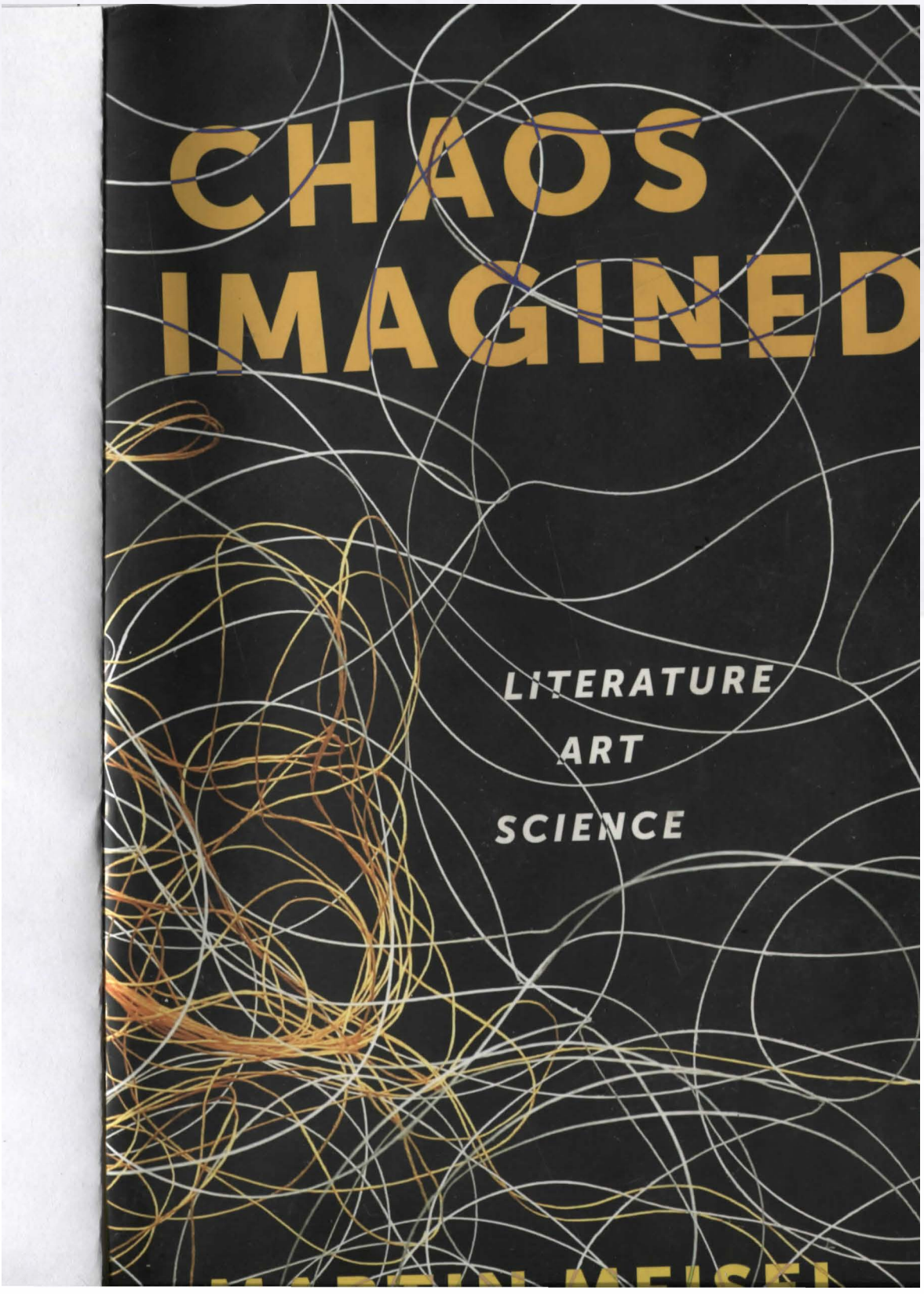
CHAOS
IMAGINED
LITERATURE
ART
SCIENCE

CHAOS EVERYWHERE

> In all chaos there is a cosmos, in all disorder a secret order, in all caprice a fixed law, for everything that works is grounded on its opposite.
>
> —Carl Jung, 1954

In that same treatise on *Matter and Motion*, James Clerk Maxwell points out that the rational commonplace "like causes produce like effects" does not hold if taken to mean that "small variations in the initial circumstances produce only small variations in the final state of the system." He points to cases where "a small initial variation may produce a very great change in the final state of the system," taking as his example a railway disaster. Maxwell might have found much support for this observation in traditional wisdom, as in Mother Goose's cautionary rhyme on the want of a horseshoe nail, as well as in the Voltairean school of history that stipulates, "Great Events from Trifling Causes Grow" (the English subtitle of a once famous play by Eugène Scribe, whose eponymous

Glass of Water brings about regime change at the court of Queen Anne and alters the history of Europe).[46] Its modern scientific equivalent is the famous "butterfly effect" of Edward Lorenz, the meteorologist who in 1972 spoke at a meeting of the American Association for the Advancement of Science on "Predictability: Does the Flap of a Butterfly Wing in Brazil Set Off a Tornado in Texas?" and so in retrospect launched the field that came to be known as "deterministic chaos" or, more inclusively, "chaos theory."

