REINVENTING THE SACRED

The Science of Complexity and the Emergence of a Natural Divinity

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Beyond Reductionism

Batter my heart, three-person'd God; for you
As yet but knock, breathe, shine, and seek to mend;
That I may rise, and stand, o'erthrow me and bend
Your force, to break, blow, burn and make me new.
I, like an usurpt town, to another due,
Labour to admit you, but Oh, to no end,
Reason your viceroy in me, me should defend,
But is captiv'd, and proves weak or untrue.
Yet dearly I love you, and would be loved fain,
But am betroth'd unto your enemy:
Divorce me, untie, or break that knot again,
Take me to you, imprison me, for I
Except you enthrall me, never shall be free,
Nor ever chaste, except you ravish me.

John Donne's exquisite "Holy Sonnet XIV: Batter My Heart, " written in about 1615, when he was a High Anglican churchman, speaks to one of

the most poignant schisms in Western society, and more broadly in the world: that between faith and reason. Donne wrote in the time of Kepler. Within a hundred years Newton had given us his three laws of motion and universal gravitation, uniting rest and motion, earth and the heavens: the foundations of modern science. With Descartes, Galileo, Newton, and Laplace, reductionism began and continued its 350-year reign. Over the ensuing centuries, science and the Enlightenment have given birth to secular society. Reductionistic physics has emerged for many as the gold standard for learning about the world. In turn, the growth of science has driven a wedge between faith and reason. It was not so much Galileo's geocentric theory (derived from Copernicus) that underlay his clash with the church but his claim that only science, not revelation, is the path to knowledge.

Today the schism between faith and reason finds voice in the sometimes vehement disagreements between Christian or Islamic fundamentalists, who believe in a transcendent Creator God, and agnostic and atheist "secular humanists" who do not believe in a transcendent God. These divergent beliefs are profoundly held. Our senses of the sacred have been with us for thousands of years, at least from the presumptive earth goddess of Europe ten thousand years ago, through the Egyptian, Greek, Abrahamic, Aztec, Mayan, Incan, and Hindu gods, Buddhism, Taoism, and other traditions. Neanderthals buried their dead. Perhaps they also worshiped gods. Recently an aboriginal tribe was unwilling to allow its DNA to be sampled as part of a worldwide study on the origins and evolution of humanity for fear that science would challenge its view of its own sacred origins. Ways of life hang in the balance. This book hopes to address this schism in a new way.

Part of my goal is to discuss newly discovered limitations to the reductionism that has dominated Western science at least since Galileo and Newton but leaves us in a meaningless world of facts devoid of values. In its place I will propose a worldview beyond reductionism, in which we are members of a universe of ceaseless creativity in which life, agency, meaning, value, consciousness, and the full richness of human action have emerged. But even beyond this emergence, we will find grounds to radically alter our understanding of what science itself appears able to tell us.

Science cannot foretell the evolution of the biosphere, of human technologies, or of human culture or history. A central implication of this new worldview is that we are co-creators of a universe, biosphere, and culture of endlessly novel creativity.

The reductionism derived from Galileo and his successors ultimately views reality as particles (or strings) in motion in space. Contemporary physics has two broad theories. The first is Einstein's general relativity, which concerns spacetime and matter and how the two interact such that matter curves space, and curved space "tells" matter how to move. The second is the standard model of particle physics, based on fundamental subatomic particles such as quarks, which are bound to one another by gluons and which make up the complex subatomic particles that then comprise such familiar particles as protons and neutrons, atoms, molecules, and so on. Reductionism in its strongest form holds that all the rest of reality, from organisms to a couple in love on the banks of the Seine, is ultimately nothing but particles or strings in motion. It also holds that, in the end, when the science is done, the explanations for higher-order entities are to be found in lower-order entities. Societies are to be explained by laws about people, they in turn by laws about organs, then about cells, then about biochemistry, chemistry, and finally physics and particle physics.

This worldview has dominated our thinking since Newton's time. I will try to show that reductionism alone is not adequate, either as a way of doing science or as a way of understanding reality. It turns out that biological evolution by Darwin's heritable variation and natural selection cannot be "reduced" to physics alone. It is emergent in two senses. The first is epistemological, meaning that we cannot from physics deduce upwards to the evolution of the biosphere. The second is ontological, concerning what entities are real in universe. For the reductionist, only particles in motion are ontologically real entities. Everything else is to be explained by different complexities of particles in motion, hence are not real in their own ontological right. But organisms, whose evolution of organization of structures and processes, such as the human heart, cannot be deduced from physics, have causal powers of their own, and therefore are emergent real entities in the universe. So, too, are the biosphere, the human economy, human culture, human action.

