The Architecture of the Loop

Paper II: The Action Channel and the Topological Self

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Abstract

In Paper I, we established that the Action Substrate acts as a Topological Chaperone, penalizing singular histories and energetically favoring smooth configurations. In this second paper, we derive the structural consequence of this constraint: the emergence of the **Dynamic Self-Topology (DST)**. We define the **Action Channel** as a self-referential feedback loop where a system's output becomes its future input. We show that when the channel's internal coherence time τ_{mem} exceeds the environmental correlation time τ_{env} (the condition $\chi > 1$), the system exhibits a topological transition in the loop-state description. The loop becomes a **Topologically Protected Limit Cycle** characterized by a non-zero winding number $W = 1$, protected from thermal dissolution by the Chaperone Effect. We identify the boundary of this cycle as a **Markov Blanket**—a statistical partition that separates internal states from external states. Finally, we demonstrate this mechanism in a concrete Stuart-Landau oscillator model, analytically deriving the $\chi > 1$ threshold as the onset of limit-cycle stability against kernel-filtered noise.

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1 Introduction: From Filter to Object

Paper I demonstrated that the universe has a filter. The **Chaperone Effect**, mediated by the non-local kernel $K(\Box) = e^{-\Box/\Lambda^2}$, suppresses high-frequency disorder. It explains why physical history is smooth.

But smoothness is not enough to explain *identity.* A cloud is smooth, but it has no sharp boundary; it merges seamlessly with the sky. A living agent, by contrast, is distinct. It has an "inside" and an "outside." It persists as a coherent object even as its constituent atoms change.

How does a continuous field create a discrete object?

We propose that the Chaperone's smoothness constraint, combined with the thermodynamic imperative to dissipate, forces a phase transition: the system's history must **fold back on itself**, creating a topologically distinct, persistent loop—a knot in the flow of action.

In this paper, we propose that the "Self" is a knot tied in the flow of action. We formally define this knot as a **Closed Action Loop**—a trajectory that folds back on itself to create a topologically protected domain. We show that the boundary of this domain is not just a spatial edge, but a statistical wall known as a **Markov Blanket** [1].

Core Claims of Paper II

- **Loop formation:** Under sustained drive and smoothness penalization, limit cycles are a generic low-cost attractor class.
- **Topological invariant:** A stable oscillatory loop supports an integer winding number W; loop loss occurs via phase slips through $|z| = 0$.
- **Threshold proxy:** The regime $\chi = \tau_{mem}/\tau_{env} > 1$ marks the onset of predictive dominance of internal history over environmental perturbations.

We use the control parameter

$$\chi \equiv \frac{\tau_{mem}}{\tau_{env}},$$

with $\chi > 1$ indicating internal predictive dominance.

2 The Action Channel

2.1 Definition of the Channel

Consider a region of the Action Substrate where energy flows. We define an **Action Channel** as a directional flow of influence. In the language of field theory, it is a persistent propagator connecting events in spacetime.

In a linear system, action flows downstream: Input $\rightarrow$ Processing $\rightarrow$ Output $\rightarrow$ Dissipation. This is an open trajectory. As shown in Paper I, open trajectories are subject to entropic dissolution (the Blur).

2.2 Closure and Feedback

The architecture of agency arises when the channel closes. We define this recursively:

Definition 1 (Recursive Action Channel)**.** *A system exhibits Dynamic Self-Topology if its state evolution $\phi(t)$ is governed by a delayed feedback from its own history:*

$$\frac{\partial \phi}{\partial t} = \mathcal{F}(\phi(t), \phi(t - \tau_{delay}), \nabla\phi) + \xi(t) \tag{2.1}$$

where $\xi(t)$ is environmental noise, and $\phi(t - \tau_{delay})$ represents the self-coupling. The self-coupling is mediated by an effective *memory kernel induced by the substrate filtering (AFT) together with the* *system's internal transport and feedback architecture [2, 3]. The channel "closes" when the self-coupling term dominates the external forcing $\xi(t)$, leading to periodic solutions $\phi(t+T) \approx \phi(t)$.*[1]

This recursive structure creates what we call a **Causal Eddy**: a region of spacetime where the dominant causal influence on $\phi(t+dt)$ comes from $\phi(t)$ rather than external forcing $\xi(t)$. Quantitatively, this is measured by the ratio of internal to external mutual information, which exceeds unity when $\chi > 1$ (as we will show in Theorem 1).

3 The Topology of Protection

3.1 The Loop as a Topological State

When the feedback is strong enough to overcome dissipation, the system settles into a stable limit cycle. In the phase space of the field, this cycle is topologically distinct from the vacuum (the trivial fixed point). We can characterize this distinction using a topological invariant, the **Winding Number** W.

