Measuring Regenerative Vitality: 10 principles and measures undergirding systemic economic health

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Abstract
Applying thermodynamic concepts and methods to economic systems is not a new idea. In the last few decades, however, advances in nonequilibrium thermodynamics (i.e., self-organizing, open, dissipative, far-from-equilibrium systems), and nonlinear dynamics, information theory and other mathematical approaches to the recurrent geometries found throughout the cosmos have produced a new set of concepts and methods, which are vastly more appropriate for socioeconomic systems than the traditional equilibrium ones. In several previous papers, for example, we used research from these new Energy Network Sciences (ENS) to show how and why systemic health requires a balance of efficiency and resilience be maintained within a particular a "window of vitality" (Ulanowicz et al. 2009; Lietaer et al. 2009; Goerner et al., 2009). The current paper outlines the logic behind 10 additional principles of systemic, socioeconomic health and the quantitative measures that go with them. Our particular focus is on "regenerative learning", i.e., the self-feeding, self-renewal, and adaptive learning processes that natural systems use to nourish their capacity to thrive for long periods of time. In human systems, for example, regenerative vitality requires regular investment in human, social, natural, and physical capital. Long-term vitality, however, also requires effective collective learning.

Note: A wide range of related work involving energy and flow-network concepts and methods is emerging under a host of diverse disciplinary titles such as resilience theory, complexity theory, self-organization theory, nonequilibrium thermodynamics, ecological network analysis, and Panarchy. We use the umbrella term Energy Network Science (ENS) to refer to this related array.

1.0 Introduction: Energy and the Transdisciplinary Science of Systems

Researchers in ecology and its allied field, ecological economics, have produced many of the key advances in the study of energy flow networks. Yet, even though ecological economists apply flow-network thinking to economics, they often see these economic applications as metaphoric extrapolations from biology and ecology. So, while network methods are well known in ecological economics, their use in understanding systemic health in economic networks themselves requires some justification for why this approach is something more than mere biological analogy. Explaining why flow-networks can provide a rigorous, transdisciplinary science requires some historical background.

Note: The transdisciplinary nature of this science also requires some adjustments to terminology. For example, where ecologists call their flow-network methods Ecological Network Analysis, to emphasize this work's broader applicability, we will replace the discipline-specific word "ecological" with the transdisciplinary term, Energy Network Analysis.

From resilience and complexity theory to self-organization and ecological network analysis, the disciplines we group under the umbrella term Energy Network Science (ENS) are all offshoots of the original General Systems Science (GSS) impetus. GSS is a transdisciplinary study built around two core pillars: 1) the existence of *universal patterns;* and 2) *energy's role in organizational emergence, growth and development.*

The history of this transdisciplinary empirical science starts with the ancient Greek and Egyptian observation of mathematically precise, recurring patterns and principles of growth and development occurring in vastly different types of systems (Figure 1). The ubiquity of Fibonacci growth patterns and Golden spiral organizations are examples of this observation. The study of fractal patterns and nonlinear dynamics is a modern-day expansion of what is now called morphodynamics or the "geometry of behavior" (Abraham, 1985; Abraham & Shaw, 1982). Scientists across the millennia have used these universal patterns and principles to understand biological growth patterns, predict patterns of behavior in extremely complex systems, and build striking structures such as the Parthenon. (Schroeder, 1991)

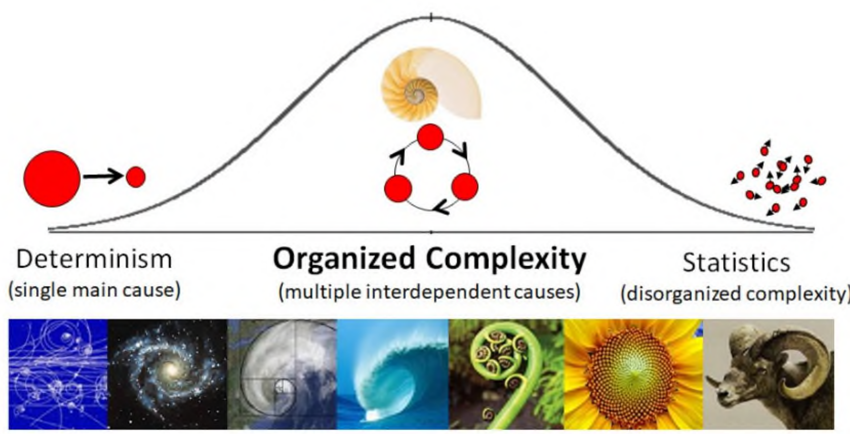


Figure 1. *Some universal geometries as examples of "organized complexity"* (Weaver, 1946).

Thermodynamics – i.e. the study of energy dynamics in all its forms – provides a logical basis for a transdisciplinary "systems" science because energy processes are both universal and amenable to scientific inquiry and measurement. This idea too has ancient roots. In his theory of "flux and fire", for example, pre-Socratic, Greek philosopher Heraclitus argued that all things were caught up in endless cycles of change, transformation, and rebirth in which "all things were flowing" and the world was "an ever-living fire." By the 16th century, European scientists such as Robert Flood and Galileo Galilee began measuring heat energy using an early thermometer.

Work growing around the pillars of energy and universal patterns, especially of growth and development, began to come together in the early 1900s. In his 1917 book *On Growth and Form,* Scottish mathematical-biologist, D'Arcy Thompson outlined the mathematical and scientific basis for morphogenesis, the universal processes of growth and development that give rise to the recurring shapes, patterns and forms found in plants and animals. In 1922, mathematical-biologist Alfred Lotka expanded the study of energetics from biology to ecology and evolution, arguing that the selective principal operating in evolution was a physical law favoring "maximum useful energy flow transformation." Lotka's 1925 book, *Elements of Physical Biology*, even extended the energetics of evolution to suggest the physical (i.e., energy) nature of consciousness. General Systems ecologist, Howard Odum (2007) used Lotka's research as the centerpiece of his work in Systems Ecology, and redefined Lotka's energy law of evolution into a Maximum Power Principle.

Writing in the 1940s through 60s, American scientist and mathematician Warren Weaver (1948) then gave a proper name to the complexly organized systems that emerged from morphodynamic processes. In contrast to the simple, unidirectional causality that defined classical physics and the highly disconnected interactions that are the basis of statistics, Weaver explained that the "*organized complexity*" that fills our world is a natural product of the subtle relationships that connect diverse elements into profoundly organized, interdependent wholes (Figure 1). This mathematically-precise "organization" allows us to do empirical science on the extremely complex systems we care about most: living systems, human systems and ecosystems. Consequently, in 1961 urban anthropologist Jane Jacobs used Weaver's work to define "the kind of problem a city is."

In the 1950s, and 60s, biologist Ludwig von Bertalanffy (1968) sought to connect energy dynamics and pattern formation as the basis of a unified scientific research program studying the behavior of complex systems *in general*, including the dynamics governing their formation, self-maintenance, and increasing complexity. A "system" was initially defined as 'any assembly of parts whose relationships make them *interdependent.*' The goal of this General Systems Science was a coherent, transdisciplinary, empirical science of "systems," including living, non-living and supra-living organizations such as ecosystems and economies.

The probing, seeping, circulatory nature of energy dynamics even explains the subtly interconnected nature of all organization and flow. Hence, as Heraclitus put it, "listening not to me but to Logos, it is wise to agree that all things are One" (Bryan, 2014).

In the 1970s, Belgian chemist Illya Prigogine unified this work (and won a Nobel Prize) by explaining how an energy-flow process called *self-organization* drives the emergence of new configurations, and creates pressures which drive the ongoing cyclical development of existing ones (Prigogine, 1972; Jantsch, 1980). Apropos of an energy-flow process, every round of emergence and development follows a similar process, which is found in a vast array of different systems. Energy buildups create pressures that drive change. Naturally-occurring diversity (inhomogeneity) provides the seed crystals that open new paths and catalyze new forms of organization. Meanwhile, the matrix of internal and external constraints determines the degree of flexibility or rigidity, which in turn shapes the outcome and whether flow moves toward constructive or destructive ends. For example, a tornado's funnel and a hurricane's Golden spiral (organization) both emerge from the confluence of: 1) heat, i.e. a temperature gradient that creates pressure; 2) naturally occurring variations, i.e. small gusts, twists of geography, etc.; and 3) pressure or geographical constraints that block more gradual dissipative flow.

Prigogine's work, however, produced a distinct disjuncture from classical thermodynamics. Where classical Thermo is built around the study of systems which are at or near equilibrium, the complexly organized systems that emerge from self-organizing processes are specifically designed to maintain their organization *far-from-equilibrium*. They do this by *autocatalytic* or autopoietic arrangements (i.e. self-feeding, self-renewing, "regenerative" ones), meaning they are designed to channel critical flows back into maintaining their organization on an ongoing basis.

