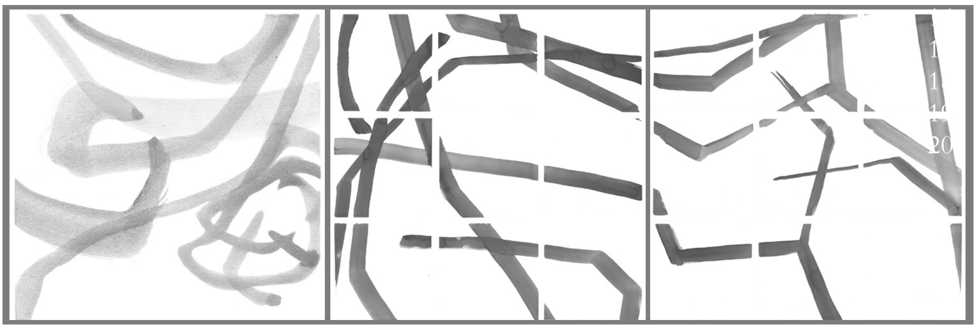
chapter one

Why a Science of Complexity?



"Quarks are simple but jaguars are complex," explained the Nobel laureate in physics and pioneer in complexity science Murray Gell-Mann (1994). So too, the inner workings of a cell in a worm are more complex than those of the sun. A survey of particle physics research finds that the "universe is a complex and intricate place" (Lincoln 2012).

Humans are even more complex than worms or jaguars—especially in world affairs as individuals and groups of humans deal with one another across borders of culture, language, politics, and geography. As Ralph Waldo Emerson put it 1847, "The last lesson of modern science is that the highest simplicity of structure is produced, not by few elements, but by the highest complexity. Man is the most composite of all creatures"—quite the opposite of the wheel insect, *volvox glob*.

The difference between complexity and complication was made clear in an essay by Daniel Barenboim on Richard Wagner (*New York Review of Books*, June 20, 2013). "Wagner's music is often complex, sometimes simple, but never complicated." Complication implies "the use of unnecessary mechanisms or techniques that could potentially obfuscate the meaning of the music. These are not present in Wagner's work." By contrast, complexity in Wagner's music is represented by multidimensionality—"many layers that may be individually simple but that constitute a complex construction when taken together." When Wagner transforms a theme, he does so by adding dimensions. "The individual transformations are sometimes simple but never primitive. . . ." Wagner's "complexity is always a means and never a goal in itself."

Human society and culture did not just drop from the sky but, like other human activities, arose from beings and processes shaped by millions of years of evolution (Wilson 2012). Humans and the estimated seven million other animals who now roam the planet, from the ocean floor to the highest mountains, evolved from single-celled ancestors who, some eight hundred million years ago, probably resembled today's *Capsapora owczarsaki,* a tentacled, amoeba-like creature barely noticed by scientists until 2002. Animal bodies can total trillions of cells, able to develop into muscles, bones, and hundreds of other kinds of tissues and cell types. From single cells arose a vast kingdom of complexity and diversity (Zimmer 2012).

Humans, however, are not just "wet robots" (Dilbert's term) and social science is not just biology or physics. Still, those who seek to understand political life need an approach to scientific inquiry with strong links to the life and other sciences. They must consider human affairs in the context of other animate and inanimate activities across a shrinking planet.

Scientists from many disciplines now mobilize to study the most complex object in the known universe, the human brain. The brain activity mapping project sponsored by the U.S. government, starting in 2013, and conducted at several universities will study how the brain is wired at all levels—from individual nerve cells to the neuronal superhighways between its various lobes and ganglia. The project will institutionalize the emerging science of connectomics. Brain mapping and the human connectome project should shed light not only on mental processes but also on mental disease, brain injuries, and psychopathologies.

The Complexity of Interdependence

The complexity of global interdependence demands a science of complexity to fathom it. The essence of life is interdependence—every element dependent on every other. Walt Whitman depicted this reality in his *Salut au Monde*:

> Such gliding wonders! Such sights and sounds!
> Such join'd unended links, each hook'd to the next,
> Each answering all, each sharing the earth with all. . . .
> I see the shaded part on one side where the sleepers are sleeping,
> and the sunlit part on the other side,
> I see the curious rapid change of the light and shade,
> I see distant lands, as real and near to the inhabitants of them as
> my land is to me.

A few years before Whitman composed his *Leaves of Grass,* Karl Marx in 1848 described how global economics intensified the planet's "unended links, each hook'd to the next." And long before Thomas L. Friedman (2007) argued that *The World Is Flat,* the *Communist Manifesto* declared: "In place of the old local and national seclusion and self-sufficiency, we have intercourse in every direction, universal interdependence of nations [*eine allseitige Abhängigheit der Nationen voreinander*]. And as in material, so also in intellectual production. The intellectual creations of individual nations become common property. National one-sidedness and narrow-mindedness become more and more impossible, and from the numerous national and local literatures, there arises a world literature."

The *Manifesto* postulated that human history is the story of class struggle rooted in a materialist dialectic. More than two millennia before Marx, Thucydides described a struggle for political hegemony that nearly destroyed the glory that was Greece. The idea that politics is dominated by zero-sum competition was set out again by Machiavelli in Renaissance Florence and by Thomas Hobbes amid England's seventeenth-century civil war. Hobbes postulated a "war of all against all" that can be quelled only by an almighty sovereign who imposes order over anarchy. Twisting Darwin's theory of evolution to rationalize European dominion over Africa and Asia, nineteenth-century Social Darwinists proclaimed that life is a struggle for survival and that might makes right. Jack London in the early twentieth century described life in Alaska as dog-eat-dog. Nazi geopoliticians asserted that East Europeans must give way so the master race could expand.

