Boundary-Maintaining Self-Organizing Systems under Finite Capacity: Maintenance Load, Phase-C Collapse, and Invariant Selection

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FDS-N1 develops a complex-systems bridge for Active Finite Distinction Systems. The FDS formal core defines active finite systems as systems that maintain boundaries through state-dependent updates under finite representational capacity and finite resource budgets. This paper translates that core into a normal-form account of boundary-maintaining self-organization. A self-organizing system, in this paper, is not merely a system that becomes structured. It is a finite system whose internal updates are causally relevant to future boundary-maintenance loss. The revised model distinguishes structural complexity $K(t)$ from maintenance load $L_M(t)$, operationalizes effective organizational capacity $C_{\text{org}}(t)$, adds resource-gated pruning, treats externalization as an accounting-boundary shift that can clog the environment, and introduces a Phase-C catastrophic-feedback regime in which boundary loss reduces resource intake and accelerates collapse. Invariant-supported persistence is connected to a T3-style survival score based on maintenance cost, verification cost, refresh cost, boundary utility, and predictive utility. The main theorem states that an active-boundary finite system with positive deficit-driven load pressure, finite resource input, and eventually resource-exceeding maintained load cannot remain indefinitely in unbounded Phase-A growth without pruning, compression, externalization, task relaxation, invariant stabilization, resource expansion, automation, or collapse. Deterministic simulations illustrate Phase-A/Phase-B/Phase-C trajectories, operational organizational capacity, pruning viability windows, externalization clogging, bounded self-organization regimes, invariant-residue selection, active-boundary ablation, and domain bridge templates. The paper does not claim that all self-organizing systems are alive, intelligent, conscious, optimal, or oscillatory; it provides a normal-form and mapping protocol for later domain-specific applications.

Scope and Boundary of the Theory. This paper is a normal-form complex-systems bridge. It does not claim that every boundary is active, that every pattern is self-organizing, that all self-organizing systems are alive or intelligent, that pruning is always beneficial, or that Phase-A/Phase-B/Phase-C dynamics are universal. It studies systems whose internal updates are relevant to future boundary-maintenance loss under finite capacity and finite resource budgets. Domain applications require explicit mappings and operational tests.

Claim-status summary

Table I summarizes the central FDS-N1 claims, their epistemic status, and the conditions under which they should be weakened or rejected.

Keywords: self-organization; boundary maintenance; active finite distinction systems; capacity deficit; maintenance load; pruning; externalization; environmental clogging; Phase-C collapse; invariant persistence; complex systems; finite capacity; normal-form dynamics.

INTRODUCTION

Self-organization as finite boundary maintenance

Self-organization is often described as spontaneous order formation. That description is useful but too broad. It does not distinguish order that merely appears from order that is actively maintained under perturbation. A crystal, a vortex, a protocell, a neural circuit, a robot controller, and an organization can all exhibit structured dynamics, but they do not all enter the same explanatory class. FDS-N1 defines the relevant class operationally: a self-organizing system is an active finite system whose internal updates help maintain a boundary against future loss.

The central question is not simply how structure forms. It is:

$$\text{which structure is maintained under finite capacity, finite memo} \tag{1}$$

This turns self-organization into a boundary-maintenance problem.

From FDS Core to N1

The FDS core defines active finite distinction systems as systems that maintain boundaries through state-dependent updates under finite representational capacity

TABLE I. Central FDS-N1 claims, epistemic status, and failure or demotion conditions.

Claim	Status	What would weaken or falsify it
Active self-organization requires boundary-maintenance-relevant internal update.	Operational definition	A system is correctly classified as active self-organizing even when freezing or randomizing its internal update has no effect on future boundary-maintenance loss.
Effective organizational capacity is task-relative and reduced by coordination, verification, latency, resource, and externalization costs.	Operational bridge	Boundary tasks are maintained at full fidelity even when all internal, channel, update, resource, verification, and latency capacities fall below task demand.
Deficit creates maintenance-load pressure, not necessarily raw complexity growth alone.	Normal-form claim	Increasing task demand never increases maintained load, repair structure, stored distinctions, control effort, or external scaffolding in any relevant implementation.
Unbounded Phase-A growth is impossible under finite resource input when maintained load eventually exceeds the resource envelope.	Conditional theorem	Active finite systems grow maintained load without bound forever while resources remain finite and no exit channel is used.
Pruning has a viability window and is resource-gated.	Model class	Pruning strength has no systematic effect on overload, task competence, or persistence across all controlled implementations.
Externalization shifts rather than removes boundary-maintenance burden, and excessive externalization can clog the environment.	Accounting bridge	External records impose no storage, verification, retrieval, latency, environmental-noise, or repair burden in every controlled implementation.
Phase-C catastrophic feedback can occur when boundary loss reduces effective resource intake.	Failure-regime model	Resource depletion and boundary loss never couple positively in any active-boundary system approaching collapse.
Phase-B residues are biased toward low-maintenance, task-relevant invariants.	Conditional bridge	Residues after repeated overload show no bias toward reduced maintenance cost, compressibility, task relevance, or perturbation invariance.

and finite resource budgets [1]. The core also separates formal definitions, physical bridge assumptions, normal-form dynamics, and quarantined applications. FDS-N1 occupies the normal-form and complex-systems bridge layer. It does not derive specific biology, cognition, robotics, or social theory. Instead, it supplies a shared dynamical language for systems that qualify as active-boundary finite systems.

