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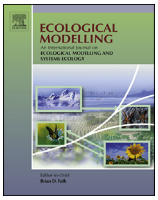

The cardinal hypotheses of *Holoecology*
Facets for a general systems theory of the organism–environment relationship

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ABSTRACT

Causality in Complex Adaptive Hierarchical Systems (CAHSystems) is bipolar. In the hierarchical organization, within-scale contributions come both from below (reductionistic) and above (holistic). *Holoecology* is ecology that seeks to bring holism and formalism into the traditional mix of descriptive, empirical approaches to elaborating ecological cause and effect. The holism is philosophical and methodological, ecological modeling being an important element in the latter. The formalism (presently) is built around a body of environmental system theory called the *Theory of Environs*. This theory encompasses a set of "principles" of transactional network organization, where a *transaction* is a flow of conservative substance (energy or matter) between two system components. These are numbered, and referred to not as principles, but as *cardinal hypotheses*, because they are conditioned on verification or falsification by empirical or theoretical means. Presently, there are 20 of them:

1. *Network pathway proliferation*—increase of pathway numbers with length.
2. *Network nonlocality*—dominance of indirect effects.
3. *Network homogenization*—trend to uniform distribution of transaction based causation.
4. *Network aggradation*—network growth and development properties move systems away from thermodynamic equilibrium.
5. *Network throughflow maximization*—system-wide virtual goal function.
6. *Network storage maximization*—system-wide concrete goal function.
7. *Network boundary amplification*—benefits of agency in boundary crossing.
8. *Network interior amplification*—benefits of high node in-degree.
9. *Network enfolding*—entwinement of boundary relations into deep interiors.
10. *Network unfolding*—conversion of networks to macrochains.
11. *Network centrifugality/centripetality*—expansion and contraction of influence from node storage in, respectively, output and input environs.
12. *Network topogenesis*—quantitative determination of stocks and flows by topological properties of qualitative digraphs.
13. *Network synergism*—system-wide benefits > costs emergent in network organization.
14. *Network interaction typing*—structural determination (by digraph topology) vs. parametric determination (by quantitative flow-storage *transactions*) of qualitative *relations* specifying binary interaction types (e.g., predation, competition, mutualism) between component pairs in systems.
15. *Network mutualism*—emergence of positive interaction types (symbioses) in network organization.
16. *Network Janus Enigma Hypothesis*—stronger adjacent transactions produce stronger ultimate expression of positive binary relations (network synergism), but also stronger proximate environmental degradation.
17. *Network clockwork stockworks (holon autonomy)*—time delay of substance flow in storage causes nodes to dominate in determining network properties; "'*net*'works" are really more like "clockwork '*stock*'works" that contribute constrained autonomy to their entities.
18. *Network environ autonomy*—boundary-based partitioning of transactional stocks and flows in systems, causing environs to be isolated "small worlds" spanning intra-system organization and expressing implicate order.

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19. *Network distributed control*—Expression among system components of distributed (indirect, decentralized, or remote) control at a network distance.
20. *Network ecogenetic coevolution*—system-wide coevolution of mutually implicated parts and wholes to achieve and sustain systemic coherence and life.

These hypotheses are grouped into sections by shared affinities. Eight of them are identified as having special potential to: transform ecology into a systems science that integrates bipolar causality; unify the reductive and holistic modes of science; and shift the ecological worldview more towards holism.

1. Introduction

This paper presents a synopsis of 20 properties of CAHSystems (Complex Adaptive Hierarchical Systems; Patten et al., 2002a,b) that arose from mathematical analyses of ecological *compartment models* (Matis et al., 1979). They form the core of an unfinished book on systems and network ecology, *Holoecology* (Patten, in preparation). This work evolved around a central research question, "What is environment?" Our answers have taken the form of an environmental system theory based on mathematically describable environmental units, *environs* (Patten, 1978a). These and associated elements and terminology are illustrated in Fig. 1. The 20 properties are potential principles of ecology; calling them *cardinal hypotheses* reflects the further need for their empirical verification. They have served as milestone markers in our emergent understanding of the organism–environment relation for more than half the years being recognized here by this 40th Anniversary Special Edition of this journal. "Holoecology" encompasses the notion that all systems are wholes with properties that transcend their parts, which are also wholes transcending their parts—and so on in hierarchical regress. The attributes of wholeness (e.g., Bohm, 1980) are not those normally revealed by reductive science, but they do touch the human desire to know, in fact some areas (existential) hardest to know scientifically. Moreover, wholeness represents the other side of the bipolar dual that is causal determination—from both above (holistic) and below (mechanistic), the two forms enforced by the laws of organization to be consistent and complementary.