We often turn to a Creator God to explain the existence of life. I will spend several chapters discussing current work on the natural origin of life, where rapid progress is being made. Self-reproducing molecules have already been demonstrated in experiments. A Creator God is not needed for the origin of life. More, you and I are agents; we act on our own behalf; we do things. In physics, there are only happenings, no doings. Agency has emerged in evolution and cannot be deduced by physics. With agency come meaning and value. We are beyond reductionist nihilism with respect to values in a world of fact. Values exist for organisms, certainly for human organisms and higher animals, and perhaps far lower on the evolutionary scale. So the new scientific view of emergence brings with it a place for meaning, doing, and value.

Further, the biosphere is a co-constructing emergent whole that evolves persistently. Organisms and the abiotic world create niches for new organisms, in an ongoing open textured exploration of possible organisms. I will discuss the physical basis of this "open texture" in the chapter on the nonergodic universe.

At a still higher level, the human economy cannot be reduced to physics. The way the diversity of the economy has grown from perhaps a hundred to a thousand goods and services fifty thousand years ago to tens of billions of goods and services today, in what I call an expanding economic web, depends on the very structure of that web, how it creates new economic niches for ever new goods and services that drive economic growth. This growth in turn drives the further expansion of the web itself by the persistent invention of still newer goods and services. Like the biosphere, the global economy is a self-consistently co-constructing, ever evolving, emergent whole. All these phenomena are beyond physics and not reducible to it.

Then there is the brute fact that we humans (at least) are conscious. We have experiences. We do not understand consciousness yet. There is no doubt that it is real in humans and presumably among many animals. No one knows the basis of it. I will advance a scientifically improbable, but possible, and philosophically interesting hypothesis about consciousness that is, ultimately, testable. Whatever its source, consciousness is emergent and a real feature of the universe.

All of the above speaks to an emergence not reducible to physics. Thus our common intuition that the origin of life, agency, meaning, value, doing, economic activity, consciousness are beyond reduction to physics can be given scientific meaning. We live in a different universe from that envisioned by reductionism. This book describes a scientific worldview that embraces the reality of emergence.

The evolution of the universe, biosphere, the human economy, human culture, and human action is profoundly *creative*. It will take some detailed exploration of what are called Darwinian preadaptations to explain this clearly. The upshot is that we do not know beforehand what adaptations may arise in the evolution of the biosphere. Nor do we know beforehand many of the economic evolutions that will arise. No one foresaw the Internet in 1920. This unpredictability may exist on many levels that we can investigate. For example, we do not know beforehand what will arise even in the evolution of cosmic grains of dust that grow by aggregation and chemical reactions to form planetesimals. The wondrous diversity of life out your window evolved in ways that largely could not be foretold. So, too, has the human economy in the past fifty thousand years, as well as human culture and law. They are not only emergent but radically unpredictable. We cannot even prestate the possibilities that may arise, let alone predict the probabilities of their occurrence.

This incapacity to foresee has profound implications. In the physicist Murray Gell-Mann's definition, a "natural law" is a compact description beforehand of the regularities of a process. But if we cannot even prestate the possibilities, then no compact descriptions of these processes beforehand can exist. *These phenomena, then, appear to be partially beyond natural law itself.* This means something astonishing and powerfully liberating. We live in a universe, biosphere, and human culture that are not only emergent but radically creative. We live in a world whose unfoldings we often cannot prevision, prestate, or predict—a world of explosive creativity on all sides. This is a central part of the new scientific worldview.

Let me pause to explain just how radical this view is. My claim is not simply that we lack sufficient knowledge or wisdom to predict the future evolution of the biosphere, economy, or human culture. It is that these things are *inherently* beyond prediction. Not even the most powerful

computer imaginable can make a compact description in advance of the regularities of these processes. There is no such description beforehand. Thus the very concept of a natural law is inadequate for much of reality. When I first discuss this in detail, in chapter 10, concerning Darwinian preadaptations, I will lay out the grounds for believing that this radical new view is correct. If it is, it challenges what I will call the Galilean spell, the belief that all in the universe unfolds under natural law.