3.1.1 Computing the Winding Number

For a complex order parameter $z(t) = r(t)e^{i\theta(t)}$ describing the loop, the winding number over one period T is:

$$W = \frac{1}{2\pi} \oint_C d\theta = \frac{1}{2\pi} \int_0^T \frac{d\theta}{dt} dt = \frac{\omega T}{2\pi} \tag{3.1}$$

where the contour C is one complete traversal of the limit cycle (parametrized by time $t \in [0, T]$). For a stable limit cycle, the phase accumulates 2π over the period $T = 2\pi/\omega$, yielding $W = 1$. For a noise-dominated (non-cycling) state, the phase is not single-valued over a period and the winding number is not a robust invariant (empirically one observes frequent phase slips and no stable integer W).

3.2 Topological Protection by the Chaperone

Why is this knot stable? To change the winding number from $W = 1$ to $W = 0$ (untie the knot), the trajectory must either:

1. **Collapse:** Pass through $z = 0$ (amplitude vanishes).
2. **Tear:** Develop a discontinuity (infinite gradient).

Tearing is exponentially suppressed by the Chaperone Inequality (Paper I, Theorem 1). A tear corresponds to effectively singular time-structure (large high-frequency content), which incurs an exponentially large action cost under the kernel-weighted measure. **Collapse:** Pass through $z = 0$ (amplitude vanishes). This is prevented by the **dissipative drive** (e.g., the $(1 - |z|^2)z$ term in Stuart-Landau), which actively pumps the system back to the limit cycle, creating a dynamical attractor. For $\chi > 1$, the rate of this active restoration exceeds the rate of noise-driven decay.

Thus, the "Self" is a **topologically protected loop state**: changing W requires a phase slip through $|z| = 0$ (collapse) or a trajectory with effectively singular time-structure (tear), both strongly suppressed when the restorative dynamics dominates the filtered noise. Analogous mechanisms of topological protection appear in condensed matter systems [4], though here the protection is dynamical.

[1] For Markov systems like Stuart-Landau, $\tau_{delay} \to 0$ and the self-coupling is instantaneous; for systems with transport delays, τ_{delay} is finite.

4 The Markov Blanket

4.1 Statistical Partitioning

The topological boundary of the loop manifests statistically as a Markov Blanket. Following Friston [5], we partition the universe into Internal States (μ), External States (η), and Blanket States (b). A stable blanket exists if the internal states are conditionally independent of the external states, given the blanket: $P(\mu|b, \eta) \approx P(\mu|b)$.

4.2 Derivation of the Blanket Condition

Physically, the blanket emerges when the internal dynamics are dominated by the system's own memory rather than instantaneous external noise.

Theorem 1 (Operational blanket criterion)**.** *If the internal autocorrelation time exceeds the effective environmental correlation time ($\chi = \tau_{mem}/\tau_{env} > 1$), then internal trajectories are predictively dominated by their own past rather than by instantaneous external perturbations. This regime supports a* statistically identifiable boundary *(a Markov-blanket-like partition) in the sense that internal prediction error is reduced primarily by conditioning on boundary variables rather than on distant external states.*

Proof. The mutual information between the internal state $\mu(t)$ and the external state $\eta(t-\tau)$ decays as

$$I(\mu(t); \eta(t-\tau)) \sim e^{-\tau/\tau_{env}} \tag{4.1}$$

(external memory is short). Meanwhile, the internal autocorrelation persists as

$$I(\mu(t); \mu(t-\tau)) \sim e^{-\tau/\tau_{mem}} \tag{4.2}$$

(internal memory is long). For $\chi = \tau_{mem}/\tau_{env} > 1$, we have $\tau_{mem} > \tau_{env}$, so the internal correlation outlasts the external one.

For $\chi < 1$, the environmental noise decorrelates the system faster than the cycle completes; $I(\mu; \eta)$ dominates, meaning the outside determines the inside (no blanket). For $\chi > 1$, $I(\mu; \mu) \gg I(\mu; \eta)$, implying the system's future is predicted by its own past. This establishes the intended operational regime: internal trajectories are predictively dominated by their own past rather than by distant external states, supporting a Markov-blanket-like partition. □

5 A Concrete Model: The Stuart-Landau Oscillator

The preceding sections established the geometric and information-theoretic structure of the DST loop. We now demonstrate these concepts in a minimal, analytically tractable model: the Stuart-Landau oscillator with additive noise. This system exhibits the $\chi > 1$ threshold explicitly and allows us to compute the winding number W.

