The Cosmic Web

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Part I

Mathematical and Scientific Models
. . . are the different styles of art an arbitrary product of the human mind? Here again we must not be misled by the Cartesian partition. The style arises out of the interplay between the world and ourselves, or more specifically, between the spirit of the time and the artist. The spirit of a time is probably a fact as objective as any fact in natural science, and this spirit brings out certain features in the world. . . . The artist tries in his work to make these features understandable, and in this attempt he is led to the forms of the style in which he works.

Werner Heisenberg, *Physics and Philosophy*

The significance of the conceptual revolution in science derives less from the field models themselves than from their philosophical and epistemological implications. It is what they imply not only about the nature of the world, but about how one interacts with the world, that is important in understanding how the new view differs from the older, atomistic perspectives. One of the most important of these implications is that the Cartesian dichotomy between the *res cognitans* and the *res extensa*, the thinking mind and the physical object, is not absolute, but an arbitrary product of the human mind. Classical physics assumed that it was possible to make a rigorous separation between the observer and what she or he observes. Relativity theory and, in a different way, quantum mechanics require that the separation into an observer and a physical system be regarded as an arbitrary distinction entailing approximations that are not always negligible.

The breakdown of the Cartesian dichotomy also has methodological
Implications. When things are thought to exist "out there," separate and distinct from the observer, the world has already been divided into two parts. The next step is to subdivide it further by regarding the exterior world also as a collection of parts. The parts, because they are intrinsically separate and individual, can then be analyzed sequentially as individual units; this is of course how Aristotelian logic proceeds. As long as the world is conceived atomistically, this approach is appropriate and, at least in theory, exact to any desired degree of accuracy. But the field concept has the effect of revealing limitations in sequential analysis. These limitations are especially likely to appear when the whole is (or can be considered as) a part of itself.

For example, consider a set $\phi = \{a, b, c, d, \ldots\}$. In this example there is no problem in regarding the set $\phi$ as the whole, and each of the elements $a, b, c, d$ as parts of that whole. But now imagine a set $a = \{a, b, c, d, \ldots\}$. From one perspective $a$ is the whole itself, the entire set of elements enclosed within brackets. But from another perspective, $a$ is a part of the whole, that is, one of the elements within the set. This problem is typical of paradoxes that arise from the field concept; it reveals an essential fallacy in the assumption that a whole can always be adequately defined as the sum of its parts. When classical, sequential analyses are applied to situations of this kind, paradoxes can become irresolvable antinomies.

I should like to turn now to more precise terminology and examine in some detail two examples in which the appearance of this kind of ambiguity proved to be decisive. In both cases, the paradoxes were revealed as a result of ambitious programs to extend the domain of classical analysis: in mathematics, the formalist program to prove that mathematics was free from contradiction; and in the philosophy of science, the positivist program to create an exact, objective language for science. These first examples are meant to convey a sense of how the generalizations I have been making about the field concept translate into specific examples from science. It is possible to see in them intimations of the complexities symbolized by the cosmic web.

In the early part of this century, the German mathematician David Hilbert suggested that it should be possible to prove that mathematics is free of contradictions by formalizing, one by one, the axiomatized theories of mathematics. Ernst Snapper, in a prize-winning article on
the philosophical roots of mathematics, explains that to “formalize” an axiomatized theory $T$ means (confining ourselves to first-order examples) to choose a first-order language $L$ so that all of the undefined terms that appear in the axioms of $T$ can be expressed through parameters of $L$. It is then possible to express in $L$ all the axioms, definitions, and theorems of $T$, as well as all the axioms of classical logic. In this approach, one manipulates the symbols of $L$ by means of exact syntactical rules, without necessarily being concerned about the content of the symbols. The advantage of creating the language $L$ is that $L$ can then be studied as a mathematical object in itself, independent of the content of $T$. Hilbert hoped that a theory $T$ could be proved free of contradiction by demonstrating that all of the allowable syntactical combinations of $L$ were free of contradiction.

At the heart of this formalist program is the attempt to create a vantage point from which one could talk about mathematics as an object in a language that would not be contaminated with what it was one wished to prove. The Hilbert program rested on the assumption that it is possible to make a rigorous separation between the theory and the theory-as-object.

The hope that this strategy would succeed was shattered in 1931 with the publication of Kurt Gödel’s paper, “Formally Undecidable Propositions in Principia Mathematica and Related Systems.” In this paper Gödel proved that for the mathematical system of the Principia, or more generally for any axiomatized theory with axioms strong enough so that arithmetic can be done in terms of them, the theory either will be inconsistent or will contain propositions whose truth cannot be demonstrated. Since inconsistencies are naturally to be avoided, mathematics finds itself impaled on the other horn of the dilemma; that is, it will

1Ernst Snapper, “The Three Crises in Mathematics: Logicism, Intuitionism and Formalism,” Mathematics Magazine, 52 (September 1979), 207–216. This article won the coveted Allendoerfer Prize in Mathematics for 1979.

contain propositions that cannot unambiguously be proven to be either true or false.

Formally undecidable propositions had long been known and formulated through various paradoxes. One classic illustration is as follows. On the first side of a piece of paper write the words “The statement on the other side is true.” Now turn the paper over and write “The statement on the other side is false.” Let us consider first Side 1 asserting that Side 2 is true. If Side 2 is true, however, then Side 1 is false. But if Side 1 is false, then Side 2 is not true, in which case Side 1 is true. One can pursue this line of reasoning forever without being able to reach a conclusive answer. The two statements together involve what Douglas Hofstadter calls a “Strange Loop,” a loop of reasoning that cannot be resolved because to accept either statement as true is to begin a loop which circles around to say that the same statement must be false. It is obvious such statements can be neither true nor false; they are inherently undecidable.

One way to analyze a Strange Loop is to consider it as a problem in self-reference. Each statement points to the other, and the other in turn points back, so that there is no independent vantage from which to evaluate either one. The Hilbert program had hoped to avoid this problem by separating the language L from the theory T. But this hope proved to be unfounded when Gödel demonstrated that it was possible to talk about number theory from within the theory itself. The problem of self-reference was thus revealed as unavoidable. Douglas Hofstadter explains:

Gödel had the insight that a statement of number theory could be about a statement of number theory (possibly even itself), if only numbers could somehow stand for statements. The idea of a code, in other words, is at the heart of his construction. In the Gödel Code... numbers are made to stand for symbols and sequences of symbols. And this coding trick enables statements of number theory to be understood on two different levels: as statements of number theory, and also as statements about statements of number theory.

