My Mother Was a Computer

DIGITAL SUBJECTS AND LITERARY TEXTS

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To my mother, who was not a computer

Contents

1 MAKING

Language and Code

1 Intermediation

Textuality and the Regime of Computation

Language and Code

Unnoticed by most, new languages are springing into existence, proliferating across the globe, mutating into new forms, and fading into obsolescence. Invented by humans, these languages are intended for the intelligent machines called computers. Programming languages and the code in which they are written complicate the linguistic situation as it has been theorized for "natural" language, for code and language operate in significantly different ways.[1] Among the differences are the multiple addressees of code (which include intelligent machines as well as humans), the development of code by relatively small groups of technical specialists, and the tight integration of code into commercial product cycles and, consequently, into capitalist economics. Although virtually everyone would agree that language has been decisive in determining the specificity of human cultures and, indeed, of the human species, the range, extent, and importance of code remain controversial. Many people would argue that natural languages are much more broadly based than programming languages, a stance that relegates code to the relatively small niche of artificial languages intended for intelligent machines. Recently, however, strong claims have been made for digital algorithms as the language of nature itself. If, as Stephen Wolfram, Edward Fredkin, and Harold Morowitz maintain, the universe is fundamentally computational, code is elevated to the lingua franca not only of computers but of all physical reality.

Given these complexities, it has become an urgent task to understand in nuanced and theoretically sophisticated ways interactions between code and language. The scholarship on human languages is, of course, immense, and a smaller but still enormous quantity of research exists on programming languages. To date, however, criticism exploring feedback loops that connect the two kinds of language has been minimal.[2] At issue are the semiotically and materially distinct ways in which code and language operate, as well as the different contexts in which they emerge and develop. The task of understanding these differences is impeded by the diversity of the expert communities attending to them, comprising humanists and linguists on the one hand and computer programmers and software engineers on the other. Despite the general lack of communication between these communities, programming code and language interact continually in millions of encounters every day. The trading zones in which these negotiations occur are global in scope, penetrating deep into nearly every aspect of environments that rely on computers to carry out everyday tasks. Language alone is no longer the distinctive characteristic of technologically developed societies; rather, it is language plus code.

This project aspires to contribute to our understanding of these complexities by creating a theoretical framework in which language and code (in both its narrow and broader senses) can be systematically thought together. In addition, it explores through a series of case studies implications of the interactions of language and code for creative, technological, and artistic practice. The case studies focus on a range of issues, including the relation of print to electronic textuality, the constitution of subjectivity through bits as well as words, and the (mis)understandings through which humans interact with analog patterns functioning as metaphors for digital processes.

In the next chapter, I consider the three principal discourse systems of *speech*, *writing*, and *digital computer code*. To focus my discussion, I choose as representative of speech the semiotic theories of Ferdinand de Saussure,[3] and of writing, the early texts of Jacques Derrida, especially *Of Grammatology*, *Positions*, *Writing and Difference*, and *Margins of Philosophy*, works where he discusses the language system as theorized by Saussure and contrasts it with his theory of grammatology. My remarks on code are drawn from a number of sources; particularly important is the work of Stephen Wolfram, Edward Fredkin, Harold Morowitz, Ellen Ullman, Matthew Fuller, Matthew Kirschenbaum, and Bruce Eckel.[4] Further, I claim that theories about speech, writing, and code as represented by these sources are fraught with presuppositions, premises, and implications, in effect constituting what, for lack of a better term, I call "worldviews." The worldviews of speech, writing, and code are inextricably entwined with the technological conditions enveloping the theorists that developed these ideas, the philosophical, linguistic, and scientific traditions in which they claimed lineage, and the purposes toward which they wanted their work to contribute. From the comparison of these worldviews emerges a series of tensions and problematics that will form the basis for the arenas of interaction—*making*, *storing*, and *transmitting*—central to contemporary creative practices in scientific simulations, digital arts, electronic literature, and print literature.

The Regime of Computation

To facilitate the comparison of speech, writing, and code, I want to explore the larger context in which code as performative practice is located. For this inquiry, let us backtrack for a moment to consider the relation of computation (and hence of code, the language in which computation is carried out) to preexisting models for understanding truth statements, especially classical metaphysics. Perhaps no philosopher in the last century has been more successful than Jacques Derrida in exposing the impossible yearning at the heart of metaphysics for the "transcendental signified," the manifestation of Being so potent it needs no signifier to verify its authenticity. Yet Derrida repeatedly remarks that we cannot simply leave metaphysics behind.[5] He frequently asserts that metaphysics is so woven into the structure of Western philosophy, science, and social structures that it continually imposes itself on language and, indeed, on thought itself, creeping back in at the very moment it seems to have been exorcised. In this sense, classical metaphysics plays the role of the hegemonic influence that makes Derrida's resistant writing necessary and meaningful as a cultural practice. Derrida's discourse, as he himself remarks, is "entirely taken up with the reading of [others'] texts" and in this sense can be considered parasitic.[6] In his early writings, this preoccupation focuses specifically on texts that reinscribe the metaphysical yearning for presence that he devotes himself to deconstructing. To paraphrase a notorious remark, if metaphysics did not exist, Derrida would have been forced to invent it.

The worldview of computation also offers new answers to metaphysical questions, although in a very different way than Derridean grammatology. "Computation" in the sense it is used here connotes far more than the digital computer, which is only one of many platforms on which computational operations can run. Computation can take place in a variety of milieu and with almost any kind of material substrate. Leonard M. Adelman has pioneered the use of solutions of DNA as computational platforms for solving certain topological problems; Daniel Hillis recounts that as a child he made a computer out of Tinkertoys; John von Neumann, brooding over the birth of the digital computer, envisioned computation taking place with giant iron I beams adjacent to a factory that could assemble them into patterns representing binary code.[7]

If computation is not limited to digital manipulations, binary code, or silicon, what is it? Alan Turing gave a formalist definition of computation in his famous 1936 article describing an abstract computer known as the Turing machine, the most general version of which is called the Universal Turing machine. The Universal Turing machine, as its name implies, can perform any computation that any computer can do, including computing the algorithm that constitutes itself.[8] The computational regime continues in the tradition of Turing's work by considering computation to be a process that starts with a parsimonious set of elements and a relatively small set of logical operations. Instantiated into some kind of platform, these components can be structured so as to build up increasing levels of complexity, eventually arriving at complexity so deep, multilayered, and extensive as to simulate the most complex phenomena on earth, from turbulent flow and multiagent social systems to reasoning processes one might legitimately call thinking.

