1

Introduction: The Problem with "Rules"and Why Words Will Not Sit Still

As a scholar of language, I knew I was onto something when I watched political scientist Elinor Ostrom speak before a group of scientists at the Santa Fe Institute in the summer of 1999. The scientists sat at a horseshoe-shaped table, eyes glancing back and forth from Ostrom to her slide presentation at the front of the room. Outside, cumulus clouds were visible as they puffed up into the deep blue sky over the valley below the Institute, a remodeled adobe ranch house. Scientists of various ages and areas of expertise sat alertly and listened as Ostrom explained her research with students at Indiana University. The students had been issued tokens worth money and asked to allocate those tokens among the group. Ostrom's research was grounded in game theoretical economics, which mimics real-world situations by requiring subjects in a group to make individual choices based upon perceived rewards. Ostrom concluded from her experiments that public policy issues—such as how to allocate ground water among farmers—should not be decided solely by a centralized governing body. Allowing the farmers to organize into smaller cooperatives to decide irrigation rights and rules is an effective alternative, she concluded, noting that, "Rules become the tools that humans use for self-organization."

Yet, when it came time for the question and answer portion of her talk, Ostrom found that much of the discussion did not focus directly on her recommendations, but was given over to a spirited debate about what the word "rules" meant to her model. For biologists, "rules" suggest regular observable behavior in an organism, Ostrom explained later. For example, a species of fish that always returns to the same place to spawn could be said to be following a rule. In the same way, I thought, perhaps even the clouds building outside were following a rule to form when the temperature, humidity, and barometric pressure reached certain levels. In contrast, however, to the meaning that biologists and other natural scientists assign the term, "rules" for political scientists are a description of action that is permitted by a social group. They require some kind of conscious choice among autonomous agents, and they are enforceable. The discussion became so mired in this semantic debate that one researcher in the audience was prompted to exclaim that for the purposes of discussion, "we just get rid of the word 'rules' because it is confusing the issue."

Of course his request, spoken in a moment of obvious frustration, was impossible to honor. Words and the problems of semantics will not go away even for scientists. One could ask whether useful discussion following Ostrom's presentation was sidetracked by the semantics debate, or whether the attention given to a single word led to a deeper understanding of the policy questions she was grappling with in her talk. But one could not ask for these semantic labyrinths to simply straighten out. Perhaps much of the best intellectual work at the Santa Fe Institute and other science centers comes out of the impromptu debates among researchers from different fields over the meanings of various words.

The story of Ostrom's talk exemplifies the constant fascination with language that I have observed at the Santa Fe Institute. The 18-year-old Institute is a think tank of scientists from various disciplines who are studying the relatively new science of complexity theory, which asks how order emerges in the world. To some language theorists, the word "rules" in Ostrom's talk would be functioning as metaphor, borrowing connotations from one field or discipline to lend meaning to another. An uncomplicated entry on metaphor from *Webster's New Collegiate Dictionary* defines it to be "a figure of speech in which a word or phrase literally denoting one kind of object or idea is used in place of another to suggest a likeness or analogy between them" (722). What confounded the scientists who were in discussion with Ostrom is that they could not agree on which fields should supply terminology definitions. They could not control the metaphoric process or the connotations that a simple word evoked among members of a mixed audience. Perhaps they thought that the word "rules" should have an exact literal meaning, but they could not get such a meaning to sit still long enough to ground a discussion.

Metaphor is the rhetorical issue that dominates the Santa Fe Institute. Erica Jen, the SFI's then vice president for academic affairs, stated in one interview with a Santa Fe magazine that, "Metaphors in science are powerful because even when you can't pin them down mathematically you relate to them on an emotional level; they get you moving" (Jarrett 16). I heard about problems with metaphor on the first day I walked into the Institute in the summer of 1997. As a scholar of rhetoric and technical writing, I was offering to help scientists write text that would summarize their research for the Institute's Web page. In the first conversation I had with Jen, and in most subsequent ones, discussion of metaphor came up. Institute members are on a constant quest that requires a delicate balancing act: they are looking for new metaphors that can stimulate productive scientific thinking, but without distorting that thinking. The SFI lexicon is filled with colorful terms like "spin glass," "complexity," "fitness," "compressibility," "emergent design," "autocatalytic sets," "sand pile catastrophes," and "cellular automata." These terms conjure up rich visual images and prompt recurring discussion among scientists over meaning. Some of these terms may be metaphors, while others may not. A useful goal for any writer who works with scientists is to help them to consider what qualities are present in metaphoric thinking. This goal recognizes that metaphor has both special powers and special dangers that must be understood before metaphor can be used wisely in directed scientific research. These SFI terms also have connotations outside the walls of the Institute that add to the Institute's mystique among the lay public, but also exaggerate the applications that may be possible from complexity science.

The purpose of my research is to examine language use at the Santa Fe Institute, specifically as it relates to rhetoric and the trope of metaphor. I am asking broadly what role rhetoric and metaphor plays in this kind of science and how scientists feel about language issues. While I have approached this project with many research questions, perhaps they could all be summed up with one: "What can the rhetorical challenges confronting members of the Santa Fe Institute tell us about the role of rhetoric—specifically metaphor—in science?" Embedded in that question are other questions, such as one I was asked by Ginger Richardson, the program director at the Institute and my closest contact there. She noted that problems of meaning confront all human beings and all discourse communities. "Is there something unique about the SFI that makes our language problems different?" she asked. I hope this project sheds light on that question and, in the process, helps those who attempt to forge scientific knowledge in interdisciplinary settings communicate better as they explore new theories.

