A Preliminary Mapping Between Ring Attractor Dynamics and the Attractor Framework

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Abstract

The attractor framework proposes that persistence under perturbation is the fundamental mark of reality, and that corrective permeability (κ)—the rate at which a system dissipates perturbation and returns to its basin—is a key diagnostic variable distinguishing reality-aligned from fantasy attractors. A recent computational neuroscience study by Chen et al. (2024) developed a ring attractor network with synaptic dynamics that exhibits structural parallels with these concepts. This paper offers a preliminary, post-hoc mapping between the ring attractor model and the attractor framework. The network's synaptic recovery speed (α) is proposed as a candidate analogue for corrective permeability (κ). The network's transition from weighted cue integration to winner-take-all dynamics maps onto the framework's distinction between reality-aligned and sealed attractor behavior. The network's multimodal integration and bistable perception also bear structural resemblance to constraint field navigation and attractor switching, though bistable perception as attractor switching is an existing interpretation in computational neuroscience. The mapping is offered as a set of testable correspondences for future formal investigation, not as

independent validation of the framework. The attractor framework remains a self-published construct awaiting independent peer review.

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1. Introduction: A Post-Hoc Mapping

The attractor framework (Galida, 2026a) is a unified naturalistic ontology grounded in the principle that persistence under perturbation is the mark of reality. Its central diagnostic concepts are corrective permeability (κ), defined in Table 1, and the distinction between reality-aligned and fantasy attractors. The framework was developed independently through philosophical inquiry, systems theory, and N=1 self-engineering experiments. It is self-published and has not yet undergone independent peer review.

A recent computational neuroscience study by Chen et al. (2024) developed a ring attractor network with synaptic dynamics that exhibits behaviors structurally similar to those described by the framework. The present paper does not claim that Chen et al. independently validated the framework; they had no knowledge of it, and their model was built within an established tradition of ring attractor research (Amari, 1977; Zhang, 1996; Skaggs et al., 1995). Rather, this paper offers a post-hoc mapping between the two, identifying structural parallels and proposing testable correspondences for future investigation. The value of such a mapping lies in the potential for the framework's qualitative claims to be anchored in a mathematically specified, biologically validated model, and for the ring attractor's quantitative relationships to be extended, hypothetically, into the domains the framework addresses.

Table 1: Key Framework Terms and Operational Definitions

Term	Definition
Dissipative attractor	A system that exports entropy while converging toward a stable basin
Basin	The minimum-energy configuration toward which the system evolves (in physical systems; the analogue in cognitive and social systems is structural, not energetic)
Corrective permeability (κ)	The rate at which a system dissipates perturbation and returns to its basin. Defined here as $\kappa = 1/\tau\_recovery$, where $\tau\_recovery$ is the time to return to baseline after a specified perturbation. This definition currently requires a specified perturbation magnitude and an independently established baseline for each domain of application. The measurement of κ in cognitive and social systems is an unresolved methodological challenge.
Reality-aligned attractor	A system with high κ that integrates perturbations and updates its basin
Fantasy attractor	A system with low κ that seals against perturbations, often via reframing or winner-take-all dynamics

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2. The Ring Attractor Model

Chen et al. (2024) developed a ring attractor network with asymmetrical neural connections and adaptive synaptic processing. Excitatory neurons are recurrently connected in a functional ring, connected to a uniform inhibitory neuron. The key innovation is the incorporation of synaptic dynamics: available presynaptic resources are depleted at a rate governed by β and recover at a speed governed by α.

The model’s behavior is governed by recovery speed α. When α is fast (low recovery time), the network sustains a stable activity bump indefinitely, even without inputs—a self-maintaining basin. When α is slow, the bump decays. The duration of sustainable activity exhibits a negative nonlinear relationship with α (Chen et al., 2024, Fig. 3D).

The network receives exogenous external cues (modeled as Gaussian functions representing sensory inputs) and endogenous shifting signals (self-motion). Its behavior—integration, competition, tracking, switching—depends on cue conflict and certainty.

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3. Structural Parallels

3.1 Synaptic Recovery α as a Candidate Analogue for Corrective Permeability κ

The ring attractor’s persistence depends on α. Fast recovery yields a stable, persistent bump; slow recovery leads to decay. The framework’s corrective permeability κ describes how quickly a system recovers from perturbation and returns to its basin. The parallel is structural: both α and κ govern the resilience of a stable state.

We propose a testable correspondence: $\kappa \sim f(\alpha)$, where the functional form f is unknown and may not be linear. A specific candidate form is $\kappa = 1/\tau\_decay(\alpha)$, where τ_decay is the bump duration as a function of α. This mapping is hypothetical. It has not been formally derived, and the functional relationship between synaptic recovery and cognitive-level corrective permeability is unknown. It is offered as a bridge for future formal work, not as an established result.

3.2 Weighted Integration vs. Winner-Take-All → Reality-Aligned vs. Sealed Attractor

When cue conflicts are small, the ring attractor integrates them via weighted averaging. When conflicts exceed a critical threshold (≈1.4 radians for $\sigma_1=0.8$, $\sigma_2=1$), it switches to winner-take-all mode. This transition is quantified.

The framework describes a similar dynamic: high-κ systems integrate perturbations (reality-aligned); low-κ systems seal against them (fantasy attractor). The ring attractor's conflict threshold provides a candidate mathematically specified analogue for the framework's qualitative tipping point. Whether the same quantitative relationship holds in cognitive or social attractors is an open hypothesis.

3.3 Multimodal Integration → Constraint Field Navigation

The ring attractor integrates cues from multiple modalities, weighting by certainty and resolving conflicts dynamically. This is structurally analogous to the framework's concept of a dissipative attractor navigating a constraint field. The grouping approach for more than two cues—small conflicts integrated first, then competition among groups—suggests hierarchical constraint navigation, a dynamic the framework predicts but has not operationalized in formal terms. Of the four parallels identified in this section, this is the most loosely specified and the most in need of formal development before quantitative correspondences can be established.

3.4 Bistable Perception → Attractor Switching (with Prior Art)

Under ambiguous cues and slow recovery, the ring attractor exhibits spontaneous alternation between two perceptual interpretations. The framework describes this as attractor switching. However, the interpretation of bistable perception as attractor dynamics is not novel to the framework; it is a standard account in computational neuroscience (Deco & Rolls, 2006; Moreno-Bote et al., 2007). The framework's contribution is the extension of this switching concept to cognitive and social systems, an extension that remains a research hypothesis rather than an established result.

