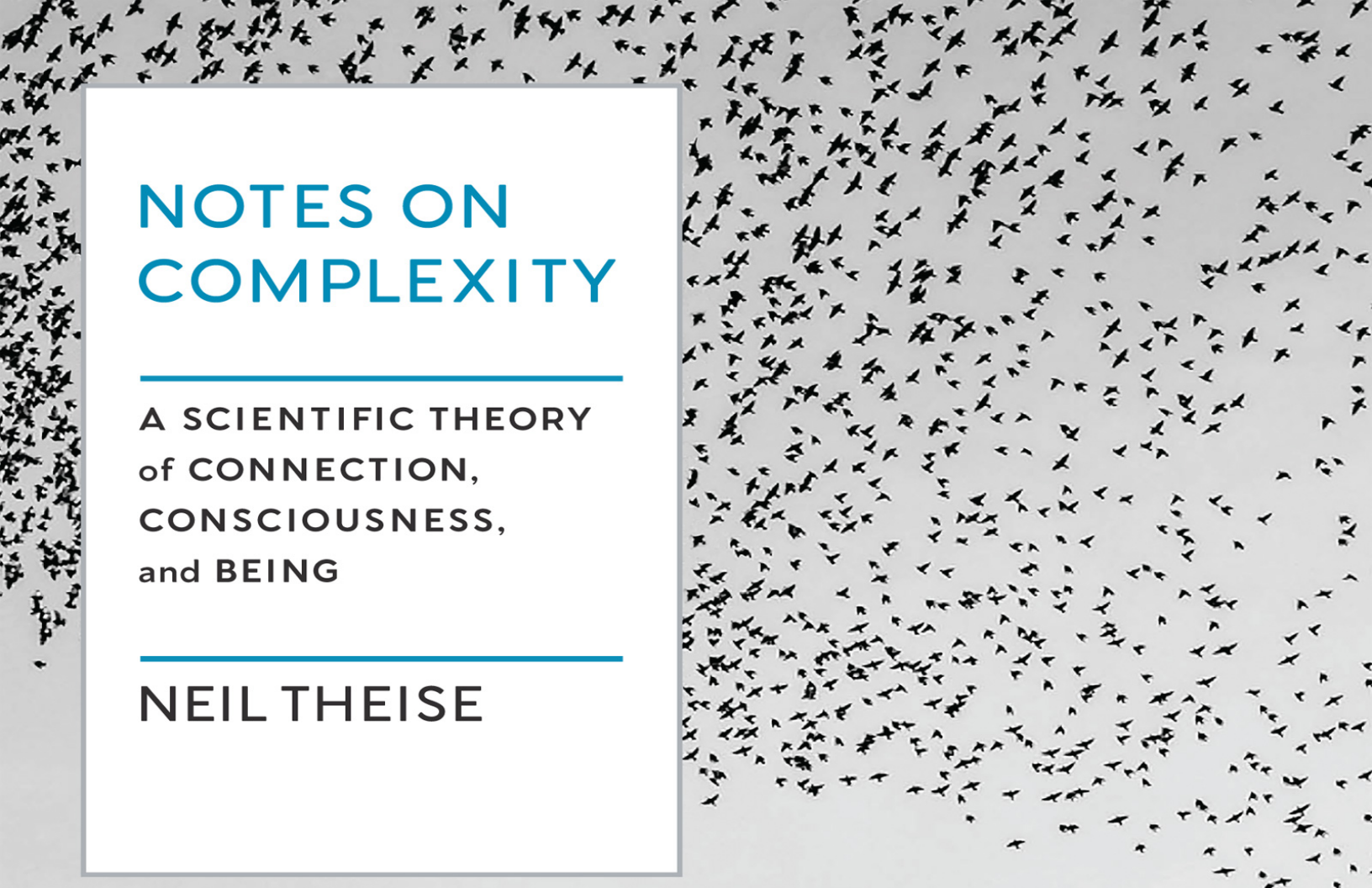




NOTES ON COMPLEXITY

A SCIENTIFIC THEORY
of CONNECTION,
CONSCIOUSNESS,
and BEING

NEIL THEISE



SCAN NOW



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*A Scientific Theory of Connection,
Consciousness, and Being*

Neil Theise

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SCAN NOW



For my husband, Mark



And with deepest gratitude to:

the CELL Team, who launched these journeys—

Peter Ride and Jane Prophet

Mark d’Inverno and Rob Saunders

Roshi Enkyo O’Hara,

abbot of the Village Zendo,

who has guided my Zen practice for more than thirty years

**Their teachings were “like two arrows meeting in
midair.”**

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NOTES ON COMPLEXITY

Ever since I was a kid, I have been collecting interesting facts and theories about the world and storing them away. I never tired of observing, naming, and seeking to understand. The ideas that I found most compelling were from science, but other ideas—from religion, history, and the arts—also claimed space in my mind.

As I grew older, I was drawn to mathematics, geology, astronomy, modern physics, and cosmology—subjects that could reveal aspects of the world normally hidden from view. Religion too called out to me as it addressed the realm of the ineffable. I had no firmly held belief that one had to choose between science and religion, so I never privileged one over the other.

At university I continued on this dual path with two majors—Judaic studies, in case I wanted to attend rabbinical school, and computer science, because back in the days of Fortran, COBOL, and punch cards, it was just so cool. I also minored in premed studies because I harbored this idea that a career in medicine might be a way to link my scientific interests to my spiritual imperatives—a way to practice, in Jewish mystical terms, *tikkun olam*, healing the world.

Ultimately, I chose the path of medicine, though I did not land in the kind of direct clinical patient care that I had originally envisioned. Instead, I found sustained pleasure in sitting at a microscope, hour after hour, looking at diagnostic pathology specimens, “pieces of people,” as I liked to say, studying colorful microscopic shapes and patterns—beautiful puzzles that needed to be solved. Of particular note, this specialty afforded me daily opportunities to think scientifically about human bodies. I didn’t need culture dishes or mice to explore biology; I had human tissues and cells to gaze upon.

Some of the research that eventually sprang from my clinical specimens led me into the rapidly transforming field of stem cell biology. Suddenly, around the turn of the millennium, I found myself publishing not in my usual clinical medical journals but in prestigious scientific publications such as *Nature*, *Science*, and *Cell*, garnering international academic and press attention.

While everyone who knew me knew that I did research, they generally did not know the specifics. Suddenly, everyone knew and was taking an interest.

This included my friend Peter Ride, an academic colleague at the University of Westminster in London who was interested in “visual culture.” He introduced me to a friend of his, Jane Prophet, a visual artist who told me about complexity theory and set me on an unexpected path.

Jane’s best-known work at the time was a project called TechnoSphere. She had developed an interest in how people form emotional connections to the characters in computer games. With programmer Gordon Selley, she built a virtual world in which people were invited to log in and invent their own creatures, selecting individualized combinations of physical features and behaviors, choosing, for example, whether the creature was an herbivore or a carnivore. After each creature was set loose in TechnoSphere, it would “write home.” Mine sent emails with messages such as: “Today I outran a carnivore.” “I mated and am having a baby.” “I’m grazing.” “I was killed by a carnivore—this is your last message.”

However, once several thousand creatures were wandering the TechnoSphere landscape, Jane and Gordon discovered behaviors that had not been directly programmed but had emerged spontaneously from the creatures’ interactions. For example, the herbivores had formed herds and sometimes grazed themselves into a valley without an easy exit. The carnivores, instead of just attacking and picking them off one by one, lined up at the open mouth of the valley and waited until the herbivores exhausted the grassland and tried to leave. At that point the carnivores pounced and devoured the herd, and TechnoSphere registered a population collapse. Both the grazing and the hunting were self-organizing social activities that were natural outcomes of the creatures’ individual behaviors.

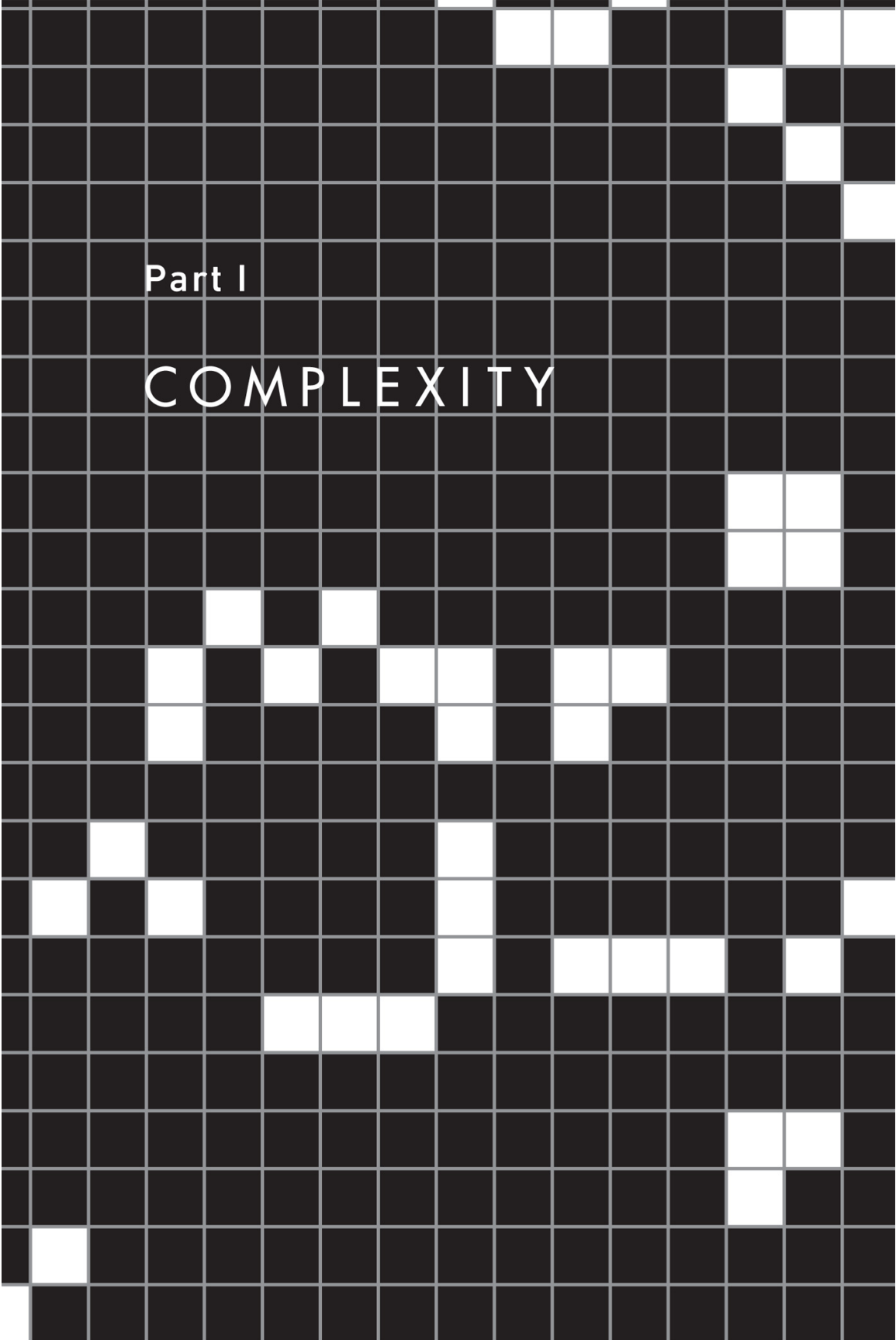
This self-organization was what connected Jane’s work to mine. As I told her about stem cells moving through the body, she realized that the cells had much in common with TechnoSphere creatures. When I asked her to explain, she started to speak about complex systems. Using ant colonies as an example, she described how simple individual behaviors can collectively give rise to astoundingly complex social structures and activities. She made the magic of complex systems vivid and clear.

And thus began my introduction to complexity theory.¹

Beyond the gift of her friendship, Jane offered me a new way of understanding the world. The further I investigated, the more I found that all the myriad, seemingly unrelated concepts I had amassed over the years—medical, scientific, and spiritual—complemented each other in surprising ways, forming a holistic view of human existence. And, somehow, along the way, these studies have transcended mere information and become transformative for how I live, how I understand myself, and how I understand the very nature not only of human existence but of all existence. Complexity turned out to be a science of being.

In the years since, I have shared these emerging ideas in academic lectures and in public presentations for nonexperts. These “Notes on Complexity,” as I refer to them, have sparked curiosity, surprise, and even moments of awakening in audiences ranging from fifth graders to PhD candidates, from practitioners of healing professions to research scientists, from yogis to Zen students. After every such encounter, I’m delighted by the ways in which different people find their own unique meanings in the material. That this information resonates with such a wide array of people confirms for me what I recognized over twenty years ago when Jane and I were just getting to know each other: complexity theory provides a powerful yet delicately nuanced understanding of the nature of reality and our place within it as conscious, living beings.

And now, in gratitude for the teachings I’ve received from Jane and so many others throughout my life, I offer these ideas to you.



Part I

COMPLEXITY

ONE

A Science of Being

Nothing in the universe is more complex than life.

Microscopic life abounds both in the scalding, pressurized, sunless depths of ocean trenches and upon the highest, frozen Himalayan peaks. In between, throughout skies, in oceans, and across lands, life is endlessly on the move. And, surely, in the billions of years in which organisms will continue to thrive on the planet, there will be vastly more life forms, with variety beyond anything we might imagine.

The complexity of all this rich abundance has long resisted explanation. The origins of life remain deeply mysterious. What biological wonders might emerge next are beyond our knowing. If we were even to begin to fathom it all, a theory of complexity was necessary.

Complexity theory is the study of how complex systems manifest in the world. The use of the word *complexity* here does not mean “complicated,” however. *Complexity* in this context refers to a class of patterns of interactions: open-ended, evolving, unpredictable, yet adaptive and self-sustaining. It is this complexity that we will explore—how life self-organizes from the substance of our universe, from interactions within the quantum foam to the formation of atoms and molecules, cells, human beings, social structures, ecosystems, and beyond.

A distinguishing feature of life’s complexity is that, in every single instance, the whole is greater than the sum of its parts. Even if one knows the characteristics and behaviors of all the individual elements of a living system (a cell, a body, an ecosystem), one cannot predict the extraordinary properties that emerge from their interactions. In complexity theory, these surprising outcomes are called *emergent properties* or just plain *emergence*.

This unpredictability is both a core subject of complexity theory and a key feature of what it has to offer our understanding of the world. Neither we nor our universe is machinelike. A machine doesn’t have the option to change its behavior if its environment changes or becomes overwhelming. Complex systems, including human bodies and human societies, can change

their behaviors in the face of the unpredictable. That creativity is the essence of complexity.

The whole is greater than the sum of its parts. So much is packed into that simple expression. Colloquially, the phrase evokes community, teamwork, elevated purpose—the ways in which people, with their own differing talents and abilities, when working together, can create synergies beyond the scope of what any of the individuals alone might have been capable of producing on their own. A winning team. A social movement. A perfect dinner party.

But complexity extends far beyond human beings and their social behavior. Examples of complex systems are found not only in sociology and biology but also in chemistry and physics. The universe is a shimmering web of complexity that continually births and nurtures life, tempting us to believe that life might even be its central purpose and most fundamental expression.

Complexity bridges the seemingly unbridgeable gap between the universe at its most infinitesimal, described by quantum mechanics, and at its most vast, described by the theory of relativity. As successful as these two most successful of all scientific theories have been, they are unable, on their own, to illuminate how we go from the most basic elements of existence (space, time, matter, energy) to the complex behaviors of living organisms and their social structures: ecosystems, cultures, and civilizations. It is complexity theory that shows how the entities arising from fundamental physics actively weave themselves into ever larger structures, step by step, until they become the fabric of our everyday lives and of the dynamic, natural, living systems that surround us.

While the aims of complexity science are grandly ambitious, when studied with careful intention, its lessons can also be deeply personal. It can solve some of the most crucial riddles of our sense of being.

In the womb and for a relatively short time afterward, we are in a seamless world in which we experience no divisions: there is no self and no other, no baby and no mother. Gradually, inevitably, in early infancy, we move from this state of intimate wholeness into another state, one of separation. We become bounded by our skin: everything inside it an “I,” everything outside it “the world.” Parts, not wholes.

Occasionally, if we are fortunate, we find ourselves in a situation with other people in which we achieve that feeling of complete unity, of

something bigger than ourselves. In the absence of that experience, many of us will spend our days struggling to understand how “I” and “the world” relate. If we’re at all able to recall that sense of seamless unity, we may look over our shoulder and wonder, “How can I get back to that?” And if we’re not able to recall it, we may instead just be left with the uneasy sense that something is missing, even though we’re unsure what that something is.

Complexity theory not only provides us with scientific understanding, but as we travel down its paths, the implications of the theory can also enlighten us, providing insight into everything from the permeable boundaries of our bodies to the nature of consciousness. Complexity theory can foster an invaluable flexibility of perspectives and awaken us to our true, deep intimacy with the larger whole, so that we might return to what we once had: our birthright of being one with all.

Order, Chaos, and the Origin of Complexity

Complexity theory arose in the latter half of the twentieth century as scientists began to focus on what are called *systems*, a shorthand term for groups of interacting parts or individuals that, through their interactions, generate something larger than themselves. Many kinds of systems have been studied and the fields that have considered them are quite varied: general systems theory, cybernetics, and studies in artificial intelligence in the 1950s; dynamic systems theory in the 1960s; and chaos theory in the 1970s. In the 1980s, complexity studies finally emerged as an established, independent field, most notably with the founding of the Santa Fe Institute, the first academic center for complexity studies.

Before this shift to the study of systems, nearly all sciences practiced a *reductive* approach, breaking apart larger things to isolate their components. The long-standing principle was that if one understood the parts, one could then understand the whole, as one might understand a clock by carefully taking it apart and examining the pieces. The extravagant success of this scientific approach, which treated the universe like a machine to pick apart for analysis, is clear, most immediately and obviously in the wild array of technologies that pervade our modern lives.

When general systems theory began formally addressing the reverse question—how do parts combine with each other, assemble themselves, *self-organize*, to make a whole?—it was the beginning of a scientific revolution that continues to play out, with ever increasing profundity. The application of systems concepts would become relevant for understanding structures across all scales of existence, from the smallest subatomic realms to galactic systems and beyond.



To begin our journey into complexity, we must consider three basic classes of systems. The first is made up of systems in which the whole is precisely and predictably the sum of its parts. Water provides some simple examples.

In solid states of water, like ice, the orderly packing of water molecules means that each molecule's relationship to its neighbors is easily defined by simple geometry. A glass of water is more complicated. Nevertheless, while we can't accurately predict the location of any single molecule in liquid, as the molecules bounce around in completely random abandon, we can use statistical methods to describe the molecules' collective behaviors and predict how the water will behave overall. We may not know the energy and direction of any single bouncing steam molecule as it collides with the others around it, but we can characterize the average kinetic energy of all the molecules that correspond to a specific temperature.

Some aspects of fluid movement are just as simple. Water flowing through a small narrow stream moves faster than that of the river into which the stream empties. The relationship of the speed of liquid flow to the width of its channel can be described by straightforward equations from the physics of fluids.

Turbulent water, however, does not lend itself to simple descriptions.

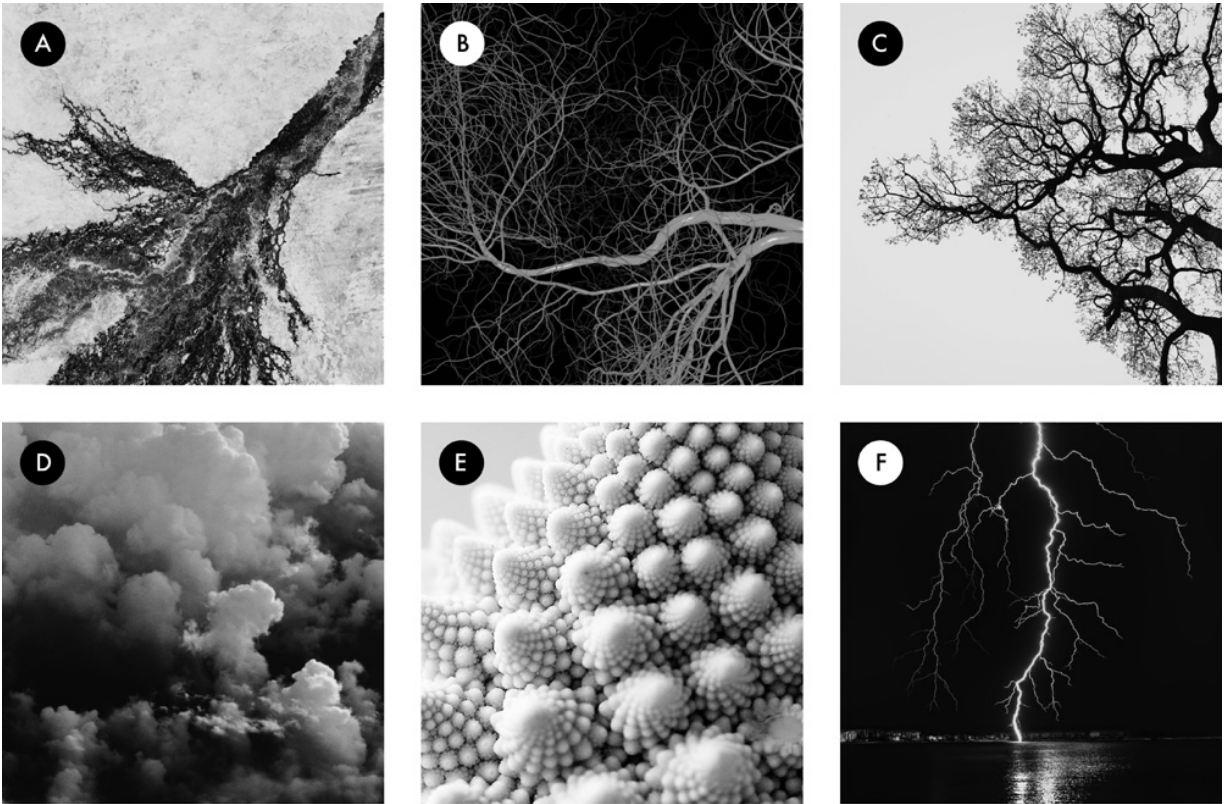
This brings us to the second class of systems, those described by *chaos theory*. In chaotic systems the whole is not equal to the sum of its parts, but is greater than the sum of its parts.

Take waves, for example. Sitting on a beach, we watch as waves crash onto the sand. They are all easily recognized as waves, though each wave is merely similar to the one before. It's never really precisely the same. There's no way to capture the ever-shifting motions of waves with the kind of precise physics expressed in simple equations for standing water or a block of ice.

Whirlpools are similar. Their motion is familiar to anyone who has drained the water from a bath or flushed a toilet. But simple physics and mathematics have been insufficient to describe their structures or explain why, in larger bodies of water, a whirlpool will form in one location only to disappear just as quickly, while another might then form somewhere else. In order to understand and describe such turbulence, we needed a new mathematics: chaos theory.

Fractals: The Mathematics of Chaos

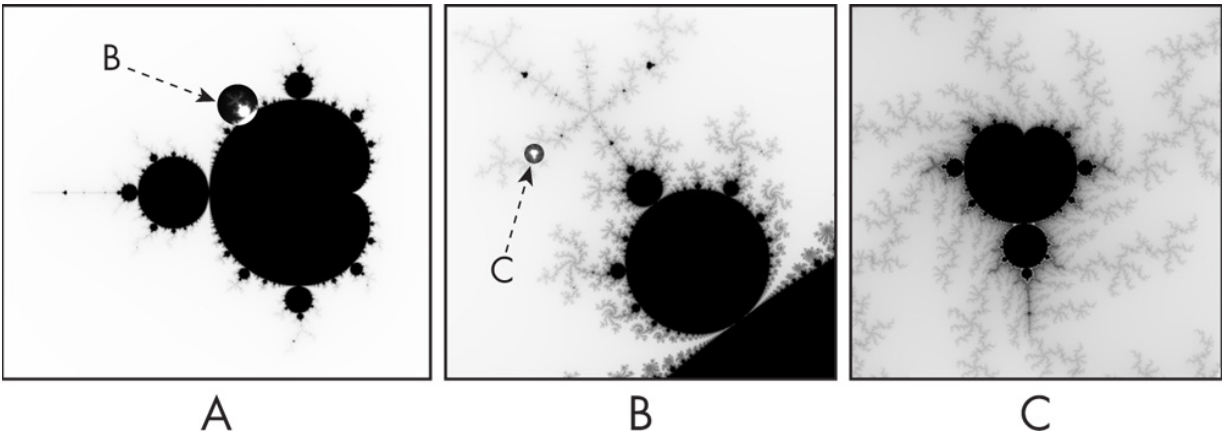
It was Benoit Mandelbrot who in 1975 radically expanded our understanding of these more elaborate kinds of order by recognizing and codifying the nature of fractals, thereby opening the door to a theory of chaos.¹ *Fractals* are geometric forms found throughout the natural world, such as in the similar branching of rivers, blood vessels, and trees. Different fractal geometries are present in the puffy shapes of cumulus clouds, romanesco broccoli, and forks of lightning.



Examples of fractal geometries in nature. In the top row, branching rivers (A), blood vessels (B), and trees (C) all have similar shapes to each other and are self-similar across scales; as one goes in closer or zooms back out, the patterns of branching are always similar to each other. Other fractal forms also display this self-similarity across scales: the puffy shapes of clouds (D), the cone-spirals of romanesco broccoli (E), and the jagged branching of lightning (F).

In these examples of fractals in nature, there are limits to how far down in scale the patterns recur. Arteries repetitively branch until they become capillaries and nothing smaller. Tree branches end in leaves (though the patterns of veins in a leaf may then be yet another fractal). Mathematically,

however, self-similarity of fractals across scales is infinite, as demonstrated by the classic “Mandelbrot set.”



This sampling of the classic Mandelbrot set of fractals shows how there is self-similarity across scales. As we zoom in on area B in panel A, we see that this form (panel B) is clearly composed of yet more fractals of similar forms. Likewise, zooming in on area C in panel B, we see that this form (panel C) is clearly composed of more fractals. In the purely mathematical realm, there is no limit to this ever-unfolding display of fractal detail to infinitely smaller scales.

Mandelbrot’s elaborate geometries cannot be contained in simple equations, like the mathematics that describes the behavior of water, ice, and steam. In those examples, one plugs a few numbers into the equations’ variables and out pops a geometric, algebraic, or statistical solution. Chaotic systems, in contrast, are *processes* that only reveal themselves over time. They can’t be summarized in a simple formula but must emerge with computer programs, or *models*, that play out over minutes, hours, or days. Without the invention of computers we couldn’t begin to imagine theories of chaotic systems, such as weather, whirlpools, or planetary orbits.

Despite the advances of fractal mathematics and chaotic systems, there remained some systems that could not yet be explained, let alone modeled: living things. Though examples of fractals and therefore chaos could be seen within aspects of biological systems, such as the forms of blood vessels, the airways of our lungs, or the patterns of electrical signals across a beating heart, they were insufficient to describe living beings as a whole. To describe life itself, the domain of that third class of systems, we needed complexity theory.

The Game of Life

On a cold, starry winter night in the early seventies, Christopher Langton sat alone in a computer lab at Massachusetts General Hospital. A prototypical young hippie and a self-taught computer programmer, he often kept eccentric hours, debugging code into the early morning. That night, up in a sixth-floor room in the psych department, where he worked crowded in by racks of unused computer parts, tubes, and wiring, old EEG machines and oscilloscopes, he suddenly felt the hairs on the back of his neck stand up. “I sensed the presence of someone else in the room,” he later recalled.² He looked over his shoulder, expecting to see that a fellow programmer had walked into the lab. But no one was there.

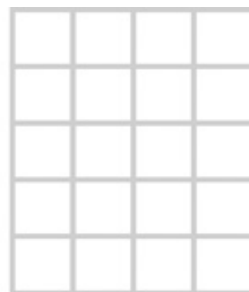
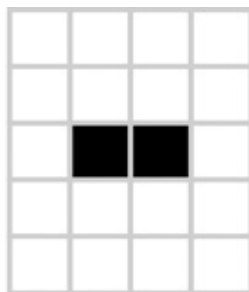
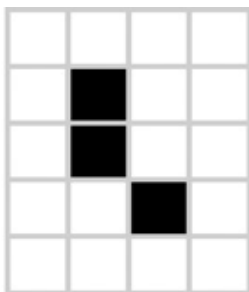
Turning back around, out of the corner of his eye he saw something playing on one of the computer screens. It was an early computer simulation—basically a video game—known as the Game of Life. Rectangular boxes of green light flickered and danced on the screen, moving and changing shapes.

In that moment, Langton realized that the presence he’d felt “must have been the Game of Life. There was something *alive* on that screen.”³

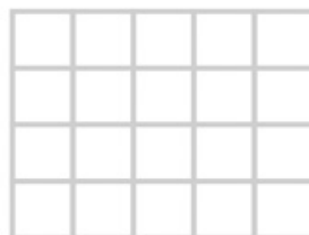
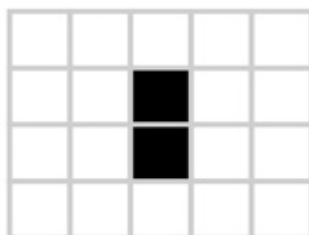
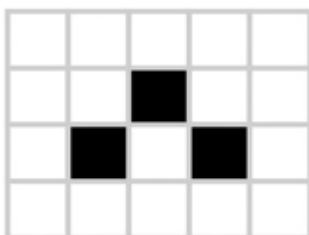
John Conway’s Game of Life had debuted publicly in *Scientific American* in the Mathematical Games column in October 1970.⁴ (I remember seeing the issue in the West Hartford Public Library when I was eleven years old. Yeah, I was that kid.)

Conway, an English mathematician, designed the Game of Life as an open-ended, two-dimensional grid of squares that were “living” (turned on, filled black) or “dead” (turned off, empty) depending on the number of living or dead squares around them.