The wide-reaching claims made for the Regime of Computation are displayed in Stephen Wolfram's *A New Kind of Science*. The ambition of this book is breathtaking, especially considering the modesty with which scientists have traditionally put forth their claims. The book makes a fascinating contribution to the Regime of Computation, demonstrating through Wolfram's twenty years of research into cellular automata that simple rules can indeed generate complexity through computational means. Cellular automata have been around for decades. John von Neumann experimented with them, learning from Stanislaw Ulam how they could be reduced to a grid of two-dimensional cells;[9] Konrad Zuse in the 1950s suggested that they could form the basis for the physical universe;[10] in the 1990s researchers at the Santa Fe Institute, particularly Christopher Langton and his colleagues, explored the conditions under which cellular automata create, modify, and transmit information;[11] and John Conway showed that they could give the impression of living systems in his famous *Game of Life*.[12]

The basic idea is disarmingly simple, illustrated through this typical configuration.[13] Imagine a square grid, with each square representing a cell that can be either "on" or "off"; further suppose that we represent these states by black or white. An initial state is defined for each cell, as well as a set of rules telling each cell how to update its state. For example, a cell might have a rule specifying that it is "on" if two or more of its four neighbors are "on"; otherwise it is "off." Each cell in parallel then canvases the state of its neighbors and updates its state accordingly, while all of the other cells do the same. This update results in a new state for the system, which transforms in yet another iteration during which all the cells again canvas their neighbors and update their states accordingly. With contemporary computing power, it is possible to run through hundreds or thousands of iterations in a relatively short time. Through extensive research into various categories of cellular automata with simple rules, Wolfram shows that these conceptually simple systems are nevertheless capable of emergent behaviors in which astonishingly complex patterns appear. In particular, he discovered that the one-dimensional cellular automata described by Rule 110 yielded a Universal Turing machine, previously thought possible only in complex cellular automata of high dimensions.[14] That it should prove possible to create a Universal Turing machine in a system this simple is indeed a remarkable discovery.

Wolfram is not slow to draw sweeping implications from his work. He summarizes them in the Principle of Computational Equivalence, explored at length in chapter 12 of *A New Kind of Science*. In one of its formulations, the principle states, "Whenever one sees behavior that is not obviously simple—in essentially any system—it can be thought of as corresponding to a computation of equivalent sophistication" (5). The principle, as I read it, has three interlocking claims. The first is that all complex behavior can be simulated computationally, up to and including human thought and action (at least in principle). The second claim is that complex systems are "computationally irreducible" (6). Although the computations may be generated through simple rules (as are the cellular automata Wolfram discusses), there is no way to shorten the labor of computing the system's behavior (for example, by reducing it to mathematical equations). Simulating the behavior of these complex systems requires roughly the same amount of computation as the system itself puts forth to generate its actions, which implies a redistribution of intellectual labor. In a classical system susceptible to explicit solution, the equations may be difficult to solve but, once solved, serve to explain a wide variety of disparate behavior. For the cellular automata Wolfram discusses, the rules are extremely simple, but the labor of computing the behavior is intensive, requiring hundreds (or thousands or more) of iterations. The third claim, often not stated explicitly, is implied by the sweeping consequences Wolfram envisions for his research. This is the strong claim that computation does not merely *simulate* the behavior of complex systems; computation is envisioned as the process that actually *generates* behavior in everything from biological organisms to human social systems.

Wolfram's slide from regarding his simulations as models to thinking of them as computations that actually generate reality can be tracked at several places in his massive text. For example, he comments that "countless times I have been asked how models based on simple programs can possibly be correct, since even though they may successfully reproduce the behavior of some system, one can plainly see that the system itself does not, for example, actually consist of discrete cells that, say, follow the rules of a cellular automaton" (366). He answers this objection by claiming that "there is no reason that the model should actually operate like the system itself" (366). Elsewhere, however, he equivocates:

> My approach in investigating issues like the Second Law is in effect to use simple programs as metaphors for physical systems. But can such programs in fact be more than that? And for example is it conceivable that at some level physical systems actually operate directly according to the rules of a simple program? . . . At first the laws might seem much too complicated to correspond to any simple program. But one of the crucial discoveries of this book is that even programs with very simple underlying rules can yield great complexity. . . . And so it could be with fundamental physics. Underneath the laws of physics as we know them today it could be that there lies a very simple program from which all the known laws—and ultimately all the complexity we see in the universe—emerges. (434)

In this passage and in similar ones, Wolfram introduces a crucial ambiguity into his claims for the Computational Universe. At issue is whether computation should be understood as a metaphor pervasive in our culture and therefore indicative of a certain "climate of opinion" (in Raymond Williams's phrase) at the turn of the millennium, or whether it has ontological status as the mechanism generating the complexities of physical reality. Rather than attempting to argue one side or the other of this controversial issue, I explore the implications of what it means to be situated at a cultural moment when the question remains undecidable—a moment, that is, when computation as means and as metaphor are inextricably entwined as a generative cultural dynamic. As we shall see, this entanglement has extensive implications for the positioning of humans in relation to intelligent machines and the broader landscape of the Computational Universe.

What does it mean to say that the Computational Universe functions simultaneously as metaphor and means? One way to understand their entanglement is through feedback loops that connect culturally potent metaphors with social constructions of reality, resulting in formulations that imaginatively invest computation with world-making power, even if it does not properly possess this power in itself. In *The Second Self* and *Life on the Screen*, Sherry Turkle shows compellingly that such feedback loops can dramatically influence how people perceive themselves and others. This influence extends even to the interactions of young children with intelligent toys. One of my favorite examples comes when one of her respondents, a shy and socially inept young man, comments, "Reality is not my best window."