Contrary to Marx, to Social Darwinists, and to disciples of Ayn Rand, we now see that evolution is complex—shaped by cooperation as well as competition—between and within species (Kropotkin 1904; Minelli and Fusco 2008; Flannery 2011). The red-toothed "survival of the fittest" interpretation of evolution is much too simplistic. Humans, like other living things, often collaborate to increase their survival prospects and other interests. Scientists debate whether cooperative tendencies result from a "selfish gene" or other factors. The Nobel Prize for Economics in 1986 went to James M. Buchanan, who warned that politicians and publics seeking their own self-interest could institutionalize irresponsibility as government outlays exceeded revenue. The Nobel Prize for Economics in 2012 went to an economist and a mathematician, Alvin Roth and Lloyd Shapley, who used cooperative game theory to show how goods could be shared to mutual advantage.[1]

As humans specialized, society became more complex and interdependence mounted. Adam Smith posited an "invisible hand" that served the common good. This was not the whole story, however, for interdependence can cut two ways. The term denotes *mutual vulnerability*—a relationship so close that the parties can help or hurt one another If an actor cannot deflect the changes made by another, it is "vulnerable." If it can thwart the change, it is merely "sensitive" (Keohane and Nye 2011). The policy implication is that the invisible hand may need guidance and even regulation.

A fit society thrives on complexity and its capacity to create values from the challenges and opportunities arising from an ever-changing environment.

Like a coral reef, participants in a fit society exist in a symbiosis that protects and nourishes both individuals and the wider community. Mutual gain and high fitness are the products of self-organization and creative responses to complexity. Diminished fitness, by contrast, is the consequence of a zero-sum, exploitative approach to life—the usual pattern when there is no law or rigid, top-down rule. These concepts are elaborated in later chapters, but the basic argument is summarized in Figure 1.1.

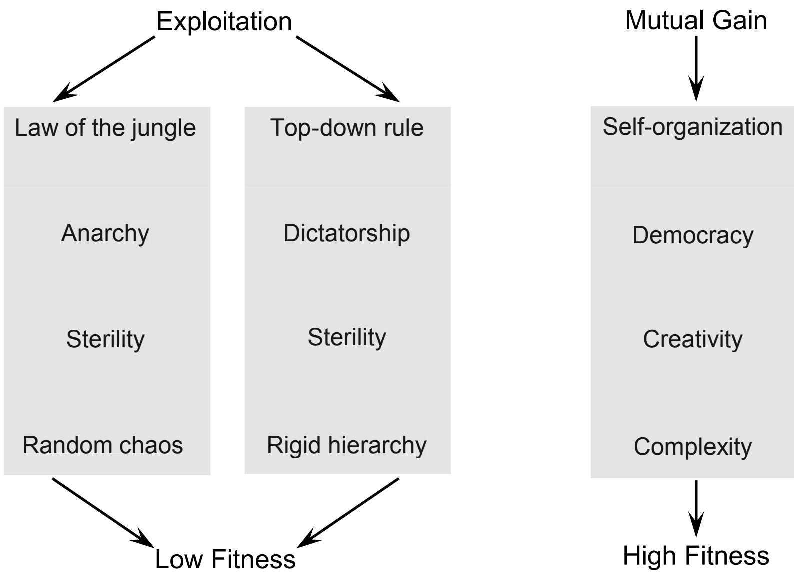


FIGURE 1.1. Exploitation, Mutual Gain, and Fitness: Likely Linkages

CHAOS OR COMPLEXITY?

The deep realities of life are difficult to discern and assess. As John Muir cautioned, "Touch one thing and you find it is linked to everything in the universe." If a butterfly flaps her wings in China, how will this affect the next day's weather in Kansas? As weather develops, it feeds back on itself and influences future weather. The butterfly effect underscores the interconnectedness of all things. Even if we could trace long chains of interaction, however, small errors in initial measurements would multiply and lead to erroneous conclusions. Chaos theorists conclude that the chains of cause and effect in many domains—weather, turbulent rivers, insect populations, stock markets, and others—cannot be accurately predicted. Some chaotic structures may be in principle deterministic, but in practice they are virtually unpredictable (Marshall and Zohar 1997, 81–86; Krasner 1990). A miniscule error in the initial measurement of just one variable will skew the entire calculation.

Complexity science agrees with chaos theory and worldviews such as Buddhism that all things are interdependent. But it avers—or hopes—that common patterns characterize the evolution of all things, and that, with hard work and some luck, we may identify them and begin to fathom their interactions. Thus, complexity scientists have discovered fractal properties within heartbeats as well as in stock market movements and air flow turbulence.[2] They have investigated scalability. It appears that some of the same principles apply to animals of different sizes and species—even to cells. Thus, the metabolic rate is proportional to body mass in everything from a mouse to a goose to an elephant. Organisms reach a certain weight at a certain age. Or look at a forest. At first, it may seem to be a wild thicket, randomly organized, with no structure. But there is structure. A forest has trees of a certain type, size, and age—often spaced at a similar distance from each other, each consuming a similar amount of energy and growing at a similar pace. In bodies, as in entire ecosystems and in sprawling cities, networks provide basic functions that range from blood circulation to irrigation to electric transmission. The pace of life slows as size of organism increases. There are economies of scale. Cities, like organisms, seem to obey power laws of scaling. As cities expand, we see fewer gas stations per capita. With more people, the length of electric lines needed to serve each person decreases. The dynamics of life go beyond mere natural selection (West 2011).

It may appear that complexity can be reduced to regularity and simplicity. Thus, Acemoglu and Robinson (2012) studied many complex and seemingly quite different cases over time and concluded that "nations fail" because their leaders exploit the common good for private gain.[3] Similarly, Emerson (1847) believed that Goethe possessed "a power to unite the detached atoms again by their own law." Goethe contributed a key to many parts of nature through the rare turn for unity and simplicity in his mind.[4]

Following in the footsteps of Goethe and—before him—Leonardo Da Vinci, complexity scientists seek to identify and understand the patterns of behavior common to all forms of life.[5] But many structures—from a beehive to the weather to the human brain—seem to defy any reductive approach. Isaac Newton appeared to have discovered the basic laws underlying the flux of physical motion, but Newtonian physics was later supplemented or supplanted by relativity and quantum mechanics.[6] Reductionism does not work where reality breaks from linear sequencing—with outcomes not proportional to ostensible causes, and where wholes cannot be understood from analyzing their parts (Kauffman 2008).

