EXCERPTED FROM

# STEPHEN WOLFRAM
# A NEW KIND OF SCIENCE

SECTION 6.1

## *The Emergence of Order*

# 6

# Starting from Randomness

## The Emergence of Order

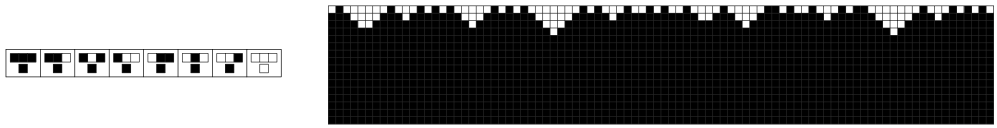
In the past several chapters, we have seen many examples of behavior that simple programs can produce. But while we have discussed a whole range of different kinds of underlying rules, we have for the most part considered only the simplest possible initial conditions—so that for example we have usually started with just a single black cell.

My purpose in this chapter is to go to the opposite extreme, and to consider completely random initial conditions, in which, for example, every cell is chosen to be black or white at random.

One might think that starting from such randomness no order would ever emerge. But in fact what we will find in this chapter is that many systems spontaneously tend to organize themselves, so that even with completely random initial conditions they end up producing behavior that has many features that are not at all random.

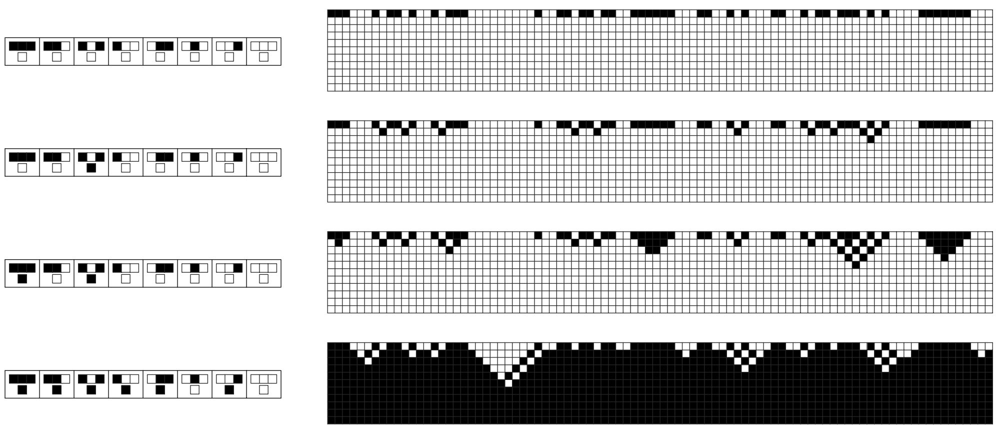
The picture at the top of the next page shows as a simple first example a cellular automaton which starts from a typical random initial condition, then evolves down the page according to the very simple rule that a cell becomes black if either of its neighbors are black.

What the picture then shows is that every region of white that exists in the initial conditions progressively gets filled in with black, so that in the end all that remains is a uniform state with every cell black.



A cellular automaton that evolves to a simple uniform state when started from any random initial condition. The rule in this case was first shown on page 24, and is number 254 in the scheme described on page 53. It specifies that a cell should become black whenever either of its neighbors is already black.

