EXCERPTED FROM

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A NEW KIND OF SCIENCE

SECTION 9.5

Ultimate Models for the Universe

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The history of physics has seen the development of a sequence of progressively more accurate models for the universe—from classical mechanics, through quantum mechanics, to quantum field theory, and beyond. And one may wonder whether this process will go on forever, or whether at some point it will come to an end, and one will reach a final ultimate model for the universe.

Experience with actual results in physics would probably not make one think so. For it has seemed that whenever one tries to get to another level of accuracy, one encounters more complex phenomena. And at least with traditional scientific intuition, this fact suggests that models of progressively greater complexity will be needed.

But one of the crucial points discovered in this book is that more complex phenomena do not always require more complex models. And indeed I have shown that even models based on remarkably simple programs can produce behavior that is in a sense arbitrarily complex.

So could this be what happens in the universe? And could it even be that underneath all the complex phenomena we see in physics there lies some simple program which, if run for long enough, would reproduce our universe in every detail?

The discovery of such a program would certainly be an exciting event—as well as a dramatic endorsement for the new kind of science that I have developed in this book.

For among other things, with such a program one would finally have a model of nature that was not in any sense an approximation or idealization. Instead, it would be a complete and precise representation of the actual operation of the universe—but all reduced to readily stated rules.

In a sense, the existence of such a program would be the ultimate validation of the idea that human thought can comprehend the construction of the universe. But just knowing the underlying program does not mean that one can immediately deduce every aspect of how the universe will behave. For as we have seen many times in this book, there is often a great distance between underlying rules and overall behavior. And in fact, this is precisely why it is conceivable that a simple program could reproduce all the complexity we see in physics.

Given a particular underlying program, it is always in principle possible to work out what it will do just by running it. But for the whole universe, doing this kind of explicit simulation is almost by definition out of the question. So how then can one even expect to tell whether a particular program is a correct model for the universe? Small-scale simulation will certainly be possible. And I expect that by combining this with a certain amount of perhaps fairly sophisticated mathematical and logical deduction, it will be possible to get at least as far as reproducing the known laws of physics—and thus of determining whether a particular model has the potential to be correct.

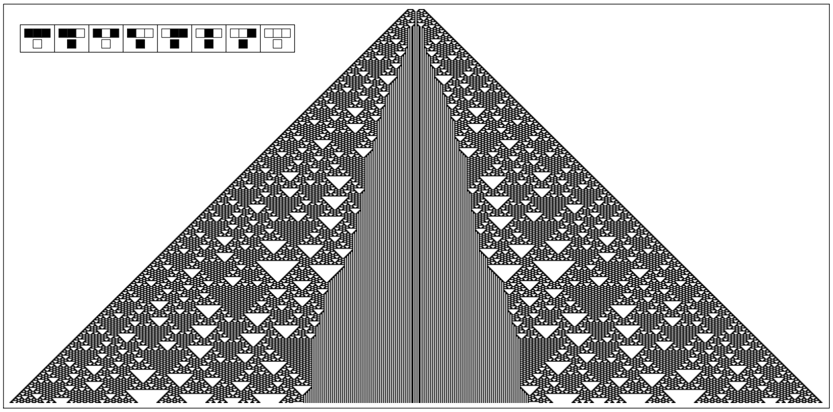
So if there is indeed a definite ultimate model for the universe, how might one set about finding it? For those familiar with existing science, there is at first a tremendous tendency to try to work backwards from the known laws of physics, and in essence to try to "engineer" a universe that will have particular features that we observe.

But if there is in fact an ultimate model that is quite simple, then from what we have seen in this book, I strongly believe that such an approach will never realistically be successful. For human thinking—even supplemented by the most sophisticated ideas of current mathematics and logic—is far from being able to do what is needed.

Imagine for example trying to work backwards from a knowledge of the overall features of the picture on the facing page to construct a rule that would reproduce it. With great effort one might perhaps come up with some immensely complex rule that would work in most cases. But there is no serious possibility that starting from overall features one would ever arrive at the extremely simple rule that was actually used.