The compact thesis is

$$\begin{aligned}&\text{self-organization}\\&= \text{boundary-maintenance-relevant updating}\\&\quad\text{under finite capacity and finite resources.}\end{aligned} \tag{2}$$

Why distinguish structural complexity from maintenance load?

A key revision in this version is the distinction between structural complexity $K(t)$ and maintenance load $L_M(t)$. Complexity is not automatically bad. A modular controller, error-correcting routine, institution, or invariant compression scheme can increase structural complexity while lowering the operational load required to maintain a boundary. FDS-N1 therefore does not claim that all complexity growth is costly in the same way. It claims that maintained structure must fit inside a finite resource envelope, and that unbounded non-compressed maintained load cannot persist without an exit channel.

RELATED WORK

Classical cybernetics and self-organization

Cybernetics framed regulation and survival in terms of feedback, requisite variety, and control under disturbance [6, 7]. General systems theory emphasized organized wholes and open-system persistence [8]. Dissipative-structures theory and synergetics studied order formation in far-from-equilibrium systems [9–11]. Complex adaptive systems, self-organized criticality, and autocatalytic-set approaches studied emergence, adaptation, and macrostructure under local rules [12–14]. A recent review by Gershenson surveys self-organizing systems across physics, chemistry, biology, collective behavior, robotics, and social science [22]. FDS-N1 does not replace these traditions. It offers a narrow accounting-oriented normal form: self-organization is classified by whether internal updates are relevant to future boundary-maintenance loss under finite capacity.

Viability, free energy, and information bottlenecks

Viability theory studies state constraints and survival sets under control [15]. The free-energy principle and active inference treat adaptive systems as minimizing variational free energy or prediction error under generative models [16, 25]. Autopoietic and chemical-organization frameworks study self-producing unity and closure under metabolic constraints [19, 23, 24]. Information-bottleneck theory studies compression that preserves task-relevant information [17, 18]. FDS-N1 is compatible with these approaches but uses a different entry point: the finite distinction system, its boundary, update rule, loss function, and resource budget.

FDS Core and the physical accounting ladder

The FDS core defines the twelve-component finite distinction system and the active-boundary qualification. FDS-P1 defines the physical accounting interface between formal distinctions and physical records; FDS-P2 studies bounded-memory reversible computation and finite reuse [2, 3]. FDS-T3 studies capacity overflow and Phase-B invariant selection [4]. FDS-O2 studies register-time and synchronization bottlenecks [5]. N1 sits above P1/P2 in abstraction: it uses the physical accounting ladder as a background constraint but focuses on self-organization as a normal-form boundary-maintenance process.

ACTIVE FINITE SELF-ORGANIZING SYSTEMS

The FDS tuple as complex-systems anatomy

The FDS core defines a finite distinction system as

$$\mathcal{S} = (X, E, B, M, Y, A, U, \pi, \ell, \Phi, \mathcal{P}, \tau), \tag{3}$$

where X is internal state, E environment, B boundary, M memory or model state, Y observation channel, A action space, U update rule, π finite projection, ℓ boundary-maintenance loss, Φ resource budget, $\mathcal{P}$ perturbation family, and τ update timescale [1].

For N1, this tuple becomes a complex-systems anatomy: the boundary B is the maintained inside/outside interface, M is the finite organizational state, U is the adaptive update channel, ℓ is future boundary-maintenance loss, and Φ is the resource envelope available for sensing, repair, storage, pruning, externalization, and update.

Active self-organization

Definition 1 (Active self-organizing system)**.** *A system qualifies as active self-organizing over a task window τ when it satisfies: (i) it has a boundary variable B whose future loss is measured by ℓ; (ii) it has finite internal state or memory M; (iii) it performs nontrivial internal updates; and (iv) those updates are relevant to future boundary-maintenance loss.*

The minimal relevance screen is

$$\mathbb{P}\{U(M_t, Y_t) \neq M_t\} > 0 \quad \text{and} \quad \mathrm{I}(M_{t+1}; \ell_{t+k}) > 0 \tag{4}$$

for some $k > 0$. For empirical systems, correlation is not enough. The stronger intervention criterion is

$$\mathbb{E}[\ell_{t+k} \mid do(U)] \neq \mathbb{E}[\ell_{t+k} \mid do(U_\varnothing)], \tag{5}$$

where $U_\varnothing$ is a frozen, randomized, or identity-update null channel.