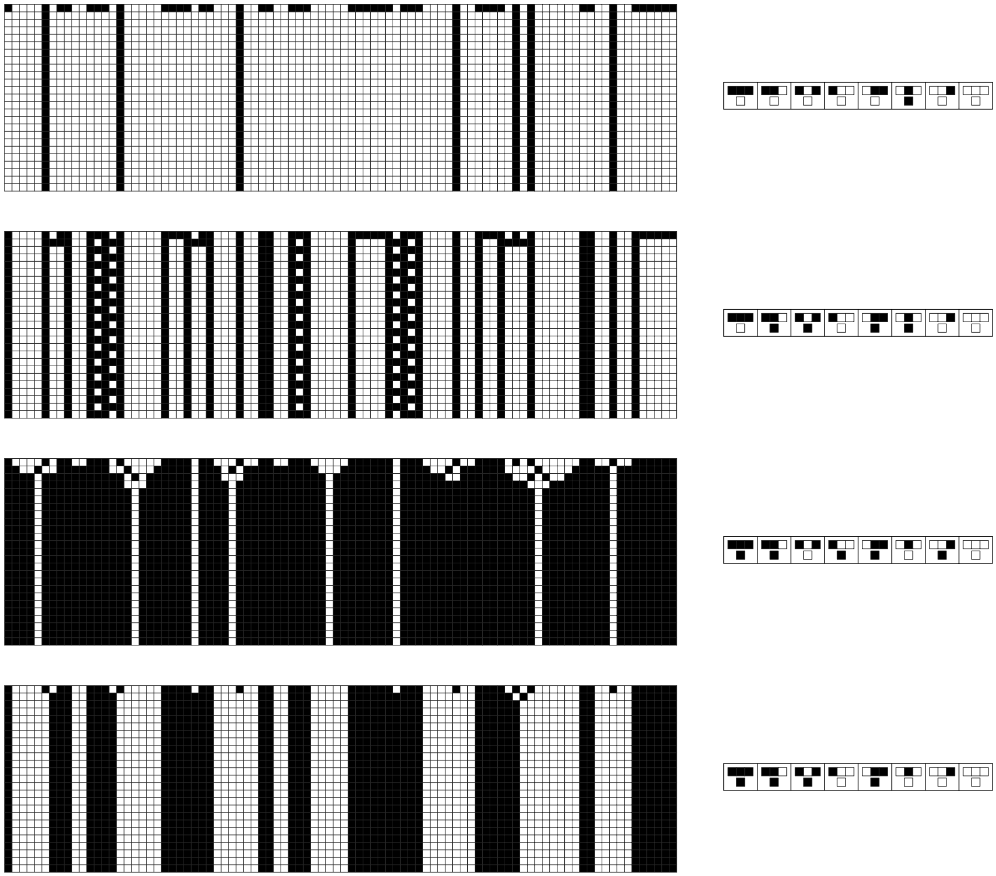
The pictures below show examples of other cellular automata that exhibit the same basic phenomenon. In each case the initial conditions are random, but the system nevertheless quickly organizes itself to become either uniformly white or uniformly black.



Four more examples of cellular automata that evolve from random initial conditions to completely uniform states. The rules shown here correspond to numbers 0, 32, 160 and 250.