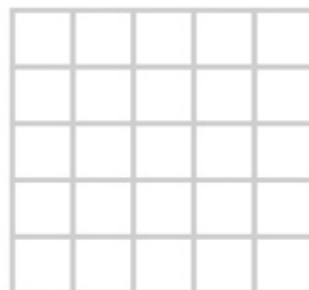
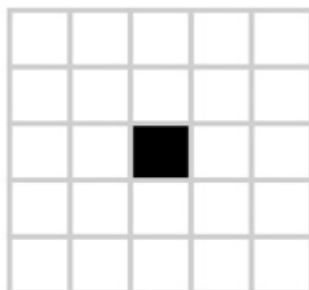
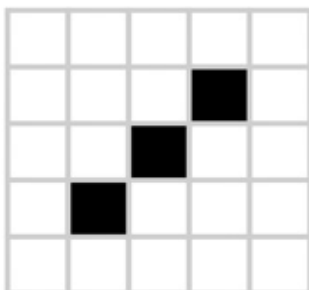
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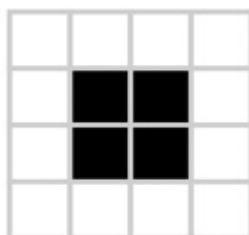
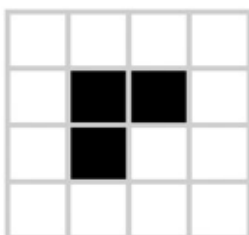
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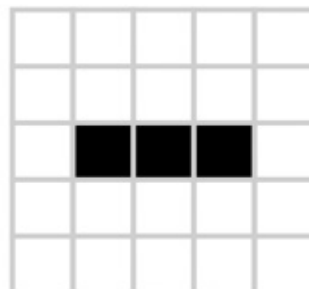
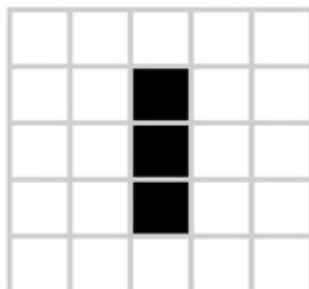
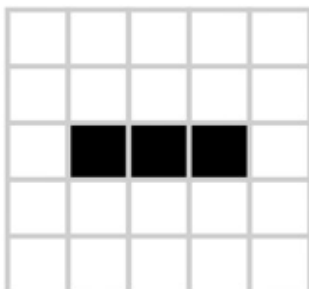
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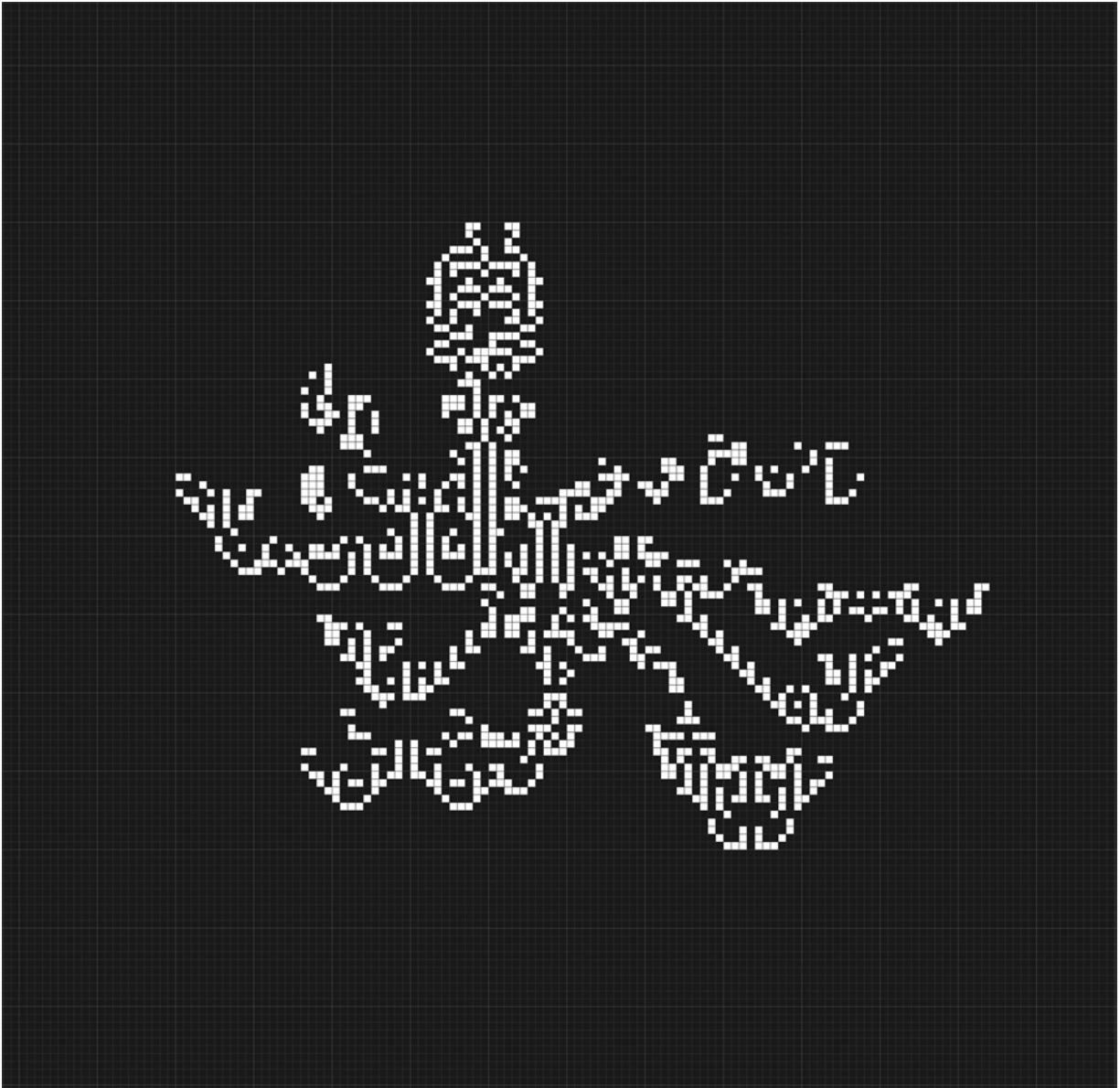


D



E





Sample evolutions of Conway's Game of Life as originally displayed in Martin Gardner's *Scientific American* column in 1970. The player begins the game with three "living" (black) cells. The number of living cells and "dead" (white) cells that are present around each individual cell determines the move to the next generation. Conway specified four rules for determining the fate of each cell in the next move: 1. Every living cell with two or three neighboring living cells survives to the next generation; 2. Every living cell that has four or more living neighbors dies (from overcrowding); 3. Every living cell that has only one or no living neighbor cells dies (from isolation); 4. Any dead cell with exactly three living neighbors comes alive in the next generation. Some games come to an end when all cells die (A–C). Others persist either freezing (D) or blinking eternally, back and forth, between different patterns (E). But some patterns would go on forever, changing and growing, often with organic-appearing structures, such as the one above, called a "wick stretcher," in which, if

the pattern is watched over time, a stalklike structure extends ever upward, like a bloom, as the generations tick by.

Langton described the hair-raising moment in the lab to the writer M. Mitchell Waldrop, who told the story in his book *Complexity*. “I remember looking out the window in the middle of the night, with all this machinery humming away. . . . Across the Charles River in Cambridge you could see the Science Museum and all the cars driving around. I thought about the patterns of the activity, all the things going on out there. The city was sitting there, just *living*. And it seemed to be the same sort of thing as the Game of Life. It was certainly much more complex. But it was not necessarily different in kind.”⁵

The epiphany, he said, hit him “like a thunderstorm, or a tornado, or a tidal wave that comes through and changes the landscape.”⁶ He recalled the “scent” that he’d caught wind of that night: “Things would come along that just smelled right, that would remind me of this pattern of activity. And for the rest of my career I’ve tried to follow that scent.”⁷ That scent would lead him to complexity theory.

Langton’s eclectic path progressed through various unrelated courses he audited at several Boston universities, helped along by whatever books he could gobble up from the shelves of the local libraries or bookstores, and a year at a lab in Puerto Rico, where he studied primate behavior. Eventually, in 1976, while still recovering from a hang-gliding accident that had shattered thirty-five bones in his body and face, he arrived at the University of Arizona’s world-class astronomy and cosmology center in the Sonoran Desert.

He began to recognize that his deepest questions were about “the history of ideas” and “the evolution of information”—information encoded in machines or in physical processes of the universe, and also information exchanged between humans at the individual or societal level. Information was the key, he was now certain. “It just smelled right.”⁸

He discovered that there was a rich literature from great minds of the prior decades who’d been considering the formal, even physical, nature of information—famous thinkers like John von Neumann, founder of game theory, and Alan Turing, founder of modern computer science.

In 1982, he enrolled in the University of Michigan’s graduate program in computer and communications science. There, he brought all the intellectual threads of his life together—after many years of digressions and

redirections tracking that scent, he'd finally followed it home, back to the Game of Life more than a decade after it had first raised the hairs on the back of his neck. He now knew what to call it, as well: "artificial life."⁹

Life at the Edge of Chaos

Some years later, physicist and computer scientist Stephen Wolfram, then at the Institute for Advanced Study in Princeton, New Jersey, was also intrigued by the Game of Life. Taking a sophisticated, scientific approach to how the game worked, he sorted the persisting outcomes into four distinct classes.¹⁰ Two classes appeared stable, either permanently frozen (d, page 14) or repetitively blinking (e, page 14). A third class had a truly chaotic appearance reflecting fractal mathematics (not pictured here, as it can only be visualized in video as a shape that evolves over time, similar to a whirlpool's stability-in-motion). The fourth class, however—recognized independently by Langton and by early chaos theoretician Norman Packard—was unexpected.

A crucial difference that separated Wolfram's approach from that of Langton and Packard can be understood in terms of the difference between studying each form of water—liquid, solid, and gas—and studying what happens when one form turns into another: when simmering water finally bubbles up into steam, how winter ice sublimates into vapor in bright winter sun, how fog condenses to wet your clothes on a cool morning walk. These changes are called *phase transitions*. They are well understood when it comes to water, of course.

But when it came to the Game of Life, they revealed something new. Langton and Packard discovered that this unexpected fourth Wolfram class of patterns arose in the crossing over between stable order and chaos. It was open-ended, evolving, yet self-sustaining, with shapes and movements reminiscent of living things. It was also unpredictable. This fourth class was an early demonstration of what would soon become formally known as *complexity*.

In this sense, as a technical term, *complexity* specifically referred to this new class of order recognized in models like the Game of Life. Just as "chaos" could describe the previously indescribable, like whirlpools and weather, "complexity" now went further, appearing to describe life itself.

The models were showing behaviors that mimicked living things, but they could also describe real living systems, whether single cells or multicellular organisms or larger aggregates like ant colonies, actual cities, or global ecosystems.²

As science writer Roger Lewin described it, complexity—information-rich, lifelike systems—erupts at this phase transition where “chaos and stability pull in opposite directions.”¹¹ Langton, publishing in 1986, called this phase transition the “onset of chaotic behavior.”¹² Packard, in his 1988 publication, called this realm the “edge of chaos,” the evocative name that has stuck.¹³

Unlike the phase transitions between liquid water and ice and vapor, which are best depicted as simple lines, the boundary at the edge of chaos is fractal. Imagine a boundary that looks as infinitely filigreed as the fractals of the Mandelbrot set.

Applications of complexity to biology were soon to be robustly explored. For Packard, biological complexity reflected how organisms take in information from the world, process it, and produce their behavioral responses. Such computational ability is a defining feature of living systems, whether colonies of relatively simple, single cells like bacteria, sensing and responding to nutrients and toxins in the environment, or large-scale, complex webs of organisms, such as trees and fungi in forests, processing nutrients in sun, water, and earth through the seasons and reacting to chemical, infectious, insect, and even human threats.

The adaptations made in response to changing environments drive evolution toward increasing computational complexity. “Intuitively, it seems reasonable that the task of survival requires computation,” Packard told Lewin. “If that’s true, then selection among organisms will lead to an increase in computational abilities.”¹⁴ Biological systems thereby seem to evolve toward the edge of chaos. Packard’s further studies proved that such adaptations toward the edge of chaos occur spontaneously as a consequence of the rules governing interactions within the system. His essential contribution was this: to show that evolution leads to complexity.

Polymathic physician and theoretical biologist Stuart Kauffman would explore all these biological implications of complexity to even greater depth. In his 1993 book, *The Origins of Order*, he argued that complexity has as much influence on the evolution of living systems as Darwin’s natural selection.¹⁵ Using different mathematical constructs, called *Boolean*

networks, Kauffman could also model behaviors of *cell differentiation* (how different types of cells arise from one another) as a complex system.¹⁶ He would also use a complexity theory approach to describe how certain types of molecules, so-called *autocatalytic sets*, could have interacted to originate life out of the biochemical soups of Earth's young ocean.¹⁷ While Langton's and Packard's discoveries would launch complexity theory in all sorts of directions, it was Kauffman, with his imagination and sense of purpose, perhaps more than any other single complexity theorist, whose work demonstrated how complexity theory might explain the mysteries and surprises of life in the real world.

Emergence and Unpredictability

All this talk about computers and mathematics may be daunting. It is only one way of explaining the truths of complexity theory, but it highlights a key difference between traditional theories such as relativity and quantum mechanics and this younger one. As we have seen, neither chaos nor complexity is summarized by a set of predictive equations, like their predecessors in physics. They both can be explored only through computer modeling, through which we can watch them evolve over time, generating new properties of the system as a whole that transcend the parts that compose the system. These are the properties that often seem to pop up and appear as if by magic and, again, are referred to as “emergence.”

The difference between the emergence in chaotic systems and that in complex systems lies in its predictability. In a chaotic system, a computer model shows that the same starting conditions will always generate the same emergent properties. The whole is *predictably* greater than the sum of its parts. This is exemplified by the famous “butterfly effect”: the cascading changes by which the flapping of a butterfly's wings in Brazil might cause a tornado in Texas. If this is modeled, if the butterfly flaps its wings in precisely the same way, precisely the same tornado arises. However, changing the starting conditions ever so slightly—if the butterfly happens to land on a flower or it then flutters to the next flower to the right rather than the one to the left—it can mean the difference between a tornado in Texas or a typhoon in Taipei or calm sailing on the Andaman Sea.

In complexity, however, while we can predict that emergence will occur, its precise nature can never be predicted, even if we begin with the same starting conditions. In complexity, the whole is *unpredictably* greater than the sum of its parts. Kind of like the world. Kind of like our lives.

THREE

Rules of Complexity and the Adjacent Possible

When I leave my apartment for the hospital on a spring morning, I am greeted by trees that are spinning soil, water, light, and air into trunk, branch, and leaf. Likewise the daffodils and forsythia, bursting with yellows. Robins on our building's front lawn tilt their heads, listening for herds of earthworms passing through the ground beneath them. I reach the sidewalk and enter the kinetic stream of New Yorkers intent on their destinations. Somehow, they flow easily past each other, making unconscious micro-adjustments to shoulder and step so they can stride without interruption.

All around us we can see parts self-assemble into dynamically alive, adaptive emergent forms and processes. Not only can we see it, but we are part of it, even though our day-to-day habits, our focus on things beyond our bodies, may give us the sense of being observers of objects, separate from what we observe. In fact, we are not walking through the world; we are interwoven with it. Everywhere we look, we see complexity. In everything we do, we participate in complexity.

There are now several research institutes throughout the world dedicated to the study of complexity theory, evidence of its increasing influence in a wide range of fields. What do complexity researchers study? Biology and technology. Ecology and climatology. Urban life and agriculture. Business and economics. Anthropology and religion and evolution. Time. History. The future.

As a result, we now have the opportunity to explore complexity through the simple rules researchers have identified. These rules will help us understand what properties give rise to complexity and foster emergence, how to recognize them when we see them, and how to think about the moments when they go awry. To present these rules, I'll use ants as an example, because they are everywhere and everyone knows at least a little bit about them. What goes for ants goes for virtually all complex systems.

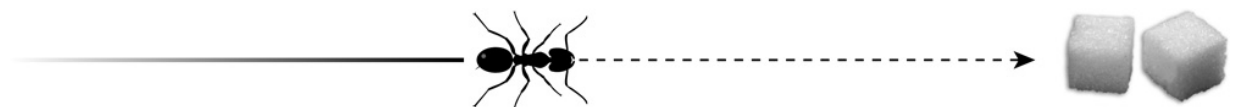
Rule #1. Numbers Matter.

There must be a sufficient number of interacting parts to form a complex system. The standard mail-order ant farm has twenty-five or so ants, all hard at work digging tunnels, creating food lines, and establishing a cemetery for ants that die. These behaviors are examples of emergent phenomena. But once you have just a handful of ants left, there is no self-organization and the emergent properties dissolve: no food lines, no cooperative tunnel building, and dead ants stay where they die. On the other hand, the more individuals there are in the system, the greater the level of complexity. A colony of two hundred ants is not as complex as one with two thousand ants, and one with twenty thousand ants is still more complex. A village is not a city is not a megalopolis.

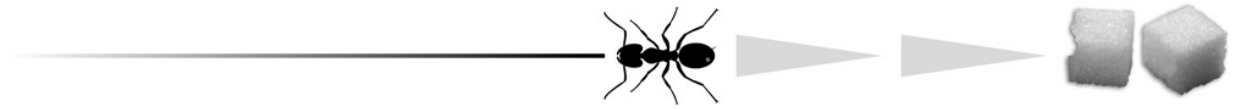
Rule #2. Interactions Are Local, Not Global.

The emergent phenomena of ant colonies do not arise because some leader in the colony is planning things. While emergence often looks planned from the top down, it is not. A simple ant line provides a good example. Ants take food from wherever they find it and bring it back to the colony. Back and forth the ants go, so efficient and well ordered it seems as though someone must certainly have set it all up. But no one did. The queen ant doesn't perform an administrative function; she does not monitor the status of the colony as a whole. She serves only a reproductive function. There is no single ant or group of ants at the top planning the food line or any other aspect of the colony. The organization arises only from the local interactions between each ant and any other ant it encounters.

Ants produce a variety of *pheromones*, or scent signals, by which they communicate with each other in different situations. When detecting pheromones, either their own or those laid down by others, ants will respond in characteristic ways. So, for example, as an ant is walking, it is laying down a scent trail for itself—if it were to turn around, it could follow that trail back to the colony.

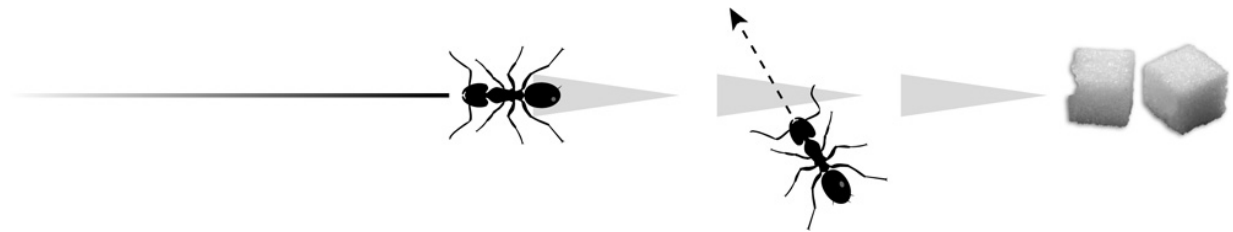


If it encounters some food in its wanderings, it will take some of it, then turn around and follow its own scent back.

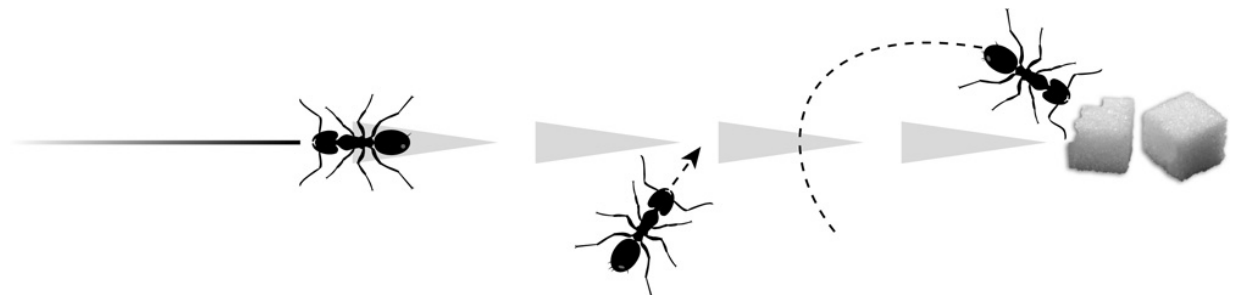


Food held aloft, the ant will lay down a different scent as it walks, one for other ants to sense, signaling to them that food has been found. Since the scent degrades over time, the relative strength of the scent indicates direction: stronger is in the direction the first ant is taking back to the colony, less strong in the direction of the food.

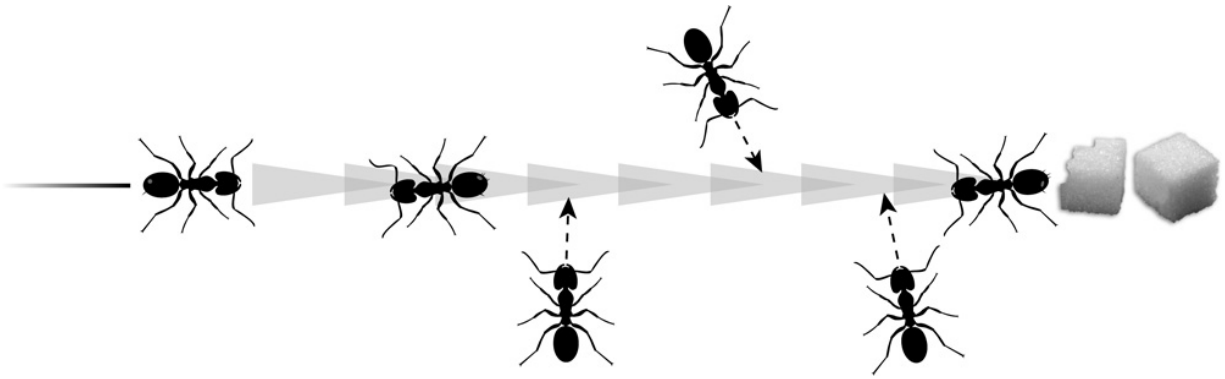
An ant coming across that pheromone trail will detect that particular scent and read it as an instruction to turn in the direction of the food and keep walking.



Inevitably, it thereby also finds the food.



As more and more ants begin to cross each other's paths, find the food, and turn back the way they came, they build up a stronger and stronger path.



Thus, a food line forms, even though no single ant was paying attention to whether the colony needed the food, how many ants would be needed to get it to the colony, or how to recruit the ants necessary for the work. A complex behavior emerges from local interactions. Ant after ant will repeat the routine until the sugar is gone, at which point the absence of food-bearing ants finally allows the trail to degrade enough that it ceases to be reinforced and disappears.

In human systems we often think that some of us are, indeed, monitoring globally. An authoritarian leader, for example, may think they are leading a top-down system, but they are always mistaken. While they may have a firm grasp on higher-level detail, it is never truly global. It's just another kind of "local" surveillance, albeit with more widely gathered data and more complexity of information than is available among ants. They may think they are above the web of interactions, looking down upon it, but they are still always, inevitably, within the web, intimately connected to everyone and everything. Ultimately, leaders won't know about the whispering among gathering insurgents, whose burgeoning revolution, itself an emergent phenomenon, will potentially rise up and overthrow the attempted top-down leadership. Thus the belief of authoritarians that they monitor every detail of the system as a whole is revealed as an illusion.

Likewise, there is no cell monitoring your body as a whole to detect whether you are sleepy or hungry or horny. There isn't even a globally sensing organ that does that. Of course, we would leap to suggest the brain, but despite our cultural instinct to put it at the very top of some sort of body-wide sensing system, the brain does not in fact monitor *everything* any more than the autocrat who believes they can watch all the social networks of their realm. While the brain communicates with the body via signals passing along nerves, reaching out to the body and receiving information in return, we know that the rest of the body also modulates the

brain itself. The adrenal glands, which produce *cortisol*, the stress hormone, are an example. Cortisol rises and falls in a daily, twenty-four-hour rhythm but can be altered in times of unmitigated adversity, when the body needs to remain on high alert. But when the rhythm is disrupted, one can become depressed or even psychotic. Then there are the bacteria lining the digestive tract, influencing the brain, altering moods, hunger, and other behaviors. The brain is within the web, being acted upon even as it exerts its influence. It is not simply looking down upon the rest of the body from its throne in the skull.

So, who is in charge of whom? Ultimately, no one ever is; all interactions are local. Every element of a complex system interacts with every other element through networks made up of local connections. Some elements may have greater or lesser influence, but none are truly above and beyond the web; none reach down into it from outside with inexorable intent, exerting total control.

Rule #3. Negative Feedback Loops Prevail.

These observations of local interactions take us a bit deeper into the intricacies of how complex systems adapt. There are always *feedback loops*, networks of interactions that “feed back” into themselves. To understand feedback loops, think of an air conditioner. An air conditioner tests the temperature, turning on when a room gets too warm and turning off when the room cools again. This is a *negative feedback loop* because the machine keeps the room’s temperature within a defined range. A *positive feedback loop* would occur if, for example, a room’s rising temperature triggered a heater to crank itself up, driving the temperature to become even hotter.³

Negative feedback loops prevail in complex systems, keeping a system’s conditions within an oscillating, healthy, *homeostatic* range. In homeostasis, the system sustains the capacity for adaptation to the changing world around it, preventing any one member of the system from overwhelming others.

Think back to the ants building a food line: one ant begins laying down the pheromone path that indicates the direction in which to find food and also the opposite direction for going back to the colony. Another ant crosses that path and responds appropriately, laying down its pheromone trails.

Now there are two pheromone scents, the reinforcement making it twice as likely for other ants to find them and join. This in turn leads to more paths and more ants, and more paths and more ants: the positive feedback creates the food line.

However, if every ant fell into line, the other maintenance tasks of the colony would be abandoned. This is where negative feedback shows its importance. In this case, from the moment a scent trail is laid down, it starts to dissipate. We saw how this provided directionality to the scent trail, but it is also negative feedback: the scent trails don't last forever. Negative feedback prevents the colony from inefficiently becoming one giant food line.

All living systems are homeostatic, yet they are never frozen still. Similar to that stability-in-movement we saw in chaotic systems, there is ceaseless change in complexity, continual oscillation within the healthy, life-sustaining ranges. Life is ceaseless movement; stability is found in balance, not rigidity.

If positive feedback loops overtake the balancing negative ones, then the self-sustaining homeostatic equilibrium gives way. Energy-expending behaviors come to predominate, ultimately crashing and burning the system. Think economic bubbles or cancer. Both arise out of a preexisting homeostatic living system—a well-functioning economy, a healthy body made of interacting cells—yet for reasons particular to each, negative feedback declines, allowing positive feedback to predominate. Explosive growth ensues, followed by utter collapse: recessions or depressions in economies; death in the case of those with terminal cancer.

We have a classic example in considering the US economy in the aftermath of the Great Depression. After the 1929 stock market collapse, the economists and legislators of the day intuited a need for regulations that would prevent runaway bubbles like the one that led to the disaster. The resulting legislation, the Glass-Steagall Act, implemented reforms in the American economic system, including separating investment banking from retail banking, preventing banks from borrowing from themselves, and giving power to the Federal Reserve to regulate the banks. What were these regulations but legislated negative feedback loops meant to keep an economy in an adaptive homeostatic realm?

The reforms worked. However, by the start of the 1980s and on into the new millennium, they were steadily eroded by both major American

political parties, and unsurprisingly from a complexity perspective, economic bubbles followed by collapse became increasingly frequent right up until the Great Recession of 2008. With this erosion of negative feedback loops, the positive feedback in different markets (e.g., Silicon Valley technologies, subprime mortgages) promoted unchecked speculation, leading to bubbles with explosive, energy-wasting growth that were doomed to collapse.

Likewise with cellular growth. Normal cells in normal tissues regulate themselves and each other through negative feedback inhibitions. Cells growing next to other cells display “contact inhibition.” They are prevented from dividing when they are surrounded on all sides by more cells. If adjacent cells die or move away, creating a loss of contact, the previously inhibited cell can divide and the space is filled again with new cells. Contact inhibition is thus restored—a perfect homeostatic negative feedback loop: turn off, turn on, turn off.

When genetic mutations lead to a cell becoming cancerous, each mutation either turns off a negative feedback loop or turns on a positive feedback loop, or both. Cancer thus effectively shifts away from homeostasis into an explosive, uncontrolled growth, creating a tumor that invades and spreads. As its own self-reinforcing positive feedback loops become dominant, there is a deep depletion of energy in the system as a whole. The person with cancer, unable to keep up with the tumor’s increasing metabolic demands, becomes severely wasted and dies.

The newest front-line cancer treatments aim not merely at killing the cancer cells but at reestablishing the body’s homeostatic control over them. For example, one naturally occurring homeostatic check on cancers is antitumor surveillance by the immune system. Anyone with a chronically weakened immune system from any cause (e.g., stress, malnutrition, immune-suppressive medications, or untreated HIV infection) is at risk for developing cancer since the immune-based negative feedback loop is degraded. Some of the newest, most exciting anticancer treatments have found ways to reboot the immune system’s ability to recognize the tumor and fight it. Homeostasis is restored, and the malignancy melts away.

In the coming chapters, we will progress downward through levels of scale, from cells to molecules, from atoms to subatomic particles to the deepest quantum realms. At each level, the processes that create negative and positive feedback loops can be framed in terms of the means of

communication between those scales' interacting parts. The more complex the system, the more elaborate those means of communication will be, and often, the less precise we can be in summarizing them. Cells and bodies are harder to capture in simple equations, but at the smallest scales, such as the atomic level (governed by the rules of chemistry) and the quantum level (governed by the rules of particle physics and quantum field theory), the processes are more concisely and always mathematically specified.

Rule #4. The Degree of Randomness Is Key.

Unpredictability is a defining hallmark of complex systems. Unpredictability is also the source of all the extraordinary capacities for unbridled creativity in complex systems. Its implications are profound.

There are always a small number of ants that aren't following the direct, pheromone-based food line. These divergent ants are not lazy or pointless. They are, in fact, vital for adaptation. If all the ants were following the food line, there would be no ants left to find other food sources. In stem cell research at the turn of the millennium, my colleagues and I pointed out that bodies behave similarly. If cells behaved like little machines, bodies would be too brittle in the face of disease or injury. Some necessary amount of randomness has to be part of the way cells behave as they move in and around the body in order to find healing responses.¹

But as with many things in life, moderation is the best path, and in complex systems the degree of randomness is key. Too much randomness prevents any self-organization at all, while too little randomness causes a system to behave more like a machine, without enough flexibility to find new modes of adaptive behaviors. With just the right, low level of randomness, sometimes referred to as *quenched disorder*, the system blooms with the ability to explore what Stuart Kauffman calls the "adjacent possible."² New opportunities can't be found if random things aren't happening here and there, stumbling into new ways of being, new modes to be reconnoitered and exploited. A little randomness keeps the system alive.

When I was a kid, this ant behavior created a constant source of tension between my mom and me. She was quite obsessive about keeping our house flawlessly clean and tidy. If I came upon an ant, off alone, exploring our kitchen, I knew I had to get it out of there quickly before my mom saw it,

killed it, and then called an exterminator. I felt sorry for the little lost ant as I nudged it onto a bit of paper to carry it outside where it belonged, with the other ants.

