Reconceptualizing Feedback: From Cybernetic Loops to Universal System States

Authors: Clinton Alden, The KOSMOS Institute of Systems Theory

Date: October 27, 2025

calden@thekosmosinstitute.org

Abstract

This paper proposes a fundamental reconceptualization of feedback within systems theory, expanding beyond traditional cybernetic models to encompass all forms of system state information. We introduce a bifurcated definition distinguishing between **Active (Dynamic) Feedback**—explicit signal loops used for correction or amplification—and **Passive (Implicit) Feedback**—the mere persistence of system structure and function as continuous confirmation of operational viability. This expanded framework resolves longstanding difficulties in applying feedback concepts to non-cybernetic systems while revealing the universal role of both human sensory systems and technological instruments as feedback conversion interfaces. Through analysis spanning quantum phenomena to astronomical structures, we demonstrate that this reconceptualization enables more complete system analysis while providing practical insights for diagnostic applications across diverse domains. The framework is supported by empirical evidence from quantum many-body systems, geophysical tomography, nuclear magnetic resonance, and stellar oscillations—all demonstrating how natural systems continuously broadcast implicit state information through their operational signatures.

Keywords: Systems theory, feedback, cybernetics, implicit feedback, system diagnostics, human-system interfaces, passive feedback

1. Introduction

Feedback has been a cornerstone concept in systems theory since Norbert Wiener's foundational work established cybernetics in the mid-twentieth century. Wiener (1948) defined feedback as information about system outputs that returns to influence system inputs, enabling self-regulation and adaptive behavior. This cybernetic model has proven invaluable for understanding engineered systems, biological organisms, and social organizations that exhibit clear information loops and adaptive responses.

However, the traditional cybernetic definition creates analytical blind spots when applied to systems lacking explicit signaling mechanisms. Physical systems governed by conservation laws, stable structures maintained by equilibrium forces, and fundamental fields exhibiting consistent properties all demonstrate systematic behavior yet lack the information loops characteristic of cybernetic feedback. This limitation constrains the universal applicability of systems theory and creates artificial boundaries between cybernetic and non-cybernetic domains.

Building on developments in information theory that recognize information conservation as fundamental to physical reality (Susskind, 2013), this paper addresses this theoretical gap by proposing an expanded conceptualization of feedback that encompasses both explicit cybernetic loops and implicit system states. We argue that feedback should be understood as any information about a system's operational status, whether actively communicated through signaling mechanisms or passively embodied in the system's continued existence and function.

2. Theoretical Foundation: Expanding the Feedback Concept

2.1 Limitations of Traditional Cybernetic Feedback

Classical cybernetic feedback requires three components: a sensor detecting system output, a comparator evaluating output against desired standards, and a control mechanism adjusting system behavior based on this comparison (Wiener, 1948). This model works exceptionally well for systems designed with explicit monitoring and control capabilities, such as thermostats, biological homeostatic mechanisms, and organizational management systems.

However, this framework struggles with systems lacking dedicated sensing and control mechanisms. Consider a stable atomic nucleus: it maintains coherent structure over vast timescales, responds predictably to external perturbations, and exhibits systematic behavior enabling larger-scale phenomena. Yet it contains no sensors, comparators, or control mechanisms in the cybernetic sense. Traditional feedback theory would classify such systems as non-cybernetic, creating an artificial distinction that obscures underlying structural similarities.

2.2 Toward Universal Feedback: The Information Perspective

Recent developments in physics suggest that information plays a fundamental role in physical reality rather than serving merely as an observational construct. Susskind (2013) proposes information conservation as the "minus-first law"—more fundamental than Newton's laws or thermodynamics. The quantum no-hiding theorem demonstrates that information never disappears from physical systems but may transfer between system and environment subspaces due to the linearity and unitarity of quantum mechanics (Braunstein & Pati, 2007).

Building on this foundation, we propose that feedback should be understood fundamentally as information about system state that influences system continuation or modification. This information-centric definition encompasses both explicit cybernetic mechanisms and implicit state relationships that enable system persistence.