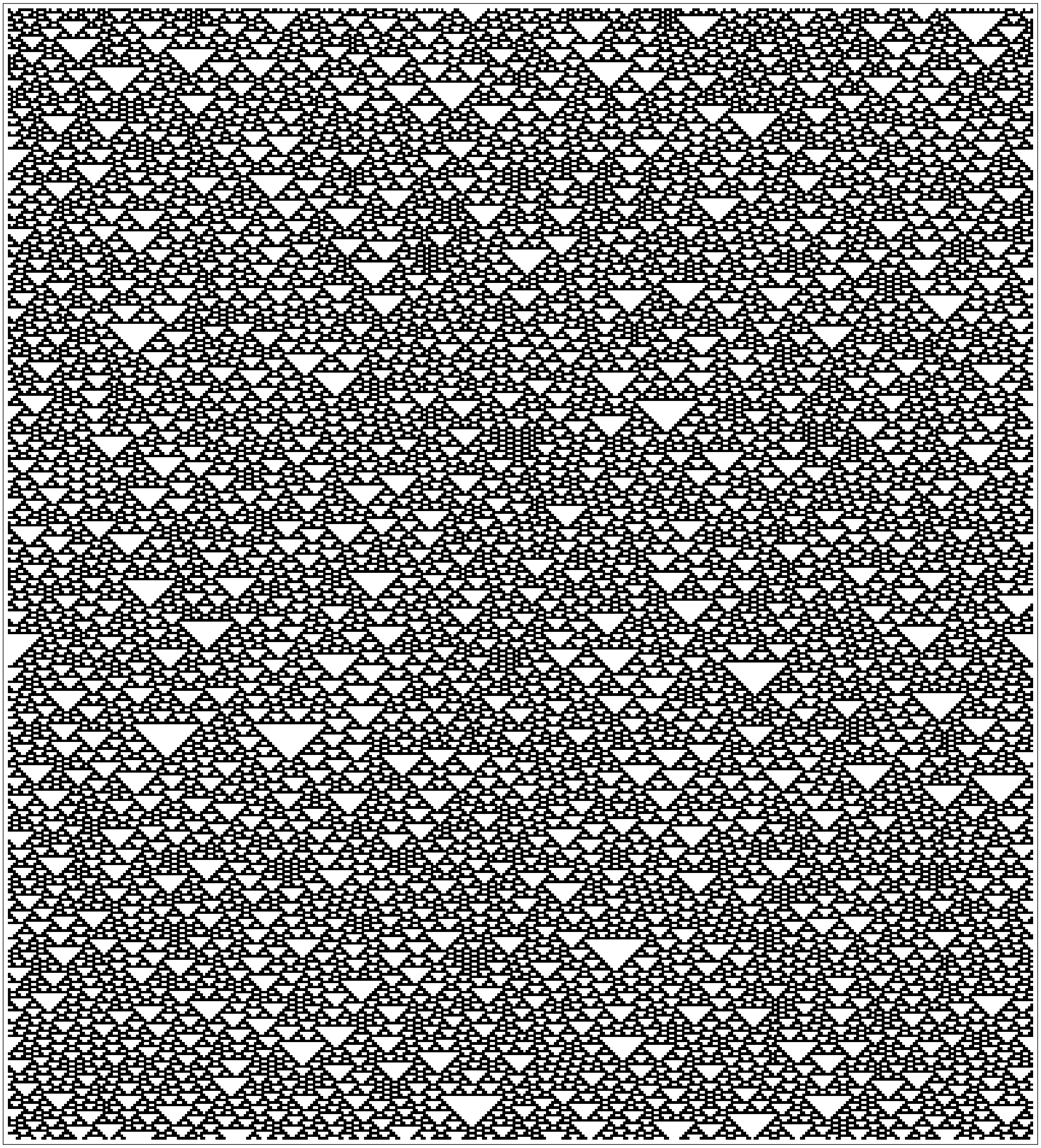
The facing page shows cellular automata that exhibit slightly more complicated behavior. Starting from random initial conditions, these cellular automata again quickly settle down to stable states. But now these stable states are not just uniform in color, but instead involve a collection of definite structures that either remain fixed on successive steps, or repeat periodically.

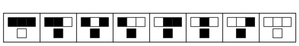
So if they have simple underlying rules, do all cellular automata started from random initial conditions eventually settle down to give stable states that somehow look simple?



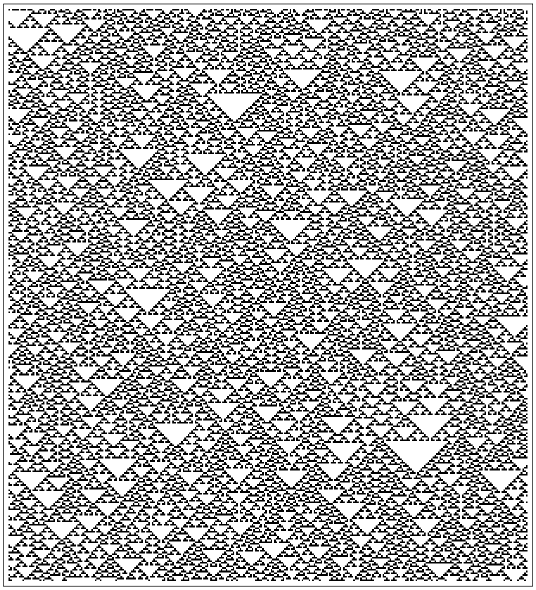
Examples of cellular automata that evolve from random initial conditions to produce a definite set of simple structures. For any particular rule, the form of these structures is always the same. But their positions depend on the details of the initial conditions given, and in many cases the final arrangement of structures can be thought of as a kind of filtered version of the initial conditions. Thus for example in the first rule shown here a structure consisting of a black cell occurs wherever there was an isolated black cell in the initial conditions. The rules shown are numbers 4, 108, 218 and 232.