Classical economics is also reductionist. It assumes that the real value of goods is determined by the price they fetch in the market place. Put into practice, however, this approach is unfair and conduces to huge disparities in income. Theoretically, it is untenable because one cannot know in advance what goods and what supply/demand conditions will exist. Nor, in biology, could we anticipate that from the lungs of lung fish would evolve the swim bladders that assure neutral buoyancy in the water column of certain fish—nor what kinds of creatures would find their niche within those bladders (Kauffman 2008; 2011).

The Evolution of Societal Fitness

A system of cooperative bands provides the social infrastructure that can nurture creativity. The social institutions and behaviors that differentiate humans from other primates developed in large part because they were enabled by biological and historical accidents. Cooperation is a key behavior that distinguishes humans from other primates. A system of cooperative bands provides the social infrastructure that nurtures human creativity. No individual can construct a rocket ship. To build and fly the International Space Station required the collaboration of thousands of persons, most of whom never met one another, and many of whom came from "tribes" with distinct languages and ways of life.

Social institutions and world affairs, like all evolution, have been decisively impacted by accidents. "Evolution is, fundamentally, a process of cumulative integration: Novel combinations of older material or otherwise ordinary features generate systems of new properties—emergent properties—which in turn promote further evolutionary change" (Chapais 2008, 303). Nothing appears to have been unidirectional or foreordained.

Biology is not physics.[7] Very little in evolution was preset. Little could be prestated or anticipated. Living beings evolve in ways that defy prediction. Each step in evolution is a kind of preadaptation. Each innovation arises from and builds on what precedes it. Each creates an "enablement" or "adjacent possible" from which new adjacent possibles can emerge (Kauffman 2008). Mutant genes gave some individuals traits better adapted to survive and prosper in their environment.

The evolution of society and life itself is impossible to predict because of adjacent possibles. Each new adaptation opens the way to other innovations, as the laptop computer opened the way to iPhones and social networking—all undreamed of by those who, during World War II, sought a mechanical system to break German codes. Who could have predicted Facebook without first anticipating the invention of the Internet and then of miniature computers? We cannot prestate such innovations.

Both serendipity and synergy contribute to unforeseeable outcomes. Still, once a series of enabling conditions has conduced to a new set of conditions, one can look back and say that such-and-such factors seemed to have led to such-and-such effects. In retrospect, it seems clear that growing complexity has bred still more complexity.

Many features that make humans more adaptable than other primates and some human societies more fit than others have resulted from biological and historical accidents. Once humans learned to communicate and plan, some gained fitness by acts of cognition and volition—they made smart (or lucky) choices and tried to execute them. If we go far back in time, however, successful adaptation to a changing environment depended in large part on accident—an opportune conjunctions of self with other.

The distinctive qualities of human behavior derive from many factors. The genomes of humans and chimpanzees are 99 percent the same, but humans learned to cooperate in ways that gave them powers unknown to chimps and any other animals. How did humans—unlike other primates—learn to cooperate? The answer began four to six million years ago when the apelike creatures from which hominoids descended broke off from the ancestral line shared with chimpanzees. Some apelike creatures acquired a more human *form* approximately one hundred thousand years ago, but distinctly human *behavior* did not emerge until about fifty thousand years ago. *Homo sapiens* acquired a more nuanced language about that time and an instinct for reciprocity that governed social relations within the group and trade with outsiders. These people practiced religious rituals and could mobilize for war. The cold and dryness of the great Ice Age had reduced this group to some five thousand individuals, but as the Pleistocene glaciers receded, some recovered and some moved out of Africa. The migrants cohabitated with but eventually displaced two sets of earlier hominids—*homo neanderthalensis* who had emigrated from Africa many thousands of years earlier and settled in the Middle East and Europe, and the *homo erectus* who had found their way to East Asia. These developments have been traced mainly by the studies of the human genome, because written histories of mankind go back only five thousand years and most archeological finds stop fifteen thousand years ago (Wade 2006).

Two foundations of cooperation, fire and weapons, served as adjacent possibles whose consequences could never have been prestated. Having observed how natural phenomena can start fires, early hominids learned to make and sustain fire. As some hominids huddled around a fire, they improved their communications and launched a division of labor. Some continued to hunt and gather but others could plant and harvest. In time, still other enabling conditions permitted some to develop writing, mathematics, and other technologies that permitted even larger and more complex communities (Wilson 2012).

Weapons also generated cooperation. Their advent helps explain why humans—unlike chimpanzees—need not be subject to an alpha male and his allies. When some hominoids became bipedal, they could walk more efficiently than on folded knuckles. Just as important, their hands were liberated to gesture and to manipulate objects—not just digging tools for agriculture but also weapons. Clubs and spears became equalizers. No longer could the physically stronger alphas readily dominate other males and females. When all males were armed, the cost of monopolizing a large number of females became higher.[8] Females became allocated to males more equally. The orgiastic promiscuity of apes gave way to the pair bond between male and female. Each male now had an incentive to guard his mate and his paternity. The deep structure of human society arose from the sequence *male kin group + pair-bonding → exogamy* (Chapais 2008).

Pair bonding opened the way to hominid evolution. Pair bonding transformed a social organization loosely based on kinship into one exhibiting the strong hold of kinship and affinity. Having two parents permitted infants to be dependent for longer periods and, as a result, to enjoy continued brain growth. Bonding also revealed the genealogical structure of the family. Now males could recognize their sisters and daughters in neighboring bands. The presence of female relatives in neighboring bands became a bridge that permitted a new and more complex social structure. Neighboring males could be seen as in-laws rather than as enemies. Bands that exchanged women learned to cooperate. Some formed a group or tribe. Cooperation could become the norm within a tribe, even though one tribe might fight another as relentlessly as chimpanzee bands.

