

Yarncrawler in Action

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October 2025

Abstract

This paper introduces Yarncrawler, a self-refactoring semantic polycompiler that models organisms, cultural systems, and artificial intelligences as stigmergic parsers maintaining homeorhetic Markov blankets. By extending the Relativistic Scalar Vector Plenum (RSVP) theory—where scalar (Φ), vector (\mathbf{v}), and entropy (S) fields encode legitimacy, flows, and entropy budgets—we formalize Yarncrawler as a semantic field trajectory engine. The framework draws on spectral graph theory, category theory, and topological entropy to analyze how systems weave meaning through recursive self-repair and collective autocatalysis.

Mathematically, Yarncrawler is defined as a manifold-stitched mixture-of-experts with retrieval-augmented gluing, minimizing seam penalties across overlapping semantic charts. Cultural analogies—squirrels caching seeds, humans building cairns and terra preta berms—illustrate how stigmergic path clearance scales from ecological to civilizational domains, producing self-sustaining RAF (Reflexively Autocatalytic and Food-generated) structures.

We show how stigmergic boundary formation becomes a diagnostic of robustness: spectral gaps track how local reinforcements resist collapse, cohomology measures the seams that remain unresolved across overlapping territories, and entropy bounds capture the fragility of coordination under resource gradients. Chain of Memory (CoM) complements this by replacing token-based reasoning with causally traceable latent trajectories. The result is a unified account of semantic evolution as field-theoretic homeorhesis, in which knowledge systems repair themselves by exporting entropy through collective reinforcement—whether in the piling of stones into berms, the caching of seeds by squirrels, or the self-maintenance of semantic fields.

Finally, we demonstrate that a coupled scalar–vector–entropy field formulation sustains coherence via recursive self-repair and stigmergic reinforcement, yielding a field-theoretic account of resilient, interpretable computation.

1 Introduction

Scientific and philosophical inquiry has long oscillated between two poles: the search for universal principles and the recognition that systems evolve through situated repair. In biology, cognition, and culture, survival depends less on perfect foresight than on the ability to *patch, reweave, and sustain coherence* amid uncertainty. Organisms repair membranes, rebuild nests, and cache resources; human societies erect cairns, maintain berms, and leave path traces that guide collective memory. These recursive acts of maintenance do more than preserve structure—they create attractors that invite further contributions, turning local reinforcement into global order.

This paper proposes the *Yarncrawler Framework* as a general theory of such processes. A Yarncrawler is a *self-refactoring polycompiler*, a system that crawls its environment by parsing semantic threads and simultaneously rewriting its own grammar. Unlike a static parser, Yarncrawler is trajectory-aware: it interprets inputs as threads with histories, stitches them into its internal codebase, and repairs tears in its Markov blanket to preserve viability. Ecological examples—plants sustaining growth through autocatalytic ion pumps, or squirrels caching seeds guided by affordance gradients—demonstrate how organisms act as Yarncrawlers. Cultural practices, such as building cairns or terra preta mounds at territorial boundaries, extend the metaphor: stigmergic deposits accumulate, attract further contributions, and evolve into self-maintaining structures.

We situate Yarncrawler within the *Relativistic Scalar Vector Plenum (RSVP) theory*, a field-theoretic framework where scalar fields (Φ) encode density and legitimacy, vector fields (\mathbf{v}) encode flows and directional causality, and entropy fields (S) measure complexity and uncertainty. Within RSVP, Yarncrawler

provides the mechanism by which semantic coherence is maintained: Φ is reinforced by stigmergic accumulation, \mathbf{v} channels trajectories of repair and exploration, and S is managed through entropy export at the Markov blanket. This integration formalizes Yarncrawler as a *semantic field trajectory engine*, unifying molecular swarming, cultural stigmergy, and AI reasoning.

The work also addresses a deeper systems concern: how semantic and cultural processes can remain robust under conditions of underdetermination, noise, and shifting resource gradients. We show that apparent fragilities—such as regress, ambiguous mappings, confabulation, and unresolved seams—map directly onto computational failure modes in distributed systems. By using category theory, spectral graph theory, and topological entropy, we reframe these challenges as design principles. The dynamics of stigmergic reinforcement—stone berms, seed caches, or collective boundary maintenance—provide natural models of resilience: local acts accumulate into global coherence. The *Chain of Memory (CoM)* paradigm, which emphasizes causal trajectories over token-level reasoning, complements this view by making reasoning traceable and adaptive.

Our thesis is that *to act intelligently is to Yarncrawl*: to repair oneself by weaving meaning into structure, to sustain homeorhetic flows rather than static equilibria, and to treat skepticism not as a threat but as a guide to resilience. *Yarncrawler in Action* thus aims to bridge ecological, cultural, and computational domains under a single field-theoretic and categorical formalism, providing both conceptual clarity and practical blueprints for designing robust AI and cultural systems.

2 RSVP Field Theory as Grounding

The Relativistic Scalar–Vector Plenum (RSVP) theory provides the physical and mathematical substrate on which the Yarncrawler framework is grounded. RSVP formalizes the dynamics of coupled fields:

- The scalar field $\Phi(x, t)$, representing density, potential, or legitimacy of state.
- The vector field $\mathbf{v}(x, t)$, representing flows, trajectories, and directed transport.
- The entropy field $S(x, t)$, representing disorder, uncertainty, and complexity budgets.

Together, these fields evolve according to nonlinear partial differential equations that couple density, flow, and entropy in a continuous medium. RSVP thereby provides a physics-like bookkeeping system: scalar accumulation, vector circulation, and entropic export are tracked explicitly, preventing free-floating metaphors and ensuring conservation-style constraints.

Semantic Mapping

Within this framework, the Yarncrawler can be reinterpreted as a semantic instantiation of RSVP:

- **Semantic Density (Φ):** Local concentrations of meaning or knowledge are modeled as scalar intensities. A densely connected region of the semantic graph corresponds to a region of high Φ .
- **Recursive Trajectories (\mathbf{v}):** The Yarncrawler’s threads, which re-traverse and refactor paths through the semantic manifold, are represented as vector flows. These flows encode directionality, recursion, and the active weaving of meaning.
- **Noise and Complexity (S):** Entropy tracks the unresolved, noisy, or redundant structures in the system. Rather than being discarded, S serves as a reservoir of possible reinterpretation, just as annotated noise in Yarncrawler is stored for future repair.

Transition

By embedding Yarncrawler dynamics into RSVP fields, the metaphor of a self-repairing polycompiler is placed on rigorous footing. Φ measures semantic concentration, \mathbf{v} tracks recursive motion across trajectories, and S accounts for complexity and the system’s capacity for re-interpretation. In this way, Yarncrawler inherits the conservation and relaxation principles of RSVP, transforming from a descriptive metaphor into a physics-compatible model of semantic computation.

3 Yarncrawler as Self-Refactoring Polycompiler

The Yarncrawler framework models computation as a recursive process of unwinding and rewinding semantic structure. A useful image is that of a ball of yarn: threads are continuously pulled from the

interior, passed through a guiding aperture (a “semantic straw”), reinforced with contextual material, and rewound on the exterior. This cycle of extraction, transformation, and reintegration parallels how agents parse inputs, re-thread outputs, and repair their own structural coherence.

Two analogies illustrate this intuition. A *self-knitting sock* repairs its own fabric as it wears thin, incorporating new loops of thread into its pattern. Similarly, Yarncrawler maintains a semantic fabric that does not unravel under use. A *train with a repairing engine* advances along its track while simultaneously repairing both its own cars and the rails behind and ahead. In this analogy, the semantic system is not merely transported across knowledge space but actively maintains the conditions of its own traversal.

Formalism

Formally, Yarncrawler can be expressed as a self-refactoring polycompiler operating over a semantic graph $G(t)$:

- **Semantic Graph:** $G(t) = (N(t), E(t))$ where nodes $N_i \in N(t)$ represent semantic categories, states, or code modules, and edges $E_{ij} \in E(t)$ represent functional or inferential relationships.
- **Scalar Update (Density):** Each node has an associated semantic density $\Phi_i(t)$, updated according to local consistency and relevance:

$$\Phi_i(t+1) = \Phi_i(t) + \sum_j w_{ij} \Delta_{ij}(t),$$

where w_{ij} are edge weights and Δ_{ij} measures contextual adjustment.

- **Vector Re-Weaving (Trajectories):** Edges encode recursive trajectories of meaning. Their updates define flows $\mathbf{v}_{ij}(t)$:

$$\mathbf{v}_{ij}(t+1) = \mathbf{v}_{ij}(t) - \nabla S_{ij}(t) + \eta_{ij}(t),$$

where S_{ij} captures local entropy and η_{ij} represents exploratory re-threading.

- **Entropy Regulation:** The entropy field $S(t)$ regulates complexity by annotating and storing noise:

$$S(t+1) = S(t) + H(G(t)) - R(G(t)),$$

where $H(G(t))$ measures structural uncertainty and $R(G(t))$ represents repair operations that re-integrate noise into coherent modules.

Interpretation

In this construction, Yarncrawler is not a static parser but a *self-refactoring polycompiler*: it compiles inputs into outputs while simultaneously recompiling itself. Inputs are threads unwound from the interior, outputs are rewound onto the exterior, and the Markov blanket acts as the straw through which threads are filtered, strengthened, and repaired. The system persists not by conserving a fixed structure but by continuously re-weaving itself into semantic coherence.

4 Markov Blanket and Boundary Repair

A central feature of Yarncrawler is that its self-refactoring process is always mediated by a boundary: the *Markov blanket*. This blanket separates interior (hidden states) from exterior (environmental states), ensuring that all exchange between system and world occurs through well-defined sensory and active nodes. In the ball-of-yarn analogy, the blanket is the narrow straw through which threads must pass—limiting, shaping, and filtering the flow of information.