Using this method, Gödel was able to map statements about numbers

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4Hofstadter, p. 18. The italics are his.
into the number system itself. Recall that Hilbert's axiomatization attempted to create a strict separation between the theory and the theory-as-object. By making numbers stand for theoretical statements, Gödel circumvented this separation and thereby involved theoretical statements about numbers in paradoxes of self-reference, since numbers then became statements about numbers. These paradoxes led to the same sort of circular reasoning we saw earlier, with the result that the statements so involved could not be proven to be either true or false. Through this mapping procedure, Gödel was able to demonstrate that theories capable of embracing the theory of whole numbers cannot be both complete and consistent. If they are not inconsistent, then they will be incomplete, in the sense that they will contain statements which cannot be proven to be true under their axioms.

What happens if one takes the statements one cannot prove and converts them to axioms? (Axioms, of course, are unproven statements.) In this case one has generated a new theory, because the set of axioms has changed; and in this new theory, new statements will arise that cannot be proven within that system. If these new statements are in turn converted into axioms, still other statements will arise elsewhere in the system that cannot be proven under those axioms. The process is interminable.

The implication of Gödel's theorem, then, is that any theory that is not demonstrably false cannot be demonstrated to be completely true. Thus the program to prove all of mathematics true did not succeed. This does not necessarily mean that mathematics is false, of course—only that it cannot be proven true. The crux led Hermann Weyl to say that God must exist because mathematics is intuitively consistent, and the devil exists because it cannot be proven to be consistent. Whatever intuitive consistency one may grant mathematics, however, the inability to prove the truth of number theory is significant, for it reveals that even in mathematics, the most exact of the sciences, indeterminacy is inevitable.

Nor, it turns out, is this indeterminacy confined to axiomatic mathematics. It also appears in computation theory, in a problem that Martin Davis calls the Halting Problem. ⁵ The question that the Halting Prob-

lem asks is whether it is possible to determine in advance if a computer will be able to find a definite answer—that is, come to a halt—for any given problem. The question has practical importance, for if it cannot be answered, one can suddenly find one's computer involved in a Strange Loop of its own, which consumes expensive computer time and, in extreme cases (as in the infamous “page fault” error), renders the program useless. The answer to the Halting Problem, Davis explains, is no: there will be some computations which cannot be proven in advance either to have a solution or not to have a solution, in much the same way that the Incompleteness Theorem says that there are some statements within number theory which cannot be proven to be true or false. In fact, Davis shows how Gödel's theorem (the Incompleteness Theorem) can be restated in terms of the Halting Problem, so that if the Halting Problem had a solution, the Incompleteness Theorem could not be true. Therefore, since the Incompleteness Theorem is true, the Halting Problem will not have a solution. The important point is that certain kinds of logical problems have no solution, not even using the most sophisticated computers imaginable. Davis makes this point explicitly: “Note that we are not saying simply that we don’t know how to solve the problem or that the solution is difficult. We are saying: there is no solution.”

What the Incompleteness Theorem does in mathematics, and what the Halting Problem does for the linear sequences of binary choices that comprise computer programs, is to imply that certain limitations in linear analysis are inescapable because of the problem of self-reference. It is because the tools for analysis are inseparable from what one wants to analyze that Strange Loops appear. In these examples, problems that cannot be solved through logical analyses appear as a result of considering both the tools for analysis, and the object to be analyzed, as part of the same “field.” They illustrate one way in which the emergence of a field approach has revealed limits to classical logic.

In his introduction to City of Words, Tony Tanner explains that he has taken his title from the common thread he finds in contemporary fic-

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6 More technically, the problem asks whether there is a way to decide in advance if a universal program of the Church-Turing type will halt, given an initial input; Martin Davis explains these terms in detail, pp. 241–267.

7 Davis, p. 255.
tion: its “foregrounding” of language. Tanner’s book has been influential not because it consistently maintains this focus—one reader complains that it degenerates into a “City of Themes”—but because, in suggesting that modern fiction is deeply concerned with the self-conscious use of language, Tanner has put his finger on a major characteristic of twentieth-century fiction. Modern readers are experiencing the same kind of situation that mathematicians experienced when Gödel’s theorem burst upon the scene: the object for analysis (the text, number theory) refers self-referentially to that of which it is composed (language, statements within number theory). Like Gödel’s theorem and the Halting Problem, modern fiction tends to place us within rather than outside the frame, so that when we speak about it, we are speaking from within the picture that contains us. The resulting paradoxes have sparked important debates and theoretical work in literary criticism.

As we shall see in Chapter 6, Borges is well aware of this conjunction between mathematical and literary self-referentiality. In his story “The Aleph,” Borges looks into a small sphere, “less than an inch in diameter,” that contains everything in the earth, including another Aleph that contains within itself another earth . . . Borges’s name for this sphere playfully alludes to Cantor set theory, for Georg Cantor chose to name his infinite sets “Alephs.” The paradoxes that surfaced as a result of these infinite sets were instrumental in causing mathematicians to feel that it was necessary to axiomatize mathematics, and this in turn led to a realization that the paradoxes were not accidental but intrinsic to the structure of mathematics. As we explore these connections in Chapter 6, we shall see how, by transforming a scientific model into a literary sign, Borges makes it the basis for his distinctive narrative mode.

In the next example, the parallel between science and literature is even more apparent, for here the scientific debate was explicitly concerned with the nature of language. In the wake of the great successes of Newtonian mechanics, it seemed to many scientists that all physical phenomena would eventually yield to mechanical descriptions. Consider—

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9An observation—and a phrase—that is the subject of Richard Pearce’s “Enter the Frame,” TriQuarterly, 30 (1974), 71–82.
erable attention was therefore devoted to refining scientific discourse so that it would establish unambiguously the link between this predictable reality and the theory that predicted it. The goal of the positivists was to "purify" language by removing from it anything that could not be empirically verified or logically demonstrated—in short, anything suspected of being "metaphysical." Statements that had "cognitive significance" were to be composed of three, and only three, kinds of terms: observational statements taken directly from experiment; theoretical terms; and logical terms indicating how the other two kinds of terms should be combined. Statements that did not fulfill these criteria did not possess "cognitive significance," or in plain words, were nonsense. 

It was thought possible to extend the program beyond the experimental sciences into related fields such as the philosophy of science, and indeed to any field that proposed to engage in cognitively meaningful discourse. The attempt to reform scientific discourse is similar to Hilbert's mathematical program in that both strove for rigor by separating the object of discourse from the theory interpreting it. Like the Hilbert program, the positivist program failed when it was recognized that language creates a field that encompasses the observer as well as the observation.