Hominid society entered a runaway, snowballing evolutionary process that conformed to the basic pattern of evolution—integration of old and new material to form emergent properties and new adjacent possibles. The process benefited from many accidental conjunctures: Kinship structures dominated by fathers emerged when fathers could recognize their offspring and by lengthened father-son bonds. Kin-group exogamy and postmarital residence patterns resulted from the merging of pair bonding and kin-group dispersal. Bilateral kinship networks occurred after uterine kin recognition processes combined with consistent paternity recognition and the tribal level of organization (Chapais 2008, 303).

Changes in the environment also pressed hominoids to cooperate. The Ice Age dried up forests, pushing some of our ancestors into the savannah. Those who could walk on two legs could cover larger distances with less energy than those still on four legs. Some learned to cooperate not only to guard against predators but also to hunt and gather food. They became obligate collaborators.

Another accident helped humans to communicate and share their intentions and plans (Tomasello 2009). The whites of human eyes are three times larger than those of any other primate. When a human shifts his or her gaze, others can infer his or her intention. Chimps infer the direction of a gaze by looking at another's head; human infants do so by watching the eyes.

There was no single pressure that made us human, because "human" evolved by a series of accidents. The fact that humans could recognize their patrilineal kind was not selected for. Still, this development permitted movement toward peaceful relations with other groups. *"Effects" had "causes," but the synergistic relationships among coevolving genes, temperaments, and contexts could be perceived only after they took shape.* A multiplicity of factors combined to reduce violence among humans from prehistoric times to the twenty-first century (Pinker 2011). This trend would be invisible to news junkies and could be traced only by historical analysis.

The trends toward less violence and longer life expectancy could be shattered by imaginable events such as nuclear war and pandemics and by unimagined "Black Swans." Would-be forecasters often underestimate the size and frequency of "thick tails"—critical events that occur more frequently than usually believed. People should count on the appearance of more Black Swans, some of them long present but undiscovered, plus others freshly emerged from adjacent possibles. Both thick tails and Black Swans curtail the scope of meaningful prediction (Taleb 2007).

In a world dominated by chaos and uncertainty, some people, systems, and institutions do not succumb but rather manage to benefit from shocks of the new. They resemble the Greek hydra that grew two heads for each one it lost (Taleb 2011; 2012). Antifragility can be seen as a crowning attribute of societal fitness.

Meanwhile, most innovations are Janus-faced. Walking on just two legs freed humanoids to travel far and use their hands, but bipedalism also contributed to back and hip pains. Enablements that permitted each hominoid to wield weapons led to polygyny and later to monogamy, but individuals and groups with the most lethal weapons could still dominate others or die trying. The combination of larger brains and improved weapons produced carnage on scales hitherto unknown. Pair bonding led to cooperation and harmony among ever-larger social entities, but when one large political unit confronted another, whole peoples were decimated, enslaved, or even exterminated. Pair bonding helped defend mothers and infants, prolonging the time when children could develop. But it also fostered jealousy, distrust, and divorce so the point where many people now eschew formal bonding altogether.

Still another paradox remains: Why altruism? If living beings are driven to perpetuate their genes, why do humans as well as ants sometimes sacrifice themselves for others? Humans and certain insects are the only species that form communities that contain multiple generations and where, as part of a division of labor, community members sometimes perform altruistic acts for the benefit of others. Social insects such as bees and ants exhibit the Darwinian paradox of evolved sterility. How could sterility evolve by a process that favors reproduction? For years most scientists answered, "*kin* selection for inclusive fitness." On this view, sterile workers that serve the hive are selected for because they spread their genes through helping their mothers, sisters, and brothers to reproduce. But E. O. Wilson (2012) and some other scientists challenged the consensus with a theory of *group* selection. They attributed "altruism" to a gene-based drive to perpetuate the group. When it is advantageous to cooperate, those genes that promote cooperation will be favored. Competition of one group against others rewards self-sacrificial behaviors by individuals that benefit all group members, even those that are not kin.[9] The gene for high-order sociality is not linked to kinship but to social organization. A gene that guides a human or other animal to help its relatives could spread through the population even if the helping action harmed the animal itself.

But theories derived from insect behavior may not apply to humans. What looks like altruism can arise simply from experience and enlightened self-interest. It is well established that unrelated individuals can benefit from repeated cooperation with one another, so long as there are mechanisms in place to encourage reciprocity and punish betrayal by cheats and freeriders (Bloom 2012).

Altruism can also spring from a sense of human solidarity and empathy—products of nurture as well as nature. Many individuals risk themselves to save absolute strangers and foreigners. Some take risks to assist nonhumans.

Teaching is another form of altruism. Individual teachers and schools donate information to others, including non-kin and even foreigners. According to Tomasello (2009), both teaching and norms of conformity contribute to *cumulative* culture by *conserving* innovations. Like other species, humans learn to exploit to meet their survival needs. But humans seem also born and bred to cooperate. Machiavelli was probably correct when he said that "a prince must learn how not to be good." Babies cooperate as they begin to walk and talk. Their indiscriminate cooperativeness is later mediated by judgments of likely reciprocity and concern for how others will judge them. In time they internalize social norms. Humans imitate to be like others in their group. They develop rules to enforce conformity. These behaviors arise from *gene-culture coevolution* and from processes of cultural niche construction—adaptations to help humans function in any one of the many self-built cultural worlds.

Languages and the cultures that spawn them are also complicated. The world's lingua franca became English in the twentieth century. At some time the balance may shift to Chinese, but—derived from many cultures and emerging sciences—English has acquired a richer vocabulary than any other language. This trove could reduce ambiguity and improve clarity of expression. But to master the meanings of these many words and the irregular grammar that joins them is not easy. The pitfalls were manifest in an announcement posted in a hotel in the former Yugoslavia: "The flattening of underwear with pleasure is the job of the chambermaid. Turn to her straightway." A British motorist in Tokyo might also be taken aback by an instruction to "tootle with vigor" any pedestrian who "obstacles his passage." Even well-versed Americans can confuse meanings. Jimmy Carter said Iran should not "flaunt" the world community when he meant *flout*. George H. W. Bush spoke of the "enormity" of his election in 1988—a term connoting monstrous wickedness (Bryson 1990, 11, 140).