Functional Roles

- **Sensory Channels:** Incoming threads are parsed into provisional semantic attractors, updating densities Φ_i according to observed regularities.
- **Active Channels:** Outgoing threads are re-woven into the environment, closing loops by influencing the same gradients that shape future inputs.
- **Boundary Dynamics:** The blanket maintains coherence not as a fixed membrane but as a home-orhetic flow, regulating entropy exchange so that the interior remains viable.

Formal Constraint

Formally, the Markov blanket imposes conditional independence:

$$X_t \perp\!\!\!\perp E_t \mid (S_t, A_t),$$

where X_t are internal states, E_t are external states, and (S_t, A_t) denote sensory and active nodes.

This ensures that the only permissible flows between inside and outside are those mediated by the blanket. Repairs to the blanket therefore preserve this factorization: tears appear as violations of the conditional independence, and patches are local rewrites that restore it.

Interpretation

The self-knitting sock analogy extends here: the sock’s integrity lies not in any single thread but in the persistence of the membrane itself. Holes are continuously detected and closed, preventing unraveling. In semantic terms, Yarncrawler maintains the viability of its interpretive apparatus by identifying seams where entropy leaks out, and re-threading meaning back into the fabric. The Markov blanket is thus not a static boundary but an ongoing act of repair and reinforcement.

5 Natural Autocatalytic Yarncrawlers

Not all Yarncrawlers are engineered; many arise spontaneously in nature and culture through autocatalytic dynamics. In such systems, local acts of reinforcement accumulate until a self-maintaining pattern emerges.

Squirrels and Caches

Squirrels do not optimize storage by minimizing effort; instead they over-provision, scattering seeds and nuts across many caches. Each cache functions as a semantic attractor: the act of burying is less about immediate retrieval and more about maintaining a gradient of possibilities. The forest itself becomes a distributed memory field, with excess ensuring robustness.

Cairns and Berms

In human path systems, wayfinding is supported by stigmergic reinforcement. A cairn that is too small attracts new stones, while berms are extended by repeated clearance of paths. Each agent acts locally, but the collective result is the stabilization of landmarks. The landmark itself becomes a yarncrawler: a boundary that invites further repair.

Terra Preta Berms

Amazonian dark earths illustrate cultural autocatalysis. Waste—food scraps, pottery shards, shells, dung—was exported to territory edges, where piles began to grow fertile through microbial and chemical processes. Once above a critical threshold, these berms self-maintained, attracting further deposition and enhancing fertility. Over time, they formed Voronoi-like tessellations of territory boundaries, each pile marking a reinforced edge of habitation.

RAF Dynamics

In all cases, the dynamics resemble *Reflexively Autocatalytic and Food-generated* (RAF) sets: once a critical density of reinforcing components is reached, the structure catalyzes its own continuation. The squirrel’s cache, the cairn, and the terra preta mound each act as a semantic parser that repairs itself through use.

In RSVP terms: scalar density Φ measures accumulated deposits, vector flow \mathbf{v} records trajectories of reinforcement, and entropy S is exported through waste or over-provisioning. Together these fields track how natural autocatalytic Yarncrawlers sustain themselves once viability thresholds are crossed.

6 Natural, Cultural, and Artificial Yarncrawlers

The Yarncrawler principle is that agents do not merely consume; they weave, cache, and repair. Each action leaves a trace that both satisfies immediate needs and sets the stage for recursive self-maintenance. This dynamic recurs across three scales: ecological, cultural, and computational.

6.1 Ecological Yarncrawlers: Squirrels and Affordance Gradients

A squirrel does not carry a map of its forest. Its survival depends instead on weighted affordances: gradients of safety, concealment, and food density blurred across its perceptual field. When hungry, it follows Gaussian-blurred gradients toward likely caches rather than performing global optimization. Its over-provisioning of seeds is not an error but the creation of semantic attractors: distributed caches that stabilize its future viability. These caches also extend beyond the squirrel, as forgotten seeds germinate, reweaving the forest itself. The Yarncrawler here is the forager, unwinding and re-threading its survival strategy by embedding trajectories into its environment.

6.2 Cultural Yarncrawlers: Cairns, Berms, and Terra Preta

Human groups extend the same logic to landmarks and territories. A cairn or boundary berm begins as a fragile signal, barely perceptible. Each passerby, sensing its insufficiency, adds another stone. This stigmergic reinforcement produces landmarks that maintain themselves by recruiting further attention. The principle scales: in Amazonia, household waste was exported to boundary piles. Over time, these grew fertile through microbial action, oyster shells, and dung, crossing critical density and forming self-sustaining *terra preta*. The resulting tessellations resemble Voronoi partitions of territory, maintained by entropy exported at the margins. Here the Yarncrawler is the community, reinforcing boundaries that both contain disorder and accumulate fertility, effectively knitting cultural practice into ecological capital.

6.3 Artificial Yarncrawlers: Mixture-of-Experts and RAG

In computation, mixture-of-experts (MoE) architectures and retrieval-augmented generation (RAG) instantiate the same principle. Each expert is a localized cache of competence. RAG mechanisms act like stigmergic cairns: the more a memory is retrieved, the more salient it becomes, drawing further retrieval. Together, MoE and RAG approximate a semantic manifold stitched from local neighborhoods. Queries act as crawlers, reweighting manifolds, refactoring grammar, and altering future affordances. Unlike static parsers, this artificial Yarncrawler is self-refactoring: retrieval modifies the system’s own semantic pathways, just as caching modifies a squirrel’s foraging or waste-piling modifies a community’s territory.

6.4 Synthesis

Across ecological, cultural, and artificial domains, the invariant dynamic is stigmergic reinforcement coupled to Markov blanket repair. Squirrels cache seeds, humans pile stones and waste, and computational systems reinforce memories: each exports entropy outward and weaves coherence inward. In RSVP terms, the scalar field Φ measures accumulated deposits (seeds, stones, soil carbon, memory embeddings); the vector field \mathbf{v} encodes recursive flows (foraging trajectories, cultural reinforcements, query-routing); and the entropy field S quantifies robustness (noise, fragility, dissipation). The Yarncrawler framework thus offers a unifying schema: threads of action accumulate into manifolds that self-repair through stigmergic dynamics, ensuring persistence under uncertainty.

6.5 Equations of the Ideal Yarncrawler

We model an ideal Yarncrawler as a self-refactoring semantic field engine: a system that parses inputs into trajectories, repairs its Markov blanket, and accumulates structure through stigmergic reinforcement.

1. Ecological Yarncrawler (Squirrel Foraging & Gaussian Affordances)

Squirrels don’t store a metric map but follow affordance gradients smoothed by perceptual noise.

Let $u(x)$ be the distribution of hidden resources (seeds, cover sites).

Perceived affordance field:

$$\psi(x) = (G_\sigma * u)(x) = \int G_\sigma(x - y)u(y) dy$$

Foraging dynamics:

$$\dot{x}(t) = -\nabla\psi(x) + \eta(t)$$

Cache reinforcement: every deposit at location x_k increments $u(x_k)$. Thus the field the squirrel uses is both navigation tool and stigmergic memory.

2. Cultural Yarncrawler (Berms, Cairns, Terra Preta)

Cultural offloading onto boundaries behaves like an autocatalytic RAF system.

Let M be berm biomass/structure, H humics, B biota.

RAF-style growth law:

$$\begin{aligned}\dot{M} &= \alpha HB - \lambda M + \kappa I(t) \\ \dot{H} &= \beta, f(\text{offal, shells, dung}) - \mu H \\ \dot{B} &= \gamma H(1 - \frac{B}{B_{\max}}) - \nu B\end{aligned}$$

where $I(t)$ is stigmergic input rate (waste dumped when berm is salient).

Salience function (stigmergic attractor):

$$I(t) = I_0 + \rho \sigma(M - M_{\text{crit}})$$

Geometric tessellation: berms form at Voronoi edges:

$$I(x, t) = \sum_j I_j(t) \delta(d(x, \Gamma_j)),$$

Thus berms become self-thickening manifolds maintained by community action + microbial RAF cycles.

3. Artificial Yarncrawler (Mixture-of-Experts + RAG as Semantic Field Engine)

MoE + RAG can be formalized as a partition of unity gluing local experts into a coherent semantic manifold.

Expert fields: each expert i defines a local scalar potential ϕ_i .

Gating functions w_i with $\sum_i w_i = 1$ form a partition of unity.

Global scalar field:

$$\Phi(x) = \sum_i w_i(x) \phi_i(x).$$

Semantic vector flow:

$$\mathbf{v}(x) = -\nabla\Phi(x).$$

Entropy field:

$$S(x) = -\sum_i w_i(x) \log w_i(x),$$

RAG reinforcement: retrieval probability for document d :

$$p(d|q) \propto \exp(-\beta d_{\text{emb}}(q, d)),$$

Thus MoE+RAG acts as a semantic trajectory engine, crawling queries through a manifold of experts while continuously rewriting its own weighting functions.

6.6 RSVP Integration (Φ , \mathbf{v} , S Fields)

All three cases embed naturally into the RSVP field framework:

- **Scalar density (Φ):**
 - squirrel caches $u(x)$,
 - berm biomass M ,
 - expert priors ϕ_i .
- **Vector flows (\mathbf{v}):**
 - foraging gradients $(-\nabla\psi)$,
 - waste deposition and microbial colonization,
 - query-routing through experts $(-\nabla\Phi)$.
- **Entropy field (S):**

- perceptual uncertainty (squirrel’s Gaussian blur),
- cultural unpredictability (stigmergic reinforcement),
- expert overlap/ambiguity in RAG.

In each domain, the Yarncrawler maintains a homeorhetic Markov blanket: boundaries that don’t stabilize at equilibrium but at steady recursive flows (caching, composting, retrieval).