It is already difficult enough to work out from an underlying rule what behavior it will produce. But to invert this in any systematic way is probably even in principle beyond what any realistic computation can do.

So how then could one ever expect to find the underlying rule in such a case? Almost always, it seems that the best strategy is a simple one: to come up with an appropriate general class of rules, and then just



A typical example of a situation where it would be very difficult to deduce the underlying rule from a description of the overall behavior that it produces. There is in a sense too great a distance between the simple rule shown and the behavior that emerges from it. I suspect that the same will be true of the basic rule for the universe. The particular rule shown here is the elementary cellular automaton with rule number 94, and with initial condition .

to search through these rules, trying each one in turn, and looking to see if it produces the behavior one wants.

But what about the rules for the universe? Surely we cannot simply search through possible rules of certain kinds, looking for one whose behavior happens to fit what we see in physics?

With the intuition of traditional science, such an approach seems absurd. But the point is that if the rule for the universe is sufficiently simple—and the results of this book suggest that it might be—then it becomes not so unreasonable to imagine systematically searching for it.

To start performing such a search, however, one first needs to work out what kinds of rules to consider. And my suspicion is that none of the specific types of rules that we have discussed so far in this book will turn out to be adequate. For I believe that all these types of rules in some sense probably already have too much structure built in.

Thus, for example, cellular automata probably already have too rigid a built-in notion of space. For a defining feature of cellular automata is that their cells are always arranged in a rigid array in space. Yet I strongly suspect that in the underlying rule for our universe there will be no such built-in structure. Rather, as I discuss in the sections that follow, my guess is that at the lowest level there will just be certain patterns of connectivity that tend to exist, and that space as we know it will then emerge from these patterns as a kind of large-scale limit.

And indeed in general what I expect is that remarkably few familiar features of our universe will actually be reflected in any direct way in its ultimate underlying rule. For if all these features were somehow explicitly and separately included, the rule would necessarily have to be very complicated to fit them all in.

So if the rule is indeed simple, it almost inevitably follows that we will not be able to recognize directly in it most features of the universe as we normally perceive them. And this means that the rule—or at least its behavior—will necessarily seem to us unfamiliar and abstract.

Most likely for example there will be no easy way to visualize what the rule does by looking at a collection of elements laid out in space. Nor will there probably be any immediate trace of even such basic phenomena as motion.

But despite the lack of these familiar features, I still expect that the actual rule itself will not be too difficult for us to represent. For I am fairly certain that the kinds of logical and computational constructs that we have discussed in this book will be general enough to cover what is needed. And indeed my guess is that in terms of the kinds of pictures—or *Mathematica* programs—that we have used in this book, the ultimate rule for the universe will turn out to look quite simple.

No doubt there will be many different possible formulations—some quite unrecognizably different from others. And no doubt a formulation will eventually be found in which the rule somehow comes to seem quite obvious and inevitable.

But I believe that it will be essentially impossible to find such a formulation without already knowing the rule. And as a result, my guess is that the only realistic way to find the rule in the first place will be to start from some very straightforward representation, and then just to search through large numbers of possible rules in this representation.

Presumably the vast majority of rules will lead to utterly unworkable universes, in which there is for example no reasonable notion of space or no reasonable notion of time.

But my guess is that among appropriate classes of rules there will actually be quite a large number that lead to universes which share at least some features with our own. Much as the same laws of continuum fluid mechanics can emerge in systems with different underlying rules for molecular interactions, so also I suspect that properties such as the existence of seemingly continuous space, as well as certain features of gravitation and quantum mechanics, will emerge with many different possible underlying rules for the universe.

But my guess is that when it comes to something like the spectrum of masses of elementary particles—or perhaps even the overall dimensionality of space—such properties will be quite specific to particular underlying rules.

In traditional approaches to modelling, one usually tries first to reproduce some features of a system, then goes on to reproduce others. But if the ultimate rule for the universe is at all simple, then it follows that every part of this rule must in a sense be responsible for a great many different features of the universe. And as a result, it is not likely to be possible to adjust individual parts of the rule without having an effect on a whole collection of disparate features of the universe.