In his history of the positivist program, Frederick Suppe recounts how the positivistic view of language, the heart of what he calls the "Received View" of scientific theories, was predominant in the philosophy of science through the early years of this century. The "Received View" held that it was possible to distinguish unambiguously between theory and observation, and therefore possible to establish well-defined logical rules of correspondence between the two. The Received View came under increasing attack because the distinction between "observational terms" and "theoretical terms" could not be sustained as rigorous or complete. N. R. Hanson, for example, argued that what we see depends upon our cultural, scientific, and linguistic contexts. Hanson pointed out that what the Received View had called "observational

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10Positivists did recognize a genre called "emotive discourse," but whether this could be said to have meaning was considered problematic.


12N. R. Hanson, Patterns of Discovery (Cambridge: Cambridge University Press, 1958); Suppe summarizes Hanson's views at pp. 151–166.
terms" were in fact not sensory data per se, but sensory data as interpreted, at the very least, through an experimental apparatus that already had certain assumptions built into it, as well as through the unconscious perceptual sets of the observer. The positivist program was gradually yielding to the Weltanschauungen argument that observation was inherently theory-laden.

Thomas Kuhn took the argument further by suggesting that scientists, during their apprenticeships in their fields, absorbed a set of more or less unconscious assumptions about how science was "done." These assumptions, transmitted by learning model experiments or by mastering currently accepted theories, comprise the intuitive part of what Kuhn called the "paradigm" for that field. Kuhn pointed out that there are always known facts that contradict accepted theories; but these will be ignored as long as the paradigm allows enough other data to be correlated satisfactorily. It is only when the paradigm begins to break down that anomalies will be noticed, or even reported. Only in this period of "revolutionary science," as Kuhn called the transition between paradigms, does an open-ended search for new kinds of facts come into play.

Michael Polanyi developed similar arguments in his analysis of "tacit knowledge," that is, knowledge which is in some sense known, but which cannot be formulated explicitly. It is the scientist's "tacit knowledge," Polanyi contends, that guides him to the interesting fact, the one datum or experiment out of thousands that will prove useful. According to Polanyi, without this "tacit knowledge" science would degenerate into aimless forays or trivial experiments; it is the scientist's intuitive and nonverbal knowledge that gives direction to scientific inquiry and guides him toward significance.

Hanson, Kuhn, and Polanyi (along with others too numerous to mention here) have in common the belief that the distinction between "objective" facts and "subjective" reactions cannot be made in a complete

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or rigorous way.\(^\text{15}\) They believe that what appear to be the "objective" facts of science are inextricably linked with important intuitive elements that are not susceptible to formal analysis or articulation. In this view, it is not possible to separate the observation from the scientist who observes. That the scientist's cultural and linguistic set helps determine what he or she sees implies that there is no way to create a language of observation that will not contain subjective elements. Thus self-referentiality has also entered in a crucial way into the question of whether it is possible to express scientific results in an objectively exact language. It has proven impossible to create such a language because the terms that comprise it already contain assumptions that cannot be validated independently of the language.

In *Zen and the Art of Motorcycle Maintenance* Robert Pirsig develops a similar argument by pointing out that any analytical hierarchy is created by an observer wielding a knife, even though the passive constructions of Aristotelian rhetoric work to conceal both the knife and, behind it, the observer who determines where the cuts will be made. In trying to find a rhetoric that will acknowledge that "part of the landscape, inseparable from it . . . is a figure in the middle of it, sorting sands into piles," Pirsig involves himself in the same paradoxes that the positivists encountered, for he himself is also "in the landscape," sorting into "piles" the different levels of narrative within his text. As we shall see in Chapter 3, it is when the narrator recognizes this paradox that the text comes to its climax and explodes into a series of contradictions that Pirsig cannot altogether control.

Concerning the two scientific examples discussed so far, the formalist program to reform mathematics and the positivist program to reform scientific discourse, a number of key issues have arisen—indeterminacy, self-referentiality, and the inability to make an unambiguous separation between subject and object—and they are linked by a common concern for the language. Recall that Gödel's theorem, the Halting Problem, and the *Weltanschauungen* analyses all emerged in response to programs that attempted to create a formally exact language. The question of how

\(^{15}\) So successful have these *Weltanschauungen* analyses been that the trend in the philosophy of science now is alarm that we might lose sight of the logical and rational elements in science—see, for example, Suppe's "Afterword—1977," pp. 619–730. Although the field is still in disarray, it seems safe to say that any new view around which these positions might consolidate will have to incorporate at least some elements of the *Weltanschauungen* argument.
language is used, or, more accurately, how its use is perceived, is crucial because language mediates across the subject-object dichotomy. When this dichotomy is redefined in a the field concept, the perception of how language functions also changes.

Why language should play this key role will be apparent if we review the differences between the atomistic and field perspectives of language. In the atomistic view, the gap between subject and object is not "contaminated" by the circular paradoxes of self-referentiality because it is assumed that reality can be divided into separate, discrete components. Consequently, it is assumed that language can be used to define the relation between subject and object in a formally exact way. But the field concept assumes that these components are interconnected by means of a mediating field. When language is part of the mediating field (i.e., the means by which the relation between subject and object is described), it participates in the interconnection at the same time that it purports to describe it. To admit the field concept thus entails admitting that the self-referentiality of language is not accidental, but an essential consequence of speaking from within the field. As we have seen in a number of cases, when the atomistic approach failed it was because it proved to be impossible to create a language that would be free from problems of self-referentiality. Thus the shift from atomistic models to the field concept had the effect of bringing the self-referentiality of language into focus.

We are now in a position to develop further the parallels between modern literature and modern science. The modern novel emerged from exploring the Cartesian dichotomy in literary terms; or, to put the proposition in its more usual form, from exploring the relation between the teller and the tale. Modern physics developed from exploring the Cartesian dichotomy in scientific terms; or, to state it in its accustomed form, by exploring the relation between the observer and the observed system. Literary readers are well acquainted with the former assertion, scientific readers with the latter. What has not been sufficiently recognized by either is the isomorphism of the two propositions, and the resulting implication that both entail the self-referentiality of language. As self-referentiality of language is virtually the defining characteristic of post-modern criticism and texts, so is it also of post-Newtonian science. Whether the topic under discussion is Gödel's theorem or Gravity's Rainbow, self-referentiality is a crucial issue.
MATHEMATICAL AND SCIENTIFIC MODELS

It also figures in an important way in the metaphor of the cosmic web, for it is what makes the web "sticky." This "stickiness" will become increasingly apparent as we turn to quantum mechanics and particle physics. First, however, it will be useful to understand in a more precise way how the assumptions of the older atomistic models, especially Newtonian mechanics, both reinforced and relied upon the Cartesian dichotomy, since it is the breakdown of the Cartesian dichotomy that brings the self-referentiality of language into focus as an important issue.

