GLOBAL CHANGE AND HUMAN CHANGE: A PRESCRIPTION FOR ADAPTIVE EVOLUTION FROM ECOLOGICAL NETWORK THEORY

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ABSTRACT

Homo sapiens appears to be evolving into a new kind of species not seen before in organic evolution. This is *Homo holisticus*, systems man, the first species in the earth's history with a global reach, entailing global selective forces charting its evolutionary change. Living things make models of their reality, converting physical causes to mixed physical–phenomenal ones, a defining characteristic of life. The ontic biosphere accordingly generates a virtual noosphere, the aggregate of implicit biological epistemologies. These operate collectively to shape global change, to which human change is both entrained and contributes. Developing a network perspective on global change, ecology's 'AWFUL theorem', resulting from zero-sum *transactions* (ontic, conservative, energy-matter exchanges), is reviewed and illustrated by two examples of anthropogenic environmental degradation. Indirect *relations* (epistemic, nonconservative and informational) develop automatically in transactional networks and introduce nonzero-sumness into the causal stream. This enables systems to move and remain away from thermodynamic equilibrium, in a process of *network aggradation* wherein internal negentropy generation exceeds boundary entropy dissipation. A third example shows how more mature ecosystems radiate photons at lower temperatures, reflecting increased internal organization – distance from thermodynamic equilibrium. Six network properties contributing to nonzero-sumness are identified, one being system size (number of components). Nonzero-sumness increases *utility*, expressed as benefit/cost ratios, and *network synergism* is the universal tendency in transactional networks to produce ratios >1. However, the degree of positiveness diminishes with system size so that network aggradation experiences diminishing returns as size increases. The organization of nature into a graded series of systems (cells, organs, organisms, etc.) based on size reflects this. Although unlimited network aggradation (negentropic growth and development) is possible with increasing interconnection, diminishing utility returns restrict optimal system size to relatively small numbers of interacting components. The global reach of the emerging *H. holisticus* may thus contraindicate sustainable entrainment of human change to global change by reducing network synergism even as network aggradation marginally rises.
Keywords: AWFUL theorem, benefit/cost ratio, Homo holisticus, Homo sapiens, negentropy, network aggradation, network synergism, nonlocality.

1 INTRODUCTION – *Homo holisticus*

A new confrontation is emerging in the human relationship with nature. It is registered in metaphors such as 'Spaceship Earth', 'Gaia Hypothesis', 'Unitary Ecosphere', and '*Homo holisticus*', and it concerns coming to terms with planetary bio-geo-physicochemical wholeness.

Homo holisticus? Yes. Systems man, the first of a kind in organic evolution. All prior species have been local in their orientation and the selective forces acting upon them – making a living, finding food and shelter, mates, room to grow – achieving fitness in the evolutionary game of life. Living is local, life is global – but not for *H. holisticus*, which in a very real sense is a new kind of product in evolution. For this emerging species, living is global, and that is an altogether different state of affairs on the surface of this planet. Holistic planet, holistic species. What could be more consistent from a common process operating at two different scales – ecospheric and biologic.

The human genus is 2 million years old, the species *sapiens* a half million years old. *H. holisticus* dawned 1.1 centuries ago, a product of the Industrial Revolution. It radiated rapidly with technological development throughout the 20th century, establishing as its central characteristic *causal nonlocality*, and as an outcome of this *nonlocal selection*. The phenomenon of nonlocality includes the Internet, satellite-based telecommunication, mass transportation, and economic globalization to mention a few.

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The terrorism of September 11, 2001, against the USA by a diffuse and poorly defined adversary striking at a discrete, high profile, nation-state is a part of it. Many more examples and episodes will come, reflecting the locking of humanity into irreversible interdependence of all its parts on a nonlocally determined global whole. The situation is reminiscent of the symbiotic unions of free-living microbiota that earlier traded relative independence for the constrained interdependence of the metazoan habit [1].

What does the rise of *holisticus* mean for the future of the planet and its increasingly unitary Ecosphere?

2 THE ECOSPHERE: REAL AND VIRTUAL

The lithosphere, the atmosphere, the hydrosphere, and the biosphere are the four elements of the ecosphere that are usually considered. They are real, or ontic, and make up a whole – bio-geo-physicochemical wholeness. There is a fifth element and it is surreal, ontically based but otherwise virtual. To get at it we have to rework our concept of life a little.