In these endeavors I am proud to have known and been associated with, almost from the start, the founding father of *Ecological Modelling*. This pleasure is continued into my own paternity with the knowledge that one of my former students is now ably at its scientific helm. I heartily congratulate both Sven and Brian for their good works.

2. The theory of environs

A brief review of the concepts and notations of environ theory will facilitate description and understanding of the cardinal hypotheses. Figs. 1–3 show the basic scheme for compartment models. The *system* is the focal unit; its n compartments (x_k, $k = 1, \ldots, n$) of stored energy or matter are its component parts. As wholes in a hierarchical continuum, compartments and their systems both are *holons* (H_k; Koestler, 1967). All ecological holons are *open systems* that exchange energy and matter with their surroundings. Interior flows (f_{ij}) between compartment pairs, $j–(f_{ij}) \rightarrow i$, originate as boundary *inputs* (z_k) and terminate as boundary *outputs* (y_k). Each system or compartment has therefore two environments, one afferent (*input environment*) and the other efferent (*output environment*). The holon is partitioned into a receptor component, *creaon*, and an effector component, *genon*, to accommodate the duality (Patten et al., 1976). A premise of environ theory is that mathematical descriptions of systems contain the portions of their compartments' environments that are circumscribed by and contained within the systems' boundaries. These comprise kth *input* (E'_k) and *output* (E_k) *environs* (Patten, 1978a) the latter driven by inputs and the former referenced to outputs (Figs. 1 and 2). Environs are partition elements of systems' stocks and flows; an n-compartment system has $2n$ environs (n afferent, n efferent). Fig. 2 illustrates environ partitioning of the stocks and flows (including notations) for a simple three compartment system. Fig. 3.1 exhibits matrices, vectors, and other notations for throughflow and storage environ analyses of this system, and Fig. 3.2 displays in scalar notation various algebraic relationships between key parameters in these analyses.

3. The cardinal hypotheses

The cardinal hypotheses apply first to *transactional networks*, which feature flows and storages of conserved quantities (in ecology, energy and matter). These give rise secondarily to nonconservative *relational networks*. Both enter the frames of ecological network knowledge. Each description of this section will be followed by one or more key references, in addition to others cited in the text.

3.1. Grounding hypotheses

The first two cardinal hypotheses concern fundamental properties of network structure (pathways) and function (flows and storages) foundational to all other aspects of network organization, including the entire hypothesis set. They deviate significantly from accepted understanding, and have potential to make ecology more holistic.

3.1.1. Network pathway proliferation (CH# 1)

This hypothesis concerns exponential increase in pathway numbers with length between each pair of nodes (compartments) in an interconnected system. Rates of increase are determined by the dominant eigenvalues of system adjacency matrices, $A_{n \times n}$. The matrices are of two kinds, $A0_{n \times n} = (a0_{ij})$ with zero principal diagonal elements, and $A1_{n \times n} = (a1_{ij})$ with ones on the diagonals (Fig. 3.1). Zero diagonals denote no self-looping (storage impedance) in j to i transfers, such as in the length $m = 2$ pathway, $x_1 \rightarrow x_2 \rightarrow x_3$ in the Figs. 2–4 models. Unit diagonals specify self-loops; with time passage (Δt) implicit, these signify storage impedance (time delay) in transit, as in $x_1–(\Delta t) \rightarrow x_1–(\Delta t) \rightarrow x_3$, or $x_1–(\Delta t) \rightarrow x_3–(\Delta t) \rightarrow x_3$ in the model of Figs. 2–4. Sequential powers, $A0^m$ and $A1^m$, enumerate pathways of lengths m connecting each jth to each ith compartment. In storage analysis (Fig. 3.1), where time is explicitly considered, passage over pathways of lengths $m = 1, 2, \ldots$ require $m\Delta t$ units of time to traverse. Infinite series of adjacency matrices raised to mth powers, $\sum_{m=0,\infty} A^m$, are divergent.

Ecological significance: Ecological systems at all scales are, by their higher order indirect ($m \geq 2$) pathways, more highly interconnected and interdependent than denoted by adjacent, first order