There is a further profound implication: If the biosphere and the global economy are examples of self-consistently co-constructing wholes, and at the same time, parts of these processes are not sufficiently described by natural law, we confront something amazing. Without sufficient law, without central direction, the biosphere literally constructs itself and evolves, using sunlight and other sources of free energy, and remains a coherent whole even as it diversifies, and even as extinction events occur. The same is true of the global economy, as we shall discuss in chapter 10. Such a self-organized, but partially lawless, set of coupled processes stands unrecognized, and thus unseen, right before our eyes. We appear to need a new conceptual framework to see and say this, then to understand and orient ourselves in our ever creative world. We will find ourselves far beyond reductionism, indeed.

Is it, then, more amazing to think that an Abrahamic transcendent, omnipotent, omniscient God created everything around us, all that we participate in, in six days, or that it all arose with no transcendent Creator God, all on its own? I believe the latter is so stunning, so overwhelming, so worthy of awe, gratitude, and respect, that it is God enough for many of us. God, a fully natural God, is the very creativity in the universe. It is this view that I hope can be shared across all our religious traditions, embracing those like myself, who do not believe in a Creator God, as well as those who do. This view of God can be a shared religious and spiritual space for us all.

This view is not as great a departure from Abrahamic thought as we might suppose. Some Jesuit cosmologists look out into the vast universe and reason that God cannot know, from multiple possibilities, where life will arise. This Abrahamic God is neither omniscient nor omnipotent, although outside of space and time. Such a God is a Generator God who

does not know or control what thereafter occurs in the universe. Such a view is not utterly different from one in which God is our honored name for the creativity in the natural universe itself.

The Four Injuries

It would be a sufficient task to unravel the implications of this new scientific worldview for our unity with nature and life. But the project before us appears to be even larger. T. S. Eliot once wrote that with Donne and the other metaphysical poets of the Elizabethan age, for the first time in the Western mind, a split arose between reason and our other human sensibilities. The anguish between faith and reason in Donne's "Holy Sonnet XIV" is but one of these emerging schisms. With the growth of science and the Enlightenment, the Western mind placed its faith in reason and subordinated the rest of our humanity, Eliot's "other sensibilities," the fullness of human life.

Almost without our noticing, our secular modern society suffers at least four injuries, which split our humanity down the center. These injuries are larger than the secular-versus-religious split in modern society. What the metaphysical poets began to split asunder—reason and the remaining human sensibilities—we must now attempt to reintegrate. This is also part of reinventing the sacred.

The first injury is the artificial division between science and the humanities. C. P. Snow wrote a famous essay in 1959, "The Two Cultures," in which he noted that the humanities were commonly revered as "high culture" while the sciences were considered second-class knowledge. Now their roles are reversed: on many university campuses, those who study the humanities are often made to feel like second-class citizens. Einstein or Shakespeare, we seem to believe, but not both in the same room. This split is a fracture down the middle of our integrated humanity.

I believe it is important that this view is wrong. Science itself is more limited by the un-prestatable, unpredictable creativity in the universe than we have realized, and, in any case, science is not the only path to knowledge and understanding. I shall show in this book that science cannot

explain the intricate, context-dependent, creative, situated aspects of much of human action and invention, or the historicity that embraces and partially defines us. These, however, are just the domains of the humanities, from art and literature to history and law. Truth abides here, too.

A second injury derives from the reductionistic scientific worldview. Reductionism teaches us that, at its base, the real world we live in is a world of fact without values. Wolfgang Kohler, one of the founders of Gestalt psychology, wrote a mid-twentieth-century book hopefully entitled *The Place of Value in a World of Fact*, in which he struggled unsuccessfully with this issue. His efforts had no effect on reductionism and its claims. The French existentialist philosophers struggled with the same issue, the view that the real universe is devoid of values. Our lives are full of value and meaning, yet no single framework offers a secure place for these facets of our humanity to coexist with fundamental science. We need a worldview in which brute facts yield values, a way to derive ought from is, just the step that Scottish Enlightenment philosopher David Hume, warned against. Agency, values, and "doing" did not come into being separately from the rest of existence; they are emergent in the evolution of the biosphere. We are the products of that evolution, and our values are real features of the universe.

A third injury is that agnostic and atheist "secular humanists" have been quietly taught that spirituality is foolish or, at best, questionable. Some secular humanists are spiritual but most are not. We are thus cut off from a deep aspect of our humanity. Humans have led intricate and meaningful spiritual lives for thousands of years, and many secular humanists are bereft of it. Reinventing the sacred as our response to the emergent creativity in the universe can open secular humanists to the legitimacy of their own spirituality.