Remark 1. *A passive boundary may be stable. An equilibrium crystal, an inert solid, or a static mathematical structure can persist. But unless an internal update channel participates in future boundary-maintenance loss, it is not in the N1 class.*

CAPACITY DEFICIT AND MAINTENANCE LOAD

Task-relevant demand

Let

$$Z_t = \psi(E_t, B_t) \tag{6}$$

be an admissible task-relevant statistic needed to keep boundary-maintenance loss below tolerance ε over window τ. The minimal rate-distortion demand over a preregistered admissible family Ψ is

$$R^{(\tau)}_{\min}(\varepsilon; \Psi_t) = \inf_{\psi \in \Psi} R^{(\tau)}_{\psi(E,B)}(\varepsilon). \tag{7}$$

Effective organizational capacity

The effective organizational capacity $C_{\mathrm{org}}(t)$ is the usable capacity for the boundary-maintenance task after bottlenecks, externalization overhead, verification, latency, and resource limits are included. A minimal decomposition is

$$C_{\mathrm{org}}(t) = C^{\mathrm{eff}}_{\mathrm{int}}(t) + C^{\mathrm{eff}}_{\mathrm{ext}}(t) - C_{\mathrm{coord}}(t) - C_{\mathrm{verify}}(t) - C_{\mathrm{latency}}(t). \tag{8}$$

TABLE II. Positioning of FDS-N1 relative to neighboring frameworks. The entries are schematic and indicate emphasis rather than exclusion.

Framework	**Core object**	**FDS-N1 emphasis**
Dissipative structures	Far-from-equilibrium order	Maintained boundary under finite capacity and resource budg
Autopoiesis	Self-producing unity	Active boundary plus deficit, pruning, externalization, and co
Cybernetics	Feedback and regulation	Update relevance to future boundary-maintenance loss
Free-energy principle	Variational free energy / prediction error	Task-relative boundary-maintenance loss under finite capacity
Information bottleneck	Compression preserving relevance	Rate-distortion demand $R^{(\tau)}_{\min}(\varepsilon;\Psi)$ and C_{org} deficit
Complex adaptive systems	Adaptation and emergence	Bounded self-organization exit theorem and domain bridge te

The internal term may itself be bottlenecked:

$$C^{\mathrm{eff}}_{\mathrm{int}} = \min\{C_{\mathrm{mem}}, C_{\mathrm{chan}}, C_{\mathrm{upd}}, C_{\mathrm{res}}, C_{\mathrm{timing}}, C_{\mathrm{verify}}\}. \tag{9}$$

This form links N1 to the bottleneck logic of finite observers and finite record systems.

All penalty terms in Eq. (8) are expressed in capacity-equivalent units after conversion through the task-specific bottleneck. Latency penalties are converted into unavailable update capacity over the task window. Verification and repair costs are converted into unavailable distinction-processing capacity. Coordination costs are converted into capacity lost to synchronization and interface overhead. The decomposition is therefore a capacity-equivalent accounting equation, not a mixture of heterogeneous quantities.

The N1 capacity deficit is

$$\Delta_{N1}(t) = R^{(\tau)}_{\min}(\varepsilon;\Psi_t) - C_{\mathrm{org}}(t). \tag{10}$$

When $\Delta_{N1} > 0$, the system cannot maintain all task-relevant boundary distinctions at the required fidelity inside the current organizational capacity.

Structural complexity and maintenance load

Definition 2 (Structural complexity and maintenance load)**.** *$K(t)$ denotes structural or organizational complexity: the amount of maintained internal or coupled structure. $L_M(t)$ denotes maintenance load: the operational burden of keeping that structure usable for boundary maintenance.*

A convenient normal-form relation is

$$L_M = L_0 + aK^{\beta} + L_{\mathrm{coord}} + L_{\mathrm{repair}} + L_{\mathrm{clock}} - \eta_q q - \eta_{\mathrm{auto}} A_{\mathrm{auto}}, \tag{11}$$

where q is invariant-supported residue and A_{auto} denotes automation, modularization, compiled routines, or invariantized procedures that reduce active maintenance load by moving repeated operations into lower-maintenance structure. Automation is not free structure: it carries its own construction, verification, update, and repair costs. It is an exit channel only when

$$C_{\mathrm{build}} + C_{\mathrm{verify}} + C_{\mathrm{update}} + C_{\mathrm{repair}} < \Delta L_M.$$

The exponent β represents the local scaling elasticity of maintenance load with structural complexity. Regimes with $\beta > 1$ correspond to diseconomies of scale, often produced by coordination, repair, verification, and synchronization overhead. Regimes with $\beta < 1$ are possible when modularity, automation, hierarchy, or invariant compression reduce marginal maintenance load. The N1 exit theorem does not require $\beta > 1$ everywhere; it requires that unbounded maintained load cannot remain inside a finite resource envelope without an exit channel.

Equation (11) allows complexity to reduce load when it acts as compression, automation, modularity, or invariant stabilization. N1 is not an anti-complexity theory. It is a finite-maintenance-load theory.

BOUNDARY-MAINTENANCE NORMAL FORM

The minimal N1 normal form tracks structural complexity K, maintenance load L_M, resource reserve Φ, pruning effort S, externalization load E^{ext}, environmental clogging Z_{ext}, invariant residue q, and boundary loss ℓ.

