The Re-emergence of "Emergence": A Venerable Concept in Search of a Theory

One Solution: The "Synergism Hypothesis"

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THE ORIGIN OF EMERGENCE

If "complexity" is currently the buzzword of choice for our newly minted millennium, as many theorists proclaim, "emergence" seems to be the explication of the hour for how complexity has evolved. Complexity, it is said, is an emergent phenomenon. Emergence is what "self-organizing" processes produce. Emergence is the reason why there are hurricanes, and ecosystems, and complex organisms like humankind, not to mention traffic congestion and rock concerts. Indeed, the term is positively awe-inspiring. As physicist Doyne Farmer observed, "It's not magic…but it *feels* like magic" [1].

Among other things, emergence has been used by physicists to explain Bénard (convection) cells, by psychologists to explain consciousness, by economists and investment advisors to explain stock market behavior, and by organization theorists to explain informal "networks" in large companies. Indeed, a number of recent books view the evolutionary process itself as a self-organizing, emergent phenomenon (see below). But what is emergence? What does it explain, really? And why is it so readily embraced, in spite of its opacity, by reductionists and holists alike? There are very few terms in evolutionary theory these days—not even "natural selection"—that can command such an ecumenical following.

Though emergence may seem to be the "new, new thing," from the title of the recent bestseller by Michael Lewis about high technology in Silicon Valley, in fact it is a venerable term in evolutionary theory that traces back to the latter 19th and early 20th centuries. It was originally coined during an earlier upsurge of interest in the evolution of wholes, or, more precisely, what was viewed unabashedly in those days as a "progressive" trend in evolution toward new levels of organization culminating in mental phenomena and the human mind. This long-ago episode, part of the early history of evolutionary theory, is not well known today, or at least not fully appreciated. Nonetheless, it provides a theoretical context and offers some important insights into what can legitimately be called the re-emergence of emergence.

THE ORIGIN OF EMERGENCE

According to the philosopher David Blitz in his definitive history of emergence entitled, appropriately enough, *Emergent Evolution: Qualitative Novelty and the Levels of Reality* [2], the term "emergent" was coined by the pioneer psychologist

G. H. Lewes in his multivolume *Problems of Life and Mind* [3]. Like many post-Darwinian scientists of that period, Lewes viewed the evolution of the human mind as a formidable conundrum. Some evolutionists, like Alfred Russel Wallace (the codiscoverer of natural selection), opted for a dualistic explanation. The mind is the product of a supernatural agency, he claimed. But Lewes, following the lead of the philosopher John Stuart Mill, argued that, to the contrary, certain phenomena in nature produce what he called "qualitative novelty"—material changes that cannot be expressed in simple quantitative terms; they are emergents rather than resultants. To quote Lewes:

> Every resultant is either a sum or a difference of the cooperant forces; their sum, when their directions are the same—their difference, when their directions are contrary. Further, every resultant is clearly traceable in its components, because these are homogeneous and commensurable.... It is otherwise with emergents, when, instead of adding measurable motion to measurable motion, or things of one kind to other individuals of their kind, there is a cooperation of things of unlike kinds.... The emergent is unlike its components in so far as these are incommensurable, and it cannot be reduced to their sum or their difference (p. 413).

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SHADES OF ARISTOTLE

Years earlier, John Stuart Mill had used the example of water to illustrate essentially the same idea: "The chemical combination of two substances produces, as is well known, a third substance with properties different from those of either of the two substances separately, or of both of them taken together" [p. 371, 4]. However, Mill himself had an illustrious predecessor. In fact, both Mill and Lewes were resurrecting an argument that Aristotle had made more than 2000 years earlier in a philosophical treatise, later renamed the *Metaphysics*, about the significance of "wholes" in the natural world. Aristotle wrote: "The whole is something over and above its parts, and not just the sum of them all..." (Book H, 1045:8–10). (We will return to Aristotle's famous catch-phrase later on.) So the ontological distinction between parts and wholes was not exactly a new idea in the 19th century. The difference was that the late Victorian theorists framed the parts–wholes relationship within the context of the theory of evolution and the challenge of accounting for biological complexity.

The basic quandary for holistic theorists of that era was that evolutionary theory as formulated by Darwin did not allow for radically new phenomena in nature, like the human mind (presumably). As every first-year biology student these days knows, Darwin was a convinced gradualist who frequently quoted the popular canon of his day, *natura non facit saltum*: nature does not make leaps. (The phrase appears no less than five times in *The Origin of Species*.) Indeed, Darwin rejected the very idea of sharp discontinuities in nature. In *The Origin*, Darwin emphasized what he called the "Law of Continuity," and he repeatedly stressed the incremental nature of evolutionary change, which he termed "descent with modification" [5]. Darwin believed that this principle applied as well to the evolution of the "mind." In the *Descent of Man*, he asserted that the difference between the human mind and that of "lower" animals was "one of degree and not of kind" [I , p. 70, 6].

Many theorists of that era viewed Darwin's explanation as unsatisfactory, or at least incomplete. Emergent evolution theory was advanced as a way to reconcile Darwin's gradualism with the appearance of "qualitative novelties" and, equally important, with Herbert Spencer's notion (following Lamarck) of an inherent, energy-driven trend in evolution toward new levels of organization. Emergent evolution had several prominent adherents, but the leading theorist of this school was the comparative psychologist and prolific writer, Conwy Lloyd Morgan, who ultimately published three volumes on the subject, *Emergent Evolution* (1923), *Life, Spirit and Mind* (1926), and *The Emergence of Novelty* (1933) [7–9]. [Other theorists in this vein included Samuel Alexander, Roy Wood Sellars, C. D. Broad, Jan Smuts, Arthur Lovejoy, and W. M. Wheeler. Jan Smuts, a one-time Prime Minister of South Africa, deserves special note because his volume, *Holism and Evolution* (1926), advanced the concept of "holistic selection"—the idea that wholes of various kinds might be units of selection in nature [10]. It was a prescient precursor to such later concepts as David Sloan Wilson's "trait group selection," John Maynard Smith's "synergistic selection," and my Synergism Hypothesis (see below).]