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4. Hypothetical Implications (Research Hypotheses)

The structural parallels documented above suggest several testable hypotheses. These are not supported by Chen et al. (2024) and require independent investigation. They are listed in descending order of current testability.

1. **The conflict threshold hypothesis.** The framework’s transition from belief integration to belief sealing may exhibit a quantifiable conflict threshold, analogous to the ring attractor’s 1.4 radian transition point. This could be tested in belief-updating paradigms where the degree of conflict between existing beliefs and new evidence is systematically varied, and the point of transition from integration to rejection is measured. Of the three hypotheses presented here, this is the most amenable to current experimental methods.
2. **The κ-α correspondence hypothesis.** If κ and α share a functional relationship, then interventions that modulate synaptic recovery (neuromodulators, pharmacological agents) should analogously modulate corrective permeability in cognitive systems. This hypothesis requires operationalizing κ in cognitive domains, a measurement challenge acknowledged in Table 1.
3. **The hierarchical navigation hypothesis.** Complex belief systems facing multiple simultaneous perturbations may exhibit hierarchical resolution strategies similar to the ring attractor’s grouping approach for multiple

cues. This hypothesis is the most speculative of the three and requires further specification of the domain of application (e.g., small-group decision-making, multi-source evidence integration in individual cognition) before it can be tested.

These hypotheses are speculative. They are offered as potential bridges between the framework and empirical research programs, not as established implications.

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5. Limitations

This mapping is post-hoc. The ring attractor model was not designed to test the attractor framework, and the correspondences identified here were constructed after the fact. The framework itself remains a self-published construct that has not undergone independent peer review. The operational definitions of κ, while stated here, have not been validated against empirical data in cognitive or social domains. The measurement of κ in these domains requires specifying perturbation magnitudes and establishing independent baselines, challenges that are currently unresolved. The value of this paper lies not in demonstrating validation, but in proposing concrete, testable correspondences that could, if investigated, either strengthen or falsify the framework’s claims.

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6. Conclusion

The ring attractor model of Chen et al. (2024) provides a mathematically specified, biologically validated system that bears structural parallels with the attractor framework.

Synaptic recovery speed α is proposed as a candidate analogue for corrective permeability κ. The transition from integration to winner-take-all maps onto the framework’s reality-aligned/fantasy distinction. Multimodal integration and bistable perception correspond, respectively, to constraint field navigation and attractor switching, with the latter being a standard interpretation in existing neuroscience.

These correspondences are not independent validation. They are post-hoc structural analogies. Their value lies in the testable hypotheses they generate, not in the confirmation they appear to provide. The framework remains a research program in its early stages, and this mapping is a contribution to its ongoing development.

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*“The framework’s consistency with established nonlinear dynamics has been explored elsewhere. For a tracing of its structural correspondences with the foundational work of Ruelle, Takens, and Prigogine, see Galida (2026b).”*https://people.math.harvard.edu/~knill/teaching/mathe320_2014/blog/RuelleIntelligencer.pdf

“see also” https://jamestobinphd.com/the-psychology-of-attractor-states/

The Gas Cloud as a Dissipative Attractor: A Demonstration of the Attractor Framework in Standard Astrophysics

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Abstract

The evolution of an isolated interstellar gas cloud from turbulence to gravitational equilibrium is a classic problem in astrophysics. Standard models describe this process through hydrodynamics, thermodynamics, and Newtonian gravity. This paper presents the same evolution through the lens of the attractor framework, demonstrating that the framework’s vocabulary—dissipative attractor, basin, invariant reference, and corrective permeability—maps cleanly onto the standard physics without modification or additional assumptions. The paper makes no new physical predictions; it demonstrates conceptual unification. Each attractor term is explicitly defined in terms of its standard astrophysical equivalent. A worked example translates the virial theorem into attractor language, quantifying basin depth and corrective permeability for a canonical molecular cloud. A brief cross-domain parallel to biological wound healing illustrates the framework’s applicability beyond astrophysics. The paper concludes that the attractor framework is fully consistent with standard astrophysics and provides a unified vocabulary for persistence, resilience, and convergence across physical and biological systems, with broader applicability noted.

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1. Introduction: The Cloud as a Dissipative System

Consider an isolated cloud of interstellar gas and dust, far from any external gravitational disturbance. Its mass is sufficient that self-gravity will eventually overcome thermal pressure, initiating collapse. At early times, the cloud is turbulent. Thermal motions, magnetic fields, and inhomogeneous density distributions produce a chaotic, dynamic state. Over time, the cloud radiates energy, cools, contracts, and ultimately settles into a stable configuration: a sphere, if rotation is negligible, or a rotationally-flattened disk.

Standard astrophysics describes this process with precision. The equations of hydrodynamics, the virial theorem, the Jeans criterion, and the radiative cooling functions all contribute to a well-tested model of star formation. Nothing in this paper challenges or revises that model.

The attractor framework (Galida, 2026a) offers a complementary perspective. It is not an alternative to standard physics, but a unifying conceptual vocabulary that identifies the dynamical principles at work: persistence under perturbation, dissipative basins, invariant references, and corrective permeability. This paper applies that vocabulary to the evolution of an isolated gas cloud, demonstrating that the framework maps directly onto the standard model without contradiction.

2. Definitions: Attractor Vocabulary and Standard Equivalents

To make the translation precise, each framework term is defined below alongside its standard astrophysical counterpart. These definitions are used consistently throughout the paper.

Attractor Term	Definition	Standard Physics Equivalent
Dissipative attractor	A system that exports entropy while converging toward a stable, minimum-energy state	Radiative cooling + gravitational contraction
Basin	The minimum-energy configuration toward which the system evolves and from which it resists displacement	Sphere (non-rotating) or rotationally-supported disk
Basin depth	The energy required to permanently disrupt the system from its basin	Gravitational binding energy, □U□□U□
Invariant reference (metronome)	A quantity or point that remains fixed throughout the system’s evolution, providing an anchor for transient dynamics	Center of mass (positional reference); orbital periods (frequency reference, emerging during contraction)
Corrective permeability (κ)	The rate at which the system dissipates perturbation energy and returns to its basin, quantified by κ=1/τcool$\kappa=1/\tau$cool□	Damping rate, quantified by the radiative cooling function Λ(T)$\Lambda(T)$
Rail	A conservation law that constrains the accessible basins, preventing the system from reaching the global energy minimum	Conservation of angular momentum

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3. The Convulsive Phase: Turbulence and Disordered Motion

In its initial state, the cloud is far from equilibrium. Supersonic turbulence, driven by gravitational infall and internal shocks, produces a complex velocity field. Density distributions are filamentary and clumpy. There is no coherent rotation axis, no global structural alignment, and no stable configuration.