In classical mechanics, the physical world was considered to be composed of isolated objects separated from one another in an empty space that was rigid and unchanging, with a universal "now" pervading all space at any given moment. Because time was handled as though it consisted of a succession of universal moments, there was never any ambiguity about the order of events. Hence causality could be unidirectional and absolute. Moreover, the kind of causality predicted by the equations of classical mechanics was thought to have been laid down at the creation of the world as immutable principle. Albert Einstein recounts how the generations of physicists preceding him believed that "God created Newton's laws of motion together with the necessary masses and forces . . . everything beyond this follows from the development of appropriate mathematical models by means of deduction."

Since these laws were unchanging, they held good for the indefinite future. It was in theory enough to know the initial set of conditions and Newton's equations of motion to predict any future state, assuming only sufficient intellect (or computer space) to do the calculations. The great French mathematician Pierre Laplace imagined "an intellect which at a given instant knew all the forces acting in nature, and the position of all things of which the world consists"; this vast intellect could then "embrace in the same formula the motions of the greatest bodies in the universe and those of the slightest atoms; nothing would be uncertain for it, and the future, like the past, would be present to its eyes." In the classical model, the emphasis thus fell on well-defined interactions that could be exactly predicted by the Newtonian equations

of motion and projected infinitely far into the future. The equations themselves were considered immutable and complete, not susceptible to further change or modification.

These assumptions also had important methodological implications. Because interactions were unidirectional, the dominant mode by which systems were related to one another, and hence the dominant mode of analysis, were causal. Because the physical world consisted of discrete bodies separated in space, analysis of systems could be carried out through interlocking series of discrete logical steps. Because systems were already inherently discrete, there was no problem in separating the observer from what he observes. And finally, because the physical world existed "out there," independent of the observer, it was determinate and infinitely knowable. There were no theoretical limits to how much the rational mind could understand about the physical world because the mind, in understanding physical reality, did not have simultaneously to understand itself.18

All of these assumptions were fundamentally questioned, and finally overthrown, by developments emerging from two papers that Albert Einstein published in 1905. One, drawing on Max Planck's suggestion that light was quantized, was instrumental in the creation of quantum mechanics; the second set forth the Special Theory of Relativity. With these two seminal papers, the new physics was launched. In a little over a decade Einstein would extend his conclusions to the General Theory of Relativity. Meanwhile, intense attention was being devoted to quantum phenomena, and by 1927 the mathematical formalism of quantum mechanics was essentially complete. With the formalism and theories in place, the debate on what they meant began in earnest. What became increasingly clear throughout the subsequent decades was that the new scientific models implied not only a new physics, but a new world view.

Before physicists became concerned about such questions as self-referentiality, indeterminacy, and the lack of a rigid separation between

18For a fuller and more precise explication of the model of reality implied by Newtonian mechanics, see Clifford Hooker's excellent analysis in "The Nature of Quantum Mechanical Reality: Einstein versus Bohr," in Problems and Paradoxes: The Philosophical Challenge of the Quantum Domain, ed. Robert G. Colodny (Pittsburgh: University of Pittsburgh Press, 1972), pp. 69-72. Hooker concludes his analysis of the classical model of reality with this observation: "The general conception of the physical world conveyed in the preceding statements will no doubt be familiar to the reader. It is a measure of the revolution brought about by the advent of the quantum theory that every one of these claims has been challenged" (p. 72, italics his).
subject and object, they encountered the startling ways in which the field concept transformed traditional views of time and space. With characteristic generosity Einstein, in a tribute written on the hundredth anniversary of James Clerk Maxwell's birth, attributes to him this revolutionary change in notions of physical reality. Maxwell is remembered for his work in developing a field theory that united magnetism and electricity into the single entity that is now called the electromagnetic field. Before Maxwell, Einstein remarks, “people conceived of physical reality—in so far as it is supposed to represent events in nature—as material points, whose changes consist exclusively of motions, which are subject to total differential equations. After Maxwell they conceived physical reality as represented by continuous fields, which are subject to partial differential equations.”

Maxwell had established the notion of a field as a concept equal in explanatory power to the Newtonian idea of material points when he showed how electromagnetic phenomena (including light) could be represented through a system of differential equations. Even a writer like D. H. Lawrence, who understood little of the mathematics, grasped the essence of this change and fashioned a literary model of it in the “polarities” and “fields” that we shall encounter in Chapter 4. Lawrence understood also that Einstein was connected with this transformation and that Einstein, even more than Maxwell, was “knocking that eternal axis out of the universe.” In this premonition Lawrence was correct, for it was Einstein who, in relativity theory, gave Maxwell's classical notion of a field its most powerful expression.

So much nonsense has been written on the implications of relativity that one can sympathize with Martin Gardner's abrupt dismissal of the topic in his popular book on relativity. “If the reader wonders why the book contains no chapter on the philosophical consequences of relativity,” Gardner remarks, “it is because I am firmly persuaded that in the ordinary sense of the word 'philosophical,' relativity has no consequences.”

Gardner's assertion is an overstatement, for as he goes on to admit, relativity theory does have important epistemological implica-

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tions. But it is necessary to sort out what relativity does and does not imply.

Relativity does not imply that "everything is relative." Indeed, before he settled on "relativity," Einstein had considered calling his hypothesis the "Theory of Invariance." In his Autobiographical Notes Einstein says that he believes scientific theories should possess what he calls "logical simplicity," that is, that their fundamental postulates should not be the result of arbitrary restrictions but should flow naturally from the initial conception.21 What Einstein found "particularly ugly" about Newtonian mechanics was that it gave special priority to stationary or nonaccelerating systems over all other kinds of rigid systems, without it being obvious why this should be so.22 Similarly, it had been hypothesized that it was possible to define absolute motion by regarding all motion as taking place within an "ether," an invisible and virtually undetectable medium that was supposed to permeate space. In retrospect it is evident that these restrictions were necessary to preserve congruity with everyday experience. As Werner Heisenberg points out, the concepts of classical physics—mass, velocity, momentum, force—are simply the experiences of everyday life cast into more exact and rigorous terms.23

Relativity theory, by contrast, derives many results that are startlingly at odds with everyday experience. Rather than beginning with "common sense," Einstein's thought was guided by a search for harmony among fundamental principles. It is this, rather than its extraordinary predictions, that struck Cornelius Lanczos, a physicist of Einstein's generation, as the most revolutionary aspect of relativity theory. Einstein saw science in a new light, Lanczos comments. "To him science did not mean the primacy of the experiment or the primacy of the theory, but the primacy of a deep reverence for the all-embracing lawfulness which manifests itself in the universe."24