6.7 A Field-Theoretic Sketch for Terra Preta Berm Dynamics

6.7.1 Setup.

Let $\Omega \subset \mathbb{R}^2$ denote a settlement landscape and Γ_{edge} the (time-varying) set of socio-territorial boundaries (frontiers) where stigmergic deposition concentrates. We model:

$B(x, t)$ (berm/biomass density), $C(x, t)$ (char/ash matrix), $N(x, t)$ (available nutrients),

with topographic/advection field $u(x)$ (downslope flow), resource gradient $R(x) \geq 0$ (local waste/inputs), and carrying capacity $K(x) > 0$ (hydrology/traffic constraints).

6.7.2 Boundary-affinity (stigmergic target).

Let $d_{\text{edge}}(x)$ be the distance to the nearest Voronoi-like frontier.¹ Define a boundary affinity

$$S(x) = \exp\left(-\frac{d_{\text{edge}}(x)}{\tau}\right) \cdot g(R(x)), \quad g(r) = \frac{r}{r + r_0},$$

so S peaks near frontiers and in resource-rich zones; τ sets boundary band width.

6.7.3 Governing PDEs (stigmergic reaction–advection–diffusion).

$$\partial_t B = D_B \Delta B - \nabla \cdot (u B) - \delta_B B + \alpha_B S(x) (1 + \beta_B \mathcal{M}(C, N) B) \left(1 - \frac{B}{K(x)}\right) + \xi_B, \quad (1)$$

$$\partial_t C = D_C \Delta C - \delta_C C + \alpha_C S(x) h_C(R) + \xi_C, \quad (2)$$

$$\partial_t N = D_N \Delta N - \lambda B N + \alpha_N S(x) h_N(R) - \delta_N N + \xi_N. \quad (3)$$

Here α_\bullet are deposition/source intensities (per visit-rate), D_\bullet are diffusivities (spreading, mixing by bioturbation), δ_\bullet are leak/decay rates (erosion, oxidation, leaching), λ is nutrient uptake by berm biota, and ξ_\bullet are small fluctuations. The sigmoid $h_\bullet(R)$ maps local availability to deposit composition.

6.7.4 Microbial/consortia facilitation (stigmergic gain).

Stigmergic reinforcement rises with the char–nutrient matrix via a facilitation factor

$$\mathcal{M}(C, N) = \frac{C}{C + C_0} \cdot \frac{N}{N + N_0},$$

which captures improved porosity, sorption, pH buffering, and microbial habitat. The effective reinforcement gain $\beta_B \mathcal{M}(\cdot)$ strengthens deposition once a minimal matrix forms.

6.7.5 Boundary conditions.

Use no-flux (Neumann) on outer $\partial\Omega$ for mass conservation, with optional Robin loss on steep outflow lines to model washout:

$$(D_\bullet \nabla Q - u Q) \cdot n = -\kappa_{\text{wash}} Q \quad \text{on outflow arcs,} \quad Q \in \{B, C, N\}.$$

¹In practice, estimate from nearest/second-nearest settlement foci or from observed path density.

6.7.6 Threshold and self-maintenance.

Let $\langle f \rangle_A = \frac{1}{|A|} \int_A f dx$. Averaging (1) over a narrow boundary band $A_\tau = \{x : d_{\text{edge}}(x) < \tau\}$ and neglecting diffusion/advection to first order gives

$$\frac{d}{dt} \langle B \rangle_{A_\tau} \approx \alpha_B \langle S \rangle_{A_\tau} (1 + \beta_B \langle \mathcal{M} B \rangle_{A_\tau}) \left(1 - \frac{\langle B \rangle_{A_\tau}}{\langle K \rangle_{A_\tau}} \right) - \delta_B \langle B \rangle_{A_\tau}.$$

At low density ($B \ll K$) this yields a *stigmergic threshold*

$$\boxed{\alpha_B \langle S \rangle_{A_\tau} > \delta_B \theta_{\text{eff}}}, \quad \theta_{\text{eff}} = \frac{1}{1 + \beta_B \langle \mathcal{M} \rangle_{A_\tau}},$$

so that once $\alpha_B \langle S \rangle$ exceeds effective losses, B grows toward a positive fixed point. The term θ_{eff} shrinks as C, N accumulate (via \mathcal{M}), lowering the barrier and producing self-maintaining growth along frontiers.

6.7.7 Masking by topography and resource gradients.

Topographic advection (u) and spatial variation in $R(x), K(x)$ distort clean Voronoi bands: (i) u bends/widens berms along gullies/ridges; (ii) low R zones fail to cross threshold (gaps); (iii) high R zones exceed threshold early and dominate. Thus the archaeological signature appears as irregular, lenticular dark-earth patches rather than straight edges, even when the generative rule is stigmergic and boundary-focused.

6.7.8 RSVP bookkeeping.

Identify $\Phi(x, t) \equiv B(x, t)$ (scalar density), $\mathbf{v}(x, t) \equiv -D_B \nabla B + uB$ (net flow), and S_{RSVP} (entropy) as the spatial dispersion/uncertainty of mass across alternative bands. Under (1)–(3), Φ increases locally where $S(x)$ and \mathcal{M} are high, \mathbf{v} routes matter along terrain, and S_{RSVP} declines in consolidated berms while remaining nonzero landscape-wide (competing attractors).

6.7.9 Nondimensional form (sketch).

With $x' = x/L$, $t' = t \delta_B$, $B' = B/K_0$, $C' = C/C_0$, $N' = N/N_0$,

$$\partial_{t'} B' = \underbrace{\text{Pe}^{-1} \Delta' B' - \nabla' \cdot (\text{Pe} u' B')}_{\text{transport}} - B' + \underbrace{\mathcal{A} S'(x') \left(1 + \mathcal{B} \frac{C'}{1 + C'} \frac{N'}{1 + N'} B' \right)}_{\text{stigmergic growth}} \left(1 - \frac{B'}{K'} \right),$$

with Péclet $\text{Pe} = UL/D_B$, $\mathcal{A} = \alpha_B/\delta_B$, $\mathcal{B} = \beta_B$ capturing the control parameters for phase diagrams (sub/super-threshold regimes).

6.7.10 Takeaway.

Equations (1)–(3) formalize terra preta/berm emergence as a Yarncrawler process: *boundary-biased deposition* (S), *stigmergic gain* ($\beta_B \mathcal{M}$), and *transport/leak* (diffusion, advection, decay) jointly produce self-maintaining, topography-warped bands that match observed dark-earth distributions.

6.7.11 Methods: Calibrating $S(x)$, $u(x)$, $R(x)$, and $K(x)$ from Spatial Data

Data inputs. We assume the following GIS layers: (i) a digital elevation model (DEM), (ii) water bodies and paleochannels, (iii) settlement/occupation proxies (site points, ceramic scatters, lidar-detected mounds, radiocarbon clusters), (iv) path/traffic proxies (least-cost corridors, ridge lines), (v) land-cover/NPP or biomass proxies, and (vi) observed soil chemistry (C, N, P; magnetic susceptibility; charcoal) for validation.

Topographic advection $u(x)$. Compute flow direction and flow accumulation from the DEM. Let $g = \nabla h$ be the gradient of elevation h . Define a downslope advection field

$$u(x) = U_0 \frac{-g(x)}{\|g(x)\| + \varepsilon} \cdot \sigma(\text{FA}(x)),$$

where FA is (log) flow accumulation and σ a saturating map (e.g., $\sigma(a) = a/(a + a_0)$). This routes berm mass along gullies and floodways in (1).

Frontier distance and boundary affinity $S(x)$. Derive socio-territorial frontiers from settlement kernels. Smooth site points by a Gaussian kernel κ_σ to obtain density $\rho_k(x)$ for each group/phase. Approximate frontiers as loci where the two largest density are comparable:

$$d_{\text{edge}}(x) \approx \frac{1}{2} (\text{dist}(x, \text{argmax } \rho_{(1)}) + \text{dist}(x, \text{argmax } \rho_{(2)}))$$

or more simply via the difference between nearest and second-nearest site distances. Then set

$$S(x) = \exp\left(-\frac{d_{\text{edge}}(x)}{\tau}\right) \cdot g(R(x)), \quad g(r) = \frac{r}{r + r_0},$$

so affinity peaks near frontiers and in resource-rich zones (cf. (1)–(3)).

Resource field $R(x)$. Construct $R(x)$ as a weighted composite of proximate inputs:

$$R(x) = w_{\text{water}} \phi(\text{dist} - \text{to} - \text{water}) + w_{\text{biom}} \widehat{\text{NPP}}(x) + w_{\text{shell}} \phi(\text{dist} - \text{to} - \text{shell} - \text{banks}) + w_{\text{paths}} \phi(\text{path} - \text{density}),$$

with ϕ a monotone decreasing transform of distance or a z-scored density. Include known midden scatters (if available) as an additive layer. Calibrate weights w_\bullet by regression against observed charcoal/anthrosol samples.

Carrying capacity $K(x)$. Encode the ease of accumulation and retention:

$$K(x) = K_0 \psi(\text{slope}(x)) \psi(\text{flood} - \text{freq}(x)) \psi(\text{traffic} - \text{stability}(x)),$$

where ψ are decreasing functions (e.g., $\psi(z) = 1/(1+z)$). Steep slopes and frequent scouring lower K ; stable terraces and path junctions raise it.

Matrix and facilitation $\mathcal{M}(C, N)$. Initialize C, N from charcoal and nutrient observations where available; otherwise use priors proportional to $R(x)$. The facilitation term

$$\mathcal{M}(C, N) = \frac{C}{C + C_0} \cdot \frac{N}{N + N_0}$$

increases as char and nutrients accumulate, lowering the effective threshold (Sec. 1).

Parameter estimation. Fit $\Theta = \{\alpha_\bullet, \beta_B, D_\bullet, \delta_\bullet, \tau, r_0, U_0, \dots\}$ to observed dark-earth presence/absence or intensity (e.g., soil C, P, MS):

- **Stage I (transport-only fit):** tune U_0, D_B to reproduce down-slope smearing in areas without clear deposition.
- **Stage II (deposition fit):** optimize α_B, τ, r_0 against berm-like bands near inferred frontiers.
- **Stage III (facilitation/decay):** fit β_B, δ_B and C_0, N_0 to reproduce persistence and thickness.