I wrote this book with three primary audiences in mind. One comprises scientists, especially those involved in theory building, who find that the choice of the right words can have major implications for how a theory takes shape and disseminates throughout the scientific community. A second comprises technical writers who use their rhetorical skills when working with scientists to develop, edit, and deliver knowledge. My definition of a technical writer here is loose: for example, academic scholars who write about science from various disciplinary perspectives and science journalists are practicing variations on technical writing. A third audience comprises those with a keen interest in the philosophy, sociology, and history of science. I draw heavily from these disciplines for most of this analysis.

Both scientists and technical writers share a fundamental if unstated assumption, which is that reality can be transcribed by use of symbols and, hence, made more comprehensible and useful to human beings. The symbols can appear in mathematical formulae or in ordinary sentences; what is important in this assumption is the notion of transcribing reality, representing it in a way that is true to observation and is useful. A warrant that drives this assumption is that the scientific method must close in on reality, must define it ever more precisely to remove unintended implications or spurious associations. If the word "rules" were emitting noisy associations then it would be the job of Institute scientists and writers to fix the coordinates of its meaning more precisely. Yet, as Bernadette Longo makes clear in *Spurious Coin*, her book about science and technical writing, transcriptions of science as reality always emit spurious signals. Longo's research suggests that scientists see such spurious signals as inevitable but also lamentable. Perhaps Santa Fe Institute scientists realized that any discussion of theory that involved an evocative word like "rules" was destined to break down over confusion about which signal to tune in.

My presupposition in 1997 as I began a relationship with the Santa Fe Institute was compatible with implications from Longo's book: any understanding of reality that emerges from a debate over word meaning distracts the scientist from demarcating the precise and useful aspects of that reality. I assumed that these Santa Fe Institute scientists inadvertently stumble into debates over semantics, but prefer to find ways to avoid such debates in order to get the real business of science done. If so, then these scientists would use rhetoric and its figurative language begrudgingly, primarily to communicate with non-scientists. It would follow that scientists see language not as a tool for producing knowledge, but merely as a vehicle for communicating knowledge that has been adduced by other more empirical and rigorous means. Perhaps the near obsession with metaphor that I saw from the beginning at the Institute was temporary; once the scientists got beyond the limitations of language, then the real science could begin. Even as I reveled intellectually in debates, such as the one over "rules," I still believed that perhaps language could be made to sit still.

I was influenced by the biases of post-positivist philosophy as it is commonly understood today, which holds that science is the testing of hypotheses by formal empirical methods. Language theorist Robert Hoffman, citing various researchers looking at metaphor in science, points out that the strict empirical perspective would see metaphor at best as a heuristic, to be filled in later with a real theory. "At worst it is an irreal fungus doomed eternally to a prescientific twilight zone," Hoffman adds, in summarizing this dismissive view of metaphor. "Any good theory should be literal and precise" (394).

Deep down technical writers working among subject matter experts often feel a slight inferiority complex. I too felt it upon entering the Santa Fe Institute, believing that most scientists still adhere to Francis Bacon's argument: if you look at the world long enough, the answers will emerge without the midwifery of language. A glance at scientific journals reveal page after page of mathematical symbols building to what appears to the layperson as an incontrovertible proof of some theory of reality. Having come out of master's program in economics, where the term "mathematical rigor" was held in God-like veneration, I assumed that most scientists believe reality to be knowable only through excruciating mathematical analysis. Vague language—my main area of expertise—offered at best a shadowy image of the mathematical truth.

Although language may be inherently vague, I wondered if it could not be made more precise by careful attention to definition at the outset of scientific research. As a technical writer, I felt charged with the goal of helping Institute scientists use language—even metaphoric language—in an exacting way that would transcribe reality by suppressing spurious meanings, thereby allowing precise ones to ring clearly. It seemed logical that if Ostrom had first defined her terms, or even used subscripts to distinguish one type of rule from another, certainly she would not have lost time to a semantics debate. A sensible goal for a technical writer at a place like the Santa Fe Institute would be to help its scientists to use language more rigorously, if not elevating it to the status of mathematics, at least making it a worthy junior partner.

Throughout this book, I reconsider these presuppositions, gradually revising the hypotheses that have emerged from my research. After working with those Santa Fe Institute scientists and interviewing them about language issues, I have come to realize that these scientists value metaphor and other rhetorical devices even as they are uneasy using them. They depend on metaphoric language to generate theory across disciplines and, equally important, to make their studies seem exciting, cutting edge, and worthy of publication and funding. At the same time, scientists try to distance themselves from metaphoric expressions when they want to appear rigorous and far removed from the social fray that discursive language inspires. Hence, these scientists rely on metaphor, while at the same time trying to rise above it. Their paradoxical response is similar to that of the Greek philosophers, whom we will encounter throughout this book. Recall that these philosophers coveted rhetorical skills for their inherent power to produce knowledge and to persuade, and yet they attempted to keep a safe distance from rhetoric so as to not appear lustful for the fruits of such eloquence.

The history of science is full of debates over metaphors, such as debates in ninteenth century physics over what was meant by a "field," whether energy and heat were actual entities or merely evidence of molecular motion, and whether electricity was a kind of fluid. Language, particularly metaphoric language, resonates with meaning and implication. A scientist may use a word to mean one thing, but she cannot prevent others from hearing different signals from the word—even if those signals cause the hearers to question the essence of the speaker's argument. I hope that the reader learns from this project, as I have learned, that such debate over word meaning constitutes rather than impedes scientific knowledge. This is a question of epistemology, which is a fundamental problem of philosophy that has occupied thinkers for several thousand years. I argue that metaphor is a tool of epistemology and that technical writers trained in rhetorical theory can help scientists to manage that tool.