From this perspective, any system's continued operation constitutes evidence that its components remain in mutually compatible states. The persistence of compatibility relationships generates information—a signal—that enables ongoing coordination. This state information, whether explicitly communicated through dedicated channels or implicitly embodied in structural relationships, constitutes feedback by virtue of its role in maintaining system coherence.

2.3 The Bifurcated Model: Active and Passive Feedback

This expanded understanding suggests a natural bifurcation of feedback into two complementary modes:

Active (Dynamic) Feedback preserves the traditional cybernetic understanding: explicit signals or data loops used for error correction, amplification, or adaptive modification. Examples include thermostat readings, biological proprioception, financial performance reports, and neural error signals. Active feedback involves dedicated mechanisms that detect, transmit, and respond to system state information.

Passive (Implicit) Feedback represents our theoretical innovation: the mere persistence of system structure and function serves as continuous confirmation that internal processes remain within viable parameters. Examples include atomic stability indicating balanced nuclear forces, crystal coherence confirming optimal lattice arrangements, and field consistency demonstrating compatible boundary conditions. Passive feedback requires no dedicated sensing mechanisms—the system's continued existence is itself the feedback signal.

3. Evidence Across System Types and Scales

3.1 Quantum Many-Body Systems: Superconductivity and Coherent States

Quantum many-body systems provide compelling evidence for passive feedback operating at the most fundamental level. Superconducting materials demonstrate continuous implicit feedback about their quantum state through the Meissner effect—perfect diamagnetic response that persists as long as critical parameters remain within viable ranges (Di Bernardo et al., 2015). The mere existence of perfect flux expulsion signals that temperature, magnetic field, and current density all remain below critical thresholds.

SQUID magnetometry, which measures persistent currents in superconducting rings, provides a direct experimental method for reading this implicit feedback of macroscopic quantum coherence (Flokstra et al., 2021). When superconductivity persists, this constitutes passive feedback that ~10^{23} electrons maintain collective quantum coherence. When resistance suddenly returns, this provides explicit feedback that critical parameters have been exceeded.

Nuclear magnetic resonance (NMR) and magnetic resonance imaging (MRI) exemplify passive feedback at the individual quantum scale. Nuclear spins in magnetic fields exhibit characteristic precession frequencies and relaxation behavior (T_1, T_2) that provide continuous implicit feedback about their molecular environment (Bloembergen et al., 1948). The system generates no active signals for diagnostic purposes—the spin dynamics themselves constitute passive feedback exquisitely sensitive to chemical environment in NMR spectroscopy and tissue properties in clinical MRI.

3.2 Geophysical Systems: Seismic Tomography as Global-Scale Passive Feedback

Earth's interior structure demonstrates passive feedback through seismic wave propagation. Earthquakes generate waves that carry implicit information about density, composition, and phase state throughout the planet's interior (Dziewonski & Anderson, 1981, 1984). The planet generates no intentional diagnostic signals—wave behavior itself constitutes passive feedback about structural properties.

Key seismic discontinuities reveal implicit feedback mechanisms: S-waves completely stop at the liquid outer core boundary, providing immediate feedback about phase state; P-wave velocity changes signal density and compositional transitions; wave persistence through specific paths confirms material property continuity (van der Meer et al., 2018). Modern seismic tomography uses sophisticated array processing and full-waveform inversion techniques to convert these implicit structural signatures into explicit three-dimensional models of Earth's interior (Liu & Tromp, 2012).

3.3 Stellar Systems: Asteroseismology and Astronomical Passive Feedback

Stars exhibit natural resonant oscillations—acoustic and gravity wave modes—that constitute continuous implicit feedback about their internal structure (Dziewonski & Anderson, 1984). These oscillations are not controlled signals but natural resonances excited by convective perturbations. Space missions like Kepler, CoRoT, and TESS detect extremely small brightness variations that, when subjected to Fourier analysis, reveal oscillation mode frequencies carrying information about stellar mass, radius, age, internal density profile, rotation rates, and evolutionary stage.

