EXCERPTED FROM

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A NEW KIND OF SCIENCE

SECTION 8.3

The Breaking of Materials

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In everyday life one of the most familiar ways to generate randomness is to break a solid object. For although the details vary from one material to another it is almost universally the case that the line or surface along which fracture actually occurs seems rough and in many respects random.

So what is the origin of this randomness? At first one might think that it must be a reflection of random small-scale irregularities within the material. And indeed it is true that in materials that consist of many separate crystals or grains, fractures often tend to follow the boundaries between such elements.

But what happens if one takes for example a perfect single crystal—say a standard highly pure industrial silicon crystal—and breaks it? The answer is that except in a few special cases the pattern of fracture one gets seems to look just as random as in other materials.

And what this suggests is that whatever basic mechanism is responsible for such randomness, it cannot depend on the details of particular materials. Indeed, the fact that almost indistinguishable patterns of fracture are seen both at microscopic scales and in geological systems on scales of order kilometers is another clue that there must be a more general mechanism at work.

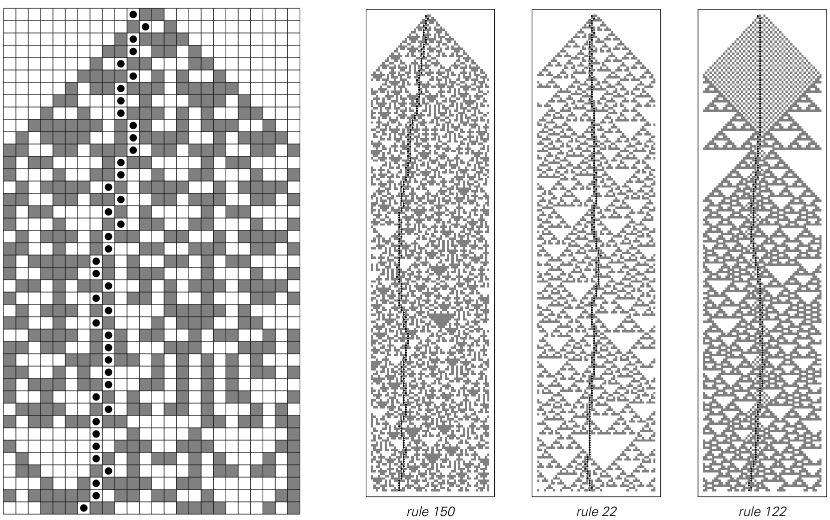
So what might this mechanism be?

When a solid material breaks what typically happens is that a crack forms—usually at the edge of the material—and then spreads. Experience with systems from hand-held objects to engineering structures and earthquakes suggests that it can take a while for a crack to get started, but that once it does, the crack tends to move quickly and violently, usually producing a lot of noise in the process.

One can think of the components of a solid—whether at the level of atoms, molecules, or pieces of rock—as being bound together by forces that act a little like springs. And when a crack propagates through the solid, this in effect sets up an elaborate pattern of vibrations in these springs. The path of the crack is then in turn determined by where the springs get stretched so far that they break.

There are many factors which affect the details of displacements and vibrations in a solid. But as a rough approximation one can perhaps assume that each element of a solid is either displaced or not, and that the displacements of neighboring elements interact by some definite rule—say a simple cellular automaton rule.

The pictures below show the behavior that one gets with a simple model of this kind. And even though there is no explicit randomness inserted into the model in any way, the paths of the cracks that emerge nevertheless appear to be quite random.



A very simple cellular automaton model for fracture. At each step, the color of each cell, which roughly represents the displacement of an element of the solid, is updated according to a cellular automaton rule. The black dot, representing the location of a crack, moves from one cell to another based on the displacements of neighboring cells, at each step setting the cell it reaches to be white. Even though no randomness is inserted from outside, the paths of the cracks that emerge from this model nevertheless appear to a large extent random. There is some evidence from physical experiments that dislocations around cracks can form patterns that look similar to the gray and white backgrounds above.

There are certainly many aspects of real materials that this model does not even come close to capturing. But I nevertheless suspect that even when much more realistic models for specific materials are used, the fundamental mechanisms responsible for randomness will still be very much the same as in the extremely simple model shown here.