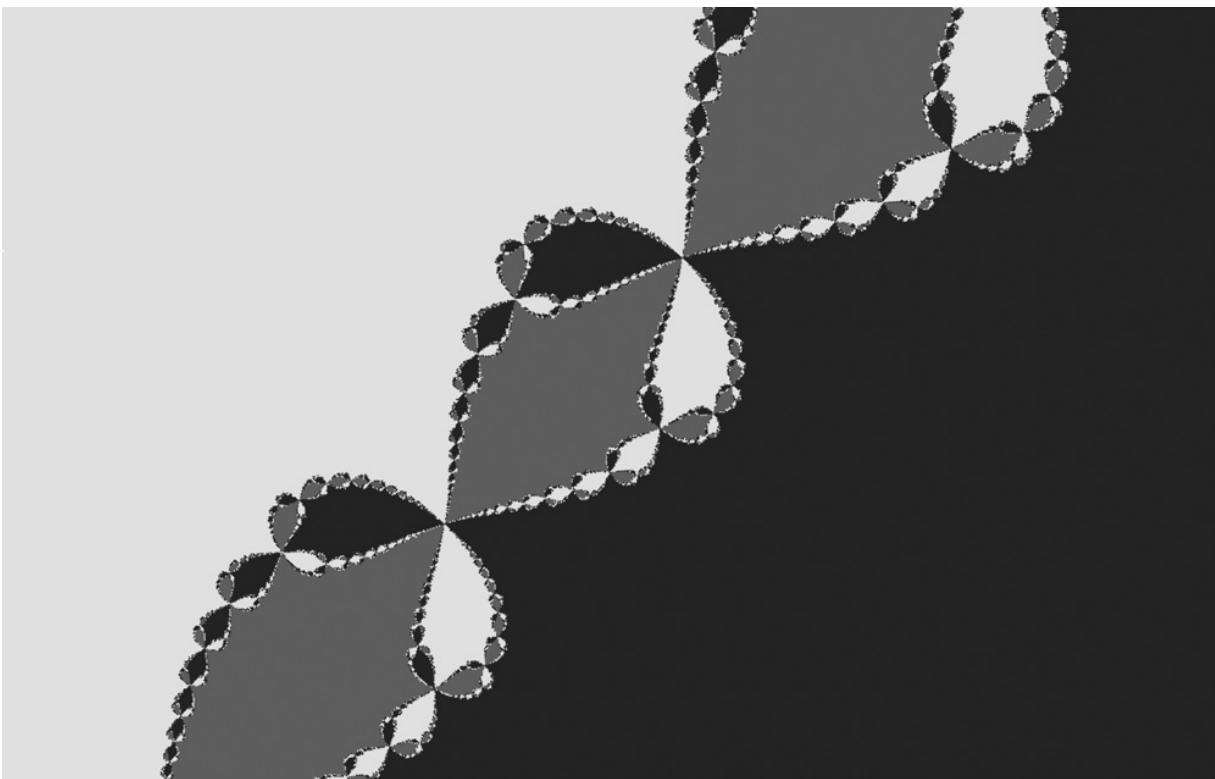
But my mother's instinct was correct. This ant was actually part of the quenched disorder in the colony, paving the way for the colony to explore the adjacent possibles of all the food in her kitchen. All it had to do was find a crumb I had dropped before my mom had the chance to sweep it away. It would quickly turn around and follow its scent back to its home while laying down a surefire route for a hundred other ants to stream into our house. This wasn't some "poor little ant," this was the vanguard of a home invasion!

This low-level disorder explains why we are unable to predict the nature of emergent structures in complex systems, even as we can be confident that they will arise. In complexity, the same starting conditions, continually subject to some low-level randomness, are unlikely ever to evolve in precisely the same way. It is as though in every moment of its life, a complex system is enveloped by a shimmering cloud of adjacent possibles, all the possibilities that *might* evolve in the very next moment. And then in that moment, one unpredictable possibility manifests from all those available. This new iteration of the complex system now faces new conditions coupled with that limited randomness, and a different cloud of potentials manifests around it. And then again. And again. And again. Moment after moment after moment.

In terms of evolution, natural selection may well push a species toward change, but the range of possible choices for those changes includes only those that represent the available adjacent possibles. The choices are not infinite and most will not be adaptive. But neither is the range of choices small. Notably, they cannot be predicted. Biological creativity, life's ability to produce diverse responses to changing environments, even leading to the evolution of whole new species and forms of ecosystems, is enabled by the quenched disorder of the system.

In the chapters that follow, we will explore how different kinds of "parts" (bodies, cells, molecules, atoms, etc.) interact to create complex, emergent wholes. For each of these, the way randomness arises, how it looks and functions, will vary according to the level of scale of the system we will explore. Likewise, the modes of communication that create feedback loops within each level differ from those at other scales—cells

talk to other cells very differently than a quark talks to another quark. So, while the generalities described in this chapter will apply across all scales, the details will appear very different. Nonetheless, at each level, we will find only a narrow range of randomness and a robustness of communication networks sufficient to produce balance even as the complex systems move to explore new, unpredictable possibilities.



Unlike the smooth boundary lines in a phase diagram of states of water, the boundary between order and chaos in which complexity arises is fractal, infinitely and subtly intricate.



There is another, somewhat darker side to this coin. What of the adjacent possibles that are not adaptive for the system, in part or as a whole?

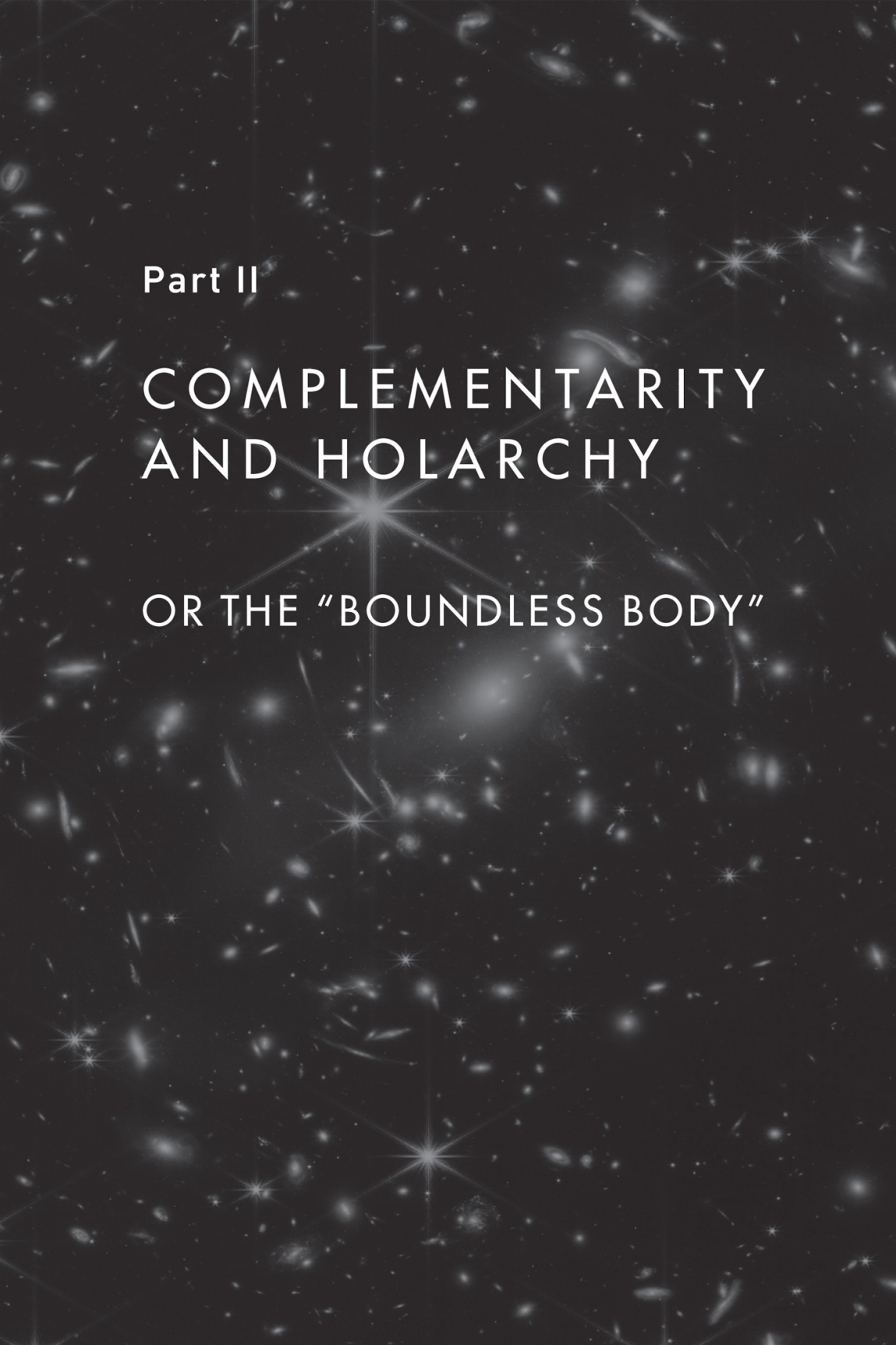
While the physical phase transitions between liquid water and ice and vapor are best thought of as simple lines, the boundaries at the edge of chaos are fractal. Imagine a (mathematical) boundary that looks as infinitely intricate and filigreed as the fractals of the Mandelbrot set. Biological creativity arises within a realm shaped by fractal geometry, where stability and chaos tug at life from either side.

With quenched disorder leading us down twists and turns of the fractal path at the boundary between stability and chaos, we may wind up in places we would prefer to avoid. Instead of remaining within this fractal phase transition in which we find life, we might be led out of it, either into rigid, machinelike determinism or into chaos. Either way the tug-of-war resolves, the self-sustaining, adaptive creativity of the system is lost, and it will undergo a partial or complete mass-extinction event.

Thus, the limited randomness that is the source of creativity in complex systems, and in all life, will inevitably lead to partial mass-extinction events and, eventually, given enough time, the death of the entire system. What makes us alive necessitates that we will die. There is no such thing as eternal life or a fountain of youth.

Though this may sound grim for us as individuals, from a larger perspective, is it? Mass extinctions always make way for new emergent forms. Without the extinction of dinosaurs, would mammals have risen to prominence? Without the Black Death in Europe, would there have been a Renaissance? Death clears the way for more extraordinary, unpredictable life. And isn't there more to life than just staying alive? What about the meaning of being part of a larger, ever-evolving whole?

And just like that, the abstractions of complexity theory—numbers, games, geometries, computational models—begin to brim with questions of fate, meaning, life, and death.



Part II

COMPLEMENTARITY AND HOLARCHY

OR THE "BOUNDLESS BODY"

FOUR

The Cellular Level: Our Bodies, Our Cells

Diagnostic pathologists like me have the daily privilege of studying samples of human tissue under the microscope. Usually, it is for the purpose of making diagnoses such as whether someone's biopsy shows a tumor and, if so, whether it is benign or malignant. As we examine case after case, often spending hours at the microscope each day, it's impossible not to be constantly reminded that bodies are composed of smaller parts: organs, tissues, cells.

Looking through a microscope, we don't see the body as a whole, or even the limb or the organ; we just see the cells, how they cluster and organize, how they connect to each other or remain apart, how each one looks different from the next even when they are the "same kind" of cell. Every skin cell looks like a skin cell, though each is actually different in minute ways from its neighbors—the same and yet not the same, exhibiting subtle or not so subtle diversity within the uniformity.

Then comes a knock on the door and we look up, returning to the everyday world in which bodies look like bodies. A trainee or colleague enters the office and we begin our social interaction at the everyday scale. With the right training, we can alternate between seeing bodies as bodies, such as other people or ants or birds, and seeing them, instead, as parts, as aggregates of cells.

We might therefore ask: "If bodies, such as ants, can self-organize and give rise to emergent properties as a complex system, can cells do the same?" They can, because they fulfill all the rules for constituting members of a complex system. Cells are rarely alone or few in number. Single-cell organisms virtually always exist in significant clusters or colonies. The simplest multicellular organisms have a thousand or more cells. Humans have trillions and blue whales have quadrillions. Cells interact with each other through both negative and positive feedback loops. And though molecular signals such as hormones may reach cells from distant parts of the body, even these interactions are still "local" from the perspective of the

targeted cell meeting its molecular signal and producing local effects. Certainly, no single cell or cluster of cells truly monitors the system as a whole. There is also quenched disorder in cellular interactions: not too much randomness, not too little. There is just enough randomness for cells to find new ways to adaptively self-organize in response to a changing environment or to recover from a partial mass extinction—a disease or injury.

Going from “bodies as complex systems” to “cells as complex systems” immediately highlights an interesting point: complex systems can be composed of other complex systems. When one looks at an ant colony from afar, it may look like a solid dark *thing* on the ground. One might get a hint of movement or see it changing shape if one stares long enough, but it essentially looks like a unitary thing. Then one goes in for a closer look and realizes that it’s not a thing at all. It’s just ants, interacting, self-organizing, in unceasing movement.

Now, imagine going in still closer, zooming in on a single ant, entering into it at the microscopic level. Just as the sight of the colony as a thing in itself dissolves into interacting ants when one draws close, at the microscopic level the ant’s body itself now dissipates into the interacting cells that constitute it. Which is it? A colony, or ants? A body, or cells?

Once, while a friend and I were out for a stroll, he asked me what research I was doing. At that moment, looking up over my friend’s head, I saw a strange kind of balloon or even a ship, dark and fluidly changing shape. For just a moment my brain struggled with the vision, until I refocused my attention and realized that it was a murmuration of starlings. “Look at that!” I said, pointing up. “That’s what I’m working on.” I was referring to the way the flock could look both like an actual thing in itself, and also like a huge number of independently flying birds. “This finger,” I said to my friend as I wagged it in front of his face, “is just the same. It looks like a finger, but is it? Is it a finger or is it a collection of cells? It’s a matter of one’s point of view, and both views are equally true.”

Whether something looks like a *thing* or like a *phenomenon* arising from smaller things depends on your scale of observation, your perspective or point of view.

This concept doesn’t have to be only abstract. If you’ve ever flown in a plane, recall the end of the flight, when you’re approaching your destination, coming in for a landing. You’re still high above the world, but

you see it getting closer and closer. You look down upon the rooftops and watch the cars moving like ants along the roads far below. The airport ahead draws nearer as the descent speeds up, faster and faster, closer and closer, until that special moment when the plane lowers just close enough to the tops of buildings, but not quite among them, and you suddenly shift from being *above* the world to being *in* the world. You just slipped from one scale of perception to another, and with the shift, for me, at least, the change is visceral. I feel it.

Complementarity

This duality might leave you feeling a bit unsettled. “At the end of the day,” you might ask, “which is it really, fundamentally?” Is your body a unitary entity or is it a phenomenon arising from its smaller parts, the interacting cells? The answer is, of course, both, equally and unequivocally.

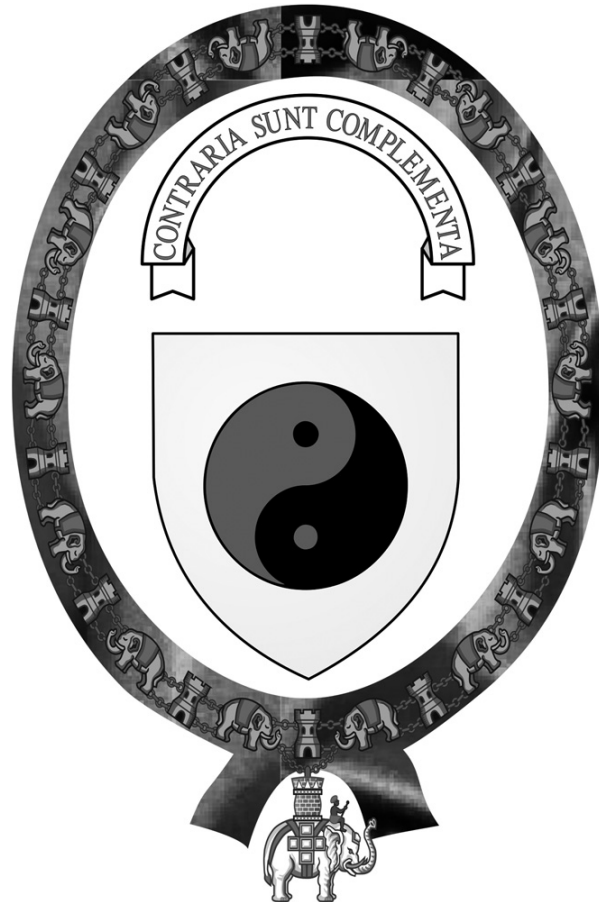
This kind of doubling of reality is a form of what quantum physicists call a *complementarity*. Perhaps the most famous example of complementarity is embedded in the now well-known, if perhaps not well-understood, notion that “light is both a wave and a particle.”

Complementarity was originally framed in regard to the “double-slit” experiment,⁴ which showed that streams of light behave like beams of individual particles if observed in one way, but behave like continuous, undulating waves if observed in a different way. This dependence on the experimental setup, on the method of observation, for whether light appeared as waves or particles was called *wave-particle duality*. It became clear that either description, on its own, was incomplete, insufficient to describe the nature of light in its totality. These two partial descriptions—waves and particles—complemented each other. Only together could they capture the full nature of light, each view providing information the other excluded. Their relationship was recognized as a complementarity.

Niels Bohr, one of the founders of quantum mechanics, thought the most deeply about this concept after he announced it in 1928. It had become clear that no single experiment could ever demonstrate both aspects of wave-particle duality at the same time. All agreed that, at the quantum level, the impossibility of capturing both states at once was a fundamental principle of the nature of existence. Bohr, however, went further, asserting that

complementarity was fundamental not just for describing existence at the incredibly minute scales of the quantum realm but for describing living beings at our normal everyday scale as well.¹

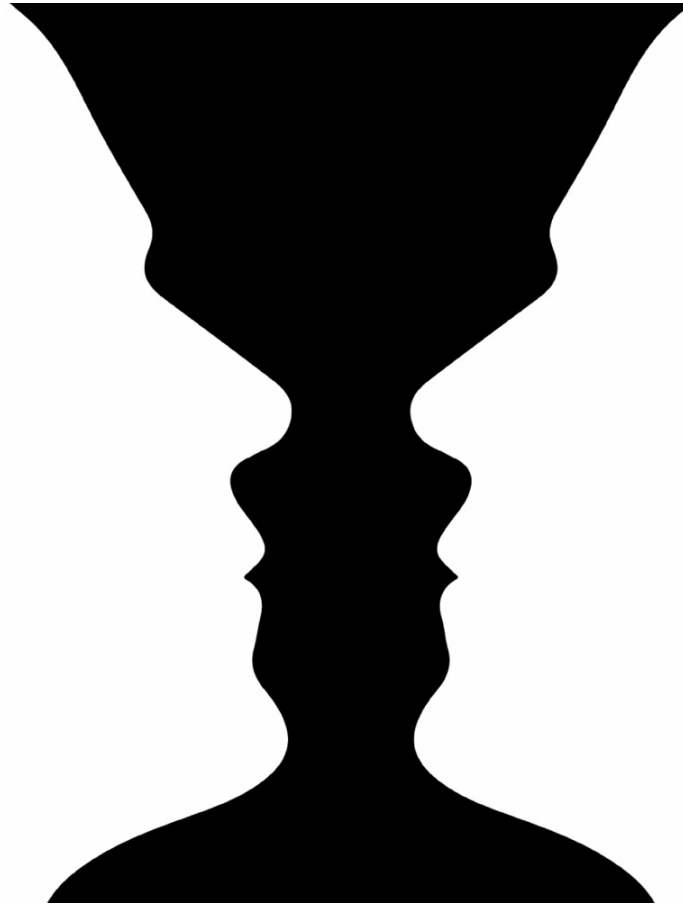
Furthermore, Bohr saw complementarity as a fundamental property of existence at *every* scale. It was so central to his thinking that, when he was awarded Denmark's highest honor, the Order of the Elephant, he designed a coat of arms for himself that featured a perfect symbol for complementarity, the yin-yang. Alas, perhaps due to the increasing subspecialization across all fields of science as the twentieth century rolled forward, these ideas about generalized complementarity were explored only in small corners of philosophy and science. Nonetheless, they remain very much alive.



The coat of arms of Niels Bohr. "Contraria sunt complementa" means "Opposites are complementary."

Here is another way to envision complementarity, the classic black-and-white image of two profiles viewed in silhouette and the space between them looking like a vase. Which is it? Two faces? Or a vase? Of course, it is

both, equally. Neither view describes the whole image, each one leaving out something essential. A complete description requires both opposite views to be united in a single complementarity.



In just the same way, whether a body is a singular entity in itself or a phenomenon arising from the nimble interactions of cells is a question easily answered. It is a complementarity as well. It is both, equally, though which of these it appears to be depends on your observational stance. Are you seeing it at the everyday scale or at the microscopic scale? At the everyday scale your body is a unitary whole. At the microscopic scale, that whole disappears into its parts—the ceaseless, dynamic cellular dance; cells in cooperation with other cells, in space and in time. Both views are simultaneously true, always, even if you can only experience them one at a time.

Where Is Your Boundary Now?

The realization that one's body is a unitary entity in itself, but also, equally, not, has important implications. One is that the boundary of one's body starts to become indistinct. At the everyday scale, my boundary is my skin and your boundary is your skin. Close your eyes and feel how your fingers meet this book or the device on which you are reading it. You feel a sharp, distinct edge between you and the not-you where skin meets object.

But at the microscopic level, just how sharp and distinct is the surface of your skin? Not very distinct at all. Cells from the top layer are constantly shedding as they die. Much of the dust of our homes, in fact, consists of sloughed cells from our skin and those of anyone else with whom we share those spaces. At the microscopic level, we are thus not actually bounded by the top of our skins. Our boundaries are at least as broad as the spaces we inhabit.

Now consider that what constitutes one's body is not composed just of one's own human cells. The *microbiome* is the community of microorganisms (mostly bacteria, but also fungi and viruses) that cover the surface of one's skin and line all the spaces within one's body that are in continuity with the outside (e.g., airways and digestive tract). These nonhuman organisms represent more than half of the living cells of one's body.

The microbiome doesn't only colonize us; it is integral to our living, healthy bodies. Indeed, our survival as human beings entirely depends on the close cooperation between our human and nonhuman cells.

Look at your finger and bend its joints. Notice the creases in your skin. The creases are lined by bacteria with functions that are specific to skin creases. These bacteria, in caring for their own needs, take in dead cell fragments and molecular components of the topmost layer of the skin and produce lubrication that moisturizes, softens, and protects the skin at the crease. That is why your skin doesn't crack from the constant wear and tear of your joints bending.

In other words, without the bacteria that coat every surface of our bodies, inside and out, we couldn't really exist as healthy human beings. In this case, without the bacteria, our skin would start to break down and we would become highly susceptible to infections. Before the introduction of antibiotics during World War II, such infections would often have been lethal.

Recent studies of the microbiome yield further surprises.^{2, 3, 4} These organisms, which are as much an integral, utterly necessary part of our bodies as are our own human cells, travel from us whenever we touch something. Doorknobs, cell phones, countertops, pens, each other. Every time you shake hands with, kiss, or hug someone else, some of “you” gets left behind and some of the person you touched travels away with you. This process of bacterial exchange is so pronounced that the microbiomes of people (and pets) who live together become one giant shared microbiome, a continuous multicellular entity enveloping the human (and dog and cat) islands. It is one large cloud or flock or colony of microorganisms. Moreover, these communities of different species and forms of life—the bacteria, the human cells, the cat cells, the dog cells—are physiologically interwoven, each part affecting the physiology of every other part and therefore, too, that of the whole.

What does that mean? Well, if we keep this fact about our shared microbiomes in mind, the boundaries between ourselves and what’s outside our skin start to look even blurrier. Our limits suddenly expand to include whatever and whomever we have casually touched in the course of the day and whoever has physically touched us back. So our boundaries in space extend beyond our skin.

Boundaries in time are also altered when one moves down to the microscopic, cellular level. Think of your body today. Now think of your body as it was yesterday. And last month and last year. Think about when you were a younger adult, a teenager, a kid, a toddler, a newborn. At the cellular level each cell traces back to a cell in an earlier version of you. Further backward, from newborn, to fetus, to embryo, there is no separation. Each cell comes from a cell before it. Embryo to fertilized egg. And before that? Again, there is no boundary. That egg and sperm that were the start of you were parts of your mother’s and father’s bodies. Focusing on your maternal origin, we discover that that egg, in turn, was part of all those earlier versions of your mother’s body and, ultimately, in the very same way, part of her mother’s body. And her mother’s before her. And her mother’s before her. All the way back to three hundred thousand or so years ago, when her mother wasn’t even *Homo sapiens* but *Homo erectus*. Then, back to *Homo habilis* and further back along the branches of the evolutionary tree to earlier mammals, to earlier amphibians, all the way

back to when we were simple multicellular organisms and then back to single-cell organisms and back to a probable common single-cell ancestor.

The teeming hordes of living things on Earth, not only in space but in time, are actually all one massive, single organism just as certainly as each one of us (in our own minds) seems to be a distinct human being throughout our limited lifetime.

Thus, we have yet another complementarity: each of us is, equally, an independent living human and also just one utterly minute, utterly brief unit of a single vast body that is life on Earth. From this point of view, the passing of human generations, in peace or turmoil, is nothing more than the shedding of cells from one's skin.

FIVE

The Molecular Level: Beyond the Cell Doctrine

The *cell doctrine* asserts that all living things are composed of cells and that all cells come from prior cells. Scientists settled upon this modern approach to biology—the conceptual basis of what we call Western medicine—after the invention of the microscope, when, for the first time, we could look at tissues under magnifying lenses and actually see the cells with our own eyes.

What did we think before the invention of microscopes and the triumph of the cell doctrine? In European culture, going back to the ancient Greeks, the composition of the body was considered a philosophical question, not a scientific one. The philosophers speculated that bodies were either made of indivisible subunits—“atoms”—or composed of a fluid that could be endlessly divided. Since there was not yet a way to look directly at the microscopic level for an answer, the philosophical debates persisted for more than two millennia.

Once microscopes were invented, lo and behold, the cell walls (plants) and cell membranes (animals) could now be seen. They appeared something like empty, many-sided boxes. If one breaks apart a box into smaller pieces, one doesn't get smaller boxes, just fragments of its sides. In this manner, the fundamental nature of bodies was solved: they are made of indivisible subunits, of atoms. These subunits were then called “cells” because they appeared similar to the cells of monks or prisoners—rooms with walls, a ceiling, and a floor, but empty of furniture. And thus the cell doctrine was born.

As years went by, microscopists discovered that different chemicals applied to tissues on glass slides could stain different parts of the cells, allowing for the discovery of new details. These stains (many of which are still used in my own daily diagnostic practice) revealed cellular substructures that had previously been invisible, such as nuclei,

mitochondria, ribosomes, Golgi bodies, and endoplasmic reticulum. In other words, we started filling in the furniture of the empty cell.

What if the technology had been different? What if the first thing seen under the microscope wasn't a cell wall or cell membrane but a nucleus? The early microscopists might then have instead said, "Look, the body *is* made of an endlessly divisible fluid!" They would see these little balls—the nuclei—scattered about in it, but the basic fluid nature of the body would have been revealed. In this alternate history, the fluid doctrine would have been born as the foundational paradigm of Western medicine and biology. In the years that followed, after applying special stains and seeing cell membranes for the first time, these scientists wouldn't have backtracked, saying, "Oh, we were wrong, the body is made of cells." They would have instead said something like, "Oh look, there is semipermeable partitioning of the body's fluid continuum."

So, which is it? Is the body made of discrete cells or is it a fluid continuum? Yet again, we find a complementarity. The two different views illuminate different truths of our bodies. Each view captures aspects that are hidden by the other, while at the same time concealing details the other view reveals. Once more, a complete understanding of the whole depends on *both* views, equally, even though they seem contradictory.

What might a different model for the body, like the fluid doctrine, have led us to understand that the cell doctrine concealed? One possibility is a better understanding of the effects of acupuncture. By this point, it's clear to medical professionals that applying acupuncture needles to appropriate sites on the body (acupoints) can reduce inflammation, resolve muscle spasms, and relieve unpleasant sensations like pain or nausea. These effects are testable and reproducible, but so far they have not been sufficiently explained by standard anatomy or by the cell doctrine. Anatomically, those acupoints do not correspond to any nerves, blood vessels, lymphatics, or any other apparent anatomic structure. Nor have cell types specific to those acupoints been identified. The cell doctrine seems unable to explain acupuncture then, but thinking of the body as a fluid might provide useful insights.¹

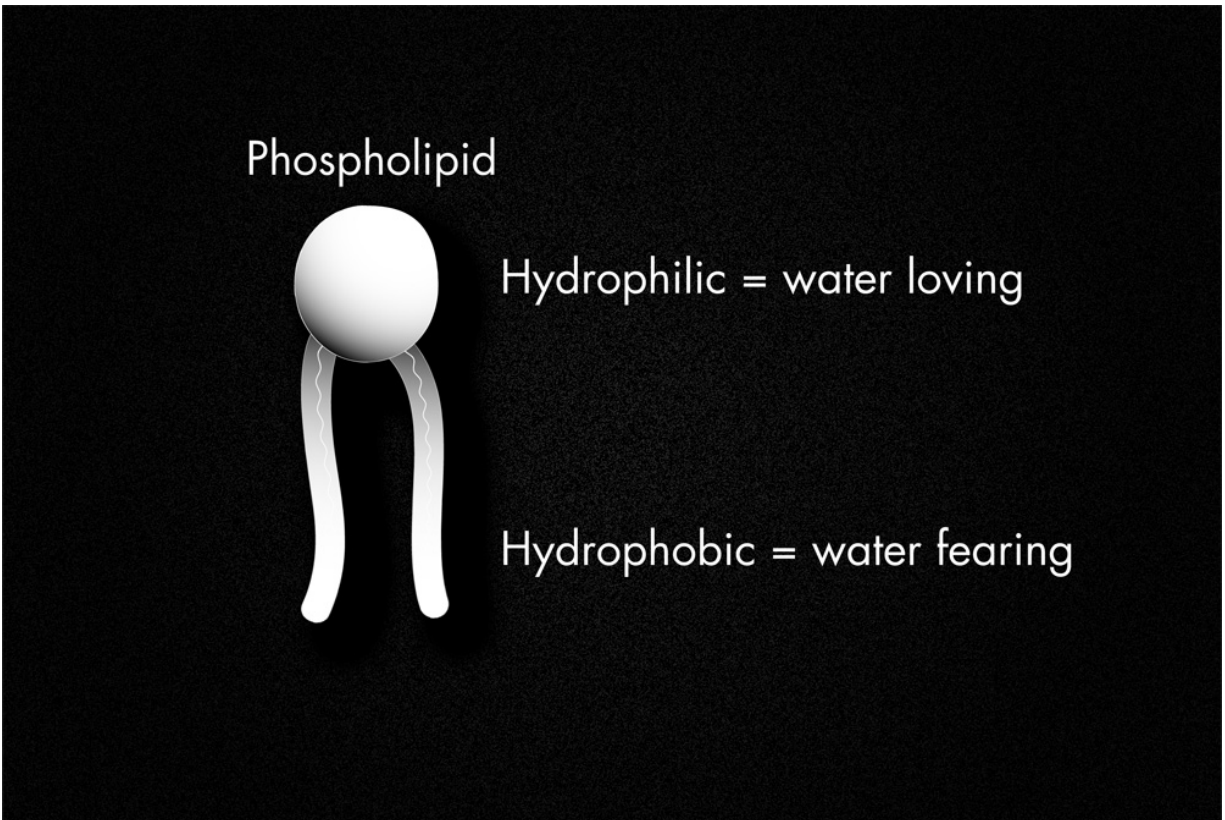
Indeed, we might very well benefit from a more flexible perspective on the nature of the body than Western science and medicine usually allow. Complementary views of the body as cells, or as a fluid continuum, or even as electromagnetic and quantum fields, may help bridge conceptual or

descriptive gaps between Western medicine and other cultures of health and healing, such as those of South Asia, Tibet, China, and shamanic traditions of many lands. Complexity theory now helps us explore these ideas further.