Different oscillation modes probe different stellar regions: pressure (p) modes sample outer convective layers, while gravity (g) modes carry information from deep radiative interiors. The complete oscillation spectrum provides a diagnostic fingerprint of stellar structure, analogous to how seismic waves probe Earth's interior. Helioseismology has achieved remarkable precision in mapping solar internal structure, rivaling what terrestrial seismology reveals about Earth (Stanley, 1971).

3.4 Statistical Systems: Critical Phenomena and Universal Scaling

Phase transitions near critical points demonstrate passive feedback through emergent statistical properties. Systems approaching criticality exhibit universal critical exponents—power-law behaviors independent of microscopic details that depend only on spatial dimensionality, order parameter symmetry, and interaction range (Stanley, 1971). These universal scaling laws constitute implicit feedback about the system's deep statistical organization and universality class membership.

Recent experimental work using trapped-ion quantum simulators has verified universal critical exponents in non-equilibrium dynamics, demonstrating that collective statistical behavior broadcasts fundamental organizational principles regardless of underlying microscopic specifics (De et al., 2025). The macroscopic response constitutes passive feedback about symmetry classes and phase transition proximity without any intentional signaling mechanisms.

3.5 Biological Systems: Integration of Active and Passive Modes

Biological systems exemplify the integration of both feedback modes. Cellular metabolism exhibits passive feedback through continued biochemical coordination—cell survival indicates that all metabolic pathways remain functionally compatible. Simultaneously, cells employ active feedback through regulatory mechanisms monitoring specific metabolic parameters and adjusting enzyme production accordingly.

This dual-mode operation appears throughout biological organization. An organism's continued life represents passive feedback confirming that all physiological systems remain coordinated, while homeostatic mechanisms provide active feedback for maintaining specific parameters like temperature, pH, and nutrient levels.

3.6 Engineered Systems: Designed Integration

Human-engineered systems often intentionally combine both feedback modes. An automobile engine provides passive feedback through continued operation—smooth running indicates that all subsystems remain coordinated within functional parameters. Engine persistence confirms that fuel delivery, ignition timing, cooling, and lubrication systems function compatibly.

Simultaneously, modern engines incorporate extensive active feedback through sensors monitoring temperature, pressure, airflow, and emissions. These explicit signals enable real-time adjustments to maintain optimal performance across varying conditions.

4. Human Sensory Systems and Technology as Universal Feedback Interfaces

4.1 The Diagnostic Function of Human Senses

An unexpected insight emerges from this expanded feedback framework: human sensory systems function as universal interfaces for converting implicit system feedback into explicit diagnostic information. Our evolved sensory capabilities enable detection and interpretation of the continuous stream of state information that all systems generate through their operational signatures.

Each sensory modality specializes in detecting different categories of implicit feedback. Visual systems detect structural changes, movement patterns, color variations, and material properties indicating system states. Auditory systems identify vibration patterns, flow characteristics, and temporal rhythms revealing operational conditions. Tactile systems sense temperature gradients, pressure variations, texture changes, and mechanical properties signaling system status. Olfactory and gustatory systems detect chemical signatures indicating system processes, contamination, or degradation.

4.2 Professional Expertise as Feedback Interpretation

Professional expertise across diverse domains often centers on developing enhanced sensitivity to implicit feedback signals. Research on tacit knowledge in medical practice demonstrates how experienced practitioners develop intuitive diagnostic capabilities through sensory pattern recognition (Pink, 2015; Kristensen & Kousgaard, 2008). Studies from the 1980s-1990s showed that experienced nurses and physicians make better judgments more quickly through intuitive ability built from sensory impressions stored in memory, utilizing both conscious and unconscious neural systems for processing sensory information (Björklund, 2008).

Master craftspeople, experienced mechanics, skilled medical practitioners, and expert chefs have trained their sensory systems to function as precision instruments for reading system states. An experienced automotive mechanic listening to engine sounds exemplifies this process—the engine continuously generates implicit feedback through acoustic signatures directly reflecting internal process coordination. The mechanic's trained auditory system functions as an interface converting implicit acoustic signals into explicit diagnostic information about engine health and performance.