Einstein's allegiance to fundamental principle can be seen in his account of how he arrived at the Special Theory. When he was sixteen, Einstein tried to imagine how a light wave would look to someone

21Einstein, Autobiographical Notes, p. 21.
22Ibid., p. 25.
traveling at the speed of light.\textsuperscript{25} He decided that to such an observer, the light beam would appear as a standing wave, oscillating back and forth without forward movement. This result puzzled Einstein not only because it was contradicted by Maxwell’s equations, which implied that nonpropagating light was impossible, but more fundamentally because it implied that phenomena can appear different from different vantage points. Einstein decided that if he had to choose between the laws of physics being universal or phenomena appearing invariant, he would choose the laws of physics. In the Special Theory, Einstein begins by assuming that the laws of physics should not depend on whether one is at rest or in uniform motion. He also assumes that the velocity of light in a vacuum is constant, regardless of the motion of its source. In order to preserve these invariances, Einstein reasoned that motion could only be defined relative to some arbitrarily chosen reference frame. With this reasoning, Einstein arrived at the now-familiar predictions that measurements of time, mass, and length are not absolute quantities but subject to change, depending on the reference frame from which they are made.\textsuperscript{26} Paradoxically, these quantities are made relative so that others may become absolute. The primary absolute is that the laws of physics remain invariant for any rigid system in uniform motion.

A more sweeping absolute emerges from the interpretation that Hermann Minkowski, the Polish mathematician, gave to the interdependence of time and space in the Special Theory. As he set forth his interpretation before an assembly of colleagues, Minkowski predicted, “Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality.”\textsuperscript{27} In the Minkowski interpretation, time and space are combined into the four-dimensional matrix of “spacetime.” It is when this four-dimensional matrix is projected into the three dimensions of traditional Cartesian space that different observers can disagree about what happened. If, however, time is added as a “fourth dimen-


\textsuperscript{26} It should be emphasized that the relativity of these quantities is not merely a perceptual ambiguity in the observer. The most sensitive instruments (for example, nuclear decay clocks) will record a time that is not absolute, but relative to the reference frame to which they are attached. Bertrand Russell makes this point with special clarity in \textit{The ABC of Relativity}, rev. ed. (Fair Lawn, N.J.: Essential Books, 1958), p. 133.

sion,” the resulting (four-dimensional) description will be the same for all observers. By thus expanding the traditional three-dimensional Cartesian space into a four-dimensional matrix, invariance is achieved. In E. F. Taylor and J. A. Wheeler’s words, “Space is different for different observers. Time is different for different observers. Spacetime is the same for everyone.”

The absolute time and absolute space of Newtonian physics have thus given way to a new absolute composed of both time and space.

In the General Theory, Einstein extended his conclusions by postulating that the laws of physics are invariant not only for bodies in uniform motion but also for bodies in accelerating motion, so that the long-recognized equivalence of gravitational mass and inertial mass (the “weight” an accelerating object will assume in space, as a result of inertial resistance to the acceleration) is established theoretically. Thus not only the choice of reference frame became arbitrary, but also the type of motion, for accelerating systems are treated in the General Theory with the same equations as nonaccelerating or stationary systems. As a result, a radically different view of spacetime emerged. In the General Theory, gravitation is seen not as some mysterious force that mass exerts over distance, but as a result of the nature of spacetime itself. Einstein suggested that we should think of spacetime as being curved around large masses, and that it is this curvature which accounts for gravitational phenomena. Spacetime, in this view, is not an empty container for mass. Rather it exists, and is given its characteristic structure, because of the distribution of mass. Indeed it cannot, properly speaking, be considered apart from mass. Whereas the Special Theory joined space and time into the single field of spacetime, the General Theory further correlated spacetime and mass, regarding gravitation as a physical expression of the interaction between them.

In both the Special and General Theories, then, Einstein arrived at a view of physical reality that transformed the isolated entities of Newtonian mechanics into unified, mutually interacting systems. Instead of seeing time as a series of independent and omnipresent moments, Einstein conceived of it as inextricably linked with space to form the four dimensions of spacetime; instead of thinking of space as a rigid container, Einstein postulated that it took its structure from matter; instead

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28The passage is from Spacetime Physics, quoted in Gardner, p. 101.
of seeing energy and matter as fundamentally separate and inconvertible, Einstein showed that they are essentially equivalent and potentially interconvertible. In all these results, relativity theory had the effect of transforming isolated parts into an interconnected whole. In seeing fundamental interconnections between entities that had been discrete quantities in classical physics, Einstein helped to prepare the way for a field concept of reality—whose more radical implications, however, he was to resist for the rest of his life. Einstein deeply believed in causality, in an objective world that exists independently of human perception, and in the universal truth of scientific law. As we have seen, all of these notions come into question when the field concept is expanded to include the language of observation, whether natural or scientific. With quantum mechanics, especially as interpreted by Niels Bohr, this expansion took place within physics itself.

Meanwhile, even Einstein’s classical formulations were disquieting to many of his contemporaries, because they involved a new way of looking at the world as an interconnected, mutually interactive unity. Cornelius Lanczos recounts how a colleague walked out of an early seminar on relativity in disgust, remarking “I am a physicist, not a philosopher.” Lanczos himself admits, “To get used to this much more abstract way of thinking [necessitated by relativity theory] was not easy.”29 But he also argues that the “gradual abstractization of our primitive concepts” that “may appear on the surface as a loss” is more than offset by the gain. “We admit the loss of simplicity,” Lanczos remarks, “but we are willing to pay the price for the tremendous advance in unity.”30 Einstein himself saw the advance in unity as the decisive factor. In a lecture at Princeton University in 1921, Einstein commented: “The possibility of explaining the numerical equality of inertia and gravitation by the unity of their nature gives to the general theory of relativity, according to my conviction, such a superiority over the conceptions of classical mechanics, that all the difficulties encountered must be considered as small in comparison.”31

But this is unity of a very special kind. If relativity asserts that apparently different phenomena follow the same general laws, it emphasizes that our particular experience of those phenomena is not especially

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30Ibid., p. 110.
31Quoted in Gardner, p. 83.
privileged. The angle from which we view the universe is only one among many, no more (or less) valid than any other. Relativity theory permits a more general formulation of the laws of physics; but at the same time any perspective from which we might actually view the world is made partial and contingent.³²

Relativity, then, contains two fundamental and related implications that were to be absorbed into the field concept: first, that the world is an interconnected whole, so that the dichotomies of space and time, matter and energy, gravity and inertia, become nothing more than different aspects of the same phenomena; and second, that there is no such thing as observing this interactive whole from a frame of reference removed from it. Relativity implies that we cannot observe the universe from an Olympian perspective. Necessarily and irrevocably we are within it, part of the cosmic web.