A second kind of feedback loop emerges when belief in the Computational Universe is linked with an imagined future through which anticipation cycles to affect the present. A striking example of the Regime of Computation's ability to have real effects in the world, whatever its status in relation to the underlying physics, is the initiative to reorganize the U.S. military to pursue "network-centric warfare." Presupposing the ontology of code, military strategists argue that information has become a key military asset and that the U.S. military must be reorganized to take full advantage of it. They aim to abandon a centralized command/control structure in favor of a highly mobile and flexible force, a transformation that involves moving from platform-based strategies (based on tanks, airplanes, ships, etc.) to "network-centric" structures in which units are seen not as independent actors but as "part of a continuously adapting ecosystem."[15] Vice Admiral Arthur K. Cebrowski of the U.S. Navy and his collaborator, John J. Garstak, writing for the *Naval Institute Proceedings Magazine*, proclaim, "We are in the midst of a revolution in military affairs (RMA) unlike any seen since the Napoleonic Age." They quote Chief of Naval Operations Admiral Jay Johnston to the effect that network-centric warfare marks a "fundamental shift" in military thinking (1).

A principal advantage of network-centric warfare is the presumed ability to create "lock-out" effects through superior flexibility and speed. (The textbook example of lock-out occurred when video producers made the decision to produce for VHS equipment instead of Beta, thus converting a slight numerical advantage in the marketplace into interrelated equipment-content-consumption networks that decisively locked out Beta, despite the fact that in some ways it was technically superior to VHS). Cebrowski argues that lock-out can happen even faster in warfare and be even more decisive. Creating lock-out in military terms means acting fast and flexibly enough so that the opponent's very ability to plan strategically is disrupted. Cebrowski argues that such action demands a high-performance information grid combined with interoperable sensor and engagement grids. Moreover, it also requires the ability to achieve "self-synchronization" in which the commander's intentions, instead of filtering from the top slowly down the chain of command, are activated through the bottom-up organization of flexible units called "swarms," which can continually reorganize and restructure themselves (the nomenclature is no doubt indebted to the artificial-life software called "Swarm," designed to create self-organization and emergent behaviors).

Anticipating a future in which code (a synecdoche for information) has become so fundamental that it may be regarded as ontological, these transformations take the computational vision and feed it back into the present to reorganize resources, institutional structures, and military capabilities. Even if code is not originally ontological, it becomes so through these recursive feedback loops. In *Wetwares*, Richard Doyle makes a similar observation about the belief that we will someday be able to upload our consciousness into computers and thereby effectively achieve immortality. Doyle comments, "'Uploading,' the desire to be wetware, makes possible a new technology of the self, one fractured by the exteriority of the future. . . . Uploading seems to install discursive, material, and social mechanism for the anticipation of an *externalized* self, a techno-social mutation that is perhaps best characterized as a new capacity to be affected by, addicted to, the future" (133).

We will return to the entanglement of means and metaphor in chapter 9 through an analysis of Greg Egan's "subjective cosmology" trilogy: *Quarantine*, *Permutation City*, and *Distress*. An enormously inventive writer, Egan is arguably the most admired and influential novelist associated with the Regime of Computation. In the trilogy, feedback cycles between human cognition and the Computational Universe function to construct the nature of both reality and human beings. The novels will be contrasted with Slavoj Žižek's analysis of the symptom, which presupposes that such phantasmatic imaginations function as symptoms pointing toward repressed trauma and underlying psychopathologies. Thus in the final chapter we return to the issues raised here through a sharp contrast between a view that sees the Computational Universe as metaphoric and symptomatic, and one that sees the Computational Universe as physically real and deeply bound up with human thought. Through the encounter staged in chapter 9 between Egan and Žižek, the book cycles back to the beginning, although from the changed perspective articulated in the epilogue.

I am, however, getting ahead of my story. The third way in which the Computational Universe functions indeterminably as means and metaphor is through its current status as a provocative hypothesis that has neither won wide consensus nor been definitively disproved. Although many physicists remain skeptical of Wolfram's claims and of the Computational Universe generally, the idea of the Computational Universe has also attracted considerable attention and speculation. To understand the controversy in more detail, let us return to explore the different levels at which the Computational Universe has been postulated to run. To this end, it will be useful to summarize where we are at this point by indicating how the Regime of Computation positions itself in relation to classical metaphysics.

The regime reduces ontological requirements to a bare minimum. Rather than an initial premise (such as God, an originary Logos, or the axioms of Euclidean geometry) out of which multiple entailments spin, computation requires only an elementary distinction between something and nothing (one and zero) and a small set of logical operations.[16] The emphasis falls not on working out the logical entailments of the initial premises but on unpredictable surprises created by the simulation as it is computed. The consequences of a simulation are not logically entailed by the starting point, which is why there is no shortcut to the computational work of running the simulation, and why the behaviors of complex systems cannot be compressed into more economical expression such as mathematical equations. Consequently, the Regime of Computation provides no foundations for truth and requires none, other than the minimalist ontological assumptions necessary to set the system running. Far from presuming the "transcendental signified" that Derrida identifies as intrinsic to classical metaphysics, computation privileges the emergence of complexity from simple elements and rules. Underscoring the point, Wolfram comments that "throughout most of history it has been taken almost for granted that such complexity—being so vastly greater than in the works of humans—could only be the work of a supernatural being" (3). Now complexity is understood as emerging from the computational processes that constitute the universe, and that changes everything. "The crucial idea that has allowed me to build a unified framework," Wolfram summarizes, ". . . is that just as the rules for any system can be viewed as corresponding to a program, so also its behavior can be viewed as a computation" (5).