Complexity, pruning, and externalization

A simple load-coupled complexity equation is

$$\dot{K} = G(\Delta_{N1}, K) - P_S(S, K) - X_E(E^{\mathrm{ext}}, K) - I_q(q, K) - d_K K. \tag{12}$$

Here G is deficit-driven growth, P_S is pruning, X_E is externalization relief, and I_q is invariant compression. For example,

$$G(\Delta_{N1}, K) = g_0[\Delta_{N1}]_+ + g_1 K[\Delta_{N1}]_+. \tag{13}$$

Pruning effort is resource-gated:

$$\dot{S} = \sigma(\Phi)\left(k_S[K - K_{\mathrm{target}}]_+ + k_{S\Phi}[\Phi_{\mathrm{crit}} - \Phi]_+\right) - \gamma_S S, \tag{14}$$

with

$$\sigma(\Phi) = \frac{\Phi}{\Phi + K_{\Phi}}. \tag{15}$$

Thus resource stress can motivate pruning, but severe resource depletion can also disable pruning capacity.

Externalization and environmental clogging

Externalization shifts the accounting boundary:

$$\mathcal{A}_{\text{local}} \to \mathcal{A}_{\text{coupled}} = \mathcal{A}_{\text{local}} \cup \mathcal{A}_{\text{ext}}. \tag{16}$$

It can increase effective capacity, but it also writes records into an environment. Let Z_{ext} denote environmental record/noise load. A minimal clogging model is

$$\dot{Z}_{\text{ext}} = \alpha_E E^{\text{ext}} - \gamma_E Z_{\text{ext}}. \tag{17}$$

Retrieval and verification costs can grow with clogging:

$$C_{\text{retrieve}}(Z_{\text{ext}}) = C_0 + c_1 Z_{\text{ext}} + c_2 Z_{\text{ext}}^2. \tag{18}$$

The effective external capacity is therefore

$$C_{\text{ext}}^{\text{eff}} = C_{\text{ext}}^{\text{raw}} - C_{\text{write}} - C_{\text{verify}}(Z_{\text{ext}}) - C_{\text{retrieve}}(Z_{\text{ext}}) - C_{\text{sync}} - C_{\text{latency}} - C_{\text{repair}}. \tag{19}$$

This is the normal-form route by which over-externalization becomes information pollution, indexing burden, or environmental clogging. N1 does not claim that such costs are always exponential; it claims that they must be audited and can become superlinear in crowded external stores. Environmental clogging of this form has been identified as a systemic information-overload risk in digital ecosystems [26].

Resource and loss dynamics

A resource equation is

$$\dot{\Phi} = \dot{F}_{\text{in}}^{\text{eff}}(\ell) - \dot{Q}_{\text{hk}}(L_M, S, E^{\text{ext}}, Z_{\text{ext}}) - D_\ell(\ell), \tag{20}$$

where $\dot{F}_{\text{in}}^{\text{eff}}$ may decrease as boundary loss increases. Boundary loss evolves as

$$\dot{\ell} = a_\Phi[\Phi_{\text{crit}} - \Phi]_+ + a_L[L_M - L_{\text{crit}}]_+ + a_\Delta[\Delta_{N1}]_+ - r_{\text{repair}}(S, E^{\text{ext}}, q, \Phi) \tag{21}$$

Phase-C catastrophic feedback

Phase C is a failure regime in which boundary loss reduces effective resource intake and therefore accelerates further boundary loss:

$$\Phi < \Phi_{\text{crit}}, \qquad \dot{\ell} > 0, \qquad \frac{\partial \dot{F}_{\text{in}}^{\text{eff}}}{\partial \ell} < 0. \tag{22}$$

Phase C is not a new universal law. It is a normal-form collapse regime for systems where resource acquisition depends on an intact boundary. Death, bankruptcy, institutional collapse, and runaway controller failure are possible domain projections, not proofs.

In dynamical-systems terms, Phase C is a region in which the resource-loss feedback has positive loop gain: boundary loss reduces effective resource intake, while reduced resource reserve increases boundary loss. Locally this corresponds to the sign pattern

$$\frac{\partial \dot{\Phi}}{\partial \ell} < 0, \qquad \frac{\partial \dot{\ell}}{\partial \Phi} < 0, \qquad \frac{\partial \dot{\Phi}}{\partial \ell}\frac{\partial \dot{\ell}}{\partial \Phi} > 0.$$

This places Phase C within the broader class of critical transitions and tipping-point dynamics studied in complex-systems resilience theory [27].