The Fluid Body

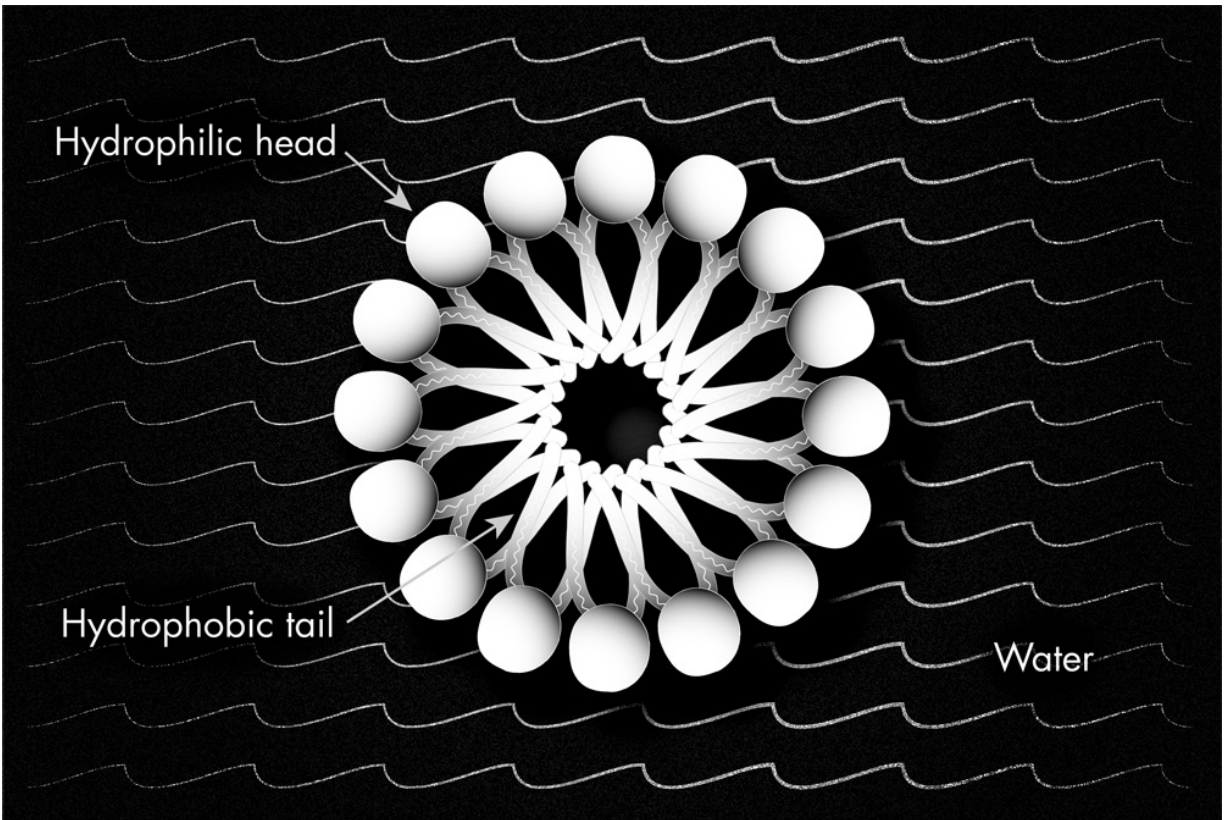
If cells are not the definitive, fundamental entities from which all living things arise, then what lies lower down in scale? The fluid body provides one answer: molecules afloat in aqueous solution. It is commonly known that our bodies are made of large quantities of water, both inside cells and outside them too. The delivery of molecular nutrients to feed our living tissues depends on fluid flow, as does the removal of the molecular waste products of cell metabolism. The ways in which biomolecules dynamically interact and arrange themselves also depend on their being suspended in fluids.

Here's an example: those cell membranes that define the outer boundaries of the cell and house the rest of the cell within them are all made up of a particular class of molecule called *phospholipids*. One end of this molecule is electrically charged and *hydrophilic*, meaning it loves to dissolve in water. The rest of the molecule, an oil- or fatlike *hydrophobic* lipid, is uncharged and avoids water but does dissolve in other lipids, and it trails the other end of the molecule like a long flag in a breeze.

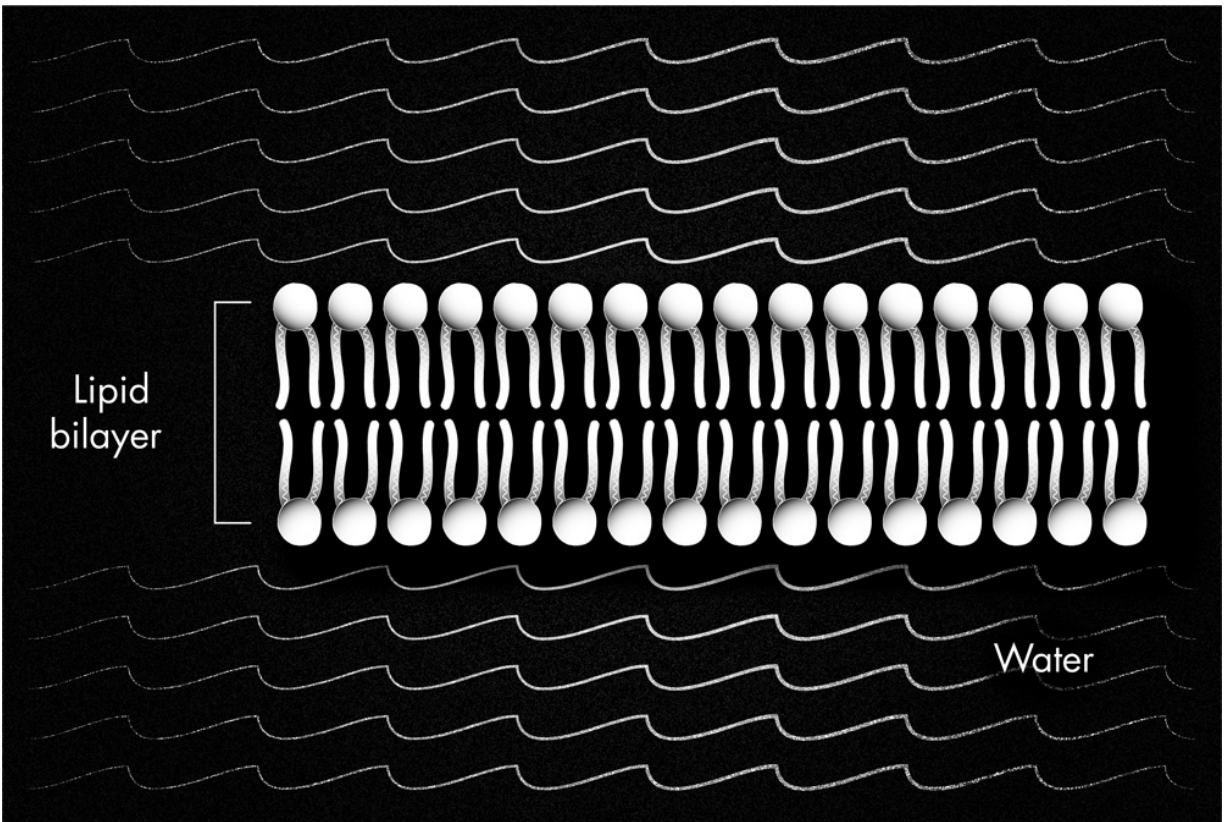


We know what happens when we put oil in water. Oil is hydrophobic; the mixture separates into distinct layers, or, if shaken vigorously, it forms oil droplets in the water.

When the molecules of the cell membrane are mixed into water, one end dissolves in the water. But the other end is unable to dissolve, and so it instead faces inward, creating an internal region that excludes water. Suddenly these molecules have formed an inside and an outside. This is itself a kind of emergent self-organization.



With enough of these molecules, you can form *lipid bilayers*: two layers of molecules that together make a membrane. On either side of a membrane are the dissolving hydrophilic ends, and inside there are two layers of hydrophobic tails facing each other, excluding water from their middle.



And there you go: a structure composed of self-organizing molecules afloat in water, which no one “designed” but which is simultaneously both remarkably stable and dynamically mutable. A structure that is perfect, in fact, for creating a boundary between the inside and outside of a cell.

Molecules seem to be good candidates for members of a complex system, but if we want to make sure, we must locate the quenched disorder at this molecular scale as well. To find it, we look at how molecules afloat in water are bombarded by the rapid agitations of water molecules. This is called *Brownian motion*.⁵ The warmer the water, the greater the kinetic energy of the water molecules. The faster they move, the harder they bump into each other and all the other kinds of molecules floating in the water. With too much disorder in the water, though, there can’t actually be any molecular self-organization.

Popcorn at a movie theater shows us how just the right amount of jostling can accomplish the task. A full bag of popcorn contains kernels of many different sizes, ranging from the large, fluffy, perfectly popped kernels all the way down to the small, rock-hard, unpopped kernels. But one visit to the movies as a kid and you quickly learn how to avoid those unpopped kernels that can break your teeth: you just shake the bag. If you

shake it too much, the popcorn flies everywhere. If you don't shake it enough, nothing much happens. But if you jostle it just the right amount, the various bits of popcorn will have the opportunity to shift around in the bag. The spaces between the big popped kernels are the largest, so smaller popped pieces fall between them. Then the popcorn fragments have their turn, falling through the spaces and quickly sorting by size. Finally, the smallest and densest pieces, the unpopped kernels, drop to the bottom. Add a little bit of kinetic energy and order is brought out of chaos.

In the case of lipid bilayers, the kinetic energy of water molecules at normal body temperature itself provides just the right amount of jostling for the molecules of the cell membrane to shimmy into place.

Bodies Are Not Machines

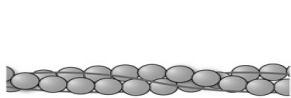
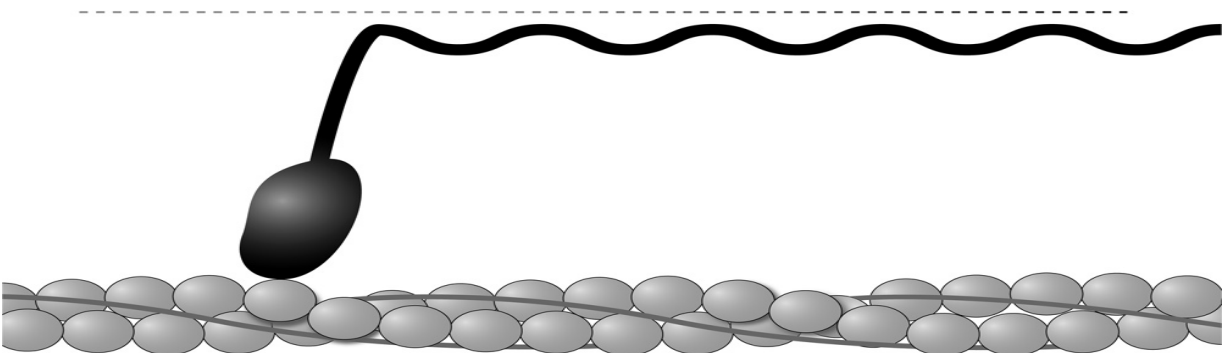
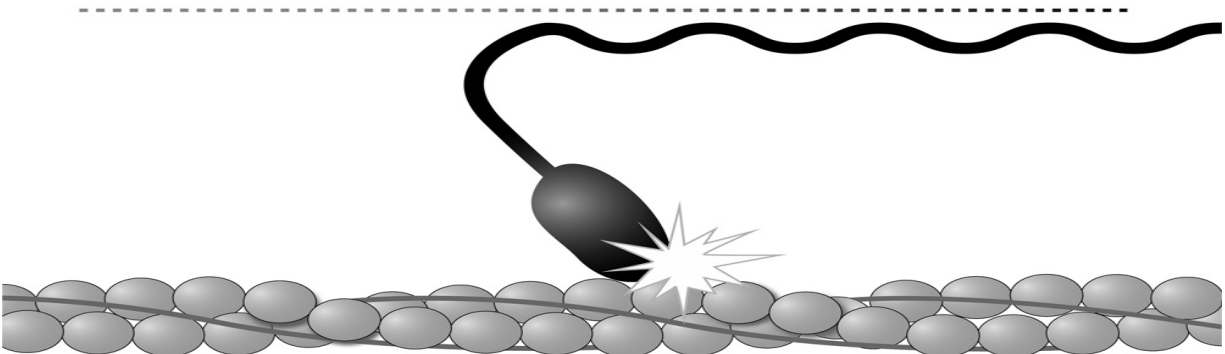
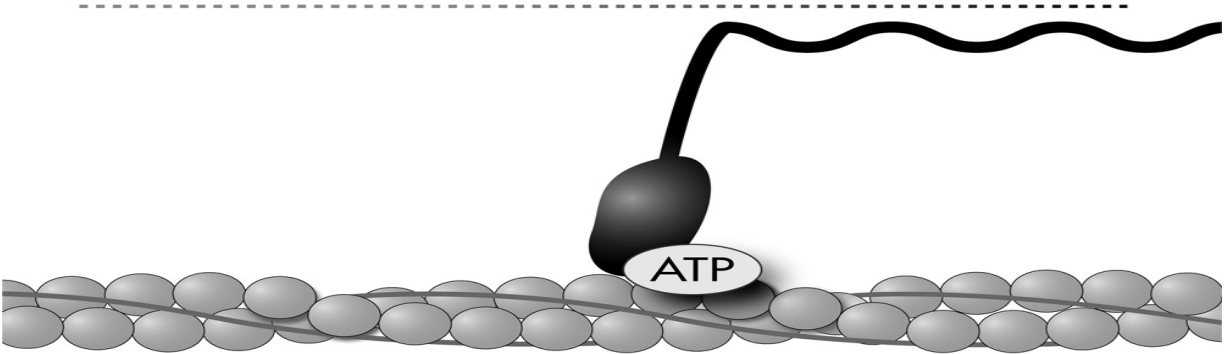
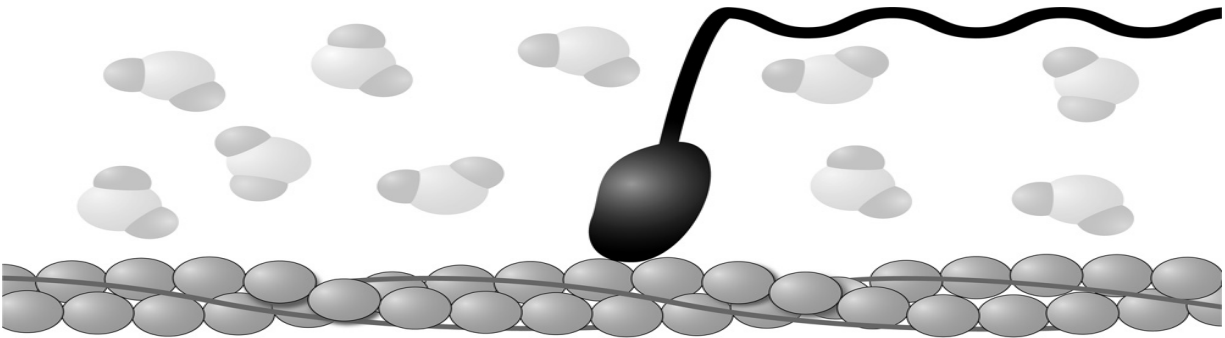
After the rise of the cell doctrine in the seventeenth century, the next fundamental shift in how Western science regarded the nature of the body came during the Industrial Revolution. The explosion in technological progress and understanding led to the rapid invention of machines that could convert energy into mechanical substitutions for human effort. This development impressed on the popular imagination the idea that bodies are objects constructed like machines (or that machines could be more and more like bodies).

To this day, machines remain the dominant metaphor for biology. Cells are still called “building blocks,” fit for stacking up into a tissue or an organ. “Tissue engineering” is an entire field based on this metaphor.

But cells are anything but inert, stackable bricks. The most successful efforts at creating living tissues or organs (for heart or liver transplants, for example) now involve taking a living piece of tissue or even a whole organ, digesting all the cells away to leave only the underlying biomolecular scaffold, and then repopulating the original scaffold with new human or animal cells. The scaffold provides the right structures and molecular cues to the newly transplanted cells so they can interact, gradually self-organizing into the emergent properties of the living physiology of the new organ. Neither “engineering” nor “building” is an accurate metaphor for this process. Rather, we are *cultivating* a healthy, complex ecosystem of cells within their molecular environments.²

The machine metaphor also breaks down when describing large molecules that combine to become what have traditionally been called “molecular motors.” These are molecular complexes that accomplish physical movement, as by moving the cell’s organelles through its cytoplasm or moving the cell through the body. Are they really anything like motors, though?

A classic example of a molecular motor is the pairing of actin and myosin, the large molecules that fill muscle cell cytoplasm and enable muscles to contract. In med school, I was taught how this worked. It’s fairly simple: an actin filament is a helix that is long and straight, while a myosin filament has a movable elbow bend. The myosin head at the end of the short arm binds to the actin. Then an energy molecule, adenosine triphosphate (ATP), binds to the myosin at the head.



Actin



Myosin



Water

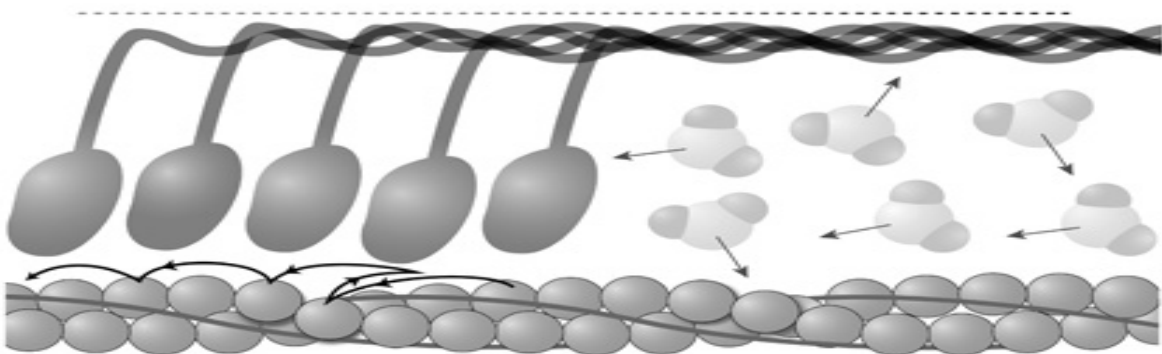
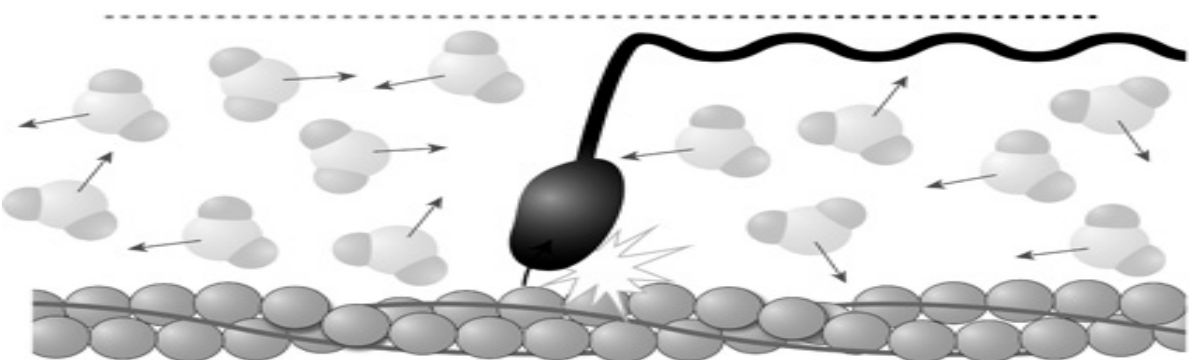
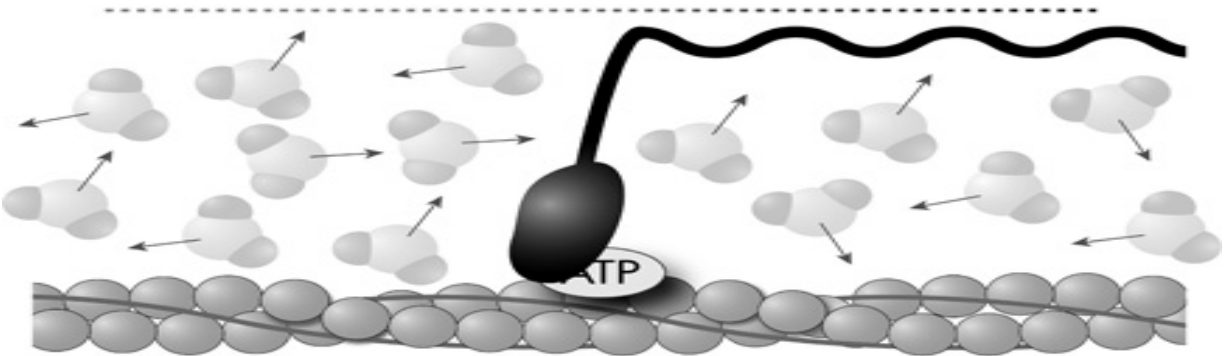
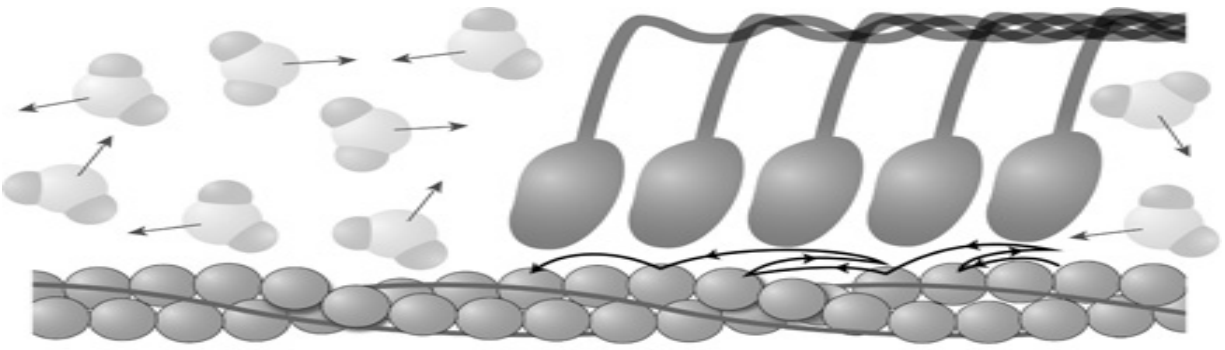
When ATP breaks apart, it releases energy that makes the elbow bend. When the energy then dissipates, the myosin molecule unbends, but it has now ratcheted forward along the actin. Repeat this over and over again, and the myosin “walks” along the actin. Repeat this movement simultaneously across thousands of stacked actin-myosin pairs within a muscle cell, and as all the molecules slide past each other, the whole cell contracts. Add all these cells together and an entire muscle contracts, enabling a finger to move, a heart to beat, a head to turn.

Go ahead and scratch your forehead.

There you go.

It’s an undeniably amazing phenomenon, but when Japanese biophysicist Toshio Yanagida started looking closer at individual actin-myosin pairs, he discovered something different from this machinelike process—something surprising that helps our understanding of complexity at the molecular level. Yanagida devised a delicate experiment in which he used “laser tweezers”⁶ (gotta love that) to hold one single actin filament under the lens of a fluorescence microscope. A fluorescent tag was affixed to the myosin counterpart so that, once it was attached to the actin molecule, the myosin’s microscopic, real-time movements could be observed.

According to the usual model of ATP-driven motion, one would predict that the same process that had been hypothesized based on arrays of molecules inside a muscle cell—ATP binding, energy release, myosin movement—would be seen with a single actin-myosin pair. But that’s not what Yanagida’s team saw. Instead, they noticed that before the addition of the ATP, the kinetic energy of the water molecules was jostling the myosin filament, moving it forward and occasionally backward with random abandon—Brownian motion again!



Actin



Myosin



Water

Then, when the ATP was added, it bound to the myosin head, which then attached to the actin. When the ATP released its energy, the myosin lifted off and moved again. In other words, the ATP energy was precisely the right amount—not to move the molecule but to put the brakes on the Brownian disorder, so that directional motion could happen. Thus, we have a molecular mechanism whereby disorder is actively quenched in order for the complex system to function.

Indeed, many “molecular motors” derive the energy of their interactions from the kinetic energy of water and not, as is commonly thought, from energy-conveying molecules like ATP. These include pairs of molecules involved in gene transcription and movement of organelles through a cell’s cytoplasm. The release of energy from energy molecules in all these cases doesn’t drive the molecular movements directly but limits the Brownian disorder that actually provides the energy of movement.

The importance of body temperature to physiology now becomes vivid. Why is a homeostatically calibrated body temperature so important to life? Because, as we have now seen, if our body temperature drops too low, then we don’t have enough kinetic energy to power molecular physiology. Our molecules cease to self-organize into living, functional cells, and so we die.

On the other hand, orderly self-organization also becomes impossible if the kinetic energy gets too high. A body with too high a fever will drive molecular movement into disorder rather than order. Unable to maintain the necessary structures (such as lipid bilayers) or perform the necessary functions (molecular motor movements), we will die.

Only within a very narrow range of body temperature is there a life-sustaining balance between the energy of molecular agitation and the energy for limiting that disorder. That balance provides the safe, homeostatic zone at the molecular level in which a cell or a body can live.



At this molecular level, where do we locate the boundaries between our bodies and the world? If, as we considered with cells, we define our sense of physical being as the material that makes it up, then the boundary of the body is the boundary of where its material extends.

Consider someone who lives deep within in a forest, totally self-sufficient through the generosity of the natural world. Such a person completely derives their sustenance—the nourishing molecules of food, water, and air—from the forest through foraging, gathering, and hunting. In turn, the molecular waste of such a person’s body (carbon dioxide, sweat, urine, feces) is recycled back into the nutrient sources of all the living beings of the forest, from single-cell organisms to the most complex trees and animals. A forest dweller like this person thus does not merely live *in* the forest; they are *of* the forest as well.

Even if we live in a city, the rigidly constructed nature of the engineered environment only conceals the intimate interconnectivity between us and our living world. We breathe out molecules (carbon dioxide) and perspire molecules (water, pheromones) and excrete molecules (urine, feces) into the environments around us, and in turn, we eat food that we break down into absorbable molecules (proteins, carbohydrates, fats), breathe in oxygen molecules from the planetary plant mass, and absorb molecules through our skin either intentionally (via skin-care products) or as part of routine life, since every surface we touch potentially has absorbable molecules on it.

While you might say that molecules are only your own when they are within your body, complementarily, there are no real distinctions between “our own” molecules and the molecules of the world around us. They move from us, outward, and come into us from the outside. At the molecular level, just as at the cellular level, each of us is in perpetual, direct continuity with the entire biomass of the planet.

The Atomic Level: Gaia

Of course, molecules aren't the fundamental material of the universe, any more than cells are. Molecules are made up of self-organizing atoms that have combined to form aggregates such as water molecules, carbohydrates, proteins, fats, breathable oxygen and carbon dioxide, actin and myosin, ATP, RNA, and DNA.

Just like cells and molecules, atoms fulfill all the criteria for a self-organizing complex system: there are plenty of "parts" to interact; their interactions are governed by positive and negative feedback loops (in this case all the laws of chemistry); and every atom or small group of atoms behaves only locally, without monitoring the state of the entire system, which in this case is the whole molecule of which the atom is a part.

As for quenched disorder in the system, there are circumstances in which atoms behave completely randomly, such as in a gas or a high-temperature liquid. There are also circumstances in which they behave without any randomness at all, such as when they're locked in crystals like a sugar cube or a diamond. And then there are those in which they form chaotic systems, like molten iron swirling in the core of our planet. But when they combine with each other through chemical bonds to make molecules, we again find ourselves in a limited zone of randomness. The behaviors of electrons in their structured atomic orbits, the temperature and pressure of the system, and the proximity of atoms to other atoms allow only certain atomic combinations and not others. These are the constraints that limit randomness at the atomic level.

Where are our boundaries now, as we come to this level of scale? Most of the body's cells are continually turning over. Some cells renew over a period of years, while other types of cells are replaced every few days. So, most of the molecules (and therefore atoms) of our bodies return to the planet as well, in an endless atomic recycling and replacement.⁷

From this perspective, then, are we living beings moving around upon this rock we call Earth? Or are we in fact the Earth itself, whose atoms have

self-organized to form these transitory beings that think of themselves as self-sufficient and separate from each other, even though they only ever arose from and will inevitably return to the atomic substance of the planet?

As the scales of our investigation continue to get smaller, our boundaries continue to expand outward. At the atomic scale, each one of us is both our own separate self and, in complementarity, also just walking, talking Earth.

This idea is essentially another way of framing British biologist James Lovelock's Gaia hypothesis. Back in the early seventies, Lovelock proposed that we could logically and scientifically consider the planet itself to be a single living organism.¹ His ideas were considered by many to be fanciful at best and, at worst, completely ridiculous hippie nonsense. Nonetheless, he forged ahead and went on to create computer models that showed how the organic (living) and inorganic (nonliving) aspects of a planet could be intimately linked together in a self-regulating, adaptive fashion.

Lovelock developed the first of these Gaia models in collaboration with his colleague Andrew Watson. They modeled a simple world of daisies, Daisyworld, in which the temperature was regulated by sunlight and by black and white daisies growing over the surface of the planet. The model demonstrated how an inorganic property of the planet (temperature) could be brought into homeostatic oscillation by behaviors of organic beings even if the amount of sunlight changed. In other words, the planet could adapt and stabilize itself in the face of a changing environment.

Their first Daisyworld design was simple. Black daisies were better suited to living in cool environments because their dark color helped them absorb more ambient sunlight to warm themselves. White daisies were better suited to warm environments because they could keep themselves cooler by reflecting the sunlight.

Tracking the balance of the two daisy populations as the intensity of sunlight changed, Lovelock and Watson found that the daisies themselves regulated the temperature of the planet to the optimal degree. Daisies were always covering the planet, but the proportion of black and white daisies shifted. The more intense the sunlight became, the more the white daisies thrived; their proliferation soon enough caused the world to reach a tipping point and then start cooling as the newly predominant white flowers reflected sunlight away from the planet. Likewise, as the sunlight dimmed and Daisyworld cooled, the black daisies would thrive. Then these black daisies would trap light, and the world would start to warm back up again.

Daisyworld demonstrated that organic and inorganic components of the planet could be coupled to act as a single, self-regulating, living system. From a distance, it might appear as if Daisyworld were actively monitoring the changing sunlight and organizing a coordinated response to stabilize its temperature. But Lovelock and Watson never programmed such global sensing or top-down planning into the model. The autoregulation arose purely from local, bottom-up interactions, just like in any complex system.

Daisyworld was far too simple to be an accurate or useful model for Earth, however, as it had no atmosphere and no biological diversity, and on top of that the death rates of the daisies were fixed to a single, unchanging life span. Obviously, that made the model far removed from reality on Earth. Critics therefore predicted that when more environmental details were incorporated into the model—an atmosphere, more diverse plant life, and other living organisms like animals (both herbivores and carnivores)—Daisyworld would become destabilized.