The main tenets of Lloyd Morgan's paradigm will sound familiar to modern-day holists: quantitative, incremental changes can lead to qualitative changes that are different from, and irreducible to, their parts. By their very nature, moreover, such wholes are unpredictable. Though higher-level, emergent phenomena may arise from lower-level parts and their actions, there may also be "return action" or what Lloyd Morgan also called "supervenience" ("downward causation" in today's parlance). But most important, Lloyd Morgan argued that the evolutionary process has an underlying "progressive" tendency, because emergent phenomena lead in due course to new levels of reality.

It was a grand vision, but what did it explain? As Blitz observes, it was not a causal theory. "Emergent evolution related the domains studied by the sciences of physics, chemistry, biology, and psychology—a philosophical task not undertaken by any one of them—but did not propose mechanisms of change specific to any one of them—a scientific task which philosophy could not undertake" [p. 100, 2]. Indeed, Lloyd Morgan ultimately embraced a metaphysical teleology that portrayed the evolutionary process as an unfolding of inherent tendencies, which he associated with a creative divinity (shades of Spencer, Henri Bergson, Pierre Tielhard de Chardin, and other orthogenetic and "vitalistic" theorists, not to mention some of today's complexity theorists).

Despite its current popularity, "emergence" is a concept with a venerable history and an elusive, ambiguous standing in contemporary evolutionary theory.

In short, emergent evolution in Lloyd Morgan's hands was not really a scientific theory, though the boundary line was not so sharply delineated back then. But far more damaging to the cause of emergent evolution was the rise of the science of genetics in the 1920s and 1930s and the triumph of an analytical, experimental approach to biology. In its most strident form, reductionism swept aside the basic claim of emergent evolutionists that wholes had irreducible properties that could not be fully understood or predicted by examining the parts alone. Critics like Stephen C. Pepper, Charles Baylis, William McDougall, Rudolph Carnap, and Bertrand Russell claimed that emergent qualities were merely epiphenomena and of no scientific significance. Russell, for instance, argued that analysis "enables us to arrive at a structure such that the properties of the complex can be inferred from those of the parts" [pp. 285–286, 11]. Although the reductionists conceded that it was not currently possible, in many cases, for science to make such inferences and predictions, this shortcoming was a reflection of the state of the art in science and not of some superordinate property in nature itself. In time, it was said, reductionism would be able to give a full accounting for emergent phenomena.

THE SUBMERGENCE OF EMERGENCE

Under this theoretical onslaught, the doctrine of emergent evolution went into a prolonged eclipse, although it never succumbed completely to the promissory notes proffered by the reductionists. During the decades that followed, the Aristotelian argument that wholes have distinctive, irreducible properties "re-emerged" in several other venues (though often with different terminology). In the 1930s, for example, embryologist Joseph Needham advanced the idea of "integrative levels" in nature and argued for "the existence of [different] levels of organization in the universe, successive forms of order in a scale of complexity and organization" [p. 234, 12]. A decade later, the biologist Julian Huxley, a principal architect of the "modern synthesis" in evolutionary biology, sought to define evolution as "a continuous process from star-dust to human society." Among other things, Huxley asserted that "now and again there is a sudden rapid passage to a totally new and more comprehensive type of order or organization, with quite new emergent properties, and involving quite new methods of further evolution" [p. 120, 13]. Biologist Alex B. Novikoff also defended the idea of emergent levels of reality in a much-cited 1945 article in *Science* entitled "The Concept of Integrative Levels in Biology" [14].

The growth of the new science of ecology in the 1930s also stimulated an interest in whole systems and macro-level relationships. Among the pioneer ecologists, such as Charles Elton, A.G. Tansley, Raymond Lindeman, G. Evelyn Hutchinson, and others, there was much talk about how the natural world is an integrated "economy," a biological "community," and even, for some theorists, a "quasi-organism" (Tansley). Ironically enough, the seminal concept of an "ecosystem"—which has since become a centerpiece of modern ecology—was originally conceived by Tansley in the context of his belated conversion to reductionism. "Wholes," he wrote, "are in *analysis* nothing but the synthesized actions of the components in associations." (For an in-depth history of ecology, see Donald Worster's *Nature's Economy: A History of Ecological Ideas*, 1977 [15].)

A much broader reaffirmation of the importance of wholes in nature occurred in the 1950s with the rise of "general systems theory." Inspired especially by the writings of biologist Ludwig von Bertalanffy [16,17], the systems movement was to that era what complexity theory is today, and the Society for General Systems Research, founded in 1956, provided an interdisciplinary haven for the beleaguered band of holistic theorists of that era. (The organization was later renamed The International Society for the Systems Sciences.) Indeed, the Society's yearbook—*General Systems*—was a beacon (and a treasure-trove) for the systems movement for more than a generation. It included the contributions of such luminaries as Kenneth Boulding, Ralph Gerard, Anatol Rapoport, H. Ross Ashby, Heinz von Foerster, Russell Ackoff, Stafford Beer, Donald T. Campbell, Herbert Simon, George Klir, Robert Rosen, Lawrence Slobodkin, Paul Weiss, James Grier Miller, and many others. (Herbert Simon's 1962 article "The Architecture of Complexity" was seminal, along with Paul Weiss's 1969 article "Determinism Stratified" [18,19].)

"RE-EMERGENCE"

It is difficult to attach a date to the re-emergence of emergence as a legitimate, mainstream concept, but it roughly coincided with the growth of scientific interest in the phenomenon of complexity and the development of new, nonlinear mathematical tools—particularly chaos theory and dynamical systems theory—that allowed scientists to model the interactions within complex, dynamic systems in new and insightful ways. Among other things, complexity theory gave mathematical legitimacy to the idea that processes involving the interactions among many parts may be at once deterministic yet for various reasons unpredictable. (One oft-noted constraint, for instance, is the way in which initial conditions—the historical context—may greatly influence later outcomes in unforeseeable ways.)