2.1 State-space dynamical systems

Living things make models – representations of reality to live by. Nonliving things never do this. This is an essential difference and it may be characterized in terms of state-space system theory in the following way. The standard formulation for a state-space dynamical system is:

$$\phi\colon Z \times X \to X, \tag{1a}$$

$$\rho\colon Z \times X \to Y. \tag{1b}$$

Z is a set of exogenous inputs whose values drive the system from outside. X, the *state space*, is the same for a set of endogenous variables and values representing the system's state or internal condition. $Z \times X$ is their Cartesian product. Y is the set of output values and variables propagated to the system exterior. The function ϕ defines state transitions through time, and ρ is a function specifying the generation of outputs by the changing states. Everything in eqn (1) is ontic.

One way to represent living entities is to add a third function, μ [2, 3]:

$$\mu\colon Z \times X \to Z', \tag{2a}$$

$$\phi\colon Z' \times X \to X, \tag{2b}$$

$$\rho\colon Z' \times X \to Y. \tag{2c}$$

This function adds virtual elements to the environment such that Z (ontic environment) $\subset Z'$ (modeled plus ontic) and it is the latter that produces state changes and outputs in eqn (2b) and (2c). We can call the collection Z' *phenomenal inputs* to distinguish them from the purely *physical inputs*, Z, of eqn (1). The latter are ontic while the former are in part epistemic, and using eqn (2) we come to associate with life elements of made-up realities that we can only call epistemic. Living things – all of them, as posited by Patten and Auble [2, 3] – possess epistemologies, while nonliving things never do. This is a fundamental distinction, and furthermore the epistemologies are closed and unique. They do not cross the species barrier, nor even fully the individual organism barrier. They impact physical reality because biota manipulate their environments and shape them for their own purposes.

2.2 Noosphere

The collection of closed unrealities that push and pull on ontic reality represents an additional element of the ecosphere – the *noosphere*. This refers to Vernadsky's [4], and later Tielhard de Chardin's [5], term for the human mental sphere generalized to all life on the globe. The ecosphere thereby acquires a new, mysterious element that however elusive it might be to science, nevertheless, figures prominently in shaping the planet. Noosphere – the aggregate of biological epistemologies generated in the biosphere – is another wild card to be considered in understanding global change.

2.3 Transactions and relations

The noosphere and *H. holisticus* – respectively, nowhere and everywhere – comprise an elusive pair for future science to have to deal with. Epistemologies give rise to *relation*s, which are phenomenal. Without these there would only be *transactions*, which are physical (electromagnetic). For example, in ecology a prey category shared by two predators links the triad by a pair of electromagnetic exchanges – food transfer. This is physical – ontic. Ecologists see the two predators as competitors, however, and this is phenomenal – relational, epistemic, noospheric. As transactions increase, say arithmetically, in extended electromagnetic networks of the ecosphere, relations increase combinatorially by power laws. Therefore, in the planetary surface system, phenomenology vastly outdistances the physics such that the dominant sphere in the ecosphere is not any of the other four, more concrete and easily recognized, but the phantom noosphere. Life was never easy for any form in such a realm, but for *holisticus* expanding to encompass everything, it will be uncommonly difficult – perhaps unmanageable, and holistic selection will take its toll. It will, that is, unless a new science of wholeness rises out of analytical reductionism to meet the challenge.

2.4 Ecodynamic entrainment of biotic change to global change

An assumption of this new science must be that biotic change and human change are entrained to global change, not the other way around. The planet has been in perpetual change for all of its 12–15 Ga of existence. The biosphere and noosphere are a superficial crustal phenomenon 4.6 Ga old but the energies powering biogenic and ecodynamic phenomena are dwarfed by those powering the globe. That most species to ever evolve have become extinct is evidence of the tight coupling of biotic change to global change.

3 GLOBAL CHANGE: THE NETWORK PERSPECTIVE

Human contributions to global change are probably widespread and deep, but hard to determine due to factors such as small relative energies, complex causalities, long timescales, and large spatial scales. Ecological network theory can help identify some of the underlying principles. Three of these will be enunciated here in an effort to show how the first holistic species in the history of the world might self-organize and coevolve with other planetary compartments.

