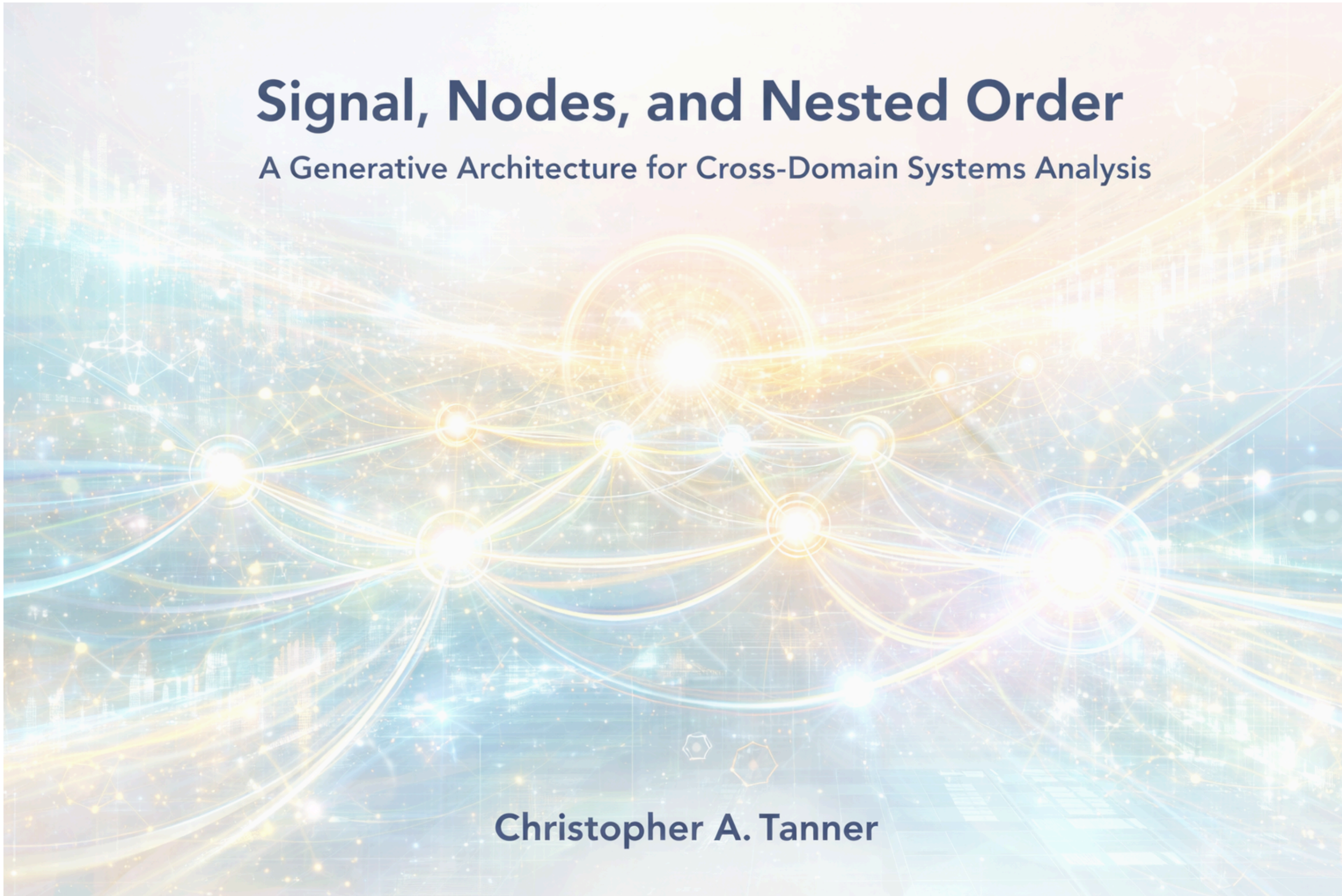
Signal, Nodes, and Nested Order: A Generative Architecture for Cross-Domain Systems Analysis