When we read about knowledge we often find several key concepts in the proximity; these include observation, belief, reason, and reality. Knowledge for my purposes is reasons and beliefs that link an observer to reality in a consistent way. That is, what we know today we should also know tomorrow, even if tomorrow's knowledge is not synonymous with today's, but only aware of it. Plato's dialogue *Theaetetus*, the foundational text in epistemology, suggests that knowledge is the shaping of belief, derived from perception, by reason. Plato uses a metaphor of knowledge as clay shaped by the human hand into bricks (147a–c6). Whether knowledge as clay exists prior to that shaping is unresolved, but the key point for this study is that scientific knowledge is the result of some kind of scientific reasoning process—a scientific method—that is applied to observation. Of course, as philosopher of science Helen Longino points out, direct experience is not a prerequisite of knowledge; most statements about reality are accepted even if not directly experienced by the knower (148–156). (I know that World War II happened even though I wasn't alive then. Scientists know that unstable uranium atoms can be driven to a chain reaction even if they have never witnessed nuclear fission.) Thus, we accept the shaping of clay that we have not seen happen. Since I will draw parallels to music theory, this Platonic image of brick making may be confusing. An image consistent with my argument would be that of scientific knowledge as musical notes assembled into some kind of meaningful and evocative pattern.

HARMONICS: USING MUSIC THEORY TO EXPLAIN HOW METAPHOR WORKS IN SCIENCE

A scientist using a metaphor like the word "rules" may intend for audience members to hear the fundamental meaning of that word in her field, "a codified, consensual social structure." She cannot prevent others from hearing different meanings, however, such as "a regular pattern of involuntary biological behavior." Borrowing from the physics behind music theory, I use the term "harmonics" to refer to the various implications or signals that a word carries. Musical harmonics are tones that sound in addition to the fundamental tone when a note is played. So, for example, when a violinist plays a note at middle C, nearly twenty different tones may sound simultaneously (Seashore 98). These tones, known as "partials" or "overtones," fall at various frequencies above the main tone, meaning that each note is a blend of musical intervals. It is the unique combination of overtones associated with each instrument that give it a subjective quality known as "timbre." The different array of overtones is what distinguishes a clarinet from an oboe, for example.

Most instruments offer this collage of tones every time one note is played, although the ear usually does not distinguish among the various overtones. Intuitively, we can assume that a metaphor functioning as a musical note would convey a fundamental tone, denoting the primary meaning, but also other tones at regular intervals, the harmonics. The implication of this way of explaining metaphor is that some meanings resonating from a word will sound consistent with the listener's expectations of sounds, while others will not. A "rule" as a sociological phenomenon may sound appropriate to the social scientist, but the harmonic meaning suggesting a biological aspect may be disconcerting to that same scientist. The social scientist in this example must either find a way to suppress the unpleasant sounds, adapt her sense of sonority to accommodate the new sounds, or reject the fundamental tone altogether. In this way, metaphor (as a tone on an instrument) changes the meaning of the whole piece of music; it "constitutes" the piece. This, I argue, is how metaphor constitutes theory in science.

The analogy of words to musical notes that we have seen so far implies that metaphors stand alone as individual notes filled with multiple meanings. Yet, language and music are about relationships, intervals between word meanings or tones. Although one word or one tone does carry unique sounds or meanings, the real focus in my theory of metaphor is on the way that words interact in building and refining scientific theory. In music, when a tone is heard among others or immediately after others, our ears make a judgment about the overall sonority. The fundamental sound of individual bells sounding a close succession of notes can be disturbing, for example, because so many dissonant harmonic overtones can make it difficult to distinguish the fundamental pitch ("Harmonics," Sadie). Likewise, pianists rarely play bass notes together because these notes generate many harmonics that together sound discordant.

In examining the way scientists use metaphors, I have found that metaphors tend to be accepted if they sound sonorous amid the overall paradigm in which those scientists operate. So a metaphor and all of its meanings must fit into the theory in the same way a note and all of its harmonics must fit into a melodic phrase. A scientist who is developing a theory about social activity, or any activity that involves choice among the agents, will hear that the word "rules" sounds consonant with the theory. Dissonance appears when the word is pushed to apply to situations where behavior is involuntary. (How can something follow a rule if it has no choice?) The dissonance need not destroy the theory; instead it may cause scientists hearing it to accept new implications of a word within that theory just as Beethoven's genius pushed audiences of his day to accept sounds previously thought to be jarring.

The musical way of understanding metaphor seems appropriate because it is consistent with knowledge that language originated as an oral/aural system of communication. Obviously my argument is not trying to carry the analogy with music so far as to suggest that word meaning depends on the actual sound of a word. This is not a theory of *onomatopoeia*, where a word literally sounds like what it means. I am arguing that any word conveys multiple meanings, whether we hear those words spoken, we read them, or simply think of them in our minds. These meanings consciously or unconsciously affect the way we accommodate that word into a larger syntactical cluster—the sentence that attempts to represent reality. Metaphors by definition are filled with associations and, hence, they add many dimensions of meaning to any sentence in which they appear. These dimensions of meaning are what I liken to musical harmonics.

The physics of harmonics has occupied philosophers at least as far back as the Classical Greeks. Parts of their analyses of harmonics are relevant to my project because they explore the ways in which musical and philosophical meaning is a combination of sensory perception and reason. Spanning the more than 800-year-period from the Pythagoreans and Plato (circa 400 B.C.E.) through Claudius Ptolemy (circa 140 C.E.) to the later theorists, Greek philosophers held forth on whether music had its effect primarily because of the inexplicable delights of sound that it brought to the ear or because of the rational, mathematical relationships inherent in the frequencies that conveyed those sounds. The debate in science over whether knowledge is what we induce empirically or whether it is what we reason deductively has it origins in the Greek analysis of the effects of music. Extending the debate to metaphors functioning as musical notes, we can see that our response to a metaphor in science can emerge from our rational analysis of word meaning, but also from how words strike the ear in combination with other words. Language originated as a spoken system of communication, so even when we read words we hear them in our minds. Meaning is reasoned but also sensed aurally.