3.1 Zero-sumness – ecology's AWFUL theorem

Electromagnetic transactions are at base binary, always between two things, and are *zero-sum* because of the conservation principles for energy and matter. In zero-sumness, whatever passes from one member of an interacting pair is lost from that member and gained by the other. Nothing is left out, so the sum of the transferred quantities (lost and gained) is zero. This dyadic tie is forged by system theory's *identity constraint of coupling*, the exact point where systems originate (as partially interconnected sets of components, by usual definition). The tie is exact by the zero-sumness, amounting to a strong principle of system formation.

At the level of species interacting in a resource-limited electromagnetic field, the zero-sum principle gives rise to Ecology's AWFUL theorem [6]:

$$\text{As We Flourish yoU Lose.} \tag{3a}$$

In formal if–then conditional statement form, this is written: IF we flourish (WF) THEN you lose (UL), or WF $\Rightarrow$ UL, where $\Rightarrow$ means 'implies'). Soulé [7] showed that the last thousand years of human exponential population growth was mirrored by a corresponding downturn (50%–70%) in global species biodiversity. This can be taken as an outcome of the AWFUL theorem. The contrapositive form, which is logically equivalent, is particularly pernicious:

$$\text{IF you don't lose, THEN we don't flourish,} \tag{3b}$$

($\sim$UL $\Rightarrow$ $\sim$WF).

Zero-sumness, always an affiliate of dyadic transactions, can be seen as the cause for most of the environmental degradation caused by technologically aided human activity. Two examples will serve to illustrate this point.

Example 1 Verity [8, 9] reported on the development of anthropogenic intrusions in the formerly pristine Skidaway Estuary near Savannah, GA, USA. This was reflected in 10 years of weekly samples taken from the dock of the Skidaway Institute of Oceanography during 1986–96. No decadal trends could be discerned in water temperature, river discharge, salinity, nitrate, ammonia, phosphate, and total chlorophyll. But dissolved organic nitrogen and silica, $Si(OH)_4$, showed steady increases over the period, when human population in the adjacent county (Chatham) grew about 20%. The sources of the organic nitrogen include fertilizers, pesticides, and sewage. Ground breaking in construction activities is the likely source of the silica. So, rising human development is reflected in the beginnings of degraded estuarine water quality, and since conservative quantities are involved, the relationship is zero-sum. Zero-sum awfulness is beginning to be expressed in the Skidaway Estuary, and the ultimate consequence under human expansion is foreordained.

Example 2 In China, during 1950–90 the population doubled from 540 to 1140 million, and the human-built environment tripled from 10.9 to 32.8 million hectares. Yue *et al*. [10] documented from satellite remote sensing imagery the corresponding decline in diversity $d(t)$ of 26 Holdridge life zones:

$$d(t) = \sum_{i=1}^{26} [p_i(t)]^{1/2} / \ln A(t), \tag{4a}$$

where t is time, p_i is the probability of the ith life zone, and A is the total area of China. The main results of the study were:

1. Life-zone diversity declined at a significant rate:

$$d(t) = 0.85 + t^{-0.00853}, \quad r^2 = 0.95. \tag{4b}$$

2. The incidence of flooding and dust storms rose:

$$\text{Rate of rise} = 17.67 + t^{0.7625}, \quad r^2 = 0.99. \tag{4c}$$

3. Economic losses due to flooding rose rapidly:

$$\text{Loss rate} = 25.42 + 27.08t, \quad r^2 = 0.83. \tag{4d}$$

In these data zero-sum awfulness is expressed again, this time on a subcontinental scale.

3.2 Nonzero-sumness – network aggradation

As *H. holisticus* spreads and consolidates its influence web over the globe, opportunities will exist to combat zero-sumness with its antithesis, *nonzero-sumness*. This is inherent not in the *direct* energy–matter transactions between entity pairs, but in higher-order *indirect* relations inherent in every interaction web. Again, the transactions are ontic while the relations are epistemic, recognized only through human intelligence.

Nonzero-sumness is the basis for the accrual of order and organization in systems beyond the zero-sum limits imposed by thermodynamics. The second law of thermodynamics (entropy principle) contravenes order, which is negentropic. In systems, *network aggradation* produces order against second-law degradation by the proliferation of transactive coupling. As transactions increase arithmetically in networks, relations do so exponentially. This makes it possible for systems to develop negentropically far beyond the local entropy generated at their boundaries.