It turns out that they do not. And indeed the picture on the next page shows one of many examples in which starting from random initial conditions there continues to be very complicated behavior forever. And indeed the behavior that is produced appears in many respects completely random. But dotted around the picture one sees many definite white triangles and other small structures that indicate at least a certain degree of organization.

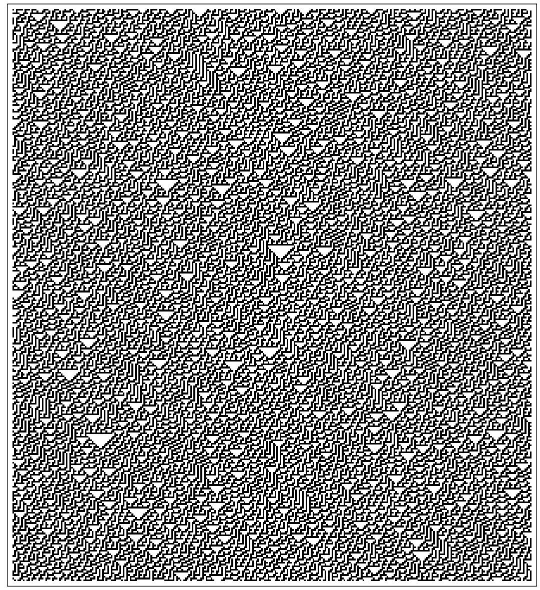




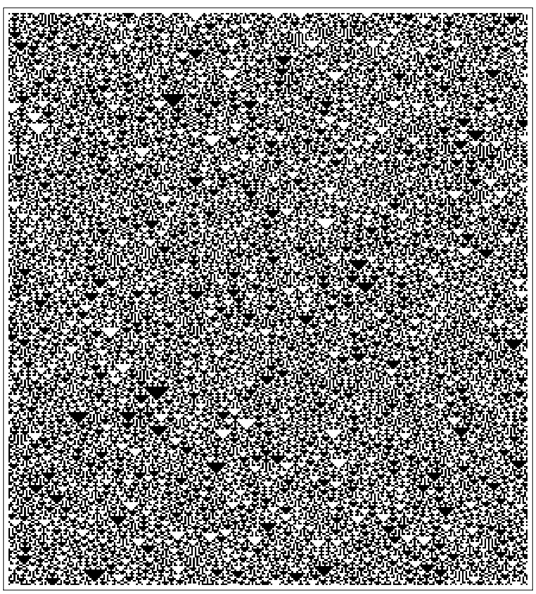
A cellular automaton that never settles down to a stable state, but instead continues to show behavior that seems in many respects random. The rule is number 126.