In Plato's dialogue *Timaeus* we find a discussion of the craftsman of the world—a divine mind—dividing the soul of the world into harmonious intervals, which have a mathematical basis (36a,b). These intervals are modeled after the perfect "Forms," from which the elements of reality are modeled. In the *Cratylus*, Plato describes words as another means of dividing the world in the same way that a weaver's shuttle is used to divide yarn. "So just as a shuttle is a tool for dividing warp and woof, a name is a tool for giving instruction, that is to say for dividing being" (388b13). In this dialogue, the craftsman god uses names to divide reality in the "natural way." For Plato the process of naming the world would have to follow the natural harmonic intervals into which it was divided. Metaphors would be measured by how consonant they sounded in the context of such a rational system.

This consonance could be determined by spirited debate in the same way we saw Santa Fe Institute scientists work out whether the term "rules" was acceptable for the theory they were discussing. Debate over word meaning was the prime method of clarifying knowledge for the Greek philosophers. Plato in the *Cratylus* argues that correct words are divinely inspired. Yet, such words are refined by those who ask questions—the dialecticians (390c,d). Plato's suspicion of rhetoric would have prevented him from trusting this semi-divine task to rhetoricians alone, but the point is nonetheless prescient. Hence, we can conclude that knowledge making in science is a cognitive process by which scientists as Platonists attempt to find the appropriate theories, or names, for reality. Yet, this is a far more social process than perhaps Plato would have acknowledged; scientists continually sound out their theories against the background of knowledge and beliefs that have been accepted as sonorous by their peers.

Scientists and those who help write science may have trouble accepting that knowledge is in any way a function of what sounds good. Indeed, this argument would have troubled Plato. He argued that the effect of harmonics on the ear was a less accurate indicator of consonance than was the mathematical relationship among the frequencies of the tones. While sympathetic to the early Pythagoreans, Plato criticized those who relied on the ear and who "don't investigate, for example, which numbers are consonant and which aren't or what the explanation is of each" (*Republic* 531c). Andrew Barker, a professor of Classics, shows that for Plato and for anti-empiricists ever since, the senses were too easily deceived to be reliable. "The distinction between the beautiful and the merely pleasant is at least as old as Plato, as is the tendency to associate beauty with rationally intelligible form, pleasure with mere titillation of body parts" (265). This Platonic criticism of the senses wends its way throughout the history of scientific knowledge. Traces of it are evident in the interviews I present with the Santa Fe Institute scientists. We will see that these scientists rely on metaphor, but at the same time view it as less trustworthy than mathematics, albeit potentially more titillating.

Aristoxenus, a follower of Aristotle who lived in the late fourth century B.C.E., argued that such devotion to reason over the senses was illogical. His philosophical investigations suggest that no intrinsic mathematical law can determine which harmonics sound pleasing any more than the description of an animal can serve as a substitute for the actual animal. Aristoxenus and his followers pointed out musical intervals that sounded good to Greek ears (and would still to ours), but which were rejected by Pythagoreans because they could not be expressed in appropriate mathematical ratios (Mathiesen 379).

Claudius Ptolemy, working at the Library at Alexandria, developed an extensive theory of musical harmonics that accepted arguments from the followers of the Pythagorean School and Plato about the rationality of music and, also, arguments from the more empirical side. As Barker reveals, sound for Ptolemy is *pathos* of the air, a phenomenon not ruled by reason. Yet, Ptolemy recognizes that the senses by themselves are unreliable because their perceptions are not consistent from person to person, or even within the same person over time. Hence, Ptolemy concludes that the science of harmonics requires both reason and perception. Barker offers this summary:

> The senses, then, are insufficiently exact instruments to make the precise discriminations required by the scientist. Reason, on the other hand, is powerless on its own. It has no independent

> access to the data, but must take from other sources the rough and ready information they give about the contents of the world. (19)

It would follow that unreliable data are inevitable in science and, likewise, that potentially discordant harmonics are inevitable when the scientist uses words to interpret, represent, and organize that data.

Musical harmonics for Ptolemy were not merely sounds, however, but the relations among sounds. "No one thing, be it a note or a distance, can be concordant in its own right, but only in relation to something else" (Barker 93). This Ptolemaic dictum is central to my argument that metaphor functions in the context of many words, which together make a claim about reality. Knowledge emerges through the perception of a signal—metaphor, in this case—that evokes associations/harmonics. We accommodate those associations by listening to and reasoning about them in relation to the other words in the discourse cluster. A metaphor in a biological context conjures up different associations than it would in a political science context, almost as if the metaphor were "played" on two different instruments.

Discussion over associations builds new theory at places like the Santa Fe Institute. Revisiting the age-old debate about whether metaphor shapes theory or merely decorates it, I will show that it constitutes theory by ringing forth with various signals, various meanings. These force scientists to confront the implications of any theory. Paradoxically, imprecise language sometimes leads to a greater and more thorough understanding, which is, after all, the goal of interdisciplinary research. Despite the occasional moment of frustration over semantics, interdisciplinary scientists need their terminology to be vague enough to embrace a variety of meanings, the variety of guises that reality may wear. A technical writer who works with scientists must come to realize that despite the writer's strong instincts to the contrary, the goal of scientific communication may not always be precise representation of subject matter. The writer's job is challenging in such a setting because he must intuit from the subject matter experts how much vagueness is acceptable, even desirable, in a text. The goal in writing is to choose words that, while being accurate, also ring forth with enough degrees of freedom to be coherent with reality's complex nature.