Jørgensen *et al.* [11] demonstrated this by comparing two abstract four-compartment systems. The first was a transactive chain (like a food chain) at steady state (boundary inputs and outputs equal). Ten units of input (= output) generated 24.7 kJ/m^2 · day of internal flow (total system throughflow), giving an aggradation/dissipation ratio of $24.7/10 = 2.47$. Something similar to this is known as the 'multiplier effect' in economics. To a second network, additional internal couplings were added, keeping the boundary inflow (outflow) at 10. This network generated 39.7 kJ/m^2 · day of internal throughflow, achieving an aggradation/dissipation ratio of 3.97. This second system, by the accrual of internal linkages, increased its negentropic organization, and moved 61% further from thermodynamic equilibrium $[(39.7 - 24.7)/24.7 \times 100]$ with reference to the first system. The source of this network aggradation is nonzero-sumness, as shown further below [eqn (7c) and (7d)]. First, a concrete example:

Example 3 The earth is a photon multiplier. All systems that do work degrade energy in proportion to the work done. The useful energy in energy is process dependent, and accordingly is not conserved. This is *exergy*, or in chemical thermodynamics, *free energy.* The sun radiates high-energy photons at 6000 K temperature, and the earth at 300 K. The 20-fold differential means that processes on earth degrade solar to infrared photons in a ratio of 1 : 20. The production and dispersal of more particles in the universe represents entropy generation. Systems that degrade energy more fully radiate photons at lower temperatures. Therefore, internal organization is reflected in radiative surface temperatures.

Debeljak [12] showed this from infrared aerial photography of a sequence of vegetation types from a pasture to a mature forest, approximating a succession of seral stages. The pasture radiated at the highest temperature, and relative to it the other communities emitted photons at progressively lower temperatures. The seral sequence approximated the curve form of a hyperbola and, referring to the Jørgensen *et al.* [11] four-compartment hypothetical systems, one can infer network aggradation from the aerial photography results. A blacktop parking lot would have emitted the highest energy (hottest) photons. Such a system would have almost no internal organization and would be close to the ideal black body radiation. The pasture, with low organization, can be likened to the four-component chain in the Jørgensen *et al.* [11] example. Its internal energy use is low in relation to boundary inputs, reflecting a low aggradation/dissipation ratio. The mature and mixed forests at the other end of the sere can be likened to the more fully connected network of the other hypothetical system. In their successional development, they evolved a richly cross-connected set of internal transactions and relations; their organization is greater (further from equilibrium) than those of the earlier communities and the pasture. Their network aggradation/dissipation ratios are relatively high, and their radiative temperatures are relatively cool, reflecting energy-degrading work done in the ecosystems and manifested in more photons of lower energy being emitted than higher energy photons received – the condition of local entropy increase.

The following points can be made in conclusion:

1. By establishing unlimited transactions and relations within systems, fixed boundary inputs can support indefinite aggradational development under fixed boundary dissipation (the multiplier effect).
2. Therefore, the development of order (negentropy) can exceed the generation of disorder (entropy) per unit of the boundary energy received.
3. Since the exergy in energy is process dependent, less organized systems have less energy in their received energy than more aggraded ones receiving the same energy.
4. Transition from *H. sapiens* to *H. holisticus* is consistent with these observations. As the web of *holisticus* spreads over the globe, technology-assisted network aggradation will, by the AWFUL theorem, channel more and more of the available resources and energy of the ecosphere into anthropic development, to the detriment of other sectors. This will be true, i.e. if planetary organization is restricted to the zero-sum realm, but aggradation of all sectors can occur if nonzero-sumness can be accessed. Before this is possible, however, it is necessary to understand where in ecological networks it resides. Some mathematical analysis helps to uncover the hiding place.

3.3 Network indirectness – basis of nonzero-sumness

The general nature of a cause/effect or input/output relation is as follows:

$$\text{Effect, or output} = (\text{Transfer function}) \times \text{Cause, or input.} \tag{5a}$$

The transfer function represents how a system or process receiving a cause reacts to produce an effect. To do this accurately, the function must account for everything in the system's internal workings that links particular causes to particular effects. In other words, a transfer function must be holistic.