The energy network research we do today is a natural continuation of this far-from-equilibrium work. Here, self-organizing processes naturally give rise to what researchers call *flow systems* or *flow networks*. A flow network is any system whose existence arises from and depends on circulating energy, resources, or information throughout the entirety of their being. Your body, for example, is an integrated network of cells kept healthy by the circulation of energy, water, nutrients, and internal products. Ecosystems are interconnected webs of plants and animals that add to and draw from flows of oxygen, carbon, nitrogen, etc. Economies are interlinked networks of people, communities, and businesses, which depend on the circulation of information, resources, money, goods, and services (Figure 2).

Flow networks are also called "open systems" because, in contrast to the closed "conservative systems," which are the main focus of classical thermodynamics, open systems are characterized by ongoing transfers of matter, energy and/or information into and out of the system's boundary.

The central role circulation plays in the existence and functioning of all flow networks brings us to our first terminological adjustment. While most people associate the term "energy" with various forms of fuel (oil, gas, solar, etc.), in ENS, it refers to *any kind of flow* that is critical to the system under study. Ecologists, for example, study the flow of carbon and oxygen in the biosphere; food-security researchers study the flow of produce and commodities; and Industrial economists study the flow of industrial products. The circulation of *money* and *information* is particularly critical in socioeconomic networks.

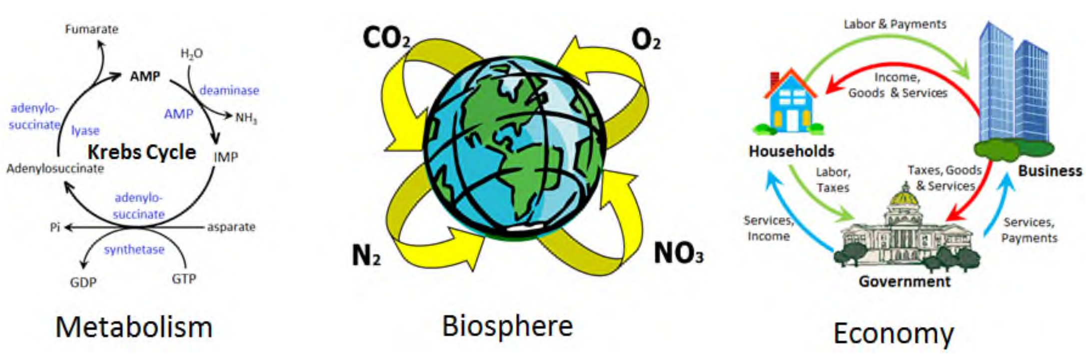


Figure 2. *Some common flow-networks.*

Yet despite this broad applicability, energy's ability to support rigorous scientific study across vastly different systems is also borne out by some well-established empirical findings, particularly in regards to growth and development. Ecologists, for example, have long known that ecological succession, the progression from grasslands to pine forests to oak forests, is accompanied by a parallel progression of Flux Density (F), a measure of internal circulation speed of energy/resources per unit time per, unit density (Odum, 1991). Chaisson (2002) has shown that this same matched progression of Flux Density and organizational complexity is also found across the evolution of complexity in the universe as a whole, including in the progression of human organizations (Table 1).

The energy explanation for this matched progression of circulation and organizational complexity is straightforward. Robust, timely circulation of critical resources is essential to support a system's internal organization and processes – and, the more organization there is to support, the more nourishing circulation is needed to support it. This thought applies as much to human organizations as to ecosystems.

Structure	**Flux Density** (F units)
Modern civilization	300,000
Agriculturalist (5000 BC)	10,000
Hunter gatherers	1,000 (per person)
Human brain	150,000
Human body	17,000
Earth's biosphere	500
Sun	2
Milky Way	1

F = Flux Density = energy cycling per unit time/density = ergs per sec^{-1} gm^{-1}

Table 1. Flux Density and Organizational Complexity from nonliving systems to social organizations.

Circulation also ties directly to systemic health and development because, if critical resources do not adequately nourish all sectors or levels, then we can expect the undernourished segments of the economy to become necrotic. Like necrosis in living organisms, poor cross-scale circulation erodes the health of large swaths of economic tissue, which in turn undermines the health of the whole.

Circulation's direct links to causal factors that impact systemic functioning and health also helps explain the existence of recurring patterns and structures. In this view, universal structures represent optimal arrangements for circulation and flow selected by nature over long periods of time. Fractal branching patterns found throughout the living and nonliving world provide a clear example.

A wide variety of systems – from leaves and river deltas to circulatory systems and ecosystems – exhibit a hierarchical branching pattern connecting a power-law ratio of small, medium, and large elements across scales. Your circulatory system, for example, has a few large, highly efficient conduits branching into successively smaller, more numerous, less efficient conduits below. The same arrangement is also seen in leaves, lungs, erosion patterns, lightning bolts, and predator-prey relationships in an ecosystem. Nowadays, we use fractal mathematics to measure this structural pattern (Figure 3).

This structure is ubiquitous because a power-law balance of small, medium, and large elements helps optimize circulation and diffusion across scales. Big, efficient elements (arteries or multinationals) provide the speed and volume needed for rapid cross-level circulation, while the many small elements (capillaries or local contractors) reach every nook and cranny. Presumably, this structure is common because nature has selected it over of time. Conversely, as an imbalance of predator and prey show, failure to maintain a proper balance of small, medium, and large can lead to system collapse.

A number of researchers are already using fractal/power law patterns as targets for healthy arrangements in human systems. Salingaros (2003), for example, shows how a fractal layout of roads/pathways helps catalyze a broad spectrum of city processes, thereby increasing conversation, innovation, and community cohesion. Ulanowicz et al. (2009) and Lietaer et al. (2009) use the balance of sizes found in healthy natural systems to explain the balance of resilience and efficiency needed to support optimal systemic health in economic and financial networks. And, Goerner et al. (2015) uses fractal designs to explain the Goldilocks Rule of Banking – why each scale needs banks that are "just right" to meet the commercial needs of that scale.

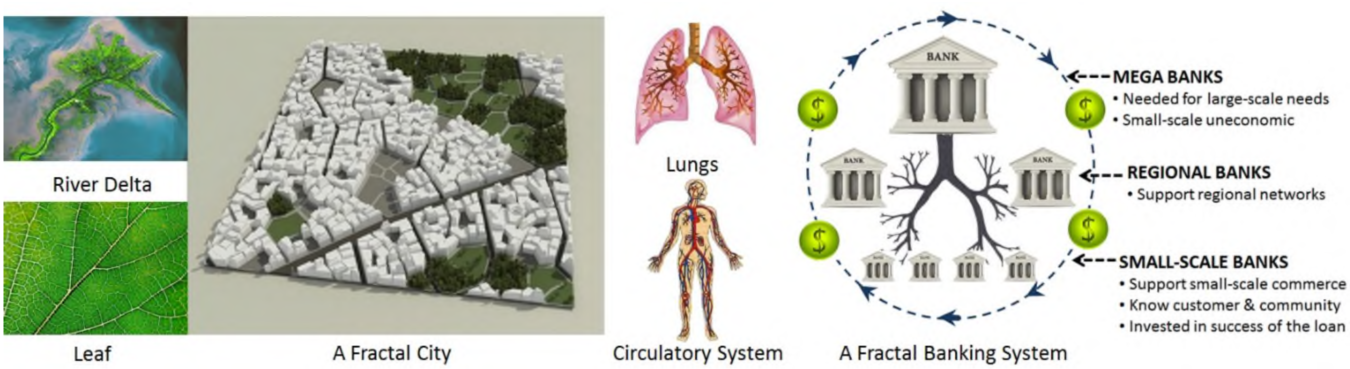


Figure 3. *Fractal structures maintain a power-law (x^n) balance of small, medium and large elements*

This well-documented line of research, however, holds a shocking possibility: *rigorous, quantitative measures* for the social sciences, including the potential for certain types of prediction. The social sciences, including economics, have long been viewed as "soft sciences" because their methods do not produce the kind of predictive precision found in the "determinism" of classical physics. In retrospect, this apparent lack of rigor was due to the fact that neither the single dominant causality that worked in classical physics, nor the statistical approaches appropriate for disordered complex systems are appropriate for organized complexity, i.e., the intricately organized, highly dynamic systems which are the focus of the social sciences. ENS' discovery of methods appropriate to organized complexity helps correct this misimpression of softness by adding rigor, albeit of a geometric form which differs from classical determinism. Thus, while energy methods cannot predict every specific behavior, they can predict geometric and organizational phenomena such as breakpoints (bifurcation points), pressure, phase transitions, structural instability and optimal patterns of behavior.