Rhetorician Jeanne Fahnestock makes precisely this point in her analysis of the debate in archaeology about when the first humans entered the New World. Rather than debating to resolve the argument, the goal may be to continue the debate. As Fahnestock writes, "The true exigence may favor not agreement but continuation of the controversy" ("Arguing . . . " 65). In this context, the writer's contribution to science is not in suppressing metaphor harmonics, if that were even possible, but in helping scientists recognize how those harmonics resonate within what might be called the "tonality of meaning."

STRUCTURE OF THE BOOK

This project begins with analysis of my own rhetorical challenges as an occasional freelance technical writer for the Institute. The main part of the research then involves interviews with many scientists affiliated with the SFI. In these interviews the scientists talk often about metaphors in their field that are evocative, but often frustrating because of their tendency to oscillate among different meanings. I also draw freely upon texts produced by those scientists for examples of rhetorical strategies, and to explore how those scientists deal with problems of language meaning and audience in their own writing. I have tracked the use of a key term at the Institute, the word "complexity," examining how it has moved in and out of science and popular discourse over the years. In my research I have repeatedly engaged questions put to me by Institute members. Some of these questions go to the heart of metaphor studies, such as, "What is a metaphor?" and "What is a metaphor's purpose?" One version of these questions came up, for example, when I was referring to "complexity" as a metaphor and two people at the Institute in separate discussions asked why it would be a metaphor, as opposed to "just being a word." I could not answer the question. Nor could I say then with conviction why it matters that scientists recognize metaphors when they use them, or why they should accept the power of rhetoric. Yet, somehow I have always believed it does matter. That belief has motivated my work.

Researching these core questions has forced me to take a position between two extreme poles of thought. One, identified with I.A. Richards, and perhaps with George Lakoff and Mark Johnson, assumes that all language is metaphorical, even when not intentionally so. Another, drawn from Aristotle's founding work on rhetoric, assigns a narrower role to metaphor as the intentional use of language by gifted or skilled rhetors to highlight resemblances across fields—an action undertaken for specific epistemological or persuasive purposes.

At one extreme, metaphor is pervasive, inescapable, and involuntary. It is the essence of word formation within language. At the other, it is sporadic, ornamental, and deliberate—something layered onto the surface of language. The first part of this book attempts to close in on an understanding of metaphor as an epistemological concept by exploring these theories in the larger context of rhetoric and science.

Chapter 1 continues with a brief description and history of the research site. The purpose of this chapter is twofold: to situate the reader at the Santa Fe Institute and to outline the research that I have conducted there. Chapter 2 is a narrative essay that reviews the writing projects I had been involved in at the Institute prior to beginning the interviews. Technical writers reading this book will no doubt recognize some of the joys and frustrations that come when trying to produce various texts for a group of brilliant but at times impatient subject matter experts. Here I explain my informal participant-observer role as an occasional writer, and offer insights into the rhetorical challenges I have observed while researching and writing these projects. These observations came during visits to the Institute to attend meetings and gather information for the writing projects, and during email and telephone conversations with Institute members throughout the research, writing, and editing stages. The observations I made while writing for the Institute led to the questions that launched the formal study.

Chapter 3 plumbs the depths of the literature related to metaphor theory and the rhetoric of science, examining the relationship between questions from those two fields. I situate the reader in the ongoing debate over the roles that metaphor and other rhetorical devices play in the development and dissemination of scientific knowledge. From here it becomes possible to explore these language issues at the Institute.

Chapter 4 pulls together and analyzes the findings from the formal study. It involved interviews with seventeen people affiliated with the SFI, including resident scientists, visiting scientists, and administrative personnel. In this chapter I explore the function of metaphor in theory building as seen by the SFI people. Because the scientists frequently considered metaphor (and all discursive, lyrical language) in contrast to mathematical expressions of knowledge, I found it worthwhile to do the same. Hence, the chapter also explores a fundamental debate in the philosophy of science over the indispensability of mathematics to scientific knowledge. Scientists in general are sympathetic to the Platonic argument that truth is objective and that it can be accessed only by objective epistemologies, of which mathematics would be supreme. Anyone who writes in a scientific setting will find this discussion of the tension between mathematical knowledge and lyrical knowledge to be helpful, for this tension lies at the center of scientific practice.

Hence, as the chapter builds from the semantics debates ever present at the Institute, such as that over the word "rules," it asks whether replacing such language with perhaps the more pure representations of mathematics could filter out the unwanted harmonics of metaphor. I show that mathematical and metaphoric thought processes are often intertwined and impossible to isolate. Scientific intuition cannot be reduced to one epistemological method. Here is where my image of word harmonics among scientists takes full shape and leads to the claim that such harmonics are not spurious, but theory constituting. I dip into the theoretical literature again and draw on the theories of additional philosophers, rhetoricians, and scientists when necessary to help make sense of the issues that emerged in the interviews.

Chapter 5 develops a secondary theme that emerged from the interviews—the challenge that scientists face in presenting their findings to other scientists and to the outside world. This involves issues of style and eloquence and the best way to communicate with scholars in different fields; rhetoricians know this as the problem of "incommensurability." During the interviews, several scientists expressed frustration that communication was difficult even at a science think tank whose mission was interdisciplinary research. The problems of metaphor harmonics can make it difficult for one scientist to know what another means. Yet, not all problems of communicating across disciplines are so abstract; these interviews reveal that Institute scientists often face inertia among their peers when trying to develop interdisciplinary research. The problem often is as simple as trying to find a journal that will accept an article hewn from disparate fields, or trying to find grant agencies that will fund such research. Delivering ideas can be especially confounding for scientists when they try to rewrite their work for a general audience, as my analysis of the work of Institute biologist Stuart Kauffman reveals. The technical writer who works with such scientists should take away some insights into how to help them to navigate the rhetorical challenges involved in delivering knowledge to different audiences.