So this means that one cannot reasonably expect to use some kind of incremental procedure to find the ultimate rule for the universe. But it also means that if one once discovers a rule that reproduces sufficiently many features of the universe, then it becomes extremely likely that this rule is indeed the final and correct one for the whole universe.

And I strongly suspect that even in many of the most basic everyday physical processes, every element of the underlying rule for the universe will be very extensively exercised. And as a result, if these basic processes are reproduced correctly, then I believe that one can have considerable confidence that one in fact has the complete rule for the universe.

Looking at the history of physics, one might think that it would be completely inadequate just to reproduce everyday physical processes. For one might expect that there would always be some other esoteric phenomenon, say in particle physics, that would be discovered and would show that whatever rule one has found is somehow incomplete.

But I do not think so. For if the rule for our universe is at all simple, then I expect that to introduce a new phenomenon, however esoteric, will involve modifying some basic part of the rule, which will also affect even common everyday phenomena.

But why should we believe that the rule for our universe is in fact simple? Certainly among all possible rules of a particular kind only a limited number can ever be considered simple, and these rules are by definition somehow special. Yet looking at the history of science, one might expect that in the end there would turn out to be nothing special about the rule for our universe—just as there has turned out to be nothing special about our position in the solar system or the galaxy.

Indeed, one might assume that there are in fact an infinite number of universes, each with a different rule, and that we simply live in a particular—and essentially arbitrary—one of them.

It is unlikely to be possible to show for certain that such a theory is not correct. But one of its consequences is that it gives us no reason to think that the rule for our particular universe should be in any way simple. For among all possible rules, the overwhelming majority will not be simple; in fact, they will instead tend to be almost infinitely complex.

Yet we know, I think, that the rule for our universe is not too complex. For if the number of different parts of the rule were, for example, comparable to the number of different situations that have ever arisen in the history of the universe, then we would not expect ever to be able to describe the behavior of the universe using only a limited number of physical laws.

And in fact if one looks at present-day physics, there are not only a limited number of physical laws, but also the individual laws often seem to have the simplest forms out of various alternatives. And knowing this, one might be led to believe that for some reason the universe is set up to have the simplest rules throughout.

But, unfortunately perhaps, I do not think that this conclusion necessarily follows. For as I have discussed above, I strongly suspect that the vast majority of physical laws discovered so far are not truly fundamental, but are instead merely emergent features of the large-scale behavior of some ultimate underlying rule. And what this means is that any simplicity observed in known physical laws may have little connection with simplicity in the underlying rule.

Indeed, it turns out that simple overall laws can emerge almost regardless of underlying rules. And thus, for example, essentially as a consequence of randomness generation, a wide range of cellular automata show the simple density diffusion law on page 464—whether or not their underlying rules happen to be simple.

So it could be that the laws that we have formulated in existing physics are simple not because of simplicity in an ultimate underlying rule, but rather because of some general property of emergent behavior for the kinds of overall features of the universe that we readily perceive.

Indeed, with this kind of argument, one could be led to think that there might be no single ultimate rule for the universe at all, but that instead there might somehow be an infinite sequence of levels of rules, with each level having a certain simplicity that becomes increasingly independent of the details of the levels below it.

But one should not imagine that such a setup would make it unnecessary to ask why our universe is the way it is: for even though certain features might be inevitable from the general properties of emergent behavior, there will, I believe, still be many seemingly arbitrary choices that have to be made in arriving at the universe in which we live. And once again, therefore, one will have to ask why it was these choices, and not others, that were made.

So perhaps in the end there is the least to explain if I am correct that the universe just follows a single, simple, underlying rule.

There will certainly be questions about why it is this particular rule, and not another one. And I am doubtful that such questions will ever have meaningful answers.

But to find the ultimate rule will be a major triumph for science, and a clear demonstration that at least in some direction, human thought has reached the edge of what is possible.