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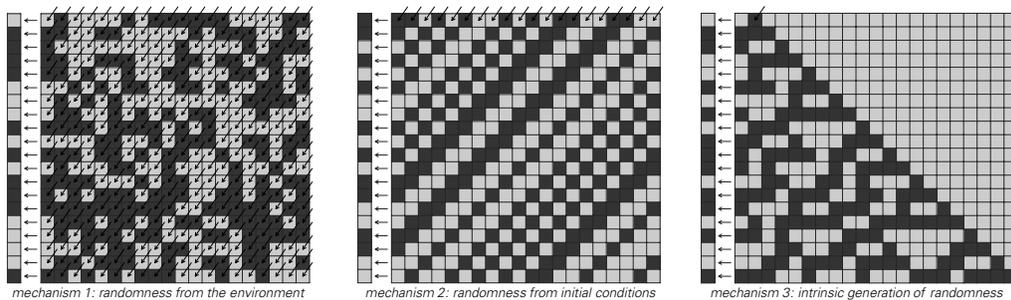
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SECTION 7.2

*Three Mechanisms  
for Randomness*

### Three Mechanisms for Randomness

In nature one of the single most common things one sees is apparent randomness. And indeed, there are a great many different kinds of systems that all exhibit randomness. And it could be that in each case the cause of randomness is different. But from my investigations of simple programs I have come to the conclusion that one can in fact identify just three basic mechanisms for randomness, as illustrated in the pictures below.



Three possible mechanisms that can be responsible for randomness. The diagonal arrows represent external input. In the first case, there is random input from the environment at every step. In the second case, there is random input only in the initial conditions. And in the third case, there is effectively no random input at all. Yet despite their different underlying structure, each of these mechanisms leads to randomness in the column shown at the left. The first mechanism corresponds to randomness produced by external noise, as captured in so-called stochastic models. The second mechanism is essentially the one suggested by chaos theory. The third mechanism is new, and is suggested by the results on the behavior of simple programs in this book. I will give evidence that this third mechanism is the most common one in nature.

In the first mechanism, randomness is explicitly introduced into the underlying rules for the system, so that a random color is chosen for every cell at each step.

This mechanism is the one most commonly considered in the traditional sciences. It corresponds essentially to assuming that there is a random external environment which continually affects the system one is looking at, and continually injects randomness into it.

In the second mechanism shown above, there is no such interaction with the environment. The initial conditions for the system are chosen randomly, but then the subsequent evolution of the system is assumed to follow definite rules that involve no randomness.

A crucial feature of these rules, however, is that they make the system behave in a way that depends sensitively on the details of its initial conditions. In the particular case shown, the rules are simply set up to shift every color one position to the left at each step.

And what this does is to make the sequence of colors taken on by any particular cell depend on the colors of cells progressively further and further to the right in the initial conditions. Insofar as the initial conditions are random, therefore, so also will the sequence of colors of any particular cell be correspondingly random.

In general, the rules can be more complicated than those shown in the example on the previous page. But the basic idea of this mechanism for randomness is that the randomness one sees arises from some kind of transcription of randomness that is present in the initial conditions.

The two mechanisms for randomness just discussed have one important feature in common: they both assume that the randomness one sees in any particular system must ultimately come from outside of that system. In a sense, therefore, neither of these mechanisms takes any real responsibility for explaining the origins of randomness: they both in the end just say that randomness comes from outside whatever system one happens to be looking at.

Yet for quite a few years, this rather unsatisfactory type of statement has been the best that one could make. But the discoveries about simple programs in this book finally allow new progress to be made.

The crucial point that we first saw on page 27 is that simple programs can produce apparently random behavior even when they are given no random input whatsoever. And what this means is that there is a third possible mechanism for randomness, which this time does not rely in any way on randomness already being present outside the system one is looking at.

If we had found only a few examples of programs that could generate randomness in this way, then we might think that this third mechanism was a rare and special one. But in fact over the past few chapters we have seen that practically every kind of simple program that we can construct is capable of generating such randomness.

And as a result, it is reasonable to expect that this same mechanism should also occur in many systems in nature. Indeed, as I will discuss in this chapter and the chapters that follow, I believe that this mechanism is in fact ultimately responsible for a large fraction, if not essentially all, of the randomness that we see in the natural world.

But that is not to say that the other two mechanisms are never relevant in practice. For even though they may not be able to explain how randomness is produced at the lowest level, they can still be useful in describing observations about randomness in particular systems.

And in the next few sections, I will discuss various kinds of systems where the randomness that is seen can be best described by each of the three mechanisms for randomness identified here.

### **Randomness from the Environment**

With the first mechanism for randomness discussed in the previous section, the randomness of any particular system is taken to be the result of continual interaction between that system and randomness in its environment.

As an everyday example, we can consider a boat bobbing up and down on a rough ocean. There is nothing intrinsically random about the boat itself. But the point is that there is randomness in the continually changing ocean surface that forms the environment for the boat. And since the motion of the boat follows this ocean surface, it also seems random.

But what is the real origin of this apparent randomness? In a sense it is that there are innumerable details about an ocean that it is very difficult to know, but which can nevertheless affect the motion of the boat. Thus, for example, a particular wave that hits the boat could be the result of a nearby squall, of an undersea ridge, or perhaps even of a storm that happened the day before several hundred miles away. But since one realistically cannot keep track of all these things, the ocean will inevitably seem in many respects unpredictable and random.

This same basic effect can be even more pronounced when one looks at smaller-scale systems. A classic example is so-called Brownian