In more ways than one, "chaos" was a misnomer, both for the theory and the phenomena it addressed, just as Jan van Helmont's seventeenth-century coinage labeling his discovery "gas," from the Greek *chaos*, was a misnomer or, at best, poetic license. But "chaos" turned out to be a brilliant stroke of evocative branding on the part of its inventor (the mathematician James Yorke) and its early promoters,[47] and it drew into its vortex diverse areas of inquiry and avenues of exploration, albeit with potential commonalities. What is named "chaos" comes down to, by and large, a matter of transitions: not chaos but the road to (and from) chaos, a way of approaching "complexity," the somewhat more restrained rubric for the field as it evolved. Some have likened its dynamics to phase transitions, as from solid to liquid to gas. Formally, the approach is through algorithmic modeling, which proved to be a simpler matter and one more widely applicable than heretofore suspected. Actually, the transition is through regular stages, from all that we see as orderly—say, a smooth-running stream—to all that we see as chaotic—the turmoil of the rapids, violent, confused, and locally unpredictable. The mechanism supplied by the model, acting in a range of disparate phenomena, can be described as "period doubling." Chaos—or, more accurately, mapping the road to chaos—becomes a matter of finding a pattern and a degree of predictability in the changes. It becomes "deterministic chaos."

In its larger ambitions, this science, also labeled "nonlinear complexity" ("nonlinear" meaning that small variations in initial conditions will have an exponential effect on outcomes), aims at a broader, more inclusive account of the familiar universe of experience than "reductive" analysis provides and as such has been touted as a new paradigm, a revolution as profound as those launched by Newton and Einstein. It also offers a countering impulse to the accumulated pessimism seeded

by the entropic vision associated with the second law of thermodynamics and reinforced by the foundational insecurity, conceptual remoteness, and alienated and co-opted subjectivity that shadowed the great achievements of the last century in deconstructing the physical world. For one thing, rather than import indigestible lumps of chaos into an increasingly recondite, disjunctive, and foundationally insecure description of nature ("Chaos is a name for any order that produces confusion in our minds," said the philosopher George Santayana),[48] it does what science has always done: it brings regions heretofore dismissed as noise and confusion and abandoned to the cloud of unknowing out of chaos and into cosmos. In the language of T. H. Huxley, presumably greeting the Darwinian sunrise, "from the region of disorderly mystery, which is the domain of ignorance, another vast province has been added to science, the realm of *orderly mystery.*"[49] Or in Santayana's more cautious but prescient reflections: "Hence we may say paradoxically that a fresh recognition of chaos at the heart of nature may mark an advance in science. It will mark, at least, a closer view of the facts, rendering our preconceptions more consciously human."[50]

Latent throughout the history of Western science (embedded, for example, in the tension between British science with its empirical bent and the algebraic and theoretical bent of its continental neighbors) is the issue of the relation of scientific description to the world of our experience. As we have seen, modern physical science, notably those branches most fully engaged with fundamentals, projects an abstraction of reality that is no longer imaginable as reality. But even putting that aside, the approach that breaks up a problem and reduces it and the relevant phenomena to their simplest form, eliminating "accidentals," what cannot be generalized, and manifest complexity, leaves out much of the continuum we inhabit. The turn that gave itself the name of chaos theory claimed as its territory those very regions that have seemed too disordered, too complicated, and too unpredictable to be nailed down by reductive analysis and generalization. Its practitioners have used its toolkit to give an account of what actually happens when a faucet drips, or galaxies collide, or a heartbeat goes wild, or clouds change shape, or stock prices and grouse populations fluctuate, or oak trees and nervous systems branch out in predictable unpredictability—something the precocious young heroine in Tom Stoppard's *Arcadia*, anticipating Benoit