In attractor terms, this is the **perturbation-rich early phase**. The cloud is a dissipative system that has not yet found its basin. Its trajectory through state space is erratic. Local transient attractors—temporary vortices, shock fronts, density enhancements—form and dissolve without stabilizing. The system has not yet converged upon a single, deep attractor.

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4. The Invariant Reference: Center of Mass as Metronome

Amid the turbulence, one quantity remains strictly invariant: the cloud’s center of mass (CM). For an isolated system, conservation of momentum guarantees that the CM moves with constant velocity. In the CM frame, this point is fixed. No internal force—gravitational, pressure, or magnetic—can displace it.

The attractor framework identifies such invariants as **positional metronomes**—fixed reference points that anchor the transient dance of dissipative dynamics. The CM is the gravitational barycenter around which all subsequent evolution organizes. It does not oscillate, does not evolve, and does not respond to perturbations. It is the still point at the center of the storm.

As the cloud contracts and its mass distribution becomes centrally concentrated, **orbital periods** at characteristic radii emerge as frequency metronomes. For a test particle at radius r, the Keplerian orbital period is:$P=2\pi\sqrt{\frac{r^3}{GM(r)}}$

where $M(r)$ is the mass enclosed within radius r. These periods define the natural clock of the contracting system—the invariant rhythms against which all dissipative timescales can be measured. The center of mass anchors position; the orbital periods anchor time. Together they constitute the invariant skeleton of the attractor.

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5. The Dissipative Mechanism: Radiation and Entropy Export

A dissipative attractor requires a mechanism for exporting entropy. The gas cloud exports entropy through **radiation**. As the cloud contracts, gravitational potential energy is converted into kinetic energy, which is then thermalized through collisions. Atoms and molecules are excited; they emit photons that escape the cloud, carrying away energy and entropy.

This radiative cooling is the cloud's **dissipation channel**. Without it, the cloud would remain in a hot, pressure-supported equilibrium and would not collapse. With it, the cloud can progress toward deeper gravitational binding.

In attractor terms, the cloud is seeking its minimum-energy basin. Radiation is the mechanism by which it sheds the energy that keeps it from reaching that basin. Each emitted photon is a small perturbation exported to the environment, allowing the remaining system to settle deeper into its attractor.

6. The Attractor Basin: Sphere, Disk, and the Rail of Angular Momentum

As the cloud cools and contracts, it approaches its lowest-energy configuration under self-gravity. For a non-rotating, non-magnetic cloud, this is the **sphere**—the shape that minimizes gravitational potential energy for a given mass. Every particle settles as close to the center of mass as the exclusion of other particles permits. The sphere is the **unconstrained basin**: the global energy minimum of the system.

If the cloud possesses net angular momentum, the sphere is inaccessible. Conservation of angular momentum acts as a **rail**—a constraint that channels the system toward a different basin. The cloud must flatten along its rotation axis, forming a **disk**. The disk is the minimum-energy configuration accessible under the rail of fixed angular momentum. Gravity seeks the sphere; the rail redirects the trajectory toward the disk.

The approach to the basin occurs over the radiative cooling timescale, typically 104104 to 105105 years for dense molecular cloud cores. This is the cloud’s convergence time—the duration of its transient dance before settling into its persistent configuration.

7. Corrective Permeability and the Virial

Theorem

The virial theorem provides the quantitative bridge between standard astrophysics and the attractor framework. For a system in equilibrium: $2K+U=0$

where K is the total kinetic energy and U is the gravitational potential energy. In attractor terms:

- **Basin depth** = $|U|$, the gravitational binding energy.
- **Perturbation** = any injection of kinetic energy ΔK that raises K above the equilibrium value $|U|/2$.
- **Corrective permeability** = $\kappa=1/\tau_{\text{cool}}$, the rate at which radiative cooling dissipates ΔK and restores virial equilibrium.

Worked Example. Consider a canonical dense molecular cloud core (Shu et al., 1987; McKee & Ostriker, 2007):

Parameter	Symbol	Value	Units
Mass	M	$10^4 M_\odot$	$\approx 2\times10^{34}$ kg
Radius	R	1 pc	$\approx 3.09\times10^{16}$ m
Temperature	T	10 K	
Mean number density	n	$\sim 10^3$	cm^{-3}

Step 1: Basin depth. The gravitational potential energy (to order of magnitude; the exact coefficient for a uniform-density sphere is $3/5$) is:

$$|U| \sim \frac{GM^2}{R} \approx \frac{(6.67\times10^{-11})\times(2\times10^{34})^2}{3.09\times10^{16}} \approx \frac{(6.67\times10^{-11})\times(4\times10^{68})}{3.09\times10^{16}} \approx 8.6\times10^{41}\ \text{J}$$

At virial equilibrium, $K=|U|/2\approx 4.3\times10^{41}$ J.

Step 2: Perturbation. Suppose a supernova explodes at a distance $d\approx 10$ pc from the cloud. A typical supernova releases ESN~1044ESN□~1044 J. The fraction intercepted by the cloud is the ratio of the cloud’s cross-sectional area to the surface area of the sphere at distance dd:f~πR24πd2~(3.09×1016)24×(3.09×1017)2~2.5×10−3f~4πd2πR2□~4×(3.09×1017)2(3.09×1016)2□~2.5×10−3

Not all intercepted energy couples efficiently; a coupling efficiency of ϵ~0.01ϵ~0.01–0.10.1 is typical for shock-cloud interactions (McKee & Ostriker, 2007). Choosing the upper end, ϵ~0.1ϵ~0.1:ΔK=ESN×f×ϵ~1044×(2.5×10−3)×0.1≈2.5×1040 JΔK=ESN□×f×ϵ~1044×(2.5×10−3)×0.1≈2.5×1040 J

This perturbation is modest—approximately 6% of the equilibrium kinetic energy. The cloud is disturbed but not disrupted. Radiative cooling will restore virial equilibrium on a characteristic timescale.