BOUNDED SELF-ORGANIZATION EXIT THEOREM

Theorem 1 (Bounded self-organization exit)**.** *Consider an active-boundary finite system with finite effective resource input* $\dot{F}_{\text{in}}^{\max} < \infty$*. Suppose it experiences positive deficit-driven load pressure and its maintained load cannot remain uniformly bounded under unbounded Phase-A growth unless it is compressed, externalized, automated, made invariant-supported, or made non-maintained. If no exit channel is available, then the system cannot remain indefinitely in unbounded Phase-A growth without reaching a resource or boundary-maintenance failure condition.*

Proof. Phase-A growth increases the amount of structure that must remain task-available for boundary maintenance. By hypothesis, under unbounded growth and absent compression, externalization, automation, invariant stabilization, or non-maintenance, the maintained load eventually exceeds the finite resource envelope. Once L_M forces $\dot{Q}_{\text{hk}} + D_\ell(\ell) > \dot{F}_{\text{in}}^{\max}$ for a sufficiently long interval, Eq. (20) drives Φ downward. If the system does not exit through pruning, compression, externalization, task relaxation, invariant stabilization, resource expansion, or automation, then Φ crosses Φ_{crit} or ℓ crosses the boundary-loss tolerance. The system therefore enters collapse or Phase-C feedback. The conclusion follows from finite resource input and the absence of exits. ☐

Remark 2. *The theorem does not require every added structure to increase cost. It permits modularity, automation, compression, and invariant-supported structure to reduce* L_M*. The theorem targets unbounded maintained load under finite resource input, not complexity as such.*

Corollary 1 (Finite-maintenance impossibility triangle)**.** *An active-boundary finite system cannot jointly satisfy:*

$$L_M(t) \to \infty \quad \wedge \quad \dot{F}_{\text{in}} \le F_{\max} < \infty \quad \wedge \quad \textit{no exit channel.}$$

At least one of the three must fail: load must be bounded, resources must expand, or an exit channel (pruning, compression, externalization, automation, invariant stabilization, task relaxation, or collapse) must occur.

The admissible exits are

$$\text{prune / compress / externalize / relax / automate / invariant-stabilize / expand resources / collapse.} \tag{23}$$

PHASE A, PHASE B, AND PHASE C

Phase A: growth-dominant adaptation

Phase A occurs when deficit-driven growth dominates regulation:

$$G(\Delta_{N1}, K) > P_S(S, K) + X_E(E^{\text{ext}}, K) + I_q(q, K). \tag{24}$$

Typical signatures are model proliferation, repair patches, increased structural complexity, and rising maintenance load.

Phase B: maintenance, pruning, and invariant selection

Phase B occurs when pruning, externalization, compression, or invariant stabilization catches up with growth:

$$P_S + X_E + I_q \geq G. \tag{25}$$

Phase B can produce simplification, consolidation, external scaffolding, or low-maintenance residue. Oscillation between Phase A and Phase B is possible but not universal.

Phase C: catastrophic feedback

Phase C occurs when resource depletion and boundary loss reinforce one another. It is characterized by Eq. (22). Phase C can follow failed pruning, excessive externalization, overcompression, loss of invariant support, or loss of repair capacity.

PRUNING, EXTERNALIZATION, AND INVARIANT PERSISTENCE

Pruning as active simplification

Pruning removes, compresses, deactivates, or downranks maintained distinctions. It is useful only inside a viability window. Under-pruning leaves overload unresolved; over-pruning destroys task competence. In N1, pruning is not merely deletion. It is active simplification relative to boundary-maintenance loss.

Proposition 1 (Pruning viability window)**.** *If under-pruning leaves L_M above the resource envelope and over-pruning increases task loss ℓ_{task} by destroying required distinctions, then there exists an intermediate pruning range that minimizes total expected boundary loss for the modeled task.*

Invariant-supported persistence

Let $R_A(x)$ be an identity predicate and let $q : X \to Q$ be a quotient map. Invariant support holds relative to a specified perturbation family $\mathcal{P}$, task window τ, and identity predicate R_A when

$$R_A = \bar{R}_A \circ q, \qquad q(P_i x) = q(x) \tag{26}$$

for admissible perturbations $P_i \in \mathcal{P}$. Invariant support is not absolute indestructibility. It is persistence relative to a chosen perturbation class, task window, and identity predicate.

To connect N1 to T3, define a survival score for a candidate residue ϕ_i:

$$S(\phi_i) = \frac{U_i^{\text{boundary}} + U_i^{\text{pred}}}{C_i^{\text{maint}} + C_i^{\text{verify}} + C_i^{\text{refresh}} + \epsilon}. \tag{27}$$

A soft selection rule is

$$P_i^{\text{survive}} = \frac{\exp(\beta S(\phi_i))}{\sum_j \exp(\beta S(\phi_j))}. \tag{28}$$

Equations (27) and (28) are a selection functional, not a universal biological law. They express the hypothesis that Phase-B residues are biased toward structures with high boundary or predictive utility per unit maintenance burden.

NUMERICAL MODELS AND SIMULATIONS

The simulations are deterministic synthetic demonstrations. They are not fits to physical memory devices, biological systems, robots, organizations, or human-subject data. They provide reproducible model diagrams for the N1 normal form. All figures and CSV outputs are generated by `code/generate_results.py`.

DOMAIN BRIDGE TEMPLATE AND PROTOCOLS

N1 is a bridge protocol, not a license for uncontrolled analogies. A domain application must specify the entries in Table III before claiming that the N1 normal form applies.