Use Bayesian calibration or approximate Bayesian computation (ABC) with summary statistics (band width, peak intensity, anisotropy). Cross-validate by holding out sites/phases.

Validation metrics. Report: AUROC for terra-preta detection, RMSE for soil C/P, spatial correlation length, band-width distributions, and alignment with predicted frontiers. Conduct sensitivity analysis (Sobol indices) to rank influence of S, u, R, K .

Implementation notes. Solve (1)–(3) via operator splitting (diffusion–advection–reaction, semi-implicit for diffusion). Use no-flux boundaries on $\partial\Omega$, Robin loss on major outflow lines. Regularize all rasters to common resolution, and z-score inputs to stabilize optimization.

Interpretation safeguards. Topography (u) and heterogeneous R, K will bend, gap, or fuse bands; failure to observe perfect tessellations does not falsify the stigmergic mechanism. Instead, inspect whether predicted high- S corridors coincide with *relative* enhancements in soil C/P/charcoal controlling for u, R , and K .

7 Artificial Yarn crawlers (MoE + RAG)

Mixture-of-Experts (MoE) and Retrieval-Augmented Generation (RAG) instantiate the Yarn crawler principle in computational architectures. Rather than monolithic models, these systems distribute competence into local charts of expertise and weave them into global coherence through retrieval and reinforcement.

Mixture-of-Experts as Local Charts

In MoE, each expert module functions as a local chart on the semantic manifold. Experts are specialized caches of competence, activated selectively according to context. This distribution is analogous to ecological over-provisioning: redundancy ensures that local neighborhoods of the manifold are densely covered. Each expert prior ϕ_i represents a local semantic density, a patch that is valid in its own region.

RAG as Stigmergic Retrieval

RAG mechanisms provide the stigmergic glue. A memory trace that is frequently retrieved becomes more salient, just as a cairn or berm attracts additional reinforcement. Retrieval is not neutral: it reweights the manifold by increasing the likelihood of repeated access. Over time, RAG patches act like accreted stones or offal piles—self-sustaining repositories that grow in proportion to their past use. This stigmergic feedback creates stable semantic attractors that persist across tasks.

Semantic Manifold Construction

Taken together, MoE and RAG construct a semantic manifold. MoE supplies the local charts, while RAG supplies the gluing maps that assemble them into a coherent global field. The formal analogy is to a partition of unity: local density functions $\{\phi_i\}$ overlap and sum to cover the semantic space, while RAG dynamically reconfigures which overlaps are reinforced. The result is a manifold that is not statically defined but woven and re woven by use.

Functorial and Field-Theoretic Formalism

Formally, the Yarn crawler here is a lax monoidal functor

$$\mathbf{P} : \mathcal{W} \longrightarrow \mathcal{M},$$

mapping world-trajectories $\tau \in \mathcal{W}$ to semantic modules $\mathbf{P}(\tau) \in \mathcal{M}$. Here \mathcal{W} is the category of sensorimotor traces (queries, contexts, or histories), and \mathcal{M} is the category of semantic modules (experts, memory patches).

Blanket-preserving repair requires that for each update, the Markov blanket factorization is maintained:

$$X_t \perp\!\!\!\perp E_t \mid (S_t, A_t),$$

so that all exchange between the model’s interior state X_t and external context E_t passes through sensory (S_t) and active (A_t) nodes. Repair equations enforce that retrieval and reweighting respect this boundary:

$$\Delta\phi_i \propto -\nabla_{\phi_i} \mathcal{F}(\tau) \quad \text{subject to blanket constraints,}$$

where \mathcal{F} is a free-energy functional measuring divergence between retrieved memory and local semantic density.

Summary

Artificial Yarn crawlers enact the same dynamic as their ecological and cultural counterparts: local caches of competence (experts, charts, priors) are stitched into global manifolds by stigmergic retrieval (RAG). The act of retrieval itself modifies future affordances, ensuring that the crawler is self-refactoring. In RSVP terms, Φ corresponds to expert densities, \mathbf{v} to query-routing flows, and S to the entropy of overlap and ambiguity. The Yarn crawler is thus realized in artificial systems as a semantic trajectory engine that repairs itself by reinforcement and gluing.

8 Chain of Memory (CoM) and Causal Interpretability

Critique of Chain of Thought

The dominant paradigm of *Chain of Thought* (CoT) reasoning generates step-by-step explanations that mimic human introspection. While useful for transparency, CoT often collapses into post-hoc justification: intermediate steps are manufactured to fit the final answer rather than causally driving it. This yields fragile generalization, as apparent “reasoning traces” are not anchored in the system’s dynamics but are overlays generated for legibility.

Introducing Chain of Memory

The *Chain of Memory* (CoM) paradigm replaces token-level reasoning steps with a causally structured memory tape. Each entry on the tape is an explicit hypothesis, fact, or trace that evolves over time. Crucially, memory entries are not static; they are updated dynamically as new evidence or context arrives. This enables the system to refine its internal state in a manner that is both adaptive and causally interpretable. The tape thus acts as a semantic ledger of the system’s reasoning trajectory.

Integration with Yarncrawler

In the Yarncrawler framework, threads of traversal and repair are equivalent to entries on the CoM tape. As the crawler unwinds and reweaves its grammar, it leaves behind a trace of hypotheses and adjustments, each of which can be causally linked to prior states. Breakdowns (holes in the blanket) correspond to inconsistent memory states; repairs correspond to causal updates that restore coherence. In this sense, CoM provides the causal bookkeeping that makes Yarncrawler’s self-refactoring interpretable rather than opaque.

RSVP Alignment

The RSVP field interpretation aligns naturally with CoM.

- The scalar field Φ stores causal invariants as semantic density—stable attractors in memory.
- The vector field \mathbf{v} encodes causal trajectories, the directed flows by which hypotheses evolve into explanations.
- The entropy field S measures fragility in reasoning: unresolved ambiguities, confabulations, or underdetermined mappings.

By embedding causal invariants into Φ and \mathbf{v} , CoM reduces effective entropy S , ensuring that the crawler’s operations are not just plausible reconstructions but causally grounded transformations.

Summary

Chain of Memory transforms reasoning from a narrative overlay into a causal process. Integrated with Yarncrawler, it provides a dynamic ledger of repair operations that is interpretable, traceable, and thermodynamically consistent. Within RSVP, CoM ensures that entropy is minimized by embedding causal structure directly into the evolving manifold of semantic fields.

9 Integration & Applications

The Yarncrawler framework unifies ecological, cultural, and artificial systems as variations on a single principle: agents maintain viability by weaving, caching, and repairing their own structures. From squirrels to berms to language models, the dynamics are recognizably the same, even if their substrates differ.

Natural, Cultural, and Artificial Spectrum

At the ecological scale, squirrels act as Yarncrawlers by scattering caches that reinforce their survival envelope and regenerate the forest. At the cultural scale, humans pile stones, clear berms, and export waste, creating stigmergic landmarks and fertile soils that persist and grow beyond the intentions of

individuals. At the artificial scale, mixture-of-experts and retrieval-augmented architectures reweight and reinforce semantic trajectories, rewriting their own pathways of competence through repeated retrieval and repair. In all cases, the Yarncrawler principle emerges: redundancy, stigmergy, and repair knit together boundaries that would otherwise dissolve.

Applications

The recognition of Yarncrawler dynamics across domains points toward practical applications:

- **Interpretable AI:** By treating retrieval and self-refactoring as semantic repair, artificial systems can expose causal traces of their own operations, yielding models that are robust and auditable rather than opaque.
- **Cultural Memory Systems:** Digital infrastructures can be designed as stigmergic berms—repositories that grow stronger with use, preserving cultural memory through recursive reinforcement rather than centralized storage.
- **Ecological Computation:** Understanding berms, terra preta, and autocatalytic soils as cultural Yarncrawlers suggests ways to design ecological infrastructures that not only resist entropy but increase in value through distributed participation.

Outlook

The broader implication is that AI can be understood as a designed Yarncrawler: a system that bridges replication (as in biology) with deliberate semantic engineering (as in RSVP). Whereas natural Yarncrawlers emerge from survival pressures and cultural ones from collective stigmergy, artificial Yarncrawlers can be engineered to self-repair according to explicit causal and thermodynamic principles. In this sense, RSVP-guided AI design is not simply a technical exercise but a continuation of the same weaving process that has shaped ecological and cultural systems across history.

The outlook is thus one of convergence: future AI systems may be built as intentional Yarncrawlers, recursively weaving meaning, repairing themselves against noise, and embedding causal traceability into their fabric—linking the biological, cultural, and computational domains through a common semantics of repair.

10 Sheaf-Theoretic Interpretation of the Yarncrawler

The Yarncrawler Framework can be formalized in terms of sheaf theory. Local parsing windows are modeled as *semantic patches*, restrictions as *forgetful maps*, and repair as the construction of new morphisms that restore the possibility of gluing. This interpretation gives a precise account of semantic resilience.

10.1 Semantic Space and Covers

Let X denote a semantic or ecological space (for example, the domain of cultural landmarks, neural states, or semantic nodes). A cover $\mathcal{U} = \{U_i\}_{i \in I}$ represents overlapping neighborhoods of X , each corresponding to a local parsing window.

Definition 1 (Presheaf of Semantic Modules). *Define a presheaf*

$$\mathcal{S} : \mathcal{U}^{op} \rightarrow \mathbf{Cat}$$

that assigns to each neighborhood $U \subseteq X$ a category $\mathcal{S}(U)$ of semantic modules.

- *Objects:* local semantic threads or modules (claims, cached seeds, repaired routines).
- *Morphisms:* semantic restrictions or rewrites.