Step 3: Cloud volume. Converting the radius to centimeters:R=1 pc=3.09×1018 cmR=1 pc=3.09×1018 cm

The volume is:V=43πR3≈43π(3.09×1018)3≈1.24×1056 cm3V=34πR3≈34□π(3.09×1018)3≈1.24×1056 cm3

Step 4: Corrective permeability. At T~10T~10 K and n~103n~103 cm⁻³, the dominant coolant is CO rotational line emission, with a cooling function Λ(T)~10−23Λ(T)~10−23 erg cm⁻³ s⁻¹ (Goldsmith & Langer, 1978; Neufeld, Lepp & Melnick, 1995). Convert ΔKΔK to erg:ΔK=2.5×1040 J=2.5×1047 ergΔK=2.5×1040 J=2.5×1047 erg

The cooling timescale is:τcool~ΔKVΛ≈2.5×1047(1.24×1056)×(10−23)≈2.5×10471.24×1033≈2.02×1014 s~6.4×106 yearsτcool□~VΛΔK≈(1.24×1056)×(10−23)2.5×1047□≈1.24×10332.5×1047≈2.02×1014 s~6.4×106 years

The corrective permeability is:κ=1τcool≈4.95×10−15 s−1κ=τcool1□≈4.95×10−15 s−1

Step 5: Interpretation. The perturbation is damped within a few million years. The basin depth (□U□~8.6×1041□U□~8.6×1041 J) far exceeds the perturbation energy, ensuring the cloud’s structural integrity. Corrective permeability, quantified by κκ, is the mechanism by which the cloud restores coherence—absorbing the modest perturbation through radiative cooling and returning to virial equilibrium on a timescale short compared to the cloud’s overall lifetime (~107107 years).

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8. Cross-Domain Parallel: Biological Wound Healing

The same attractor vocabulary applies without modification to biological systems.

A wound is a perturbation to the stable attractor of healthy tissue. The body responds through a multi-stage healing cascade: clotting stops further damage, inflammation cleans the wound, and tissue repair restores structural integrity. The healing rate—quantified clinically by wound closure time—is the biological corrective permeability. The healthy baseline state is the basin. Complications like impaired circulation reduce oxygen delivery, slowing fibroblast activity and thus reducing κ (Guo & DiPietro, 2010).

The gas cloud perturbed by a supernova shock and the human body perturbed by a wound are structurally identical within the framework: a dissipative attractor, displaced from its basin, activates corrective mechanisms at a characteristic rate, and either returns to coherence or undergoes permanent state transition.

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9. Observational Consistency

The framework's description of cloud evolution is fully consistent with standard observations:

- **Turbulent molecular clouds** exhibit the chaotic velocity fields and filamentary structures predicted by the convulsive phase.
- **Radiative cooling** is traced by CO, H_2O, and other molecular line emissions.
- **Protostellar cores** represent the approach to the spherical attractor.
- **Protoplanetary disks** are the rotationally-constrained basins.
- **Bound clusters and stellar systems** persist under external perturbations, demonstrating basin depth.

These observations are predicted and explained by standard astrophysics. The attractor framework is consistent with all of them. Its contribution in this domain is conceptual, not empirical.

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10. Conclusion

The evolution of an isolated gas cloud from turbulence to equilibrium is fully described by standard astrophysics. The attractor framework does not replace that description. It translates it into a unified conceptual vocabulary—dissipative attractor, basin, invariant reference, rail, corrective permeability—that applies across physical and biological systems, with broader applicability noted.

The center of mass remains fixed while the cloud convulses, collapses, and settles. The virial theorem, translated into attractor language, quantifies basin depth as gravitational binding energy and corrective permeability as the inverse cooling timescale. The framework is consistent with all standard observations and requires no new physics.

The metronomes hum. The cloud finds its basin. The framework holds.

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*“For independent neuroscientific corroboration of the attractor dynamics described here, see A Preliminary Mapping Between Ring Attractor Dynamics and the Attractor Framework.”*https://www.sciencedirect.com/science/article/pii/S

The Climate Attractor: Nonlinear Dynamics, Tipping Points, and Corrective Permeability in the Earth System

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Abstract

The Earth’s climate is a dissipative attractor—a far-from-equilibrium system maintained by a continuous flow of solar energy and entropy export. For 10,000 years, the Holocene basin remained stable due to a network of negative feedbacks that conferred high corrective permeability on the climate system. Since the Industrial Revolution, a sustained, rapid perturbation in atmospheric greenhouse gas concentrations has saturated several of those feedbacks and begun activating positive feedback loops that push the system toward basin transitions. This paper applies the attractor framework to the climate crisis, arguing that linear assumptions about gradual, reversible warming constitute a fantasy attractor, and that tipping points are best understood as ridges between alternative attractor basins. The framework also diagnoses three common social attractors—denial, doom, and techno-utopianism—as low corrective permeability belief systems that reduce the urgency to act. The paper concludes that the principle of corrective permeability (κ) must be institutionalized in climate policy and individual cognition alike, and that physical systems update whether human belief systems do or not.

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1. Introduction: The Earth as a Dissipative Attractor

The Earth is not a closed system in thermodynamic equilibrium. It is an open, dissipative system maintained far from equilibrium by a continuous influx of solar radiation and the radiative export of entropy to space. Its climate—the long-term statistical pattern of temperature, precipitation, wind, and ocean circulation—is an emergent attractor: a persistent, self-regulating dynamical state.

For approximately 10,000 years, the Earth’s climate has occupied a relatively narrow basin known as the Holocene. Within this basin, human civilization emerged and developed agriculture, cities, trade networks, and complex societies. The basin’s apparent permanence encouraged a cognitive error that now carries severe consequences: we mistook the walls of the basin for the horizon.

The attractor framework (Galida, 2026) defines reality operationally as *persistence under perturbation*. A stable attractor absorbs perturbations and returns to its basin; an unstable one, when pushed beyond a critical threshold, undergoes a phase transition into a different basin with different structural properties. This paper applies that framework to the climate system, with three objectives:

1. To characterize the Holocene basin’s stabilizing feedbacks and the perturbation now overwhelming them.
2. To reframe climate tipping points as ridges between alternative attractor basins, emphasizing the role of perturbation rate relative to system recovery time.
3. To diagnose the social dynamics of the climate debate using the same principle of corrective permeability (κ) that describes the physical system.