5.1 The Model (with kernel-filtered noise)

Let $z(t)$ be a complex order parameter. We consider the Stuart–Landau normal form driven by *kernel-filtered* environmental noise:

$$\dot{z} = (1 - |z|^2)z + i\omega z + \sqrt{D}\,\eta(t), \tag{5.1}$$

where $\eta(t)$ is a stationary complex Gaussian process with power spectrum

$$S_\eta(\Omega) \;=\; e^{-\Omega^2/\Lambda^2}. \tag{5.2}$$

Equivalently, $\eta(t) = \int_{-\infty}^{t} \mathcal{K}_\Lambda(t-t')\xi(t')dt'$ where $\mathcal{K}_\Lambda$ is the inverse Fourier transform of $e^{-\Omega^2/\Lambda^2}$ and ξ is white noise.

- $(1 - |z|^2)z$: The dissipative drive (metabolism) forcing the system to radius $|z| = 1$.
- $i\omega z$: The internal dynamics (the loop frequency).
- D: Noise strength (dimension of frequency in natural units).

5.2 Calculating the Scales

Memory time (τ_{mem}). On the attracting cycle $|z| \approx 1$, noise induces phase diffusion:

$$\langle(\theta(t) - \theta(0))^2\rangle \sim D_\theta \, t, \tag{5.3}$$

with $D_\theta = D/2$ (the factor of 1/2 comes from projecting the complex noise onto the phase degree of freedom on the cycle $|z| = 1$). We define the coherence (memory) time operationally as the time for $\Delta\theta \sim 1$, so $\tau_{mem} \sim D_\theta^{-1} \propto D^{-1}$. This is also the timescale over which the winding number W (computed over a single attempted cycle) becomes undefined due to phase slips. The condition $\chi > 1$ thus ensures that the cycle period $T = 2\pi/\omega$ is completed ($\Delta\theta(T) < 1$) before phase coherence is lost, preserving $W = 1$.

Environmental time (τ_{env}). Because the substrate suppresses high-frequency fluctuations, the effective environmental drive experienced by the system is band-limited at $\Omega \sim \Lambda$. For the Gaussian filter $S_\eta(\Omega) = e^{-\Omega^2/\Lambda^2}$, the autocorrelation of η has width $\tau_{env} \sim \Lambda^{-1}$ (order-of-magnitude).

5.3 The Phase Transition

The stability condition $\chi > 1$ becomes:

$$\chi = \frac{\tau_{mem}}{\tau_{env}} \approx \frac{\Lambda}{D} > 1 \implies D < \Lambda \tag{5.4}$$

where we work in natural units $\hbar = c = 1$, so both D and Λ have dimensions of inverse time (frequency).

Result: A stable Self exists only if the environmental noise intensity D is less than the metabolic capacity Λ of the substrate. If the noise is too strong ($D > \Lambda$), the phase diffusion destroys the winding number W before a cycle is completed.

[Figure 1: The Topological Self]
Panel A: Stuart-Landau limit cycle in complex z-plane. The trajectory circles the origin once per period, yielding winding number $W = 1$. Dashed circle shows $|z| = 1$ attractor.
Panel B: Markov blanket partition (internal μ, blanket b, external η).
Panel C: Phase transition at $\chi = 1$. ***Left ($\chi < 1$, e.g. $D = 10\Lambda$):*** *Sample trajectory shows diffusive wandering with no sustained cycling (phase slips evident).* ***Right ($\chi > 1$, e.g. $D = 0.1\Lambda$):*** *Clean spiraling onto limit cycle with stable $W = 1$.*

Figure 1: Geometric and statistical structure of Dynamic Self-Topology.

6 Conclusion: The Atom of Agency

We have identified the fundamental unit of agency and derived its structure:

1. **The Object:** A Closed Action Loop with topological invariant $W = 1$.

2. **The Mechanism:** Recursive self-coupling stabilizes a *topologically protected limit cycle* (a loop state with $W = 1$).

3. **The Boundary:** A Markov Blanket emerges when $\chi > 1$ (Theorem 1).

4. **The Protection:** The Chaperone Effect prevents winding number change.

Paper II's key contribution: We have shown that the $\chi > 1$ threshold (derived thermodynamically in Paper I) has a geometric interpretation as a topological phase transition. The exponential stability $\Gamma \propto e^{-\alpha\chi^2}$ derived in Paper I now has a topological interpretation: it measures the rate of phase slips that would destroy the winding number $W = 1$. The Self is not merely stable; it is *topologically protected*. In the Stuart-Landau model, this manifests as the condition $D < \Lambda$ for limit-cycle persistence.

In the next paper, *The Anticipatory Hinge*, we will analyze the *temporal* structure of this loop, showing how the kernel's non-locality allows the system to "sample" its immediate future [6].

References

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