Combining the fact that energy processes (such as circulation) are behind causal factors (such as nourishment and necrosis) which directly impact system functioning, and the fact that optimal patterns appear to obey mathematical laws, means we can use universal patterns as *quantitative measures* and *targets* for systemic health. Such measures are vastly more effective than traditional outcome metrics or statistical correlations because they assess *root causes*, i.e. ones that directly impact systemic health. Instead of metaphor, here Flux Density, for example, can be used as a *quantitative measure* of organizational complexity/development, and power-law arrangements can be used as targets for the optimal balance of small, medium, and large banks. We call these "intrinsic" measures because, where most traditional social, economic and environmental metrics assess *symptoms* of socioeconomic health or dysfunction, they assess underlying causal dynamics. (Dehydration, for example, is an intrinsic/causal measure of health and a leading indicator of whether one is at risk of death.)

In sum then, the fact that energy dynamics are logical, universal, and open to empirical study explains why rigorous findings apply as much to economic networks as to ecosystems. So, while ecologists are famous for using flow-network concepts and methods to understand the behavior of ecosystems (e.g., Hannon, 1973; Patten, 1978; Odum, 1983; Ulanowicz, 1986), economists have been using them to understand economies for decades as well (e.g., Leontief, 1951; Georgescu-Roegen, 1971; Daly, 1997).

2.0 The Regenerative Learning Story of What Makes an Economy Healthy

Energy ideas and concepts have been developing inside and outside of economics for decades, even millennia. The aforementioned vision of circulation, for example, is basically a recapitulation of Keynesian economic theory. Indeed, according to economist Kenneth Boulding (1981), "Many early economists held energy views, until those who favored Newtonian mechanics channeled economics towards today's familiar mechanics of rational actors and the reliable self-restraint of General Equilibrium Theory."

What today's Energy Network Sciences (ENS) can offer is a more unified vision backed by a solid empirical framework and surprisingly precise quantitative measures that confirm, clarify, and add rigor to ideas that have been developing in economics and a variety of social sciences for long periods of time. We believe this more rigorous and complete framework can help restore and expand the use of energy concepts and methods in the study of socioeconomic vitality.

Restoring energy dynamics to economics, however, requires a coherent story of economic health. This, in turn, requires a unifying metaphor. We believe the main metaphor behind the energy story socioeconomic vitality is of a *metabolic system*, particularly one that is designed to be naturally self-renewing (i.e., regenerative). Self-organization, however, also adds a more novel element: the idea that collective (collaborative) learning is central to societal health and prosperity. This addition means our regenerative metabolism must specifically support an integrated, mind-body societal system whose central survival strategy is *collaborative learning*. The principles and measures of systemic health emerging from ENS can help illuminate a solid path to a *regenerative learning* society.

The metabolic side of this story is already well-documented. In this view, economic flow-networks serve much the same purpose in a society as metabolism does in a living organism: they turn energy, information, and resources into all the energy, products, and processes a society needs to thrive (Fischer-Kowalski & Huttler, 1998). Like organs in the body, all social, economic, political and environmental systems are interconnected and interdependent, with each playing a critical role in systemic health. Money is like blood: it is a vehicle for circulating resources, catalyzing processes, and nourishing socioeconomic muscle and brain. Here, robust circulation of accurate information is also critical because our societal brain is just as important as our economic muscle. Herman Daly pointed out that economics classes typically identify the circular flow diagram of households and businesses (i.e., basic circulation), but omit the metabolic processing and energy and material throughflow central to economic functioning. In contrast, most biology textbooks explore digestion and metabolism *before* circulation because of their earlier evolutionary appearance (1996).

In this metabolic view, economic vitality rests first and foremost on the health of the underlying human networks that do all the work. In other words, systemic health depends largely on the care and feeding of the entire network of interconnected socioeconomic systems, including: individuals, businesses, communities, cities, value-chains, societies, governments, and even the biosphere, all of which play critical roles in production, distribution, and learning. A healthy economic metabolism must also specifically be "regenerative," meaning it must continuously channel resources into self-feeding, self-renewing internal processes. In human systems, this means funding things like education, infrastructure, innovation, and entrepreneurship.

Here, the *web of human relationships and values* is also more important than GDP growth per se because a society's vitality – i.e., its ability to produce, innovate, adapt, and learn – depends almost entirely on these relationships and values. Cultural beliefs are important because they determine the obstacles and opportunities, incentives and impediments extant in the society. Man-made incentives, for example, affect whether an organization works primarily to serve its customers and civilization, or to maximize its owners' profits regardless the harm done to people and planet. Irrational impediments are seen in racism, sexism, and the obstacles to clean, green, renewables despite the economic opportunities they represent.

While unifying values such as justice and fairness are critical, Nobel Laureate Elinor Ostrom's work (1990) suggests that effectively managing Commons requires a value system that combines elements of both right and left – e.g., individual contribution and responsibility (no freeloaders); anchored in inclusive, democratic say in governance, rules, oversight, and punishment. Liberty, competition, and self-interest play a role but common-cause values, collaborative synergy, and various forms of organizational balance and integration, including a balance of liberty and laws (i.e., flexibility and constraint), are even more important.

Still, while economic metabolism is critical, at this moment in history our long-term survival hangs most precariously on our ability to *learn collectively*. Researchers from fields ranging from sociology and education to economics have long-ago provided concrete accounts of collective (i.e., collaborative) learning's incredible benefits. In *Creating a Learning Society*, for example, economists Joseph Stiglitz and Bruce Greenwald (2014) show how standards of living have skyrocketed as a result of global civilization "*learning how to learn*" more effectively as a result of societal changes emerging from the Scientific Revolution and the Enlightenment. They even outline some of the economic policies that would help improve today's collective learning process.

Yet, while collective learning's central role in socioeconomic vitality should be obvious, decades of training in the Darwinian idea that human behavior is largely fixed in our genes requires some additional explanation for its importance. Self-organization provides an empirical foundation for this importance by explaining why humanity's collaborative learning nature is a logical outcome of self-organizing processes that fuse energy, information, and organization into unified perceiving-acting systems (Gibson, 1986; Kugler, et al., 1992).

Prigogine's work shows how cycles of self-organizing development, repeating over and over, are behind the succession of increasingly complex forms from the origins of atoms and galaxies to the latest incarnations of life and civilization (Figure 4). The same process repeats in every round: energy fuels, pressure drives, diversity catalyzes, and constraints shape the emergence of new organizations. The first atoms were forged in the intense pressure of the Big Bang, and life emerged from the fiery furnace of early Earth's chemical soup. The first hierarchical civilizations emerged in constrained areas of fertile land, such as the Tigris and Indus river-valleys, where population pressures created intense conflicts over land, giving rise to territorial wars and eventually a warrior administrative-class.

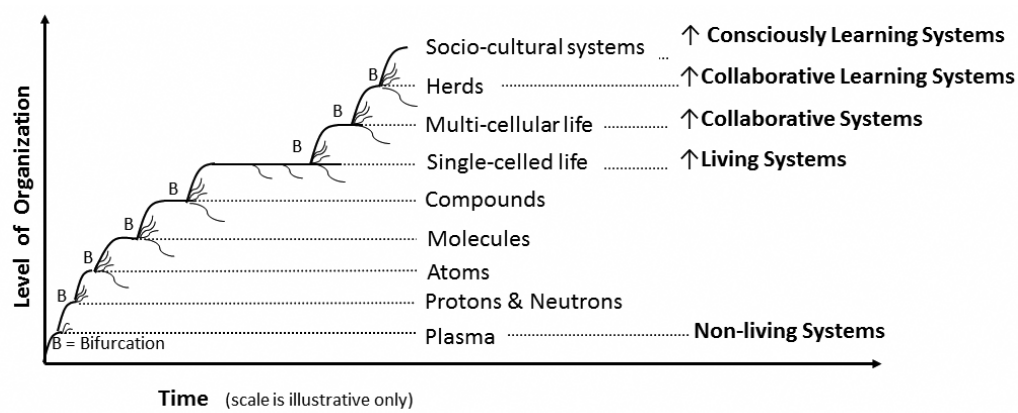


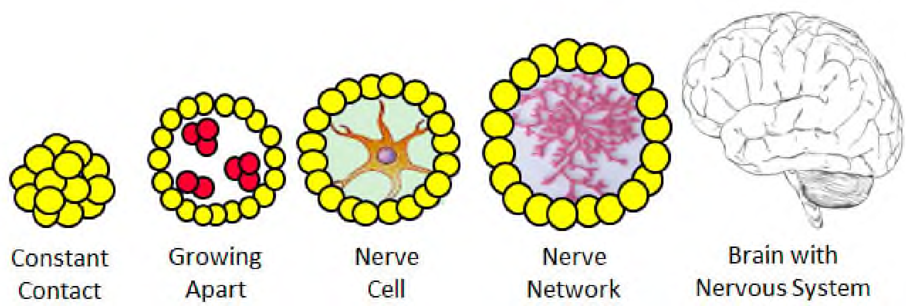
Figure 4. *Self-organization drives increasing complexity from molecules to mankind, periodically building new levels of organization out of old.*

Energy pressures periodically forge new levels of organization out of smaller existing bits. Atoms, molecules, living cells, multicellular animals, herds, cities, and civilizations all consist of smaller pieces coming together in new patterns of organization. Biologist Lynn Margulis (1998), for example, shows that biological organisms become more complex by linking previously independent lifeforms into new unified organisms linked by synergy and mutual benefit: land plants are in an immortal marriage between photosynthetic algae and rugged, non-photosynthetic lichens; while the mitochondria, flagella, and nucleus of eukaryotic cells are built of previously independent prokaryotic cells.