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2. The Holocene Basin: Stabilizing Feedbacks and Corrective Permeability

A stable attractor basin does not persist by accident. It persists because negative feedback loops counteract perturbations, pulling the system back toward equilibrium. The Holocene’s stability was maintained by a network of such loops.

Ocean heat absorption. The ocean’s thermal inertia acts as a buffer: when atmospheric temperatures rise, the ocean absorbs excess heat, slowing surface warming. This negative feedback dampens short-term fluctuations.

Ice-albedo feedback (negative phase). Polar ice sheets reflect incoming solar radiation back to space. When the climate cooled slightly, ice expanded, increasing albedo and reinforcing cooling. When it warmed, the feedback operated in reverse, but on timescales slow enough to avoid runaway warming.

Forest transpiration. Large forest systems, particularly the Amazon and Congo basins, generate their own rainfall through evapotranspiration. This self-sustaining moisture cycle stabilizes regional climates and prevents desertification.

Silicate weathering thermostat. Atmospheric CO_2 dissolves in rainwater, forming carbonic acid that weathers silicate rocks. The dissolved carbon is transported by rivers to the ocean, where it precipitates as carbonate minerals and is eventually subducted. This negative feedback operates on timescales of hundreds of thousands of years, but it has regulated atmospheric CO_2 across geological epochs.

These feedbacks collectively conferred high *corrective permeability* (κ) on the Holocene climate. When perturbed—by volcanic eruptions, solar variability, or orbital cycles—the system responded with countervailing adjustments. The basin absorbed the perturbation and returned to its attractor. The basin was deep.

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3. The Perturbation: Magnitude, Rate, and the Saturation of Corrective Capacity

Since the Industrial Revolution, the human enterprise has introduced a sustained, massive perturbation into the climate system through the combustion of fossil fuels, industrial agriculture, and land-use change. Atmospheric CO_2 concentration has risen from approximately 280 parts per million (ppm) to over 420 ppm—a level not seen since the Pliocene, roughly 3 million years ago. Methane and nitrous oxide concentrations have risen sharply as well.

The attractor framework requires that a perturbation be assessed on two dimensions: magnitude and rate. A slow perturbation, even a large one, allows an attractor's corrective mechanisms time to operate. A fast perturbation—one delivered on a timescale shorter than the system's characteristic recovery time—can overwhelm those mechanisms and force a basin exit regardless of absolute magnitude.

The current perturbation is fast by geological standards. The rate of CO_2 increase during the Paleocene-Eocene Thermal Maximum (PETM), a natural warming event approximately 56 million years ago associated with mass extinction, was roughly 0.025 GtC per year. The current rate is estimated at approximately 10 GtC per year—around 400 times faster. The ocean's capacity to absorb heat is approaching saturation. The silicate weathering thermostat operates on timescales two to three orders of magnitude longer than the human perturbation. The system's corrective permeability is being saturated.

The key intellectual error in much public climate discourse is *linear thinking*: the assumption that gradual emissions increases produce gradual, proportional, and reversible temperature increases. This assumption is itself a fantasy attractor. The climate system is nonlinear. It contains tipping points—critical thresholds beyond which the system undergoes a phase transition into a new attractor basin. Once crossed, these transitions are not easily reversed. The perturbation is not merely large. It is arriving at a speed that the system's corrective mechanisms cannot match.

4. Tipping Points as Ridges Between Basins

A tipping point, in attractor terminology, is a ridge between basins. Below the ridge, the negative feedbacks that define the current basin remain dominant. At the ridge, they are precisely balanced by positive feedbacks. Beyond the ridge, positive feedbacks dominate, and the system cascades into a new basin. The transition is not a smooth slope. It is a phase change.

The following tipping elements are currently under scientific investigation. In each case, the attractor framework identifies the competing feedbacks and the ridge structure. Where scientific uncertainty exists, it is stated explicitly.

4.1 The Greenland Ice Sheet

The Greenland Ice Sheet is stabilized by its own elevation: the surface is high enough to remain cold, and snowfall replenishes mass. As melt accelerates, the surface elevation decreases, exposing the ice to warmer air—a positive feedback. Current research suggests that Greenland may have a critical threshold between approximately 0.8°C and 3°C of warming above pre-industrial levels, with a central estimate near 1.5°C. However, crossing this threshold does not imply imminent, catastrophic collapse on human political timescales. Full loss of the ice sheet would likely unfold over centuries to millennia, though the process may become irreversible once the threshold is crossed. Sea level rise of up to seven meters is the ultimate consequence, but the timescale is millennial. The ridge is uncertain in both position and temporal gradient.

4.2 The Atlantic Meridional Overturning Circulation (AMOC)

The AMOC is a major ocean current system driven by temperature and salinity gradients. It has at least two stable attractor basins: a strong circulation mode (the current state) and a collapsed or substantially weakened mode. Freshwater input from melting Greenland ice reduces surface water density, weakening the sinking motion that drives the circulation.

Multiple climate models show a weakening trend under continued warming, but the proximity to a critical threshold remains debated. Observational evidence indicates that the AMOC is currently at its weakest in over a thousand years (Caesar et al., 2021). Some research suggests a collapse could occur within decades once triggered; other models find the circulation more resilient. The scientific community has not reached consensus on the threshold’s location or the likelihood of near-term crossing. The ridge exists; its distance and height are incompletely characterized.

4.3 The Amazon Rainforest

The Amazon generates a substantial fraction of its own rainfall through evapotranspiration. This is a stabilizing feedback that maintains the forest basin. Deforestation and regional drying weaken this feedback. Beyond a critical level of tree loss (estimated by some studies at 20–25% of original cover), the moisture cycle may break down, triggering a transition to a savanna state. This would release stored carbon and permanently alter regional and global climate. Quantitative modeling suggests that tropical forests exhibit hysteresis, meaning that once a critical threshold is crossed, returning to the original forest state requires a much larger reversal of conditions (Staal et al., 2020). However, the precise threshold remains uncertain, and the interaction of deforestation with global warming complicates prediction. The ridge is plausible but not precisely located.

