1 Prologue: The New Evolutionary Paradigm

> True innovation occurs when things are put together for the first time that had been separate.
>
> Arthur Koestler
> *Beyond Reductionism*

When Arthur Koestler, the famed novelist and respected polymath, penned those words more than 30 years ago, he was seeking to draw our attention to a phenomenon that is greatly underrated and vastly more important even than Koestler imagined. I call it nature's magic.

Grand theories are commonplace these days. It seems that new ideas must shout to be heard. So the claims for this book may sound like hyperbole as usual. The thesis, in brief, is that synergy – a vaguely familiar term to many of us – is actually one of the great governing principles of the natural world. It has been a wellspring of creativity in the evolution of the universe, and it has greatly influenced the overall trajectory of life on Earth. It has played a decisive role in the emergence of humankind. It is vital to the workings of every modern society. And it is no exaggeration to say that our ultimate fate depends upon it.

All this may sound like so much dust-jacket rhetoric, but the Synergism Hypothesis (as I call it) is a serious scientific theory that is fully consistent with Darwin's theory, and with the canons of the physical, biological, and social sciences, not to mention the new science of complexity. The theory, in a nutshell, is that synergy is not only a ubiquitous effect in nature; it has also played a key *causal* role in the evolutionary process. It has been at once the fountainhead and the *raison d'être* for the progressive increase in complexity over the broad span of evolutionary history. Far from being

law-like and predictable, however, this trend has always involved an open-ended, creative, historically constrained experiment in which economic criteria (broadly defined) have predominated. Complexity – in nature and human societies alike – is not the product of some inexorable force, or mechanism, or "law." It has been shaped by the immediate functional advantages – the "payoffs" – arising from various forms of synergy.

What Is Synergy?

How do I define synergy? Very broadly, the term refers to the combined, or cooperative, effects produced by the relationships among various forces, particles, elements, parts, or individuals in a given context – effects that are not otherwise possible. The term is derived from the Greek word *synergos*, meaning "working together" or, literally, "co-operating." Synergy is often associated with the cliché, "the whole is greater than the sum of its parts" (which dates back to Aristotle, in the *Metaphysics*), but this is actually a rather narrow and even misleading characterization. In fact, synergy comes in many different forms; sometimes wholes are not greater than the sum of their parts, just different. We will examine the phenomenon of synergy in greater depth in the next few chapters. Here are just a few brief examples, starting with some of the basic forces of nature:

- The center of gravity of an object, say an automobile, is actually a synergistic effect. It depends upon how the combined weight of all its parts is distributed, as we learned in school. But if we were to disassemble the car, its center of gravity would disappear; it would be parceled out (so to speak) among each of the 15,000 or so individual parts.
- The vortex, or whirlpool, that occurs when your bath water flows down the drain is actually a complex effect produced by the combined actions of several different forces – gravity, water pressure, air pressure, rotational forces, centrifugal forces, even the initial state of the bath water.
- "Supermolecules" of 50 atoms or more may take on wholly new collective properties that their lightweight cousins lack – greater stability, better binding capabilities, a different geometry, less energy dissipation (entropy), and the like.
- Chlorine and sodium are both toxic to humans by themselves, but when they are combined they produce a totally new substance that is positively beneficial (in moderate amounts) – ordinary table salt.

- Chrome–nickel–steel, an alloy synthesized from three natural elements, may be stronger by 35% than all of its constituents added together. In the bargain, chrome–nickel–steel has rust-free properties, another synergistic effect. (The nickel adds strength to the steel and the chromium reduces its tendency to oxidize.)
- Synergy is commonplace in medicine and health care. One example is the effect produced by using atropine and prednisone together to treat eye inflammations. The atropine serves to dilate the eyes so that the prednisone, an anti-inflammatory drug, can work more effectively.
- Our alphabet is also highly synergistic. Take the words "rat," "cat," and "bat." Each combination of letters produces a different image in the reader's mind. But imagine what would happen if the vowels were removed. Like the coins that magically disappear into a prestidigitator's folded handkerchief, the synergy would vanish and we would be left with the two-letter nonsense combinations rt, ct, bt.
- One cup of beans, eaten by itself, provides the nutritional equivalent of 2 ounces of steak. Three cups of whole-grain flour consumed alone provides the equivalent of 5 ounces of steak. But when they are ingested together, they provide the equivalent of 9.33 ounces of steak, or 33% more usable protein. The reason is that their constituent amino acids are highly complementary. Grains are low in lysine, while legumes are low in methionine. When combined they compensate for each other's deficiencies. In other words, the whole taco is truly greater, nutritionally, than the sum of its parts.
- Lichen, patchy growths that are found on tree trunks, rocks, and even bare ground in many woodland areas, are legendary for their ability to colonize barren environments as well. The key to their success as "nature's pioneers" lies in their complementary talents. Lichens actually consist of symbiotic partnerships between 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 to the partnership both surface-gripping and water-storage capabilities – talents that are especially useful in a harsh environment. The partners may even join forces to create a specialized reproductive organ called a thallus that produces combined, symbiotic spores. Together, the "team" can do what neither partner can do alone.[1]
- "Tensegrity" (tensional integrity) refers to the way in which the counteracting effects of compression and tension can be used synergistically