The fourth injury is that all of us, whether we are secular or of faith, lack a global ethic. In part this is a result of the split, fostered by reductionism, between the world of fact and the world of values. We lack a shared worldwide framework of values that spans our traditions and our responsibilities to all of life, one another, and the planet. Secular humanists believe in fairness and the love of family and friends, and we place our faith in democracy. Our diverse religions have their diverse beliefs. But in the industrialized world all of us are largely reduced to consumers. It is

telling that the Nobel laureate economist Kenneth Arrow, when asked to help evaluate the "value" of the U.S. national parks, was stymied because he could not compute the utility of these parks for U.S. consumers. Even in our lives in nature we are reduced to consumers; and our few remaining wild places, to commodities. But the value of these parks is life itself and our participation in it.

This materialism profoundly dismays many thoughtful believers in both the Islamic world and the West. The industrialized world is seen to be, and is, largely consumer oriented, materialistic, and commodified. How strange this world would seem to medieval Europe. How alien it seems to fundamentalist Muslims. We of the industrialized world forget that our current value system is only one of a range of choices. We desperately need a global ethic that is richer than our mere concern about ourselves as consumers. We need something like a new vision of Eden, not one that humanity has forever left but one we can move toward, knowing full well our propensities for both good and evil. We need a global ethic to undergird the global civilization that is emerging as our traditions evolve together.

Part of reinventing the sacred will be to heal these injuries—injuries that we hardly know we suffer. If we are members of a universe in which emergence and ceaseless creativity abound, if we take that creativity as a sense of God we can share, the resulting sense of the sacredness of all of life and the planet can help orient our lives beyond the consumerism and commodification the industrialized world now lives, heal the split between reason and faith, heal the split between science and the humanities, heal the want of spirituality, heal the wound derived from the false reductionist belief that we live in a world of fact without values, and help us jointly build a global ethic. These are what is at stake in finding a new scientific worldview that enables us to reinvent the sacred.

2

Reductionism

Our scientific worldview deeply affects our view of our place in the universe, and the worldview put forward by reductionist science has created a dilemma for many people of faith. Those who believe in a transcendent God, one who answers prayers and acts in the universe, find that their God must either become a God of the gaps, active only in the areas science has yet to explain, or must act in contravention of scientific expectations. Neither alternative is satisfactory. For secular humanists, the very reality we cleave to is largely based upon reductionism. This, for reasons I will explain, is also proving to be unsatisfactory.

What, then, is reductionism? This philosophy has dominated our scientific worldview from the time of Descartes, Galileo, Kepler, and Newton to the time of Einstein, Schrödinger, and Francis Crick. Its spirit, still adhered to by the majority of scientists, is captured by the physicist Steven Weinberg's two famous dicta: "The explanatory arrows always point downward" to physics, and "The more we comprehend the universe, the more pointless it seems." In brief, reductionism is the view that society is to be explained in terms of people, people in terms of organs, organs by cells, cells by biochemistry, biochemistry by chemistry, and chemistry by physics. To put it

even more crudely, it is the view that in the end, all of reality is *nothing but* whatever is "down there" at the current base of physics: quarks or the famous strings of string theory, plus the interactions among these entities. Physics is held to be the basic science in terms of which all other sciences will ultimately be understood. As Weinberg puts it, all explanations of higher-level entities point down to physics. And in physics there are only happenings, only facts.

The reductionist world, where all that exist are the fundamental entities and their interactions, and there are only happenings, only facts, has no place for value. Yet we humans, who are presumably reducible to physics like everything else, are agents, able to act on our own behalf. But actions are "doings," not mere happenings. Moreover, agency creates values: we want certain events to happen and others not to happen. How can values and doings arise from particle interactions where only happenings occur? Nowhere in the reductionistic worldview does one find an account of the emergence and reality of agency in the universe, which I discuss in chapter 7. The eighteenth-century skeptic philosopher David Hume, without recognizing it explicitly, bases his view on reductionism without the emergence of agency when he reasoned that one cannot deduce "ought" from "is." This is the so-called naturalistic fallacy. That is, he would have said, from the fact that women give birth to infants it does not follow that mothers should love their children. In short, reasoned Hume, from what happens, we cannot deduce what ought to happen. There is no scientific basis for the reality of values in the reductionistic worldview. This feature of reductionism led the post–World War II French existentialist philosophers to say, in anticipation of Weinberg, that the universe is meaningless and thus absurd, and to seek values in the choices we make. Yet choices themselves presume an agency capable of making choices, an agency whose reality is denied by reductionism. Thus, again, here are only happenings, no doings, actions, values, or choices, in reductionism.