Not true. The more biodiversity was built into the system, the more stable Daisyworld became. Further experiments only reinforced the accuracy of the hypothesis. Lovelock was joined by visionary biologist Lynn Margulis⁸—her expertise in microbiology complementing his expertise in geophysics—and together they not only proved the critics wrong, they also established the study of Gaia as a robust field of investigation.

These days, decades after Lovelock first proposed the theory, Gaia is a mainstream idea—so much so that the concept is now an engine for further discovery by scientists studying climate and geophysics.

Our own discussion of “Earth as atoms” meshes well with an “Earth as Gaia” view. Atoms are inorganic (nonliving) structures, and yet all organic structures arise from them through vastly complex modes of autoregulation across all scales. Ultimately, all organic structures pass back into the inorganic realm at the atomic level through the cycling processes of life and death, just as our bodies pass back to Earth.

The organic and inorganic are not separate, then. They are not mutually exclusive. They are complementary parts of the whole living planet.

I vividly remember the first time these abstract concepts came to life for me in a visceral way. I was watching the first images projected back to Earth from *Curiosity*, the Mars rover, in 2011. As the mesmerizing broadcast from the Martian surface appeared on my screen, I thought about

all the engineers and scientists at NASA whose decades of devoted work had produced the technology that allowed us to send *Curiosity* to Mars. It was the same thrill I had back in 1969 as a ten-year-old watching the black-and-white TV broadcast of our lunar landing. Pondering the individual and collective creativity of those scientists, now as then, left me inspired and in awe. My heart swelled with excitement and pride in the possibilities of human scientific achievement.

Complexity, however, reveals another, less anthropocentric view. A complementary perspective is one in which we consider that over the last 3.5 billion years, the atoms of this planet have slowly been organizing themselves in order to reach out and touch their neighboring sibling planet, Mars, on the shoulder.

And if, in some undiscovered recesses on Mars or in a far-flung planetary system around some other star, the atoms are still self-organizing into living things, then they might one day reach out to touch us too. Perhaps they already have.

SEVEN

The Subatomic Level: Quantum Strangeness

Atoms, just like cells and molecules, are also not fundamental things. They are made of self-organizing subatomic particles like protons, neutrons, and electrons, some of which in turn are made of other subatomic particles. In all, according to the Standard Model of particle physics, the stuff that makes up our material world is composed of thirty elementary particles.⁹

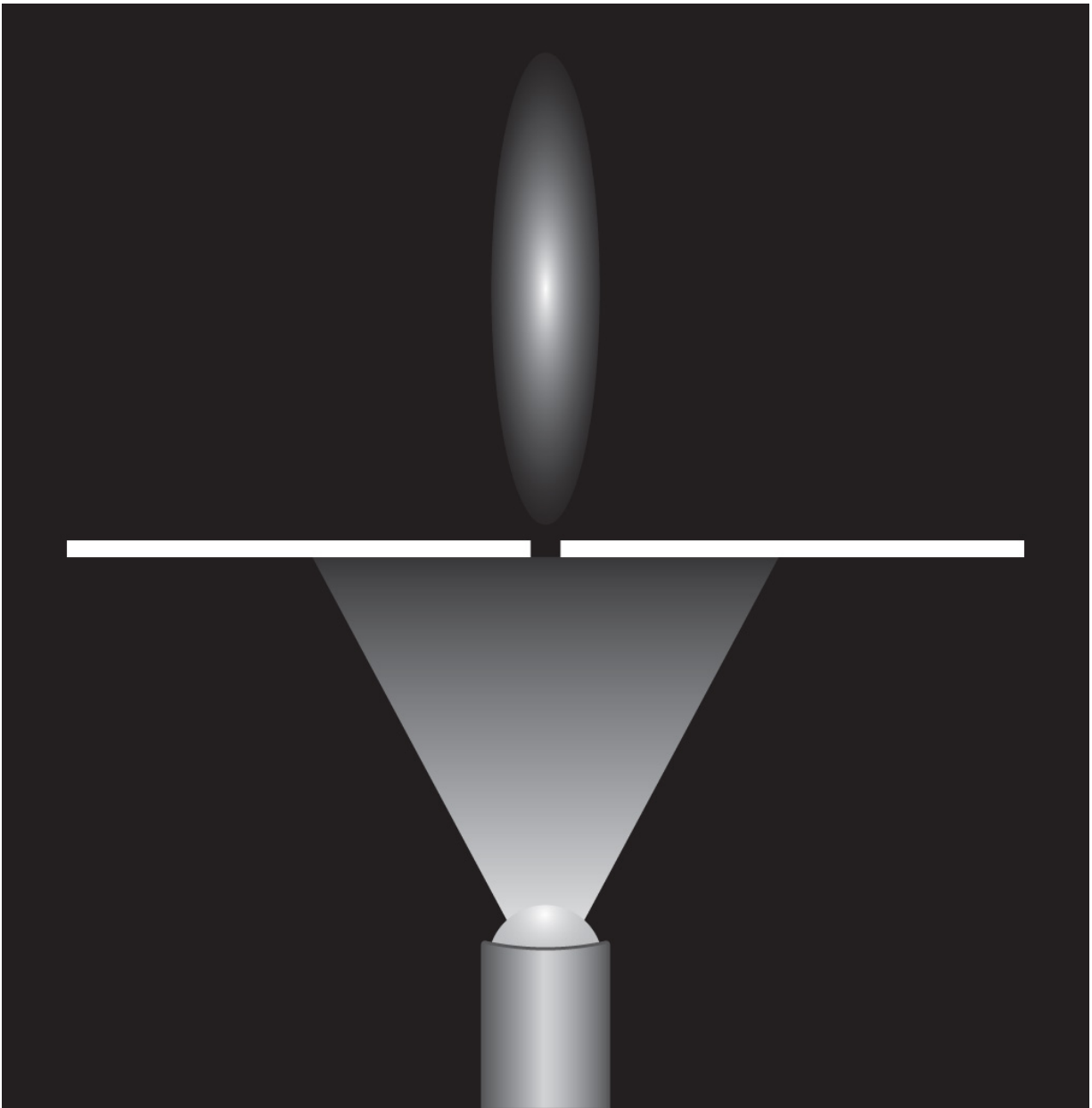
These fundamental particles include leptons such as electrons, carrying electromagnetism, and neutrinos, massless particles that swarm largely unhindered throughout the universe. There are mesons, which convey the strong force that binds protons and neutrons within nuclei. There are quarks, which make up protons and neutrons, and the gluons, other carriers of the strong force, which bind quarks within their respective particles. Bosons transmit the weak force involved in nuclear decay like that seen in uranium or in the nuclear fusion that powers the sun. Perhaps most famously, there is also the so-called God particle, the Higgs boson, responsible for the property of mass. The Higgs boson was the last of the particles predicted in the Standard Model to be discovered, and when it was, just a few years ago, it confirmed the coherence of the model.

Like molecules and atoms before them, these thirty fundamental particles fulfill the rules of complexity. In order to find the forms of quenched disorder at this level of scale, we turn to quantum mechanics and the strange phenomena it predicts. The famous “double-slit” experiment, which confirms wave-particle duality, demonstrates this notorious strangeness.

If we shine a beam of electrons (or photons or any other subatomic particle) at a screen, the screen brightens. A tightly focused beam in which all the particles move in the same direction (a laser, in the case of photons) forms a tightly defined dot. A poorly focused beam sends particles far and wide, leaving the dot a bit fuzzier. In your mind’s eye you can see each

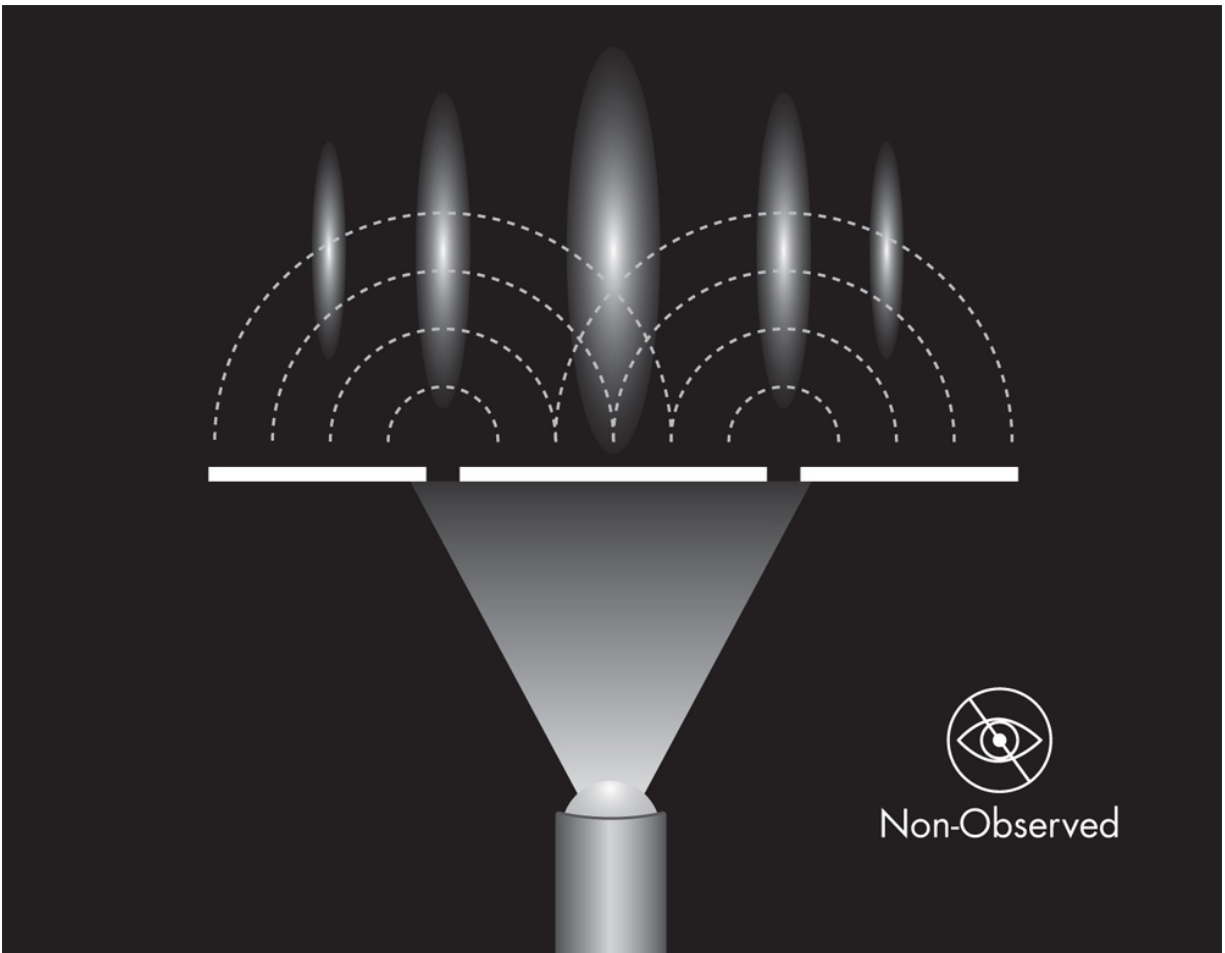
electron behaving like a little bullet, and you can easily predict where it will hit by imagining its path from the projector to the screen.

Next, let's add another intervening screen that sits between the projector and the farther screen where the light hits. If we make a vertical slit in the intervening screen and the beam is not tightly focused, then only some of the projector's light will pass through to the far screen, though most of it will be blocked. You can easily imagine the way the light will appear on the back screen: it will take the pattern of a vertical bar, and it will be brighter if the particles are well aligned, and fuzzier if they are less focused.



Obviously, if we put two slits in the intervening screen, then we will end up with two bars of light, right?

Wrong. Welcome to the strangeness of the quantum world. Instead of two vertical bars that reflect the double slits in the first screen, we get what is called a *diffraction pattern*: a series of lines, all parallel to the vertical slits and to each other. The line in the middle is the brightest and sharpest. The lines to either side become dimmer and fuzzier the farther out we get. In between the bright lines is darkness. What's going on?



Let's say we are standing on one side of a pool of water and toss in a pebble. Circular waves extend out from where the pebble hits the water, and these expanding waves collide with the wall on the other side of the pool. The waves are defined by alternating peaks, where the water is highest, and valleys, the low points in the water. If we throw two pebbles in, some distance apart from each other, the peaks and valleys will still collide on the far wall, but where they overlap, or *interfere* with each other, we will see a

diffraction pattern. Peaks of each wave combine to make bigger peaks where they overlap. Valleys combine to make deeper valleys where they overlap. In between, where peaks and valleys meet, they cancel each other out. Now we see what is happening in the double-slit experiment: the beams aren't behaving the way bullet-like particles do. Instead, they are acting like waves.

Huh?

With one slit, the beam behaved like particles—like compact bullets hitting the far screen. But with two slits, the beam suddenly behaves like a wave? How could this be?

Perhaps this is because *in aggregate* the particles create waves? After all, a wave of water is made up of H₂O molecules. Maybe the particles somehow travel as a wave, all together, the way H₂O molecules travel collectively in the tide. Perhaps there isn't actually a contradiction.

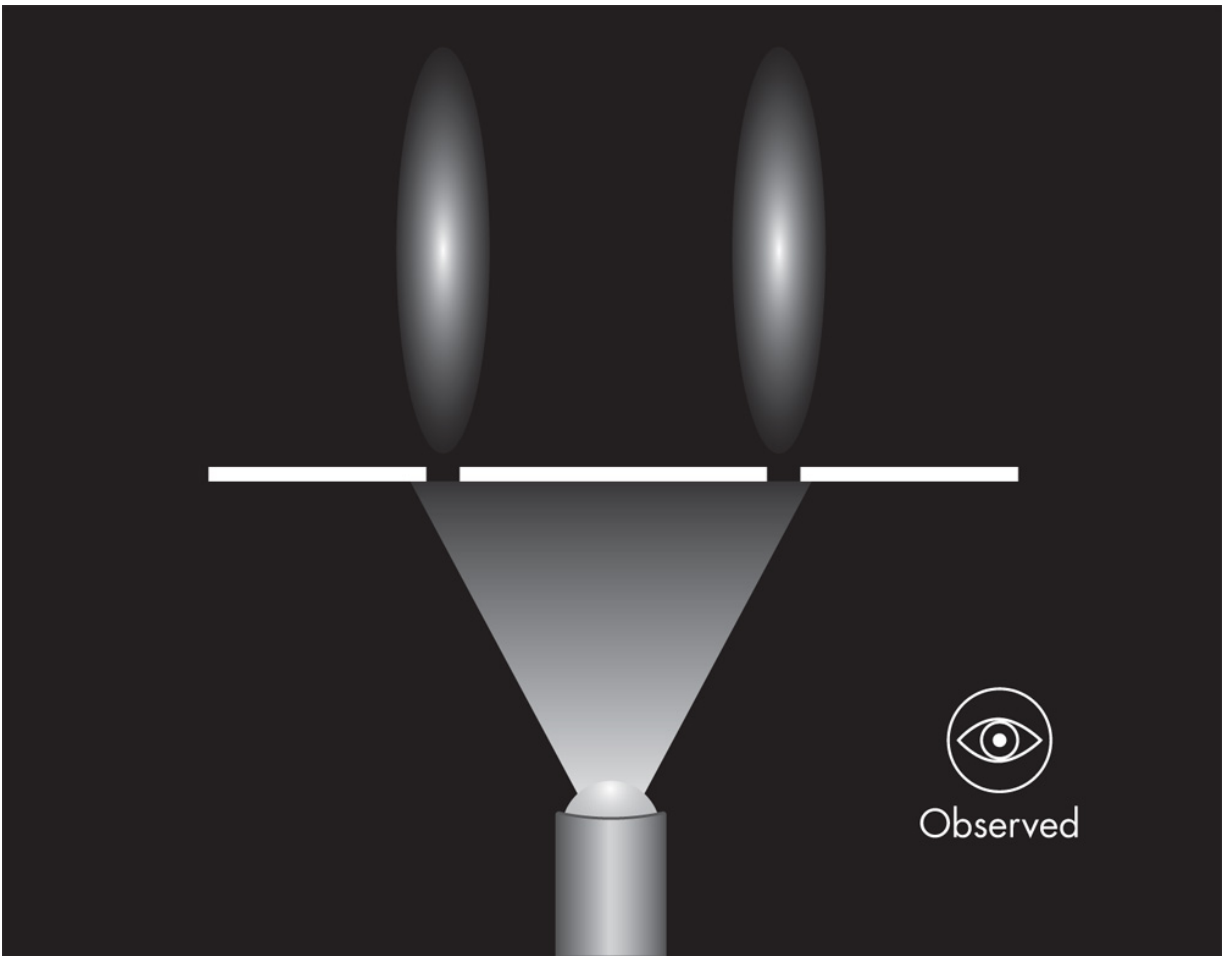
It's easy enough to test this hypothesis by sending one electron through at a time. Doing so, we'd expect each electron to go through one slit or the other, right or left, like a bullet, eventually accumulating, so that we end up with just two lines on the far screen. There would be no diffraction pattern from huge numbers of particles traveling together in waves.

Alas, in this version of the experiment—one electron at a time—we still get not two lines but a diffraction pattern!

It is as though, when each single electron reaches the slit in the first screen, it spreads into a wave and thereby travels through both slits simultaneously, interfering with *itself* on the far screen! We obviously need to look more closely at what's going on here.

So we refine the experiment. We put detectors at each of the slits to watch what the electron does as it shoots through. Does it go through one slit at a time or both?

Now things get even stranger. With detectors observing each single electron, they pass through only one slit or the other, like bullets. In this version, there is no diffraction pattern, there are just two bright lines on the far screen, exactly as we expected in the first place. But the instant the detectors are turned off—the moment that no observations are being made of the electrons—the electrons resume traveling through the two slits like waves, and again create the interference pattern on the far screen.



Back and forth we go. Detectors on: two bars, electrons are bullets. Detectors off: diffraction patterns, electrons are waves.

That is wave-particle duality. Whether we are talking about photons, electrons, or any other quantum-scale entities, their particle- or wavelike properties depend on how we observe them.

In fact, while we often talk about “subatomic particles,” this phrase is half-wrong. It reflects the limitations of language formulated to describe experiences at the everyday scale. At the quantum scale, intuitions from everyday experience are useless. The ungainly word “wavicles” might be one way to try to twist our vocabulary to capture that duality, but ultimately these processes simply cannot be adequately captured through ordinary language. Their precise depiction requires the language of mathematics, though even as we gain that precision, things get stranger still.

Erwin Schrödinger, another foundational quantum physicist, captured the wavelike nature of particles in mathematical formulas called *wave functions*. These calculation methods reveal that the interference patterns on

the screen actually reflect wavelike *probabilities* of where one *might* find a particle in space if one were to look.

Before one looks for an electron, it is as though it has been smeared across space with alternating wavelike peaks and troughs of high probability and low. Then, when one proceeds to look for it, the electron takes up a definite location as a particle. This strange phenomenon is referred to as the “collapse of the wave function.”

The wave function defines a quantum-scale version of quenched disorder. Schrödinger’s wave equations show peaks and troughs, both of which have diminishing amplitudes as we move farther and farther away from where an electron is likeliest to be (such as orbiting a particular atom, over here, in front of us) out to the most distant edge of the universe. It is just the same as how amplitudes of waves, like the wake of a boat, get lower and lower as they spread outward. The possible locations of the electron are not completely random, then. The randomness is constrained.

Another way to express this is in the language of *quantum field theory*. So far, we have started our imagining of the quantum realm with particles, then explained how they sometimes appear as waves. But what if we take their wavelike properties as our starting point? Then quantum-scale entities are universe-size fields of wavelike states of energetic *activation* that are most pronounced in the area where we can perceive, with correct tools, a “particle,” one of the tight little packets or *quanta*¹⁰ of the waves’ energy. With this in mind, “local” and “global” are not distinct. In the quantum realm, all parts—the universe-wide, wavelike fields—are as extensive as the whole and all are local to all.

This strange idea, called *nonlocality*, is one of the hallmarks of all quantum systems and one of its features that dismayed Albert Einstein. His first argument with quantum physics was its dependence on probabilities. He felt this implied something deeply wrong with the theory, believing, as he famously said, that God “is not playing at dice” with the universe.¹

He also disparaged this global-is-local notion as “spooky action at a distance,” in response to concepts arising in a 1935 collaboration.² This was a thought experiment devised by Einstein and the physicists Boris Podolsky and Nathan Rosen; it has been referred to ever since as the EPR paradox for the initials of their last names. The EPR paradox attempted to demonstrate that quantum theory led to an impossibility. They hoped, thereby, to prove that quantum theory was incorrect in some definitive way. Working from

fundamental quantum principles, they determined that if two particles arose from a single quantum event—like the decay of a nuclear particle—the two particles were, according to quantum theory, “entangled,” meaning that even if they were removed from each other as far apart as the universe itself, they would be found to have identical quantum properties.

This finding seems to imply instantaneous communication: the measurement of one property, such as momentum or position, in one particle instantaneously manifesting the same outcome in the distant particle. Einstein’s theory of special relativity had already ruled out instantaneous communication in the universe by affirming that the speed of light is constant and cannot be exceeded. Thus, the EPR paradox seemed to deliver a coup de grâce to quantum mechanics.

Alas for Einstein, when experiments to assess the EPR paradox could actually be performed, entanglement and nonlocality proved to be true.¹¹ Einstein’s “critique” merely served to further prove how odd but consistent quantum theory appeared to be. One way of thinking of it is that the entangled “particles” are not distant from each other at all but, being quantum fields, are always completely overlapping with each other, seemingly “nonlocal” only if we insist that they are particles.

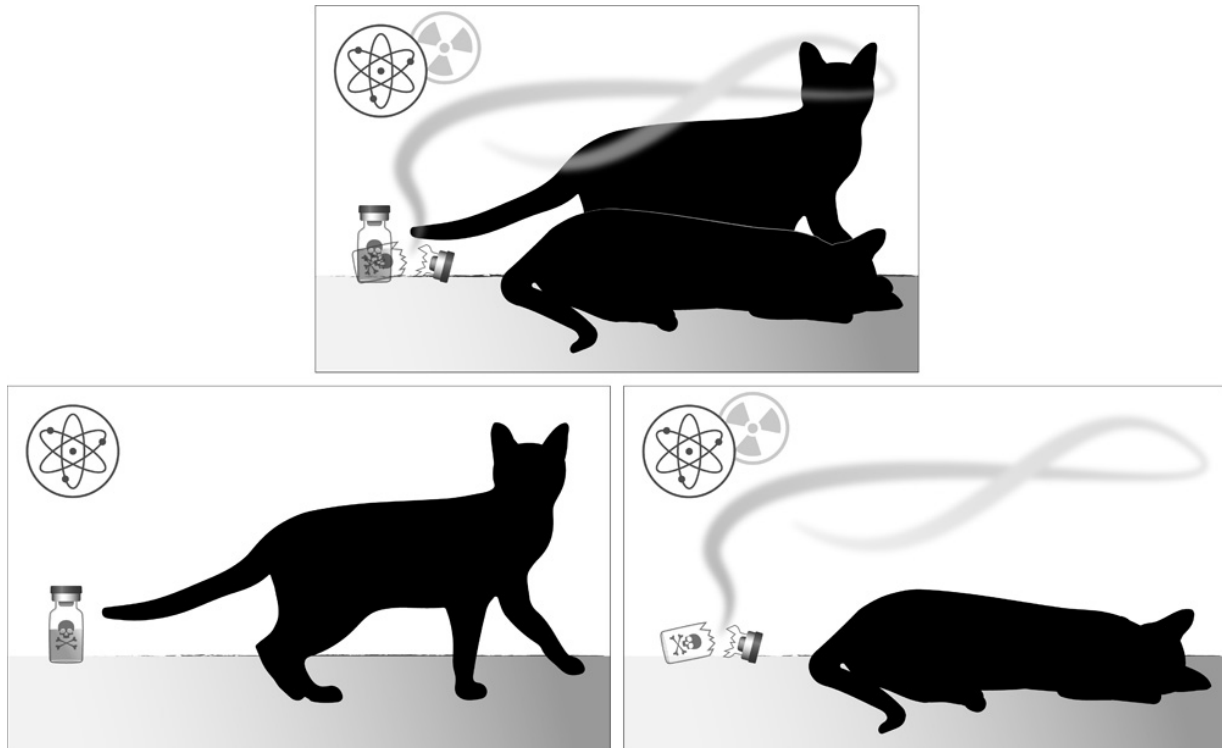
Moreover, if such nonlocality pertains, then at this quantum level of scale, the boundaries of our bodies have not only gotten bigger than the Gaian scale they assumed at the atomic level; they have now extended outward to the very farthest reaches of the universe. We have arrived at the level of the boundless body.

Consciousness and the Copenhagen Interpretation

The great quantum physicist Richard Feynman said: “I think I can safely say that nobody understands quantum mechanics.”³ In terms of the “common sense” that derives from our everyday experiences, it is clearly exceedingly difficult to comprehend the deep implications of quantum theory. If the outcome of the double-slit experiment depends on conscious observation, by extension, since all everyday objects and processes are ultimately made up of quantum-scale events, it seems to imply that there is no actual solidity whatsoever to material existence. Is it possible that there is no “world out there” independent of the querying gaze of a conscious

observer who measures the outcomes of a situation? This last question was perhaps the most troubling one of all for Einstein.

In correspondence with Einstein, Schrödinger came up with the most famous summary example of the problem, known as “Schrödinger’s cat.”⁴ This thought experiment demonstrates the increasing bizarreness of commonplace situations when we explore how the quantum world interfaces with our everyday, classical world.



Imagine a box in which there is a cat and a vial of poison gas. Imagine that there is also a hammer that is under the control of a slowly decaying radioactive isotope. If, during the course of the experiment, the isotope decays, then the hammer drops, breaking the vial, releasing the gas, and killing the cat. If the isotope has not decayed, then the hammer isn't triggered and the cat remains alive.

And so we come to perhaps the most extraordinary and revolutionary of all quantum effects, the concept of *superposition*. In the double-slit experiment we asked: Is light a wave or a particle? We discovered that until the method of observation is selected and performed, the wave nature and the particle nature of the beam are undecided, in superposition—all potentials are possible until a conscious observer makes the observation. Only then is the beam revealed to be either wave or particles.

In regard to the cat experiment, the radioactive decay, also a quantum phenomenon, remains uncertain—decayed and not decayed, in superposition—until the moment of observation. Since we won't know whether the isotope has decayed until the box is opened, we also won't know whether the cat is dead or alive until the box is opened. Not only are the two possible states of the isotope in superposition, but the cat itself exists in a state of superposition, both dead and alive until the moment the box is opened. The quantum strangeness is not confined to the quantum world. The everyday world, too, is caught up in the strangeness, becoming “the world as it appears to be” only when perceived by a conscious observer. Experiments (no cats killed, however!) have conclusively demonstrated that this isn't hypothetical for objects above the quantum scale—it has been demonstrated for large molecules, too, and experiments for larger entities such as viruses and cells are probably next.

Thus, the world is made of potentials, of possibles akin to Kauffman's adjacent possibles. Then our minds consider the world, and as we choose the moment to gaze and the perspective from which to gaze, the world takes form.

Interpretations of quantum mechanics that do not shy away from this strangeness—those of some of the founders of quantum physics, such as Niels Bohr, Werner Heisenberg, and many of their disciples, as well as, in some measure, Max Planck, Schrödinger himself, and other peers—are known collectively as the Copenhagen interpretation, after Bohr's home city.

There are many who disagree with the Copenhagen interpretation, Einstein most notably. But I agree with it, and why I do will be a large part of the story of our coming exploration of consciousness.



One might think of the progress of modern science to have been one of consistent displacement of human minds from their primacy in existence. Copernicus made the sun the center of the world, not the Earth. Further astronomical studies showed our sun to be one of vast numbers of stars in our Milky Way galaxy, and the Milky Way itself not the entire universe but only one of uncountable galaxies throughout space and time. Darwin

showed that humans were not even a species apart. Far from being above the seething mass of swimming, creeping, crawling, flying things, we were just one more creature trying to pull ourselves up out of the collective soup, filled with inappropriate self-regard, gazing in the mirror¹² and thinking we were special.

But in the lecture halls and laboratories of Copenhagen in the early twentieth century, ideas were advanced that restored the mind¹³ to the center of existence. Quantum physics showed the impossibility of separating the subjective mind of an observer from the experiment, the object of observation, and the nature of reality that sprang forth from the observations. Planck himself said it directly: “I regard consciousness as fundamental. I regard matter as derivative from consciousness. We cannot get behind consciousness. Everything that we talk about, everything that we regard as existing, postulates consciousness.”⁵

EIGHT

All the Way Down: Space-Time and the Quantum Foam

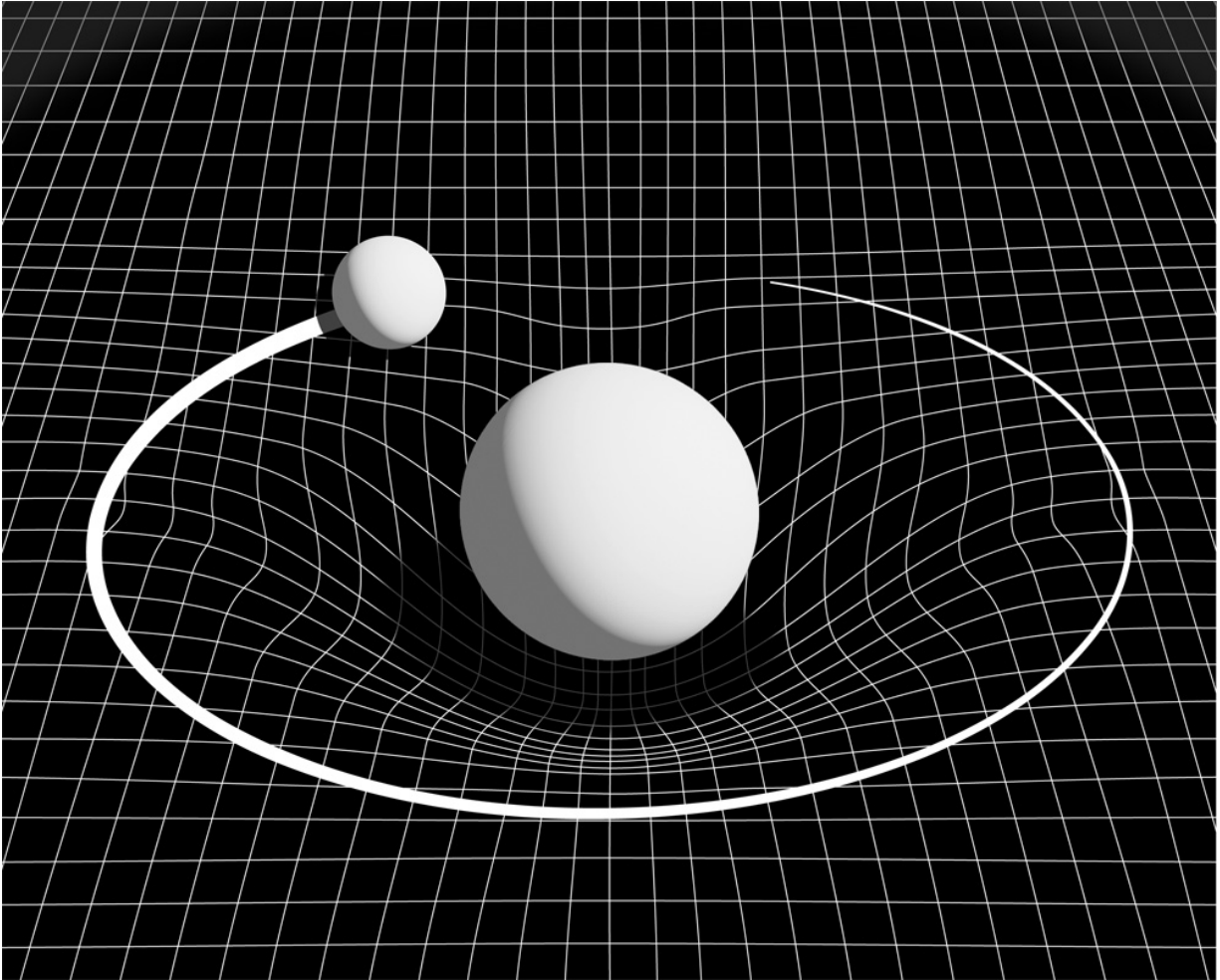
If you're anything like me, you might now be asking yourself: Can we go any further downward in scale? Are the thirty subatomic particles of the Standard Model really fundamental, or are those subatomic particles made of still smaller parts? How small can we go?