to achieve structural "integrity" in certain self-stabilizing physical structures. The term tensegrity was coined by the well-known engineer–inventor Buckminster Fuller (who, incidentally, also promoted the concept of synergy) to characterize his most famous invention, the remarkable geodesic domes that today number in the hundreds of thousands world-wide.[2] We now know that many kinds of tensegrity structures also exist in nature. One example is the appropriately named "buckminsterfullerene" – carbon-60 and several variants. The great stability and remarkable binding properties achieved by these recently synthesized "supermolecules" of pure carbon (affectionately known as "Bucky Balls") derive from their physical resemblance to geodesic domes and soccer balls. Another example of tensegrity, closer to home, is the human body. The interaction between our bones, muscles, tendons, and ligaments gives our bodies their distinctive combination of structural stability and mobility. Likewise, every one of the ten trillion or so cells in each of our bodies is supported by an internal scaffolding, called a cytoskeleton, which is composed of actin filaments and microtubules. The actin filaments counteract pulling forces that are exerted on the cell and the microtubules resist compression forces. We are totally dependent on these and many other kinds of synergy. (Indeed, Harvard pathology professor Donald E. Ingber sees tensegrity as one of the basic organizing principles in life.[3])

The Causal Role of Synergy in Evolution

Accordingly, I will argue that synergy ranks up there with such heavyweight concepts as gravity, energy, entropy, and information as one of the keys to understanding how the world works and how we got here – not to mention where we are going. Moreover, synergy has been a creative dynamo and a prolific source of innovation in evolution, as we shall see. Synergy was present at the "Big Bang." It has been deeply involved in the evolution of our physical universe. Some time after the Earth first evolved, some 4.5 billion years ago, synergy provided the payoffs (the emergent functional effects) that arose in the still-mysterious process by which networks of complex prebiotic molecules joined together to catalyze the first living systems. It also provided the "benefits" which, over time, produced the awesome complexity of photosynthesis. (Entire books have been devoted to describing our as-yet-imperfect understanding of how photosynthesis works.) Synergy

is found also in the intricate combination of labor in complex eukaryotic cells and in the "enchanted loom" of the human mind – to use the soaring image of neurobiologist Charles Sherrington – where wondrous new synergies are invented and actualized every day. In other words, the unique cooperative effects produced by various combinations of "parts" in a given context are themselves distinct, partially independent causes of subsequent evolutionary events.

The universe can be portrayed as a vast structure of synergies, a many-leveled edifice in which the synergies produced at one level serve as the building blocks for the next level. Moreover, unpredictable new forms of synergy, and even new principles, emerge at each level of organization. I like to call it a "Magic Castle" (with a nod to Walt Disney), because there is something truly magical about this creative aspect of nature. In the course of providing a guided tour of this Magic Castle (in Chapters 2, 3, and 4), I will show that synergy is of central importance in virtually every scientific discipline, though it very often travels incognito under various aliases (mutualism, cooperativity, symbiosis, win–win, emergent effects, a critical mass, coevolution, interactions, threshold effects, even non-zero-sumness).

According to the reigning dogma of evolutionary biology – commonly known as Neo-Darwinism – "random" gene mutations (and related molecular-level phenomena) are said to be the underlying source of creativity in evolution. It is said that the course of biological evolution has been shaped over time by relentless competition among "selfish genes." I will argue that the Neo-Darwinists have got things skewed. In fact, it is the functional benefits – the survival advantages – produced by novelties of *various* kinds and at various levels (including even behavioral innovations, as we shall see) that have defined the trajectory of evolution. Contrary to the popular misconception, natural selection does not (literally) select genes. It differentially rewards (or disfavors) different genes, and gene combinations, based on the *effects* they produce in a given environment. It is the functional payoffs that matter.