Thinking along similar lines, Edward Fredkin has proposed a worldview that he calls "digital philosophy," a term that, like Wolfram's remarks, implicitly positions itself as providing answers to metaphysical questions. Fredkin argues that the discrete nature of elementary particles indicates that the universe is discrete rather than continuous, digital rather than analog. Electrons, protons, and neutrons always have charges represented by a small integer (–1, +1, 0); atomic nuclei are composed of neutrons and protons that are always (relatively) small integers; other qualities like spin and charm are either integers or halves of integers. These observations are consistent with Fredkin's major thesis: that the universe is digital all the way down and, moreover, can be understood as software running on an unfathomable universal digital computer. "Digital Philosophy carries atomism to an extreme in that we assume that everything is based on some very simple discrete process, with space, time, and state all being discrete."[17] Moreover, the discreteness he takes as axiomatic implies that information is conserved, a radically different view than, for example, Ilya Prigogine's view of thermodynamic dissipative systems.[18] "Digital Philosophy supports the beliefs that at different levels information is often best thought of as digital, and processes can often be best understood as digital processes. Thus anything in the world of Digital Philosophy that is changing or moving does so in a manner similar to how things are made to change or move in the memory of a computer."[19]

Acknowledging that quantum mechanics in some sense "works," Fredkin argues that the theory is ugly because it is largely ad hoc, concluding that we should prefer digital mechanics because it yields a more intuitively plausible and beautiful picture, one so simple and coherent it can be grasped by schoolchildren. His theory implies that quantum mechanics may describe what happens at the quantum level but fails to penetrate into the essential mechanisms generating the behavior. These mechanisms, in his view, are discrete and computational. The proof that digital mechanics underlies quantum mechanics will be demonstrated, Fredkin believes, when his research team is able to show that quantum mechanics *emerges* from the underlying digital mechanics base (a goal so far not achieved, although some progress toward it has been made). He remarks, "As one really understands the ideas of DM [digital mechanics], the currently accepted models of time, space, and process begin to seem mystical. From a Digital perspective, contemporary models of fundamental physics are a bit like looking at an animated cartoon while assuming that it's reality: that the images are moving continuously. So far, everyone we have interviewed who buys into Digital Philosophy has come to the conclusion that ordinary physics is a subject full of magic."[20]

Although Fredkin's claims are not as sweeping as Wolfram's, he too remains confident that a computational approach will explain living as well as nonliving systems. "Most biologists do not think about the processes of life in the same ways as would a Digital Philosopher," he remarks. "Yet some kind of information processing in living things begins with the informational process of sperm and egg combining and continues with differentiation as a kind of computation based on inherited information, and finally, as is obvious for all creatures that move, behavior involves information processing at a more familiar level."[21] Yet most of his examples are drawn from particle physics and quantum mechanics, realms that operate at a much lower level of complexity than living organisms.

Ray Kurzweil's criticism of Wolfram is telling in this regard; as Kurzweil points out, the cellular automata that Wolfram explores evolve complex patterns at what might be called the first level of complexity, but these complex patterns never self-organize to create further levels of emergence and complexity.[22] They do not, for example, self-organize to create bacteria or even viruses, never mind more complex organisms such as a duck or a human. Even if Wolfram and Fredkin are correct in their claims that at the particle level the universe is a computer, this claim does not preclude higher levels of complexity emerging from different mechanisms, including analog processes (which can, of course, also be represented as computation, that is, analog computation rather than digital). Kurzweil further criticizes Wolfram for downplaying the role of evolution as a mechanism favoring the emergence of complexity; Kurzweil suggests that emergence at higher levels of complexity may well require the selective pressures and fitness criteria essential to evolutionary explanations.[23]

At best, then, the claims of Fredkin and Wolfram are incomplete, especially with regard to the emergence of higher-order from lower-order complexity. This is where the views of Harold Morowitz and like-minded researchers become important, for they offer a way to think about emergence as a process that not only operates at a single level of complexity but also continues up a dynamical hierarchy of linked systems to produce complexities out of complexities. In *The Emergence of Everything: How the World Became Complex* (a glitzy title for a good book), Morowitz reviews twenty-eight stages in the history of the cosmos to show that they can be characterized as emergent processes, each of which builds on the complexities that emerged from the preceding level.

"Emergence" carries special weight in this discourse. The term refers to properties that do not inhere in the individual components of a system; rather, these properties come about from interactions between components. Emergent properties thus appear at the global level of the system itself rather than at the local level of a system's components. Moreover, emergences typically cannot be predicted because the complex feedback loops that develop between components are not susceptible to explicit solution. As with Wolfram's simulations, the only way to determine the behavior of such a system is to run the simulation and see what emerges.

The new idea Morowitz adds is the insight that the emergences of a first-order complex system become properties that a second-order system can use to create a new dynamics from which further emergences will come. To the second-order system can be added a third-order system, a fourth-order system, and so on, with each level creating new emergences made possible by the emergences of the previous system. Multileveled complex systems synthesized in this way are called "dynamical hierarchies" (sometimes, significantly, "dynamic ontology"),[24] and the complexities they generate are potentially unlimited in scope and depth. Building on these ideas, Morowitz groups his twenty-eight events into four main stages: the emergence of the cosmos; the emergence of life; the emergence of mind; and the emergence of mind contemplating mind, or reflexivity. Presently, he believes, we are on the threshold of this last stage, whose development will be the catalyst for further evolution of the human into the posthuman in the centuries and millennia ahead. He finds the noosphere, the distributed global intelligence postulated by Pierre Teilhard de Chardin as the next stage in the evolution of intelligent life, suggestive of what might lie ahead for this fourth period.[25]

Whatever the future, the implications of this view for the present are clear, and it is here that the links between the "emergence of everything" and the Computational Universe become explicit. When the scope expands to the universe, simulations that could compute such behaviors become impossibly large, or in the terminology of the field, "transcomputable." To understand what "transcomputable" means, suppose that all the computing power on the planet was harnessed together and programmed to compute a given simulation. If the simulation qualified as "transcomputable," even this powerful array would not make more than a dent in the problem the simulation represented. For transcomputable situations, researchers must use pruning algorithms and selection rules to identify from an extremely large possibility space the conditions most likely to apply. The application of successive constraints, then, is crucial. What emerges has the force of an explanation but differs significantly from typical explanations in the physical sciences because it is not causal in nature and frequently is retrodictive rather than predictive.