One of the benchmarks associated with the re-emergence of emergence was the work of Nobel psychobiologist Roger Sperry [20–23] on mental phenomena and the role of what he was the first to call "downward causation" in complex systems like the human brain. (Donald Campbell may have coined the term independently [24].) Sperry spoke of the need for "new principles" of "cognitive and emergent causation and top down determinism." To illustrate, he used the metaphor of a cart wheel rolling down hill; the rim, the spokes, the hub, indeed, all of its atoms are compelled to go along for the ride. Sperry also used Lloyd Morgan's term, "supervenience."

Meanwhile, in physics Herman Haken and his colleagues broke new ground with "synergetics"—the science of dynamic, "cooperative" phenomena in the physical realm (though he later ventured into neurological and cognitive phenomena as well). Over the past 20-odd years, synergetics has produced a large body of holistic theory [25–30]. Likewise, the Nobel physicist Ilya Prigogine's work in nonequilibrium thermodynamics, especially his concept of "dissipative structures," represents yet another holistic approach to the rise of complexity in nature [31–37].

In the United States, much of the recent work on the subject of emergence has been fueled by the resources and leadership of the Santa Fe Institute. Beginning in the mid-1980s, the Institute's annual proceedings have contained many articles related to this subject, and a number of the scholars who are associated with the Institute have published books on complexity and emergence. (See especially the volumes by Stuart Kauffman, John Casti, and John Holland and also the two popular books by science writers Roger Lewin and Mitchell Waldrop [1,38–44].) Kauffman, for instance, theorizes that life is an emergent phenomenon in the sense that it represents a "spontaneous crystallization" of prebiotic molecules that can catalyze networks of reactions. Life is a collective property of a system of interacting molecules, says Kauffman: "the whole is greater than the sum of its parts" (1995, pp. 23–24). Likewise, Holland published an entire book devoted to the subject, entitled *Emergence: From Chaos to Order* (1998).

Reductionism, or detailed analysis of the parts and their interactions, is essential for answering the "how" question in evolution: how does a complex living system work? But holism is equally necessary for answering the "why" question: why did a particular arrangement of parts evolve?

WHAT DOES EMERGENCE MEAN?

Despite the recent proliferation of writings on the subject, it is still not clear what the term denotes or, more important, how emergence emerges. One problem is that the term is frequently used as a synonym for "appearance," or "growth," as distinct from a parts–whole relationship. Thus, one of the dictionaries I consulted defined the term strictly in perceptual terms and gave as an example, "the sun emerged from behind a cloud." Even the Oxford English Dictionary, which offered four alternative definitions, gives precedence to the version that would include a submarine that submerges and then re-emerges.

It is not surprising, then, that the overwhelming majority (close to 100%) of the new journal articles on "emergence" and "emergent" that are identified each week by my computer search service involve such subjects as the emergence of democracy in Russia, the emergence of soccer as a school sport in the United States, the emergence of the Internet, the emergence of mad cow disease, and the like. I have deliberately played on this conflation of meanings in this article to illustrate the point, but even avowed complexity theorists commonly use the term (perhaps unwittingly) in both ways. Thus, the subtitle of Mitchell Waldrop's book *Complexity* (1992) is *The Emerging Science at the Edge of Order and Chaos* [1].

Unfortunately, some theorists seem to take the position that emergence does not exist if it is not perceived; it must be apparent to an observer. But what is a "whole"—how do you know it when you see it, or don't see it? And is the mere perception of a whole—a "gestalt" experience—sufficient, or even necessary? John Casti, like Lewes and Morgan, associates emergence with dynamic systems whose behavior arises from the interaction among its parts and cannot be predicted from knowledge about the parts in isolation [41]. "The whole is bigger than the sum of its parts," echoes editor Michael Lissack in the inaugural issue (1999) of the new journal *Emergence* [45]. John Holland [43], by contrast, describes emergence in reductionist terms as "much coming from little" and imposes the criterion that it must be the product of self-organization, not centralized control. Indeed, Holland tacitly contradicts Casti's criterion that the behavior of the whole is irreducible and unpredictable. Holland's approach represents reductionism of a different kind—more like Herbert Spencer's search for a universal "law" of evolution than Bertrand Russell's focus on identifying the parts. (Holland does not stand alone these days, as we shall see.)

Perhaps the most elaborate recent definition of emergence was provided by Jeffrey Goldstein in the inaugural issue of *Emergence* [46]. To Goldstein, emergence refers to "the arising of novel and coherent structures, patterns and properties during the process of self-organization in complex systems." The following are common characteristics: (1) radical novelty (features not previously observed in the system); (2) coherence or correlation (meaning integrated wholes that maintain themselves over some period of time); (3) a global or macro "level" (i.e., there is some property of "wholeness"); (4) being the product of a dynamical process (it evolves); and (5) being "ostensive" (it can be perceived). For good measure, Goldstein throws in supervenience (downward causation).

Goldstein's definition is hardly the last word on this subject, however. One indication of the ambiguous status that the term currently holds in complexity science is the discordant dialogue that occurred in an on-line (Internet) discussion of the topic hosted by the New England Complex Systems Institute (NECSI) during December 2000 and January 2001. Here are just a few abbreviated (and paraphrased) excerpts:

- Emergence has more to do with concepts and perceptions;
- Emergence arises when an observer recognizes a "pattern";
- Perception is irrelevant; emergence can occur when nobody is there to observe it;
- The mind is an emergent result of neural activity;
- In language, meaning emerges from combinations of letters and words;
- A society is an emergent, but it is in turn composed of emergent collections of cells;
- When water boils and turns to steam, this is emergence—something new in the macro- world emerges from the micro-world;
- Temperature and pressure are emergents—macro-level averages of some quantity present in micro-level phenomena;
- Emergence involves a process. Thus, economists can say that a recession emerges;
- It's like a dynamical attractor, or the product of a "deep structure"—a pre-existing potentiality;
- Another participant responded to this with: "I don't know what a deep structure is, but it feels good to say it;"
- Still another objected that dynamical attractors are mathematical constructs; they say nothing about the underlying forces;
- Emergence requires some form of "interaction"—it's not simply a matter of scale;
- Others disagreed: if the properties of the whole can be calculated from the parts and their interactions, it is not emergence;
- Emergents represent rule-governed creativity based on finite sets of elements and rules of combination;
- Emergence does not have logical properties; it cannot be deduced (predicted);
- Another participant replied, maybe not, but once observed, future predictions are possible if it is deterministic;
- Another discussant asserted that a "very simple example" is water, and its properties should in principle be calculable by detailed quantum-level analysis:
- A discussant familiar with quantum theory disagreed; given the vast number of "choices" (states) that are accessible at the quantum level, one would, in effect, have to read downward from H_2O to make the right choice.
- Yet another discussant pointed out that quantum states are always greatly affected by the boundary conditions—the environment.
- Finally, one discussant disputed the entire concept of emergence—it's all in the eye of the beholder—if we cannot even know that there is a real world, that hydrogen and oxygen actually exist, how can we 'know' what they do in combination?

In short, contradictory opinions abound. There is no universally acknowledged definition of emergence, nor even a consensus about such hoary (even legendary) examples as water. And if emergence cannot be defined in concrete terms—so that you will know it when you see it —how can it be measured or explained? As Jeffrey Goldstein noted in his *Emergence* article, "emergence functions not so much as an explanation but rather as a descriptive term pointing to the patterns, structures or properties that are exhibited on the macro-scale" [p. 58, 46]. Editor Michael Lissack, in his own inaugural *Emergence* article, acknowledged that "it is less than an organized, rigorous theory than a collection of ideas that have in common the notion that within dynamic patterns there may be underlying simplicity that can, in part, be discovered through large quantities of computer power…and through analytical, logical and conceptual developments…" [p. 112, 45]. (Well, not always; see below.)

SYNERGY IN NATURE

How can we sort all of this out? The place to start, I believe, is with the more inclusive (and more firmly established)

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concept of "synergy." This concept has been treated in depth elsewhere by this author [47–53]. (See also the two volumes on the evolution of complexity by Maynard Smith and Szathmáry [54,55].) So here I will be brief. Broadly defined, synergy refers to *the combined (cooperative) effects that are produced by two or more particles, elements, parts or organisms—effects that are not otherwise attainable*. In this definition, synergy is not "more" than the sum of the parts, just different (as Aristotle long ago argued). Furthermore, there are many different kinds of synergy. One important category involves what can be called "functional complementarities" effects produced by new combinations of different parts. Water is an obvious example, but so is sodium chloride—ordinary table salt. NaCl is composed of two elements that are toxic to humans by themselves, but, when they are combined, the resulting new substance is positively beneficial (in moderate amounts). Another commonplace example is Velcro, where the two opposing strips, one with many small hooks and the other with loops, are able to create a secure bond with one another.

Another important form of synergy—in living organisms and complex social organizations alike—involves the division of labor (or what could perhaps more felicitously be called a "combination of labor"). *Anabaena* provides an unusual example. *Anabaena* is a cyanobacterium that engages in both photosynthesis and nitrogen fixing. However, these two processes are chemically incompatible. So *Anabaena* has evolved a way of compartmentalizing these two functions. The nitrogen fixing is done in separate heterocysts, and the products are then passed through filaments to other cells [56]. Likewise, there are many different kinds of "symbiosis" between two or more different species in the natural world that involve a division/combination of labor. Thus, virtually all species of ruminants, including some 2000 termites, 10,000 wood-boring beetles, and 200 *Artiodactyla* (e.g., deer, camels, and antelope) are absolutely dependent on the services provided by endosymbiotic bacteria, protoctists, or fungi for the breakdown of the cellulose in plants into usable cellulases [57].

Still another form of synergy involves what I refer to as a "synergy of scale"—an aggregation of interchangeable, like-kind parts that produce unique cooperative effects (say a river or a sand pile). Indeed, many synergies of scale produce yet another form of synergy commonly known as "threshold effects" (say a flood or an avalanche). An elegant example involves the *Volvocales,* a primitive order of marine algae that form colonies of different sizes, from a handful of cells to quasi-organisms with several dozens to hundreds of functionally integrated cells. As it happens, *Volvocales* are subject to predation from filter feeders, and a detailed study some years ago by the biologist Graham Bell documented that *Volvox*, the largest of the Volvocale species, is virtually immune from filter feeders [58]. The reason, as it turned out, was that there is an upper limit to the prey size that the filter feeders can consume. In a similar vein, in the orb web spider, *Metabus gravidus,* 15–20 females are able to produce a synergy of scale when they band together to build a giant collective web that can span a stream where their prey are especially abundant [59]. These and many other forms of synergy—such as joint environmental conditioning, information-sharing and joint decision-making, animal-tool "symbioses," gestalt effects, cost- and risk-sharing, convergent effects, augmentation or facilitation (e.g., catalysts), and others—are discussed in several recent and forthcoming publications by this author [48–53].

It should also be stressed that, far from being vague or ephemeral, synergistic effects are, as a rule, very concrete and eminently measurable. To cite one of the many examples in the publications cited above, during the bitterly cold Antarctic winter emperor penguins (*Aptenodytes forsteri*) huddle together in dense colonies, sometimes numbering 10,000 or more, for months at a time. In so doing, they are able to share precious body heat and provide insulation for one another. A careful study of this collective behavior many years ago showed that these animals were thereby able to reduce their individual energy expenditures by up to 50% [60]. Similarly, in a comparative study of reproduction among southern sea lions (*Otaria byronia*) during a single breeding season, it was documented that only one of 143 pups born to gregarious group-living females died before the end of the season, compared with a 60% mortality rate among solitary mating pairs. The main reasons were that pups in colonies were protected from harassment and infanticide by subordinate males and were far less likely to become separated from their mothers and die of starvation [61]. In short, functional synergies are the source of many "economies" in the natural world.