In this light, it is novel forms of functional synergy (cooperative effects) that have been responsible, over time, for shaping the progressive evolution of complexity in nature through a process that can be characterized (after biologist John Maynard Smith) as "synergistic selection." I call this new paradigm "Holistic Darwinism," and I side with the growing number of contemporary biologists who hold that evolution must be viewed as a multi-leveled process in which selfish genes are most often subordinated to the

dictates of "selfish genomes" – synergistic systems. Outlaw genes are the exception rather than the rule. The Synergism Hypothesis and the theory of Holistic Darwinism will be developed in some detail in Chapters 5 and 6.

The "Synergistic Ape"

Many different theories of human evolution have been proposed over the years. (I will briefly describe some of them in Chapter 7.) Humans have been variously characterized as the "killer ape," the "naked ape," and the "talking ape." We have been called "man the hunter," "woman the gatherer," and even the "selfish ape" (looking out primarily for ourselves and our kin).

However, I will propose a radically different scenario for human evolution. I will develop the theory that, in effect, we invented ourselves through a process that I have dubbed "Neo-Lamarckian Selection." We are uniquely the "inventive ape." Moreover, the many new kinds of synergy that our ancestors invented over the course of perhaps 6 million years played a starring role; we are also, quintessentially, the "synergistic ape." Finally, the Synergism Hypothesis also applies to the explosive rise of complex human societies during the past few thousand years (as described in Chapter 8). Indeed, the mostly unrecognized common denominator in every one of the recent game theory models (so-called) of cultural evolution is synergy. It is synergy that has been responsible for the evolution of cooperation in nature and humankind, not the other way around.

The Perils of Prediction

It is a common misconception that synergy always refers to positive effects; synergy is presumed always to be a good thing. But this is not so. Every day, in a thousand different ways, our lives are shaped, and re-shaped, by synergy. Yet our attitude toward it – our judgment about whether it is a good thing or a bad thing – depends on our values and where we stand (or perhaps which side we're on). In fact, there is a mirror image on the "dark side" for every one of the different categories of positive synergy that I will describe in Chapter 2. I will discuss "negative synergy," or sometimes "dysergy," in some detail in Chapter 4 ("Black Magic"). I will also highlight some special categories of positive and negative synergy – what I call the "Bingo Effect"

(when some new combination crystallizes, often unexpectedly), as well as the twin phenomena of "synergy plus one" and especially "synergy minus one." As we shall see, both kinds of disruptions may represent a potentially serious threat to any complex system.

A colleague, the science writer Connie Barlow, has pointed out that the Synergism Hypothesis is more than a hypothesis, or a theory. It also provides a worldview that focuses on the effects produced by the relationships between things. It highlights a fundamental property of the universe and, more relevant for humankind, a fundamental property of human societies. One of the most important implications of this worldview, in fact, is developed in the penultimate chapter, where it is argued that the enduring search for some hidden "law" of history – some deterministic force or mechanism – that will allow us to predict the future course of the "human career" (in anthropologist Richard Klein's term) is fundamentally flawed. The "Neo-Pythagoreans" – as I call them – exclude a priori (by the very nature of their quest for universal "laws") the contingent, historical, synergistic phenomena that have shaped the overall course of the evolutionary process. As a result, these theorists are blind to a major causal agency in evolution. What is required instead, I will argue, is a "science of history."

The implications of this worldview are discussed in the final chapter: "Conjuring the Future: What Can We Predict?" The synergy paradigm provides an answer to this "ultimate question" that is at once challenging, empowering, and threatening. If we should choose to ignore these implications, we will do so at our peril.

2 The "Enchanted Loom"

> The brain is waking and with it the mind is returning . . .
> Swiftly the head-mass becomes an enchanted loom,
> where millions of flashing shuttles weave a dissolving pattern . . .
> a shifting harmony of sub-patterns.
>
> Charles S. Sherrington

Sherrington's famous metaphor for the human mind could be applied to the rest of nature as well. The natural world could be likened to an enchanted loom that weaves a golden tapestry of synergy. For synergy is all around us, and within us; we are completely dependent on it. Yet we often take it for granted or fail to appreciate its *gravitas*, its weightiness. It's profoundly paradoxical. And potentially dangerous. (We'll come back to this point in the final chapter.)