TABLE III. Minimal domain bridge template for applying FDS-N1.

Item	**Required domain definition**
Boundary B	What boundary or interface is being maintained?
Loss ℓ	How is boundary-maintenance failure measured?
Memory/organization M	What structure stores task-relevant distinctions?
Update U	Which updates influence future boundary loss?
Capacity C_{org}	How is usable organizational capacity estimated?
Demand $R_{\min}$	What task-relevant distinction demand is pre-registered?
Resource Φ	What finite resource or free-energy budget constrains maintenance?
Pruning S	What counts as active simplification, forgetting, or deletion?
Externalization E^{ext}	What records or functions are moved outside the local boundary?
Environmental clogging Z_{ext}	How does externalization affect retrieval, noise, and verification?
Invariant q	What low-maintenance residue supports identity or task function?
Ablation	How is $do(U)$ compared with frozen or randomized update?

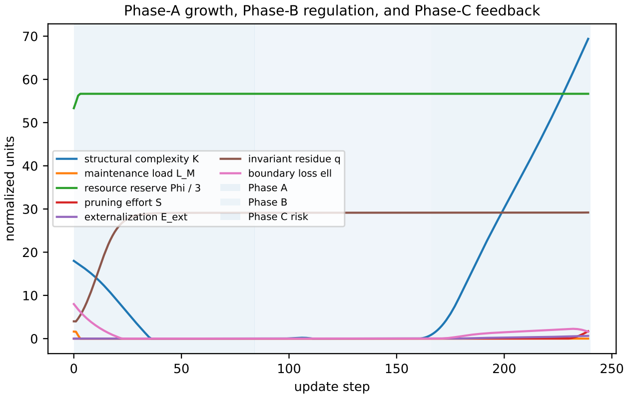


FIG. 1. Phase-A growth, Phase-B regulation, and Phase-C feedback. Structural complexity K and maintenance load L_M rise under deficit pressure. Pruning, externalization, and invariant residue can stabilize the system, but severe resource depletion can trigger boundary-loss feedback.

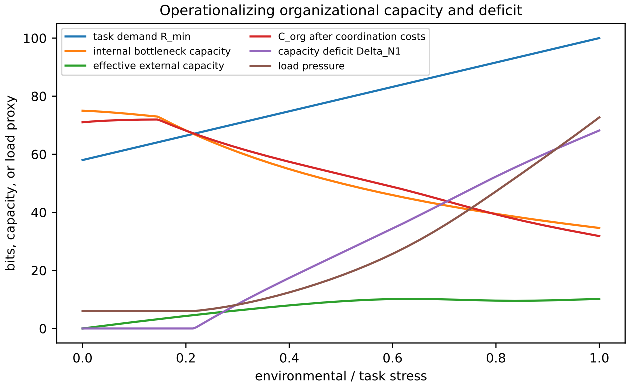


FIG. 2. Operationalizing C_{org}. Effective organizational capacity combines internal bottleneck capacity, useful external capacity, and coordination costs. Capacity deficit Δ_{N1} rises when task demand exceeds usable organization.

Protocol 1 (Active-boundary ablation). *Compare normal update $do(U)$ with frozen, randomized, or identity update $do(U_\varnothing)$ and measure future boundary-maintenance loss ℓ_{t+k}. If the intervention has no effect on future loss, the system does not qualify as active self-organizing for that task.*

Protocol 2 (Deficit crossing). *Increase task demand or environmental complexity and measure Δ_{N1}, K, L_M, S, E^{ext}, Φ, and ℓ. N1 predicts load growth, pruning/externalization responses, or collapse as demand crosses effective organizational capacity.*

Protocol 3 (Pruning-window test). *Vary pruning strength. N1 predicts under-pruning overload, an intermediate viability window, and over-pruning task loss when task-relevant distinctions are destroyed.*

Protocol 4 (Externalization ROI and clogging). *Increase externalization fraction and measure local relief, write cost, verification cost, retrieval cost, latency, and environmental record load. N1 predicts that externalization can become negative ROI when coordination, latency, or clogging costs dominate.*

Protocol 5 (Invariant residue test). *Apply admissible perturbations and measure which structures survive. N1 predicts a bias toward residues with high survival score $S(\phi)$, not arbitrary survival of all structure.*

LIMITATIONS AND FALSIFICATION

FDS-N1 is not a universal theory of life, intelligence, consciousness, organizations, or culture. It is a finite-boundary normal form for active systems. It does not claim that all self-organizing systems are optimal, that Phase-A/Phase-B/Phase-C dynamics must oscillate, or that invariant residues always emerge.