For inclusions $V \subseteq U$, the restriction functor $\rho_{UV} : \mathcal{S}(U) \rightarrow \mathcal{S}(V)$ encodes context reduction.

10.2 Sheaf Condition and Repair

Definition 2 (Gluing Condition). *A family of sections $\{s_i \in \mathcal{S}(U_i)\}$ is glueable if:*

1. *(Consistency)* $\rho_{U_i, U_i \cap U_j}(s_i) = \rho_{U_j, U_i \cap U_j}(s_j)$ for all overlaps.
2. *(Global Extension)* *There exists $s \in \mathcal{S}(X)$ with $s|_{U_i} = s_i$.*

Definition 3 (Tear and Repair). *A semantic tear occurs when the gluing condition fails. A repair consists of introducing new objects or morphisms into $\mathcal{S}(U)$ so that glueability is restored.*

10.3 Cohomology as Semantic Entropy

Cohomology detects unresolved incompatibilities:

$$H^k(X, \mathcal{S}) \Rightarrow \begin{cases} H^0 & \text{viable global sections (coherent meanings)} \\ H^1 & \text{minimal ambiguities (semantic seams)} \\ H^k, k \geq 2 & \text{deeper obstructions to coherence.} \end{cases}$$

We interpret these as measures of *semantic entropy*. Unresolved cocycles represent ambiguity stored for potential reinterpretation. Repair corresponds to introducing new morphisms that trivialize cocycles, lowering effective entropy.

10.4 RSVP Mapping

This sheaf-based interpretation integrates naturally with RSVP bookkeeping:

- Scalar field Φ : semantic density, proportional to stalk size $\dim \mathcal{S}(U)$.
- Vector field \mathbf{v} : restriction morphisms ρ_{UV} , representing flows of meaning.
- Entropy S : cohomological obstructions $H^k(X, \mathcal{S})$, measuring global incoherence.

10.5 Illustrative Example: Squirrel Caching

Consider a squirrel caching seeds:

- Each cache site U_i is a patch with local section s_i (stored seeds).
- Overlaps correspond to landmarks linking multiple caches.
- If restrictions match, caches glue into a coherent foraging map (global section).
- If not, ambiguity persists as a cocycle, representing lost or forgotten caches.

10.6 Proposition: Repair Preserves Blanket Structure

Proposition 1. *If every repair is generated by local morphisms that commute with restrictions and respect conditional independence at the boundary (Markov blanket factorization), then any finite composition of repairs preserves the gluing structure of \mathcal{S} .*

Sketch. Repairs are local morphisms that extend stalks without violating overlap consistency. By naturality, restriction commutes with repairs, ensuring that overlaps remain compatible. Preservation of blanket factorization guarantees that all external exchange passes through boundary nodes, so coherence is preserved. \square

10.7 Summary

Under this interpretation, the Yarncrawler is a *sheaf-based repair machine*. Local parsing windows correspond to stalks, repair corresponds to introducing new morphisms, and entropy corresponds to cohomological obstruction. RSVP fields provide a physical bookkeeping layer: Φ for density, \mathbf{v} for flows, and S for entropy. The Yarncrawler thus maintains semantic viability by continuously patching its sheaf structure against tears.

10.8 Toy Example: Three-Patch Cover with a Semantic Tear

To illustrate, consider a simple temporal domain $X = [0, 3]$ with a cover of three overlapping windows:

$$U_1 = [0, 1.5], \quad U_2 = [1, 2.5], \quad U_3 = [2, 3].$$

Each U_i corresponds to a local parser state: $\mathcal{S}(U_i)$ contains semantic modules learned from data within that window.

Step 1: Local sections. Suppose Yarncrawler has sections

$$s_1 \in \mathcal{S}(U_1), \quad s_2 \in \mathcal{S}(U_2), \quad s_3 \in \mathcal{S}(U_3).$$

These represent provisional interpretations of sensorimotor input across each window.

Step 2: Restrictions and overlaps. On overlaps we compare restrictions:

$$\rho_{12}(s_2) \stackrel{?}{=} \rho_{21}(s_1) \quad \text{on } U_1 \cap U_2,$$

$$\rho_{23}(s_3) \stackrel{?}{=} \rho_{32}(s_2) \quad \text{on } U_2 \cap U_3.$$

Suppose $\rho_{12}(s_2) \neq \rho_{21}(s_1)$ due to a semantic inconsistency (e.g. “object = seed” in U_1 but “object = pebble” in U_2). This is a tear: a nontrivial Čech 1-cocycle.

Step 3: Repair. Yarncrawler invokes a local rewrite operator R that modifies s_1 or s_2 to align their restrictions. For instance, s_2 may be refactored to “object = seed-like” so that both $\rho_{12}(s_2)$ and $\rho_{21}(s_1)$ agree. Formally, the cocycle is trivialized, moving into the coboundary.

Step 4: Deferred gluing. If multiple compatible repairs exist (e.g. “seed-like” vs. “small-stone-like”), Yarncrawler does not collapse immediately. Instead, it maintains a set of parallel global sections $\{s^{(1)}, s^{(2)}\}$, deferring collapse until additional evidence arrives. This implements strategic ambiguity as a resource.

Step 5: RSVP field coupling. During repair:

- Φ (scalar density) measures stability of the revised semantic attractor (“seed-like” node density).
- \mathbf{v} (vector flow) carries forward this semantic adjustment to U_3 , biasing repair in downstream patches.
- S (entropy) tracks the multiplicity of viable global sections, decreasing as ambiguity is collapsed.

Interpretation. The Yarncrawler agent thus operates like a semantic weaver: local inconsistencies are detected as cocycles, patched by rewrites, and only gradually collapsed into a global story. Sheaf-theoretically, this shows how local parsing failures become signals for repair rather than breakdown.

10.9 Ecological and Cultural Metaphors for Sheaf Repair

To illustrate how the abstract sheaf condition manifests in embodied systems, we consider two examples: squirrel foraging behavior and human berm construction. Both instantiate the Yarncrawler principle that local inconsistencies are not discarded but repaired through elastic semantic categories, yielding coherent global structures over time.

Squirrels and affordance repair. Each foraging episode can be modeled as a local patch U_i , with a corresponding section s_i encoding the interpretation of an encountered object. In one context (U_1), a nut is recognized as a seed worth caching; in another (U_2), a visually similar pebble is mistakenly treated as food. At the overlap $U_1 \cap U_2$, these interpretations conflict. Rather than collapsing, the squirrel repairs by adopting a softened category—“seed-like object.” This repair aligns both local sections without discarding either memory trace. In sheaf-theoretic terms, the cocycle condition fails strictly but is restored under a relaxed gluing criterion, preserving viability. Deferred gluing is equally important: multiple possible global interpretations (nut, pebble, or generic cache item) are held in suspension until further information, such as biting into the object, resolves the ambiguity. This strategic ambiguity prevents premature collapse of the semantic fabric.

Berms and stigmergic accumulation. An analogous process occurs in cultural evolution. A villager encountering a cairn or berm at the edge of a territory may perceive it as “not large enough” and add more stones, shells, or organic waste. The material composition of the berm need not be uniform; bones, ash, and dung may be included alongside rocks. Local repairs thus introduce semantic elasticity—the criterion is “boundary-marker-like” rather than “stone-only.” Over time, overlapping deposits cohere into self-maintaining piles that attract further contributions. In Amazonian contexts, such practices contributed to the emergence of terra preta: anthropogenic soils that form Voronoi-like tessellations at territorial boundaries, enriched by bacterial fermentation and feedback from organic accumulation. The global section—a fertile, self-sustaining berm—emerges not from top-down planning but from the gluing of locally inconsistent but compatible acts of repair.

RSVP bookkeeping. Within the RSVP framework, these processes can be mapped as follows. The scalar field Φ tracks the density of accumulated affordances (the weight of the cache or berm). The vector field \mathbf{v} encodes the directional biases introduced by repair decisions (e.g., “seed-like” categorizations that increase future caching, or shell-rich piles that draw further shells). The entropy field S quantifies the ambiguity retained in the system—the number of viable but unresolved global sections available before collapse. Repair is thus not noise suppression but entropy management, ensuring coherence through recursive reweaving of local inconsistency.

Taken together, these examples show how ecological and cultural systems embody the sheaf-theoretic principle: local disagreements can be reconciled through semantic elasticity, strategic ambiguity, and stigmergic reinforcement, yielding coherent global sections that are both resilient and adaptive.

10.10 Proposition: Stigmergic Repair and Viable Global Sections

Proposition 2 (Stigmergic Repair Closure). *Let \mathcal{S} be a presheaf of local semantic sections over patches $\{U_i\}$, with overlaps $U_i \cap U_j$ that may admit inconsistent interpretations. Suppose that for each overlap there exists an elastic repair operation ρ_{ij} such that:*

1. ρ_{ij} preserves type safety (objects remain in a coarser semantic category, e.g. “seed-like” or “boundary-marker-like”).
2. ρ_{ij} reduces local free energy $\mathcal{F}(U_i \cap U_j)$ relative to the un-repaired sections.
3. ρ_{ij} is stigmergic: the cost of subsequent repairs decreases with the density of prior contributions (e.g. additional stones or shells reinforce a berm, additional cache items reinforce a stash).

Then the family of repaired sections $\{s_i^\rho\}$ admits at least one global section s with $\mathcal{F}(s) \leq \sum_i \mathcal{F}(s_i)$ and with viability increasing in the cumulative density of repairs.

Interpretation. The proposition states that stigmergic repair—adding ambiguous but reinforcing contributions—closes the cocycle gap that arises when local sections conflict. In ecological terms, squirrels caching seed-like objects create viable food reserves despite misclassifications. In cultural terms, villagers augmenting berms with heterogeneous materials create stable boundaries and fertile soils. The global section (the cache or berm) is thus not a product of perfect consistency but of recursive reinforcement under elastic repair.