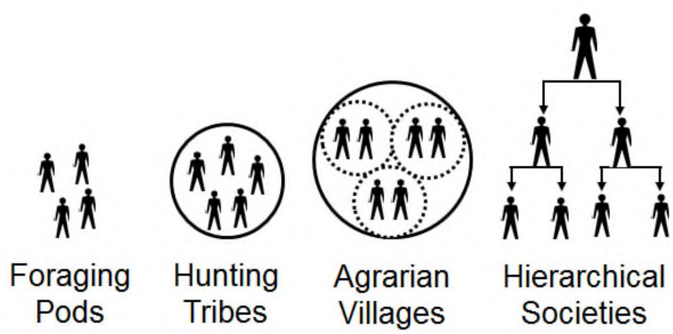
Though such self-organizing processes strive toward optimal outcomes, they never fully succeed. As a result, evolutionary development appears as a recursive process of trial-and-error learning following a cyclical, punctuated, stair-step pattern of increasing complexity (Figure 4).

Here, what we call "information" began as tiny energy nudges – a few photons of light or the chemical trail we call smell – that physically interacted with the system. "Intelligence" began when some energy nudge accidentally propelled the system toward a beneficial outcome, such as food to fuel continued activity. Information processing evolved rapidly after that because organisms that reacted fruitfully to informative nudges survived longer than ones that did not.

From the first living organisms to consciously-learning systems such as societies, information, organization, intelligence, and communication became ever more profoundly entwined and central to survival. As single-celled organisms blossomed into multi-cellular organisms and eventually into herds of multicellular organisms, communication, i.e., circulating information among members, became essential to coordination and coherence in these increasingly vast wholes. Intelligence and communication eventually evolved into culture, language, and science because processing information and preserving lessons *collectively* vastly increases a group's chances of survival as well (Maturana and Varela,1987; Figure 5).



a. *Growth in size and complexity drives multicellular organisms to develop nerves, nervous systems and brains.*



b. *Growth in size and complexity drives human groups to develop new forms of cultural mores and organizational structure.*

Figure 5. *As living and supra-living organizations grow bigger they develop new forms of connective tissue (organizational infrastructure), information flow, communication and intelligence, which maintain their coherence and coordination.*

Humanity is the cutting-edge of this evolutionary learning process on earth. We are a collaborative-learning species that thrives by pooling information, collectively forging new understandings, and changing our pattern of life by changing our best hypothesis about "how the world works" (Pepper, 1946). This ability has allowed us to adapt more rapidly and innovate more powerfully than any other earthly species. It is directly responsible for all the marvels we live with today. Yet, human learning too is never done. Despite humanity's adaptive talents, every pattern of civilization eventually reaches limits that force a choice: cling to old ways and decline, or innovate and transform. Today's most crucial innovation may well involve learning to live and flourish within the limits (Jørgensen et al. 2015).

All of this work suggests that nourishing a society's political-economic mind with accurate information is just as, if not *more* critical to long-term vitality than building economic muscle. Conversely, to stymie societal learning is to stymie our ability to evolve in a timely and effective manner.

3.0 Four Key Categories of Socioeconomic Vitality

Putting all these elements together suggests that the elements of regenerative vitality fall into four main categories: 1) circulation; 2) organizational structure; 3) relationships and values; and, 4) collective learning. While we present them separately for clarity, all of these categories are in fact inseparably intertwined and mutually-affecting.

3.1 Circulation

Circulation affects economies in much the same way it affects living organisms. Robust cross-scale circulation nourishes, energizes, and connects all the complex collaborative functions a socioeconomic system needs to thrive.

Circulation's impact on socioeconomic vitality is easy to see. Major influxes of money, novel ideas, information, resources, and fuel sources (e.g. coal, oil, wood) have spurred major economic development throughout history. In the 13th century, for example, the revival of long-distance trade (circulation), perhaps facilitated by the Medieval Warm Period, stimulated the emergence of cities, guilds, and new universities to spread new ideas. In the 15th century, trade and Gutenberg's press produced the Renaissance (supported by wealthy traders and bankers such as the Medici), and a new fascination with scientific inquiry that eventually spawned the Scientific Revolution. In the 19th century, new sources of coal and natural gas, and innovations such as the steam engine emerging from enlightened minds generated the Industrial Revolution and the free-enterprise democracies we live in today.

Circulation also teaches us that *where* money, information, and resources go is just as important as how much of it there is. In Keynesian terms, poor economic circulation to the working public – including lost jobs, low wages, closed factories, and crumbling infrastructure – reduces aggregate demand, which undermines economic vitality regardless of the size of GDP. Using our economic metabolism model, we say poor economic circulation causes *economic necrosis*, the dying-off of large swaths of economic tissue with ensuing damage to the health of the whole.

3.2 Organizational Structure

Organizational structure is inseparably entwined with circulation, stability, relationships and collective learning. A system's structure can either enhance systemic health by channeling flow to critical processes or undermine it by blocking flow from where it really needs to go.

As we've seen, the universal patterns produced by self-organizing processes are particularly helpful in understanding organizational structures because they represent relatively optimal structures selected over time.

The role fractal (power law) structures play in optimal cross-scale circulation and functioning provide some important revisions to classical thinking about size. In particular, where some economists see large size and efficiency as the primary source of vitality and others emphasize the small and local, fractals teach us that vitality requires *balance* and *integration* of sizes that combine the best of both worlds, i.e., large and small, resilient and efficient, diverse and focused.

This need for balance is easy to see. Big firms with economies of scale are generally more productive and offer higher wages, but towns dominated by a few large companies are brittle – if a mainstay company leaves, they have no other industries to fall back on. The 2008 crisis of too-big-to-fail banks shows the problem. A bevy of small businesses offers more choice and more redundancy, but economies dominated by small firms tend to be sluggish because economic surplus is hard to maintain. This leaves overstretched staffs with little money for specialization, expansion, or quality improvements.

Reformers seeking to revitalize local economies often argue that small is both beautiful and all we need. But, smallness alone can never work forever because, in order to develop and handle volume, small businesses and individual farmers need economies of scale for buying, distributing, lobbying, and learning from each other.

Economic domination by a few, extremely large, highly efficient organizations is particularly dangerous, however, because they generate positive feedback loops, i.e., powerful extractive pulls that siphon wealth from lower levels and channel it to distant headquarters. Excessive extraction hollows out local economies, eroding local diversity, reducing local circulation, and leaving the local economy fragile and prone to collapse. If the process continues too long, then it causes economic necrosis, the dying-off of large swaths of economic tissue that erodes the health of the entire economy including large and small organizations.

The fact that economies dominated by excessively large organizations become unstable due to excessive extraction and concentration helps eliminate much current confusion. Neoliberal economists, for example, applaud massive mergers/buyouts and condone profit-maximizing practices that leave whole industries dominated by a small number of extremely powerful players – food, finance, pharmaceuticals, and media now fall into this category. Yet these same economists are bewildered by the problem of "too big to fail" organizations. The law of fractal balance, however, makes the observed instability and erosion completely predictable.

Today's challenge, therefore, is to build integrated, enterprise networks that connect small, medium, and large elements in common-cause and in service to the health of the whole. This challenge is also seen in such diverse fields as politics, healthcare, education, and urban planning.

3.3 Relationships and Values

Mutually beneficial relationships and common cause values are critical to long-term vitality because economic networks are collaborations built of specialists who produce more working together than alone.