In later chapters I will attempt to lay out the scientific foundations for agency and therefore value in the biological world, and for the evolutionary origins of ethics and "ought." As we shall see, agency is both real and emergent and cannot be reduced to the mere happenings of physics. This will provide an answer to Hume who rightly says we cannot deduce

"ought" from "is," values from mere happenings. Values are part of the language appropriate to the nonreducible, real, emergent, activities of agents. Thus agency and value bring with them what philosophers call teleological language, that is, language involving a sense of purpose or "end," as in our common explanations for our actions based on our reasons and intentions. Teleological language has long been a contentious issue among scientists and philosophers, many of whom consider it unscientific. I strongly disagree. Agency is emergent and real, but not reducible to physics, I shall argue, because biology is not reducible to physics. The biosphere, I will argue, is laden with agency, value, and meaning. Human life, which is certainly laden with agency, value, and meaning, inherits these qualities from the biosphere of which it is a part.

To better understand reductionism we may start, interestingly, with Aristotle. Aristotle argued that scientific explanation consisted of deduction via syllogism, as in: All men are mortal. Socrates is a man. Therefore, Socrates is mortal. Aristotle thus gave Western culture a model of reasoning that began with universal statements of fact (all men are mortal), considered specific cases (Socrates is a man), and then deduced the conclusion by applying the universal rule to the specific case (Socrates is mortal).

Now consider Newton's laws of mechanics, which consist of three laws of motion and a law of universal gravitation. They conform beautifully to Aristotle's mandate that scientific explanation should begin with a universal statement and systematically apply this statement to specific cases

A central feature of Newton's laws is that they are deterministic. Roughly, here is how they work: picture a billiard table with balls moving on it. The balls are confined in space by "boundary conditions," namely the cushions on the walls, the pockets, and the tabletop. At any instant, all the balls are moving in specific ways. Their centers of mass have precise positions, and they have precise directions and speeds of motion, or velocities. These initial and boundary conditions are analogous to the specific case, Socrates is a man. Newton's laws, applied to this trivial case, state that given the current positions and velocities of all the balls and the boundary conditions, it is possible to compute, i.e., deduce, the trajectory of each ball as it bounces off other balls or the walls, or falls into a pocket. If the balls were started again in exactly the same positions and with the

same motions, precisely the same trajectory of each ball would recur. This precise recurrence is what we mean by determinism. The initial conditions and boundary conditions exactly determine the system's evolution.

The position and velocity of each ball can each be represented, in general, by six numbers, three numbers for the position of the ball in three-dimensional space, plus three numbers for the velocity of the ball "projected" onto the three spatial axes. Thus six numbers specify the position and velocity of each ball. If there are N balls, then the combined positions and velocities (or momenta) of the *N* balls can be specified by *6N* numbers in what is called a *6N*-dimensional "state space." In general, we cannot draw a picture of more than a three-dimensional space, but mathematically we can consider a dimensional space where each axis corresponds to one of the *6N* numbers. In this *6N*-dimensional state space, each unique set of positions and velocities of the all the balls on the table corresponds to a single point. The time evolution of the whole system can thus be represented as a single trajectory in this massively multidimensional-state space.

Determinism means that under Newton's laws of motion (and in the absence of outside forces), there is only one possible trajectory from any point in the state space. Newton's laws are wonderfully successful. We send rockets on complex voyages through the solar system guided by nothing else. But these laws raise a profound problem. One of their fundamental features is that they are time-reversible: if the motions of all the balls on our billiard table were exactly reversed, the same laws would apply, and the balls would precisely retrace backwards their former forward motions. Yet as Humpty Dumpty famously discovered, we are not time reversible. Neither is the world around us. This time reversibility of Newton's laws (and also the time-reversible laws of quantum mechanics, described in chapter 13) has given rise to the so-called problem of "time's arrow," the distinction between past and future. Many physicists consider the famous second law of thermodynamics, which states that disorder in the universe will always increase, to be the physical foundation of the arrow of time. As a crude start on the second law, imagine a drop of ink in a dish of water. In time it will diffuse out to a uniform distribution. But if you start with the uniform ink distribution, it will not spontaneously diffuse back to an ink drop. The forward direction of

time looks different from the backward direction. But in either direction, the ink particles and water molecules all follow Newton's time-reversible laws. The second law hopes to explain why the time asymmetry, forward time versus backward time, arises despite the time reversibility of Newton's laws. (As we shall see, doubts are now arising about the explanation of the second law of classical thermodynamics from statistical mechanics.)