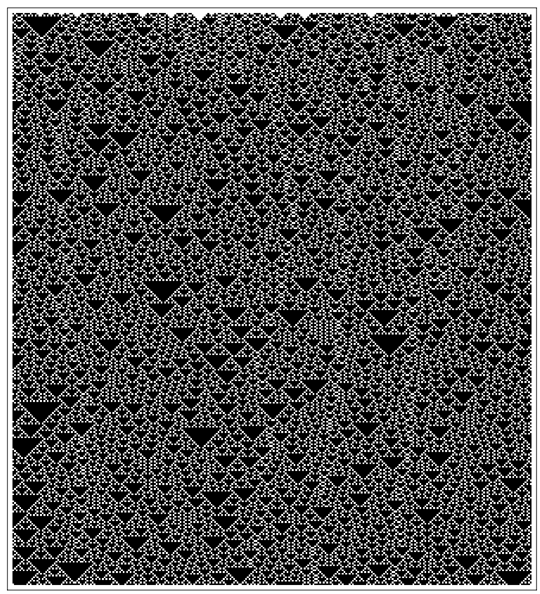
*rule 22*



*rule 30*

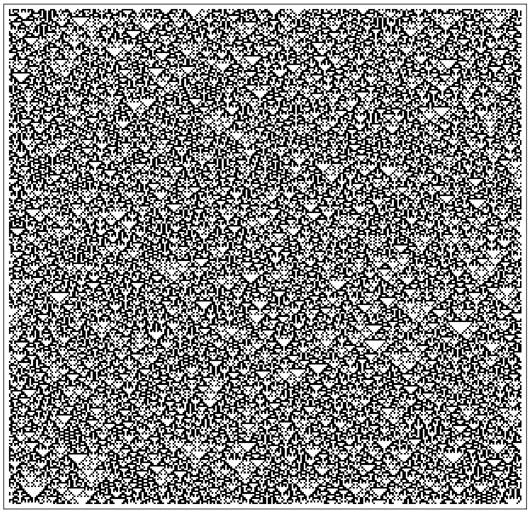


*rule 150*

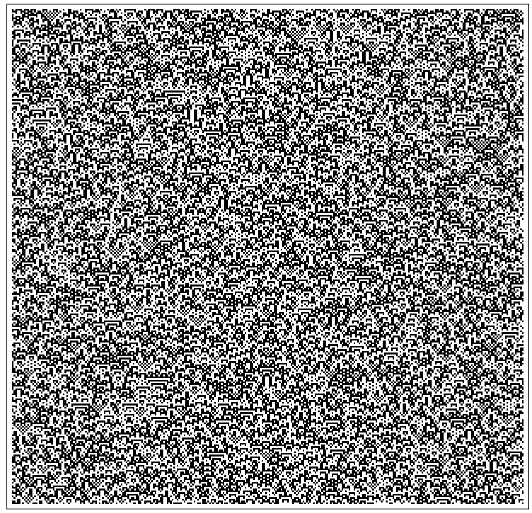


*rule 182*

Other examples of cellular automata that never settle down to stable states when started from random initial conditions. Each picture is a total of 300 cells across. Note the presence of triangles and other small structures dotted throughout all of the pictures.