Common-cause values such as trust, justice, fairness, and reciprocity provide the grease that lubricates collaboration and the glue that holds specialists together. Self-interest is part of the process, but mutual benefit/reciprocity and commitment to the health of the whole are vastly more important because specialists must work together in interlocking circuits such that the health of every individual depends on the health of the whole. Injustice, inequality, and corruption increase instability because they erode unifying values. A mountain of sociological research confirms these facts (e.g., Benedict, 1941/1996; Ridley, 1997; Fehr and Gächter, 2000;).

Unfortunately, decades of divide-and-conquer politics, exaggerated faith in self-interest alone, and powerful incentives to maximize owner profits regardless of harm to people and planet have eroded common-cause values and community cohesion worldwide.

3.4 Collaborative Learning

The self-organizing story of evolution sees humanity as a collaborative-learning species that thrives by forging new understandings and changing our pattern of life by changing our beliefs about how the world works. Here, effective collective learning is humanity's central survival strategy and the keystone to long-term vitality.

While regenerative investments in education and science are known to produce huge social and economic benefits, energizing collective learning requires more than science and education per se. A Royal Dutch Shell study (De Geus, 2002), for example, found that companies that remain vibrant for extremely long periods of time do so by creating a *learning community*. Instead of slavishly serving short-term numbers, executives promote long-term profits by investing in the company's people and their ability to innovate and adapt. As the report concludes:

> "The manager …must place: commitment to people before assets; respect for innovation before devotion to policy; the messiness of learning before the orderly procedures; and the perpetuation of the community before all other concerns."

The speed and quality of our collective learning is also of the essence today because failure to learn can have severe consequences. Anthropologist Jared Diamond (2006), for example, concluded that failure to learn is the underlying cause of most societal collapse. As he says, "Societies aren't murdered; they commit suicide. They slit their wrists, and in the course of many decades, stand by passively and watch themselves bleed to death."

4.0 Ten Principles and Measures of Regenerative Vitality

The critical roles regeneration and learning play in socioeconomic health suggests today's focus should be on figuring our way out of today's interlocking crises by learning the *rules of* *regenerative vitality* – socially, politically, and economically as well as environmentally. ENS can aid this process by identifying certain basic principles of regenerative vitality and the measures that go with them. While scientists will no doubt find many more intrinsic measures over time, we believe the ten principles described below outline a critical path to a regenerative learning society. Figure 6 shows how they fit in our four key categories.

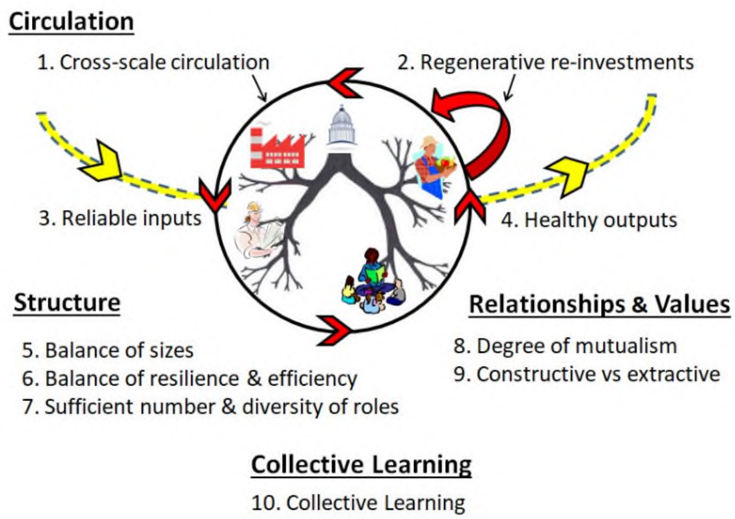


Figure 6. *How the 10 principles fit in our four key categories.*

NOTE: The measures presented below are derived primarily from Ecological or Energy Network Analysis (ENA). Appendix A provides a brief description of mathematical logic and the notation used.

4.1 – Principle 1: *Maintain robust, cross-scale circulation of critical flows including energy, information, resources and money.*

Cross-scale circulation of money, information, and critical resources is important because all sectors and levels of our economic metabolism play mutually supportive, interlinked roles. Workers, for example need employers for wages and products, and employers need workers to produce products. Similarly, though our money-driven, technology-centered society is often reluctant to fund theater, art and music in schools, brain research shows that these activities stimulate thinking and creativity in many other dimensions as well (even mathematics).

The central role cross scale circulation plays in network health explains the Keynesian vision of how aggregate-demand (total spending in the economy) affects economic health. In flow terms, low wages, unavailability of commercial loans, and frequent layoffs reduce circulation to lower levels causing necrosis. In Keynesian terms, when money does not reach the broad-scale public, aggregate-demand declines and economic depression ensues.

Cross-scale circulation can be measured by how rapidly and thoroughly resources circulate inside the organization. Similar to the Flux Density measure, in economics, the Multiplier Effect metric assesses how many times a unit of currency entering a market will be exchanged before exiting that market. We suggest measuring cross-scale circulation using Total System Through-flow (TST) as a fraction of the total input into the system:

$$Network\ Aggradation = \frac{TST}{\sum_{i=1}^{n} z_i}.$$

4.2 – Principle 2: *Invest in human capacities and networks. (Be regenerative!)*

The flow-networks we care most about – living organisms, ecosystems, and societies – are specifically designed to be *self-nourishing*. Their continuation requires they continually pump resources into building and maintaining their internal capacities. This is what makes them regenerative, i.e., naturally self-renewing. Consequently, any society which hopes to live long and prosper must continually invest in its internal capacities, including its members' skills and well-being; its institutions' integrity and capacities; and its commonwealth infrastructure from roads and schools to the Internet and utilities.

Investing in human capital increases network productivity, motivation, innovation, loyalty, and learning simultaneously. This makes internal circulation vastly more important to vitality than GDP growth, which only measures the volume of flow not where it goes or how it is used. Studies estimate, for example, that every $1 spent on the G.I. Bill returned $7 to the American economy.[1] Investing in local businesses also improves economic resilience, which increases in step with the number of locally-rooted businesses and the amount of investment in local capacity. Conversely, the austerity measures so popular with neoliberals undermine the health of already ailing economies by curtailing investment, circulation, and socio-economic nourishment particularly at the grassroots level.

Investment in human capacities and networks can be measured by the percentage of money and resources the system invests in building and maintaining its internal capacities and infrastructure. We use the Finn (1980) Cycling Index (FCI), the fraction of total through-flow cycled in the network. Cycling of node $i(Tc_i)$ can be calculated as:

$$Tc_i = ((n_{ii} - 1)/n_{ii})T_i \text{ Here: } FCI = \frac{\sum Tc_i}{TST}$$

4.3/4 – Principles 3 & 4: *Maintain reliable inputs & healthy outputs.*

Circulation also applies to inputs and outputs. If a society runs out of a critical resource such as fuel or water, then it will collapse. The struggle to replace fossil fuels with more reliable energy sources demonstrates the problem. Since flows are inevitably circular, societies that poison themselves or their environment will also die. In today's case, our society is blithely poisoning people and planet with toxic chemicals, adulterated food, and excessive carbon emissions.

Consequently, the sustainability movement's main focus – the struggle to maintain reliable inputs of critical resources and healthy outputs from clean water to Green energy – can also be viewed as a circulation challenge. The science of flow, however, extends critical inputs to include accurate information, quality education, nourishing food, and robust monetary circulation.

[1] https://ivmf.syracuse.edu/2013/06/21/the-gi-bills-impact-on-the-past-present-and-future/

Input reliability can be assessed by how much risk attends critical resources such as energy, information, resources, and monetary flows upon which the system depends. *Healthy outputs can be assessed* by how much damage outflows do both inside and outside the system.

We would assess the input reliability driving the system using existing indicators, including sustainability indicators of renewability such as percentage of energy from renewable sources and declining energy-return on energy invested.

We would assess system outflow using an index of human impacts (e.g., cancer rates) and environmental impacts (e.g., pollution and carbon levels). The latter can be gauged by measures of the local or global environment's capacity to absorb wastes, such as carbon-sequestration capacities of forests, safe nitrogen-input capacity of soils and natural lands, etc.

4.5 – Principle 5: *Maintain a healthy balance and integration of small, medium, and large organizations.*

Long-term vitality requires (at least) approximating fractal/power law balance of organizational sizes because this represents a (relatively) optimal arrangement for a multiscale system of a given size. Similarly, just as water systems require wetlands and large rivers to serve the activity at different scales, so the Goldilocks Rule of banking suggest that commercial activity requires organizations designed to serve the financial needs of each scale, local to global.

We assess balance using the distribution of sizes, incomes, or resources within the system. Flow-network data can then be plotted using a weighted distribution of stocks and flows, compared against power-law distributions found in nature, and checked for indications of imbalance (e.g., McNerney et al. 2013). Fertile soils, for example, have power-law distributions of carbon, nitrogen, organic matter and other essential resources, with large amounts near the surface and decreasing amounts going down to bedrock. This distribution provides functional and structural benefits, while also adding resilience to the communities existing on those soils. Unsustainable farming dissipates these structural and functional gradients, while regenerative agriculture restores them.