Thus, the history of human culture has been autocatalytic. Jumping ahead to events since the first large human settlements, Jared Diamond (1997) explained how geographical peculiarities such as the existence of cattle and horses in Eurasia bolstered the fitness of Eurasians compared to Americans and other peoples. Cattle and horses proved invaluable both in peace and war. Aztecs and Incas, for example, had nothing comparable. In chapters 3 to 6 below we shall see how, starting six centuries ago, other developments, intangible but not entirely accidental, helped Westerners dominate the world. Mass literacy and free thought took root in Europe and became a force more fundamental than guns, germs, or steel. Literacy and free thought, together with a new respect for individual dignity (of both genders) fed on the synergies of the Renaissance and the Reformation. Martin Luther's demand that all persons read Holy Scripture in their vernacular went against the official language of the established church, incomprehensible to most peoples whose languages had long departed from imperial Latin or Greek. The recently perfected printing press served as an adjacent possible that made mass literacy a feasible ambition. Gold and other riches from the New World funded still other innovations. These riches were a kind of accident, for they might have been acquired earlier by Chinese or Arab sailors had their sponsors possessed the boundless greed and curiosity of Europeans. In the 1830s, Alexis de Tocqueville asserted that two nations were destined to rule the world—one rooted in slavery, the other in freedom. By the 1990s, freedom appeared to have prevailed—thanks in part to geographical factors such as the protection afforded by two oceans.

The future of the twenty-first century will probably be greatly influenced the complex interdependence of China and the United States. Circumstances gave China a huge population of studious and hardworking people but a poor resource base and a diminished moral code. The United States continued to harbor vast hard and soft power assets, albeit vitiated (as we shall see in chapters 7 and 8) by a growing deficit of wisdom and smart power. Depending on many adjacent possibles and their choices, the two countries could build on their complementary needs—or fight. Neither course is predetermined.

Huge mysteries remain: How did some hominids acquire consciousness and, it seems, a conscience? How to explain the "sapiens paradox" that complex civilizations with monuments and astronomy arose in widely separated regions at about the same time? Is increasing complexity tantamount to successful adaptation? Or does growing complexity eventually lead to atrophy and self-destruction? The number of complex entities seems to increase, causing the envelope of complexity to expand, but entropy and other forces may be able to reverse these trends.

Is Complexity Good or Bad?

Is greater complexity good or bad—in ecosystems and/or in human affairs? Should rule makers try to regulate every contingency or just deal with the basics?

Alan Siegel and Irene Etzkorn (2013) want to conquer "the crisis of complexity." They report that the U.S. tax code tripled in size in the early twenty-first century to nearly four million words. The tax code is not just "complicated" but also complex, as its many elements interact in nonlinear ways. Its complexity generated work for accountants, lawyers, and lobbyists but made it nearly incomprehensible for most taxpayers. The message from Siegel and Etzkorn to governments and other organizations amounted to this: "Strip away the red tape. Be fruitful and simplify."

"Red tape" might be burdensome, but some regulation is necessary. How and where to strike the appropriate balance? The Office of Information and Regulatory Affairs under President Barack Obama backed high efficiency standards for motor vehicles but postponed rules to cut ozone emissions (Sunstein 2013). Did the office regulate too much or too little? Its decisions reflected a complex of interacting economic, environmental, and—in the end—political concerns.

The May-Widmer stability theorem holds that greater complexity in ecosystems, with more species and interactions among them, increases their vulnerability to external shocks. A small perturbation can disrupt a large, complex system. The introduction of an exotic species—a toad, pig, goat, or mongoose—can destabilize an entire ecosystem. Professor May (2012) grants that complex, species-rich ecosystems, such as coral reefs or tropical rain forests, are able to arise and persist in relatively predictable environments, but harsh, unpredictable environments favor simpler life forms. Thus, monocultures of *Spartina alterniflora* flourish in the highly stressed marshlands of New Jersey.

Professor May, a zoologist, suggests that financial systems and products have become too complex and too costly. In finance, as in ecology, complexity adds to system vulnerability. Highly connected structures are best avoided. There is no evidence that big and highly interconnected banks are less liable to failure than small ones. The epidemiology of H.I.V./AIDS shows how "superspreaders" can disseminate infection. "Arguably, the pressures that have driven financial ecosystems to ever-increasing complexity have been more about rent-taking than about optimising the distribution of capital in a free market." The moral—more is less—remains. May recommends smaller agents in simpler systems regulated by simpler and shorter sets of rules.

Some critics contend that the May-Widmer theorem applies only to random systems—not to real-world networks, which have acquired structure.

Indeed, some scientists say that the theorem is wrong, because complex diversity is healthful and increases the overall productivity of ecosystems. Thus, soils with highly complex microbiological communities cycle nutrients more efficiently—as when complex and diverse fungal communities support old growth forests.

Analogous disputes arise in the analysis of international power. Which distribution of power is more conducive to stability and overall fitness—complex multipolarity or simple bipolarity or even simpler unipolarity? A complex multipolar system correlated with the long peace of the nineteenth century. If one power became too strong, others balanced against it. Still, this complex system permitted many small wars and finally erupted in the cataclysm of World War I. A much simpler, bipolar confrontation underlay a cold peace with some small wars from the late 1940s to late 1980s. When the bipolar balance became uncertain in 1962, however, efforts by the weaker side to regain its leverage by deploying missiles to Cuba nearly provoked Armageddon. Some decades later, the collapse of the USSR left just one superpower. Unipolarity promised a new world order but did not prevent Iraq's invasion of Kuwait and subsequent Gulf War. A few years later, jihadists began to terrorize the sole superpower and its allies.

So is complexity a positive or negative force in world politics? A detached observer would probably conclude that there is no simple answer. The unipolar Pax Americana, like the Pax Romana, generated both pluses and minuses both for the imperial power and for others. If China becomes a sort of superpower like the United States, will bipolarity conduce to peace or to conflict? The two countries could focus on their interests in common or on points of discord. Even if the two greatest powers seek peace, however, smaller powers—some with nuclear weapons—could act as spoilers.