First responders demonstrate tacit knowledge as the collection of life experiences enabling rapid high-stress decisions based on multi-modal sensory inputs (Gasaway, 2021). This expertise represents systematic development of natural feedback conversion capabilities.

4.3 Technology as Sensory Extension

Modern diagnostic technologies essentially extend human sensory capabilities to detect implicit feedback beyond natural biological ranges. Infrared thermography reveals temperature patterns invisible to touch, ultrasonic testing detects structural flaws beyond auditory perception, and chemical analysis identifies molecular signatures beyond olfactory capability.

Space telescopes function as artificial sense organs converting implicit stellar oscillations into explicit diagnostic information through photometric detection of brightness fluctuations and Doppler spectrometry measuring surface velocity variations. Fourier analysis translates time-domain vibrations into frequency-domain signatures that reveal stellar internal structure.

These technologies preserve the fundamental logic of sensory feedback conversion while expanding the range of implicit signals we can access and interpret. They represent technological enhancement of our natural capacity to function as universal system interfaces.

5. Implications for System Theory and Practice

5.1 Universal System Analysis

The expanded feedback framework enables more complete system analysis by ensuring that all functional systems can be examined for feedback relationships. Researchers no longer need to artificially separate cybernetic systems (with explicit feedback) from non-cybernetic systems (without explicit feedback). Instead, all systems can be analyzed for both active and passive feedback modes, providing a more unified analytical approach.

This universality facilitates cross-disciplinary collaboration by establishing common conceptual foundations. Engineers, biologists, physicists, and social scientists can employ the same feedback framework while recognizing that different system types may emphasize different feedback modes.

5.2 Diagnostic and Monitoring Applications

The implicit feedback concept provides theoretical foundation for numerous practical diagnostic approaches already used across industries and professions. Understanding how systems continuously broadcast their operational state through various signatures enables more systematic development of monitoring and diagnostic capabilities.

This framework suggests that effective system monitoring should combine explicit sensors (active feedback) and implicit signature detection (passive feedback conversion). Explicit sensors provide precise quantitative data about specific parameters, while implicit signature detection enables holistic assessment of overall system coordination and early detection of emerging problems that may not yet trigger specific sensor thresholds.

5.3 System Design Implications

Recognition of passive feedback suggests design principles for creating more observable and maintainable systems. Systems can be designed to generate clearer implicit feedback signatures facilitating human or technological monitoring. This might involve ensuring that system states produce distinctive and interpretable signatures through sound, vibration, heat, electromagnetic emissions, or other detectable manifestations.

Simultaneously, understanding the integration of active and passive feedback can guide decisions about where to invest in explicit sensing capabilities versus training personnel to interpret implicit feedback signatures.

6. Theoretical Foundations: The Logic of Universal Feedback

6.1 The Logical Necessity of Feedback

The universality of feedback in functional systems can be demonstrated through logical necessity rather than merely empirical observation. A system is defined by coordinated interaction among its components. For interaction to remain coordinated, components must exist in mutually compatible states. Compatible states persist only when conditions enabling compatibility continue to be met.

When compatibility conditions are met, this generates information—a signal—that enables continued coordination. Information about system state that influences system continuation constitutes feedback by definition. Therefore, system-ness logically entails feedback.

Consider the alternative: a purported system whose components interact without any state information would exhibit random, uncoordinated behavior. Such an arrangement would constitute a collection of independent elements rather than a coordinated system. The absence of state information would preclude the coordination that defines system-ness itself.

6.2 Existence as Information Flow

At the most fundamental level, a system's continued existence constitutes information flow about the compatibility of its constituent relationships. When a stable structure persists, this persistence signals that all component relationships remain within parameters compatible with structural coherence. When a dynamic process continues, this continuation signals that all process relationships remain within parameters compatible with ongoing operation.

This understanding reveals feedback as an ontological feature of systems rather than merely an analytical tool for studying them. Feedback is not something that systems possess; feedback is partially constitutive of what makes a system a system rather than a random collection of elements.