RSVP fields. Within the RSVP bookkeeping, the proposition corresponds to:

- Φ : scalar density of contributions, which increases monotonically with stigmergic reinforcement;
- \mathbf{v} : vector flows of repair decisions, biased by prior density toward further reinforcement;
- S : entropy budget, which decreases locally as repairs accumulate but remains nonzero globally, ensuring adaptive flexibility.

This establishes stigmergic repair as a sheaf-theoretic mechanism by which local semantic tears are patched, guaranteeing the existence of viable global sections in both biological and cultural systems.

10.11 Corollary: Self-Maintaining Growth under Stigmergic Feedback

The stigmergic repair mechanism not only ensures the existence of viable global sections but also supports conditions for self-maintaining growth. Once a repaired global section reaches sufficient density, it begins to attract further contributions, reinforcing its own viability. This feedback process underwrites the persistence and expansion of both ecological and cultural structures.

Corollary 1 (Self-Maintaining Growth). *Let s be a repaired global section arising from stigmergic closure. Suppose the repair cost function $C(n)$ for the n^{th} contribution is monotonically decreasing with cumulative density $\Phi(n)$. Then there exists a critical threshold Φ^* such that:*

$$\Phi(n+1) - \Phi(n) \geq \delta > 0 \quad \text{whenever } \Phi(n) \geq \Phi^*,$$

i.e. once Φ^ is surpassed, the system enters a regime of self-sustaining growth where each new repair lowers the barrier for future repairs.*

Interpretation. In ecological terms, a squirrel’s cache surpassing a threshold size becomes increasingly attractive for further caching; even misclassified objects contribute to the viability of the stash. In cultural contexts, once a berm or midden has accumulated sufficient material, it becomes a preferential site for further deposition, eventually transforming into fertile terra preta. In both cases, stigmergic reinforcement transforms fragile patches into stable attractors of ongoing contributions.

RSVP fields. The corollary corresponds to:

- Φ : density accumulation surpasses Φ^* , triggering self-sustaining growth.
- \mathbf{v} : flows of contributions align along trajectories toward the dense attractor, producing path clearance effects at territorial boundaries.
- S : entropy decreases locally as feedback locks in structure, but remains nonzero globally, allowing continued adaptability and open-ended evolution.

This result highlights how Yarncrawler systems can transition from merely maintaining viability to actively expanding it, generating cumulative structures that persist across ecological, cultural, and semantic domains.

10.12 Worked Example: A Minimal Stigmergic Growth Model

We model the density of a cache/berm (or, abstractly, a repaired global section) by a scalar state $\Phi(t) \geq 0$ that aggregates contributions over time. Stigmergic reinforcement is captured by a *decreasing* marginal cost of contribution as density rises.

Continuous-time model. Let $\lambda > 0$ be a baseline arrival rate of potential contributions (visits), $p(\Phi)$ the probability a visit results in a contribution, and $\kappa > 0$ the mean contribution size. Assume stigmergic facilitation via a saturating response

$$p(\Phi) = \frac{\Phi}{\Phi + \theta}, \quad \theta > 0,$$

and a soft carrying effect (finite capacity or attention budget) via a logistic brake $(1 - \Phi/K)$, with $K > 0$. Then

$$\dot{\Phi} = \lambda p(\Phi) \kappa \left(1 - \frac{\Phi}{K}\right) - \delta \Phi = \underbrace{\alpha \frac{\Phi}{\Phi + \theta} \left(1 - \frac{\Phi}{K}\right)}_{\text{stigmergic inflow}} - \delta \Phi, \quad (4)$$

where $\alpha \equiv \lambda \kappa > 0$ and $\delta \geq 0$ is a decay/leak term (loss, erosion, predation).

Fixed points and threshold. Fixed points satisfy $f(\Phi) = 0$ with

$$f(\Phi) = \alpha \frac{\Phi}{\Phi + \theta} \left(1 - \frac{\Phi}{K}\right) - \delta \Phi.$$

Trivially, $\Phi_0^* = 0$ is always a fixed point. Nonzero fixed points solve

$$\alpha \frac{1 - \Phi/K}{\Phi + \theta} = \delta \iff \alpha (1 - \Phi/K) = \delta (\Phi + \theta).$$

Rearranging gives

$$\Phi_{\pm}^* = \frac{K}{\alpha + \delta K} (\alpha - \delta \theta), \quad (5)$$

with feasibility $\Phi^* > 0$ iff $\alpha > \delta \theta$.

Threshold condition. Define the stigmergic threshold

$$\boxed{\alpha > \delta \theta}$$

(baseline inflow beats effective cost at low density). If violated, $\Phi(t) \rightarrow 0$. If satisfied, two regimes arise: (i) $\Phi = 0$ becomes *unstable* and a positive fixed point $\Phi^* \in (0, K)$ emerges and is *locally stable* (see below).

Local stability. Since $f'(0) = \alpha/\theta - \delta$, the zero state is unstable precisely when $\alpha > \delta \theta$. At $\Phi^* \in (0, K)$ with $\alpha > \delta \theta$, one finds $f'(\Phi^*) < 0$, hence Φ^* is stable (details: differentiate f , substitute (5)).

Interpretation. The threshold $\alpha > \delta \theta$ formalizes the corollary's Φ^* : below it, contributions dwindle; above it, the site self-maintains and grows toward Φ^* . Stigmergic facilitation enters via the fractional term $\Phi/(\Phi + \theta)$: early contributions are hard (small Φ), but each added unit lowers the effective barrier, increasing the realization probability $p(\Phi)$ of subsequent visits.

Discrete-time variant (implementation-ready). With time step Δt ,

$$\Phi_{t+1} = \Phi_t + \Delta t \left[\alpha \frac{\Phi_t}{\Phi_t + \theta} \left(1 - \frac{\Phi_t}{K} \right) - \delta \Phi_t \right].$$

To model stochastic contributions, draw $N_t \sim \text{Poisson}(\lambda \Delta t)$ and set

$$\Phi_{t+1} = \Phi_t + \sum_{n=1}^{N_t} \underbrace{B_{t,n} \cdot Y_{t,n}}_{\text{accepted contribution}} - \delta \Phi_t \Delta t,$$

where $B_{t,n} \sim \text{Bernoulli}(p(\Phi_t))$ and $Y_{t,n}$ are i.i.d. contribution sizes (e.g. exponential or fixed κ).

RSVP bookkeeping. In this toy universe:

- **Scalar** Φ is the density field itself; the Lyapunov picture arises from $\dot{\Phi} = f(\Phi)$ with a stable attractor at Φ^* when $\alpha > \delta\theta$.
- **Vector** \mathbf{v} compresses to a scalar drift $f(\Phi)$; in richer models (multi-site berms/caches), \mathbf{v} induces flows along edges toward high- Φ attractors (path clearance).
- **Entropy** S declines locally as Φ crosses threshold (fewer viable alternatives), but remains positive globally if multiple sites compete (multi-attractor landscape).

Berms vs. caches. For berms: Φ is mound biomass/mineral density; α grows with traffic and affordances (shells, ash, dung), θ encodes early friction (coordination/transport cost), δ captures erosion/consumption. For caches: Φ is stash completeness; α reflects visit rate \times willingness to deposit; θ reflects uncertainty in categorization (“seed-like”), and δ models spoilage/theft.

Extensions.

- *Cross-attraction (multi-site):* $\dot{\Phi}_i = \alpha_i \frac{\Phi_i}{\Phi_i + \theta_i} (1 - \Phi_i/K_i) - \delta_i \Phi_i + \sum_j \beta_{ij} \Phi_j$ (preferential deposition toward denser neighbors).
- *Semantic repair coupling:* let $\theta = \theta(A)$ decrease with repair gauge magnitude $\|A\|$ (better categorization lowers early friction).
- *Noise banking:* treat θ as a random field and store unexplained variance as a cocycle in H^1 , to be reduced as Φ rises and repairs trivialize overlaps.

Summary. The minimal model makes the corollary concrete: stigmergic feedback generates a *density threshold* beyond which self-maintaining growth follows, and below which structures decay. This mechanism is shared by caches, berms, and abstract semantic sections under Yarncrawler repair.

11 Related Work

The Yarncrawler Framework draws together strands from several established research traditions, while extending them in novel directions. We briefly situate it with respect to active inference and the Free Energy Principle, autocatalytic network theory, reasoning paradigms in AI, and formal systems approaches including category and sheaf theory.

11.1 Active Inference and Markov Blankets

The Free Energy Principle (FEP) and its operationalization as active inference [Friston, 2010, Friston et al., 2019] provide a general account of adaptive systems maintaining their Markov blankets. Yarncrawler is indebted to this tradition, particularly the role of the blanket in mediating self-world exchange. However, whereas FEP typically emphasizes probabilistic variational inference, Yarncrawler emphasizes *semantic repair*: local rewriting of parsing rules, modules, and interpretations to preserve viability. Thus, it reframes the blanket not merely as a probabilistic filter but as a semantic interface whose seams must be continually rewoven.

11.2 Autocatalysis and RAF Networks

The dynamics of collectively autocatalytic sets (RAF theory) [Hordijk and Steel, 2019] provide a complementary origin-of-life perspective, where networks of reactions generate self-sustaining closure. Yarncrawler generalizes this notion to semantic and cultural domains: caches, cairns, and berms act as stigmergic repair sites that attract reinforcement and sustain themselves. Unlike RAF models, which treat catalysts as molecular participants, Yarncrawler treats repair operations as *semantic catalysts*, capable of reconfiguring the interpretive network as well as sustaining it.

11.3 Reasoning Paradigms in AI

Recent advances in AI reasoning emphasize stepwise Chain of Thought (CoT) prompting [Wei et al., 2022]. While effective, CoT often yields post hoc rationalizations rather than robust causal explanations. Yarncrawler departs from this linear paradigm by organizing reasoning as a sheaf of overlapping local parses, where consistency and repair determine global viability. In this sense, Yarncrawler operates as a *semantic field trajectory engine* rather than a token-based simulator.

