EXCERPTED FROM

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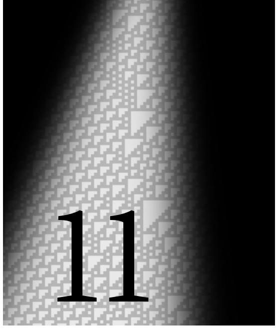
A NEW KIND OF SCIENCE

SECTION 11.1

Computation as a Framework



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The Notion of Computation

Computation as a Framework

In earlier parts of this book we saw many examples of the kinds of behavior that can be produced by cellular automata and other systems with simple underlying rules. And in this chapter and the next my goal is to develop a general framework for thinking about such behavior.

Experience from traditional science might suggest that standard mathematical analysis should provide the appropriate basis for any such framework. But as we saw in the previous chapter, such analysis tends to be useful only when the overall behavior one is studying is fairly simple.

So what can one do when the behavior is more complex?

If traditional science was our only guide, then at this point we would probably be quite stuck. But my purpose in this book is precisely to develop a new kind of science that allows progress to be made in such cases. And in many respects the single most important idea that underlies this new science is the notion of computation.

Throughout this book I have referred to systems such as cellular automata as simple computer programs. So now the point is actually to think of these systems in terms of the computations they can perform.

In a typical case, the initial conditions for a system like a cellular automaton can be viewed as corresponding to the input to a computation, while the state of the system after some number of steps corresponds to the output. And the key idea is then to think in purely abstract terms about the computation that is performed, without necessarily looking at all the details of how it actually works.

Why is such an abstraction useful? The main reason is that it potentially allows one to discuss in a unified way systems that have completely different underlying rules. For even though the internal workings of two systems may have very little in common, the computations the systems perform may nevertheless be very similar.

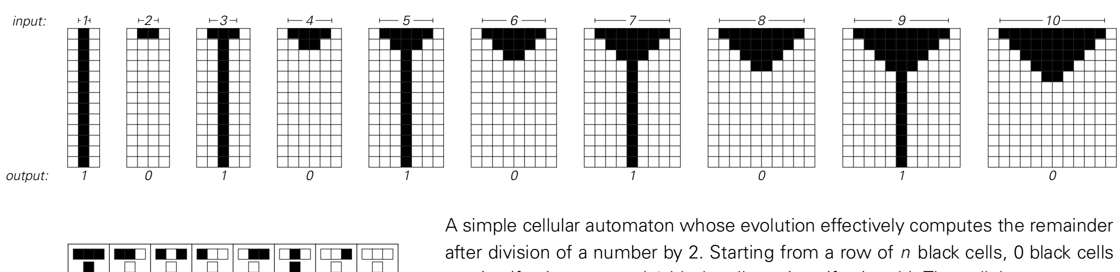
And by thinking in terms of such computations, it then becomes possible to imagine formulating principles that apply to a very wide variety of different systems—quite independent of the detailed structure of their underlying rules.

Computations in Cellular Automata

I have said that the evolution of a system like a cellular automaton can be viewed as a computation. But what kind of computation is it, and how does it compare to computations that we typically do in practice?

The pictures below show an example of a cellular automaton whose evolution can be viewed as performing a particular simple computation.

If one starts this cellular automaton with an even number of black cells, then after a few steps of evolution, no black cells are left. But if instead one starts it with an odd number of black cells, then a single black cell survives forever. So in effect this cellular automaton can be viewed as computing whether a given number is even or odd.



A simple cellular automaton whose evolution effectively computes the remainder after division of a number by 2. Starting from a row of *n* black cells, 0 black cells survive if *n* is even, and 1 black cell survives if *n* is odd. The cellular automaton follows elementary rule 132, as shown on the left.