Abstract

This paper proposes a generative ontology grounded in two irreducible primitives: nodes and signal. A node is any system of sufficient organizational complexity to receive, process, and retransmit state changes; signal is the propagation of those state changes between nodes. We argue that this two-element grammar provides a coherent account of structural patterns observed across physical, biological, linguistic, and social systems, each representing a higher order of signal modulation nested upon a first-order physical substrate. Drawing on established work in information theory (Shannon, 1948), thermodynamics of self-organization (Prigogine & Stengers, 1984), the informational interpretation of quantum mechanics (Wheeler, 1990), and complex adaptive systems (Kauffman, 1993), the framework situates Signal Alignment Theory (SAT; Tanner, 2025a) within a coherent foundational architecture. We further contend that several major theoretical traditions, in physics, biology, linguistics, and cybernetics, have each been describing distinct organizational levels of the same underlying node-signal structure, and that recognizing this shared grammar enables principled cross-domain comparison and predictive analysis.

Author:
Christopher A Tanner
System Analyst, Researcher and Founder:

mail@alignedsignalsystemsconsulting.com
X.com @alignedsignal8
Aligned Signal Systems Consulting

1. Introduction

A recurring challenge across the natural and formal sciences is the identification of a minimal substrate from which observed complexity arises. In physics, this drives the search for unified field theory. In biology, it underlies efforts to derive life's organizational properties from chemistry. In cognitive science, it motivates accounts of how higher-order cognition arises from physical processes. Each project has proceeded largely within disciplinary boundaries, which has limited recognition of what may be a shared structural grammar operating across all of them.

This paper proposes that the apparent diversity of these explanatory targets, matter, life, language, cognition, reflects not fundamentally different ontological categories, but different organizational regimes of a single two-element architecture: nodes and signal. The claim is not metaphorical. Physical causality, biological self-organization, linguistic communication, and cognitive self-reference are treated here as nested elaborations of the same generative structure, distinguished by the complexity of the nodes involved and the order of signal they process and retransmit.

The theoretical lineage for this claim is substantial. Wheeler's (1990) "it from bit" thesis proposed that physical reality is at its base informational, that every particle interaction constitutes a binary state resolution written into the configuration of the universe. Prigogine and Stengers (1984) demonstrated that open systems far from thermodynamic equilibrium, under sustained energetic throughput, spontaneously evolve toward lower-dimensional attractor states, producing the coherent structures we identify here as nodes. Shannon's (1948) mathematical theory of communication formalized the conditions under which structured information is transmitted with fidelity across a noisy channel. Wiener (1948) and Ashby (1956) described the feedback dynamics between nodes that govern adaptive behavior. Chomsky (1957) identified the generative grammar of human language as a structured carrier capable of encoding and transmitting internal states across the physical gap between nervous systems.

The present framework synthesizes these traditions by showing that they are not competing accounts but complementary descriptions of different organizational levels within the same node-signal architecture. Signal Alignment Theory (Tanner, 2025a) is situated within this framework as a diagnostic methodology for identifying phase dynamics and coherence patterns across systems at multiple scales.

2. The Irreducible Substrate: Nodes and Signal

2.1 First-Order Signal

At the base of the proposed architecture is first-order signal: physical state change propagating between material substrates. Electromagnetic interaction, gravitational influence, chemical bonding, and mechanical force are all instances of this class. First-order signal requires no interpretation layer. It is pure causality, the transmission of constraint from one region of physical state space to another at the speed the medium permits.

This characterization is consistent with Wheeler's (1990) participatory universe proposal, in which the fundamental entities of physics are informational rather than material. Every interaction between particles constitutes a measurement, a binary state resolution, that writes information into the configuration of the universe. The medium of first-order signal is physical reality; its grammar is the laws of physics.

2.2 Node Formation and the Law of Coherence

Nodes arise when signal interacts with itself under sufficient constraint and over sufficient time to produce a stable, self-maintaining structure. This is not a metaphysical claim but a thermodynamic one. Prigogine and Stengers (1984) demonstrated that open systems far from thermodynamic equilibrium, subject to sustained energetic throughput, spontaneously self-organize into dissipative structures, configurations that maintain internal order by exporting entropy to their environment.