The strong version of FDS-N1 would be weakened or rejected by any of the following:

1. systems classified as active self-organizing despite update ablation having no effect on future

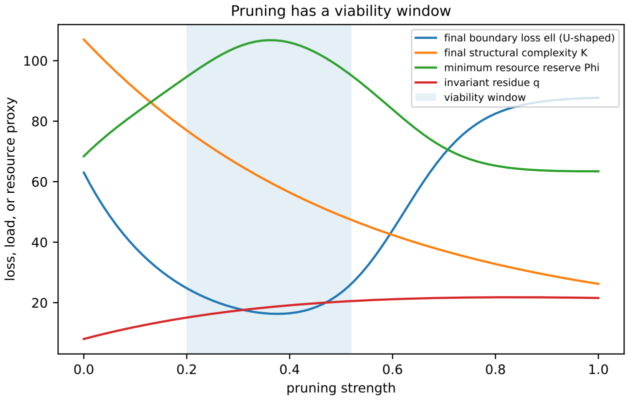


FIG. 3. Pruning has a viability window. Under-pruning leaves overload; over-pruning destroys task competence. The synthetic boundary-loss curve is U-shaped, while structural complexity falls and resource reserve is best preserved in an intermediate range.

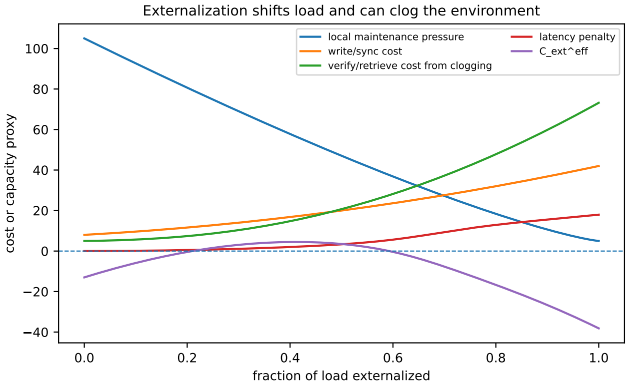


FIG. 4. Externalization shifts load and can clog the environment. Local maintenance pressure falls as more records are externalized, but write, verification, retrieval, and latency costs grow. Effective external capacity can become negative when environmental record load increases.

boundary-maintenance loss;

2. sustained unbounded maintained load under finite resource input with no pruning, compression, externalization, task relaxation, automation, invariant stabilization, resource expansion, or collapse;

3. effective organizational capacity remaining unchanged under severe channel, memory, update, resource, verification, and latency bottlenecks;

4. pruning strength having no systematic effect on overload, task competence, or persistence across controlled cases;

5. externalization imposing no write, verification, retrieval, synchronization, latency, repair, or environmental-clogging burden;

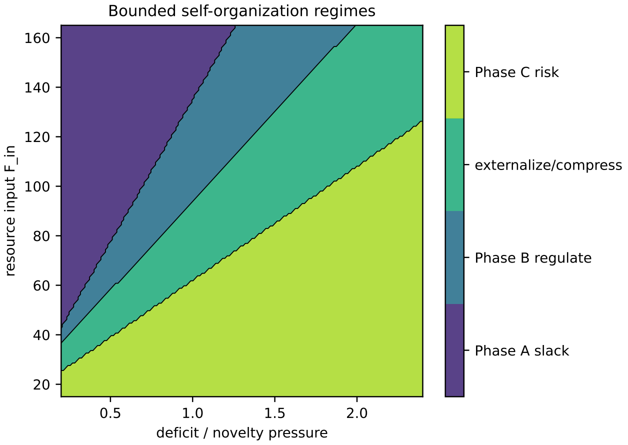


FIG. 5. Bounded self-organization regimes. The synthetic phase portrait separates Phase-A slack, Phase-B regulation, externalization/compression dominance, and Phase-C collapse risk as a function of deficit pressure and resource input.

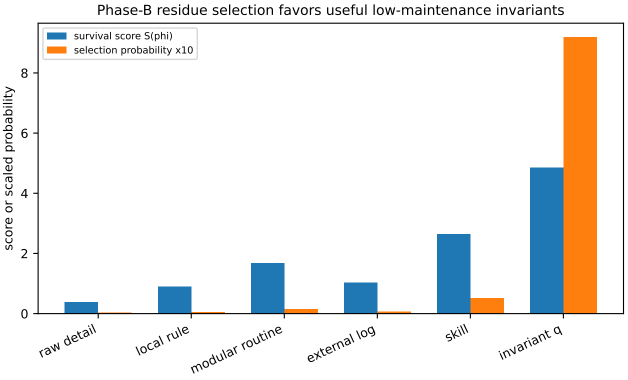


FIG. 6. Phase-B residue selection favors useful low-maintenance invariants. The survival score $S(\phi)$ increases when boundary and predictive utility are high relative to maintenance, verification, and refresh costs.

6. Phase-B residues showing no bias toward low-maintenance, task-relevant, perturbation-stable structures;

7. boundary loss and resource acquisition never coupling in collapse-prone active systems.

CONCLUSION

FDS-N1 reframes self-organization as boundary-maintenance-relevant updating under finite capacity and finite resources. The central object is not unconstrained order. It is a finite system maintaining a boundary through costly updates, limited memory, imperfect externalization, resource-gated pruning, and possible invariant stabilization.