These modes of explanation are necessary because complex systems cannot be described by mathematical equations that would allow precise prediction through linear causality. Like Wolfram and Fredkin, Morowitz emphasizes that the kinds of systems for which equations can be used constitute only a small set of all possible systems. According to Morowitz, although the traditional mathematical approach will continue to be useful, it will be understood increasingly as a specialized tool applicable only in (relatively) few situations. Future progress, he maintains, lies largely in the realm of computation and simulation. In a revealing analogy, Morowitz likens the invention of calculus and its central importance to the rise of modern science to the invention of the digital computer and the crucial role it plays in simulation. What calculus has been to physics and mathematics, the digital computer will be to understanding complex systems, evolution, and emergence.

Although the simulations and complex systems Morowitz discusses are not teleological (a characteristic related to the ontological minimalism of their starting points and to the lack of entailments these starting conditions embody), there is nevertheless directionality at work in their operations. The arrow of emergence points in the direction of increasing complexity, both for the preferred simulations and, presumably, for the evolution of the universe itself (a proposition endorsed by Stuart Kauffman in his work on the evolution of life through autocatalytic networks).[26] In Morowitz's view, humans are the most complex systems yet to emerge, and they now have sufficient complexity to emulate the very processes of emergence that created them and everything else. Far from needing to presume or construct a separation between the observer and the observation—a premise necessary in the classical understanding of science to ensure objectivity—the computational perspective endorsed by Morowitz, Wolfram, and Fredkin has no need of such a stipulation. These researchers can account for the presence of the observer simply by introducing a component into the simulation that performs this function. Indeed, in Morowitz's view the human observer plays an indispensable role in the jump from the third stage (emergence of mind) to the fourth stage (emergence of reflexivity), for our ability to simulate complex processes within computers makes possible the next stage of emergences.[27]

The Regime of Computation, then, provides a narrative that accounts for the evolution of the universe, life, mind, and mind reflecting on mind by connecting these emergences with computational processes that operate both in human-created simulations and in the universe understood as software running on the "Universal Computer" we call reality. This is the larger context in which code acquires special, indeed universal, significance. In the Regime of Computation, code is understood as the discourse system that mirrors what happens in nature and that generates nature itself.

Having looked at the claims, I turn now to a critical examination of them. From my perspective, all of these researchers claim much more than they actually demonstrate. Wolfram's assertion that cellular automata underlie and explain the complexity of living systems, including human culture and social processes, is a giant (and mostly unwarranted) leap from the simple systems he has explored. He shows convincingly only one level of emergence, from individual cells to group behavior. He does not show how this group behavior, however complex, provides the basis for further emergences that would build upon it. In my view, analog processes are undervalued in Fredkin's and Wolfram's accounts and are likely to play a central role as first-level complexities evolve into second-level complexities and further levels beyond that. Moreover, Wolfram often does not tie his cellular automata models to actual mechanisms at work in physical systems, a connection that must be made to validate the kind of ontological claims he advances. In this sense, Fredkin's program is more ambitious, for it tries to show how phenomena described by particle physics can emerge from the group behavior of cellular automata. If this result can be achieved, it would indeed be a striking accomplishment and might well lead to radical rethinking of such foundational concepts as space and time, as he believes. Even in this best-case scenario, however, the leap Fredkin makes to higher-level complexities would remain to be demonstrated.

As for Morowitz, the novel component he adds is the interpretive framework of dynamical hierarchical emergences. Virtually all the phenomena he instances are well-known within their respective fields (cosmology, origins-of-life biology, evolution, psychology, etc.). Although he offers a compelling overall picture, he does not explicate the mechanisms that link one level of emergence to another, other than as a precondition (for example, there must be a planet before life can emerge on that planet). This sort of linear causality is well-known and offers nothing new. What would be new is a detailed understanding of how one dynamical level enchains and emerges from the next lower one through their intersecting dynamics. This he does not show, nor does he explore the specific mechanisms that bring it about.

In fact, no one to date has demonstrated clearly how complex dynamics in simulations can progress more than one level. Accordingly, such a demonstration has become the goal of the community of artificial-life researchers, who are devoting several major conferences to the problem in addition to organizing a special issue of the *Artificial Life Journal* on dynamical hierarchies.[28] History provides many examples of scientific and technological breakthroughs that occurred because researchers became convinced a certain goal was achievable and were willing to devote significant resources to accomplishing it (often aided by substantial government funding), from mapping the human genome to building an atomic bomb. In my view, it is likely that within the next three or four years multilevel dynamical hierarchies will be created in simulations, and I expect that much will be learned from detailed studies of their dynamics. Whether these insights will significantly alter the current picture remains to be seen.

The central problem of achieving emergence through more than one level is bound up tightly with issues of representation. As Nicholas Gessler, among others, has pointed out, one way to think about this process is to imagine a mechanism whereby the patterns that emerged at the first level are represented by a different kind of mechanism, which then uses these representations as primitives to create new emergent patterns, which in turn would undergo further re-representation and be turned into primitives for the third level, and so on.[29] This schema suggests a new interpretation of Wolfram's interaction with his cellular automata.

As noted above, one weakness of Wolfram's argument is his underestimation of the importance of analog processes, and especially of the productive interplay between analog and digital processes. Take DNA replication for example. DNA is often understood to operate as a digital code, in the sense that it is discrete rather than continuous. With the sequencing of the human genome, however, it has become clear that sequence is only part of the story, perhaps even the less important part. Protein folding, an analog process that makes use of continuous transformation in form, is essential to understanding how the genome actually functions. The *combination* of the two processes, the digitality of DNA sequences and the analog process of protein folding, gives the gene its remarkable power of information storage and transmission. Similar cooperations between digital and analog processes occur everywhere in nature and in contemporary technologies. Music CDs, for example, which Jean Baudrillard famously and mistakenly characterized as purely digital, rely on analog processes (such as microphones and other analog equipment) to capture the morphology of sound waves, which then can be represented numerically and transformed into computer code. That the combination of analog and digital should prove far more powerful than either by itself is no mystery, for each has properties that complement the other. As explained more fully in chapter 2, digital representations allow for precise error control, extreme fragmentation and recombination, whereas analog processes have the advantages of the continuum, including the ability to transmit informational patterns between differently embodied entities.