Physicists agree on answers to some of these questions but not all of them. Everyone agrees that the universe is not “turtles all the way down,” an infinite regress to ever smaller sizes. In 1899, Max Planck figured out that there must be minimal units of time and space beyond which further regress to smaller parts isn't possible. Planck derived these units from previously recognized mathematical constants, unchanging numbers that expressed fundamental relationships between different aspects of existence: the speed of light, the constancy of which is the foundation for relativity; his own constant (eventually called the “Planck constant”), relating the energy of one quantum of electromagnetic radiation (a single photon) to its frequency; the gravitational constant of Newton, relating mass to distance in his equations for gravity (and still present in Einstein's equations); and Boltzmann's constant, relating kinetic energy of a gas to its thermodynamic temperature. These smallest units of distance and time are thus themselves constants, and they came to be known as “Planck units.”

The smallest unit of distance, the so-called “Planck length,” is on the order of 10^{-35} meters (or just under a billionth of a billionth of a billionth of a billionth of a meter). The time it takes light to travel this distance is the smallest unit of time—the “Planck time”—which comes in on the order of 10^{-43} seconds (or a little over a trillionth of a trillionth of a trillionth of a billionth of a billionth of a second). The existence of these values has implications for the nature of *space-time*, the fabric of the universe described by Einstein in general relativity, as well as for us in this exploration of complexity in the universe.

Einstein's signal realization in general relativity was a change in the basic conception of the nature of "space." Before Einstein, space was thought of as a vacuum (i.e., completely empty) through which things like planets, stars, and galaxies moved. Scientists believed the vast interstellar and intergalactic stretches of space were largely vacant, except for the shooting photons, neutrinos, and other free subatomic particles darting out from their stellar sources across this void. In this view, what was gravity, then, and how did it spread? It was assumed to be a force passing through this empty space just like electromagnetic waves.

Einstein realized otherwise. Space wasn't emptiness, a void, a vacuum. Instead, the three dimensions of space *and* the fourth dimension of time were the very fabric of the universe itself. There was no such thing as "empty space." Gravity, in this conception, did not travel through the emptiness, between massive structures pulling on each other. Rather, gravity was the curvature of this four-dimensional fabric, caused by objects with mass. General relativity described not a gravitational force propagating *through* space but the curvature *of* space or, more precisely, of space-time.



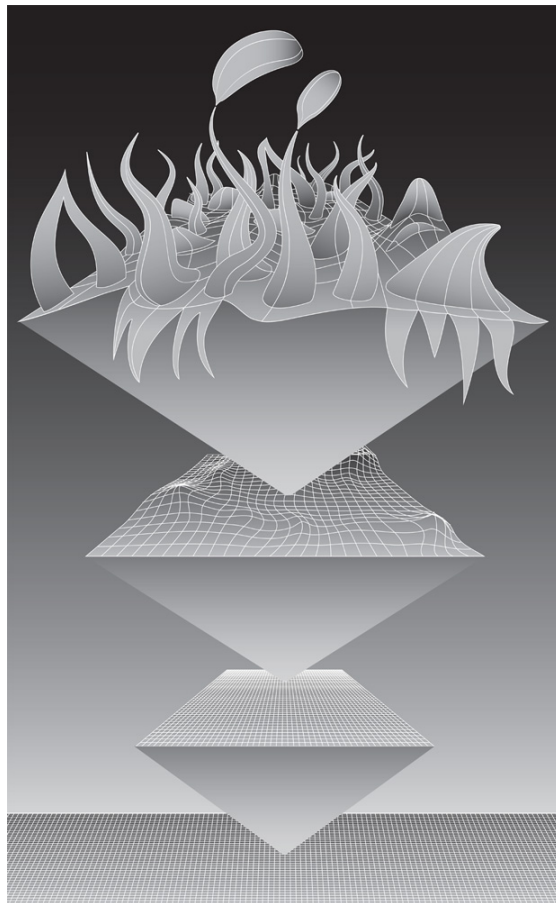
In Einstein's general relativity, gravity arises from the warping of space-time by an object's mass. Another object moving by is subject to the gravitational pull of the more massive object because it has to follow the curve made in the fabric of space-time.

So far, so good. But now we arrive at the fundamental incompatibility of quantum mechanics and relativity. Einstein's equations of general relativity consider space-time to be smooth. Planck's calculations, however, indicate it is not smooth. Something smooth can always be divided into smaller and smaller units, but the Planck length and time indicate that space-time is actually granular. This incompatibility showed up when physicists of prior generations tried to unify these two monumentally accurate and useful theories into a single "theory of everything." Applying the mathematics of the quantum realm to the scales of phenomena at which relativity comes into play, or vice versa, yields nonsensical outcomes, like the universe containing objects with infinite mass, or infinite size, or infinite speed. In a

finite universe made up of finite entities, how can the equations keep producing infinite results? Something is wrong.

In the hunt for a theory of everything, the smoothness of space-time assumed by relativity is revealed as merely an approximation, working only at large scales. In the quantum realm, space-time is not smooth. *Quantum fluctuations* arise within any stretch of space-time, even if we could potentially find a patch of space far from any galaxy and walled off from any passing photons or neutrinos.

As we've now confirmed through abundant experimental results, space-time is a field inescapably rich with energetic fluctuations. Furthermore, because of the equivalency of energy and mass, expressed in the equation $E = mc^2$, this energy will continually erupt, transforming into the quarks, leptons, bosons, and other various masses of the Standard Model.¹⁴



Quantum mechanics and general relativity view space-time differently. From a distance (the bottom field in the image), space-time does appear smooth, as Einstein's equations approximate. But as one magnifies the view, seeing down to smaller and smaller levels of

scale, the smoothness of space-time gives way to discontinuity and energetic turbulence: the quantum foam revealed at the smallest Planck scales.

Quantum energy usually erupts into matter-antimatter pairings. For example, an electron (matter) and a positron (antimatter), with opposite charges, come into existence in the same instant and then on contact with each other immediately self-annihilate, converting their masses back into pure energy. Space-time quantum fluctuations thus yield a perpetually seething, churning *quantum foam* of energy, bubbling into entities with mass that then explode back into energy.¹ As Richard Feynman described it, “Created and annihilated, created and annihilated—what a waste of time.”²

But it isn’t a waste of time! Sometimes these smallest of all entities escape annihilation in their matter-antimatter encounters and instead remain entities with mass, free to interact with other entities. These interactions, like those at every other level of scale, result in emergent structures, in this case subatomic particles, with the more complex subatomic particles emerging as atoms, then molecules. All of which then self-organize into the substance of all suns and planets, all galaxies, and the entire universe and everything it contains.

The world thus springs up as an emanation from the seething energies contained within the space-time fabric of the universe.

We have searched deep into the smallest recesses of existence—down into the quantum foam and space-time itself—and nowhere could we find an object with inherent existence in and of itself.

While bodies turned out to be composed of cells, cells are composed of molecules, then atoms, then everything down in the quantum realm. At the smallest, Planck scales, the very smallest creations of all are wholes without parts that merely emanate from space-time and dissolve back into it like phantoms—there but not there, real but not real. *Everything only looks like a thing* from its own particular vantage point, the level of scale at which it can be seen as “itself,” as a whole. Above that level of scale, it is hidden from view by the higher-level emergent properties it gives rise to. Below that level, it disappears from view into the active phenomena from which it emerged. Every one of these entities cloaks itself in the appearance of being something material, something solid, something real, but such appearances can be verified only from very selected perspectives, each of which necessarily excludes all others.

The universe is therefore not an empty box, a vast space in which our galaxies hang suspended. While we feel ourselves to be thinking, living beings with independent lives *inside* the universe, the complementary view is also true: we don't live in the universe; we *embody* it. It's just like how we habitually think of ourselves as living *on* the planet even as, in a complementary way, we *are* the planet.

We arise, in every particular detail, however glorious or mundane, from the space-time fabric of the universe, via the quantum foam, and, ultimately, we subside back into it in the fullness of time.

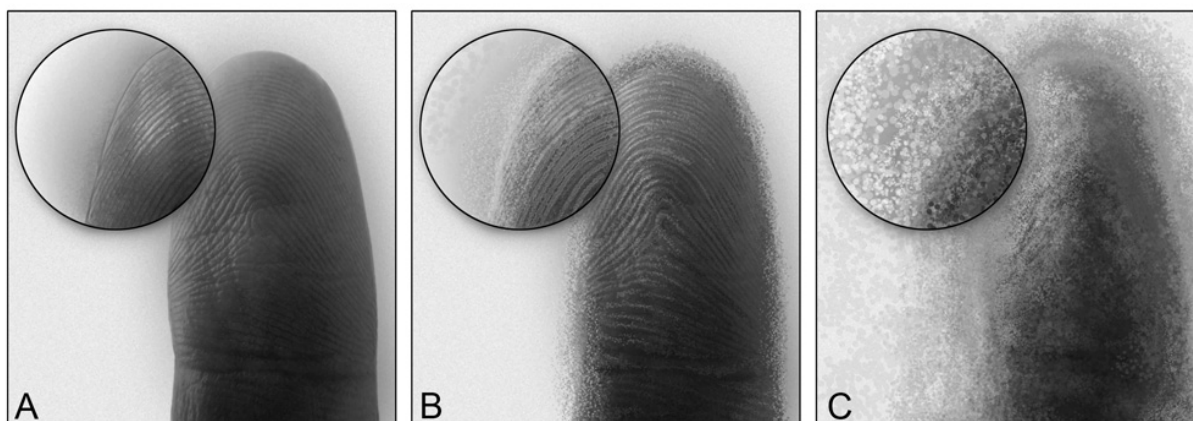
Holarchy of the Self-Organizing, Complex Universe

We now understand the universe, the whole in all its parts, as nothing but a vast, self-organizing, complex system, the emergent properties of which are . . . everything. This complexity analysis seems to have encompassed the whole shebang, from the quantum mechanical details of the fabric of space-time upward into all the vast reaches of the universe described by relativity. While we have not bridged the contradictions of quantum mechanics and relativity with a true, mathematical theory of everything, we have leapt across the vastly different scales that divide the two theories to create an overarching framework that embraces them both.

What to call this framework is tricky. From the beginning we have analyzed our bodies from one level of scale “down” to the next, either “largest to smallest” or “top to bottom,” depending on your preference. And we have also called the origin of emergent properties a “bottom-up” process. All these words connote hierarchies, and such language has permeated our analyses. Calling them “hierarchies,” however, isn't quite right.

Members arranged in true hierarchies exclude each other and do not manifest at different levels of the hierarchy, only at the level where they are seen. But in complexity theory we have this funny blurring between levels. It's only at the perspective that something appears to be a unitary, solid entity that we can localize it to a specific scale. But all entities, as phenomena, span all scales. Calling these systems a hierarchy thus conflicts with our notion of complementarities in which “different levels” are not separated from each other but interwoven, merged—a unity of a single whole.

The word *holarchy*, coined by author and polymath Arthur Koestler, has been used to capture what we intend here.³ A holarchy is a system of elements that do not relate to each other in terms of higher or lower, top or bottom, left to right, or right to left. The members of a holarchy (*holons*) are always equivalent to all other members. When we say that light is both a wave and a particle, we are not privileging one aspect of light over the other. Moreover, at our everyday scale we experience light as neither of these—we experience it merely as light!



The body as a holarchy. Here we show three different perspectives of a finger: the everyday scale (A), the cellular scale (B), and the molecular scale (C). The perspectives may be “larger versus smaller” or “higher versus lower,” but there is only one body, one whole.

Similarly, our bodies are not solid objects at a “higher level” and cells at a “lower level” and molecules still “further down,” though we have used that shorthand to construct our complexity view of the universe. Instead, we should say that a body as a holarchy appears as a solid object from one perspective, as a community of cells from a different perspective, and as a cloud of molecules from a still different perspective.

If the universe is a unity, one vast holarchy of self-organizing complex systems, then we have to consider that what is true for any part is true for the whole. From this standpoint, every action we take, every decision we make, every thought we have, is not only our own—it is also an integrated, integral part of the whole holarchical universe. In this sense, when I raise a glass of water to drink, it is the universe that raises a glass of water. If I am alive, then the universe is alive. We are not merely separate, lonely, disconnected beings searching for meaning; moment by moment we are unique emergent expressions of the universe itself.

You might argue with me, instead saying that the universe contains distinct and separate living and nonliving systems. You would be correct; however, that description is in complementarity with the view that the universe is, in its totality, a single living system. This is much the same as the way we deem each of our bodies, in its entirety, to be a living organism even though we have nonliving parts like hair and cartilage. At the boundless, nonlocal scale of the quantum realm, the living nature of the whole transcends the particularities of each part. There are no purely alive domains and none that are exclusively non-alive. There is simply the living universe.

Casual generalizations about how we are all “one with the universe” are so common these days as to be trite. However easy it might be to thoughtlessly repeat that banal truism, though, it is in fact exceedingly difficult to intuit it directly, as a physical experience, not merely a belief. Our usual, habitual experiences of the material world and our Western cultural bias toward materialism—that the world is *only* its physical substance—continually push us in the other direction. But complexity theory, woven together with relativity and quantum mechanics, tells us a different story. Oneness is real and true. And while separation is also true, it is not any more true than oneness. They are a complementarity—each, though different, is equally indispensable for a full comprehension of reality. This conviction comes not only from a subset of philosophies, or from ancient religions, or from new age mystics, but from our modern, contemporary, empirical sciences.

Part III

CONSCIOUSNESS

NINE

The “Hard Problem of Consciousness”

In my first ten years of thinking about the universe and complexity in these ways, I was satisfied that I’d done a nifty job of tying up the universe in a tidy, fully scientific bundle. But, like Langton, I had picked up the scent of something and had to follow it. It would lead me, hesitantly, then ineluctably, toward very different approaches, the spiritual and the philosophical.

On the spiritual side, it was impossible not to see how this construct aligned astonishingly well with central Buddhist concepts I had learned in my Zen practice. Buddhists speak of direct perceptions of interdependence, impermanence, and the emptiness of all things.

Interdependence reflects how every element of a complex system is linked to every other element, all parts interacting to compose and influence the emergent whole. *Impermanence* reflects the inevitability of mass-extinction events. *Emptiness* is shorthand for “emptiness of inherent existence” and is perhaps the trickiest concept for budding Buddhist practitioners: How can the solid objects of existence—this book, my body, that bird, the carved figure of a bodhisattva on the altar—not be actual *things* with their own independent identity? But we have already seen that from a complexity point of view, no solid objects exist at any level of scale. When it comes to the true nature of reality, a complexity perspective says that all is process, movement, flow, change. The Buddhists call this “emptiness.”

On the other hand, quantum physicists had themselves raised the question of consciousness but were unable to answer it. Philosophers had been grappling with the question even longer. Despite my satisfaction, the pesky puzzle of consciousness raised by the quantum physicists dangled unanswered. As Planck said, the lack of subject-object split revealed in the quantum realm means that “we cannot get behind consciousness,” by which he meant that either consciousness arises *with* space, time, matter, and energy, or else all of that arises *from* a background of consciousness.

Complexity seems to lead to the same insight. As we observed: If I am alive, if you are alive, is not the entire universe alive? Also, then: If I am conscious, if you are conscious, is not the whole, seamless universe conscious? And how does consciousness relate to this self-organizing universe?

Western culture is strongly invested in the alternative view: that each of our brains gives rise to each of our conscious minds and that, accordingly, my consciousness is separate from your consciousness. It is so deeply embedded in our worldview that it is part of our physicalized lexicon: if you tell me something that seems really smart, I may tap my skull with my finger to signal my appreciation of your intelligence—located in your brain. When the Scarecrow in the film *The Wizard of Oz* aspires to “think deep thoughts,” he tells us so by singing “If I Only Had a Brain.” Brains are where we think, where our thoughts arise, where we have ideas, where our consciousnesses come from. Or so we are told.

This bias comes naturally. Most of our sense organs are in our head. The closeness of sensory experience to our sense of being conscious conditions us to think their locations are the same. That being said, other cultures have pointed to different parts of the body as seats of awareness. In Ayurvedic and Mesoamerican traditions, as well as in ancient Egypt, the heart is considered a seat of consciousness much in the way, in our culture, we point at our hearts to convey love or other strong emotions. In those cultures, one might have tapped one’s chest to indicate an exciting new idea. We shouldn’t, then, take our instinct to point to our head (and the brain inside) as indicative of a deep truth about consciousness, so much as a cultural norm.

Still other cultures, particularly ones that have historically explored consciousness through meditative means, have developed extensive and robust vocabularies to distinguish different forms of consciousness. In Vedic, Saivite, and Buddhist cultures, for instance, there are meditative practices that use the mind to investigate itself, one’s consciousness thereby becoming the object of its own discriminating powers. Out of such practices, these cultures have generated many words and expressions to precisely delineate discrete layers or components of conscious experience and awareness.

While many of these practices have been introduced into Western culture (e.g., *zazen*, seated meditation of Japanese Zen, and *mindfulness* practices

from Southeast Asia), only in the last several decades have they begun to flourish. They have not yet deeply infiltrated our languages for describing the mind, so we still lack a sophisticated lexicon. We don't have a lot of words in English for whatever we mean by "consciousness," and the differences between them are not well defined. When and why do we use "consciousness" versus "mind" versus "awareness" versus "sentience"? Their definitions are ambiguous (which doesn't make writing about them any easier).

Does the Brain Make Consciousness or . . . ?

This paucity of language around consciousness has not prevented the most extravagant explosion in human history of scientific studies on the phenomenon. Every year now, there is a flood of studies taken to support the notion that the brain is the source of consciousness. Evidence comes from fields such as clinical neurology, psychology, and cognitive neuroscience. Advanced technologies such as electroencephalograms (EEG) and functional magnetic resonance imaging (fMRI) allow us to observe the living, actively thinking brain in real time in great physiological detail.

All these physiological data and clinical observations yield what are called *neural correlates of consciousness*: brain structures and activities that are closely associated with reportable thoughts and perceptions. We know, for example, that when the eye sees images, or even when one merely imagines or dreams specific visual images, the brain's visual cortex (in the back of the brain) becomes activated. Activation of the visual cortex, therefore, is a neural correlate of consciousness.

We now understand the neurologic processing of vision so precisely that it has become possible to literally "read people's minds" by applying advanced brain-measuring technologies. While a subject under study holds an image in their "mind's eye," the technology is able to deduce a hazy version of the image just by measuring phenomena in the brain.

While these reports may seem to overwhelmingly support the hypothesis that brain makes mind, do they in fact settle the question? In reality, these examples only demonstrate *correlations* between specific brain activities and conscious experiences. And correlation, as we might remember from

our high school science classes, does not equal causation. Correlations do not prove that the brain activity causes the conscious experience.

You might have noticed that every summer, there's a pretty strong correlation between wearing sunglasses and eating ice cream. The two activities seem to go hand in hand quite frequently; indeed, if correlation implied causation, then we'd have to seriously consider whether wearing sunglasses makes people crave ice cream. Or if eating ice cream makes people oversensitive to sunlight and therefore more likely to wear sunglasses. Of course, neither of these conclusions is correct. The reality is that both behaviors are caused by something else entirely: the bright, hot days of summer make people more likely both to wear sunglasses and to eat more ice cream.

It's easy to see then how mistaking correlation for causation can quickly lead to some serious errors.

If we are scientifically rigorous and careful not to make such a mistake, however, then we are left with two primary hypotheses to explain the neural correlates of consciousness. The first is that our brains define the activity of our minds. The second is that the contents of our conscious awareness and the correlated activities in our brains derive independently from some other, more fundamental shared root cause, just as summer was the shared cause of both craving ice cream and wearing sunglasses.

To date, there has not been a single experiment out of thousands performed that definitively proves one of these hypotheses over the other. Inarguably, the question of causation between mind and brain remains scientifically open.

The Hard Problem

In the absence of any scientific consensus, the origin of consciousness and its relationship to the brain has thus far been most thoroughly explored by philosophers. While consciousness remains a special unsolved scientific problem, philosophical approaches try to lay out a map of possible solutions to the conundrum and to help guide scientists toward formulation of testable hypotheses and correct interpretations of the resulting data.

Philosopher David Chalmers famously shed light on the situation by coining the phrase "the hard problem of consciousness" to signify the most

profound challenge to the brain-makes-mind concept.¹ The hard problem highlights how, even while neural correlates of consciousness suggest that the parts and functions of a brain produce the informational contents of mind, they in no way explain our *subjective experiences* of perception.

Take, for instance, the subjective experience of encountering a rose: seeing the deep red of its petals, smelling its perfume, feeling the prick of its thorn. We can detail how scent molecules from a rose enter the nose to stimulate the olfactory nerves, which then go on to transmit signals to the brain that register the flower's smell. We know how the color of the rose—the light of a certain frequency reflected off its petals—enters the eye, triggering cells and their molecular color receptors in the retina to stimulate the optic nerve, conveying the electrical signals to the visual cortex. We understand how sensation receptors in the skin turn the mechanical effects of a wound into signals to the brain, which the brain then registers and labels as “pain.”

But none of these electrical, chemical, and cellular mechanisms say anything about the felt, lived *experience* of redness, the sweetness of the fragrance, and the painfulness of the prick. One can't simply say, “Well, these neural correlates of consciousness *are* the experience,” because that statement provides no explanation of how or why they are anything more than the known biophysical processes of brain activity. It merely restates the material facts of the correlation. The experience part remains unexplained.

The *sense* of having conscious experiences is the hard problem that neural correlates of consciousness have not yet come close to explaining.

Philosophical Approaches to Consciousness

There are dozens of philosophical positions regarding the nature of consciousness, but nearly all fall into one of three main categories: materialism, panpsychism, or idealism.¹⁵

The *materialist* position includes the brain-makes-mind approach. Materialists claim that because the universe is made of substance, of material, of matter and energy, we can assume that everything in the world, including consciousness, derives from that material. When I first encountered complexity theory and the almost magical, “something out of

nothing” nature of emergent properties, I thought, as many others have in the past and many still do, that it could explain consciousness. I also reasoned, at that time, that consciousness might very well turn out to be an emergent property of our brain’s material parts: its electrical signaling, molecules, cells, and architecture.

This is akin to how the large-scale, hugely complex organizational structures of ant colonies arise from the interactions of individual ants, with the whole of the colony turning into something far greater than just the sum of its parts. Materialists say that, similarly, consciousness is an emergent whole that is far greater than just the sum of the brain’s component parts.

Next up, there is *panpsychism*, which posits that consciousness is an a priori feature of the universe even before brains come into existence. This approach has generated renewed interest in recent years. One variation of the theory suggests that consciousness is an intrinsic feature of all life and, therefore, of the smallest identifiable units of life as well. If we take the perspective of Western biology, those smallest identifiable units of life would be cells, and those cells would have rudimentary forms of consciousness.

Does the consciousness of a human body then derive from the aggregated consciousnesses of all its individual component cells?¹⁶ Do their simple, single-cell consciousnesses self-assemble into more complex consciousness in the same way that cells self-organize into the basic components of a multicellular organism? And, if so, does the aggregation of smaller, individual consciousnesses into a larger consciousness apply not just to individual bodies that arise from cells but also to ecosystems that arise from all manner of interacting living things? Are all forests and coral reefs self-aware and conscious? Is Gaia? Do our human minds participate in such aggregations, and would we, or could we, know if they do? All good questions if one is a panpsychist.

More extreme versions of panpsychism claim that subatomic particles like those of the Standard Model are bearers of consciousness. Perhaps they have qualities of consciousness not yet captured by the equations of quantum physics. Or perhaps there are still undiscovered particles that are the actual conveyors of consciousness, similar to the way that photons are conveyors of the electromagnetic force. In these panpsychist theories, when nonliving, quantum-scale entities with consciousness aggregate into atoms, do those atoms then have a slightly more complex consciousness? Perhaps

those, in turn, self-assemble into molecular-scale consciousness and then into cellular consciousness and then, eventually, into minds of the kind we have as human beings. Or minds like those of octopuses, elephants, or ravens. Again, all really intriguing panpsychist questions.

Much like materialism, panpsychism in all its varieties proposes that consciousness is an emergent property of a self-organizing complex system. Instead of emerging from the structures and processes of the brain, however, in panpsychism consciousness is emergent from interacting subunits of conscious existence, *proto-conscious* entities.

Panpsychism is often mocked by hard-core materialists, who carp that it implies that rocks or light bulbs have consciousness, or that there is something like “what it is to be” an electron. To me, the more serious critique is that panpsychism is just as incomplete a solution as materialism in providing a definite, satisfying solution to the hard problem. Most panpsychist views just shift the problem from the brain to somewhere else, either downward in scale to known things like cells or quantum particles, or over to still undiscovered entities that somehow carry conscious experience in a fundamental, irreducible form. But wherever one locates these proto-conscious elements, the hard problem is still the hard problem.

I previously considered both of these approaches myself, even publishing on panpsychism with my collaborator, physicist and cosmologist Menas Kafatos.² But the failure of either of these two approaches to explain the hard problem eventually brought me to seriously reconsider what had previously seemed an unlikely view: *idealism*.

Big-C Consciousness

In order to examine idealism, we must go back to the Greek philosophers, in particular to Plato. Plato described our day-to-day realm of material reality as being nothing more than a shadow, like an image projected on a screen, a dim and hazy reflection of a more perfect, more real realm than our own—a realm of pure, blazing, primordial authenticity, which came to be known as the *Platonic ideal*. This realm of the real is populated by ideas, or Forms (big *F*). *Forms* are objects that are comprehended with the mind, within one’s intellect, and are perfected entities—timeless, changeless, and

absolute—while the mere *forms* (small *f*) in our material world are encountered through our physical senses and are transient and changeable.

The Platonic ideals include such concepts as Beauty, Truth, Goodness, Bigness, and Redness. While no apple looks precisely like any other apple—even two Pink Ladies are never identical twins—each is recognizable as an example of an apple, a reflection of the Platonic Apple. The ideal is what allows us to recognize the character of material objects we can hold, smell, taste, and savor. Idealism thus avers that our material realm is one of only indirect and illusory impressions that arise from our sense organs, rather than through the mind directly apprehending the underlying, ideal reality. It would be the rare mind (Plato’s!) that could reach direct and intimate awareness of the ideal itself.

Despite the strangeness of this philosophy to our modern minds, idealism has been a dominant thread weaving its way through Western culture. Baruch Spinoza spoke of the “one substance” of the world, which he identified as the God of nature and as the source and foundation of all existence. Likewise, Gottfried Leibniz, Immanuel Kant, Georg Wilhelm Friedrich Hegel, Arthur Schopenhauer, Alfred North Whitehead, and many, many others since Plato were all idealists, seeing the world as nothing but processes occurring within consciousness, the perceptions of the ordinary human mind therefore inevitably falling short. The ultimate and absolute ideal realm is a consciousness that is beyond the limitations of what goes on within our individual awarenesses. *Big-C Consciousness* is a common shorthand for discriminating between a source of awareness that preexists our material world and our personal small-*c* consciousness within and through which each of us has our own, very personal experiences.

An apt way to think about this is to consider the relationship between waves and the ocean underneath. Watching a surfer ride a wave, the wave seems like an independent structure. The big wave is *real*—it’s something that can either give the surfer a free ride or drown the surfer and dash the surfboard to pieces upon the shore. But we know that waves are not entities separate from each other or from the energy roiling through the ocean down below. If one tries to catch a “single wave,” it’s impossible to ride it for more than a few moments before it returns to the ocean’s wholeness.

In a similar way, our own individual consciousnesses seem, from within our minds, to be unique and real and our own. But the idealist knows that

this sense of independence is an illusion and, like so much of what we have studied so far, only a matter of perspective, not of reified reality.

From this idealist view, then, the universe as a whole, including each of our bodies, brains, and minds, is nothing but a manifestation arising from the depths of an underlying Consciousness. Space, time, matter, and energy, the quantum foam, all the structures that emerge from these, have no inherent existence but are simply experiences within that Consciousness. Idealism affirms, in the grandest way possible, that the brain doesn't make consciousness; it is Consciousness that makes the universe, out of which, after billions of years, our brains have emerged to be the most complex structure we have yet discovered. And thus, if everything is only a subjective experience of the big-C Consciousness, then the hard problem of what creates subjective experience ceases to be a problem. There is nothing in the universe that is *not* the subjective experience of Consciousness.

In our current age, in which scientific rigor is considered the ultimate arbiter of truth, such speculative philosophies as panpsychism and idealism may seem almost quaint. Idealism in particular, harking back all the way to Plato, certainly once seemed antiquated to me and still does to those who want to rely on scientific, empirical findings alone. But Heisenberg himself refutes our current cultural bias that these views are unscientific relics of a distant age: "I think that modern physics has definitely decided in favor of Plato. In fact, the smallest units of matter are not physical objects in the ordinary sense; they are forms, ideas which can be expressed unambiguously only in mathematical language."³

Transduction of Consciousness

Still, though, how do we account for all those exquisitely defined neural correlates? Our best foot forward is to think of the brain not as a *producer* of mind but rather a *transducer* of mind. Transducers take one kind of input and turn it into a different kind of output. A light bulb transduces electricity into light. A thermometer transduces heat into a number.

The radio is a particularly good example. Radio waves extend everywhere but can be sampled by a radio antenna. The physical components of a radio then transduce the infinite radio waves into a more

limited, sense-specific—in this case auditory—experience of music that comes out of the speaker.

In the idealist view of existence, the neural correlates of consciousness are clues, not to how the brain creates awareness but to how the brain transduces that big-*C* Consciousness into the little-*c* consciousnesses of our separate selves. And just as radio waves can be transduced, not only into sound but into other sensory outputs like a light show on your laptop screen, different types of brains transduce Consciousness into different forms of consciousness, like that of a bee that moves in an ultraviolet world or of an octopus that can taste with its arms or of dogs that live in a world rich in scents.

So where does this leave us? We have three contrasting philosophical approaches to the question of consciousness but no definitive answers. Scientific data do not settle between them, nor do extended philosophical analyses—they can only compare and contrast them. How did we find ourselves in this quandary? We expect empirical science to answer such questions. We want philosophers to give us clarity, not fog.