In various elaborations of input–output analysis, this is accomplished by employing matrices that incorporate the fullness of system interiors. For conservative systems consisting of n energy–matter storages (also called, in various applications, stocks, compartments, nodes, or vertices) interconnected by a network of flows, let $x_{n\times 1}$ be a vector of the storages, $z_{n\times 1}$ be a vector of the boundary inputs, and $T_{n\times 1}$ be a vector of the summed internal flows (throughflows) at each node. Implementing the above concept of a transfer function, boundary inputs $z_{n\times 1}$ (causes) are taken into throughflows $T_{n\times 1}$ and storages $x_{n\times 1}$ by two dimensionless mapping matrices:

$$T_{n\times 1} = N_{n\times n} \cdot z_{n\times 1}, \tag{5b}$$

$$x_{n\times 1} = Q_{n\times n} \cdot z\Delta t_{n\times 1}. \tag{5c}$$

In the second case, the input must be discretized ($z\Delta t$) to match the units of storage (kJ/m^2, kg/m^2, etc.) which differ from those of flows (kJ/m$^2 \cdot$ day, kg/m$^2 \cdot$ day, etc.). To obtain N and Q, the direct flows $F_{n\times n} = (f_{ij})$ comprising the throughflows (defined as $T_i = \Sigma_{j(\neq i)=0,n} f_{ij}$, 0 being the index for the system exterior) and contributing to the storages, respectively, are nondimensionalized to represent normalized direct links between each (i, j) pair of components:

$$G_{n\times n} = (g_{ij}) = (f_{ij}/T_j) \tag{6a}$$

$$P_{n\times n} = (p_{ij}) = I_{n\times n} + (f_{ij}/x_j)\Delta t, \tag{6b}$$

where T_j and x_j are the throughflows and storages, respectively, at compartments j, and I is the identity matrix. With these notations the transfer function matrices N and Q of eqn (5b) and (5c) have the following decompositions into infinite power series:

$$N = I + G + G^2 + G^3 + \cdots + G^m + \cdots, \tag{7a}$$

$$Q = I + P + P^2 + P^3 + \cdots + P^m + \cdots. \tag{7b}$$

The first-order terms G and P are nondimensional expressions of the direct internal energy or matter flows in the system. Since these are transactions, the terms are zero-sum. And since the values of g_{ij} and p_{ij} lie between 0 and 1 (having interpretations as fractional transfers or probabilities), when they are multiplied to form power series the series converge because eventually the powers go to zero. G^2 and P^2 represent the nondimensional flows associated with indirect paths of length 2 (such as $j \to k \to i$), G^3 and P^3 account for paths of length 3 (e.g. $j \to k \to l \to i$), and so on for all powers G^m and P^m needed to bring convergence.

With this, one can see that transfer functions of the form (7a) and (7b) capture the entire internal connectivity of the system, direct and indirect, and make possible a holistic mapping from boundary sources (z, $z\Delta t$) to internal effects (T, x):

$$T = (I + G + G^2 + \cdots + G^m + \cdots) \cdot z, \tag{7c}$$

$$x = (I + \underset{\substack{\uparrow \\ \text{zero-sum}}}{P} + \underbrace{P^2 + \cdots + P^m + \cdots}_{\text{nonzero-sum}}) \cdot z\Delta t. \tag{7d}$$

The first terms I bring the inputs into the system ($I \cdot z$, $I \cdot z\Delta t$). The second terms G and P effect the zero-sum direct transfers. The remaining terms of higher orders quantify indirect transfers, and these are always nonzero-sum. Therefore, one prescription for overcoming zero-sum awfulness is to develop interactive networks in which the higher-order terms are, in aggregate, dominant.

3.4 Network properties contributing to nonzero-sumness

The following network properties due to M. Higashi foster indirect (nonzero-sum)/direct (zero-sum) ratios > 1 ([13], pp. 302–305):

1. *Increased number of compartments:* This is a network-based technical reason for conserving biodiversity in ecosystems.
2. *Increased connectivity:* Generalists, which tend to have broader interactions than specialists, contribute more to nonzero-sumness than the latter.
3. *Increased storage:* Conservation of resources and reduction of flow/storage ratios (turnover rates) enhance storage, and to that extent are sources of nonzero-sumness.