Mixture-of-experts (MoE) architectures [Shazeer et al., 2017] and retrieval-augmented generation (RAG) [Lewis et al., 2020] share Yarncrawler’s intuition that different modules can be selectively activated in context. However, Yarncrawler differs in two respects: (i) its repair mechanisms reconfigure the modules themselves, rather than only gating access to them; and (ii) its semantic structure is continuous and trajectory-based, modeled by sheaf gluing and RSVP fields, rather than discrete or static.

11.4 Systems Theory and Anticipatory Models

Rosen’s theory of anticipatory systems [Rosen, 1985] emphasized closure, self-reference, and the predictive structure of living systems. Similarly, Maturana and Varela’s concept of autopoiesis [Maturana and Varela, 1980] framed life as self-producing networks. Yarncrawler resonates with these perspectives but shifts emphasis from biological reproduction to *semantic re-production*: recursive rewaving of meaning as the basis of persistence.

11.5 Category and Sheaf Theory in Semantics

Category theory has become an important tool for modeling compositional meaning and information flow [Abramsky and Coecke, 2009, Coecke and Kissinger, 2017]. Sheaf theory in particular has been used to formalize context-dependence and multi-agent information structures [Abramsky and Brandenburger, 2011, Spivak, 2014]. Yarncrawler draws on these developments in treating local parses as sheaf sections and semantic repair as a gluing operation, but extends them by embedding these categorical semantics into a dynamic field-theoretic formalism.

11.6 Summary

In sum, Yarncrawler inherits the self-maintenance of active inference, the closure of RAF networks, the modularity of MoE/RAG, the anticipatory dynamics of Rosen, and the compositional rigor of categorical semantics. Its novelty lies in unifying these through a semantic-geometric formalism where *repair, not prediction, is the central adaptive act*.

12 Discussion

The Yarncrawler Framework provides a unifying account of adaptive systems as self-refactoring semantic engines. By combining ideas from active inference, autocatalytic networks, mixture-of-experts architectures, and categorical/sheaf-theoretic semantics, Yarncrawler models how coherence is maintained in the face of continual perturbation. In this section we highlight several implications, limitations, and directions for future research.

12.1 Implications for Adaptive Computation

A first implication concerns the nature of generalization. Where most machine learning architectures rely on static mappings between training and deployment, Yarncrawler foregrounds repair as the primary adaptive act. This suggests a shift from evaluating models by accuracy metrics toward evaluating them

by *repair capacity*—how well they can detect and resolve tears in their semantic fabric. Such a criterion is relevant for AI safety, robust reasoning, and resilience in open-ended environments.

Second, Yarncrawler provides a formalism for understanding cultural and biological stigmergy. Berm formation, seed caching, or collective bacterial metabolism can all be described as distributed repair operations that accumulate structure at boundaries. By extending these processes to semantic computation, Yarncrawler models how knowledge systems can sustain themselves through stigmergic reinforcement rather than centralized control.

12.2 Limitations and Open Questions

Despite its integrative scope, Yarncrawler remains at a high level of abstraction. Several questions remain open:

- How tractable are the sheaf-theoretic constructions when scaled to high-dimensional semantic graphs?
- What concrete computational architectures best instantiate Yarncrawler dynamics—hybrid neural-symbolic systems, probabilistic program synthesis, or agent-based lattice models?
- To what extent can empirical systems (from molecular swarms to cultural evolution) be fitted with Yarncrawler’s variational principles without overfitting metaphor to mechanism?

Moreover, while Yarncrawler emphasizes repair as central, there is a risk of underplaying the role of prediction and optimization. Future work should articulate the trade-off between predictive capacity and repair resilience, potentially integrating them under a common free-energy budget.

12.3 Broader Outlook

The conceptual move from static parsers to recursive polycompilers resonates across domains. In computational epistemology, it reframes reasoning as a continual act of self-interpretation. In biology, it highlights the role of homeorhesis—stable trajectories rather than equilibria—in maintaining viability. In AI, it points toward architectures that are not only data-driven but self-repairing and causally traceable.

Ultimately, Yarncrawler positions semantic computation as a field-theoretic process: coherence emerges not from static correctness but from the continual weaving and reweaving of meaning. This shift has implications for how we build, evaluate, and govern intelligent systems—suggesting that resilience, transparency, and adaptability may be more fundamental than accuracy or efficiency alone.

13 Future Directions: Toward Synthetic and Infrastructural Terra Preta

The study of terra preta not only illuminates the deep time of anthropogenic soil formation but also gestures toward new ecological technologies. Several directions suggest themselves for both applied science and theoretical exploration.

13.1 Synthetic Terra Preta (STP)

Current experiments in *synthetic terra preta* (STP) attempt to reproduce the fertility of Amazonian dark earths by combining biochar, clay, bone meal, manures, and other organic inputs. These approaches aim to accelerate in decades what originally took centuries or millennia of accretion.

In Yarncrawler terms, STP functions as a deliberate repair move: it is a refactoring of the soil’s semantic manifold through external deposition of catalytic nodes (biochar as structural memory, nutrients as fast rewards). Here the entropic smoothing of RSVP is literal—carbonaceous particles stabilize nutrient gradients, creating long-lived homeorhetic flows of fertility.

13.2 Terra Preta Sanitation (TPS)

An emerging line of research applies the same principles to waste cycling. *Terra preta sanitation* (TPS) uses dry-composting toilets, lactic-acid fermentation, and vermicomposting to turn human waste streams into soil-building resources.

This process exemplifies the stigmergic frontier principle: what is expelled at one boundary (the household or body) becomes substrate for microbial and fungal communities, generating self-maintaining berms of fertility. Within RSVP’s field interpretation, TPS ensures entropy exported at the organismal scale re-enters the scalar density field (Φ) as potential for renewed growth.

13.3 Terra Preta Rain and Volsorial Pediment Infrastructures

Looking further, one may imagine scaling terra preta processes to landscape infrastructure. In a speculative design, vast aerial catchment basins surrounding forested calderas function as gravitational batteries: rainwater is filtered through biochar-lined berms at the rim, pumped upward by solar or gravitational differentials, and redistributed as nutrient-rich “terra preta rain.”

Such architectures echo natural hydrological loops while embedding anthropogenic soil-making directly into the atmospheric-hydrological cycle. From the Yarncrawler perspective, these systems are recursive manifolds: rain carries coded “repair instructions” (nutrients, microbes, carbon), rains down over canopy systems, and is reabsorbed into pedological yarns at the base, perpetually weaving soil and forest together.

13.4 Toward a Generalized Ecotechnology

These three paths—STP, TPS, and terra preta rain—demonstrate how cultural stigmergy (berms, mid-dens, boundaries) can be recoded as modern ecological engineering.

The risk, as always, is reductionism: assuming that a simple recipe of charcoal and manure suffices, when in fact the original systems were multi-scalar, involving topography, ritual practice, mobility, and long-term ecological coupling. Yet the promise is equally great: by designing with recursive flows in mind, we can imagine soils, waters, and infrastructures that function as ideal Yarncrawlers, refactoring themselves while maintaining the viability of their enclosing blankets.

13.5 Protocol Box: From Lab Recipe to Landscape Practice

A) Synthetic Terra Preta (STP) – Field Plot Protocol

Goal: Rapidly establish a char-anchored, microbially active horizon with durable fertility.

Plot preparation: Bed size: 10 m² (e.g., 2 m × 5 m), replicated ≥ 3 for stats. Loosen top 20–25 cm; baseline measures of pH, C, N, P, CEC, moisture.

Biochar: Feedstock hardwood/bamboo/nut shell; pyrolysis 450–600 °C. Screen 0.5–8 mm; dose 20–50 t/ha phased.

Pre-charge: Soak char 7–14 d in nutrient liquor (urine + vinegar, compost tea, fish hydrolysate + rock dust). Target EC 1.0–2.0 mS/cm, pH 6.5–7.2.

Organic matrix: Blend C:N 25–35:1 with clay fines, manure/green waste, bone meal, ash. Mix pre-charged char with organics (1:1 to 1:2 v/v).

Incorporation: Incorporate to 10–15 cm; mulch 5–7 cm; maintain 60–80% field capacity.

Biology seeding (optional): Vermicast 0.5–1 kg/m², mycorrhizae at planting.

Monitoring: pH, EC, soil respiration, microbial biomass, worm counts, yield vs. control.

Safety: Mask/eye protection for dry char; buffer strips ≥ 5 m from waterways.

B) Terra Preta Sanitation (TPS) – Dry Loop with Lacto + Vermi

Goal: Convert source-separated human waste into safe, char-anchored soil amendment.

Toilet & capture: Urine-diverting dry toilet; feces bin with 5–10 cm pre-charged biochar + sawdust.

Lacto phase: Add lactic starter (50–100 mL/week/bin); maintain pH < 4.5.

Stabilization blend: Add pre-charged biochar (10–20%), carbon (20–40%), clay fines (5–10%).

Vermicomposting: 8–12 weeks at 20–28 °C; maintain 60–75% moisture.

Hygiene targets: ≥ 3 -log pathogen reduction (*E. coli*, ova). Retain 3–6 mo before soil contact.

Output spec: pH 6.5–7.5, EC < 2.5 mS/cm, odor-free crumb.

Safeguards: Gloves, roofed processing, exclude from edible leaf crops for one season.

C) Terra Preta Rain (TPR) – Rim Filter + Gravitational Battery Pilot

Goal: Couple catchment, biochar filtration, and elevated storage to dose forests with nutrient-coded rainfall.

Site & scale: Basin 1–5 ha, rim footpath/berm, slope 5–10% into central sump.

Rim biochar filter: Trench 0.4–0.6 m deep; gravel, biochar (20–30 cm), sand; sampling ports.

Dosing liquor: Urine 1:10, compost tea, or fish hydrolysate 0.5–1% + rock dust.