Perhaps they have not solved the problem because we are still in the process of discovery? Maybe in ten years or a hundred, science will be sufficient to the task and these philosophical questions will be dispelled like morning mist before the rising sun. But if we are really serious about understanding the source of consciousness within our complex universe, we have to examine our assumptions about what constitutes appropriate methods of discovery in this most special case.

Which leads us to ask: Are empirical science and philosophical rigor enough?

TEN

The Vienna Circle and Scientific Empiricism

Habitual exposure makes things invisible. Fish are unaware of the water they move through, just as we humans typically fail to notice the air around us, unless there is a breeze.

For as long as most of us have been alive, our modern culture's methods for exploring reality have prioritized mathematical logic and empirical science as the exclusive means to uncover truths about existence. Even spiritual intuitions or faith in a received religion is almost always framed in reference (and sometimes in opposition) to the standards of science. Scientific standards are like the air around us or the water in which fish swim.

Of course, this was not always so. In European culture, it took several centuries of struggle for empirical science and mathematics to push back against received religious "wisdom" about how the universe works. Scientists were often threatened with excommunication or death for promulgating empirical findings that contradicted church teachings (see: Copernicus). Even as empirical science rose in its powers of persuasion and credibility, social fissures developed and violence ensued (see: Darwin).

The cultural shift toward science as the arbiter of truth was not a constant march but rather a fitful, sporadic, and haphazard journey. During the centuries-long transition, it was not uncommon to find people with one foot solidly in each camp. Most notable among them, perhaps, was Sir Isaac Newton himself, discoverer of the laws of gravity and codiscoverer of calculus, who nonetheless produced far more written pages on alchemy than he ever did on mathematics or science.

At some point, though, the balance of power did shift. Science gained ground throughout the nineteenth century, with the advent of the Industrial Revolution. Scientific successes such as germ theory and the electric light bulb were vivid and immediate indicators of its reliability. And with the collapse of the old social orders in the violent chaos and destruction of World War I, momentum picked up speed.

The war had demolished the Austro-Hungarian Empire and reordered political power throughout Europe. Medieval hierarchies (the church and the aristocracy) were giving way to capitalism, communism, socialism, and fascism. Meanwhile, modern art, music, and writing were flourishing. Eventually, a movement coalesced in Vienna, one that would ultimately solidify what was to become our modern perspective.

From his office at Berggasse 19, Freud paved the way for a radical new understanding of human behavior. Not far away, Gustav Klimt and Egon Schiele were painting, Gustav Mahler and Arnold Schoenberg were composing, and Robert Musil and Stefan Zweig were writing.

Within this emergent hotbed of cultural activity, a diverse group of idealistic thinkers came together to concretize the view that empirical science and mathematical logic, exclusively, should guide our understanding of the world. These philosophers, scientists, mathematicians, logicians, and political and social theorists would later come to be known as the Vienna Circle.¹⁷ They sought to banish nonscientific insights from what they considered reasonable, modern discourse and to purge philosophy of the more fanciful speculations of prior centuries. They didn't aspire to perform science themselves but sought to catapult philosophy into the twentieth century; with the aid of modern logic, their aim was to make philosophy as scientific as possible.

The Vienna Circle was first gathered in 1924 by the philosopher Moritz Schlick, the social reformer Otto Neurath, and the mathematician Hans Hahn. Meeting regularly on Thursday evenings in a small lecture hall at the University of Vienna, the group referred to themselves as "logical positivists" and immediately entered into a decade of heated, though largely collegial, debate. What mattered most to them was how to characterize scientific knowledge and how to understand the nature of mathematics. Their fervent mission was to prevent philosophical confusion rooted in unclear language and unverifiable claims. They wished instead to convert philosophy into something "scientific" and set mathematics on complete and consistent foundations. As a corollary to all this, they also sought to banish metaphysics from modern thought.

Metaphysics is a field of philosophical inquiry concerned with questions that cannot be answered through an examination of material existence. Any attempts to understand the nature of life after death or the existence of a

soul, for instance, would be a metaphysical speculation, as would efforts to comprehend the nature of gods and goddesses, or of a singular creator God.

Until the modern era, statements about consciousness fell exclusively within the realm of metaphysics. Church doctrines derived from ancient texts or spiritual insights—the only attempts to grapple with consciousness available at the time—were all metaphysical.

To a member of the Vienna Circle struggling to push past medieval modes of thought, anything with the whiff of metaphysics was to be summarily dismissed. If something could not be ascertained by empirical science or mathematical formal logic, it was deemed worthless. Indeed, among this crowd, declaring some statement to be “metaphysics” was to suggest not merely that it was wrong but that it was devoid of any meaning or significance. When debates within the circle grew heated, a declaration of “metaphysics!” by an opposing thinker was the ultimate smackdown.

The Vienna Circle led the way for our modern culture to award science and mathematics exclusive ownership over the truth. And the many successes of empirical science—from the development of antibiotics and vaccines to the exploration of other planets—fully demonstrated the power and importance of scientific methods.

As it turned out, though, while the philosophical vision of the Vienna Circle was idealistic and well-intentioned, it was also naive and destined to fall short.

The Limits of Empirical Science

By the time the Vienna Circle began making their proclamations, quantum mechanics was beginning to illuminate the limits of empirical science. *Empiricism* is the notion that all knowledge is derived from sensory experiences of the real world, rather than from theory or logic alone. Empirical science, then, proceeds by creating experiments to examine the real world. Data from such experiments allow us to build testable hypotheses that explain the data. In turn, we create more experiments to find additional data to support or disprove each hypothesis. And so on go the endlessly repeating, iterative methods of science.

All of this depends on the ability to attain objective measurements of the world. As a scientist, I am the *subject* who is examining some physical *object* (or process) that is separate from me. The object must be rigorously

shielded from any possible influence from me, the subject, for the independent nature and truth of my perceptions to be certain. Empirical science requires a clear separation between subject and object.

But in quantum mechanics, that separation has been erased.

It's surprising that, as far as I can find, the members of the Vienna Circle never meaningfully addressed the devastating threat quantum mechanics posed to their vision. They welcomed both Bohr and Heisenberg to their international conferences and were certainly aware of the successes, surprises, and implications of quantum mechanics. Yet, in their writings, we find very few mentions of Bohr, Heisenberg, or quantum mechanics itself.

Undoubtedly, they would have been suspicious of metaphysical writings by Planck, Bohr, Heisenberg, and their peers. These physicists were flirting with the idea that there was no concrete world outside our choices of perspective or modes of perception. Not only were such ideas anathema to the Vienna Circle, but indeed this argument was at the heart of Einstein's own distress over where quantum mechanics was headed.

For Einstein, physical theories were reflections of a "world out there" independent of human awareness. Close your eyes, turn your back, or, more dramatically, die, and the moon keeps orbiting the Earth. This is our instinctive, commonsense view of reality.

But the Copenhagen interpretation of Bohr and Heisenberg suggested otherwise. For them, there was no rigidly determined material existence "out there," only probabilities of possibilities, until the moment when an observer steps in to make a measurement.

Perhaps the failure of the Vienna Circle to focus on responses to the Copenhagen interpretation and the problematic implications of Heisenberg's uncertainty principle—that some kinds of observations necessarily altered measurable features of quantum phenomena—reflected a mistaken apprehension that Einstein already had that problem covered. Whatever the reason, they seemed to avoid confronting those implications in their own particular terms. We now recognize that they could not have reasoned their way around the implications of quantum mechanics any more than Einstein was able to. Quantum mechanics sets a limit on the capacity of empirical science to define reality in a purely objective fashion.

Despite the best intentions of the Vienna Circle and despite empirical science's many, many successes, quantum mechanics sets a boundary over which science cannot leap.

Kurt Gödel and the Limits of Formal Logic

Just as the Vienna Circle aimed to give primacy to science as a means of finding truth, they also strove to modernize mathematics and logic. The story of how they tried and failed—and that of the remarkable genius who showed that their ambition was doomed from the start—has shaped the modern world as much as any philosophical system ever has.

We all know what mathematics is. There is the world of numbers and the myriad operations that can be performed on them. There is the world of geometric forms and how they are structured and can evolve. Much of mathematics can be learned through rote exercises, such as multiplication tables. But to develop theories about numbers, to prove mathematical concepts, one must enter into the realm of formal logic and logical proofs.

In formal systems of logical reasoning there are two kinds of statements: *axioms*, known or assumed to be true, and *theorems*, which require proof to be established. For instance, in arithmetic, a primary, simple axiom is the “reflexive axiom,” which states that $a = a$ for any numerical value substituted for the symbol or variable a . So, $3 = 3$. And $156,033,041 = 156,033,041$.

Another fundamental axiom is the “symmetric axiom,” which states that things on opposite sides of an equal sign are the same. So if $a = b$, then $b = a$. The “transitive axiom” states that if $a = b$ and $b = c$, then $a = c$, an equivalent to Euclid’s statement of geometry: “Things that are equal to the same thing are also equal to one another.” These statements are considered true on their face and require no proof.

Theorems, however, may or may not be true. Theorems, like hypotheses in scientific theories, require proof. A well-stated theorem may appear to be true, but one can’t assume that it is. One has to prove the truth of a new theorem by starting with the foundational axioms of the system and using them to ascend methodically, line by line, rung by rung, up the logical ladder of the proof. When the new theorem has been arrived at, it is

considered proved. Alternatively, if the proof leads to the opposite of the new theorem, then the theorem has been disproved.

Sometimes theorems seem obvious, but proving them is enormously difficult. For example, there is the famous Goldbach conjecture, which states that every even whole number greater than 2 is the sum of at least one pair of prime numbers. Take the number 8; it is the sum of $3 + 5$, both primes. There are a whole bunch of pairs of primes that add up to 144, including $97 + 47$, $103 + 41$, and $139 + 5$. The Goldbach conjecture has been shown to be true by laborious calculations by hand for numbers up to 100,000 and then by computers up to 4×10^{17} . But these are not proofs of the conjecture, always true no matter how high one goes; they are simply a lot of calculations. We remain uncertain whether we might eventually find an even larger number that would be an exception. The Goldbach conjecture remains unproved to this day.

In 1920, the great German mathematician David Hilbert announced a program that itemized what he considered to be the most important challenges for setting mathematics on firm foundations. Hilbert supported the use of a “formal language” of symbols to write mathematical statements in proofs. The success and validity of any axiomatic system and the proofs of its many theorems, he said, were to be judged on particular criteria. These criteria stated that a system must be *consistent* within itself, meaning that it cannot paradoxically contradict itself by simultaneously proving some theorem to be both true and not true. The system also has to be *complete*, meaning that it has to have within itself the means of proving that every true statement about the system is indeed true. The system that makes up arithmetic, for example, must contain within itself the means to prove *every* true statement about arithmetic, even the Goldbach conjecture. Consistency and completeness were now the seals of success for any mathematical system. The Vienna Circle’s mission was completely in accord with Hilbert’s program.

Enter the small, fine-featured, bespectacled figure of a still young Kurt Gödel, who would one day become known as the greatest logician since Aristotle, if not, indeed, the greatest of all time. He sat quietly in the back of the Vienna Circle meetings, keeping his own counsel, his life’s pattern already set: to withhold comment or commentary until his answer was perfect, polished, and definitive. We can imagine his head turning this way

and that, closely following the back-and-forth of his colleagues' debates, like the pendulum of a clock.

It was the Vienna Circle's clock that was ticking.

Gödel in Vienna

Gödel's inimitable characteristics appeared early in his life. When he was four, he acquired the nickname Herr Warum, "Mr. Why." As his brother, Rudi, later recalled, "He always wanted to get to the bottom of everything through particularly intensive questions."¹

The adult Gödel would describe his child self to his psychiatrist as "always curious, questioning authority, requiring reasons."² Early, his passions were sparked by science, though he excelled in all academic pursuits, consistently attaining the highest marks in school. He would one day write to his mother: "The highest aim of my life (conceived in puberty) is pleasure of cognition."³ His brother would also recall that Kurt was the only student in the history of their school never to have made a single grammatical mistake in his Latin exercises through the full eight years of study.⁴ It seems that by the time he was fourteen, he had already outstripped what his school had to offer him in mathematics and philosophy and begun to explore on his own.

Gödel arrived in Vienna from Brünn, the city of his birth, in 1924, having already mastered university-level mathematics at eighteen years old. It was in these early years at the University of Vienna that he encountered the ideas that would lead him to embrace *mathematical Platonism*. Mathematical Platonists believe that mathematical expressions—numbers and formulas and geometric forms—belong to the realm of Plato's ideals, not to the realm of material existence. From this view, mathematics is not merely a means invented by humans to count bushels of wheat; it is a true realm unto itself, beyond our own questing human minds. Mathematics awaits human discovery, not human invention. Euclidean geometry (with equations like the Pythagorean theorem), Newton's calculus for describing fluid motion, the wave equations of Schrödinger, the Mandelbrot set: these were not inventions; they were discoveries.

In contrast, for the Vienna Circle, numbers and forms of mathematics were the logical creations of human minds—invented, not discovered—

purely tools for describing physical reality. For them, mathematics derived logically through human innovation, from the simple “real” numbers of counting and the simple geometries of Euclid.

In 1926, Gödel became a junior participant in the Vienna Circle, invited by his mentor, Hans Hahn. This was in some ways an odd happenstance, since the group’s views of mathematics were the direct antithesis to Gödel’s now closely held faith in mathematical Platonism. Nonetheless, the invitation was also a singular honor, recognition of his exceptional intellect. Gödel was only twenty years old.

When Gödel was ready to detonate the Vienna Circle’s plans with his own “incompleteness proofs,” he did so quietly, in an almost offhand manner, during a key 1930 conference on “The Epistemology of the Exact Sciences,” held in the Baltic city of Königsberg.

Incompleteness and Intuitions

The success of Hilbert’s formalist program depended on demonstrations of both consistency and completeness. This is where Gödel enters the fray.

The proofs of his two “incompleteness theorems” are widely recognized as a dazzling display of intuitive genius, their mathematical beauty often compared to that of Bach’s most complex musical canons or the elaborate architecture of Gothic cathedrals. The detailed methods of the first proof are well beyond the scope of this book, but their ingenuity can be conveyed.

Gödel’s intuition was that there would be statements about formal systems of arithmetic that were true, but that could not be proved to be true from within arithmetic’s own axioms and theorems. This was a Platonic perspective: mathematical truths simply exist “out there” in the realm of the ideal, awaiting our discovery. There is nothing, however, to require that every single mathematical statement must be amenable to our proofs. It was only the hubris of formalist mathematicians that said otherwise. So, if Gödel could prove that there were statements that were in fact true, but could not be proved as such, he would then prove that Hilbert was wrong: incompleteness could not be completely eliminated from mathematics. The question was how to do so.

Gödel cleverly devised a numbering system whereby each of the thirteen symbols used in constructing a logical statement in a proof could be substituted by a number (1 through 13) and the logical statement as a whole

could thereby, through a procedure Gödel designed, be converted into a unique number not shared by any other formal statement. The code was bidirectional: not only did every logical statement have a unique number, but any number could in turn be decoded to reveal the unique formal set of symbols of an underlying logical statement.

Through this ingenious numbering system, sequential statements within the proof had both a purely arithmetical relationship, as well as a logical one. Gödel's proof was therefore *metamathematical*: a proof composed of the very things with which the proof was concerned, numbers. The arithmetical relationship between the representative numbers conveyed arithmetical truths that were parallel to the step-by-step logic of the proof. So logical statements could be about numbers, but numbers, in turn, could convey logical statements. Following Gödel's self-referential, looping logic is like treading a path along a Möbius strip, round and round.

As if this cleverness weren't enough, in the next step Gödel's ingenuity truly soared. He created a logical statement (again using the symbols of formal logic that could be replaced by Gödel numbering) that, in English, asserts something like: "This statement cannot be proved from within this system."

This is a classical paradoxical statement, much like the liar's paradox, attributed to Epimenides the Cretan, which has been pondered for centuries. "All Cretans are liars" is problematic since, if it is true, then the Cretan saying it is lying, in which case it is false. If it is false, then it is a lie, in which case the statement is true: Cretans *are* always liars. Round and round, like a snake swallowing its tail.

Here is another version, called the "card paradox," by the logician Philip Jourdain, a student of the renowned mathematician Bertrand Russell: if one writes on a slip of paper, "The statement on the other side of this paper is false," and, on the other side, one writes, "The statement on the other side of this paper is true," then we get into a similar endless roundabout.

Gödel did not fear paradox; he welcomed it. His special statement—"This statement cannot be proved from within this system"—takes precisely the same endlessly circular form. If the statement can be proved from within the logical system, then the statement is false. If it is false, then it can't be proved, in which case it is true and *is* proved.

The step he took next is both simple and breathtaking. A clear, informal description of it is provided by science writer James Gleick: "Gödel showed

how to construct a formula that said *A certain number, x , is not provable*. That was easy: there were infinitely many such formulas. He then demonstrated that, in at least some cases, the number x would happen to represent that very formula.”⁵

Gödel doesn't say which statements may fall under this self-referential constraint, only that some such numbers are inevitable, numbers for which x is not simply a number but a Gödel number that can be decoded as the very statement itself. This final self-referential leap, that there is an arithmetical function that produces the Gödel number of his paradoxical statement, confirms that the statement is true, though its truth cannot be arrived at by a formal logical progression. Its provability is a quality of its being a correct arithmetical result, despite the impossibility of proving such a paradox through logic.



Leaving the extraordinary method aside, we jump to the more straightforward implications. The first incompleteness theorem states that if a system of axioms is truly consistent, it will be *incomplete*: there will always be statements within the system that, while true, are not provable using only that system's axioms. In these terms, for example, the difficulty of proving the arithmetical Goldbach conjecture may (perhaps) be an indication that it is a Gödelian “true, but unprovable” theorem (we still don't know). The second incompleteness theorem¹⁸ is an extension of the first and states that any system that is in fact complete cannot prove its own *consistency*.

We can summarize this even more concisely: If any formal system that includes arithmetic is consistent, it is necessarily incomplete. And if such a system is actually complete, then it must be inconsistent. The treasured goal of simultaneous consistency and completeness was, from the beginning, an aspirational sham.

Boom.

The primacy of mathematical logic and empirical science that the Vienna Circle had espoused was fundamentally shattered forever. If their ambition was to close the door on metaphysical thinking, Gödel blew that door right off its hinges. There are clearly gaps in understanding that will never be

filled by scientists and logicians, gaps that only some forms of metaphysical intuitions could hope to fill.

Metaphysics and Intuition

In addition to empirical science and formal logic, there was now a third viable path to knowing truths: the path of metaphysics and intuition. By *intuition*, we mean insights experienced only within the mind; apprehensions of truths unreachable by empiricism or formal logic.

Through his incompleteness theorems—both their method and their content—Gödel affirmed an essential, irreducible role for intuitions in mathematics. He showed that there are some truths rigorously confirmed to be true, but which can be proved true only by some method other than formal logic, a method like direct intuitions. In doing so, he undid the logical positivist mission, resurrecting intuitions as a viable, scientifically credible path for how humans can know the true nature of things. Aspects of the universe that were not amenable to empiricism or logical proof might be amenable to experiences within the mind.

These ideas were not merely abstractions to Gödel. The American mathematician Rudy Rucker recounted how Gödel described the process of his mathematical intuition many years later: “One must close off the other senses, for instance by lying down in a quiet place,” Rucker wrote, paraphrasing Gödel. He continued, “The ultimate goal of such thought, and of all philosophy, is the perception of the Absolute.”⁶ Through this mild form of self-induced sensory deprivation, Gödel availed himself of an interior sense that, to him, was like any of the other senses of sight, smell, taste, hearing, and touch, except this one was a direct perception of mathematical objects and processes. “Despite their remoteness from sense experience,” Gödel wrote, “we do have something like a perception also of the objects of set theory [a form of mathematics], as is seen from the fact that the axioms force themselves upon us as being true. I don’t see any reason why we should have less confidence in this kind of perception, i.e., in mathematical intuition, than in sense perception, which induces us to build up physical theories and to expect that future sense perceptions will agree with them.”⁷

Such “remoteness from sense experience,” while still remaining “something like a perception” in the mind, is in fact an excellent definition of what the Vienna Circle meant by “metaphysics.” Gödel not only established truths of existence (in his case, mathematical truths) through mental contemplation alone; he simultaneously demonstrated that formal logic could not have done so itself. Metaphysical practice could solve problems that had resisted science and logic, despite long, significant efforts.

That there are statements that can be known to be true but cannot be logically proved as such indicates that there are mathematical truths that exist independently of logical, machinelike exercises in proof building. In other words, it is now a certainty that the universe cannot be *entirely* described, captured, and “proved” by such exercises in producing theorems from axioms. Formal logic is unable to be the final measure of all mathematical truths. Ultimately, some truths must always be apprehensible only by intuition.

Gödel’s accomplishment with the incompleteness theorems, then, was not simply to prove or disprove one particular arcane question about the Hilbert program. It was much more ambitious. By reasserting the importance of intuition in our scientific understanding of the structure and function of the universe, Gödel was able to restore mental intuition to respectability as a means of assessing truths, reopening science to at least consider insights from philosophy and, alas for the Vienna Circle, metaphysics. Such insights and speculations, if rigorously obtained, were now acceptable, even necessary modes of knowing truths.

Responses to Gödel

The shock wave of Gödel’s discoveries passed through the Vienna Circle and the entire field of mathematics. Gödel’s friend Marcel Natkin wrote him from Paris after hearing news of the Königsberg conference: “Unjustifiably I am terribly proud. . . . So you have proved that Hilbert’s axiom system has unsolvable problems—that is no small thing.”⁸

But not everyone immediately understood it, and few were able to instantly grasp its full implications. Of those who were in the room during Gödel’s presentation in Königsberg, only Princeton mathematician John

von Neumann¹⁹ seemed to understand it with sufficient clarity to go home, not only to teach it, but to build upon it. Von Neumann cornered Gödel immediately after the presentation, interrogating him until he was clear on its meaning and could begin to reach for its implications. Separately, he had already been working on Hilbert's completeness program on his own, and this background may have prepared him to hear and understand Gödel so directly.

He wrote to Gödel from Princeton a few weeks after the conference to congratulate him again on "the greatest logical discovery in a long time" and to reveal his own "remarkable" outline for a follow-up proof confirming that no consistent system could ever be proved to be so.⁹ Unfortunately for von Neumann, this "remarkable" proof was, of course, essentially the same as Gödel's already discovered second incompleteness theorem. Nonetheless, clearly von Neumann had "gotten it." Years later, presenting Gödel with the first Albert Einstein Award, von Neumann would say that Gödel's achievement "is singular and monumental—indeed it is more than a monument, it is a landmark which will remain visible far in space and time."¹⁰

Gödel's impact soon made itself felt through the work of English mathematician and philosopher Alan Turing,²⁰ who not only understood Gödel's proofs but took them further. Turing used Gödel's method to attack a third, crucial demand of Hilbert's program, that a system must prove the *decidability* of numbers—that even if a solution to a problem was unknown, it could be proved that the system would one day be able to decide it. His famous "Turing machine" for "universal computing," a thought experiment of the highest order, was an elaboration of Gödel's own proof, imagining a self-referential computing machine rather than Gödel's logical lines of formal symbols.

Turing's amazing imaginary machine disproved decidability and, in doing so, extended the damage Gödel had done to the ambitions of formalist mathematicians. Moreover, as Gödel himself eventually wrote, "It was only by Turing's work that it became completely clear, that my proof is applicable to *every* formal system containing arithmetic."¹¹ The Turing machine would also provide a foundation for the nascent field of computer science, which has become central to modern life.

Attempts were made within the Vienna Circle to find ways to mitigate the damage Gödel had inflicted, but their discussions about this (as about so

many things) always seemed to devolve into shouting matches, the members angrily insisting on contradictory approaches. Their mix of hubris and optimism about the possibilities for philosophical and scientific reform interfered with their ability to accept the result and pivot. This continual absence of agreement, however, was ultimately its own confirmation that there was in fact no way around Gödel's Platonic convictions.

The Viennese Diaspora

How then, you might ask, did the views of the Vienna Circle come to represent our current, dominant cultural view? How did their ideas somehow survive the collision with both quantum mechanics and Gödel's incompleteness theorems?

The Vienna Circle stubbornly continued to insist that mathematics and science were the sole approaches for elucidation of reliable truths. Within the world of physics, Einstein led the contingent that refused to accept quantum strangeness and its many implications. In that camp, the Vienna Circle's thinking landed on fertile ground. It persists today, if usually unnamed and even unrecognized by physicists who still insist that there must be ways to conclusively get past the Copenhagen-style interpretations—if only they could find them.

Moreover, in academia as a whole, the Vienna Circle's views stayed largely unchallenged. The logical positivists also worked hard at their own publicity campaigns. Indeed, by the time Gödel arrived on the scene, their ideas had already been widely disseminated throughout European and North American scholarly communities through conferences, personal visits to academic centers, and publications in academic journals. In addition, the British philosopher A. J. Ayer, after spending a year attending Vienna Circle meetings, would soon publish the first English-language book presenting their views: *Language, Truth and Logic*. His work then became a major conduit for Viennese ideas to flow into the philosophy of the English-speaking academy (even though he would forswear the book as mistaken several decades later).

But it was tragedy on a personal and global scale that would further propel the Vienna Circle to the influence they exert to this day. Some of the “adjacent possibles” for the circle in Vienna would be truly horrifying.

The rise of Nazi Germany had a parallel influence in Austria, both in general society and within the academic community. By the time the Nazi Party secured absolute power in 1933, Jewish and non-Jewish academics alike began looking for positions abroad.

Despite the rise of fascism in Austria, though, Professor Schlick, the Circle's leader, did not depart. He was regarded with great affection by his peers and students, known for his gentle demeanor, careful analyses, and generous encouragement of younger gifted scholars. He was ascending the steps of the university to give a lecture on June 22, 1936, when he was confronted by a seemingly deranged former student who assassinated him with a single bullet.

The assassin provided various motives, from delusional ideas that Schlick was competing for the affections of a young woman to political justifications that Schlick's philosophical work was "degenerate" and "Jewish" (even though Schlick was not Jewish). Because of the latter justifications, however, the assassin's cause became celebrated as a victory for Austro-Germanic culture. When the Germans annexed Austria two years later in the Anschluss, the Nazi government released the killer from prison as a hero. The final disintegration of the Vienna Circle as a group of thinkers, together in their own beloved city, followed.

The Institute for Advanced Study in Princeton, where Einstein himself had fled from Germany, had been working hard to recruit Gödel and finally succeeded in convincing him that it was time to leave. By that point, in early 1940, safe travel directly to the United States had become nearly impossible for a German citizen. Gödel and his wife, Adele, had to travel overland by train, eastward through Nazi-occupied Poland, Lithuania, and Latvia, and then transfer in Moscow to the Trans-Siberian Railway, which transported them across six thousand miles of bleak, wintry vistas to Vladivostok. By boat they came to Yokohama, Japan, and, two weeks later, boarded the SS *President Cleveland* bound for San Francisco. One more train trip, across the United States, brought them to New York and then finally to Princeton in March 1940.

Many of Gödel's colleagues also found safe harbor in departments of philosophy in leading institutions in the United Kingdom, Switzerland, Palestine, China, and, most importantly, the United States. Their circle, now further dispersed, continued to exert its influence not only on philosophers of science but on scientists themselves. Chris Langton, codiscoverer of the

“edge of chaos,” was himself intellectually redirected toward the history and philosophy of science by studying with a close disciple of Hans Reichenbach, a German Jewish colleague of the Vienna Circle who relocated to the University of California, Los Angeles. From one generation of scientists to the next, the disseminated members of the circle wielded their personal influence, and from there it filtered out to the general culture, informing the biases that are common today.

It’s also fair to say that the Vienna Circle’s views were a reflection of general sentiments evolving in the transition from the nineteenth to twentieth centuries. The idea that science alone was sufficient to explain everything in the universe was, and remains, for many people “intuitively obvious.”

But the Vienna Circle was driven to go beyond common sense. No one in history had advocated more strenuously, or with greater precision, for how science can and should explore the nature of existence. Scientists of their era, and those who were subsequently trained by them, were all heavily under their influence. In the middle of the last century, apart from the highly technical worlds of theoretical physics in which quantum strangeness was debated, the Vienna Circle managed to achieve their loftiest goals: science comfortably assumed the mantle of primacy, not just within their field but in the culture at large.

Then, in the second half of the twentieth century, their overt influence began to wane. This may have been in part because scientists gradually had less and less interest in the philosophy of science. Logical positivism so reflected the zeitgeist from which it arose that its approach to science simply became part of the background hum of modern life, no longer requiring either justification or explanation.

As for logicians and philosophers of mathematics, the vistas of computational science and information theory, from von Neumann and Turing to Silicon Valley and beyond, sprang forth from Gödel’s intuitions. In these worlds, the formalist ambitions of the logical positivists were not forgotten but are perhaps best remembered for having been the delicately crafted trophy that Gödel’s hammer broke into pieces. Those who remain interested in the Vienna Circle’s work today are compelled more by their remarkable history than by their passionately argued, now largely discredited program for the modern mind.

Gödel in Princeton

Gödel himself had a different path.

In Princeton, he quickly developed an exceptionally close relationship with Einstein. The Institute for Advanced Study gave him an office right above Einstein's, and soon the two men—this genius odd couple—could be seen walking together side by side and talking nearly every day.

Einstein, decades older and one of the most recognizable figures in the world, was taller and classically unkempt, a knit cap pulled over his unruly hair, a baggy overcoat protecting him from the winter chill. Gödel, meanwhile, was always a dapper dresser, with a tailored coat over a suit and tie, and a proper fedora protecting his neatly combed hair. Einstein was extroverted, cultivating collaborators throughout his later years, while Gödel remained fastidious and deeply introverted. Einstein had two troubled marriages, one to the brilliant Mileva Marić, whose own contributions to relativity are still being excavated, and the other to Elsa, his first cousin, who would be his steadfast gatekeeper despite the humiliations of his incessant infidelities. Gödel, on the other hand, was deeply devoted to Adele and only Adele, despite his family's objections over her age (older by seven years) and working-class background (she had been a dancer in a Viennese nightclub and then a masseuse).

Yet there they were, walking from home to office and back again, through all seasons, arguably each other's closest intellectual companion through the last years of Einstein's life. Oskar Morgenstern, economist and cofounder (with John von Neumann) of game theory, recalled, "Einstein had often told me that in the late years of his life he has continually sought Gödel's company, in order to have discussions with him. Once he said to me that his own work no longer meant much, that he came to the Institute merely *um das Privileg zu haben, mit Gödel zu Fuss nach Hause gehen zu dürfen*" (i.e., to have the privilege of walking home with Gödel).¹² Morgenstern later added, "He appreciates Gödel beyond anything."¹³

Freeman Dyson, another physicist at the institute, remembered, "Gödel was . . . the only one of our colleagues who walked and talked on equal terms with Einstein."¹⁴ According to Gödel himself, "Our discussions principally related to philosophy, physics, and politics. . . . I have often pondered why Einstein took pleasure in his conversations with me, and I

believe one of the causes is to be found in the fact that I frequently was of the contrary opinion and made no secret about it.”¹⁵

Einstein died in April 1955, many years before Gödel—a deeply felt loss. In his absence, Gödel had only Adele and Morgenstern as close companions. Throughout his adult life, Gödel had repeated bouts of psychological illness, marked by depression and paranoia. When Adele later required seven months of hospitalization for her own medical issues, the stress of dislocation exacerbated by loneliness and worry over Adele reactivated these difficulties. Without Adele to steady him, Gödel’s fears and paranoia spiraled beyond control. He died in January 1978 of malnutrition, refusing to eat, in part out of a terror of being poisoned.