The challenge of communicating across disciplines is not new to science; such challenges appeared in the eithteenth and nineteenth centuries when science as natural philosophy branched out into various fields. These fields developed specific focuses on the natural world. Practitioners in each field defined their activities according to their focus, whether it was at the atomic level, the molecular level, or the organic level. The names "biology," "physics," and the like circumscribed an area of focus for each field. At the Santa Fe Institute, scientists are attempting define a new field called "complexity," which crosses many fields. Chapter 6 attempts to determine the scope of this field by taking a close look at the etymology of the word "complexity." This history shows how meaning can change in science, and how a word like "complexity" can accompany and perhaps prompt dramatic shifts in scientific thinking. Here I get closer to resolving the questions of whether "complexity" is a metaphor and why it has been such a powerful word. The essence of this chapter is an exploration of "complexity" as found in The *Oxford English Dictionary*, where several pages are devoted to description of the term in its various forms and examples of how it has been used since Classical times. I also sample a few of the more than 200 texts that refer to "complexity," as listed in a university's electronic catalogue. The chapter also includes a few interview comments specifically related to this key term. As this chapter shows, a writer working with subject matter experts often can illuminate knowledge for those experts by revealing the histories of terms they hold dear.

Chapter 7 wraps up the book by revisiting the central questions that have been running throughout. I conclude that SFI rhetorical challenges in some ways may be more acute than the challenges facing more traditional scientists, but that those challenges are not fundamentally different. I claim that those rhetorical challenges are not impediments to good science, but instead are essential catalysts for novel thinking. Here I reconsider the ways in which metaphor adds value to science. The chapter offers general recommendations for how technical writers can assume their place in such science organizations. The underlying warrant is that technical writers trained in rhetorical theory belong in centers of science; the subtle understanding that technical writers possess of how words and their harmonics work can help scientists develop and fine tune their theories through the process of writing.

I must acknowledge at the outset that the conclusions reached through this research on metaphor and other rhetorical challenges in complexity science certainly cannot stand the test of doubt that defines the post-positivist system as it is understood today. I have made claims that cannot be falsified, for how could anyone find a case where language is not necessary to shape knowledge? That person would have to make his case without using language, which is impossible. Still, the qualitative research here is credible and honest. I have attempted a style of research known among ethnographers as "naturalistic inquiry," which aspires to standards of trustworthiness. As codified by ethnographers Yvonna Lincoln and Egon Guba, naturalistic inquiry seeks to depict a culture by allowing insights to emerge over time from among its members. A researcher should listen to the members when designing a project and should continue listening throughout the research and writing stages, not just during the so-called "data collection" stage. In doing so the researcher pursues important questions toward meaningful insights and continually modify his hypotheses. The researcher and members are partners; the resulting text becomes a kind of Platonic dialectic, from which insights emerge.

This concept of "emergent design" (Lincoln and Guba 225) is similar to the idea of emerging order found at the Santa Fe Institute. My project has evolved and taken different forms over the few years that I have been involved with the SFI. It is very much an emerging project. As I have written material for the Institute, beginning with my "Initial Impressions" report on the rhetorical challenges, I have made those texts available in draft stages to members. Responses from those members, including edited changes, have guided me in developing questions related to rhetoric at the Institute. Listening to members and reading works by various members made it clear that metaphor is not just my interest, it is a strong Institute interest. At one point late in my research, a rhetorical theorist asked why I had chosen metaphor in science as a topic of study. So much work already had been done in this area, she said, and other rhetorical devices are more interesting. I replied that because metaphor is what was on the minds of these scientists, it also was on my mind. Metaphor had emerged as an important question for these scientists, even though it may be passé for some rhetorical theorists.

Lincoln and Guba show that a naturalistic inquiry should aspire to standards of "trustworthiness" rather than to conventional positivist standards of "objectivity" and "validity." A naturalistic inquirer is not attempting to follow a strict method in order to validate a hypothesis that then can be accepted as approaching truth. A naturalistic project, instead, attempts to test findings through careful and open research to reveal insights that seem honest, believable, important, and not aberrant. A trustworthy project primarily must be "credible." This requires;

1. prolonged engagement, persistent observation, and triangulation
2. an external check on the inquiry process
3. refinement of hypothesis as evidence comes in
4. checking of new findings against archival data
5. the opportunity to check findings with the members who generated them (301).

From 1997 to 2000 I focused on the Santa Fe Institute, its research symposia, its texts, its key terms, and the spoken observations of many of its key researchers and administrators. Throughout the research I subjected my results to the credibility test by making them available to SFI members. "Member checking" is a term used in ethnography when the researcher gives the interviewees a chance to read interview transcripts and the draft analysis before publication, and a chance to modify their comments. The goal of member checking is to treat participants as people involved in the knowledge creating that goes on in research, not as objects to be mined for information. My most successful effort at member checking was in writing my final piece for the *SFI Bulletin* midway through my formal research. This column, published in 1999, served as kind of an abstract or executive summary of what I had discovered in my initial interviews: the Institute is interdisciplinary, highly philosophical, and abstract, but also burdened with great expectations from a public looking for big answers from science.

WHAT IS THE SANTA FE INSTITUTE?