It is precisely this relativity of viewpoint that Nabokov resists in Ada, though he is eager to explore the related proposition that relativistic time is not susceptible to uniform measurement. Nabokov's treatment of relativity theory in Ada is as selective as his narrator's, who renounces the "space-tainted, space-parasited time . . . of relativist literature" while still arguing that the measurement of "real" time is variable. The implicit strategy behind this selectivity is at the center of the discussion in Chapter 5, for it reveals how an artist can shape a model for his own ends, and how this shaping can be at once scientifically incoherent and artistically powerful. For this purpose Ada is a key text, because the ambiguities and tensions between what Nabokov borrows from relativity theory and what he rejects are central to the novel's artistic strategies.

If Einstein is the father of relativity theory, he is the disapproving stepfather to quantum mechanics, the discipline sparked by his other

³²The partiality of our own perspective should not be confused with the absolute spacetime projected through the Minkowski diagrams. David Bohm, in The Special Theory of Relativity, comments that when viewing Minkowski diagrams, "almost unconsciously, one is led to adopt the point of view of an observer who is, as it were, standing outside of space and time . . . surveying the whole cosmos from beginning to end" (p. 173). But as Bohm points out, the feeling is an illusion. Any human observer is necessarily in space and time, and so always in fact occupies a point within the diagram. Similarly, the timeless nature of the Minkowski diagrams (timeless in the sense that time is encompassed in the spacetime matrix) should not lead us to think that this reality already pre-exists. Relativity theory, insofar as it says anything about the future, is fully consonant with seeing it as a Becoming rather than a Being. Milic Čapek discusses this point extensively (pp. 214–243).
early paper. Relativity theory established a connection between the observer and the observation; in quantum mechanics, they are wed into an indissoluble whole. Despite profound philosophical differences, quantum mechanics is like relativity theory in that it joins together concepts that were quite distinct in classical physics—particles and waves. In classical physics, matter consisted of discrete particles that were localized in space and that had a definite trajectory through time. Electromagnetic waves, on the contrary, propagated through space much as sound waves do through the air, and hence were nonlocalized and capable of interference phenomena. But the two-slit experiment on electrons showed that in some circumstances electrons displayed interference phenomena, while the photoelectric effect demonstrated that light can act as if it were composed of a stream of particles. Electrons thus sometimes act like waves, while light sometimes acts like particles. This ambiguity is formalized in the Heisenberg Uncertainty Relation, which is a mathematical expression of the limits within which a particle can be localized. The Uncertainty Relation is concerned with how precisely the position and momentum of a particle can be known simultaneously.\textsuperscript{33} The more sharply the one value is determined, the more diffuse the other becomes; the product of the uncertainties in momentum and position cannot be less than a universal constant known as Planck’s constant.

The wave/particle duality is further expressed in the mathematical functions that quantum mechanics uses to describe “particle” behavior. These are wave functions of finite length, or “wave packets.” Because particle density varies in accord with the wave function, the expressions can be interpreted as the probability that the “particle” will be at a given location. But the particle in quantum mechanics should not be thought of as a particle in the classical sense. It is not a discrete entity localized in space, but a “probability wave,” the probability expressing the particle’s “tendency to exist” at a given point.

One of the earliest physical interpretations of the Uncertainty Relation, still given in many textbooks,\textsuperscript{34} came from Heisenberg’s “thought

\textsuperscript{33}The Uncertainty Principle can be extended to any two conjugate variables that do not commute in quantum theory, for example time and energy.

"experiment" with a gamma-ray microscope. By closely analyzing how a very small particle—for example, an electron—is “seen,” Heisenberg showed that the quantum of light used to observe the electron is sufficient to change the particle’s momentum. Therefore, by the time the image is reflected back to the microscope lens, the particle is no longer following the same path it was because observing it has also disturbed it. If light of a lower frequency (and hence less energy) is used so as to disturb the particle less, the longer wavelength means that the reflected image will not be as sharply localized. Thus, as the momentum becomes more precise because the particle is not disturbed as much, the position measurement grows less precise. The more precisely the momentum is known, the less precisely the position can be known.

Heisenberg’s analysis had a revolutionary impact because it made clear that the indeterminacy set forth by the Uncertainty Relation is not just a result of limitations in the measuring instruments, but fundamental to the process of measurement itself. It implies that there is no way to measure a system without interacting with it, and no way to interact with it without disturbing it. The observer and the system, or as Heisenberg occasionally said, the subject and object, are thus seen as an inseparable whole that cannot be subdivided without introducing the indeterminacy specified by the Uncertainty Relation.

Its continued popularity notwithstanding, Heisenberg’s “disturbance” language raises perplexing questions. Are we to understand, for example, that the particle had a determinate value before it was measured? Heisenberg sometimes answered by asserting that it is not meaningful to talk about a reality that by definition could never be measured; whether in fact there is a reality “out there,” prior to measurement, in this view is irrelevant. Under the influence of Niels Bohr, Heisenberg gradually came to the view that the process of measurement in some way determines the values, brings into actuality what was before a potentiality. In Physics and Philosophy, Heisenberg argues that in any physical experiment, “what we observe is not nature in itself but nature exposed to our method of questioning.”35 He therefore suggests that we should replace the concept of an objective reality as a thing-in-itself (Ding an Sich) with the Aristotelian idea of a “potentia.” This “potentia” is “something standing in the middle between the idea of an event

35Heisenberg, Physics and Philosophy, p. 58.
and the actual event, a strange kind of physical reality just in the middle between possibility and reality."36 According to Heisenberg, through interaction with the observing system the potential is partly transformed into actuality, though its quality as a "potentia" is never completely lost; some indeterminacy (implied by the Uncertainty Relation) remains.

Heisenberg frequently speaks of Bohr’s interpretation of the Uncertainty Relation as if it were synonymous with his own. Partly because of this, the two together have come to comprise what is usually called the “Copenhagen interpretation.” But as Clifford Hooker observes in his excellent analysis of Bohr’s philosophy, Bohr’s position was really quite different. Bohr never endorsed the “disturbance” concept of Heisenberg. Rather, in his view, the Uncertainty Relation was deeply bound up with the limitations of language. Bohr’s long-time colleague Aage Petersen recounts how Bohr loved to repeat that “we are suspended in language.”37 In Bohr’s view, the question of language is crucial; and it is in his philosophy that the connecting links between a field view of language and the field concepts of quantum mechanics are clearest.