The compact statement is:

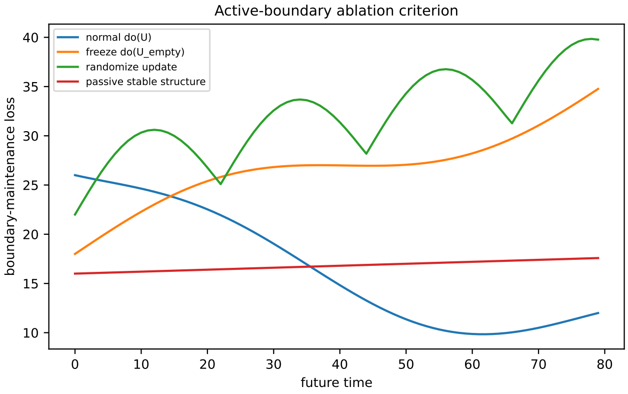
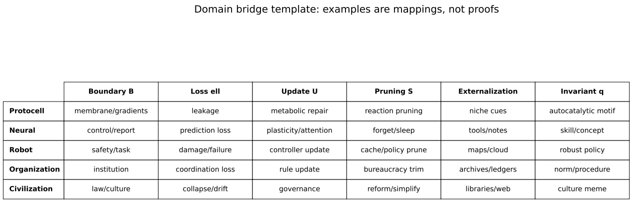


FIG. 7. Active-boundary ablation criterion. A system qualifies as active self-organizing only when normal update improves future boundary-maintenance loss relative to frozen or randomized update controls.


Domain bridge template: examples are mappings, not proofs

	Boundary B	Loss ell	Update U	Pruning S	Externalization	Invariant q
Protocell	membrane/gradients	leakage	metabolic repair	reaction pruning	niche cues	autocatalytic motif
Neural	control/report	prediction loss	plasticity/attention	forget/sleep	tools/notes	skill/concept
Robot	safety/task	damage/failure	controller update	cache/policy prune	maps/cloud	robust policy
Organization	institution	coordination loss	rule update	bureaucracy trim	archives/ledgers	norm/procedure
Civilization	law/culture	collapse/drift	governance	reform/simplify	libraries/web	culture meme

FIG. 8. Domain bridge flow diagram. The detailed template is in Table III. Every application must specify its boundary, loss, update, pruning operation, externalization channel, and invariant residue before claiming that the N1 normal form applies.

> Self-organization is not unconstrained order production. It is finite boundary maintenance by updates that must pay for the load they preserve. Complexity can help when it compresses, automates, modularizes, externalizes, or stabilizes; it fails when maintained load outruns the resource envelope.

This is the complex-systems bridge needed before later FDS treatments of entropy production in active finite systems, death-like collapse and recovery ordering, cognitive bottlenecks, organizational externalization, and civilization-scale maintenance limits.

NOTATION SUMMARY

Symbol	Meaning
B	maintained boundary or interface
M	memory, model, or organizational state
U	internal update rule
ℓ	boundary-maintenance loss
Φ	finite resource or free-energy budget
$R^{(\tau)}_{\min}(\varepsilon;\Psi)$	task-relevant rate-distortion demand
C_{org}	effective organizational capacity after bottlenecks and ove
Δ_{N1}	task-relative capacity deficit $R_{\min} - C_{\mathrm{org}}$
K	structural or organizational complexity
L_M	maintenance load
S	pruning or active simplification effort
E^{ext}	externalization load
Z_{ext}	externalized record/noise load in environment
q	invariant-supported residue or quotient structure
$S(\phi)$	survival score of candidate residue ϕ

SIMULATION PARAMETERS

The simulations are deterministic and use fixed synthetic parameters in `code/generate_results.py`. Figure 1 uses the full Phase-A/Phase-B/Phase-C normal form. Figure 2 operationalizes C_{org}. Figure 3 varies pruning strength. Figure 4 varies externalized fraction and environmental clogging. Figure 5 uses a synthetic regime classifier. Figure 6 computes survival scores. Figure 7 compares update interventions. Figure 8 renders the domain bridge template. No proprietary, biological, organizational, human-subject, or device data are used.

REPRODUCIBILITY CHECKLIST

1. Code availability: all simulation code is included in the replication package.
2. Deterministic execution: the code uses fixed synthetic parameters and deterministic arrays.
3. Figure reproduction: run `python code/generate_results.py`; the script regenerates all figures and CSV outputs.
4. Data status: all numerical outputs are synthetic demonstrations generated from the stated model.
5. Platform independence: the code uses standard Python scientific libraries.

CODE AVAILABILITY

The simulation code used to generate Figs. 1–8 is included in the accompanying replication package under `code/generate_results.py`. Running the script regenerates all figures (PDF and PNG) and CSV tables in a single pass.

AI ASSISTANCE DISCLOSURE

AI-assisted tools were used for language polishing, structural feedback, LaTeX drafting support, and code-debugging assistance. The author reviewed and edited all content and remains responsible for all claims, references, simulations, and conclusions. No AI system is listed as an author.

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