A Golden Tapestry of Synergies

Let's start our survey with something as ordinary as the humble clay brick, one of humankind's oldest and least honored technologies. Without a plan for how to use them and a supply of mortar (itself a synergistic combination of cement, lime, sand, and water), a pile of bricks will be . . . well, a pile of bricks. But when the bricks are arranged in precisely ordered patterns and then bonded together they "collaborate" to form a great variety of structures: factories, fireplaces, canals, churches, prisons, watchtowers, garden walls, roads, sidewalks, even kilns for making more bricks.[1]

When the Toronto Maple Leafs recently moved out of their famed Maple Leaf Gardens after 67 years of making hockey history (every game had been

sold out since 1949), a sentimental remembrance in a Toronto newspaper noted that the Gardens in its heyday was one of the largest brick buildings in the world. Its 750,000 bricks, if laid end to end, would stretch for 28 miles. Of course, in that case the synergy would disappear; you might then have only the longest line of bricks in the world. And so it is with any building that is demolished. In a fraction of the time that it took to build it, the synergy is gone forever – sometimes to our regret. There is an entire book filled with photographs, drawings, and descriptions of architectural masterpieces by Frank Lloyd Wright, perhaps America's greatest architect, entitled *Lost Wright*.

Synergy is such a commonplace aspect of the way we prepare our food that we don't even notice it most of the time. A particularly tasteful example is a lemon pie – a combination of butter, eggs, lemon juice, sugar, flour, and salt. How do we know it's synergistic? Imagine what would happen if an absent-minded baker switched the prescribed quantities of sugar (one and one-quarter cups in our recipe) and salt (one-eighth teaspoon). Or imagine what would happen if a slightly different combination of ingredients – say butter, egg yolks, lemon juice, salt, pepper, and vinegar – were prepared in a slightly different way. We would call it Hollandaise sauce. In each of these cases, what our taste buds respond to are the synergies – the combined effects.

Written language is also synergistic. The 26 letters of our English alphabet make meaningful words only in precise combinations (with some obvious exceptions). To illustrate, it takes only an alteration in the order of the same combination of letters to magically transform the word "being" to "begin" or "note" to "tone." Or consider "unite" and "untie," two words which have almost opposite meanings. And we can add more levels of synergy by stringing words together into phrases, sentences, paragraphs, etc. We can see how the synergy works by changing the word order in the newspaper headline "dog bites man" to "man bites dog" – the classic journalism school example of what is, and is not, a newsworthy story. (Palindromes like "Madam I'm Adam" are based on the fact that certain meaningful letter combinations will read the same in reverse.)

Note, however, that the synergy in these examples is not located in the words themselves. The words are essentially arbitrary two-dimensional patterns. The synergy is what happens in the reader's mind. The words will evoke no synergy at all for an infant or an adult who can't read English. Moreover, the very same word can produce different synergies in different languages. We all know what the word "gift" means in English. In German

it means "poison." Even within the same language, a word can have very different meanings, depending on the context. Take the following sentence: "I am at present present to present a present."

Technology as Synergy

Human technology is also rife with synergy – needless to say. Look at duralumin, a compound of aluminum, copper, manganese, and magnesium that combines the light weight of aluminum with the strength of steel. There is also synergy in the so-called superalloys composed of nickel, cobalt, and various other elements. Superalloys are favored for jet engines and spacecraft because they can resist very high temperatures, high pressures, and oxidation. Then there are the superconductors – crystalline compounds like yttrium–barium–copper oxide, or bismuth–strontium–calcium–copper oxide that, in ways still unknown, allow for the flow of electricity through the material with little or no resistance and at much higher temperatures than had previously been possible (near absolute zero).

"Two Plus Two Equals Five" reads an ad for GE's co-generation equipment. If an industrial plant needs both electricity to power its machinery and steam heat or hot water for various other needs, a co-generation system can do both jobs at once with results that are synergistic. An electrical power plant alone has an efficiency that rarely exceeds 40%. A conventional hot-water heater has an efficiency of about 65%. In both cases, the unused energy goes to waste (entropy). By combining the two processes in one system, energy efficiencies of 95% can be achieved at a much lower overall cost. Co-generation systems typically pay for themselves in three to five years.

Consider also a commonplace consumer product like an automobile. Actually, an automobile is a technological wonder that our not-so-remote ancestors of, say, 200 years ago would surely have marveled at. It represents an assemblage of (depending on the car and how you count) some 15,000–20,000 precisely designed and manufactured parts, comprising some 60 different materials. It also embodies many different technologies, from weaving to glassmaking, metallurgy, ceramics, hydraulics, rubber-vulcanizing, electricity, paints, plastics, and the latest in electronics. And it also incorporates literally thousands of different human inventions: threaded screws, articulated gears, springs, hinges, clamps, cotter pins, bolts, chains, filters, locks, lock washers, Velcro fasteners, ball bearings, fans, pumps, valves, storage batteries, electric motors, and, of course, internal combustion engines.