The main tenets of Lloyd Morgan's paradigm will sound familiar to modern-day holists: quantitative, incremental changes can lead to qualitative changes that are different from, and irreducible to, their parts.

A crucial corollary of this point is that the synergistic effects produced by "wholes" provide a definitive answer to the charge that wholes are merely "epiphenomena"—nothing more than an expression of their parts. In a nutshell, a whole exists when it acts like a whole, when it produces combined effects that the parts cannot produce alone. Moreover, the synergies produced by wholes provide a key to understanding "why" complex systems have evolved. (We will return to this crucial point shortly.) And if there is any doubt about the matter, one can test for the presence of synergy by removing an important part and observing the consequences—a test first suggested by Aristotle in the *Metaphysics* (Book H, 1043b–1044a). I call it "synergy minus one." As a thought experiment, imagine the consequences if you were to remove the gut symbionts from a ruminant animal. Or imagine the consequences for an automobile of removing, say, a wheel, or the fuel supply, or the ignition key, or the driver for that matter. Of course, there are also a great many cases where the removal of a single part may only attenuate the synergy; you may have to remove more than one part to destroy the synergy completely. (Call it synergy minus *n*.) Thus, if you take away a chrome strip from a car, it may only affect the sale price.

REDEFINING EMERGENCE

Accordingly, some of the confusion surrounding the term "emergence" might be reduced (if not dissolved) by limiting its scope. Rather than using it loosely as a synonym for synergy, or gestalt effects, or perceptions, etc., I would propose that emergent phenomena be defined as a "subset" of the vast (and still expanding) universe of cooperative interactions that produce synergistic effects of various kinds, both in nature and in human societies. In this definition, emergence would be confined to those synergistic wholes that are composed of things of “unlike kind” (following Lewes’s original definition). It would also be limited to “qualitative novelties” (after both Lewes and Lloyd Morgan), i.e., unique synergistic effects that are generated by functional complementarities, or a combination of labor. In this more limited definition, all emergent phenomena produce synergistic effects, but many synergies do not entail emergence. In other words, emergent effects would be associated specifically with contexts in which constituent parts with different properties are modified, reshaped, or transformed by their participation in the whole. In these terms, water and table salt are unambiguous examples of emergent phenomena. And so is the human body. Its 10 trillion or so cells are specialized into some 250 different cell types that perform a vast array of important functions in relation to the operation of the whole. Indeed, in biological systems (and automobiles), the properties of the parts are very often shaped by their functions for the whole. On the other hand, in accordance with the Lewes/Morgan definition, a sand pile or a river would not be viewed as emergent phenomena. If you’ve seen one water molecule you’ve seen them all.

Must the synergies be perceived/observed in order to qualify as emergent effects, as some theorists claim? Most emphatically not. The synergies associated with emergence are real and measurable, even if nobody is there to observe them. And what about the claim that emergent effects can only be the result of “self-organization”? Is this a requirement? Again, emphatically not. Self-organization is another academic buzzword these days that is often used rather uncritically. But, as John Maynard Smith points out, there is a fundamental distinction between self-organizing processes (or, more precisely, what should be called “self-ordering” processes) and wholes that are products of functional “organization”(as in the production of organ systems) [62]. Living systems and human organizations are largely shaped by “instructions” (functional information) and by cybernetic control processes. They are not, for the most part, self-ordered; they are predominately organized by processes that are “purposeful” (teleonomic) in nature and that rely on “control information.” (The role of teleonomy and cybernetic control information in biological evolution is discussed in some depth by this author and a colleague in a number of recent publications [48,63–65].)

Consider this example. A modern automobile consists of some 15–20,000 parts (depending upon the car and how you count). If all of these parts were to be thrown together in one great “heap” (a favorite word of Aristotle), they could be described as “ordered” in the sense that they are not randomly distributed across the face of the earth (or the universe, for that matter). Nevertheless, they do not constitute a car. They become an “organized,” emergent phenomenon—a useable “whole”—only when the parts are assembled in a very precise (purposeful) way. As a disorganized heap, they are indeed nothing more than the sum of the parts. But when they are properly organized, they produce a type of synergy (emergent effects) that the parts alone cannot.

In this light, let us return briefly to the NECSI Internet discussion. As defined here, emergence has nothing to do with concepts or patterns or appearances (despite the conflated usage of the term in everyday language). The mind is indeed an emergent phenomenon, but steam is not. Some emergent phenomena may be rule-governed, but this is not a prerequisite; much of it is also instruction-governed. A water molecule is also an emergent phenomenon, but the debate over whether or not the whole can be predicted from the properties of the parts in fact misses the point. Wholes produce unique combined effects, but many of these effects may be codetermined by the context and the interactions between the whole and its environment(s). In fact, many of the “properties” of the whole may arise from such interactions. This is preeminently the case with living systems.

We can use the paradigmatic example of emergence—water—to illustrate. The basic atomic properties of water have been understood for almost two centuries, thanks to John Dalton. At the micro-level, we can understand how the constituent atoms of hydrogen and oxygen are linked together by their covalent bonds. We also know that quantum theory is required to explain some of the remarkable energetic properties of water. But the properties of water also entail numerous macro-level physical principles related to the chemistry, statics, dynamics, and thermodynamics of water. For instance, additional principles of chemistry are needed to account for the state changes that produce water from its constituent gases and, under appropriate conditions, the changes that can reverse the process. Still other principles are required to account for the macroscopic properties of water as a liquid medium: its compressibility, surface tension, cohesion, adhesion, and capillarity. Thermodynamic principles are needed to understand the dynamics of temperature changes in water. Static principles relating to density and specific gravity must be invoked to account for, say, the buoyancy of a rowboat. Hydraulics are needed to understand how water reacts to a force exerted on it. Dynamics and Newton’s laws are relevant for understanding the tidal action of water in large bodies, whereas hydrodynamics is required to explain the behavior of water flowing through a pipe or in a river bed. Here Bernoulli’s principle also becomes germane. By the same token, at the most inclusive geophysical level, the problem of understanding the role of water in world climate patterns presents a formidable research challenge that has necessitated multileveled, multidisciplinary modeling efforts [66]. In sum, the properties of an emergent phenomenon like water, or proteins, or people, may be codetermined by the context(s).