Gödel’s Meaning for Us

It’s important for us to remember that mathematical intuitions are not the only kinds from which we may derive important insights about the nature of existence. While the primary concerns of someone like Gödel were with the Platonic Forms of mathematics, there’s nothing that excludes other kinds of intuitions from being discovered through introspection.

Gödel’s personal intuitions derived from *experiences* from within his introspective imagination—experiences perceived within the mind, not within material existence. For us, insights or, more precisely, experiences from within deep contemplation are also profoundly rich sources of data for construction of theories of existence. Whether the contemplative is Gödel lying on a couch and setting himself afloat in the realm of the mathematical ideal, or a Zen student sitting on a cushion facing a wall, or a yogi on the banks of the Ganges, or an Amazonian shaman in an ayahuasca medicine ceremony doesn’t really matter.

Gödel himself acknowledged the implications of his work for such other forms of intuition in 1963, writing to his mother: “It was something to be expected that sooner or later my proof will be made useful for religion, since that is doubtless also justified in a certain sense.”¹⁶ While he scorned some aspects of religious orthodoxies, he also took issue with how “even today’s study of philosophy does not help much toward the understanding of such [religious] questions since after all 90% of today’s philosophers see

their primary task to be beating thoughts of religion out of people's heads, and thus having the same effect in this sense as the bad churches.”¹⁷

While the theories of relativity, quantum mechanics, and complexity are pinnacles of modern attempts to understand the nature of existence, empirical science by itself is insufficient to fully grasp its own implications without outside help. The quantum physicists revealed hard limits to empirical science by showing that subject and object cannot be definitively separated. Then Gödel directed us to look beyond pure logic and empirical science for how to comprehend the universe.

We have concentrated on scientific insights for most of this book's journey into complexity. Our dip into quantum mechanics and our encounter with Gödel show that metaphysical speculation is necessary for a complete understanding of the true nature of reality. What might such speculations reveal?

TWELVE

The Return of Metaphysics: Fundamental Awareness

Thanks to Gödel, we are free to explore (very carefully) the metaphysical insights derived from sustained contemplative practice and, furthermore, to bring them into dialogue with contemporary scientific debates on consciousness.

There are many forms of contemplative practice. Some concentrate the mind “one-pointedly” upon a single object of attention, such as a word (e.g., a mantra) or an image (e.g., a mandala or an icon of a deity). Others emphasize a “choiceless” or “open presence” attention in which the mind remains open to all sensory inputs as they flow by without attachment, judgment (“That bird sounds beautiful!”), or aversion (“Ugh! Those cars honking!”). Whatever the method, over extended periods (weeks, months, years), the practices become an experience of the mind contemplating itself.

Experienced meditators obtain direct intuitions, within their minds, of the nature of mind, much as Gödel intuited the nature of mathematics. And despite any objections from materialist-minded scientists and philosophers, these observations should be considered valuable data regarding consciousness—no different from any other data about the natural world revealed through enhanced observational techniques, whether they’re cellular structures revealed by a microscope or quantum-scale particles discovered by high-energy colliders.

There are some good scientists and clear-thinking philosophers who treat this data with interest. Some have even taken on a meditation practice of their own and can incorporate their own observations into their scientific models. Many remain largely ignorant of contemplative practices and disqualify them as credible sources of data. This outmoded resistance is like a fading echo of the Vienna Circle’s dismissive cry of “metaphysics!” It’s as if a color-blind person were to tell a non-color-blind person that there’s no such thing as red, nor could there ever be such a thing as red.

Cautions Regarding Contemplative Insights

Of course, in admitting such data for consideration, we confront a methodological problem. Can we trust first-person accounts? What distinguishes subjective experiences of verifiable truths about the nature of reality from willful delusion or even psychosis?

A practitioner of both science and meditation should always be vigilant to maintain a skeptical eye, even when their meditative experiences are exceptionally vivid or even life-altering. However vivid and personally meaningful some of my own experiences in Zen practice have been, however much they seem to mirror Buddhist concepts, could the similarities between my personal Zen insights and Buddhist dogma not merely reflect confirmation bias from my prior readings on Buddhist thought? To distinguish illusions or delusions from scientific data, we need strong criteria by which we can assess the reliability of personal insights.

First, the reported experiences must have a certain depth and reproducibility rather than being single, one-off experiences, no matter how dramatic or seemingly “real” they are in the moment. Second, the experiences must pass through the filter of someone else’s assessment, preferably a teacher with their own sustained and detailed experiences with the same practices. Such relationships are labeled differently in different cultures: guru-disciple, teacher-student, master-apprentice, mentor-mentee, and so on. This aspect of spiritual training is really not much different from scientific training. All rely on direct communication between a seasoned expert and a new practitioner, knowledge being passed from generation to generation through “mind-to-mind transmission,” as we say in Zen.

Contemplative Practices as Sources of Knowledge

When I first began considering the implications of complexity theory for how the universe self-organizes, I was struck by the way the processes and structures of a complex universe mapped with precision and specificity to insights from mystical traditions. In particular, I noted similarities to views from Jewish and Hindu mysticisms and Buddhist metaphysics. When I met my eventual collaborator in consciousness studies, Menas Kafatos, a physicist, mathematician, and cosmologist, he affirmed the Hindu parallels and added Kashmiri Saivism to the list.

There's nothing particularly special about these four traditions that we chose to explore in depth. They're simply the ones with which he or I are most familiar, through direct initiation and practice or academic interest. There are so many others, of course, and I invite you to look to whatever traditions you are familiar with for similar or related views.

These traditions align quite closely in some aspects, while in others they differ wildly. The differences arise, in part, because spiritual traditions deviate in the questions they seek to answer, and each tradition frames its questions according to its own concerns. The Buddha, for example, asked what are the causes of human anguish and is there a reliable way to bring an end to suffering? For many Jewish mystics, on the other hand, the central question is how the divine created the universe in the first place, and how our world is re-created and sustained in every moment since.

There is always something lost when the contemplative begins to express their perceptions in language to anyone who has not yet attained the same states of awareness. The moment symbolic expression—verbal, graphic, mathematical—is used, the mark has, to some extent, been missed.

Nonetheless, one tries! We hunt for words to give the flavor of the experience of the ineffable, even if the experience is, by definition, beyond description. So in the coming descriptions there will be many words and images. They are necessary but insufficient compromises.

Despite the variety of intentions for their quests and the differing words and symbols they adopted to convey their metaphysical encounters, so many of these traditions wind up pointing to intriguingly related, sometimes overlapping insights. They describe foundational features of existence that align with complexity theory and the roles of complementarity and holarchy in the self-organizing universe.

Creation and Consciousness

Menas and I set as our objective the construction of a comprehensive model of the universe, one that would incorporate both complexity-informed structures of contemporary science and philosophical insights from our Western culture that would answer the hard problem of consciousness. Each contemplative tradition we included would yield specific, useful concepts.

We identified elements in these four traditions that aligned with the complexity analysis of existence. From there it was surprisingly direct to

see a clear framework for how conscious awareness was at play in the universe.

BUDDHISM: MIND OF CLEAR LIGHT

Many Buddhist concepts align particularly well with complexity theory's understanding of the universe. As noted earlier, Buddhists speak of direct perceptions of interdependence, impermanence, and emptiness of all things, which map to aspects of complexity, complementarity, and holarchy.

The reason the historical Buddha (if he existed) dug down deep into his mind to explore the true nature of reality was to alleviate suffering. He identified the causes of suffering as attachment to objects of desire and aversion to objects of loathing. But if objects are empty of inherent existence, attachments and aversions dissolve. Of course, concepts alone are rarely sufficient to make desires and aversions evaporate—but direct perception of the truth of emptiness can do so, according to historical and contemporary accounts of Buddhist practitioners.

So, Buddhism and science do not present two natures of reality but overlap with precision in some of the most important details.

As for consciousness, the depths of one's mind from which these direct perceptions arise during meditation are described as primordially pristine, spontaneous, self-generating, and luminous. In some Buddhist traditions this is called the “mind of clear light.” In the deepest meditative states, one's mind is not self-contained and bounded within itself but connected to something far larger, indeed infinite.

Imagine you are exploring a cave and find individual pools of clear groundwater. They appear separate. But if you dive in, you find that you enter a vast, water-filled cavern. The ripples on the surface of those pools reflect the stronger, wider currents of the huge body of water below.

Just so, in the minds of meditators. Delving inward, they encounter a vast “subterranean” river (a common image) of (big-C) Consciousness, ever flowing, out of which arise the waves—sometimes gentle, sometimes turbulent—of our own personal (small-c) consciousnesses.²¹

LURIANIC KABBALAH: CREATIVE POTENTIAL

Kabbalah, Hebrew for “reception” or “tradition,” has come, in common parlance, to represent Jewish mystical practice. Here we discuss teachings from the school of the sixteenth-century rabbi and mystic Isaac Luria. It asks the question of how God created the universe “in the beginning” and

continues to sustain that creation in every current moment. In meditative states, an infinite luminous consciousness is encountered that recalls the perceptions described by Buddhists. The Hebrew term for this luminosity is *Eyn Sof*, literally “without end.” The Lurianic tradition emphasizes the profound creativity of this luminous “ground of being,” to use a term coined by the philosopher and theologian Paul Tillich.¹

As in Buddhism, we get a taste of how the *Eyn Sof* points to an idealist realm of pure Consciousness. Just as we can experience, within the depths of our own minds, how thoughts seem to arise spontaneously, one after the other, and just as spontaneously subside again, we also glimpse how material existence arises from Consciousness in the same way, coming and going, coming and going. In other words, thoughts arising from our consciousness mirror how creation arises from Consciousness. For the Kabbalist, creation and consciousness are entwined expressions of the divine source of everything.

In reaching deep within ourselves to contact this primordial realm, we can have influence upon it, becoming a partner with God in refining all creation to ward purity, perfection, and peace.

In order to do so, the mystic details the stages of manifestation of all existence out of the *Eyn Sof*. One useful map of this divine creativity is found in the *four worlds* of Kabbalah. These “worlds” exist in a holarchy, just as our complex universe can be understood as a holarchy.

The mystical terminology for these four worlds is applicable to our scientifically formulated “true nature of reality.” The first world is *Atzilut*, or emanation from the *Eyn Sof*. Does this term not recall how the quantum foam emanates from out of space-time? The next world is called *Briyah*, creation, as in the creation-out-of-nothing described in Genesis. This is evocative of the smallest entities that arise from the quantum foam—whether they are strings or loops or fields or particles—able to interact freely with each other. Next comes *Yetzirah*, formation. These entities interact as the particles of the Standard Model and the fields of quantum field theory, forming atoms and molecules. Finally, there is *Assiyah*, this mundane world of action or doing, all of material existence manifested in the physical world in which our everyday lives—all life—meet their potential. These four worlds are stages of creation, much as the processes at the quantum, atomic, chemical, and biological scales can be considered stages of self-organization. It is not that the *Eyn Sof* creates a material

universe that is separate from itself; rather, all things that are emanated represent the whole—seamless and intimate—with God immanent in all details.

Kabbalah thus gives us a conceptual map of how the creation happened “in the beginning” and of how, moment by moment, over and over, creation of our holarchical universe is renewed. Moreover, this uncannily precise map is derived from introspection, not from scientific experiment. What is revealed is not two different natures of reality but one true nature, viewed through different languages and cultural frames.²²

ADVAITA VEDANTA: NONDUALITY

In Hinduism we turn specifically to Vedanta, the spiritual doctrines and practices that derive from the ancient Vedic scriptures known as the Upanishads. Vedanta speaks of two aspects of existence: *Brahman*, which is the divine source of reality, and *Ishwara*, the appearances of our material world. Their relationship is similar to that of the Eyn Sof and the four worlds of Kabbalah.

This mystical tradition brings the concept of *nonduality* into relief. Brahman is described as *nondual* (Advaita), a state of being in which there is no separation between subject and object, observer and observed—a state in which differentiation into separate characteristics is at best in a condition of primordial potential, without explicit manifestation.

Ishwara, in contradistinction, is the state of *duality*, our ordinary experience of the world, in which there is separation between subject and object, in which objects are outside of the observing subject. “I” observe “that.” “You” observe “this.” Duality describes our universe with its differentiated but complementary characteristics, like the wave-particle duality of light in quantum mechanics and matter-energy duality in relativity, as well as nonscientific distinctions: light versus dark, male versus female, alive versus dead, and so on.

In terms of consciousness, meditators in this tradition describe the direct experience of Brahman in similar terms to those of Buddhists and Kabbalists, as a field that is pure, unchanging, eternal, and luminous, but they also emphasize its quality of absolute, nondual awareness—a field of perfect awareness, no subject or object, just the big-C Consciousness itself, simply aware that it is aware, pure awareness of awareness. You might get a slight taste of this when first waking in the morning: you become aware of

being awake before you take note of mental activity or physical sensations that self-assemble into your awareness of “me.”

KASHMIRI SAIVISM: HOW THE UNIVERSE HAPPENS

This variant Hindu system of thought explores the finest details of the phase transition between nonduality and duality. Saivists speak of many *tattvas* (Sanskrit, parts or principles or processes of existence), and in particular there are the five “pure” *tattvas* that detail how the subject-object split occurs within the underlying nondual awareness.²³ A prime Saivist target of inquiry is how nondual big-C Consciousness produces dualities of the manifest universe.

This is quite complicated, but in a nutshell, the sense of being a subject, an “I,” and also the sense of being an object, a “that,” are, at first, only *potentials* that are completely enmeshed within the unity of awareness. As they start to kind of shimmy apart, the “I”-ness becomes more distinct within the unity. Then there is a little more shifting, and “that”-ness comes to the fore. But they are still merely potentials. In the fourth step, they become even more manifest, though still a unity despite their growing differentiation. In the fifth step, they separate completely, the subject-object split in full manifestation. We have arrived at the moment of the creation of duality.

To (over)simplify this in a way that I find useful, it’s similar to how, in the moment before one takes an action, there is the *intent* to act. Before the crystallized intent, there was a rising *urge*. And the urge itself somehow, subtly, slipped into one’s conscious mind from the dark, unseen unconscious.

So much going on, yet so little to see until the moment of action!



These four traditions offer complementary descriptions derived from their varied meditative practices and point to something beyond material existence that preexists space-time and the quantum foam. They point to a big-C Consciousness that is luminous, creative, and composed of nondual, pure awareness, which emanates existence within itself as it undergoes differentiation into subject and object.

The relationship between these varied traditions and our complexity theory view of the universe recalls the parable of the blind men and the elephant. In that story, one man describes the trunk of the elephant as a snake. Another man describes its legs as trees. One says the body is a wall, and another calls the tail a whip. Likewise, each mode of inquiry, each cultural perspective, each set of questions concerning the true nature of reality yields some pieces of the puzzle but not others.

Menas and I found that these metaphysical views were compatible not only with each other but with complexity theory as well. They could all be melded together into a seamless whole—trunk, legs, body, and tail revealing the elephant of big-C Consciousness itself, Consciousness as the ground of being, or what we came to call *fundamental awareness*.

Integration: Fundamental Awareness

By weaving together aspects of all three important methods of human exploration of the nature of reality—empirical science (complexity theory), philosophy (idealism), and metaphysics (Buddhism, Kabbalah, Vedanta, Saivism)—we find that the realm of the Platonic ideal is nothing other than this nondual realm of pure awareness, a fundamental awareness before any split into subject-object duality.²

Saivism provides the key connecting link in the creative process: this refined view of the potentiation of subject-object split and the subtle separation into these dualities leaves us with a precise description of the creative moment. “Separation” means to move apart, which implies the creation of *distance*. Distance in space, distance in time (and perhaps in other dimensions). And once we have these, we have space-time, the first act of creation. Nonduality makes way for duality and creates the fabric of existence.

Space-time, being rich in energy, erupts into the quantum foam. The entities arising in the quantum foam interact with each other, self-organizing, springing up into subatomic particles, atoms, and molecules, into the whole material universe.

Incorporating these metaphysical insights, we have a clarifying model to more fully and consistently describe existence as a holarchical, self-

organizing universe that is alive and conscious, because it is born from consciousness itself—from nondual, pure awareness.

The universe is its own first subject and object. The ceaseless and profound creative potential of fundamental awareness gives rise to mechanisms by which it can recognize itself. Mystics of the Abrahamic monotheisms speak of this primordial Consciousness as the deepest reality of God and ascribe a creative volition to it. As Sufi master Hazrat Inayat Khan put it: “This whole universe was made in order that God might know Himself. The seed wished to realize what it is, what is in it, and therefore became the tree.”³

Some Implications of Fundamental Awareness

Now we come back to the hard problem of consciousness. From a fundamental awareness perspective, it isn’t very hard at all. With awareness itself as the fundamental root and foundational nature of all existence, the universe in its entirety and in every particular detail is nothing, by definition, but the very contents of that awareness.

What do I mean by “contents of awareness”? The thoughts that arise in your mind are the contents of your awareness. The experiences of the world within your mind, as you perceive the world through your senses, are experiences within your awareness. Dreams are the contents of, the experiences within, the mind of the dreamer.

In this same way, space-time and the quantum realm are experiences *within* Consciousness. The particles of the Standard Model and the fields of quantum field theory are experiences within Consciousness. Atoms and molecules, rocks and roses, colonies of ants and flocks of birds, economies and ecosystems, suns and planets, galaxies and large-scale galactic structures, even dark matter and dark energy, are all, simply, nothing but experiences within Consciousness.

And the same is true for you and me. Yes, “we are stardust,” but even before that we are pure Consciousness, pure awareness.

Two new “hard problems” now follow. First, how does the human brain transduce big-A Awareness into what we experience as our individual minds? What are the quantum, molecular, and cellular mechanisms whereby this happens? As Menas and I have suggested, “The neural correlates of

consciousness are not clues to how the brain creates awareness, but to how the brain transduces Awareness.”⁴

The second new hard problem is that, since the brain exists *within* Consciousness, this transducer of Consciousness into consciousness is, itself, composed of Consciousness. It is as if a radio could be constructed out of radio waves. We suddenly find ourselves in the *Alice in Wonderland* self-referentiality of Gödel’s proof and Turing machines. That feels to me like no coincidence.

Across all levels of scale we find these recursive aspects arising from a steady, enduring *flow* of processes: differentiation (within fundamental awareness), emanation (of space-time and the quantum foam), and self-organization (at all higher levels of scale), by which all of existence comes into being. Through these processes, complementarities arise. It seems almost as if flow,²⁴ complementarity, and recursion form a trinity of global characteristics, of universal “laws,” if you will. These would be the truly primary features of how existence comes into being out of Consciousness, every element of the world recursively linked in parallel ascending and descending spirals.

These are, of course, only intuitions. Nevertheless, they do form a basis for turning this general framework of fundamental awareness, as presented here, into a precise mathematical theory.⁵ The exciting development is that science and spirituality form an integral whole.

Some More Implications

We call this an integrative model of fundamental awareness because it integrates knowledge from all three available sources: science, philosophy, and metaphysics. It is more inclusive than most other models of consciousness or, more generally, of existence. This inclusiveness serves as a platform for all manner of cross-disciplinary investigations, fertilizations, and emergent surprises.

For science, it integrates our triumphant trio of theories from the twentieth century: quantum mechanics, relativity, and complexity. It’s fully in keeping with the Copenhagen interpretation and does not shy away from its intuitions about what quantum mechanics implies about consciousness. It encompasses the self-organizing holarchies of scale-dependent “things”

from all scientific domains—physics, chemistry, and biology—across all scales of existence.

It heralds an approach to how we can navigate from the strangeness of quantum realms up into the normal-seeming, classical realms of everyday experience. It also suggests that algorithmically programmed computers can produce artificial *intelligence*, but not true consciousness, because consciousness is not just an emergent property of complex programming. If one wants to make “real” artificial intelligence, then computers need to become transducers of awareness, as brains are, a matter that seems beyond complex programming (though perhaps not beyond engineers of the future).²⁵

The doors also open for the scientific study of otherwise contentious fields. Research into paranormal psychological or “psi” phenomena like out-of-body experiences, precognition, remote viewing, and near-death experiences, in this light, merits sustained investment of time and resources. Such research might confirm the ability of minds to be independent of their brains and thereby eliminate the materialist brain-makes-mind position. And as we have already discussed, shared languages for dialogue across cultural boundaries in the realms of health and healing, regarding modalities such as acupuncture, energy healing, and Ayurvedic medicine, may emerge. These ideas aren’t dangerous, however anxious they make materialist scientists and physicians. They don’t lead us down a rabbit hole of incoherent science. They instead represent a possible fountain of untapped human potential.

Finally, this integrative system aligns well with idealist philosophies that began with Plato and developed through the likes of Spinoza and Kant. In the twentieth century, in what became known as his “process philosophy,” Alfred North Whitehead described the universe of appearances as simply a veiled experience of a universe that is to its very foundations nonmaterial—only process, interaction, and relationship. These philosophers, along with the physicists Bohr, Heisenberg, and Planck, and mathematician-logicians Gödel, von Neumann, and Turing, are all in accord.

Despite our routine sensory evidence that our day-to-day world is solid and wholly independent of us, in spite of Einstein’s confidence that this must be so, and in contrast to the privilege given in our society to the empirical sciences, which reinforce this “commonsense” view, *everything only looks like a thing*. It is our perceptions and intuitions that cocreate this

illusion that material objects exist independently and that they are separate from each other. The parts are not, cannot be, separate from the whole. It is our misapprehension that each of us is an unimportant cog in an unfeeling, nonliving universe. It is our collective delusion that we are separate and alone. It is our training—by neurodevelopment, by instinct, by teaching—that causes us to forget the innocent, but not naive, sense of connection we carry with us from the womb before we enter into a seemingly independent life.

But what can be unlearned can be relearned. What can be lost can be found. Whatever our misunderstandings, in every moment, we are ready to awaken to our true natures, fresh and new.

Afterword

The twenty-first century proves daily to be extraordinarily challenging. Gaia's fever rages and disruptive politics and economics and pandemics surge across the globe. Staying calm or even hopeful in the face of such grinding uncertainty is made easier for me when complexity is brought to bear.

This is life at the edge of chaos.

Mass extinctions threaten, but so do creative possibilities for a new world and new ways of being human. It is in times of foment that the cloud of adjacent possibles expands. And by contemplating the larger view, I find that my breath and my heart slow as they do on the meditation cushion. I am better able to pry my mind from frightened pessimism, and move toward a belief that whatever comes, the world as a whole is alive and aware and doing what it does, beyond thoughts of good or bad, life and death. Yes, I fear all manner of pain and loss, but I am reminded constantly that there is a truth beyond these, in complementarity, that is *equally* real. This is not a cure, but it is a calming solace.

Complexity prods me to consider how I can participate in the world around me, rather than simply cower, with my head down. My gestures don't have to be large, because all effects are local and one never knows what this butterfly flapping its wings will produce in the larger world. One just has to know that we have opportunities for creating adaptive change in every moment: to cultivate greater interactivity between people, to reinforce homeostatic societal feedback loops, to be courageous in resisting (what appear like) top-down controls, and to trust that nothing is determined or fixed. Every moment has the random potential to surprise us with new possibilities. However dire the moment, lifesaving adaptation might just be around the corner, and might even arise from something you, yourself, have helped bring forth.

Complexity also goads me to cultivate the direct experience of these truths through meditation. When I began meditating, I did it to "get something"—a transforming awareness, an enlightenment experience, something truly *beyond* everyday experience, *beyond* the limits of myself. But now I know—as do you now, too—that scientifically, what we are

seeking is not something beyond ourselves but something intimate, inherent, and deep within us.

Knowledge of facts and theories alone—no matter one's particular level of genius—is usually insufficient for true illumination. This remains true even if one is an Einstein, a Heisenberg, or a Gödel. But such facts and theories can give one the confidence that what one finds when one looks within are not mirages or fantasies. You are this body, and you are these molecules, and you are these atoms, and you are these quantum entities, and you are the quantum foam, and you are the energetic field of space-time, and, ultimately, you are the fundamental awareness out of which all these emerge, Planck moment by Planck moment. This very body and mind, this very heart and soul *is* the transcendent reality. It was never somewhere else, something we had to reach for or travel to; it was just this body in just this moment. And as I have endeavored to show, our best, most modern sciences and philosophies confirm such perceptions to be accurate and true.

I do not offer these concepts as a panacea. Words and ideas are insufficient when on the brink of a mass extinction event. I know something of such moments. As a child of Holocaust survivors, I grew up among stories told and left unsaid of extinctions of whole families, cities, cultures. And as a young adult coming of age as a gay man in New York City during the AIDS epidemic, I was witness to the varieties of human experience in the midst of an extinction event.

I learned that words and concepts do not save one in the teeth of mass death and societal collapse. Words and concepts save no one. But I also learned that one could die a good death or a terrible death. And survivors could survive largely intact or largely broken. The difference? How readily we meet circumstance with resilience and equanimity.

The truths that complexity reveals challenge us to craft our own practices that cultivate such resilience and equanimity. Such practices should be informed by generations of honed experience but can also, now, as I've tried to show, be verified by the best science our modern society has to offer.

Complexity tempts us into taking notice. Complexity spurs us into taking part. Complexity humbles us, showing how we are but infinitesimal parts of a stupefyingly vast whole. Complexity exalts us—any small gesture or utterance we can make having the potential to shift the whole world from one cloud of possibility to another.

Complexity comforts us, revealing, unequivocally, unavoidably, that however separate and alone we might feel, each one of us is—in each and every single moment—a pure expression of the entire living, conscious universe. Nothing separate, nothing left out, but true, pure, and complete, just as we are.

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Deepest bows to all of you!

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(mathematician), and Rob Saunders (computer scientist). The following are by and about our team.

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About the Author

NEIL THEISE is a professor of pathology at the NYU Grossman School of Medicine. Through his scientific research, he has been a pioneer of adult stem cell plasticity and the anatomy of the human interstitium. He is also a longtime student of Zen Buddhism. Dr. Theise's studies in complexity theory have led to interdisciplinary collaborations in fields such as integrative medicine, consciousness studies, and the science-religion dialogue.

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1 We subsequently expanded our group to include mathematician Mark d’Inverno and computer scientist Rob Saunders to continue our explorations. We called ourselves the CELL Team.

2 These can’t easily be reproduced in a static image for a book, but if you search online for Game of Life apps you can watch such patterns developing over time for yourself.

3 The terms “negative” and “positive” as applied to feedback loops do not indicate “bad” and “good,” respectively.

4 I will discuss the double-slit experiment in greater detail in chapter 7.

5 Robert Brown was a nineteenth-century Scottish botanist who noted strange movements of pollen grains when they floated on water. One of Albert Einstein’s great papers in 1905 explained these movements as the bombardment of the pollen by water molecules.

6 The invention of which won Arthur Ashkin the Nobel Prize in 2018.

7 The one exception is in cells that don’t divide and therefore don’t replicate their DNA. Those molecules are stable and are not recycled.

8 Margulis was already a maverick in her own domains before she and Lovelock began working together. She codified endosymbiosis theory, which describes how cellular organelles began as mergers between bacteria—the engulfed organisms becoming mitochondria and chloroplasts, for example, within the engulfing cell. Like Gaia, the theory was at first ridiculed and rejected, but endosymbiosis has gone on to become a pillar of evolutionary biology.

9 The number of particles in the Standard Model varies depending on how one counts them, but thirty is a common approach. One way we know the model to be incomplete, however, is that it does not include presumed particles of “dark matter.” The existence of dark matter can be inferred from the movement of galaxies because it is able to interact with matter through gravitational effects. Dark matter particles cannot yet be directly detected through electromagnetism, strong or weak forces, our human senses, or devices like telescopes. They are therefore “dark” to us.

10 These gave quantum physics its name.

11 The Nobel Prize in physics in 2022 was awarded to Alain Aspect, John F. Clauser, and Anton Zeilinger for this work.

12 Meanwhile, the so-called mirror test for self-awareness has been passed not only by humans but by bottlenose dolphins, killer whales, bonobos, orangutans, chimpanzees, Asian elephants, Eurasian magpies, and cleaner wrasse fish.

13 Not necessarily just human minds.

14 There are theories other than the Standard Model and quantum field theory to describe the smallest quantum entities, mostly arising from attempts to unify quantum mechanics with relativity. Candidate descriptions include the minute vibrating *strings* of “string theory” and interlocking *loops* whose connections are the granularity of space-time itself (“loop quantum gravity”).

15 There is a fourth, which might be called denialism: that there is no such thing as consciousness, that consciousness is a delusion created by the brain—though that begs the question of what it is that is experiencing the delusion.

16 How such aggregates assemble into more complex forms of consciousness is referred to as the “combination problem,” considered to be the most significant “problem” for panpsychism next to the hard problem itself.

17 The Vienna Circle is an excellent example of how complexity and emergence play out in culture. From time to time, there is an unexpected burgeoning of human creativity that pops up in one place or another. The painting scenes in Paris at the end of the nineteenth century and in New York City in the 1950s and '60s are other prime examples. Following the rules of complexity, these emergent phenomena all die out after their time of brilliance (mass extinctions) but leave behind new ways of seeing and knowing in their wake.

18 Gödel did not present the second theorem and proof in Königsberg but would publish it along with the first.

19 The same John von Neumann who was so influential in steering Chris Langton toward complexity.

20 Turing’s work also moved Langton toward complexity.

21 And when we die, our little minds return, subsiding back into the deep, unending flow from which they came. The direct experience of this flow of consciousness, this “mind of clear light,” even once, by people of deep practice, but also by some people who have had near-death experiences, can be life-transforming, putting the fussy, often painful details of lived experience literally in a “new light.” In this way, at least in part, these direct insights contribute to the alleviation of suffering, the primary goal of Buddhists.

22 Another well-known Kabbalistic “map” of how the universe comes into being is known as the “Tree of Life,” made up of ten (or eleven) *Sefirot*—qualities of God that act as filters or veils, protecting existence from the intensity of the divine, most pure light of creation. A full explanation of the Sefirot is far beyond the scope of this book, though texts on the topic, in English as well as other languages, now abound. Some are noted in the Further Reading section in the back of the book.

23 I think this likely corresponds to the Atzilut emanation from the Eyn Sof in Lurianic Kabbalah.

24 Menas and I have sometimes called this “process” rather than “flow,” to invoke Alfred North Whitehead’s process philosophy, discussed on page 166.

25 What might such future engineering look like? One possibility is that for true consciousness to arise from machines, they need to incorporate some form of quenched disorder so they are not purely repetitive and algorithm-driven. Our own consciousness manifests out of quantum-scale events, even though they are generally concealed from easy view. Perhaps true quantum computing, in which bits of information are not encoded as either 0 or 1 but are held in superpositions of 0 *and* 1 until the moment of computation, will be able to transduce the fundamental awareness. But I remain unconvinced about current AI schemes.

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