Within a century after Newton, Pierre Simon Laplace had generalized Newton's laws to consider an arbitrarily large set of masses, or particles. Realizing that the particles would all simultaneously follow the laws of motion, Laplace imagined a "demon" of unfathomable intelligence. If supplied with the instantaneous positions and velocities of all the particles in the universe, declared Laplace, this demon would know the entire future history of motion of all the particles, and also, thanks to the time-reversibility of Newton's laws, the entire past motions of the particles. In short, to a sufficient intelligence, the entire past and future of the universe, ourselves and our operas included, could be calculated from a precise statement of the present positions and velocities of all the universe's particles. Laplace wrote in a deeply religious era. When asked by Napoleon what place existed for God in his system, Laplace replied that he had no need for that hypothesis. We see here in stark terms the wedge science was driving between reason and faith.

Laplace's vision is perhaps the purest and simplest statement of reductionism. Here there are two features. First is determinism, which was later abandoned with astonishment when quantum mechanics began to emerge. Second is the assumption that the entire universe and all the events within it, from particles colliding to nations at war, could be understood as nothing but the motions of a very large number of particles. It is here that we find the foundation of the belief that all higher order processes in the universe, such as organisms evolving, are ultimately to be explained as nothing but particles in motion. Weinberg's explanatory arrows point ever downward.

Over the next century or so, the determinism of Newton's laws led to a transformation of religious belief. Much of educated Europe shifted its belief from a theistic God who intervened in the running of the universe, for example, to answer prayer, to a deistic God who created the universe, set the

initial conditions and boundary conditions, and allowed Newton's laws to unfold deterministically. In this worldview, there is no place for God's intervention in the running of the universe, hence prayers are not answered. God made the universe but does not act thereafter in its running. So our scientific worldview does color our sense of our place in the universe, our theology, and, equally importantly, our understanding of ourselves.

With respect to human action, determinism led to a contentious debate about "free will" that continues unabated. In the deterministic view, we are machines, and free will is an illusion. One solution to this problem was the idea that the mind and the body are composed of two radically different stuffs. The philosopher René Descartes, who preceded Newton, proposed that humans are composed of a mechanical body, part of res extensa, and a separate mental portion, res cogitans—an idea known as dualism. Free will lay in res cogitans. In part, Descartes invented dualism to save free will from what with Descartes, Galileo and later became Newtonian determinism in the material world. But dualism raised the question of how the mind acts on the body. Descartes opted for action via an organ in the brain, the pineal gland, which is a rather improbable hypothesis.

The deepest claim of reductionism is that all events in the universe, from asteroid collisions to a kiss to a court in France finding a man guilty of murder, are "nothing but" the motions of particles. As philosophers like to put it, the "furniture of the universe" is limited to Laplace's particles in motion. This "nothing but" view survived even after quantum mechanics did away with the determinism of Newton and Einstein.

Quantum mechanics fundamentally altered the deterministic world of classical physics. To state the matter very simply, on its standard Bohr, or Copenhagen" interpretation, quantum mechanics replaced the billiard-table universe of Newton and Einstein with a strange new view of persistent possibilities governed by the Schrödinger equation. The Schrödinger equation, which is itself deterministic, resembles the equations for water waves propagating across a lake. Much as water waves have a height or amplitude at each point in the lake, the Schrödinger equation determines at each point in space and time a height, that is an amplitude, of the Schrödinger wave. Mathematically, the square of this amplitude is, under the Born rule, the probability that a specific quantum process, if measured

by a classical apparatus, will occur—for example, that a photon will be polarized in a specific way. In the wonderful weird world of quantum mechanics, which applies to very small things such as atoms, *nothing actual* happens when the Schrödinger wave equation propagates its wave. *Everything remains a propagating wave of mere possibilities*, each of which has a probability of a corresponding event being observed if the event is measured. It is only when the event is measured by a big, or macroscopic, nonquantum measuring apparatus, (in the famous Copenhagen interpretation of quantum mechanics), that an *actual, real, or classical event*, say a photon hitting a photographic detector array, *happens*. The connection between quantum uncertainty and classical actualities is a matter of scientific debate to this day, seventy years after Schrödinger invented his equation. But even though little remained of classical determinism in the world of quantum probabilities, the most important part of reductionism emerged stronger than ever: the world was still nothing but particles in motion.