THE LAWS OF EMERGENCE

This conclusion, and the fundamental distinction that was drawn above between emergent phenomena that are self-ordered and the many products of “purposeful” organization (functional design), also has important theoretical implications, I contend. Indeed, this distinction goes directly to the heart of the reductionist–holist debate about the properties of "wholes" (and how to explain them) tracing back to the 19th century, and it poses a direct challenge to the contemporary search for "laws" of emergence and complexity in evolution.

Holland, in his recent book on emergence, acknowledges that this newly fashionable term remains "enigmatic"—it can be defined in various ways. Nevertheless, he believes that some general "laws" of emergence will ultimately be found. Holland asks: "How do living systems emerge from the laws of physics and chemistry… Can we explain consciousness as an emergent property of certain kinds of physical systems?" [p. 2, 43]. Elsewhere he speaks of his quest for what amounts to the antithesis of the entropy law (the Second Law of Thermodynamics)—namely, an inherent tendency of matter to organize itself. Holland illustrates with a metaphor. Chess, he says, is a game in which "a small number of rules or laws can generate surprising complexity." He believes that biological complexity arises from a similar body of simple rules. Stuart Kauffman, likewise, believes that "a few deep and beautiful laws may govern the emergence of life and the population of the biosphere." He talks about "a search for a theory of emergence"—which he characterizes as "order for free" [p. 23, 39].

There have been many variations on this basic theme in recent years, with numerous theorists invoking inherent self-organizing tendencies in nature. Francis Heylighen and his colleagues claim that evolution leads to the "spontaneous emergence" of systems with higher orders of complexity [67]. Mark Buchanan discerns a "law of universality" in evolution—from our cosmic origins to economic societies—as a consequence of self-organized criticality (after Per Bak et al.) [68]. Stuart Kauffman, in his latest book [69], speaks of a new "fourth law of thermodynamics"—an inherent organizing tendency in the cosmos that counteracts the entropic influence of the Second Law. Steve Grand views the emergence of networks as a self-propelled, autocatalytic process [70]. Albert-László Barabási invokes "far reaching natural laws" that, he believes, govern the emergence of networks [71]. And Niels Gregersen and his contributors see an "innate spontaneity" in the emergence of complexity [72]. All of these grand visions can be called reductionist in the sense that they posit some underlying, inherent force, agency, tendency, or "law" that is said to determine the course of the evolutionary process or some important aspect; emergence is thus treated as an epiphenomenon.

Edward O. Wilson also speaks in reductionist terms about emergent phenomena. In his discipline-defining volume, *Sociobiology: The New Synthesis* (1975), Wilson proclaimed: "The higher properties of life are emergent" [p. 7, 73]. He also referred to a "new holism" that would avoid what he called the "mysticism" of past holists, such as Lloyd Morgan and William Morton Wheeler. Wilson did not elaborate on this theme in his volume, but in his more recent book, *Consilience: The Unity of Knowledge* (1998), he endorses what he characterizes as the "strong form" of scientific unification [74]. His "transcendental world view," as he puts it, is that "nature is organized by simple universal laws to which to which all other laws and principles can be reduced" (p. 55). "The central idea of the consilience world view is that all tangible phenomena, from the birth of stars to the workings of social institutions, are based on material processes that are ultimately reducible, however long and tortuous the sequences, to the laws of physics" (p. 226). Wilson claims that an emergent phenomenon such as the human mind can, in theory at least, be reduced to its constituent parts and their interactions. Of course, he concedes, "this would require massive computational capacity," but he derides the claim that the mind and other such "wholes" cannot be understood by reductionist analyses alone. He calls this notion a "mystical concept" [quoted in Miele, p. 79, 75].

Among other things, Huxley asserted that "now and again there is a sudden rapid passage to a totally new and more comprehensive type of order or organization, with quite new emergent properties, and involving quite new methods of further evolution."

In a similar vein, Francis Crick, in a 1994 book [76], explains that "The scientific meaning of emergent, or at least the one I use, assumes that, while the whole may not be the simple sum of its separate parts, its behavior can, at least in principle, be *understood* from the nature and behavior of its parts *plus* the knowledge of how all these parts interact [his italics]" (p. 11). He illustrates with an example from elementary chemistry. The benzene molecule is made of six carbon atoms arranged in a ring with a hydrogen atom attached to each. It has many distinctive chemical properties, but these can be explained, he claims, in terms of quantum mechanics. "It is curious that nobody derives some mystical satisfaction by saying 'the benzene molecule is more than the sum of its parts'…"

Nobody can gainsay the fact that a great deal has been learned about how nature and living systems work through the use of reductionist methods in science, and surely there is much more to come. There may indeed be many law-like patterns at different levels and in different domains of the natural world. But the water example given above illustrates why there are ultimate limits to reductionism and why holistic systems approaches (and even systems-environment approaches) are also essential for understanding "organized" biological wholes. We can see why this is the case by revisiting some of the views expressed above.

First, consider Holland's chess analogy. Rules, or laws, have no causal efficacy; they do not in fact "generate" anything. They serve merely to describe regularities and consistent relationships in nature. These patterns may be very illuminating and important, but the underlying *causal agencies* must be separately specified (though often they are not). But that aside, the game of chess illustrates precisely why any laws or rules of emergence and evolution are insufficient. Even in a chess game, you cannot use the rules to predict "history," i.e., the course of any given game. Indeed, you cannot even reliably predict the next move in a chess game. Why? Because the "system" involves more than the rules of the game. It also includes the players and their unfolding, moment-by-moment decisions among a very large number of available options at each choice point. The game of chess is inescapably historical, even though it is also constrained and shaped by a set of rules, not to mention the laws of physics. Moreover, and this is a key point, the game of chess is also shaped by teleonomic, cybernetic, feedback-driven influences. It is not simply a self-ordered process; it involves an organized, "purposeful" activity.