We formalize this as the Law of Coherence: bounded open systems under sustained energetic constraint with entropy export evolve toward lower-dimensional attractor states. The structures produced by this process are nodes. A cell, a neural network, an organization, and a market are all nodes, not because they share material composition, but because they share functional role: each receives signal, processes it according to internal organizational constraints, and retransmits a transformed output.

The apparent discontinuity between these examples is a discontinuity of organizational complexity, not of kind. Kauffman's (1993) work on self-organization in complex adaptive systems provides a detailed account of how higher-order nodes emerge from lower-order signal interactions without requiring any additional ontological category.

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3. Modulation and the Emergence of Higher-Order Signal

3.1 The Modulation Threshold

When nodes reach sufficient internal organizational complexity, a transition occurs: the node acquires the capacity to encode its internal state onto a structured carrier and transmit that encoded state to another node. This is modulation, the transition from pure physical causality to communication about internal states.

The human nervous system is the most sophisticated known biological instance of this process. Sensory transduction converts first-order physical signal into neural representations. Higher cortical processing encodes those representations, along with stored models and contextual states, into a structured output format. That output is transmitted to another nervous system, which performs the inverse decoding operation.

3.2 Language as Carrier

Language functions as the carrier of second-order signal. The carrier is not the message; it is the infrastructure that gives the message transmissible form. Chomsky (1957) identified the deep syntactic structures of human language as a universal generative grammar, a set of recursive combinatorial rules allowing finite means to produce effectively infinite expressive capacity. In the present framework, this syntactic structure is what enables language to function as a reliable carrier: its organized form permits modulated internal states to survive transmission across the gap between two nervous systems with no direct physical connection.

The fidelity of this transmission is bounded. Shannon (1948) formalized the conditions under which information is transmitted with minimal loss across a noisy channel. Applied to language, the framework predicts what experience confirms: communication is always approximate. The carrier arrives; the internal state it carried never reconstructs perfectly on the receiving end. Language is a high-fidelity but irreducibly lossy compression of experience.

3.3 Signal Nesting and Higher Orders

The hierarchy does not terminate at the second order. Signal about signal produces third-order signal; signal about the structure of signal produces fourth-order signal, and so on without principled upper bound. A technical analysis of a communication system is signal about a carrier. A framework describing how all orders of signal relate to one another is operating at a higher order still. This nesting property, signal generating new signal-processing capacity, which generates further signal, is the engine of increasing complexity within the proposed architecture.

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4. Cognitive Systems as Self-Referential Nodes

Within this framework, higher cognitive function is characterized as self-referential modulation: a node that generates signal about its own modulation process. The recursive capacity of human cognition, the ability to represent one's own representational states, is what produces formal reasoning, scientific inquiry, and reflexive self-awareness.

Hofstadter (1979) identified self-reference as the central feature distinguishing minds from simpler information-processing systems, framing it as a strange loop in which the system's levels of description fold back upon themselves. In the present framework, this is precisely the node-signal dynamic applied reflexively: the node treating its own signal-processing activity as a signal source and processing that signal through its own organizational architecture.

This account has specific implications for artificial intelligence. A large language model (LLM) is a system trained primarily on second-order signal, on the accumulated encoded output of human cognitive states. It operates within the second-order layer, manipulating encoded representations of states it has not independently generated at the first order. This is a precise functional characterization, not an evaluative one, and it carries specific implications for questions of machine understanding, alignment, and the attribution of higher-order cognitive properties to artificial systems (Tanner, 2025b).

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5. Toward Theoretical Unification: Common Structure Across Disciplines

The central contention of this paper is that major theoretical traditions in science have been describing different organizational levels of the same node-signal structure. This is not a claim that these traditions are equivalent or that their distinctions are unimportant. It is a claim that their apparent differences reflect differences in observational level, in which layer of the nesting hierarchy is being examined, rather than differences in underlying ontology.

Shannon (1948) described transmission fidelity: the conditions under which the carrier preserves the payload across a noisy channel. Prigogine and Stengers (1984) described node formation: how coherent structures arise from and persist within signal-rich environments. Wheeler (1990) identified the informational substrate of first-order physical reality. Wiener (1948) and Ashby (1956) described feedback dynamics between nodes: how output signal is routed back as input, producing adaptive behavior. Chomsky (1957) characterized the carrier structure of human second-order signal. Kauffman (1993) described complexity bootstrapping: how higher-order nodes emerge from lower-order signal interactions.