Having outlived determinism, the "nothing but" view may soon outlive particles as well. Some physicists, namely string theorists, now doubt that the world is ultimately made of particles. Rather, they say, it is made of one-dimensional strings that vibrate, and the modes of vibration correspond to different particles. Other versions of string theory posit higher-dimensional "branes" that vibrate. If string theory should be correct, then reductionism would hold that what is real are strings and possibly two- or higher-dimensional "branes" in vibratory and other motions.

In short, while Newton's laws have been surpassed by general relativity and quantum mechanics, the firm reductionistic worldview is that, at bottom, there is nothing but whatever is "down there" at the base of physics, plus Einstein's spacetime. What we think of as "down there" has evolved as physics has grown from its original basis in mechanics to include electromagnetism and the electromagnetic field, to the discovery of the atom, to the discovery of the proton, neutron, and electron, with which all of us are familiar. Now we have the "standard model" of particle physics, which unifies three of the known forces: the electromagnetic force that underlies electric and magnetic phenomena, the weak force that governs radioactive

decay, and the strong force that holds atomic nuclei together. Beyond the standard model, there is a possible unification of general relativity and quantum mechanics, the two pillars of twentieth-century physics, through string theory, which would bring the fourth force, gravity, into the same mathematical framework as the other three.

But reductionism remains in place. As Weinberg said, all explanatory arrows point downward, from societies to people, to organs, to cells, to biochemistry, to chemistry, to physics. What is real is physics and the physical interactions of whatever is down there in the molecules, stars, organisms, biospheres, and legal proceedings in law courts.

Many outstanding scientists, including Nobel laureate physicists Murray Gell-Mann, Stephen Weinberg, and David Gross, are reductionists. Theirs is the "nothing but" view. It is not foolish. Indeed, these physicists would strongly argue that reductionism is the only sensible approach to physics. They can buttress their argument with several centuries of frankly stunning successes.

But if all explanatory arrows point downward, it is something of a quiet scandal that physicists have largely given up trying to reason "upward" from the ultimate physical laws to larger-scale events in the universe. Those downward-pointing explanatory arrows should yield a crop of upward-pointing deductive arrows. Where are they? Trouble arises, my physicist friends tell me, even in trying to generate the well-known equations for the behavior of a liquid, the Navier-Stokes equations, from more fundamental quantum physics. No one knows how to get there from the quantum mechanics of fluid atoms or molecules. Most physicists will admit that as a practical matter, the Navier-Stokes equations cannot be deduced. But most believe that, in principle, they could be deduced. Ultimately this assertion is not so much scientific as aesthetic: it amounts to a faith is that nothing is required beyond quantum mechanics to explain fluid behavior, even if there is no practical way to carry out the deductive inferences to get from quantum mechanics to a river. The fluid system is still nothing but particles in motion. Reductionism holds, claim the reductionists.

It is less clear, but probably true, that many physicists would hold to the "nothing but" view in even more challenging situations. The couple in love and the man found guilty of murder in France, they would say, are likewise

nothing but a set of basic physical events and their (extremely) complex interactions.

Why does this matter to us? The reason is Weinberg's second famous dictum: "The more we comprehend the universe, the more pointless it seems." Once again, what about organisms evolving, values, doing, acting, meaning, history, and opera? Are these all not real, not part of the furniture of the universe? Is science to have nothing to say about it? To accept this is to resign oneself to an impoverished view of both science and the world. One can empathize with the reductionist philosophy. It seems so tough-minded and clearheaded. So much outstanding science has been accomplished under its influence and guidance. I empathize but do not agree at all that reductionism alone suffices to know the truth of the world, and more broadly to understand it. As we shall see in the next chapter, it is not even clear that the Navier-Stokes equations can be reduced to the standard particles in motion of physics. The physicists are beginning to doubt the adequacy of reductionism alone in a quiet rebellion little known outside of academic physics departments. This rebellion is an initial hint that we need to change our scientific worldview.