Robert Keohane and Joseph Nye (2011) postulated that "complex interdependence" makes war nearly unthinkable. Between the United States and Canada, for example, interactions take place on many levels—governmental, economic, cultural, and social. So many interests fill each country's agenda that no one interest (for example, fishing rights) could be worth fighting for. Thus, complexity fosters peace. This argument is plausible, but Europe's complex interdependence did not prevent war in 1914. And the 2013 travails of "united Europe" point to many downsides of complexity. It was far easier to reach agreements among the six states that formed the European Coal and Steel Community in 1951 than among the twenty-eight EU members in 2013. Greece could more easily be competitive if it controlled its own currency rather than being locked into a common currency.

Bottom line: Complex interdependencies defy simple answers. A progressively fragile and interdependent world means that vulnerable people face an increased risk from shocks and disruptions (Rockefeller Foundation 2012). And yet this world also includes extraordinary growth in human knowledge and technological capacity. There is a race between mushrooming challenges and unprecedented growth in our capabilities. New technologies may bolster or erode psychological, social, and systemic resilience.

In complex systems with elements in dynamic connection, conventional scientific assumptions do not seem to hold. Instead, the behavior of a system "emerges" from the interaction of its elements (Casti 1995; Holland 1998; Levin 1999). Relationships *among* elements rather than the elements themselves become the focus of research. The elements in a complex system adapt in response to the actions of other elements in the system and to their environment—hence the concept "complex adaptive system" or CAS. Each CAS may be embedded in another CAS, as a tree is part of a forest nested in a large ecosystem. Operating through positive feedback loops, small-scale "causes" may be amplified to produce large-scale "effects." Because these interactions are nonlinear, however, study of their components in isolation cannot predict their outcomes (Hendrick 2010, 386).

Goethe's Mephistopheles explained how difficult it is to comprehend complex interdependence. Logicians may posit that life is like a syllogism—"one, two, three." But the fabric of thought (*Gedankenfabrik*) should be like a masterpiece of weaving. One step on the shuttle and a thousand threads arise. Another blow, still more threads emerge and scatter. Would-be philosophers may say things *had* to be thus and thus. But they never learned to weave. Trying to describe a living thing, some analysts begin by driving the spirit from its parts. They may hold all the pieces in one hand. They lack nothing except the essential connections (*Faust* I, 1920–41). Even history is an illusion. Our attempts to capture the spirit of an earlier time become no more than mirrors of our own temperament. As Faust warned a student, the few who see and describe things as they are "have at all times been burned and crucified" (*Faust* I, 570–93). Indeed, said Mephistopheles, "All theory is gray, while life is green like a golden tree" (*Faust* I, 2038–39).[10]

Mephistopheles was on target. "Complect" is to join by weaving. The proto-Indo-European root of complexity is *plek*—a plait, as in duplex or multiplex, and in complex and perplex. John Locke in 1690 noted that complex concepts such as beauty and gratitude are woven from several simple ideas. Thus, our concept of father embodies both guardian and master. Dealing with complexity, both the artist and the scientist weave a unity from many strands and parts. Their skills, said the Unitarian minister James Martineau in 1869, can make complexities vanish.[11]

Is there a "web" across borders? The relationships among some two hundred states and thousands of nonstate actors on the global scene surely produce a complex adaptive system. Global politics and international organization can be and have been studied as systems. Robert Jervis (1997) and other scholars have analyzed "system effects."[12] But explaining cross-border complexity is a complex undertaking. Seeking to cut through the complexity, neorealists apply their version of Occam's Razor: they purport to explain global politics as a set of responses to the hierarchy of power (Waltz 1979; 1986; 2000). Doing so, they ignore other key levels of cross-border relations—from individuals and states to transnational movements and the all-encompassing biosphere. Scientists agree that, if all things are equal, a simpler explanation is preferred to a complex one—but only if the explanation is also *sufficient,* that is, takes account of all the key variables. Since neorealists ignore important explanatory variables, their approach is not sufficient. Their effort at parsimony goes too far.[13] Ironically, Waltz (1959) had earlier demonstrated the importance of analyzing individuals and the state as well as the system.

A generation before Waltz (1979) published the foundational text of neorealism, Morton Kaplan (1957) depicted international relations (IR) as a mechanical system. But his portrait of IR struck many analysts as simplistic and misleading. Standing on the shoulders of Quincy Wright and Raymond Aron, Stanley Hoffmann (1960, 179–84) suggested that scholars instead develop a comparative historical sociology of diplomatic constellations or "fields." Each field needed to be identified by (1) its structure—the major actors, hierarchy of power, and global fault lines; (2) the transnational forces shaping the material and moral context of the field; (3) the internal constitution and culture of each actor as it formulates its foreign policy; and (4) how the actors pursue their goals and how the field accommodates these strivings.

Hoffmann provided a comprehensive check list—but no way to see both the trees and the forest. To compare fields across different eras is possible but difficult. To describe even one diplomatic constellation in Hoffmann's four terms proved a daunting task.[14] And while Hoffmann included two key levels—the state and the global system—he omitted a key variable—the individuals who fillip everything else. Graham Allison's *Essence of Decision* (1971) also focuses on system-level and state-level explanations, mentioning personality factors only in passing. But the Cuban missile crisis would probably have never been initiated without Nikita S. Khrushchev or have been managed without the Kennedy brothers and Robert S. McNamara. Nor would the world scene in the 1930s have been the same without the idiosyncrasies of Hitler, Mussolini, and Stalin.

Given all the "complexities," can complexity science be relevant and useful in international studies? We put off a detailed reply to this question until chapters 10 and 11—after a review of the evidence pro and con. But the reader should be forewarned: some observers believe that "complexity science" is not a science but an illusion. John Horgan (1996) for example, asserts there are no simple, general principles of complexity. While some scholars have found efforts to apply complexity science to world affairs to be stimulating and useful, if only as a heuristic, others have found these efforts turgid and lifeless—evidence that global interactions are even more resistant to deep analysis than many scholars had imagined (Earnest and Rosenau 2006; Rosenau 2003).

