A Minimal Structural Framework for the Emergence of Coherence: Toward a Science of Unified Systems (SSU)

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Abstract

Many scientific fields dealing with complex systems—dynamical systems, self-organization, artificial intelligence, artificial life—face a recurrent conceptual difficulty: rigorously describing the emergence of coherent structures without resorting to metaphysical entities, teleological notions, or ambiguous vocabulary (intention, "meaningful" information, consciousness, etc.).

We propose a minimal conceptual framework, called the Science of Unified Systems (SSU), based on three formal components forming the Axiom of Structural Coherence (ASC): a constraint space (R), an embodied dynamics (B = M), and a functional emergent coherence (R1).

The ASC defines system viability through the functional identity between its "Goal" and its "Method" (B = M). Depending on the nature of the system, these terms refer either to transformation dynamics and their global effects (physical and artificial systems), or to regulatory functions arising from evolutionary and social mechanisms, without postulating any fundamental teleology. This framework deliberately employs these sensitive terminologies to describe the emergence of coherent structures across diverse domains of reality while strictly avoiding metaphysical commitments.

This framework does not constitute a physical theory nor a predictive mathematical model, but a structural grammar aimed at clarifying the conditions of appearance, absence, and limitation of emergence in dynamical systems. It aims to be compatible with existing formalisms, while explicitly excluding non-scientific interpretations (fundamental consciousness, unconstrained downward causation, implicit teleology). It thus provides a conceptual foundation upon which heterogeneous scientific models can be compared, interpreted, and discussed coherently.

1 Introduction

The study of emergence suffers less from a lack of models than from persistent conceptual vagueness. Notions such as "structure," "organization," "information," or "coherence" are often used implicitly, vary across disciplines, and sometimes carry unexamined ontological assumptions. In this context, many theoretical disagreements concern not empirical results themselves, but what those results are supposed to mean.

This work proposes a minimal framework aimed at clearly distinguishing constraints, dynamics, and emergences; formalizing emergence without postulating additional entities; and providing criteria to identify when emergence is impossible. This framework does not aim to replace existing models, but to clarify their ontological and dynamical status.

2 Related Work and Scientific Positioning

SSU is positioned at the intersection of nonlinear dynamical systems, self-organization theory, cybernetics and control, complex adaptive systems, and contemporary theories of emergence. Rather than proposing a new physical theory or predictive mathematical framework, SSU introduces a minimal structural grammar designed to clarify the conceptual conditions under which coherent structures may emerge in complex dynamical systems.

2.1 Dynamical Systems and Attractor Theory

Nonlinear dynamical systems theory provides foundational tools for analyzing complex systems through attractors, bifurcations, and phase transitions. SSU remains compatible with this formalism while operating at a distinct conceptual level. It introduces a tripartite distinction between constraint spaces (R), embodied dynamics (B = M), and emergent invariants (R1), thereby clarifying how dynamical coherence arises independently of substrate.

2.2 Self-Organization and Nonequilibrium Thermodynamics

Self-organization theory explains how macroscopic order emerges from microscopic interactions under nonequilibrium conditions. SSU abstracts away from energetic considerations and focuses instead on structural constraints and dynamical coherence, enabling a substrate-independent conceptualization of emergence.

2.3 Cybernetics and Control Theory

Cybernetics investigates regulation and feedback in complex systems. SSU departs from normative control formulations by conceptualizing regulation as an emergent structural phenomenon, without invoking explicit control objectives or supervisory architectures.

2.4 Complex Adaptive Systems

Complex adaptive systems exhibit learning, adaptation, and hierarchical organization. SSU provides a minimal structural backbone for analyzing such systems, without presupposing agency, cognition, or semantic information.

2.5 Theories of Emergence

SSU adopts a structural weak-emergence stance, defining emergent coherence (R1) as dynamically stable invariance arising from the interplay between constraints and dynamics, without introducing new ontological entities.

3 Fundamental Definitions

3.1 R — Constraint Space

R denotes the set of structural constraints defining the admissible trajectories of a system. It is not a system state but a grammar specifying dynamic possibility. For artificial intelligence systems, R corresponds to architectural and axiomatic constraints. R includes evolution rules, interaction topology, bounds of state space, and temporal update conditions.

3.2 B = M — Embodied Dynamics

B = M denotes the realized system states and their effective interactions. The notation expresses the functional identity between "Goal" and "Method": dynamics and transformation form a single operational process. No dynamics exist outside B = M, and every observable trajectory is an actualization of R.

3.3 R1 — Emergent Coherence

R1 is a dynamic invariant emerging from B = M under constraints R. Once stabilized, R1 acts as a second-order constraint reinforcing B = M without modifying R. R1 is not a state, entity, or fundamental property, but a functional invariance.

4 The Axiom of Structural Coherence (ASC)

Axiom 1 — Constraint Axiom. Every dynamical system is defined by a constraint space R that conditions its possible trajectories.

Axiom 2 — Actualization Axiom (B = M). System states and their interactions constitute the sole mechanism by which trajectories are realized.

Axiom 3 — Emergent Coherence Axiom (R1). Under specific conditions, system dynamics may generate persistent invariants constraining future trajectories.

5 Conditions for Emergence and Non-Emergence

5.1 Necessary Conditions

Emergence of R1 requires minimal temporal memory, nontrivial interactions, statistical persistence, and trajectory canalization.

5.2 Counterexamples

Pure stochastic noise, fully frozen systems, and unchanneled chaos cannot generate functional emergent coherence.

6 Extension to Self-Modifying Systems

SSU extends naturally to systems capable of modifying local constraints, provided that the possibility of such modifications is itself structurally encoded in R. In such systems, R1 may correspond to emergent effective constraints.

7 Application Example: Exponential Coherence Protocol (ECP)

The Exponential Coherence Protocol illustrates how structural regularization through axiomatic prompting may channel generative AI systems toward coherent dynamical regimes. It is presented as a conceptual instantiation rather than a normative implementation.

8 Discussion and Limitations

SSU does not provide direct predictive metrics. Its contribution lies in conceptual clarification, explicit emergence criteria, and rigorous exclusion of non-scientific interpretations. Extensions toward cognition or subjectivity require additional hypotheses.

9 Conclusion

The Science of Unified Systems proposes a minimal, coherent framework for understanding emergence as a structural-dynamical phenomenon. By distinguishing constraints, dynamics, and emergent coherence, it offers a common conceptual language for comparing heterogeneous systems without introducing metaphysical commitments.