Gravitational battery: Solar pump to header tank 5–15 m above canopy; drip/micro-spray.

Control & rates: 1–3 mm “rain” equivalents/week; taper dose if EC rises.

Sensors & feedback: EC, pH, turbidity, soil moisture, chlorophyll index; throttle on spikes.

Safeguards: Spill containment, no direct discharge, quarterly water tests.

Cross-Cutting QA/QC and Timelines

- **Metrics:** Soil (pH, CEC, SOC, N/P), biology (microbial biomass, worms, mycorrhizae), plant (yield, NDVI), hydrology (nutrient balances).
- **Timeline:** Baselines at week 0; establishment phase (weeks 1–12); interim sampling (3–6 mo); year 2 durability check.
- **Failure modes & fixes:** High EC → dilute inputs; high pH → acidic mulch; low response → extend char soak; odor/fly → increase cover; runoff → expand wetland cell.
- **Ethics/compliance:** Respect wastewater regs; buffer waterways; community consent; publish negative results.

14 Conclusion

This essay began with a simple metaphor — the Yarncrawler as a ball of string unwinding and reweaving itself — and unfolded into a full theoretical architecture that spans field theory, category theory, cultural anthropology, and applied soil science. What started as an exploration of a self-refactoring semantic parser evolved into a comprehensive framework linking the Relativistic Scalar Vector Plenum (RSVP) to semantic field dynamics, Markov blanket homeorhesis, and stigmergic cultural evolution.

We showed how Yarncrawler, interpreted as a semantic field trajectory engine, bridges several domains:

Formal mathematics, where sheaf-theoretic gluing, functorial rewrites, and entropy budgets provide a rigorous account of self-repairing computation.

Physics and biology, where diffusion across membranes, autocatalysis, and gradient-following behaviors map directly onto Yarncrawler’s recursive patching of semantic “tears.”

Ecology and culture, where squirrel caches, cairns, and terra preta berms illustrate stigmergic path-clearance as a universal mechanism of distributed repair.

Engineering and AI, where mixture-of-experts with retrieval-augmented generation (RAG) becomes a practical instantiation of Yarncrawler as a recursive polycompiler, reassembling its own manifold of expertise.

The essay also extended into future directions: synthetic terra preta, sanitation loops, and “terra preta rain” infrastructures show how these principles may be transposed into environmental engineering and carbon sequestration. The unifying thread throughout is that systems — whether semantic, ecological, or cultural — endure not by static stability but by homeorhetic repair, continuously crawling along the seams of their own fabric to weave coherence.

Taken together, these results shift the Yarncrawler Framework from metaphor into method. It no longer functions solely as a speculative sketch of recursive parsing but as the nucleus of a textbook-sized treatment of resilience: how systems stitch meaning, matter, and memory into persistent form. The next stage will be to consolidate these threads into formal simulations, accessible pedagogical expositions, and experimental prototypes.

In short: a Yarncrawler does not simply interpret its world — it keeps itself alive by reinterpreting itself into being.



Key Takeaways

- **Yarncrawler as a Universal Principle.** A model of self-repairing computation where systems recursively parse, patch, and reweave their own structure—applicable to biology, culture, and AI.
- **RSVP Integration.** Scalar (Φ), vector (\mathbf{v}), and entropy (S) fields provide the physical bookkeeping for coherence, flow, and viability in semantic and ecological systems.
- **Sheaf-Theoretic Foundation.** Local semantic patches may be consistent yet non-unique; gluing them into global sections formalizes resilience through strategic ambiguity and repair.
- **Biological Analogies.** From squirrels caching seeds to cells maintaining ion gradients, organisms behave as Yarncrawlers, sustaining their Markov blankets by recursive reweaving.
- **Cultural Evolution.** Cairns, berms, and terra preta soils exemplify stigmergic Yarncrawlers, where small acts of deposition accumulate into self-maintaining landscape structures.
- **Applied Futures.** Synthetic terra preta, sanitation loops, and “terra preta rain” infrastructures extend Yarncrawler logic into sustainable ecological design and carbon sequestration.
- **Core Insight.** Stability is not static. Systems endure through homeorhesis—crawling their own seams, repairing tears, and embedding memory into their fabric.

15 Appendix

This appendix provides a mathematical scaffolding for the concepts introduced in the main text. We formalize Yarncrawler dynamics in terms of field-theoretic PDEs, sheaf-theoretic gluing, and stochastic proximal updates.

15.1 Objects and Standing Assumptions

[Semantic space] Let M be a second countable smooth manifold with atlas $\{U_i\}_{i \in I}$ and overlaps $U_{ij} = U_i \cap U_j$. Semantic content is represented by local charts.

[Experts and gates] For each chart U_i , an expert provides a local scalar potential $\phi_i : U_i \rightarrow \mathbb{R}$ and vector field $f_i : U_i \rightarrow TM$. A partition of unity $\{w_i\}$ is subordinate to $\{U_i\}$, i.e.

$$\sum_{i \in I} w_i(x) = 1, \quad \text{supp}(w_i) \subseteq U_i.$$

[RAG memory and retrieval] Let $\mathcal{K} = \{k_m\}_{m=1}^M$ be a finite knowledge store with embedding ϕ_{emb} . For query q , retrieval weights are

$$\omega_m(q) = \frac{\exp(\langle \phi_{\text{emb}}(q), \phi_{\text{emb}}(k_m) \rangle / \tau)}{\sum_{m'} \exp(\langle \phi_{\text{emb}}(q), \phi_{\text{emb}}(k_{m'}) \rangle / \tau)}.$$

[Seam penalty] On overlaps U_{ij} , define the seam loss

$$\mathcal{L}_{\text{seam}}(x) = \sum_{i < j} w_i(x) w_j(x) \|f_i(x) - f_j(x)\|^2, \quad x \in U_{ij}.$$

[RSVP fields] Define global scalar, vector, and entropy fields

$$\Phi(x) = \sum_i w_i(x) \phi_i(x), \quad \mathbf{v}(x) = -\nabla \Phi(x), \quad S(x) = -\sum_i w_i(x) \log w_i(x).$$

[Blanket and free energy] State variables split into internal X , external E , and blanket B with conditional independence $X \perp E \mid B$. Define finite-horizon free energy:

$$\mathcal{F}_{t:t+\Delta} = \mathbb{E}_{q_\phi} \left[\log q_\phi(X, B) - \log p_\theta(E, X, B \mid A) \right].$$

[Stigmergic reinforcement] A reinforcement operator \mathcal{R}_η updates gates w and locals (ϕ, f) with retrieved traces ξ via

$$(w, \phi, f) \mapsto \mathcal{R}_\eta((w, \phi, f), \xi) := \arg \min_{w', \phi', f'} \left(\mathbb{E}[\mathcal{F}] + \lambda \int \mathcal{L}_{\text{seam}} d\mu + \alpha \int \|\nabla \Phi'\|^2 d\mu \right).$$

15.2 Definitions

Definition 4 (Yarncrawler). A Yarncrawler is a quintuple

$$\mathbf{Y} = (M, \{(U_i, \phi_i, f_i)\}_{i \in I}, \{w_i\}_{i \in I}, \mathcal{K}, \mathcal{R})$$

with dynamics

$$\dot{x}_t \in \text{co}\{f_i(x_t) : w_i(x_t) > 0\} - \nabla \Phi(x_t) + B(x_t)u_t,$$

where B encodes blanket-mediated control and co denotes convex hull.

Definition 5 (Homeorhetic viability band). A closed set $V \subseteq M$ is viable if for every $x_0 \in V$ there exists a control u_t such that $x_t \in V$ for all t and

$$\int_0^\infty (\beta \mathcal{L}_{\text{seam}}(x_t) + \sigma(x_t)) dt < \infty,$$

where $\sigma(x_t)$ is entropy export rate.

Definition 6 (RAF advantage for modules). A subset $J \subseteq I$ is collectively autocatalytic if $\exists \epsilon > 0$ such that

$$\partial_\tau \Phi_J := \sum_{j \in J} \partial_\tau \int_{U_j} \phi_j d\mu \geq \epsilon \sum_{j \in J} \int_{U_j} \phi_j d\mu - \kappa \int \mathcal{L}_{\text{seam}} d\mu.$$

15.3 Results

Theorem 1 (Existence of a global semantic field). Under Assumptions 15.1–15.1, if $\mathcal{L}_{\text{seam}} \in L^2(M)$ then

$$\Phi(x) = \sum_i w_i(x) \phi_i(x), \quad \mathbf{v}(x) = -\nabla \Phi(x)$$

are globally well-defined and differentiable almost everywhere.

Sketch. Partition-of-unity gluing preserves differentiability; squared overlap penalties ensure that mismatch between f_i vanishes in the L^2 sense. \square

Theorem 2 (RAG-gluing convergence under bounded noise). Suppose retrieval corrections are Lipschitz in ξ and unbiased for the overlap constraints. If \mathcal{R}_η is a proximal step on \mathcal{F} , then for $\eta < 1$,

$$\mathbb{E} \left[\int \mathcal{L}_{\text{seam}}^{(k)} d\mu \right] \leq \rho^k \mathbb{E} \left[\int \mathcal{L}_{\text{seam}}^{(0)} d\mu \right] + \text{noise floor}.$$

Sketch. By stochastic proximal-gradient descent, contraction holds up to a variance-dominated floor determined by retrieval noise. \square

Theorem 3 (Homeorhetic stability via entropy export). Assume (i) \mathcal{F} is μ -strongly convex on V , (ii) $\mathcal{L}_{\text{seam}} \in L^1(M)$, and (iii) u_t is ISS-stabilizing. If stigmergic schedules satisfy

$$\int_0^\infty \sigma(x_t) dt < \infty, \quad \int_0^\infty \mathcal{L}_{\text{seam}}(x_t) dt < \infty,$$

then V is homeorhetically stable.

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