EXCERPTED FROM

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A NEW KIND OF SCIENCE

SECTION 12.5

Explaining the Phenomenon of Complexity

respects they seem far more random than patterns produced by systems like rule 110 that we already know are universal.

But how can we be sure that we are not being misled by limitations in our powers of perception and analysis—and that an extraterrestrial intelligence, for example, might not immediately recognize regularity that would show that universality is impossible?

For as we saw in Chapter 10 the methods of perception and analysis that we normally use cannot detect any form of regularity much beyond repetition or at most nesting. So this means that even if some higher form of regularity is in fact present, we as humans might never be able to tell.

In the history of science and mathematics both repetition and nesting feature prominently. And if there was some common higher form of regularity its discovery would no doubt lead to all sorts of important new advances in science and mathematics.

And when I first started looking at systems like cellular automata I in effect implicitly assumed that some such form of regularity must exist. For I was quite certain that even though I saw behavior that seemed to me complex the simplicity of the underlying rules must somehow ultimately lead to great regularity in it.

But as the years have gone by—and as I have investigated more and more systems and tried more and more methods of analysis—I have gradually come to the conclusion that there is no hidden regularity in any large class of systems, and that instead what the Principle of Computational Equivalence suggests is correct: that beyond systems with obvious regularities like repetition and nesting most systems are universal, and are equivalent in their computational sophistication.

Explaining the Phenomenon of Complexity

Early in this book I described the remarkable discovery that even systems with extremely simple underlying rules can produce behavior that seems to us immensely complex. And in the course of this book, I have shown a great many examples of this phenomenon, and have argued that it is responsible for much of the complexity we see in nature and elsewhere.

Yet so far I have given no fundamental explanation for the phenomenon. But now, by making use of the Principle of Computational Equivalence, I am finally able to do this.

And the crucial point is to think of comparing the computational sophistication of systems that we study with the computational sophistication of the systems that we use to study them.

At first we might assume that our brains and mathematical methods would always be capable of vastly greater computational sophistication than systems based on simple rules—and that as a result the behavior of such systems would inevitably seem to us fairly simple.

But the Principle of Computational Equivalence implies that this is not the case. For it asserts that essentially any processes that are not obviously simple are equivalent in their computational sophistication. So this means that even though a system may have simple underlying rules its process of evolution can still computationally be just as sophisticated as any of the processes we use for perception and analysis.

And this is the fundamental reason that systems with simple rules are able to show behavior that seems to us complex.

At first, one might think that this explanation would depend on the particular methods of perception and analysis that we as humans happen to use. But one of the consequences of the Principle of Computational Equivalence is that it does not. For the principle asserts that the same computational equivalence exists for absolutely any method of perception and analysis that can actually be used.

In traditional science the idealization is usually made that perception and analysis are in a sense infinitely powerful, so that they need not be taken into account when one draws conclusions about a system. But as soon as one tries to deal with systems whose behavior is anything but fairly simple one finds that this idealization breaks down, and it becomes necessary to consider perception and analysis as explicit processes in their own right.

If one studies systems in nature it is inevitable that both the evolution of the systems themselves and the methods of perception and analysis used to study them must be processes based on natural laws. But at least in the recent history of science it has normally been assumed that the evolution of typical systems in nature is somehow much less sophisticated a process than perception and analysis.

Yet what the Principle of Computational Equivalence now asserts is that this is not the case, and that once a rather low threshold has been reached, any real system must exhibit essentially the same level of computational sophistication. So this means that observers will tend to be computationally equivalent to the systems they observe—with the inevitable consequence that they will consider the behavior of such systems complex.

So in the end the fact that we see so much complexity can be attributed quite directly to the Principle of Computational Equivalence, and to the fact that so many of the systems we encounter in practice turn out to be computationally equivalent.

Computational Irreducibility

When viewed in computational terms most of the great historical triumphs of theoretical science turn out to be remarkably similar in their basic character. For at some level almost all of them are based on finding ways to reduce the amount of computational work that has to be done in order to predict how some particular system will behave.

Most of the time the idea is to derive a mathematical formula that allows one to determine what the outcome of the evolution of the system will be without explicitly having to trace its steps.

And thus, for example, an early triumph of theoretical science was the derivation of a formula for the position of a single idealized planet orbiting a star. For given this formula one can just plug in numbers to work out where the planet will be at any point in the future, without ever explicitly having to trace the steps in its motion.

But part of what started my whole effort to develop the new kind of science in this book was the realization that there are many common systems for which no traditional mathematical formulas have ever been found that readily describe their overall behavior.