Still, leading scientists in many disciplines, including Nobel laureates in physics Murray Gell-Mann and in economics Kenneth J. Arrow and Thomas C. Schelling contributed for years to complexity science, believing it to have great promise.

Aware of the difficulties, analysts of world affairs should at least consider whether complexity science (or *sciences,* since there is more than one branch) could offer them a useful tool kit—perhaps even a basic approach to studying the turbulence and nonlinearity, the cascades, and macro-micro linkages of world affairs (trenchantly described by Rosenau 1990; 2003).

The Need for a Sound Paradigm

Scholars of comparative politics, international relations (IR), and other social sciences could benefit from the late Saul Bellow's message to his students: "We are here, in this fallen state, riven by contradictions, given to understand some things but never others, faltering in our wills, flawed in our abilities, uncertain in our actions. But that is where we must begin and there is no excuse for not taking the task seriously" (Rothstein 2005). People expect from the social sciences the knowledge to understand their lives and control their futures. They want to know what will happen if society and its leaders opt for one course of action over another. Even with recent advances, can any social science contribute to that kind of knowledge?

Despite the dangers of reductionism, scholars (as well as political leaders) often succumb to hubris. Hoping that they have discovered the essence of things, students of politics, as in other domains, may proclaim, "I have found it!" Often, however, they have identified only the tail or an ear of the elephant—one facet of a much larger and more complicated whole (Hawkings 2002, 148). In politics, as in physics, it is difficult to reconcile theories with underlying uncertainties. In both disciplines the apparent realities are often contradictory. For example, Newton's theory of gravity does not mesh with Einstein's on relativity and neither seems to harmonize with quantum mechanics.

Scientists need a dependable paradigm (Kuhn 1970). Ideally, a paradigm should help scholars to organize their findings and guide their research. It should reflect the present state of knowledge; conduce to testable, falsifiable propositions; function with parsimony—require relatively few variables to explain outcomes; and connect with other branches of science (Singer 1970; Vasquez 1997). These criteria present high standards for students of human behavior. Some analysts doubt that essential human behaviors can be quantified or predicted. Good social science, they say, need not—probably cannot—match the precision of natural science.

Even economists, apparently the most rigorous social scientists, disagree on the most basic questions, for example, whether it is more useful to study macro trends or individual and group psychology. Confronted with recessions, economists debate whether governments should "prime the pump" or cut spending. Joseph Schumpeter, a rival of John Maynard Keynes, argued that Keynes's *General Theory of Employment, Interest and Money* (1936) offered not a general theory but a treatise concerning the special case of a decaying civilization.[15]

Based on the ancient Greek word for "pattern," the word *paradigm* implies a standard way to do science in a particular field of knowledge such as physics or astronomy. This standard (or "normal") form of science starts with a consensus on the puzzles to be solved, the methods for solving them, and the standards by which to measure scientific success. For Kuhn, the word paradigm also implies a universally recognized scientific achievement embodying the standard approach. For a time it provides model problems and solutions to a community of practitioners. That achievement may be expressed in a theory believed to express the relationships between the objects studied.

A *paradigm shift* occurs when the standard approach is challenged, modified, or even supplanted by another. Thus, Ptolemy's earth-centered view of astronomy was replaced by the heliocentric view of Galileo, Copernicus, and Kepler. If their heliocentric view were correct, the earth-centered view had to be wrong. All efforts to study the stars and planets will be confounded by a false paradigm. By the same token, if human motives and activities deviate sharply from an existing social science paradigm, research based on that approach will be off base.

Some paradigms seem not to be commensurate. They may even appear to contradict one another. Still, incommensurate paradigms help to highlight black holes in our knowledge or suggest unexpected linkages. Theories of gravity, relativity, and quantum mechanics appear to be incommensurate but each nonetheless captures major aspects of reality. Meanwhile, some scientists look for a theory that will unify all of physics.

Kuhn (1970, viii) noticed that psychologists and social scientists disagree about the nature of legitimate scientific problems and methods with far greater intensity than do astronomers, physicists, chemists, and biologists. In effect, social scientists recognize no standard, normal way to do science in their domains. Perhaps, Kuhn speculated, their subject matter is too complex and value-laden to generate consensus about scientific achievements or methods. Still, political and other social sciences can probably benefit from explicit description and analysis of their existing or proposed paradigms.

The present book expects a theory to be more precise than a science. Ideally, a theory should be testable and capable of prediction. Science, by contrast, is a branch or body of knowledge about facts and principles gathered by observation and experimentation. Complexity science is itself emerging and probably too young and diffuse to claim the existence of any agreed theory.[16] The situation resembles cosmology and physics where "one could never hope to construct a complete unified theory of everything all at one go."

Instead, researchers progress by "partial theories that describe a limited range of happenings and neglect other effects, or approximate them with certain numbers" (Hawkings 2002, 147). "The theory of evolution by cumulative natural selection is the only theory we know of that is in principle capable of explaining the existence of organized complexity" (Dawkins 1986).

Complexity science, as developed by Stuart Kauffman (1993; 1995; 2000) and others associated with the Santa Fe Institute, seeks to update, qualify, and enhance Darwinism by refining the concept of fitness and showing more clearly how it can be attained. If IR scholars gained nourishment from complexity science, this nexus would also tie their discipline more closely to the most significant and most widely accepted (by scholars) scientific discovery of recent centuries—evolution.[17]

While George Modelski (1996) and some other IR scholars have written on evolutionary paradigms in the social sciences, few IR specialists have pursued this path. The failure to link IR and comparative politics more closely with evolution is ironic given that many students of world affairs focus on the struggle for power. Many study human behavior without paying much attention to how other species or early humans have evolved and behaved.[18] To be sure, IR scholars rightly distanced themselves from "Social Darwinists" of the late nineteenth century. Given the advances in all the life sciences in recent decades, however, it is surely time for IR scholars to step up their efforts to learn from Darwin and neo-Darwinians (Wilson 1975, 1998; Somit and Peterson 1992, 2008). Social scientists should not ignore the capacity of biology and related scientists to understand and better the human condition (Hatemi and McDermott 2011; West 2011). At the same time, however, they must avoid any simplistic extrapolation from the behavioral patterns of other species to homo sapiens—equipped both with consciousness and some elements of free will.