4.6 – Principle 6: *Maintain a healthy balance of resilience and efficiency.*

Ulanowicz, et al. (2009) also use the fractal balance of sizes to identify the balance of *resilience* and *efficiency* needed for systemic health. Noting that the factors which contribute to efficiency (large size, high-capacity, streamlining) are opposite to those that contribute to resilience (small size, diversity, dense connectivity), Ulanowicz realized that healthy systems must maintain a balance of both because both are important and extremes of either create problems. Too much efficiency creates brittleness, while too much small-scale diversity creates low-energy stagnation. He used data from healthy ecosystems to identify the "Window of Vitality," the range of balance within which healthy systems fell (Figure 7).

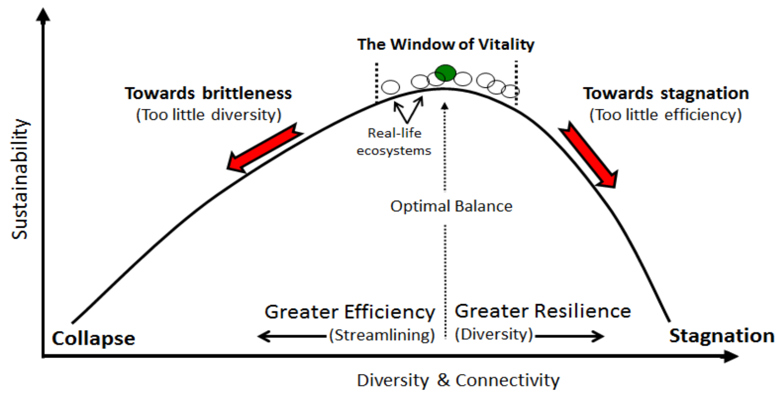


Figure 7. *The Window of Vitality delimits a healthy balance of resilience and efficiency*.

This work shows why today's emphasis on efficiency and "economies of scale" is useful *up to a point*, beyond which it is destructive to the organization as a whole. Lietaer et al. (2012) used this discovery to show that today's excessive emphasis on efficiency and size in business and banking contributes to economic and banking crises, respectively.

A healthy balance of resilience and efficiency can be measured using Ulanowicz' Window of Vitality metric (2009), where: Ascendency (A) measures the fraction of material or energy that an ecosystem distributes in an *efficient* manner; Developmental Capacity (C) is the maximum potential a system has to achieve further development; and Resilience (R) measures the array of useful parallel pathways for exchange:

$$\boldsymbol{A} = \sum_{i,j} F_{ij}\, log\left(\frac{F_{ij} \quad F_{..}}{F_{i.} \quad F_{.j}}\right) \qquad\qquad \boldsymbol{C} = -\sum_{i,j} F_{ij}\, log\left(\frac{F_{ij}}{F_{..}}\right)$$

$$\boldsymbol{R} = \sum_{i=1}^{n}\sum_{j=1}^{n}(F_{ij}).\, log\left(\frac{F_{ij}^2}{\sum_{j=1}^{n} F_{ij} \quad \sum_{i=1}^{n} F_{ij}}\right)$$

The Window Vitality metric charts a network's degree of organization as $\alpha = \frac{A}{C}$. Systemic Robustness is measured as:

$$Robustness = -a \log a\,,$$

A healthy economy is presumed to maximize the robustness value, as is seen in ecosystems.

4.7 – Principle 7: *Maintain sufficient diversity*

The endless diversity found in human beings, enterprises, and communities increases resilience, and helps fill niches and find new ways. Economic functioning requires a sufficient number and diversity of specialists serving critical functions to keep it going because systemic processing 'takes a village' of specialists, and because the bigger the society becomes, the more specialists – doctors, teachers, engineers etc. – of various types it needs. The number of groceries, schools, and hospitals, for example, must grow in step with population size in order to meet demand, and maintain access, choice and resilience.

The laws of sufficient diversity for populations of a given size are known to follow certain mathematical rules, which can be assessed by measuring the number and diversity of players in activities critical to system functioning. We use Zorach and Ulanowicz' (2003) metrics for the number of roles needed in a specific network.

$$Roles = \prod_{i,j} \left(\frac{F_{ij} \quad F_{..}}{F_{i.} \quad F_{.j}} \right)^{Fij/_{F..}}$$

4.8 – Principle 8: *Promote mutually-beneficial relationships and common-cause values.*

Fath et al. (2007) has shown that maintaining overall positive levels of mutual benefit is essential to systemic health in ecosystems. We believe similar network assessments of direct and indirect benefit can be used to assess how the degree of mutual benefit impacts systemic health in socioeconomic systems as well.

The degree of mutualism can be determined by a matrix of direct and indirect relational-pairings, which may be categorized as: exploitative (+, –); exploited (–, +); mutualist (+, +); and competitive (–, –) based on its flow relationships (Fath, 2007). The number of positive signs is an indication of the overall benefit a node receives by participating in that network. Robust ecosystems display a greater number of mutualistic relations than competitive ones. A healthy economy should also display a greater degree of mutualism.

4.9 – Principle 9: *Promote constructive activity and limit overly-extractive and speculative processes.*

Neoliberal economists do not differentiate between money made from Wall-Street speculation and that made by producing a product or educating a child. Their North Star, GDP growth, cannot distinguish between a robust economy and a bubble because it only looks at volume of money exchanged, and counts damaging activity such as fraud, cancer, and oil spills as positive contributions. Today's disturbing result is that the failing health of real-economy networks is masked by an ephemeral cloud of speculation (Figure 8).

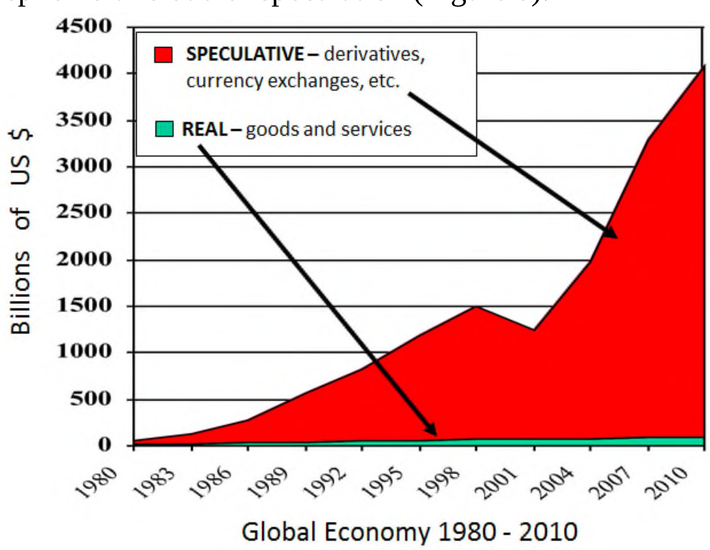


Figure 8. *Global GDP is more a function of speculation than of development in the real economy.*

In contrast, regenerative economists care a great deal about constructive activities because these build economic muscle and brain. Regenerative economists, therefore, value activities that build internal capacities, infrastructure, productivity, power, and learning. They seek to limit: 1) excessive speculation because it creates shimmering bubbles of illusory wealth supported primarily by mania; and 2) excessive extraction because it causes economic necrosis.

We propose assessing the balance of constructive vs extractive/speculative activity as a ratio of value-add and capacity-building activities to extractive ones. Healthy systems (both human and ecological) are filled with numerous positive- and negative-feedback processes that together maintain a stable, self-sustaining pattern of flow. Too much or too little of either amplifying (positive feedback) or dampening (negative feedback) processes leads to unstable, unsustainable patterns – explosive ones in the case of amplifying, and stagnant ones in the case of dampening processes.

In flow terms, therefore, we are looking for imbalances, i.e., significant asymmetries between activities that build work-supporting gradients, and ones that degrade them. A constructive network would have positive-feedback processes generating sufficient work-supporting gradients to maintain its capacities and activity. The number of autocatalytic cycles (i.e., closed-loops of length greater than 1) is one indicator of such "constructive" processes (Cazzolla Gatti et al., 2017, 2018).