rule 90



rule 105

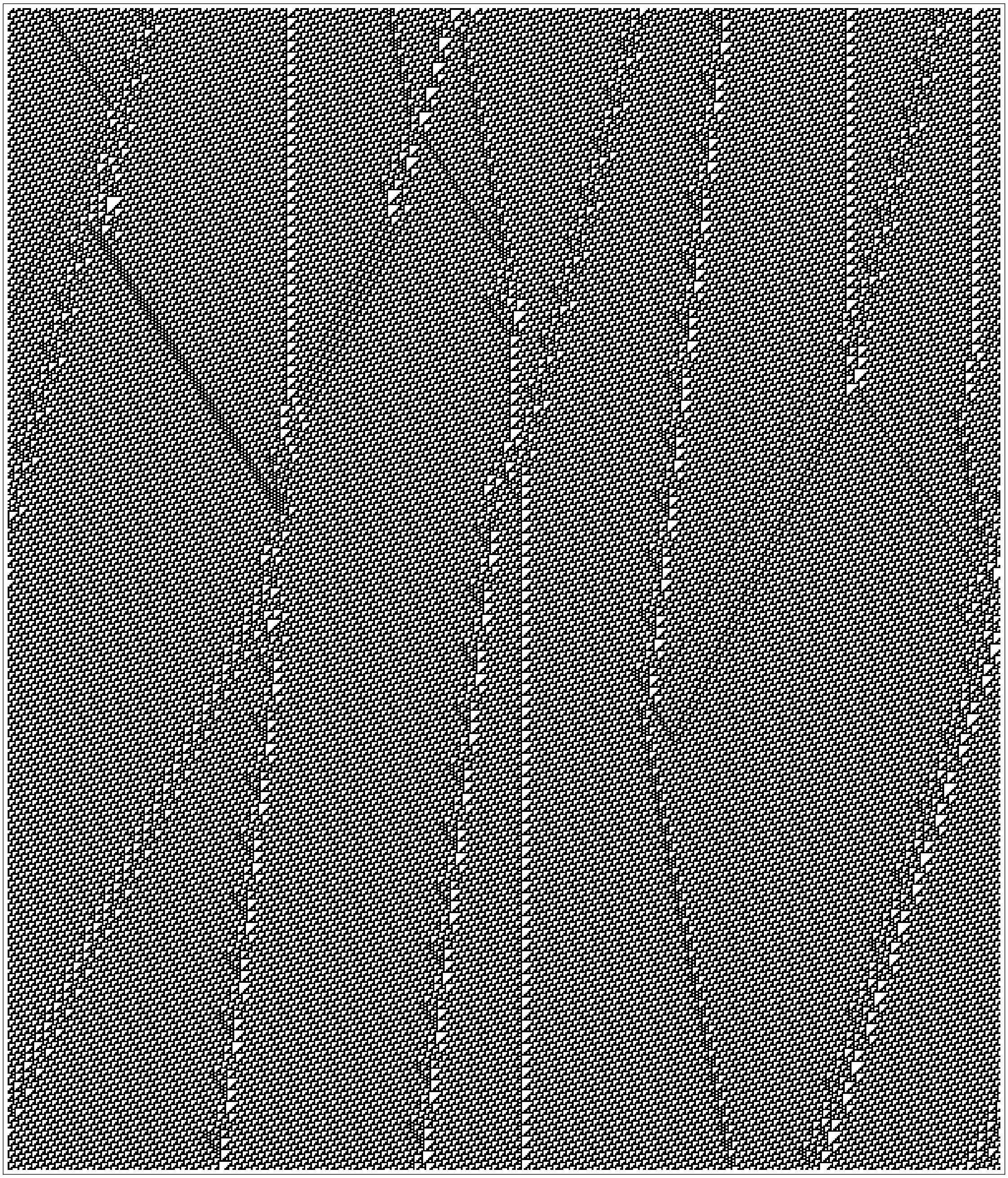
Two more cellular automata that generate various small structures but continue to show seemingly quite random behavior forever.

The pictures above and on the previous page show more examples of cellular automata with similar behavior. There is considerable randomness in the patterns produced in each case. But despite this randomness there are always triangles and other small structures that emerge in the evolution of the system.

So just how complex can the behavior of a cellular automaton that starts from random initial conditions be? We have seen some examples where the behavior quickly stabilizes, and others where it continues to be quite random forever. But in a sense the greatest complexity lies between these extremes—in systems that neither stabilize completely, nor exhibit close to uniform randomness forever.

The facing page and the one that follows show as an example the cellular automaton that we first discussed on page 32. The initial conditions used are again completely random. But the cellular automaton quickly organizes itself into a set of definite localized structures. Yet now these structures do not just remain fixed, but instead move around and interact with each other in complicated ways. And the result of this is an elaborate pattern that mixes order and randomness—and is as complex as anything we have seen in this book.

Complex behavior in the rule 110 cellular automaton starting from a random initial condition. The system quickly organizes itself to produce a set of definite localized structures, which then move around and interact with each other in complicated ways.



A continuation of the pattern from the previous page. Each page shows 700 steps in the evolution of the cellular automaton.