According to Bohr, we define matter and energy through the terms of classical physics as either particles or waves; but because they are neither one nor the other, either description will be incomplete in precisely the way laid down by the Uncertainty Relation. What the Uncertainty Relation implies is a “quantum of action,” a term that Bohr took over (its usual meaning is the numerical value of Planck’s constant) to denote an area within which no further distinction between the observer and system is possible. “The fundamental postulate of the indivisibility of the quantum of action,” Bohr writes in an early essay, “... forces us to adopt a new mode of description designated as complementary in the sense that any given application of classical concepts precludes the simultaneous use of other classical concepts which in a different connection are equally necessary for the elucidation of the phenomena.”38 In short, if we describe the phenomenon as a particle, we miss its wavelike properties; if we describe it as a wave, we miss its corpuscular properties.

36Ibid., p. 41.
38Quoted in Hooker, p. 138. The italics are Bohr’s; Hooker’s italics have been omitted.
For our purposes, the most interesting aspect of this argument is Bohr’s reason why we cannot simply abandon the classical terms and seek others. It is here that Bohr’s idea of being suspended in language enters. The classical concepts, Bohr felt, evolved as a consequence of our experience in the world; they reflect the essential distinction between subject and object that is the absolute prerequisite for the process of observation to begin. From the division into subject and object, Bohr writes, “follows . . . the meaning of every concept, or rather every word, the meaning depending upon our arbitrary choice of viewpoint.”39

The very act of speaking, Bohr felt, evolved from the distinction between the subject and object. To speak is to speak from a position that is defined as separate and distinct from that which is spoken about. Language thus implies a viewpoint, a specific place at which the subject-object split is made. But because of the Uncertainty Relation, this viewpoint will always result in an incomplete and partial description. To complete the description, another viewpoint is necessary which makes the subject-object split in a different place. But these viewpoints will be mutually exclusive, because the subject-object split can only be made in one place at a time. Hence no matter which viewpoint is chosen, there will always be aspects of reality that can only be understood from another, mutually exclusive viewpoint. To switch to that new viewpoint will render indistinct and hence indeterminate aspects that may have been clear in the former viewpoint. Consequently Bohr affirms that “we must, in general, be prepared to accept the fact that a complete elucidation of one and the same object may require diverse points of view which defy a unique description.”40 The classical concepts cannot simply be abandoned, because any concept whatever—that is, any definition of reality that is external to us—will have the same built-in limitations of viewpoint.

Although Bohr does not rely on linguistics in making this argument, it is possible to recapitulate his reasoning in these terms, through a consideration of the deep structure of Indo-European languages. To make a well-formed utterance in English, for example, is implicitly to acknowledge a structural division between actee and actant, as well as

39Ibid., p. 141.
40Ibid.
the temporal progression implicit in verb tenses. Thus not only is a speaking subject posited in opposition to an “outside” world, but that relationship is further defined as occurring at a particular place in time and space. Hence Bohr’s point—that to speak requires a subject-object dichotomy—is true not only in the general sense that to speak is to assume a separation between the speaker and the object of speech, but also in the more specific linguistic sense that to speak is to use a linguistic structure built on such distinctions.

It is this sense of being trapped inside the conceptualizations of language that, more than anything else, keeps surfacing in Pynchon’s *Gravity’s Rainbow* as the fatal barrier separating humanity from full participation in a holistic reality. Though Roger Mexico can argue for a world based on probability, neither one nor zero but somewhere in-between, Pynchon shows human cognition as fundamentally bound up with the binary distinctions characteristic of black-and-white films, inorganic chemical reactions, and the human neural system. As Pynchon explores the dependence of cognition on breaking a unified field into separate and isolated components, he mourns for the holistic, nonfragmented reality that he imagines other species can sense. The inevitable end of our relentless forcing of a holistic field into atomistic perspectives, Pynchon suggests, will be the destruction of a humanity which can never be “simply here, simply alive.”

For Bohr, the fact that we remain “suspended in language” does not mean that we cannot make progress; he would therefore be unwilling to subscribe to Pynchon’s fatalistic view. According to Bohr, we progressively refine our viewpoints not by attempting the impossible, that is, observing without a viewpoint, but by recognizing the ways in which our description of reality depends on the viewpoint we have chosen. “The development of physics has taught us that . . . even the most elementary concepts . . . [are] based on assumptions initially unnoticed,” Bohr writes. When an “explicit consideration” of these concepts is undertaken, we “obtain a classification of more extended domains of experience.” These more extended domains will in turn be underlaid by other concepts containing “unrecognized presuppositions,” the examination of which will in turn lead to a still more general description.\(^{41}\) Thus progress is made not by ignoring or underplaying

\(^{41}\)Ibid., p. 139.
limitations of viewpoint, but by systematically examining and exploiting them.

It would be possible to write the history of the modern novel using similar terms, starting from a Jamesian theory of point of view and progressing to post-modern literature in which the assumption that there is a "point" from which to "view" is called into question. Shifting viewpoints that are mutually exclusive but all in some sense true; experiments that involve making the subject-object split in different places; the radical questioning of what it means to be "objective"—these are familiar to literary readers as the central issues of modernism, just as the problem of self-referentiality is the central issue of post-modernism. If we follow Bohr's advice (and Pynchon's example), the next step is to examine the underlying assumptions behind these literary strategies, thereby preparing the way for yet another enlargement of our understanding.

Before turning to this task in the remaining chapters, however, we will find it useful to look one last time at the scientific models, now concentrating not on what they have accomplished, but on what they have failed to accomplish. If the isomorphism between the scientific models and literary strategies holds, these limitations will have something to tell us about related limitations in the literary strategies.

Throughout this chapter, two themes have been implicit, and I should like now to state them explicitly. One is the extraordinary vision of unity inherent in the field concept of reality; the second is the extreme difficulty of translating this intuitive vision into an articulated model. The difficulties of constructing a conceptually coherent model are apparent in the uneasy alliance of relativity theory and quantum mechanics. Why is the alliance uneasy? Because the thrust of quantum mechanics, as we have seen, is to render indeterminacy inherent, while the thrust of relativity theory is to extend the determinacy of Newtonian physics into the progressively larger unifications made possible by Einstein's assumptions of invariance. Thus while quantum mechanics is probabilistic rather than causal, nonlocal rather than local, in relativity theory Newton's gravitational "action-at-a-distance" is replaced with strictly local action. In relativity theory force is considered to be mediated by means of an underlying field, and the field itself is considered to be mediated through the exchange of particles. Hence the existence of gravity, for example, implies that there should also be "gravitons" and
“gravity waves” (though no generally accepted detection of them has yet been made). As a result, relativity theory, in contrast to quantum mechanics, is determinate rather than indeterminate, a theory of local action instead of action-at-a-distance.

