EXCERPTED FROM

STEPHEN WOLFRAM A NEW KIND OF SCIENCE

SECTION 2.2

The Need for a New Intuition

watch what happens. And as it turns out, in the particular case shown here, the outcome is finally clear after about 2780 steps: one structure survives, and that structure interacts with the periodic stripes coming from the left to produce behavior that repeats every 240 steps.

However certain one might be that simple programs could never do more than produce simple behavior, the pictures on the past few pages should forever disabuse one of that notion. And indeed, what is perhaps most bizarre about the pictures is just how little trace they ultimately show of the simplicity of the underlying cellular automaton rule that was used to produce them.

One might think, for example, that the fact that all the cells in a cellular automaton follow exactly the same rule would mean that in pictures like the last few pages all cells would somehow obviously be doing the same thing. But instead, they seem to be doing quite different things. Some of them, for example, are part of the regular background, while others are part of one or another localized structure. And what makes this possible is that even though individual cells follow the same rule, different configurations of cells with different sequences of colors can together produce all sorts of different kinds of behavior.

Looking just at the original cellular automaton rule one would have no realistic way to foresee all of this. But by doing the appropriate computer experiments one can easily find out what actually happens—and in effect begin the process of exploring a whole new world of remarkable phenomena associated with simple programs.

The Need for a New Intuition

The pictures in the previous section plainly show that it takes only very simple rules to produce highly complex behavior. Yet at first this may seem almost impossible to believe. For it goes against some of our most basic intuition about the way things normally work.

◀ A single picture of the behavior from the previous five pages. A total of 3200 steps are shown. Note that this is more than twice as many as in the picture on page 30.

For our everyday experience has led us to expect that an object that looks complicated must have been constructed in a complicated way. And so, for example, if we see a complicated mechanical device, we normally assume that the plans from which the device was built must also somehow be correspondingly complicated.

But the results at the end of the previous section show that at least sometimes such an assumption can be completely wrong. For the patterns we saw are in effect built according to very simple plans—that just tell us to start with a single black cell, and then repeatedly to apply a simple cellular automaton rule. Yet what emerges from these plans shows an immense level of complexity.

So what is it that makes our normal intuition fail? The most important point seems to be that it is mostly derived from experience with building things and doing engineering—where it so happens that one avoids encountering systems like the ones in the previous section.

For normally we start from whatever behavior we want to get, then try to design a system that will produce it. Yet to do this reliably, we have to restrict ourselves to systems whose behavior we can readily understand and predict—for unless we can foresee how a system will behave, we cannot be sure that the system will do what we want.

But unlike engineering, nature operates under no such constraint. So there is nothing to stop systems like those at the end of the previous section from showing up. And in fact one of the important conclusions of this book is that such systems are actually very common in nature.

But because the only situations in which we are routinely aware both of underlying rules and overall behavior are ones in which we are building things or doing engineering, we never normally get any intuition about systems like the ones at the end of the previous section.

So is there then any aspect of everyday experience that should give us a hint about the phenomena that occur in these systems? Probably the closest is thinking about features of practical computing.

For we know that computers can perform many complex tasks. Yet at the level of basic hardware a typical computer is capable of executing just a few tens of kinds of simple logical, arithmetic and other instructions. And to some extent the fact that by executing large numbers of such

instructions one can get all sorts of complex behavior is similar to the phenomenon we have seen in cellular automata.

But there is an important difference. For while the individual machine instructions executed by a computer may be quite simple, the sequence of such instructions defined by a program may be long and complicated. And indeed—much as in other areas of engineering—the typical experience in developing software is that to make a computer do something complicated requires setting up a program that is itself somehow correspondingly complicated.

In a system like a cellular automaton the underlying rules can be thought of as rough analogs of the machine instructions for a computer, while the initial conditions can be thought of as rough analogs of the program. Yet what we saw in the previous section is that in cellular automata not only can the underlying rules be simple, but the initial conditions can also be simple—consisting say of just a single black cell—and still the behavior that is produced can be highly complex.

So while practical computing gives a hint of part of what we saw in the previous section, the whole phenomenon is something much larger and stronger. And in a sense the most puzzling aspect of it is that it seems to involve getting something from nothing.

For the cellular automata we set up are by any measure simple to describe. Yet when we ran them we ended with patterns so complex that they seemed to defy any simple description at all.

And one might hope that it would be possible to call on some existing kind of intuition to understand such a fundamental phenomenon. But in fact there seems to be no branch of everyday experience that provides what is needed. And so we have no choice but to try to develop a whole new kind of intuition.

And the only reasonable way to do this is to expose ourselves to a large number of examples. We have seen so far only a few examples, all in cellular automata. But in the next few chapters we will see many more examples, both in cellular automata and in all sorts of other systems. And by absorbing these examples, one is in the end able to develop an intuition that makes the basic phenomena that I have discovered seem somehow almost obvious and inevitable.