Signal Alignment Theory (Tanner, 2025a) operates at the cross-domain diagnostic level, identifying phase dynamics and coherence patterns that recur across systems at multiple scales. The twelve conserved and semi-conserved patterns identified in SAT, initiation, oscillation, stabilization, amplification, collapse, divergence, containment, compression, phase inversion, resonance collapse, fractal self-similarity, and null, are observable signatures of node-signal dynamics playing out across different substrates and organizational regimes. The present framework provides the foundational account of why these patterns are conserved: they are structural consequences of the same two-element generative architecture operating under varying constraints.

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6. Implications and Future Directions

The node-signal framework has several implications that extend beyond theoretical synthesis.

First, it provides a principled basis for cross-domain comparative analysis. If physical, biological, linguistic, and social systems are all instantiations of the same architecture at different organizational scales, then structural patterns identified in one domain carry predictive weight in others. This is the foundational justification for SAT's cross-domain applicability in organizational, economic, and climatic contexts (Tanner, 2025a).

Second, it reframes questions about artificial intelligence. The distinction between originating and manipulating internal states provides a precise vocabulary for characterizing what current AI systems do and do not do, making questions about machine understanding and alignment more tractable.

Third, it suggests an empirical research program: identifying the precise organizational thresholds at which nodes transition between signal orders, the conditions under which a physical system becomes capable of modulation, and under which a modulating system becomes capable of self-referential signal generation. These thresholds are in principle empirically accessible and sit at the intersection of physics, biology, and cognitive science.

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7. Conclusion

This paper has proposed a generative architecture grounded in two irreducible primitives, nodes and signal, and argued that this minimal structure accounts for the emergence of matter, life, language, and cognition as nested orders of signal modulation. The framework situates established theoretical traditions in information theory, thermodynamics, linguistics, and systems science as complementary descriptions of different organizational levels within the same structure, rather than competing accounts.

Signal Alignment Theory is positioned within this architecture as a cross-domain diagnostic methodology whose conserved patterns reflect the structural consequences of node-signal dynamics across scales. The present paper provides the foundational account for that methodology and identifies several directions for empirical and theoretical development.

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Other Work by This Author:

This Is Not A Bubble: A Comprehensive Signal-Based Analysis of AI's Pre-Amplification Phase and Misdiagnosis of Systemic Collapse (2025)

https://doi.org/10.5281/zenodo.17716727

AI's volatility reflects early-phase amplification signals rather than speculative excess, labor shifts, regulatory lag, and accelerating productivity indicate structural transformation that will force improvisational policies.

The Beast That Predicts: AI Ethics Brought Under the Light (2025)

https://doi.org/10.5281/zenodo.17610117

This paper models LLMs as coherence-seeking predictors whose training induces quasi-intentional behavioral patterns. Tanner identifies emerging tensions between these dynamics and organizational constraints, outlining likely conflict points as systems become more autonomous.

Resonant Signals: Anticipating Legislative Discontinuity in AI Law Through Signal Alignment Theory **(2025)** https://doi.org/10.5281/zenodo.17587328

Using Signal Alignment Theory, this work identifies structural vulnerabilities in emerging AI regulations, including the EU AI Act. Tanner demonstrates how recursive enforcement logic and definitional ambiguity can create unexpected compliance failures.

Signal Alignment Theory: A Harmonic Interpretation of Systems and a Diagnostic Method for Coherence **(2025)** https://doi.org/10.5281/zenodo.16799429

This foundational paper defines SAT's conserved and semi-conserved signal patterns, offering a unified method for detecting coherence and instability across systems of any scale.

Meta-Coherence Stacks and Coherence Contracts: A Communication Framework for Inter-Intelligent Systems **(2025)** https://doi.org/10.5281/zenodo.17217255

Proposes meta-coherence stacks and coherence contracts as lightweight architectures for stable coordination across multi-agent systems. These tools enable adaptive trust and alignment without centralized control.

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