The dilemma for modern physicists is that both relativity theory and quantum mechanics have proven so successful within their respective spheres of applicability that it is highly unlikely either will be abandoned; moreover, both are clearly necessary when dealing with atomic phenomena. Though no entirely satisfactory way to combine the two has yet been found, the difficulties are mostly in combining quantum mechanics with general relativity; the blend with special relativity has been very successful, and quantum field theory is now well established. But because the conceptual differences between the relativistic and quantum theoretics persist, various other models have gained a hearing in the scientific community, among them “hidden variable” theories. These theories, regarded as untenable by many physicists, show how very different models, some of them conceptually very strange, can emerge from a view of reality on which there is general consensus.

Hidden variable theories postulate that in some way that is not clearly understood, “certain dynamical variables” are affected when two particles interact. Thus they assume that the unknowable area covered by Bohr’s “quantum of action” is in effect controlled by the “hidden variables,” whose presence we may infer even though they are “hidden” from sight. In general, hidden variable theories were an attempt to restore determinism and causality to quantum mechanics by postulating a causal mechanism operating within the area of uncertainty.

The efforts of the hidden variable theorists took a dramatically different turn, however, when J. S. Bell, in what is usually called “Bell’s Theorem,” showed that a hidden variable theory cannot reproduce all of the statistical predictions of quantum mechanics unless it gives up the assumption of local action. As a result, some hidden variable theories adopted a non-locality assumption that, in the words of Max Jammer, endowed them “with features that seemed to belong to magic rather than physics.”42 They assume, for example, that a connection between two particles can obtain even though they are widely separated in space.

In this assumption particle A, for example, could be influenced by the kind of measurement performed on particle B if A and B had at some previous moment been in touch, even if at the time of the measurement A and B are widely separated and have no further interaction. The two systems are thus supposed to be united in what Jammer characterizes as a “mysterious conspiracy.” “Even to many nonconformists,” Jammer concludes, “Bohr’s complementarity interpretation seemed to be less bizarre.”

In contrast to the intuitive implausibility of the model, however, is the shared vision of what a field view of reality entails. David Bohm, one of the leading hidden variable theorists, emphasizes that what he calls the “implicate order” implicit in hidden variable theory is in harmony with both relativity theory and quantum mechanics. According to Bohm, relativity theory and quantum mechanics have in common “the notion of unbroken wholeness”; “if relativity were able to explain matter, it would say that it would be all one form—a field—all merging into one whole. Quantum mechanics would say the same thing for a different reason, because the indivisible quantum links of everything with everything imply that nothing can be separated.” Bohm therefore suggests the emergence of an implicate order “which will be suitable for this unbroken wholeness.” In the implicate order, “each part . . . contains the whole in some sense. The whole is folded into each part.” In this view “points are not the fundamental notion any more as in the Cartesian system. Rather, what is fundamental is some region which contains, in some sense, the order of the whole.”

The contrast between the simplicity of the vision and the difficulty of the model is also apparent in many mainstream theories. Einstein, although he did not succeed in formulating a unified field theory that would unite relativity and quantum mechanics, nevertheless had a clear vision of what it would imply. In such a theory matter would be regarded as “being constituted by the regions of space in which the field is extremely intense. . . . There is no place in this new kind of physics

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43Ibid., p. 312.
46Ibid., p. 91.
for both the field and matter for the field is the only reality." Similarly, the prominent mathematician and physicist Hermann Weyl wrote years ago that the electron should be considered as "merely a small domain of the electrical field within which the field strength assumes enormously high values."

Clifford Hooker, in 1972, suggested that the key to reconciling this shared vision and competing models may lie in an essential change of perspective. "The general presupposition behind fundamental particle theory," Hooker writes, "is that there is a subatomic structure to physical reality, that just as macro bodies actually consist of atoms, so atoms actually consist of fundamental particles, and so on down." As Hooker points out, this view implies that the theories will assume a certain form, "where particles in hierarchy level \( n \) are seen as structured swarms of particles of level \( n-1 \)." But suppose, Hooker continues, that "the so-called subatomic world was only nature’s way of responding to high energy attacks. Suppose, for example, that the world were really continuous and the manner of its apparent breaking up was much more like the water droplets ejected as a stone strikes the surface." In this case the proliferation of fundamental particles is "best understood from the top down," as "characteristic denizens of our machines only," rather than as "revealing a pre-existing physical structure to be discovered." In words that David Bohm would echo six years later, this view of atomic phenomena in which it is seen "from the top down" would "turn theorizing, and experimenting, on its head." The turn of thought, from a view that sees the essence in the smallest indivisible part to a view that sees the essence as an indivisible whole, is clear. What remains unclear is whether it can ever be adequately expressed in an articulated model.

47Quoted in Čapek, p. 319.
49Hooker, p. 179.
50For a recent survey of where the matter stands now, see Gerard t’Hooft, "Gauge Theories of the Forces between Elementary Particles," Scientific American, 243 (June 1980), 104–137. T’Hooft reports that it now appears possible to represent all four kinds of interactions between elementary particles by the same general kind of theory. This implies that it may one day be possible to unite all four interactions under a common theoretical framework, resulting in the unified field theory of Einstein’s dream. Although no such theory has yet been found, a step in this direction was taken with quantum electrodynamics, which allows the wave/particle duality to be correlated with electromagnetic fields. But the problems encountered testify to the difficulties of conceptualizing reality as a unified field. T’Hooft recounts how the search for a workable model led to such
What our survey of the field concept in various scientific models has shown is that the problem of articulation is intrinsic to this view of reality, whether the language involved is the binary sequence of computer programs, the “wave-packet” equations of quantum mechanics, or one of the syntactically linear natural languages in which scientists attempt to come to grips with the philosophical implications of their models. Because the task of articulation requires that a vision of a dynamic, mutually interacting field be represented through a medium that is inherently linear, fragmented, and unidirectional, the novelist’s concern with language will have much in common with these scientific concerns. The strain of trying to capture the idea of a holistic field in an articulated medium will thus be as apparent—and as interesting—in the literary chapters as it has been in this chapter on scientific models. The authors to whom we now turn have their own perspective and insights to bring to this problem. Whereas the scientific theories are created through the attempt to express the field view in rigorously exact models, the literary strategies are forged by the desire to find a form, and a language, adequate to interpret its human meaning.

expediencies as “renormalization” calculations, which work by “finding one negative infinity for each positive infinity, so that in the sum of all possible contributions the infinities cancel” (p. 119), and “ghost particles” which, though they do not exist, are added to make the calculations come out right in the end. Although negative and positive infinities can be manipulated mathematically, it is very hard to connect these formal operations with an intuitively plausible reality.