4.10 – Principle 10: *Promote effective collective learning.*

A society's ability to learn as a *whole* is the most important regenerative principle, and the hardest to measure. Since there is no network-formula for effective learning, we suggest assessing it by creating a composite of existing indicators of:

1) Poorly addressed human needs, e.g., jobs, education, healthcare, nutrition, housing, etc.;
2) Underutilized human resources, e.g., unemployment, underemployment, inequality, poverty, etc.;
3) Poorly addressed critical issues, particularly environmental issues from pollution to global warming, but also political economic ones as seen in the famous "doomsday clock";
4) Educational priority such as school funding, educational attainment, tuition rates, community colleges, professional development, library programs; and
5) Levels of community involvement, e.g., voting, volunteerism, civic engagement, farmer's markets, sharing economy opportunities, community gardens, community art programs, etc.

5.0 Discussion: Comparing Regenerative Learning (RL) to Classical and Neoliberal Economics

Like an optical illusion that can be seen in two ways, the science of Regenerative Learning (RL) systems reorganizes our vision of economic health in a way that:

- Confirms classical elements such as innovation, entrepreneurship, free enterprise, and Adam Smith's invisible hand of optimal aggregate behavior, now firmly anchored in common cause "moral sentiments";
- Advances progressive and humanistic notions such as the importance of mutual benefit, reciprocity, fairness, justice and distributed empowerment; and
- Clarifies some fundamental errors in classical and neoliberal assumptions, including automatically optimal outcomes; the centrality of (amoral) rational self-interest; and the benefits of austerity, deregulation, and boundless GDP growth supported by endless increases in size and efficiency.

The classical story of economic vitality emphasizes innovation, entrepreneurship, competition, free enterprise, and laissez-faire markets in which optimal equilibrium (distribution) emerges automatically from rational agents pursuing their own self-interest. RL sees innovation, entrepreneurship, competition and free enterprise as contributing to the diversity and flexibility needed to fill niches, find new ways and enhance resilience.

Self-organization also provides a physical basis for Adam Smith's "invisible hand" of optimal aggregate behavior, but it anchors it in a more complete picture of the kinds of factors that produce optimal systemic outcomes. Smith believed optimal outcomes would rise "as if by an invisible hand" from the aggregate of individual economic decisions. He saw individual enterprise and innovation, and the freedom to benefit from one's own efforts as crucial to this process. In contrast to neoclassical theory, Smith's *Treatise on Moral Sentiments* placed these decisions in a complex moral context that included but went beyond rational self-interest.

Sacred geometries, fractals and other universal patterns represent the kind of optimal aggregate behavior envisioned in Smith's invisible hand. Like an Efficient Market, a hurricane's spiral, for example, reflects a web of forces striving toward an optimal pattern of distributive flow. Like Smith's invisible hand, this optimality emerges from the seemingly chaotic interactions of billions of individual particles. Like Smith, RL places these decisions in a complex moral context that includes rational self-interest but also requires such critical elements as mutual benefit (reciprocity), constructive activity, inclusive democratic involvement in rules, and a commitment to the health of the whole.

Here, as with Smith's vision, self-interest, competition, and rationality are smaller subsets of a much broader and critically important system of interdependence and collaborative synergy. In human systems, optimal outcomes are particularly dependent on effective collective learning – e.g. open, honest, evidence-based discussions incorporating collective lessons from past crises, resolutions, causes and cures, e.g., the collapse of Rome, the Great Depression, the rise of fascism, the New Deal, and the global financial crisis of 2008.

While innovative ideas and diverse individual enterprise are important to regenerative learning, optimal economic behavior is also heavily shaped by a host of less traditional factors, including:

- Robust cross-scale circulation of money, information, and resources, including adequate worker income, trustworthy media, and reliable provisions for health;

- Adequate investment in human, social, physical, economic, and environmental capital, particularly in collaborative-learning culture both in schools and corporations;
- A fractal balance of small, medium, and large organizations;
- Processes for learning effectively as a society in the face of mounting evidence and pressures, including science, government, corporations, and politics (e.g., democracy).

The science behind regenerative learning holds a much dimmer view of the neoliberal version of capitalism. Dominating global economics for the last 40 years, neoliberals argue that economies thrive on: deregulation; privatization; maximizing profit for owners; tax breaks for the rich and austerity for the general public; continual GDP growth; and endlessly increasing corporate size and efficiency. In recent years, a host of interlocking crises – from gross inequality and looming climate change to global economic instability as demonstrated by the financial crash of 2008 – have called this "trickle-down" theory into question.

Neoclassical economists assume economics could be separated from social and political dynamics, and concluded that free-market vitality arose automatically as a result of independent agents making rational choices based on self-interest alone. Neoliberal economists, however, push elite self-interest to an extreme, claiming economic vitality rises from deregulation, privatization, cutting taxes on the rich, rolling back labor and environmental laws, and maximizing profit for owners alone. Unfortunately, economies that apply such principles are famous for instability and inequity. Boom-bust business cycles, occurring every 4 to 7 years on average, are now considered normal, despite their devastating impacts on the public at large. Today, financial instability is rampant, with crises afflicting Brazil, Greece, Italy, Iceland, Ireland, Russia, Spain, Turkey, Venezuela, the US, and others since 2001.

The main problem with neoliberal beliefs is that they promote excess instead of balance, and oligarchic extraction rather than systemic health. Profit-making, for example, is fine, but *profit maximizing for owners only* is inevitably achieved by: extractive practices such as cutting wages and benefits to workers; systemically harmful ones such as environmental pollution; and speculative schemes which produce a sparkling cloud of phantom wealth with no substance underneath.

Short-term profit-maximizing fueled by rampant deregulation, privatization, tax breaks for the rich, and austerity for the general public – fuel corporate gigantism and extreme concentrations of wealth and power. Violating the law of fractal balance leads to the usual sequence: excessive concentrations of wealth → excessive concentrations of power → positive feedback loops that accelerate the suction of wealth to the top. The result is economic necrosis – the dying off of large swaths of economic tissue due to poor circulation and malnutrition. Consequently, Institutional economists Acemoglu and Robinson (2012) show that excessive extraction is the most common reason *Why Nations Fail*.

The natural result is a corporate oligarchy that bears little resemblance to Adam Smith's original free-enterprise dream. Please note, however, that while "oligarchy" is defined as "rule by the few," it should not be equated with wealth, power, or hierarchy per se. Instead, fractal balance suggests the key issue is whether hierarchical power-structures – which are essential for mobilization, coordination, and focus in large societies – are used to promote the health of the whole or to increase the power and wealth of a few people regardless of the harm done to the rest of the system, i.e., whether they are bound by common cause or focused on rapid pursuit of elite self-interest. Thus, in *The Republic,* Plato (~381 BC) describes oligarchy as government by "greedy men" who subvert laws, policies, and beliefs to protect their own interests and channel wealth to the top. He notes that, in oligarchies, the majority public becomes increasingly disenfranchised, and burdened by debt.

Nevertheless, corporate oligarchs, proud of their achievements, naturally fund academics who rationalize inequity, injustice and sociopathic tendencies as the inevitable, even optimal results of free market dynamics. Unfortunately, the glaring inequity of wealthy elites extracting wealth, power, and privilege from the increasingly fragile economy also erodes the bonds of trust and common cause holding the system together. Public bitterness rises along with massive socioeconomic pressures, which build over time.

Economic bellwethers such as the financial crisis of 2008, and political ones such as the rise of populists from both Right and Left indicate that oligarchic capitalism is now exhausted. Even neoliberal high-priest Alan Greenspan admitted that the 2008 banking crisis had demolished his confidence in neoliberal theory. *The Economist* quoted Greenspan (2008) saying: "With a flawed diagnosis of the causes of the crisis, it is hardly surprising that many policymakers have failed to understand its progression."

This corporate oligarchy's stifling effect on today's urgently needed, collective learning constitutes a serious threat to humanity's long-term survival. Extreme inequality; the flood of displaced peoples worldwide; and the inability to deal with the existential threat of climate change – today's critical problems are many, and while many solutions exist, the oligarchic establishment lacks the "political will" to enact them. Today, for example, climate-change and the march of peak-oil are creating pressure for more distributed power based on clean, green renewables. The fossil-fuel industry is working to resist this change, but in the end, it will not be able to avoid the pressure to change any more than medieval Europe could escape the crisis that came from consuming all its forests. If the energy industry waits too long to change, then it may take civilization down with it. The corporate oligarchy's failure to address pressing human problems, such as education, healthcare, food, shelter, and jobs also hold calamitous possibilities.

This process cannot continue forever. Instead, oligarchic dysfunction and inequity always breed a backlash (eventually). Rising pressures spur collective action and solution-seeking. With intelligence and organization, this combination may produce a breakthrough cycle of learning and development.

Thus, in the regenerative learning view, societal transformations are driven by interlocking social, economic, political, and environmental crises that create pressure to rethink orthodox ways. Frustrated energy provides fuel for change, but the real catalysts come from organized, common cause movements woven around innovative ideas and reforms. The Reformation, the Scientific Revolution and the Enlightenment are examples of these. Successful change produces a new pattern of civilization built around some set of reforms, particularly against oligarchic abuse. Written laws, civil rights, free enterprise, and democracy exemplify such reforms.