Similar limitations and biases can be seen in some of the other recent writings on emergence. Thus, for example, Barabási speaks of a "law" of network development, but the process he describes in effect amounts to a Darwinian theory of networks [71]. He tells us that the "fittest" nodes—based on the context and their functional properties—will expand and become the biggest, and most central, at the expense of other nodes. Likewise, Steven Johnson, in his book *Emergence* (2001), cites ant behavior as a model for spontaneous self-organization in nature. But this is inaccurate [77]. In fact, the behavior of the ants is highly "purposeful," even though the "machinery" of cybernetic control may be distributed; ant behavior is instruction-driven, not law-driven. Finally, in his newest book, Kauffman repeatedly hints at "laws" of evolution but concedes these are yet to be found [69]. In the meantime, he now recognizes two other important causal agencies in evolution—"autonomous agents" (a.k.a. living organisms) and natural selection! "Self-organization mingles with natural selection in barely understood ways…" (p. 2).

As for Wilson's claim that we lack only sufficient computational capacity to elucidate the workings of the human mind, the problem with this formulation is that the human mind is not a disembodied physical entity or a mass-produced machine with interchangeable parts. Each mind is also a product of its particular "history"—its distinct phylogeny, its unique ontogeny, and its ongoing, moment-by-moment interactions with its environment(s). Molecular biology and neurobiology—however important to our understanding of mental phenomena—can only illuminate some of the many levels in the life of the mind. As for all the rest of the causal matrix, unfortunately we are not omniscient and most likely never will be.

Equally important, there is a major theoretical segue involved in the modernized version of reductionism espoused by Wilson, Crick, and others. In its 19th and early 20th century incarnation, reductionism meant an understanding of the "parts"—period. Modern-day reductionists, by contrast, speak of the parts *and* their "interactions." But the "interactions" among the parts (and between the parts and their environments) *are* "the system." The "whole" is not something that floats on top of it all. So this cannot properly be called reductionism; it is "systems science" in disguise. Indeed, the interactions among the parts may be far more important to the understanding of how a system works than the nature of the parts alone. For example, we now have a relatively complete map of the human genome. Yet we still have only a sketchy idea of how the genome produces a complete organism. The great challenge for molecular biology in this century will be to do systems science at the molecular level.

EVOLUTION AS A MULTI-LEVEL PROCESS

Though reductionism will no doubt continue to play a vital role in helping us to understand "how" organized systems (emergent phenomena) work in nature, a number of theorists, including this author, have argued that a multileveled "selectionist" approach is necessary for answering the "why" question—why have emergent, complex (living) systems evolved over time? [48–55, 78–80]. David Sloan Wilson speaks of "trait group selection." John Maynard Smith utilizes the concept of "synergistic selection" [59,81,82]. I refer to it as "Holistic Darwinism" [83].

Holistic Darwinism, and the multileveled approach to complexity, is based on the cardinal fact that the material world is organized hierarchically (some prefer novelist Arthur Koestler's term "holarchy"). What the reductionist claims overlook is the fact that new principles, and emergent new capabilities, arise at each new "level" of organization in nature. (Again, our water example provides an illustration.) A one-level model of the universe based, say, on quantum mechanics and the actions of quarks and leptons, or energy flows, is therefore totally insufficient. This point was argued with great clarity and erudition many years ago in a landmark essay, cited above, by the biologist Paul Weiss entitled, "The Living System: Determinism Stratified" [19]. "Organisms are not just heaps of molecules," Weiss pointed out (p. 42). They organize and shape the interactions of lower-level "sub-systems" (downward causation), just as the genes, organelles, tissues, and organs shape the behavior of the system as a whole (upward causation). Furthermore, one cannot make sense of the parts, or their interactions, without reference to the combined effects (the synergies) they produce.

Two important articles published four years apart in the journal *Science* advanced similar arguments. In "Life's Irreducible Structure" (1968), chemist Michael Polanyi pointed out that each level in the hierarchy of nature involves "boundary conditions" that impose more or less stringent constraints on lower-level phenomena and that each level operates under its own, irreducible principles and laws [84]. Polanyi's argument was seconded and augmented by the Nobel physicist Phillip Anderson in a 1972 *Science* article called "More is Different" [85]. "The ability to reduce everything to simple fundamental laws does not imply the ability to start from those laws and reconstruct the universe… The constructionist hypothesis breaks down when confronted with the twin difficulties of scale and complexity… At each level of complexity entirely new properties appear… Psychology is not applied biology, nor is biology applied chemistry…. We can now see that the whole becomes not merely more but very different from the sum of its parts."

Accordingly, emergent phenomena in the natural world involve multilevel systems that interact with both lower- and higher-level systems—or "inner" and "outer" environments, in biologist Julian Huxley's characterization. Furthermore, these emergent systems in turn exert causal influences both upward and downward—not to mention horizontally. (If determinism is stratified, it is also very often "networked.") The search for "laws" of emergence, or some quantum theory of living systems, is destined to fall short of its goal because there is no conceivable way that a set of simple laws, or one-level determinants, could encompass this multilayered "holarchy" and its inescapably historical aspect.

One alternative is the "Synergism Hypothesis," which focuses on the "economics"—the functional effects produced by emergent wholes and their selective consequences.

THE SYNERGISM HYPOTHESIS

One alternative to a law-driven theory of emergence (complexity) in evolution is what I call the "Synergism Hypothesis." This theory is discussed in detail in the publications that were cited earlier, so I will again be brief.

In a nutshell, the core hypothesis is that synergistic effects of various kinds have played a major *causal* role in the evolutionary process generally and in the evolution of cooperation and complexity in particular. Although this may sound like a contradiction of Darwinian natural selection theory, in fact the opposite is true. It is, rather, a matter of viewing the same phenomena from a different perspective—a shift of focus from the role of the genes to the role of the "phenotype" (the organism itself in a given environment). What is often downplayed in the gene-centered, Neo-Darwinian paradigm is the fact that it is actually the phenotype that is differentially "selected."

