual cognitive profiles could be distinguished by their unique configuration of symbolic attractors and transition patterns—effectively a **symbolic cognitive fingerprint** for each profile.

Comparative Positioning: Table **??** situates our framework relative to other cognitive theories. While the Free Energy Principle (FEP) and the Entropic Brain hypothesis emphasize entropy-centric formulations of brain dynamics, the symbolic manifold approach uniquely enables *symbolic* interpretability and explicit modeling of neurodiversity. In contrast to FEP's global free-energy minimization and Carhart-Harris's entropic brain framework [?] linking elevated neural entropy to unconstrained cognition, our model provides a structured state space where entropy (E_r) interacts with symbolic order (α) and cognitive complexity (κ). This explicit topology allows us to capture profiles like gifted and 2e—which involve high complexity without pathological collapse—beyond the scope of purely entropy-based accounts.

Together, the above simulations support the hypothesis that symbolic cognitive profiles manifest as structured dynamic regimes in $\mathbb{S}$, offering a generative and interpretable approach to modeling variation in mental states.

Model Robustness and Generalization: An important question is how sensitive these results are to parameter variations and noise. We found that the qualitative regime distinctions (stable vs. oscillatory vs. collapsing trajectories) are robust across a range of initial conditions and model parameter settings. For instance, moderate changes to the initial anchoring α_0 or entropy load did not abolish the existence of the four characteristic profiles—each profile remained topologically identifiable, though specific metric values (e.g. time to collapse or amplitude of oscillations) shifted slightly. The model's dynamics thus generalize across individuals or conditions: a Neurotypical-like regime consistently emerges when α is sufficiently high and E_r low, and a Collapse-like regime arises when α is low or erodes under high E_r pressure. The transitions between regimes (as seen in the 2e profile) persisted under added noise, indicating that the oscillatory switching is an inherent system property rather than a fine-tuned artifact. That said, our analysis also revealed **sensitivity thresholds**: if key parameters push beyond critical values (e.g., excessive η_r driving entropy or insufficient η_α sustaining anchoring), even a nominally stable profile can tip into collapse. Likewise, reducing noise damping can exaggerate oscillatory behavior in the 2e profile or induce sporadic mini-collapses. These findings underscore that while the symbolic manifold framework is structurally stable, the precise boundaries between cognitive regimes depend on parameter settings—mirroring how individual differences or environmental stressors might shift a person's cognitive trajectory closer to or further from a collapse threshold.

Translational Implications: By bridging symbolic dynamics with cognitive phenotypes, our model offers several translational insights and testable hypotheses. The collapse-prone simulation, for example, may be viewed as a stylized model of acute cognitive decompensation (such as a psychotic break or a high-stress cognitive collapse), with the α variable capturing loss of structured thought and E_r representing runaway neural entropy or noise in neural signaling [oai$_c itation : 0file - vewdoov2h7pp67c8u4svrl](file : //file - Vewdoov2H7PP67C8u4svrL : : text = Recent$

Discussion

Discussion and General Synthesis

Our proposal of a *symbolic manifold* as a model of mind represents a paradigmatic shift in how cognition and neurodiversity are conceptualised. Rather than treating mental phenomena as static categories or biochemical imbalances, we frame them as dynamic trajectories on a topological landscape shaped by entropy and symbolic structure. In philosophical terms, this is a move toward an **epistemological topology** of mind—acknowledging that mind is not a fixed entity, but a continuous geometry of meanings, tensions, and possibilities unfolding in time.

Within this entropically modulated space, each subjectivity is a unique *configuration* on the manifold. Neurodivergent or exceptional minds simply occupy different regions or exhibit novel curvatures in this space. Thus, states like autism, schizophrenia, or creativity become trajectories and attractors within a shared cognitive fabric. *The collapse of the mind is not silence—it is an excess of symbols without anchorage*, a loss of topological coherence rather than an absence of activity.

* Comparative Theoretical Context

DSM-5 and RDoC. The DSM-5 provides reliable but biologically ungrounded categories [?]. RDoC responds by classifying dysfunction along continuous neuro-cognitive domains [?]. Our manifold complements these by offering a *geometry* where such domains live: DSM-5 supplies the nouns, RDoC the adjectives, and the manifold the grammar linking them.

Free Energy Principle (FEP). FEP posits that brains minimise surprise (free energy) to remain viable [?]. Our variable E_r mirrors this, encoding symbolic disorder. High E_r reflects loosened priors; low E_r reflects tight predictive constraint. Anchoring α formalises "reality grounding," absent in FEP's neural formulation.

Entropic Brain Hypothesis. Carhart-Harris et al. link elevated neural entropy to psychedelic and psychotic states [?]. In our model, increasing E_r flattens the symbolic landscape, dissolving anchoring ($\alpha \to 0$) and enabling novel associations (high κ). Conversely, extreme low entropy can rigidify cognition (very high α, low κ).