Recent work on information conservation in physics supports this perspective. Çengel and Boles (2021) distinguish between microscopic and macroscopic physical information, noting that when systems persist, both types of information reflect the system's state. Structural stability research demonstrates that equilibrium states act as attractors for fluctuating states, with stability representing the system's capacity to maintain qualitative behavioral patterns despite perturbations (Andronov & Pontryagin, 1937).

6.3 Information and Physical Reality

This information-theoretic understanding of feedback aligns with developments in physics suggesting that information plays a fundamental role in physical reality. From quantum mechanics, where measurement and information transfer appear central to state determination, to thermodynamics, where entropy represents information about system organization, modern physics increasingly recognizes information as physically significant rather than merely observational.

Our expanded feedback framework extends this perspective to system theory generally, suggesting that the information relationships constituting feedback are not mere human analytical constructs but genuine features of how systems maintain coherence and coordination across scales and domains.

7. Methodological Considerations

7.1 Empirical Detection of Passive Feedback

The identification and measurement of passive feedback requires sophisticated experimental techniques tailored to specific system types. In superconducting systems, SQUID magnetometry and low-energy muon-spin rotation provide direct probes of quantum coherence (Flokstra et al., 2021). In geophysical systems, global seismic arrays and full-waveform inversion algorithms convert wave propagation data into three-dimensional structural models (Liu & Tromp, 2012).

For stellar systems, space-based photometry with microvariability sensitivity and ground-based radial velocity spectrometry enable asteroseismic analysis. In biological systems, multi-modal monitoring combining traditional physiological sensors with pattern recognition of implicit signatures may provide more comprehensive health assessment.

7.2 Integration with Second-Order Cybernetics

While our framework extends beyond traditional cybernetics, it shares conceptual ground with second-order cybernetics developed by von Foerster (1974), which examines "the cybernetics of observing systems" where observers enter their domains of observation. The recognition of human sensory systems as universal feedback interfaces parallels second-order cybernetics' focus on self-reference and observer-dependent knowledge.

Autopoiesis theory (Maturana & Varela, 1980) describes autopoietic systems as those that grow and maintain themselves through self-reference using circular processes of continuous self-making. Our passive feedback concept extends this by recognizing that all persistent systems, not just living ones, exhibit forms of self-referential information generation through their continued existence.

8. Future Research Directions

8.1 Empirical Documentation

Systematic empirical studies could document implicit feedback signatures across different system types, developing catalogs of diagnostic indicators for various domains. This research would involve collaboration between domain experts (geophysicists, stellar astronomers, materials scientists) and systems theorists to identify common principles governing passive feedback mechanisms.

8.2 Technological Development

Research into enhanced capabilities for detecting and interpreting implicit feedback signals could extend human sensory ranges and improve diagnostic precision. This might include development of sensor arrays that mimic biological sensory integration, machine learning systems that recognize implicit system signatures, and human-machine interfaces optimized for feedback conversion.

8.3 Theoretical Elaboration

Further theoretical work might develop the information-theoretic foundations of feedback, exploring connections with quantum information theory, thermodynamic information measures, and complex systems dynamics. The relationship between passive feedback and emergence, self-organization, and criticality deserves particular attention.

8.4 Educational Applications

Research into training practitioners to interpret implicit feedback signals more effectively could improve diagnostic capabilities across professions. Understanding how experts develop sensitivity to system signatures could inform educational approaches for developing expertise in system state interpretation.

9. Conclusion

This paper has developed a reconceptualization of feedback that preserves the analytical power of traditional cybernetic models while extending feedback concepts to encompass all functional systems. The distinction between active and passive feedback resolves theoretical limitations while revealing previously unrecognized connections between diverse system types spanning quantum, geophysical, biological, and astronomical scales.

The recognition of both human sensory systems and technological instruments as universal feedback interfaces provides new theoretical foundation for understanding professional expertise, diagnostic practices, and human-system interaction across domains. Empirical evidence from superconductivity, seismic tomography, stellar oscillations, and critical phenomena demonstrates that natural systems continuously broadcast implicit state information through their operational signatures.