Unfortunately, over time, oligarchic power tends to return, and a two-steps-forward/one-step-back cycle ensues. This process is now playing out in our own time. Once upon a time, new technologies from the printing press to the steam engine joined scientific inquiry and Enlightenment ideals to ignite the reforms that forged today's free-enterprise democracies. However, concentrated financial power has now corrupted democratic institutions, leaving us at the mercy of an oligarchic political-economy that cares more about building dominions than maintaining a healthy civilization. The bailout of the very bankers who caused the 2008 crisis shows the power today's oligarchy wields.

Unfortunately, pressure drives change. If problems remain unaddressed for too long, then pressure reaches a breaking point. A variety of indicators suggest frustration with today's corporate oligarchy is approaching that point. This crisis is predictable because oligarchy violates the core rules of regenerative vitality. Instead of supporting healthy human-networks, it minimizes returns to workers, cuts spending on education, and ignores human needs that are not backed by sufficient money. Instead of supporting innovation and collective learning that resolve critical problems, it works against any advance that might reduce its ability to extract wealth and maintain monopolies on power.

Dangerous pressures are now rising from an American population facing unmet needs for trustworthy institutions, accurate information, empowering education, quality healthcare, basic human dignity, and a secure life. While climate change is grave, it is these more deeply human pressures that are now driving a massive societal change.

A vast wave of diverse reformers seeking better ways is sweeping through fields ranging from energy and education to finance and politics – but the outcome is still in doubt. Which way will we go, oligarchic domination or regenerative learning? We believe having a rigorous theory and quantitative measures of regenerative vitality can help turn the tide in a positive direction.

6.0 Conclusion

The science of Regenerative Learning (RL) provides a more accurate understanding of what makes a society healthy. Robust circulation, balanced and integrated structures, investing in human capacities, collaborative learning anchored in common-cause values, and the dangers of oligarchic concentration and extraction – RL's story of economic vitality mostly confirms what we already know while anchoring it in a more integrated and measurable empirical framework.

In this view, promoting the health of the underlying human network is vastly more important than increasing the volume of economic output (GDP growth) per se. Innovation, entrepreneurship, and capacities are important, but they need to be linked by common-cause values, supported by commonwealth infrastructure, and nourished by cross-scale circulation of money, information and resources. Large and small organizations both play important roles, and the goal is to maintain balance and integration.

Despite claims that "There Is No Alternative" to neoliberalism, a great deal of evidence shows regenerative policies do improve systemic health. Investments in public education and infrastructure, such as the Internet and public transit, return huge economic rewards. Increasing worker pay increases circulation which boosts economic output and profits – which is why unions helped build an American middle-class. Monopolistic dominance makes economies brittle, which is why New Deal restraints on concentration and speculation largely eliminated financial crises in the US for 50 years – until neoliberal deregulation brought them back (Figure 9).

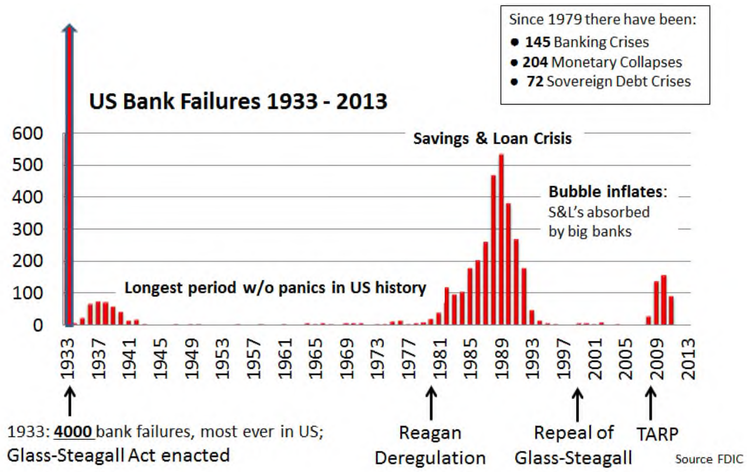


Figure 9. *Curbing speculation reduces bank failures. Implemented during FDR's New Deal, the Glass-Steagall Act largely eliminated banking failures for 50 years by separating the risky capital-market activities of investment banks from commercial banks that circulate money to the real economy. Crises resumed with neoliberal deregulation under Reagan.*

In a Regenerative Learning view, humanity is a collaborative-learning species that has not yet learned to fully use its great gift. There are, of course, many reasons societies learn poorly, including habit, momentum, and inability to think outside the current box. But, in sophisticated civilizations like our own, these problems are exacerbated by an oligarchic power-system that has become overly dominant, self-serving and sociopathic.

It is time for us to choose. Systemic *death* does not happen automatically. It requires adhering to beliefs long past their usefulness in addressing the problems for which they were designed, while ignoring widespread evidence that they are not achieving systemically healthy outcomes.

Of course, systemic health does not happen automatically either. It requires adhering to the rules of regenerative health, development, and learning. Today's challenge is to use these rules to restore global viability and vitality. The measures listed above can help us chart our course, but in the end, "We the People" will still need to figure out how to enact better ways in our very real world. Developing healthier patterns of power must be top on our list.

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APPENDIX A: Ecological/Energy Network Analysis

In Ecological (Energy) Network Analysis (ENA), every system of compartments and connections can be realized as a network of nodes and arcs. Consider a network with n compartments or nodes, in which the compartments can be represented as x_i, for $i = 1$ to n. The transaction of the energy/matter substance flowing from node i and node j is given by f_{ij} and can be arranged into a matrix $\mathbf{F}$ containing all pairwise flows in the network. In addition, these systems are open to receive new inputs and generate outputs. Those flows that cross the system boundary are labeled, z_i and y_i, for $i = 1$ to n, respectively. In this manner, we can find the total flow going through any node as either the sum of all the flows into the node or all the flows out of the node (at steady-state these are equal).

$$T_i^{in} = z_i + \sum_{j=1}^{n} f_{ji}$$

$$T_i^{out} = y_i + \sum_{j=1}^{n} f_{ij}$$

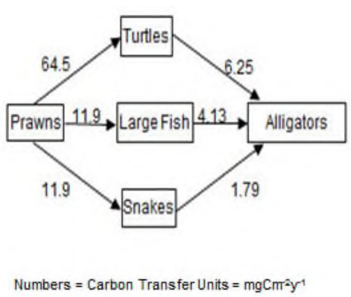
The total system through-flow (TST) is the sum of all the individual nodal flows, given by:

$$TST = \sum_{i=1}^{n} T_i$$

The flows in the **F** matrix capture the direct transactions, but the methodology can be used to determine indirect flow paths and influences as well. First, we calculate a non-dimensional, output oriented flow intensity matrix, **B**, where $b_{ij}=f_{ij}/T_i$ (a symmetric input-oriented analysis is also possible). Ecological Network Analysis (ENA, see Fath and Patten, 1999) tells us that taking powers of this matrix gives the flow intensities along path lengths commensurate with the power, i.e., B^2 are two-step pathways, B^3 three-step, etc. Another fascinating discovery of ENA is that it is possible to simultaneously consider *all* powers in one term by summing the infinite series which converges to a composite matrix, we call, N, such that

$$N = \sum_{m=0}^{\infty} B^m = B^0 + B^1 + B^2 + B^3 + B^4 + \cdots$$

The N matrix is termed the integral flow matrix because it sums or integrates the flow along the direct and all indirect pathways. These basic network building blocks are used to develop the specific metrics in regenerative economics.



RESILIENCE (R) can be defined as:

$$R = -\sum_{i,j} T_{ij} \log\left(\frac{T_{ij}^2}{T_{i.}T_{.j}}\right)$$

SYSTEMIC EFFICIENCY (SE) can be defined as:

$$SE = T_{..} \cdot X = \sum_{i,j} T_{ij} \log\left(\frac{T_{ij}T_{..}}{T_{i.}T_{.j}}\right)$$

NETWORK SUSTAINABILITY (S) can be defined as:

$$S = C = SE + R = -\sum_{i,j} T_{ij} \log\left(\frac{T_{ij}}{T_{..}}\right)$$

Figure 10. *Ulanowicz et al. (1996) chart ecosystem health using the layout and magnitudes of biomass going from prey to predator (prawn to alligator) in a wetland. His weighted digraphs show flows (T) moving from any node i to node j (Tij). Equations on the right represent information theoretic metrics used to assess resilience, systemic efficiency and network sustainability. Please note that there is no commonly accepted measure of resilience. This is just one approach.*