EXCERPTED FROM

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A NEW KIND OF SCIENCE

SECTION 11.9

The Significance of Universality in Rule 110

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Practical computers and computer languages have traditionally been the only common examples of universality that we ever encounter. And from the fact that these kinds of systems tend to be fairly complicated in their construction, the general intuition has developed that any system that manages to be universal must somehow also be based on quite complicated underlying rules.

But the result of the previous section shows in a rather spectacular way that this is not the case. It would have been one thing if we had found an example of a cellular automaton with say four or five colors that turned out to be universal. But what in fact we have seen is that a cellular automaton with one of the very simplest possible 256 rules manages to be universal.

So what are the implications of this result? Most important is that it suggests that universality is an immensely more common phenomenon than one might otherwise have thought. For if one knew only about practical computers and about systems like the universal cellular automaton discussed early in this chapter, then one would probably assume that universality would rarely if ever be seen outside of systems that were specifically constructed to exhibit it.

But knowing that a system like rule 110 is universal, the whole picture changes, and now it seems likely that instead universality should actually be seen in a very wide range of systems, including many with rather simple rules.

A couple of sections ago we discussed the fact that as soon as one has a system that is universal, adding further complication to its rules cannot have any fundamental effect. For by virtue of its universality the system can always ultimately just emulate the behavior that would be obtained with any more complicated set of rules.

So what this means is that if one looks at a sequence of systems with progressively more complicated rules, one should expect that the overall behavior they produce will become more complex only until the threshold of universality is reached. And as soon as this threshold is passed, there should then be no further fundamental changes in what one sees.

The practical importance of this phenomenon depends greatly however on how far one has to go to get to the threshold of universality.

But knowing that a system like rule 110 is universal, one now suspects that this threshold is remarkably easy to reach. And what this means is that beyond the very simplest rules of any particular kind, the behavior that one sees should quickly become as complex as it will ever be.

Remarkably enough, it turns out that this is essentially what we already observed in Chapter 3. Indeed, not only for cellular automata but also for essentially all of the other kinds of systems that we studied, we found that highly complex behavior could be obtained even with rather simple rules, and that adding further complication to these rules did not in most cases noticeably affect the level of complexity that was produced.

So in retrospect the results of Chapter 3 should already have suggested that simple underlying rules such as rule 110 might be able to achieve universality. But what the elaborate construction in the previous section has done is to show for certain that this is the case.

Class 4 Behavior and Universality

If one looks at the typical behavior of rule 110 with random initial conditions, then the most obvious feature of what one sees is that there are a large number of localized structures that move around and interact with each other in complicated ways. But as we saw in Chapter 6, such behavior is by no means unique to rule 110. Indeed, it is in fact characteristic of all cellular automata that lie in what I called class 4.

The pictures on the next page show a few examples of such class 4 systems. And while the details are different in each case, the general features of the behavior are always rather similar.

So what does this mean about the computational capabilities of such systems? I strongly suspect that it is true in general that any cellular automaton which shows overall class 4 behavior will turn out—like rule 110—to be universal.

We saw at the end of Chapter 6 that class 4 rules always seem to yield a range of progressively more complicated localized structures. And my expectation is that if one looks sufficiently hard at any