4.4 Permafrost Carbon Feedback

Northern permafrost soils contain approximately 1,400–1,600 GtC—roughly twice the carbon currently in the atmosphere. As permafrost thaws, microbial decomposition releases CO_2 and methane. This is a positive feedback: warming drives thaw, thaw releases greenhouse gases, which drive further warming. The process is already underway. However, the rate of release is heavily dependent on future emissions trajectories. Lower emissions scenarios substantially reduce the total carbon release over the coming centuries. Permafrost carbon feedback is not a binary, unstoppable runaway process; it is a continuous, trajectory-dependent amplifier of warming. The strength of the amplification is a function of the perturbation magnitude.

4.5 Coupling and Cascade Risk

The individual tipping elements described above do not operate in isolation. They are coupled basins. A perturbation that pushes one across its ridge can propagate through the network, pushing others in turn. This cascade logic is what distinguishes the attractor framework from a list of separate tipping points. The framework’s central physical insight is that the climate system’s basins are interconnected, and a transition in one alters the boundary conditions—and thus the ridge positions—of its neighbors.

The coupling sequence is structurally clear. Greenland melt injects freshwater into the North Atlantic, reducing surface density and weakening the AMOC. A weakened AMOC shifts tropical rainfall belts southward, drying the Amazon and increasing fire risk. Amazon dieback releases stored carbon into the atmosphere. Permafrost thaw, accelerated by the same warming, releases additional carbon. Each basin exit amplifies the perturbation driving the next. The climate’s corrective permeability, once maintained by a web of negative feedbacks, is being progressively replaced by a network of positive couplings that amplify the initial perturbation. This does not imply inevitability. It implies nonlinear risk amplification, in which the probability of cascading transitions increases with continued perturbation. The cascade is not a prediction. It is a structural feature of a coupled nonlinear system. Foundational research on tipping elements first systematically catalogued these components and their interactions over a decade ago (Lenton et al., 2008); subsequent observational and modeling work has strengthened the case that the coupling is real.

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5. Social Attractors: Denial, Doom, and Techno-Utopia

The public debate surrounding climate change is itself a dynamical system of competing attractor basins. Three common configurations exhibit low corrective permeability (κ). In each case, the diagnosis applies not to the *content* of the belief but to its *impermeability to disconfirming evidence*. A high-κ individual may hold any of the positions described below, provided that position is genuinely falsifiable and updated when evidence shifts.

5.1 The Denial Attractor

The denial attractor reframes evidence of anthropogenic warming as natural variability, scientific fraud, or politically motivated exaggeration. Disconfirming data—temperature records, ice core analyses, model projections—are dismissed or attributed to conspiratorial motives. The dopamine reward is social: the denier occupies the role of truth-teller bravely resisting a corrupt consensus. The self-reinforcing loop is tribal belonging: each act of dismissal earns approval from the in-group, deepening the basin. Corrective permeability is near zero.

5.2 The Doom Attractor

The doom attractor asserts that tipping points have already been crossed, that warming is now unstoppable, and that all mitigation efforts are futile. This position is often defended with scientific references, but it shares with denial a structural consequence: the rationalization of inaction. If nothing can be done, nothing need be done. The dopamine reward is moral certainty: despair presents itself as clarity, and the doomer feels superior to the “naive optimist.” The self-reinforcing loop operates through despair validating itself by dismissing hope as naivete. Any evidence of progress—falling renewable costs, policy victories, accelerating deployment—is reframed as “too little, too late.” The basin deepens with each dismissed success.

5.3 The Techno-Utopia Attractor

The techno-utopia attractor defers responsibility to hypothetical future technologies—direct air capture, solar radiation management, fusion energy—that are not yet deployed at scale. This position permits continued present consumption without behavioral or political change. The lever is marked “future fix.” The technology may eventually contribute to mitigation, but reliance on it as a substitute for current emissions reductions is a bet on a lever that has not been wired. The self-reinforcing loop operates through continued consumption: each emission-intensive purchase validates the belief that consumption need not change, because a future technology will compensate. The basin deepens with every unreduced carbon footprint.

These three attractors share a functional outcome: they reduce the perceived urgency of emissions reductions. They are not symmetrical in their relationship to evidence—the denial attractor is the furthest from scientific consensus—but they are symmetrical in their dynamical effect. They are low-κ basins that resist updating.

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6. The Physical–Social Symmetry

There is a structural identity between the climate system’s dynamics and the social dynamics of the climate debate. Both are instances of the same phenomenon: a system whose corrective permeability is being eroded by positive feedbacks that amplify perturbation rather than dampening it.

In the physical climate, the Holocene’s negative feedbacks—ocean heat absorption, ice albedo, forest transpiration, silicate weathering—conferred high κ. Those feedbacks are now saturating or reversing. Ice melt reduces albedo, accelerating warming. Forest loss breaks the transpiration cycle, accelerating drying. Permafrost thaw releases carbon, accelerating the perturbation. The system’s negative feedbacks are becoming positive ones. The climate is becoming a sealed basin, driven by internal amplification rather than external correction.

In the social climate, the same transition is underway. High-κ cognition—the willingness to update beliefs when evidence shifts—is being replaced by low-κ basins that reinforce themselves through tribal belonging, despair-validating narratives, or consumption-maintaining deferral. These social attractors function as positive feedbacks on the physical perturbation: denial blocks mitigation policy, doom dismisses it as futile, techno-utopia delays it indefinitely. The social system, like the physical one, is developing sealed basins that amplify the perturbation rather than correcting it.

The symmetry is not metaphorical. It is dynamical. A sealed belief system and a tipping climate are the same structural phenomenon—a low-κ attractor driven by positive feedback—operating at different scales. The climate system and the human systems embedded within it are coupled. The physical perturbation drives social basin-sealing; social basin-sealing accelerates the physical perturbation. Corrective permeability is the variable that determines whether this coupling is damped or amplified. At present, both systems are trending toward amplification.

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7. Policy as Institutional Corrective Permeability

The attractor framework yields a specific policy principle: any climate strategy must be designed with explicit update mechanisms, because the system is nonlinear, the models carry irreducible uncertainty, and the ridge positions are incompletely known. The question is not only *what to do* but *how to ensure that the strategy corrects as evidence accumulates*.