Founders of the Santa Fe Institute set it up in 1984 as an independent, nonprofit research center dedicated to an interdisciplinary approach to science. The stated goal at the Institute was to break down the traditional academic barriers that often keep scientists of different backgrounds from working together. Hence, the Institute draws researchers from the natural sciences and the social sciences, including physics, biology, psychology, mathematics, economics, immunology, linguistics, history, and other fields. Arguably, this mix of researchers from various disciplines creates a greater need for metaphor than might be found at research centers drawing from a single discipline. The SFI brings these researchers together temporarily—in "a floating crap game," as Institute people are fond of saying—to nurture their ideas and techniques, and to study related patterns that appear across all these disciplines. Over the course of a year, the Institute hosts some 150 scientists for varying stays, with about 35 in residence at any time. A few are on multi-year appointments, a few are graduate students, and others are scientific visitors, predominately from universities in the United States and Europe.

Complexity science is the underlying premise that unites these disparate researchers. A fixed definition of "complexity" is elusive even for Institute members, but in general the theory suggests that chemical compounds, organic cell structures, Renaissance financial banking systems, as well as other physical, natural, and social phenomena all derive from an underlying order that propels them toward organization and adaptation. Therefore, researchers are constantly on the lookout for patterns, regularities, and structures behind all sorts of real world phenomena. Scientists often borrow the genotype-phenotype paradigm from biology to envision how underlying patterns become manifest at the surface level. In this biological way of viewing the world, the "genotype" is the code in the human gene that describes how the "phenotype," or individual body, is constructed. Yet, the question of how a code or set of rules is manifest in the evolution of all types of self-organizing systems is unresolved and subject to intense theoretical contemplation and debate. Even the relationship between the genotype and phenotype remains a subject of study.

Researchers collaborate at the Institute on projects dealing with everything from the communication patterns of ants, to the way information spreads across economic markets, to how the first replicating life forms may have emerged on earth. Institute scientists say that their exploration of these phenomena is helping define new research directions at major universities. This research in complexity science has been categorized by philosophers Steven Best and Douglas Kellner as one form of postmodern science. Best and Kellner argue throughout their 1997 book that postmodern science rejects the deterministic world view of modern science for a version of reality that is indeterminate, probabilistic, relative, chaotic, complex, and in a constant struggle between entropy and emerging order.

The interdisciplinary and cross-cultural ethos of the Santa Fe Institute is easy to discern from a visit to the Institute's center, perched on a hillside at a restored ranch house outside Santa Fe. For example, a visiting economist joining other scientists for lunch on the patio might share ideas with an architect who is seeking Institute help to study complexity in the design of buildings. She might hear discussions about molecular biology in French, German, Norwegian, and various languages besides English. Later, she might attend a talk about complexity in the stock market or about game theoretical approaches to policy making, which was the subject of the talk I referred to earlier. Our visiting economist might retreat to a computer workstation with graduate students to explore the evolution of an artificial life form they are modeling. During a late afternoon tea break, she might reconnect in the kitchen with fellow scientists to share information on her impressions. Later, back at her home institution, she could continue to share ideas with fellow Institute scientists by electronic mail and telephone, or return to the Institute periodically for seminars on topics such as the mathematical power-law relationship in earthquake incidence.

The visitor who arrives at the Santa Fe Institute expecting to see traditional experiments conducted amid laboratory beakers, microscopes, Van de Graaff electrical generators, and similar accoutrements of empirical science would be surprised. Most of the research at the SFI is on computer workstations, where artificial societies of agents and organisms are simulated. Stanford anthropologist Stefan Helmreich in his 1998 ethnographic study of the SFI notes that these computer-simulated worlds are known variously as "artificial life" or "cellular automata" or "microworlds." Scientists establish the agents present in the artificial worlds and the parameters for how those agents will interact among each other and the environment; the scientists then allow the computer to proceed through multiple iterations to see what happens to those worlds. These kinds of simulation systems have been used in science for decades, and are even available in popular computer games.

An example of one artificial life simulating system is the "Swarm" software, developed by former SFI researcher Chris Langton. In late 1997, Langton showed me one "world" he had simulated with Swarm—that of a 1,000-year-old community of Native American Anasazi people who had lived in the high deserts of what is now

Southern Colorado. To give the reader here some sense of what goes on in this elusive and difficult to envision science, I offer now a few paragraphs from an article I wrote for the *SFI Bulletin* about Langton's project:

> (T)hose researchers who have become comfortable with Swarm have found it invaluable. Tim Kohler, chairman of the department of anthropology at Washington State University, says Swarm has fully lived up to his expectations. The simulation software has led to intriguing insights into the ways in which early Native American peoples coped with changes in their environments. Swarm has corroborated theories suggesting that Anasazi cultures developed maize trading among households to contend with variable patterns of rainfall.
>
> In the Swarm Artificial Anasazi model, the terrain of Southern Colorado 1,000 years ago shows up on the computer as a green topographical map, crisscrossed with streambeds. Families show up as pixels of light. The model simulates life among the people using some thirty variables—birth rates, death rates, local topography, corn storage potential, rainfall, and the like. The computer races through each year in a matter of about ten seconds, allowing researchers to tweak one or two variables and rerun the model to see what changes occur. Researchers then study the survival rates among the pixels representing families.
>
> Kohler and co-researcher Carla Van West have found that families tended to be risk averse. They would share maize with other families in exchange for a promise to return the favor . . .. But when the entire region suffered from low maize productivity, families tended to hoard.
>
> Research on the Artificial Anasazi project suggests that environmental degradation forced the people to abandon their homes in the thirteenth century. But the Swarm model also suggests that one third of the population could have survived if they had redistributed themselves on the land. (Baake, "Swarm" 22)

In writing this piece I deliberately tried to explain how the computer simulates a living environment; I believed it necessary in the modern scientific tradition to emphasize method. Yet, much of the writing about SFI research, even for a general audience, occludes method or refers in vague terms to an "integrated approach" or "model building" or "examining" how adaptive agents behave. It is often difficult from reading Institute literature to know much about what a scientist is doing in a project. Helmreich's study suggests that many artificial life researchers have become so accustomed to the idea that the worlds they create on their computers are somehow real that perhaps they overlook the fact that they are engaged in a research method that involves setting parameters and observing simulated behavior. Perhaps, for the community of SFI scientists, writing extensively about simulation methods would be stating the obvious. Yet, for the outside reader, lack of attention to method makes it difficult to discern the boundaries between a scientist's thoughts and intuitions and his or her research results. The dichotomy between deductive, rational science and inductive, empirical science that originated in Aristotle and solidified in Bacon, Hume, Locke, and other Enlightenment philosophers is blurred at the Santa Fe Institute.