The founding father of neorealism in IR called his seminal book *A Theory of International Politics* (Waltz 1979). But it is premature to suggest that any approach to the study of world affairs amounts to a scientific *theory*.[19] While neorealism and other purported "theories" do meet a basic definition as a "set of statements or principles devised to explain a group of facts or phenomena," none has been universally accepted. None has been subjected to rigorous testing over times with many variables. Most have been falsified—given the lie—by experience, not just once but often. Meanwhile, IR specialists disagree even on which are the basic actors, which of their interactions are relevant, and what methods to pursue in studying them.

Still, most IR scholars do pursue identifiable orientations that resemble paradigms. This book urges that interdependence and complexity be treated as valid paradigms—no less useful and perhaps more so than the various schools of realism, idealism, constructivism, and Marxism.

This book expresses aspiration rather than any claim for achievement. Complexity science underscores that purported explanations of world affairs are often too simple: many ignore the spatial organization of actors, temporal effects, and other features known to shape international behavior. An explanation should be as simple as possible *but no simpler.*

Neither complexity science nor its possible applications in IR can overcome what Karl Popper called the problem of *practical falsifiability*. Thus, scientists might aver that that the Earth will suffer a new Ice Age in forty million years. In theory, this prediction can be confirmed or falsified by experience. In practice, we can do neither for eons. Complexity science helps us to identify conditions under which practical falsifiability is impossible. It predicts the unpredictability of world affairs due to chaotic dynamics, feedback mechanisms, and the power of small events. Unlike chaos theory, however, complexity scientists believe—or hope—that significant patterns can be identified in the swirl of inanimate and living things.

Either/or Paradigms in International Studies

For millennia, many philosophers and analysts of world affairs have been trapped in a false choice between materialist and idealist paradigms.[20] They have asked: Are humans evil or good? And which is most basic—matter or form? Rooted in a materialist philosophy, realists explain all politics as a quest for power and wealth. Idealists, however, turn this picture upside down. Followers of Plato and Hegel portray human history as the reflection of ideas or a contest between opposed ideologies. Liberal idealists say that IR is—or should be—a pursuit of universal values, while other idealists campaign for the hegemony of one religion, civilization, nation, race, or class. Talking past one another, most realists focus on "what is," while most idealists emphasize "what should be" (Carr 1940).

Discontented with his ivory tower pursuits, Goethe's Faust doubted that "in the beginning was the Word." Instead of "Word," Faust wondered, should the all-creating source be rendered as "Mind [*Sinn*]"? No, he went on, everything starts with "Force [*Macht*]." But that concept also seemed too narrow. Mindful that a spiritual power helped him to write, Faust concluded, "In the beginning was the Deed [*Tat*]" (*Faust* I, 1224–37).

High above quotidian events, political philosophers debate the relevance of epistemology to world affairs. Can our knowledge come close to approximating reality, or can we do little more than test hypotheses about objects we cannot really observe (Jackson 2011)?

Since life consists of both material and spiritual elements, neither materialism nor idealism can capture reality in all its complexity.[21] World affairs are shaped by many forces—some material and deterministic, while others are intangible—ideational, moral, sentimental, spiritual. Karl Marx and Hegel latched onto quite different parts of the elephant; so did Machiavelli and Kant; Bismarck and Woodrow Wilson; Henry Kissinger and Jimmy Carter;

Niall Ferguson and Francis Fukuyama. While the various realisms and idealisms may describe aspects of IR, they usually fail to provide a comprehensive picture. To see the entire "elephant" becomes more difficult due to the rise of nonstate actors, the "flatness" of a world in which technology transfer becomes easier, and other features of globalization (Bennendijk and Kugler 2006). To understand not just the entire elephant but also the ways it may twist and turn is probably beyond scientific reach in the foreseeable future. Still, complexity science provides a framework for understanding how whole systems come to exceed their parts—and how these parts interact with each other. The basic concepts of complexity science, summarized below, provide a far more nuanced approach to understanding IR than the realist maxims of Hans J. Morgenthau (1978) or the idealist postulates of Johan Galtung (1996) and Richard A. Falk (2008).[22] Liberal institutionalism includes elements of realism and idealism. It helps explain movement in some domains, such as environmental protection regimes, but is too narrow to comprehend other dimensions of IR (Keohane 1989).

The realist and idealist paradigms widely used in political analysis appear to be not only incommensurate but contradictory. Still, major failings in the study and practice of IR have resulted from seeing, thinking, and acting as if world affairs were one-dimensional—either one thing or another. And while most global relationships are interdependent and variable-sum, actors have often seen them as zero-sum and acted accordingly—often to their disadvantage. Two analysts at the U.S. National Defense University have attempted to show the relevance of both Kantian idealism and neo-Hobbesian realism to U.S. security policy. Their book, appropriately, is entitled *Seeing the Elephant* (Binnendijk and Kugler 2006).

Complexity science accepts that power politics and various idealisms have played key roles in shaping world affairs and will continue to do so. Some realisms and idealisms help to describe IR at certain times and places, but—rooted in either matter or form, and in a Manichean choice between evil and good, they tend to be too reductionist. A monocausal paradigm limits any theory's potential for general explanation, projection of alternative futures, or sound policy advice. The more advanced a species in the chain of evolution, the greater the chance that a variety of factors shape its behavior.[23]

Despite the advent of various "neo" realisms and idealisms, most IR theorizing continues to present such dichotomies. To be sure, many new approaches to IR have evolved in recent decades—from the roles of gender and social constructs to polyheuristic analysis of decision making.[24] But none offers a basic paradigm like those articulated by classic writers such as Thucydides. Some can be construed as applications of realism or idealism. Some articulate a grand theory akin to a philosophy of history; others present a micro- or intermediate-range theory. Few show much recognition of advances in the life sciences, anthropology, or other disciplines likely to illuminate the interactions of humans across borders.[25]