Mandelbrot in the next century, calls a "geometry of nature." An account of such things as processes can show a path between simplicity and complexity, predictability and unpredictability, through *iteration* (by feeding outcomes back into the same equations so that "things work upon themselves again and again")[51] and *scaling* (how big details are recapitulated in little details, and so on down with no end in sight short of the granularity of matter). The generative equations for such complexity are in fact relatively simple and of wide application. Thus the tension between generality and particularity is not banished but brought into more intimate and inclusive relations with the phenomenal world. The fruit of these developments has been described as the fostering of an "alternative intuition" in science, a shift in gestalt that "almost amounts to change from never seeing chaos to seeing it everywhere."[52]

One benefit conferred through these newly opened eyes was a renewed confidence in visuality. As a working scientific tool, visualization had fallen much out of favor in many areas precisely because it chains thinking to experience. Visuality in descriptive language can also be misleading. Think what confusion lies in a "string" theory that postulates entities harboring ten or more "dimensions." By contrast, chaos put to work the eye's gift for seeing patterns, notably by converting information into computer-generated images, often set in motion; by mapping the results of iterated differential equations; and by using topological models for probing dynamical systems. In a sense the shift from algebraic reduction to geometric modeling was a return to the science of the Greeks (as we will see in chapter 3).

When Richard Feynman found himself wishing to convey the feelings he had about the beauty of the world, the mathematical beauty "of how she [nature] works inside," he put himself in the hands of an artist and learned to draw. One senses a similar aesthetic response in Maxwell when he perceives that "the whole body of dynamical doctrine" falls into a coherent set of principles working (in Feynman's phrase) "behind the scenes." Now, in the striking visuality of "the new science," the aesthetic aspect could declare itself directly. And it was the algorithm itself, feeding solutions back into the equations for as long as you liked, that did the drawing. So it was with the "Lorenz attractor," where the seemingly random results generated shapes like a moth or a mask out of a sinuous curving line that never overlapped

itself—Hogarth's "Line of Beauty"—or with iterations that, plotted as points, could produce out of randomness startlingly convincing shapes of nature, like a leaf. So it was with the "fractal" patterns in brilliant colors that soon became coffee-table books, run through a computer chip and onto a screen for all to see, mathematics behaving like plants, clouds, shorelines, auroras, galaxies—"nature's geometry," number and nature reunited. The images themselves are an embodied dialogue of self-similarity and difference, recurrence and variation, as in music: pattern entangled with infinite variety, regularity with unpredictability, extending not just horizontally but vertically, scale within scale, and endlessly so.[53]

The term "fractal"—coined by Benoit Mandelbrot—has become familiar through such computer imagery. It is often explained by the problems in mapping and measuring a coastline, whose irregularities echo one another at every scale and whose "true" length is either endless or indeterminate. The fractal aspect, that is (etymologically) the broken quality, pertains to a convention of representing dimensionality by whole integers. "Fractal" refers to a value somewhere between. It concurrently implies a conceptual space that lies between chaos entire and order unqualified, managing to partake of both. It in fact speaks to the reality of a degree of each in all natural systems, not excluding the longstanding model of nature's perfected clockwork, the Copernican/Newtonian solar system.[54] Chaos and cosmos, whose long history in the human imagination has been, almost without exception, as antinomies, now turn out to be inseparables, closely involved and even closely dependent upon each other for embodied existence. But as usual, the poets got there first: Ben Jonson, speaking of the sea and its waves and breakers as "that orderly disorder which is common in nature"; Novalis, in his vision of a transfigured "*rational* Chaos—Chaos that has permeated itself, that is both inside and outside itself—Chaos^2 or ∞."[55] And in Wallace Stevens's "Connoisseur of Chaos" (1938), a poem much cited in the scientific literature, extremes meet in a chiasmus of mirroring equations:

> A. A violent order is disorder; and
> B. A great disorder is an order. These
> Two things are one. (Pages of illustrations.)

Not without a hint of tongue in cheek, the poem offers a dialectic that transcends contradiction, but one finally grounded in the encounter of mind and nature for "the pensive man to see":

> The squirming facts exceed the squamous mind,
> If one may say so. And yet relation appears
> A small relation expanding like the shade
> Of a cloud on sand, a shape on the side of a hill.[56]

That is to say, from out of the vast confusion is born the germ and contagion of order.

Channeling the muses of Novalis and Stevens, one latter-day philosopher of science roundly declares, "Chaos is *not* disorder. It is a higher form of order."[57] In that declaration, resting on current science, a prediction by the historian Gerald Holton on a coming turn in the road for science is patently fulfilled. Having pointed out how the characteristic leanings of modern science toward motifs of "disintegration, violence and derangement" had displaced those of hierarchy, continuity, and order, Holton anticipates the return of "the antitheme," but in a new, more sophisticated guise. [58] What is new and sophisticated in this return of the elements of order is their newly forged intimate partnership with "chaos."