Consider now the moment when Wolfram bends over the output of one of his cellular automata and perceives in it patterns strikingly similarly to the shell of a mollusk. What exactly is happening in this scene? One way to understand it is as a re-representation of the patterns that emerged from the first-level operations of the cellular automata by another kind of analog mechanism we can call Wolfram's consciousness (assume for purposes of this discussion that consciousness is analog, even though in fact it may well be an emergent phenomenon itself produced by the synergistic interaction of analog and digital components). This kind of interaction between digital mechanisms and analog consciousness happens all around us every day, often resulting in emergent reorganizations across many levels of complexity, for example when digital technologies are re-represented in the consciousness of military strategists and used as the basis for reorganizing military units to create and facilitate emergent behaviors.

This larger vision of synergistic cooperation between consciousness and computer, language and code, epitomizes the kind of complex interactions to which this study is devoted. Notwithstanding the problems with the claims of Wolfram, Fredkin, and others, the computational worldview these researchers advocate contains valuable insights that should not get lost in the skeptical scrutiny to which their claims are rightfully subjected. Especially crucial are the entwined concepts of emergent processes and dynamical hierarchies, which represent ways of thinking that are powerful heuristics through which to understand the dynamics of complex systems of many different kinds. Whatever their limitations, these researchers fully understand that linear causal explanations are limited in scope and that multicausal complex systems require other modes of modeling and explanation. This seems to me a seminal insight that, despite three decades of work in chaos theory, complex systems, and simulation modeling, remains underappreciated and undertheorized in the physical sciences, and even more so in the social sciences and humanities.

Meanwhile, the pervasiveness and importance of computing in contemporary culture continue to reinforce the idea that computation is a fundamental process. Even if many of the claims associated with the Universal Computer are disproved, it is unlikely that the idea will die out altogether, particularly in communities of researchers concerned with the development of code and the construction of simulations. Already circulating are versions of the Universal Computer based on different mechanisms than cellular automata. Seth Lloyd, among others, has proposed that "the universe is a quantum computer: life, sex, the brain, and human society all arise out of the ability of the universe to process information at the level of atoms, photons, and elementary particles."[30] Significantly, this proposition came in response to "hard-edge" questions posed by popular science writer and literary agent John Brockman, questions that "render visible the deeper meanings of our lives, redefine who and what we are."[31]

Intermediation

For my purposes, I find the Regime of Computation valuable for articulating the context in which code takes shape within the worldview of computation. Speech and writing also have extensive links with their respective worldviews, which, as noted above, for the purposes of this project I identify with Saussurean semiotics and Derridean grammatology, respectively. Like computation, these worldviews imply distinctive ways of constituting communities, dealing with evolutionary changes, accommodating technological interventions, and describing the operations of systems. A thorough understanding of the interactions in which speech, writing, and code participate requires more than knowing the details of the three systems. Also at stake are the diverse conflicts and cooperations between their respective worldviews. As the worldview of code assumes comparable importance to the worldviews of speech and writing, the problematics of interaction between them grow more complex and entangled. These complex and entangled interactions are what I call "intermediation," a term suggested by Nicholas Gessler.[32]

An important aspect of intermediation is the recursivity implicit in the coproduction and coevolution of multiple causalities. Complex feedback loops connect humans and machines, old technologies and new, language and code, analog processes and digital fragmentations. Although these feedback loops evolve over time and thus have a historical trajectory that arcs from one point to another, it is important not to make the mistake of privileging any one point as the primary locus of attention, which can easily result in flattening complex interactions back into linear causal chains. The contemporary indoctrination into linear causality is so strong that it continues to exercise a fatal attraction for much of contemporary thought. It must be continually resisted if we are fully to realize the implications of multicausal and multilayered hierarchical systems, which entail distributed agency, emergent processes, unpredictable coevolutions, and seemingly paradoxical interactions between convergent and divergent processes.

A case in point is the current tendency to regard the computer as the ultimate solvent that is dissolving all other media into itself. Since sound, image, text, and their associated media (such as phonography, cinema, and books) can all be converted into digital code, many commentators, including Lev Manovich and Friedrich Kittler, have claimed that there is now only one medium, the digital computer.[33] Asserting that "one century sufficed to transform the ancient storage monopoly of writing into the omnipotence of integrated circuits," Kittler writes that "all data flows end in a state *n* of Turing's universal machine: numbers and figures become (in spite of romanticism) the key to all creatures."[34] This claim has the effect of flattening into a single causal line—the convergence of all media into one—social and cultural processes that are in fact much more complex. To take the case of books, clearly it matters that print has now become a particular kind of output for digital text. As I argue in chapter 5 with regard to Neal Stephenson's print novel *Cryptonomicon*, digitization leaves its mark even on print texts that remain entirely conventional in appearance and functionality. Moreover, a stroll through any major bookstore will confirm that print books in general have moved toward the visual and away from straight text, a tendency that bears witness to their interactions with other media.

Nevertheless, it is also true that any book, conventional or not, participates in the rich historical contexts and traditions of print that influence how books are designed, produced, disseminated, and received. The subvocalization that Kittler associates in *Discourse Networks* with the advent of phonetics and the ability of readers to hallucinate an imagined world does not disappear simply because blockbuster movies attract millions of viewers, any more than it evaporates because cinema and books are increasingly interpenetrated by digital techniques.[35] If anything, print readers relish all the more the media-specific effects of books precisely because they no longer take them for granted and have many other media experiences with which to compare them.[36] Although Sven Birkerts draws a different lesson from media proliferation in *The Gutenberg Elegies*, his book can be understood as a demonstration of the fact that print no longer exists in isolation from other media (even as it also illustrates the tendency to flatten complex interactions into a single causal chain). Recognizing entangled causalities and multiple feedback loops enables us to understand how media can converge into digitality and *simultaneously* diverge into a robust media ecology in which new media represent and are represented in old media, in a process that Jay Bolter and Richard Grusin have called "remediation."[37]

Grusin and Bolter define remediation, in one formulation, as "the formal logic by which new media technologies refashion prior media forms."[38] They trace feedback loops between the seemingly opposed but nonetheless correlated strategies of "immediacy" (the tendency of media to represent their productions as transparent and naturally accessible) and "hypermediacy" (the tendency of media to draw attention to their modes of representation and the media-specific strategies they use). This coevolution of apparently opposed trends, like the simultaneous coevolution of convergence and divergence in media, is characteristic of complex systems with multiple feedback loops.