Moreover, natural selection does not in fact *do* anything. Natural selection is often portrayed as a "mechanism " or is personified as a causal agency that is out there in the environment somewhere. The practice started with Darwin, who wrote in *The Origin* that "natural selection is daily and hourly scrutinizing throughout the world, every variation, even the slightest; rejecting that which is bad, preserving and adding up all that is good; silently and insensibly working…" [p. 133, 5]. (In a later edition, Darwin preceded this passage with the phrase: "It may be metaphorically said….") In reality, the differential "selection" of a trait, or an adaptation, is a consequence of the functional effects it produces in relation to the survival and reproductive success of a given organism in a given environment. It is these functional effects that are ultimately responsible for the trans-generational continuities and changes in nature.

Another way of putting it is that, in evolutionary processes, causation is iterative; effects are also causes. And this is equally true of the synergistic effects produced by emergent systems. In other words, emergence itself (as I have defined it) has been the underlying cause of the evolution of emergent phenomena in biological evolution; it is the synergies produced by organized systems that are the key. To be sure, a change in any one of the parts may affect the synergies produced by the whole, for better or worse. A mutation associated with a particular trait might become "the difference that makes a difference" (to use Gregory Bateson's mantra), but the parts are interdependent and must ultimately work together as a team. That is the very definition of a biological "whole." (A point often overlooked in the debate is that a particular trait may affect *differential* reproductive success, but it is still the whole organism that must survive and reproduce.) Furthermore, natural selection is a process that "weeds out" what doesn't work, but it also favors what does work; both aspects are equally important. In other words, evolution is both a trial-and-error and a trial-and-success process (as paleontologist George Gaylord Simpson put it).

The Synergism Hypothesis can also be characterized as, essentially, an economic (or better said, bioeconomic) theory of complexity; it is the functional "payoffs" produced by synergistic phenomena that have been responsible for the "progressive" complexification of living systems (and human societies as well). And natural selection is essentially indifferent to whether or not a trait is self-ordered by some law-like process or is functionally organized by the genes (or by cultural influences for that matter). No trait is exempt from being "tested" in relation to its functional consequences (if any) for survival and reproduction. To assume otherwise would be Panglossian in the extreme; it would assume away the contingent nature of life—and evolution.

Consider three brief examples of "synergistic selection," among the many contained in the writings by this author that were cited earlier. The first example is the eukaryotic cell—a triumph of both specialization (a division/combination of labor) and symbiogenesis or a merger among previously independent organisms. Eukaryotes may grow to several thousand times the size of their bacterial ancestors, and this giant step in evolution was made possible in part because the eukaryotes' abundant endosymbionts—the mitochondria and chloroplasts (in plants cells)—are able to produce some 15–20 times more energy than a typical bacterium, while the machinery of respiration in eukaryotes is able to make much more efficient use of this energy. In short, emergence often "pays" in evolutionary terms—though not always of course.

A second example is lichen, a symbiotic partnership involving various kinds of green algae, or cyanobacteria, and fungi. (There are more than 20,000 different lichen species, all told.) The algae or cyanobacteria are photosynthesizers. They provide energy-capturing services, while the fungi bring surface-gripping and water-storage capabilities to the relationship—talents that are especially useful in the barren, harsh environments that lichens are legendary for "pioneering." How do we know this is an emergent, synergistic system? Because the "team" can do what neither partner can do alone. There happen to be asymbiotic forms of various lichen partners that lack their joint capabilities and are far less efficient at energy capture [86].

A third example, close to home, is humankind. Much has been made of the role of bipedalism, tools, our large brains, language, and other supposed "prime movers" in human evolution. But the fact is that there was no prime mover. Our evolutionary success was the result of a synergistic nexus of all of these capabilities and more—most especially our ability to exploit the potential advantages (synergies) in social organization for self-defense, food acquisition, information sharing, and an ever-expanding division of labor. How do we know that human evolution involved a synergistic "package"? Just apply Aristotle's test. Imagine the consequences for evolving hominids if one could magically take away our bipedalism, our dextrous hands, our large brains, our tools, our social cooperation, or our language skills. (For a more detailed rendering of the "Synergistic Ape" scenario in human evolution, see Corning [50,53].)

In sum, the Synergism Hypothesis offers a functional (economic) explanation for the evolution of emergence and complex systems in nature. Moreover, it is fully consistent with Darwin's theory and with the growing research literature on the evolution of biological systems at various levels of organization, not to mention the "major transitions" that are the particular focus of Maynard Smith and Szathmáry's work in this area (cited earlier). It does not deny self-ordering, even "law-like" processes in nature (many of these have been documented and appreciated for generations). But it does make natural selection the ultimate arbiter in biological evolution—the "supreme court."

THE TWO FACES OF JANUS

Arthur Koestler, in his landmark 1969 volume *Beyond Reductionism: New Perspectives in the Life Sciences* (co-edited with J. R. Smythies) deployed a metaphor that was meant to convey the idea that both reductionism and holism are essential to a full understanding of living systems [87]. Janus—the Roman god of entries, exits, and doorways—has traditionally been portrayed as a head with two faces that are looking in opposite directions—both in and out, past and future, forward and back—and, for Koestler, upward and downward. Emergence (at least as defined here) is neither a mystical concept nor is it a threat to reductionist science. However, a holistic approach to emergence also has a major contribution to make. In accordance with the Synergism Hypothesis, it is the synergistic effects produced by wholes that are the very cause of the evolution of complexity in nature. In other words, the functional effects produced by wholes have much to do with explaining the parts. (Another way of putting it is that synergy explains cooperation in nature, not the other way around.) In this light, perhaps the time has come to embrace the full import of Koestler's famous metaphor; in fact, both faces of Janus are indispensable to a full understanding of the dynamics of the evolutionary process.

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