To make possible all of this SFI research, the Institute employs a support group of some 25 administrators and scientists who handle budgeting, publications, and related duties. Much of the funding for the Institute comes from National Science Foundation grants and from similar sources. Resident researchers typically stay for several months at a time. In addition, the Institute sponsors various summer programs that draw undergraduate students from all over the world. Each year, the Institute hosts summer graduate and undergraduate interns, sponsors a summer school problem in complexity science, and runs a two week "Complexity in Economics Program" for graduate students in economics. The Institute also helps to publish books, magazines, and articles related to current research, and several scientists have written popular science books based on their insights gleaned from SFI research.

The Santa Fe Institute has been the subject of many articles and books written by outside researchers and popular science and business writers who seem to be attracted to the eclectic and innovative research, but who at the same time also seem to be a bit suspicious. Several of these books are on display in a glass case near the entrance to the campus. In closing this section on the history of the SFI, it is worth mentioning briefly a few of the themes that have appeared in several of the popular science books. My purpose is to reveal the almost priestly aura that surrounds these scientists and their meeting ground in Santa Fe. I will return to some of these books later to explore their insights into metaphor at the Institute. Yet, for now the reader need only glean from the brief summaries the sense of profound significance that these authors ascribe to the Institute and its work, even when those authors are critical of that work.

The first popular book that was devoted almost exclusively to the Institute's history was M. Mitchell Waldrop's *Complexity: The Emerging Science at the Edge of Order and Chaos*, published in 1992. Waldrop, a particle physicist and writer for *Science* magazine, offers a narrative account of how various "old Turk" scientists, as he describes them, established the Institute in the mid 1980s. These veterans included various scientists from Los Alamos National Laboratories, including the former head of research, George Cowan, and several Nobel Laureates from various prestigious institutions, including physicists Murray Gell-Mann and Phil Anderson, and economist Kenneth Arrow. Waldrop is generally enthusiastic—at times even effusively reverent—about the interdisciplinary approach that launched the Institute. His book enjoys a mixed reputation at the Institute now, however; some see it as an accurate account of the Institute's founding, but others see it as an overly "gushy" work that focuses excessively on personalities.

The book by Stefan Helmreich I referred to earlier is called *Silicon Second Nature: Culturing Artificial Life in a Digital World*. This 1998 book is the product of Helmreich's doctoral research in anthropology at Stanford University. It considers the SFI as a site for cultural studies ethnographic research and offers many insights about the new "tribe" of artificial life scientists. Helmreich disdainfully paints a picture of the SFI as a male-dominated organization that is largely insulated from the outside world of Santa Fe, which includes a blend of old Hispanic cultures, new age artists, and gay emigrants. Helmreich explores language issues, writing that SFI scientists and others doing similar research have transformed the image of the computer from that of a tool of "bureaucratic rationality" to an organic metaphor for natural life (13). Helmreich writes that many of these scientists play the role of a paternalistic God in creating their "worlds" and in using religious terms to discuss their simulations. Some of the SFI people I spoke to about Helmreich's book acknowledge that he made interesting and often brilliant observations, but some say that many of his insights into the SFI culture are now dated.

Another book that considers parallels between SFI science and religion is George Johnson's *Fire in the Mind*, published in 1995, which narrates the author's ponderings and insights into the Santa Fe Institute and the current state of theoretical science in context of Northern New Mexico's mix of Catholic and Native American spiritual traditions. The book examines how information—whether it is the position of a sub-atomic particle or the body of cultural knowledge contained in a stone-aged tool—may be the most palpable manifestation of reality in the eyes of postmodern scientists. I consider this information-as-the-new-materiality theme throughout this project. Several SFI scientists recommended this book to me, although one wondered aloud what prompted Johnson, a noted *New York Times* science writer, to veer off onto a seemingly mystical tangent.

Several writers have expressed suspicion about the religious and philosophical overtones that seem to emanate from the Santa Fe Institute. For example, philosopher and cognitive studies theorist Daniel Dennett in his book, *Darwin's Dangerous Idea: Evolution and the Meaning of Life*, 1995, takes issue with Stuart Kauffman for the latter's claim that there is more to the origins of life than natural selection. Kauffman's arguments about emerging order may give people the false hope that God lies behind the scenes, Dennett writes (227). Kauffman's highly literary style of writing and his prolific use of metaphor perhaps contribute to the religious overtones that Dennett senses.

Scientific American writer John Horgan in his 1997 popular and provocative book, *The End of Science*, quotes scientists who claim that "complexity" and its cousin term "chaos" have been defined in so many ways that they cease to mean anything. Horgan argues throughout that scientific theories implying an underlying order behind random events are impossible to test because these theories assume a certain level of indeterminacy in the system. Science that cannot be tested or falsified veers perilously close to philosophy, Horgan argues. He suggests further that the SFI type of science is "ironic" in that it blends philosophy and science into a type of speculation about questions that may never be answered (7).