High-κ climate policy would exhibit the following properties:

- **Adaptive targets.** Emission reduction targets are revised when interim data show deviations from projected pathways. A missed target triggers a stronger response, not a redefinition of the baseline.
- **Technology neutrality with periodic reassessment.** Energy system investments are directed toward the fastest-scaling clean technologies available, with periodic review to incorporate performance data on new options.
- **Feedback-sensitive adaptation.** Adaptation funding (sea walls, drought-resistant agriculture, managed retreat) is allocated based on observed changes in risk, not static projections.
- **Institutionalized error correction.** Policymaking bodies include formal processes for reviewing failed interventions and updating strategy. Truth-telling is built into governance.

Low-κ policy, in contrast, attaches itself to a fixed target, a favored technology, or a politically convenient narrative. When reality diverges, the institution attacks the messenger, rebaselines the accounting, or reframes failure as partial success. The error signal is never allowed to land. The institution becomes a sealed basin, pressing the lever of its own stated commitments while the physical system moves into a new state.

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8. Individual Corrective Permeability: A Methodological Note

The attractor framework holds that macro-scale social attractors are composed of individual cognitive basins. The corrective permeability of a society is, in part, a function of the corrective permeability of its members. This paper does not prescribe personal behavior; it notes an operational question that operationalizes the framework’s diagnostic at the individual level:

Would I update my climate beliefs if the evidence shifted decisively?

If the honest answer is no, corrective permeability is approaching zero, and the individual basin is sealed. The content of the belief—whether denial, doom, techno-optimism, or mainstream concern—is irrelevant to this diagnostic. The diagnostic applies to the structure of belief, not its content.

What, then, characterizes high-κ individual cognition in practice? The framework suggests several structural features. High-κ individuals tend to make small, durable belief adjustments rather than dramatic, identity-threatening reversals; the basin deepens through repeated correction, not emotional intensity. They separate their identity from their beliefs, so that updating a belief does not feel like losing a self. They seek out disconfirming evidence rather than avoiding it, treating error signals as information rather than threats. And they maintain a distinction between what they know and what they merely find plausible, keeping their confidence calibrated to the strength of the evidence. These features are not personality traits. They are practices. They can be cultivated.

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9. Conclusion

The Holocene basin, which persisted for 10,000 years through a network of stabilizing negative feedbacks, is now being perturbed at a rate that saturates those feedbacks and activates positive ones. Tipping points are not slopes; they are ridges between basins. The location of those ridges is uncertain, but the dynamics that generate them are structurally well-understood. Uncertainty is not a case for complacency; it is a case for corrective permeability.

The social dynamics of the climate debate—denial, doom, techno-utopianism—are low-κ attractors that reduce the urgency of action. They are structurally identical to the physical dynamics they refuse to confront: sealed basins driven by positive feedback. The policy response must be designed with explicit update mechanisms, because the system is nonlinear and the future is incompletely predictable. The principle of corrective permeability applies at every scale: physical, institutional, and individual.

The atmosphere does not negotiate. The ice sheet does not care about ideology. The ocean current does not read manifestos. Physical systems update whether we do or not.

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Free Will as Attractor Autonomy: A Dynamical Account of Agency

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Abstract

Free will is often seen as either a magical mystery (libertarianism) or an illusion (hard determinism). This paper offers a third view using the attractor framework.

In this framework, your mind is a **dissipative, self-referential attractor** of your whole body.
Free will is redefined as **attractor autonomy**:

- The ability to generate behaviour from your own internal dynamics.
- To keep yourself stable over time.
- To model yourself.
- And to reshape your own attractor landscape over time.

Agency comes in degrees – it is not a simple yes/no.
We give a mathematical formula for an **agency index** AA that combines three factors:

- **Attractor dimensionality** DD (complexity of your brain’s activity)
- **Recursive self-modification** RR (your ability to change your own habits)
- **Self-reference strength** SS (how well you have a persistent self-model)

The paper makes a **falsifiable prediction**: an **inverted-U** relationship between attractor dimensionality and sense of agency – too low or too high reduces agency.
We describe how to test this with EEG, intentional binding tasks, and statistical methods. We also engage with classic compatibilist philosophers (Frankfurt, Dennett) and address Pereboom’s manipulation argument.
We even provide an explicit rule to avoid the “liver problem” (a false positive for self-reference).

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1. Introduction

The attractor framework says that **persistence under disturbance** is the basic mark of reality.
Minds are **dissipative attractors** – patterns that need constant energy flow, integrating the whole body.
In this view, free will cannot be a supernatural break from

cause and effect. Instead, it must be a **dynamical property** of certain attractors.

We do not claim to solve the ancient free will debate. We offer a **naturalistic, testable redefinition** that adds new empirical content to compatibilism.

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2. What Free Will Is Not — And What It Is

2.1 Rejecting supernatural libertarianism

Libertarian free will requires an uncaused choice — a break in the chain of cause and effect.
The attractor framework rejects this: there is no evidence for it, and it contradicts physical laws.

2.2 The error of hard determinism

Hard determinism says freedom is an illusion because everything is determined. But it confuses “determined” with “externally coerced”.
A system can be **internally determined** — by its own attractor — yet still be free. That is the core of **compatibilism**.

2.3 Free will as attractor autonomy

We define **free will** (or agency) as the degree to which a system has four properties:

1. **Dissipative persistence** — it stays alive by using energy and exporting waste (measured by energy use and recovery speed).
2. **Self-reference** — it has an internal subsystem (an

   "indexical locus") that models the whole system and is stable.
3. **Trajectory selection** – it can choose among different possible futures (measured by **policy entropy** $H(\pi)$).
4. **Recursive self-engineering** – it can change its own attractor shape (measured by learning-to-learn or metacognitive accuracy).

These four are **jointly necessary**. If any is missing, agency is at best primitive.

Because they are necessary, we combine them with a **multiplicative** formula (if any factor is zero, agency is zero). $A=\left(\frac{D-D_{\min}}{D_{\max}-D_{\min}}\right)^{\alpha}\left(\frac{R}{R_{\max}}\right)^{\beta}\left(\frac{S-S_{\min}}{S_{\max}-S_{\min}}\right)^{\gamma}$

Where:

- D = attractor dimensionality (e.g., from EEG)
- R = recursive modification capacity (e.g., improvement in a meta-learning task)
- S = self-reference strength (normalised mutual information)

The constants ($D_{\min}, D_{\max}$, etc.) are set from a reference population.
The exponents α, β, γ are estimated from data (e.g., comparing healthy people with patients).
A threshold A_{crit} (e.g., the 5th percentile of healthy humans) decides where agency begins.