Think, for example, of an ecological system in which predator and prey develop opposing strategies because each is involved in a feedback loop with the other. The opposition looms large if we look only at a single interaction between predator and prey (that is, position them in a linear causal relationship). In the more comprehensive context of the complex dynamics formed by their continuing interactions over generations of coevolution, however, the opposition becomes part of a larger picture in which one strategy catalyzes the opposing strategy, which in turn catalyzes a further development of the first one. In a similar way, extensive research on the Prisoner's Dilemma, a famous thought problem in which players must choose between competitive and cooperating strategies, demonstrates that the dynamics of this system change dramatically when the game is iterated, that is, subjected to repeated interactions between players.[39] Coevolution that extends over many cycles, such as that instantiated in iterated Prisoner's Dilemma simulations, is typical of media interactions in contemporary society, including the interactions that help to form (and in-form) the complex dynamics of textualities.

Grusin and Bolter's arguments in *Remediation* demonstrate insightfully that complex feedback occurs between the oppositional strategies of immediacy and hypermediacy. Nevertheless, for my purposes I prefer the term "intermediation." "Remediation" has the disadvantage of locating the starting point for the cycles in a particular locality and medium, whereas "intermediation" is more faithful to the spirit of multiple causality in emphasizing interactions among media. In addition, "remediation" (thanks to the excellent work Grusin and Bolter have done in positioning the term) now has the specific connotation of applying to immediate/hypermediate strategies. Because the dynamics I want to explore go far beyond this particular cycle, I would rather use the lesser known "intermediation" (which, being not as well known, is more open to new interpretations). To make the term more useful for my purposes, I want to expand its denotations to include interactions between systems of representations, particularly language and code, as well as interactions between modes of representation, particularly analog and digital. Perhaps most importantly, "intermediation" also denotes mediating interfaces connecting humans with the intelligent machines that are our collaborators in making, storing, and transmitting informational processes and objects.

In emphasizing intermediation, I have been instructed by studies that adopt different strategies to achieve different ends. I regard this project as complementary to these studies, for I see both these studies and my own project as useful in developing new frameworks with which to understand where we are and where we may be heading, both in literary studies and the broader context of contemporary Anglo-American-European culture. To some extent, this project is also intended as a corrective to the tendency in other studies, useful as they are, to privilege one medium and/or mode of interaction to the exclusion of others and thus to fall again into the trap of linear causality. By keeping the focus on intermediation, I hope to incorporate some of the insights from other studies while clarifying how the recognition of multiple causalities leads to different conclusions.

Media Technologies and Embodied Subjects

To help situate this project, let us consider the contrasting approaches of Friedrich Kittler and Mark B. N. Hansen. Kittler's strategy for escaping from the confines of humanist discourse is to focus on media rather than subjects. In *Discourse Networks*, he argues that subjects speak within discourse systems, and that discourse systems are constituted by the technological apparatuses enabling them to operate. "Media determine our situation," he proclaims in the preface to *Gramophone, Film, Typewriter*, asserting that "technologies that not only by-pass writing but suck in and carry off so-called humanity render their own description impossible" (28), thus making post-print media the sea in which we posthuman fish swim. Although Kittler does not ignore bodies and subjectivities, he positions them as being constituted by the media they use. "In order to optimize writing for machines," he asserts with typical hyperbole "it must no longer be dreamt of as an expression of individuals or as a trace of bodies. The forms, differences, and frequencies of letters have to be reduced to formulas. So-called man becomes physiology on the one hand and information technology on the other."[40] The rhetoric of force ("must no longer," "have to be") performs an epistemic break reminiscent of the early Foucault, with the important difference, as Kittler himself has observed in critiquing Foucault, that his focus is on the media technologies that produce discourse systems ("discourse networks") rather than on discourse systems themselves.[41]

Strenuously resisting Kittler's coercive rhetoric, Hansen, in *New Philosophy for New Media*, performs a violence of his own by attempting to reduce Kittler's argument to a linear causal chain that rests solely on the truth or falsity of Shannon's information theory. "What remains decisive for Kittler," he argues, "are precisely the formal properties of Shannon's model: as the basis for the technical de-differentiation that constitutes the logical culmination of the historical decoupling of information from communication, Shannon's model allows Kittler to postulate an informational posthistory. From the standpoint of the optoelectronic future, the human or so-called Man—as well as the entire range of media effects said to comprise a media ecology—must be revalued as the purely contingent by-product of a preparatory phase in the evolution of information toward truly autonomous circulation" (77). To show that this foundation cannot stand, Hansen instances Donald MacKay's alternative approach to information, which was developed contemporaneously with Shannon's. In contrast to Shannon's separation of information and meaning, MacKay develops a concept of information that places the embodied receiver at the center of his theory.[42] Hansen's recourse to MacKay is somewhat disingenuous, for it ignores the fact that it was the Shannon/Wiener theory, and not Mackay's work, that was important for the development of information theory, for the good reason that MacKay's theory, although more encompassing in correlating information with meaning, could not be reliably quantified with technologies

available in the 1950s (and still cannot today). Moreover, Hansen's refutation concerns only one line of reasoning in Kittler's extensive oeuvre, and for this reason is insufficient to discount his approach entirely, as Hansen seems to imply.