4. *Increased cycling:* Transactive closure of interactive webs is significant. Considering arbitrary (source, terminal) node pairs in networks, this property refers to cycling at original, terminal, or medial nodes. A medial node is one along a path between an originating and terminating pair such that cycles through it do not pass through either of the latter. Agents of cycling in ecosystems, such as saprovores and microbes, are important contributors to nonzero-sumness.
5. *Increased feedback:* This is cycling which includes both source and terminal nodes of a defined pair. Spanning cycles in ecosystems such as producers → consumers → decomposers → producers → …constitute a potentially important source of nonzero-sum dominance.
6. *Increased transaction strength:* It would appear that increase in the intensity of zero-sum transactions would tend to elevate direct interactions to dominance over higher-order (nonzero-sum) terms. However, due to the algebra involved in generating the power series of eqn (7), strong links tend to contribute more to nonzero-sumness than corresponding weaker links. This does not mean the latter (e.g. those contributed by the rarer species in a biodiverse set) can be ignored because the patterns of interconnection, as well as diversity or strength per se, are also important.

To summarize Section 3 to this point, indirect relationships in transactive networks are the source of nonzero-sumness. In network aggradation, mediated by eqns (5) and (7), direct transactions account for zero-sum and indirect ones for nonzero-sum causality. The source of nonzero-sum aggradation is therefore the higher order, indirect relations that come about by virtue of the first-order, direct transactions, which are primary. Systems aggrade thermodynamically, and also organizationally (it is all the same), when and to the extent that nonzero-sumness exceeds zero-sumness in their internal organization. Practical limits in the form of diminishing returns are encountered in any aggrading process, however, as next shown.

3.5 Network synergism – limits of network aggradation

Organisms have requirements for life, and transactive interchanges with their surroundings involve for them certain benefits (increased aggradation) and costs (decreased). Energy and matter are conserved in interchanges, but the values associated with these are not. Different *utilities* may be involved.

Consider, for example, a worker who earns a wage of w units of currency for a day's work in a week when $5w$ units will be earned versus in a week when $10w$ units are earned. The one-day wage of w units has greater value in the week when less money is earned ($5w$) than when more is earned ($10w$). This motivates the following utility measures.

For an arbitrary (source, terminal) node pair (j, i) in a network, g_{ij} and p_{ij} [eqn (6)] represent the source-referenced flows (f_{ij}/T_j and f_{ij}/x_j) directed from j to i. Reciprocally, g_{ji} and p_{ji}(f_{ji}/T_i and f_{ji}/x_i) denote terminal-referenced flows to j from i. For node i, the outflows to j are $g_{ji} = g^{\mathrm{T}}_{ij}$ (transpose) and $f_{ji}\Delta t/x_i = p_{ji} = p^{\mathrm{T}}_{ij}$, and the inflows from j with reference to i are $f_{ij}/T_i = g_{ij}$ and $f_{ij}\Delta t/x_i = p'_{ij}$. Therefore, the net interchange between i and j, with i taken as the focal node, is input minus output:

$$\begin{aligned} d_{ij}(T) &= (f_{ij} - f_{ji})T_i \\ &= g_{ij} - g^{\mathrm{T}}_{ij}, \ \ (-1 \le d_{ij}(T) \le 1), \end{aligned} \tag{8a}$$

$$\begin{aligned} d_{ij}(x) &= (f_{ij}\Delta t - f_{ji}\Delta t)/x_i \\ &= p_{ij} - p^{\mathrm{T}}_{ij}, \ \ (-1 \le d_{ij}(x) \le 1). \end{aligned} \tag{8b}$$

These are direct (zero-sum) utilities because net quantities gained or lost in an interval of time ($f_{ij} - f_{ji}$, $f_{ij}\Delta t - f_{ji}\Delta t$) are referenced to denominator terms (T_i, x_i) against which the numerators are fractions. Equation (8a) is throughflow (T) referenced and eqn (8b) is with respect to storage (x).