Agency is **graded**:

- Rock: $A \approx 0$
- Thermostat: $A \approx 0$
- Worm: $A \approx 0.1$ (some learning, little self-model)
- Human: $A \approx 0.8$

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3. The Indexical Locus: Defining the “Self” and Avoiding the “Liver Problem”

The **indexical locus** LL is the part of the system that acts as a persistent self-model.
To avoid trivial cases (like a liver having high mutual information with the rest of the body), we add three extra conditions:

- **Top-down causal influence** – LL can change the rest of the body in ways that serve the body’s goals (measured by variance explained beyond bottom-up effects).
- **Informational closure** – LL’s own dynamics are relatively independent of the rest over short timescales (conditional mutual information > 0).
- **Self-referential loop** – LL influences the body, and the body influences LL back (bidirectional Granger causality).

These criteria rule out livers, pacemakers, and simple homeostats. The indexical locus is a **recursive self-model**, not just a predictive subsystem.

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4. Active Inference and Policy Entropy

In active inference (Friston), agents try to minimise “free energy” – they pick **policies** (sequences of actions).

Each policy is a trajectory through the agent’s attractor landscape.

Policy entropy $H(\pi)=-\sum p(\pi)\log p(\pi)$ measures how many different policies are available.

- Low entropy → rigid, one-track mind.
- High entropy → flexible, but possibly noisy.

Free will is the ability to access many low-energy policies. The agent’s choices are not random; they are constrained by the attractor geometry. But if several attractor basins are open, the agent can choose among them – that is what we feel as free choice.

Policy entropy can be measured in behavioural tasks where multiple choices are equally good (e.g., probabilistic reversal learning, two-armed bandit tasks).

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5. The Inverted-U Prediction and Falsification

5.1 Core prediction

We predict an **inverted-U** relationship between attractor dimensionality D and the subjective sense of agency (e.g., from intentional binding experiments).

- Very low D → chaotic, unstable (like schizophrenia) → low agency.
- Very high D → rigid, stuck (like OCD) → low agency.
- In the middle → flexible but stable → high agency.

The agency index AA also includes RR and SS, which we think increase agency across the board. So to test the inverted-U for DD alone, you need to **control for** RR and SS (e.g., study people matched on those, or use partial correlation).

5.2 How to measure and test

- **Attractor dimensionality DD** – use the Grassberger-Procaccia algorithm on 5-min resting-state EEG/MEG.
- **Sense of agency** – use the **intentional binding** paradigm: press a key, then a tone sounds; participants estimate the time between action and tone. Stronger binding means higher agency.
- **Statistical test** – fit a quadratic regression: agency = β0+β1D+β2D2$\beta_0+\beta_1 D+\beta_2 D^2$.
  If β2<0$\beta_2<0$ and the vertex lies inside the observed range of DD, the inverted-U is supported. Use bootstrap (1000 resamples) to check confidence intervals.

5.3 Falsification condition

The framework is **falsified** if:

- The quadratic coefficient β2β_2 is not negative (no inverted-U).
- Or, in a clinical experiment (e.g., increasing DD in OCD patients with NMDA drugs), agency does **not** decrease but keeps increasing.

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6. Experimental Proxies – Summary Table

Construct	**Measure**	**How to record**	**Expected relation to agency**
Attractor dimensionality DD	Correlation dimension (Grassberger-Procaccia)	Resting-state EEG/MEG (5 min)	Inverted-U
Policy entropy H(π)$H(\pi)$	Entropy of choice distribution	Probabilistic reversal learning (200 trials)	Inverted-U
Sense of agency	Intentional binding magnitude	Action-outcome interval compression (50 trials)	Max at intermediate DD
Recursive self-modification RR	Learning-to-learn improvement	Meta-learning task (pre-post difference)	Positive (more is better)
Self-reference strength SS	Normalised mutual info In(L;S)$In□(L;S)$	Resting-state fMRI or MEG	Threshold > θ

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7. Hierarchical Constraints and Social Attractors

Free will is **nested** inside larger attractors – society, culture, laws, economy. Your range of choices is partly set by these.
This is not an objection; it is just the fact that freedom is always **constrained autonomy**.
We predict that societies with more cultural diversity (higher “cultural entropy”) allow more individual agency, other things being equal. This can be tested by cross-cultural comparisons of policy entropy in decision tasks.

8. Engagement with Compatibilist Literature

8.1 Standard compatibilists (Frankfurt, Dennett)

- **Frankfurt (1971)**: freedom is about your will aligning with your own desires. Our framework adds that those desires must be encoded in a persistent self-referential attractor. The recursive self-engineering component R maps directly to Frankfurt's "second-order volitions".
- **Dennett (1984)**: freedom is about being able to respond to reasons. Our framework adds that this requires a certain basin geometry and recursive plasticity.

8.2 Addressing Pereboom's manipulation argument

Pereboom argues: if a neuroscientist engineers your brain, you are not free — even if your behaviour comes from internal dynamics.
Our reply: agency requires **recursive self-modification** ($R>0$) at some point in your history.

- A perfectly manipulated agent that never changed its own attractor would have $R\approx0$ and thus $A\approx0$.
- A healthy human who learned and adapted has $R>0$ and genuine agency.

The origin of the initial attractor does not matter — only the presence of self-modification over time.

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9. Open Questions and Limitations

- **Calibrating exponents** – α, β, γ and the threshold θ need to be estimated from large-scale data (e.g., Human Connectome Project) using maximum likelihood.
- **The liver problem** – our exclusion criteria need empirical validation; we must show that organs like the liver do **not** satisfy them.
- **Inverted-U for policy entropy** – the same shape is predicted but may be hidden by decision noise.
- **Moral responsibility** – the framework gives a basis for responsibility (if $A > A_{\text{crit}}$), but it does not settle all normative questions – it only gives a scientific starting point.

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10. Conclusion

Free will is **not** a supernatural escape from physics. It is a **dynamical property** of certain dissipative, self-referential attractors:

- The ability to act from your own internal dynamics.
- To keep a stable self-model over time.
- And to reshape your own attractor landscape.

This account is compatibilist, testable, and graded.
The inverted-U prediction, with a specified statistical test,

gives a clear falsification criterion.
The dance of free will is the dance of a self that persists under perturbation.

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