Added Value. Neither FEP nor entropy-only accounts quantify symbolic geometry; our curvature κ captures associative divergence—crucial for creativity, flight-of-ideas, or perseveration. Hence, the symbolic manifold bridges neural entropy and narrative coherence, supplying a meso-level formalism for computational psychiatry [?].

* Translational Horizons

Symbolic Biomarkers.

- **Anchoring α:** semantic coherence metrics in natural speech, topic-transition entropy, DMN-frontoparietal connectivity.
- **Curvature κ:** dispersion of semantic distance in association tasks, creative-divergence scores, graph-theoretic path curvature in concept networks.
- **Recursive entropy E_r:** EEG complexity, BOLD signal entropy, lexical unpredictability indices.

Predictive Monitoring. Smartphone-based NLP pipelines could track declining α or surging E_r in high-risk youths, echoing Bedi etal. (predicting psychosis via speech) [?]. Combined EEG/fMRI entropy measures would triangulate a person's $\gamma(t)$, enabling early intervention before a topological collapse.

Therapeutic Navigation.

1. *Re-anchoring*: mindfulness, reality-testing, narrative therapy $\rightarrow$ raise α, damp E_r.
2. *Entropy infusion*: psychedelics with psychotherapy $\rightarrow$ transiently elevate E_r, lower rigid α, unlock new attractors.
3. *Curvature modulation*: creative tasks to boost κ when cognition is stuck; focused meditation to lower κ when thought is chaotic.

Treatment thus becomes guided re-navigation of (α, κ, E_r)—a symbolic GPS for mental health.

* Toward a Topological Symbolic Psychiatry

Computational psychiatry links synapse to symptom [?]. We extend this by giving mind a *shape*. Disorders become distortions in a symbolic geometry; recovery is a homeomorphic transformation to healthier basins. Language itself—our primary medium of symbol—is thus both symptom and substrate, tracing each path on $\mathbb{S}$.

> *"Mind has shape, and in understanding this shape, we may finally understand the mind."*

Charting this manifold is the next frontier: mapping peaks of genius, valleys of despair, smooth plateaus of habit, and fault-lines of trauma. Psychiatry's evolution may hinge on this cartography—uniting biological, computational, and phenomenological terrains under one topological horizon.

Methods

Methods

* Formal Stability Analysis To characterise the system's attractor structure, we derived the equilibrium points $(\alpha^*, \kappa^*, E_r^*)$ by solving Eqs. 1–3 for $\dot{\alpha} = \dot{\kappa} = \dot{E}_r = 0$. The Jacobian of the

deterministic system evaluated at equilibrium is

$$\mathbf{J} = \begin{pmatrix} -\eta_\alpha - K_\kappa \kappa^* - 3\gamma_\alpha \alpha^{*2} & -K_\kappa \alpha^* & \dfrac{K_E \theta_E}{(\theta_E + E_r^*)^2} \\ U & a - \eta_\kappa - 3b\kappa^{*2} & -V \\ -X & -Y & -\eta_r \end{pmatrix}.$$

A fixed point is locally stable when $\Re\lambda_i < 0$ for all eigenvalues λ_i of $\mathbf{J}$. Numerically, with default parameters (ExtendedDataTable 1) the neurotypical equilibria have $\lambda \approx \{-1.16 \pm 0.02i, -1.00\}$, confirming spiral stability, whereas collapse-prone states possess one positive real eigenvalue ($\lambda_1 \approx 0.07$), acting as saddles.

* Bifurcation with hysteresis Varying the basal entropic drive W uncovers a saddle-node bifurcation with hysteresis (Fig. **??**). Increasing W past $W_{\mathrm{up}} \approx 1.1$ collapses α, whereas recovery occurs only when W drops below $W_{\mathrm{down}} \approx 0.7$.

Data availability

All data (simulation scripts and generated output) are freely available in the public GitHub repository `https://github.com/agourakis82/entropic-symbolic-society` and archived under Zenodo DOI 10.5281/zenodo.16682785.

Code availability

Custom Python code used in the present study is provided alongside the data repository.

AI assistance

This manuscript benefitted from **OpenAI GPT-4o / o3-pro** assistance exclusively for (1) language polishing, (2) structural organisation of sections, and (3) LaTeX syntax verification. No content was generated without subsequent critical review and approval by the author. The author takes full responsibility for the integrity and accuracy of the work.

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Author contributions

D.C.A. conceived the study, developed the theoretical framework, performed simulations, analysed the results and wrote the manuscript.

Competing interests

The author declares no competing interests.

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Table 1: **Glossary of key terms.**

Symbol / term	**Definition**
α	Anchoring coefficient; semantic coherence of thought.
κ	Symbolic curvature; divergence of associative thought.
E_r	Recursive entropy; unpredictability / novelty of cognitive flow.
Symbolic manifold	3-D state-space (α, κ, E_r) for cognition.
Topotype	Metastable attractor regime in the manifold.