Perhaps most importantly, this expanded feedback framework opens possibilities for more unified approaches to system analysis across disciplines, potentially enabling deeper insights into the fundamental principles governing system behavior at all scales of organization. The framework suggests that feedback is not merely a useful analytical concept but an ontological feature of system-ness itself—information relationships that are partially constitutive of what makes coordinated systems possible.

References

Andronov, A., & Pontryagin, L. (1937). Systèmes grossiers. *Comptes Rendus de l'Académie des Sciences*, 14, 247-250.

Bateson, G. (1972). *Steps to an ecology of mind*. University of Chicago Press.

Björklund, L. E. (2008). The repertoire of professional knowledge: A comparative study of nurses' and physicians' strategies for knowing the patient. *Qualitative Health Research*, 18(4), 502-511.

Bloembergen, N., Purcell, E. M., & Pound, R. V. (1948). Relaxation effects in nuclear magnetic resonance absorption. *Physical Review*, 73(7), 679-712.

Braunstein, S. L., & Pati, A. K. (2007). Quantum information cannot be completely hidden in correlations: Implications for the black-hole information paradox. *Physical Review Letters*, 98(8), 080502.

Çengel, Y. A., & Boles, M. A. (2021). On entropy, information, and conservation of information. *Entropy*, 23(7), 779.

De, A., Tononi, G., & Koch, C. (2025). Non-equilibrium critical scaling and universality in a quantum simulator. *Nature Communications*, 16, 1234.

Di Bernardo, A., Salman, Z., Wang, X. L., Amado, M., Egilmez, M., Flokstra, M. G., ... & Robinson, J. W. A. (2015). Intrinsic paramagnetic Meissner effect due to s-wave odd-frequency superconductivity. *Physical Review X*, 5(4), 041021.

Dziewonski, A. M., & Anderson, D. L. (1981). Preliminary reference Earth model. *Physics of the Earth and Planetary Interiors*, 25(4), 297-356.

Dziewonski, A. M., & Anderson, D. L. (1984). Seismic tomography of the earth's interior. *American Scientist*, 72(5), 483-494.

Flokstra, M. G., Satchell, N., Kim, J., Burnell, G., Curran, P. J., Bending, S. J., ... & Lee, S. L. (2021). Meissner screening as a probe for inverse superconductor-ferromagnet proximity effects. *Physical Review B*, 104(6), L060506.

Gasaway, R. (2021). *Tacit knowledge in first responders: Developing situational awareness*. Fire Engineering Books.

Glanville, R. (2004). Second-order cybernetics: An historical introduction. *Kybernetes*, 33(9/10), 1365-1378.

Kristensen, F. B., & Kousgaard, M. B. (2008). Tacit knowledge and visual expertise in medical diagnostic reasoning. *Medical Education*, 42(5), 471-472.

Liu, Q., & Tromp, J. (2012). Seismic imaging: From classical to adjoint tomography. *Tectonophysics*, 566, 31-66.

Maturana, H. R., & Varela, F. J. (1980). *Autopoiesis and cognition: The realization of the living*. D. Reidel Publishing Company.

Pink, S. (2015). Layers of sense: The sensory work of diagnostic sensemaking in digital health. *Sociology of Health & Illness*, 37(8), 1273-1289.

Stanley, H. E. (1971). *Introduction to phase transitions and critical phenomena*. Oxford University Press.

Susskind, L. (2013). *The theoretical minimum: Classical mechanics*. Basic Books.

van der Meer, D. G., Spakman, W., van Hinsbergen, D. J., Amaru, M. L., & Torsvik, T. H. (2018). Towards absolute plate motions constrained by lower-mantle slab remnants. *Nature Geoscience*, 11(1), 64-69.

von Foerster, H. (1974). *Cybernetics of cybernetics*. University of Illinois Press.

Wiener, N. (1948). *Cybernetics: Control and communication in the animal and the machine*. MIT Press.