For all i, j components in a system, zero-sum direct utility matrices can be constructed:

$$D_T = (d_{ij}(T)), \ \ (-1 \leq d_{ij}(T) \leq 1), \tag{8c}$$

$$D_x = (d_{ij}(x)), \ \ (-1 \leq d_{ij}(x) \leq 1). \tag{8d}$$

The power series of these matrices generate integral (direct plus indirect) utilities:

$$U_T = (I - D_T)^{-1}, \ \ (-\infty < u_{ij}(T) < \infty), \tag{9a}$$

$$U_x = (I - D_x)^{-1}, \ \ (-\infty < u_{ij}(x) < \infty). \tag{9b}$$

Used as transfer functions against diagonlized matrices of throughflows (T) and storages (x) in eqns (5) and (7),

$$\Upsilon_T = (I - D_T)^{-1} \cdot \text{diag}\, T, \ \ (-\infty < \Upsilon_T < \infty), \tag{9c}$$

$$\Upsilon_x = (I - D_x)^{-1} \cdot \text{diag}\, x, \ \ (-\infty < \Upsilon_x < \infty), \tag{9d}$$

dimensional integral utilities are obtained. Due to the nonzero-sumness of the higher-order interactions contributing to the mapping matrix inverses in eqns (9a)–(9d), the integral utilities shift toward a dominance of positive values over negative values. This is network synergism. Ecological networks – all transactive networks – convey positive utilities to their constituents [13]. This is the meaning of the property 'network synergism', and since it is based in nonzero-sumness, one expects it, a priori, to increase without bound together with network aggradation. There is, however, an important caveat.

This paper was begun just before, and is being concluded in the aftermath of, the horrific events of September 11, 2001, where innocents and heroes, and innocents become heroes, perished at the World Trade Center in New York, the Pentagon in Washington, and an agricultural field in rural Pennsylvania. These happenings presage the hazardous future opening up as *H. sapiens* takes its first faltering steps toward becoming *holisticus*. The new century opening out is already besmirched by barbarism from an ignorant past, and will likely see in its coming decades even more social dysfunction and disruption of harmonious life in the wake of early explorations with global connectivity. Terrorism on a scale heretofore unimaginable is just one manifestation of zero-sum awfulness taken to new levels. The global complexification that will occur as a consequence of interconnecting technology may prove intolerable. However, network synergism suggests a path toward relief that may have been followed many times before in the history of the world. It concerns limitation of the operable size of systems.

Fath [14], employed Monte Carlo simulation trials to explore the contributions of different network properties to the integral utility benefit/cost ratios measuring network synergism. Benefits are measured as sums of nonnegative utilities [$u_{ij} \geq 0$ in eqn (9)], and costs as sums of negative ones ($u_{ij} < 0$). The study showed that benefit/cost ratios increase with network properties such as cycling, and the effect was greatest in systems of smaller size. That is, as the number n of components varied between $20 \leq n \leq 600$, network synergism always remained positive but decreased asymptotically toward a lower bound as system size (n) increased. Network synergism decreases as the number of interconnected components decreases.

4 PRESCRIPTION FOR ADAPTIVE EVOLUTION – THE EFFICACY OF LOCALITY

This limitation on network aggradation by network synergism has probably been manifested before in the evolution of biological material. Across the scales of organization, from cells to demes to cities and, in both directions, beyond, a pattern of self-organization is expressed that produces units more intraconnected than interconnected. These are the 'near-decomposable systems' of Simon [15] in hierarchy theory. Many explanations have been offered to explain the inherent modularity, as opposed to a syncytia-like global continuum, of biological organization. To these we may now add the property of network synergism.

Although unlimited network aggradation (negentropic growth) is possible with increasing interconnection, diminishing utility returns restrict optimal system size to relatively small numbers of interacting components. Not enough is known yet about the interplay of size with extent, pattern, or strength of interconnecting links. Based on the implications of the network properties discussed above – zero-sum awfulness, network indirectness conferring nonzero-sum aggradation, and the utility relations in network synergism – humanity should self-organize to form discrete population aggregations. These should be strongly intraconnected but weakly cross-connected within the forms of global nonlocality that emerging *H. holisticus* will impose. Sectional locality, discreteness, and relative autonomy must be maintained. Otherwise, the global reach may contraindicate sustainable entrainment of human change to global change by reducing network synergism even though network aggradation may marginally rise. The consequence – *H. holisticus* and perhaps also its ancestor *sapiens* (ourselves) might become just another record in the rocks, marking the end of an unusual evolutionary experiment.

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