In contrast to Kittler, Hansen privileges embodiment as the locus of subjectivity, reading new media through its effects on embodied users and viewers. "Correlated with the advent of digitization, then, the body undergoes a certain empowerment, since it deploys its own constitutive singularity (affection and memory) not to filter a universe of preconstituted images but actually to enframe something (digital information) that is originally formless. Moreover, this 'originary' act of enframing information must be seen as the source of all technical frames (even if these appear to be primary), to the extent that these are designed to make information perceivable by the body, that is, to transform it into the form of an image" (10). It is no accident, I think, that coercive rhetoric similar to Kittler's appears here ("must be seen"), for Hansen wants to unseat Kittler's media focus in order to place the embodied subject at the center of his own "new philosophy for new media."[43]

Notwithstanding their opposed viewpoints, Hansen and Kittler share a mode of argumentation that privileges one locus of the human/machine feedback loop at the expense of the other. For Kittler it is all about media: the technical configurations they impose on representations, and the content of representations that reflect and reinscribe these configurations. For Hansen it is all about embodied subjects: the perceptual and cognitive processing they incorporate as a result of the media they encounter, specifically media images, and the representations within new media that catalyze and foreground these incorporations. From where I stand, it looks like Kittler and Hansen are perched on a seesaw that teeters up and down while they fail to notice that both ends are connected by a fulcrum joining the two in correlated actions.

Certainly media are dependent on embodied subjects, not only for their reception and significance but also because researchers extensively investigate the precise nature of computer/human interfaces to develop and design networked and programmable media that will have certain effects. There would be no media without humans to invent them, and no purpose to them without humans to give them meaning and significance (notwithstanding the futuristic scenarios evoked by Kittler, Moravec, Kurzweil, and others of a postmedia, posthuman age in which media are autonomously created by other media and/or intelligent machines).[44] On the other hand, media clearly determine and help constitute humans' embodied responses, which include not only the historically specific conditioned reactions of a given epoch but also the evolutionarily evolved cognitive and perceptual capabilities that Hansen evokes. Moreover, in certain contexts the body itself becomes a medium at the same time as it is in-formed by other media, a complex dynamic ingeniously enacted by Sha Xin Wei's "Tgarden," in which performers strive to create new gestural languages in association with motion sensors and virtual projections.[45] Surely a fuller account—to which I hope to contribute by focusing on intermediation—would take into consideration both of the vectors that Hansen and Kittler mobilize, acknowledging, on one hand, the role technical configurations play and, on the other, the centrality of embodied subjects to new media productions. The trick, as I see it, is to enlarge the scope of inquiry so that it includes *both* Wolfram and his cellular automata, the embodied human and his perceptions *along with* the computational processes that he creates and that work to co-constitute him and his perceptions. In a strikingly literal sense, Wolfram and his cellular automata coevolve together in a synergistic dynamic that allows emergences to occur across many levels of complexity.

A similar pattern emerges from the contrast between Espen Aarseth's *Cybertext* and Jerome McGann's *Radiant Textuality*. Like the work of Kittler and Hansen, these texts are seminally important studies deserving close attention. Defining "ergodic literature" as literature requiring "nontrivial effort" to "allow the reader to traverse the text" (1), Aarseth makes a point of including print books as well as computer games and electronic interactive fiction. He slyly takes a poke at the literary establishment by remarking that to limit his analysis to computer-driven texts "would be an arbitrary and unhistorical limitation, perhaps comparable to a study of literature that would only acknowledge texts in paper-printed form" (1). Nevertheless, if computer games, electronic hypertexts, and interactive fiction were not on the scene, no one (including Aarseth) would have been likely to find it necessary to define "ergodic literature" as a category of analysis. In this sense, his analysis is motivated primarily by the kind of literature the computer has made popular, especially computer games, now his principal focus of interest. The centrality of computers to his analysis is indicated, among other places, by his defense of the cybertext perspective as necessary because no other existing approach takes into account "the text as a material machine, a device capable of manipulating itself as well as the reader" (24), a description much more relevant to computers than to books. Moreover, he develops several important distinctions—including "scriptons" as strings the reader sees versus "textons" as strings generating the text—that are crucially important for computer texts but infrequently so for codex books and print texts in

general. The computer orientation also helps to explain why his analysis is heavily weighted toward functionality. Most of the terms he defines to develop his typology have to do with functions available to the player/user or with functions that elements within a text can perform. Since most print texts differ little from one another in their functionality, this emphasis is an additional indication that Aarseth's perspective is oriented primarily toward computer-generated texts.

There is nothing wrong, of course, with a computer orientation. This orientation is part of what makes *Cybertext* an invaluable contribution to the field of electronic textuality, which continues to be too often seen through a print-centric perspective. More problematic is the fact that Aarseth's functionalist approach tends to flatten multiple causalities into linear causal sequences determined by a work's functionality. This flattening can be seen both in his relative neglect of the political, social, and cultural contexts in which texts are used and in the "textonomy" he develops for his typology (58). Similarly, he also neglects interactions of different modalities within electronic texts. Even though many of his examples include visual displays and animations, he defines a text as "any object with the primary function to relay *verbal* information" (62, emphasis added), leaving out of account visual, graphic, sonic, kinetic, and other nonverbal signifiers. Although he recognizes that materiality should be part of the picture, his analysis pays scant attention to the material specificity of texts. He asserts—astonishingly, given the contemporary legal and political debates over Gnutella and Napster—that in "the transition from long-playing records to compact discs in the music industry," the "analog-to-digital shift of the artifact did not change any substantial aspects of the cultural production or consumption of music" (59). To be fair, it is much easier to see the importance of these issues in 2004 than it would have been in 1997, when *Cybertext* was published, for the intervening seven years have seen remarkable growth in the visuality of electronic media and the accelerating digitization of all media. Nevertheless, there remains an important gap between Aarseth's emphasis on typology as a list of static functionalist components located on a grid of 576 positions, and the kind of dynamic multicausality required to understand complex emergent processes characterized by entangled feedback loops cycling back and forth between different levels.

In contrast to Aarseth's methodology is the approach Jerome McGann takes in *Radiant Textuality*. As I argue at more length in chapter 4, McGann's primary interest lies in using electronic textuality to deepen our understanding of how print literature works. In this the book is successful, as its deserved recognition by the James Russell Lowell Prize indicates. A brilliant