EXCERPTED FROM

STEPHEN WOLFRAM
A NEW KIND OF SCIENCE

SECTION 9.11

Uniqueness and Branching in Time

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If our universe has no built-in global clock and no construct like an active cell, then it is almost inevitable that at the lowest level there will be at least some arbitrariness in how its rules can be applied.

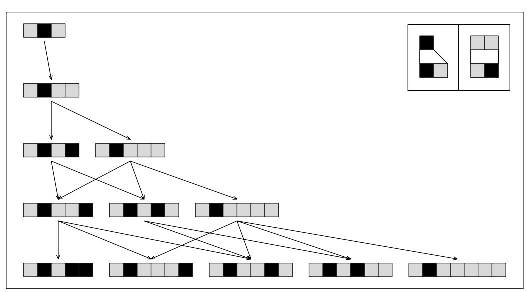
Yet in the previous section we discovered the rather remarkable fact that there exist rules with the property that essentially regardless of how they are applied, the same causal network—and thus the same perceived history for the universe—will always emerge.

But must it in the end actually be true that the underlying rules for our universe force there to be a unique perceived history? Near the end of Chapter 5 I introduced multiway systems as examples of systems that allow multiple histories. And it turns out that multiway systems are actually extremely similar in basic structure to the substitution systems that I discussed in the previous section.

Both types of systems perform the same type of replacements on strings of elements. But while in a substitution system one always carries out just a single set of replacements at each step, getting a single new string, in a multiway system one instead carries out every possible replacement, thereby typically generating many new strings.

The picture below shows a simple example of how this works. On the first step in this particular picture, there happens to be only one replacement that can be performed consistent with the rules, so only a single string is produced. But on subsequent steps several different replacements are possible, so several strings are produced. And in general every path through a picture like this corresponds to a possible history that exists in the evolution of the multiway system.

A simple example of a multiway system in which replacements are applied in all possible ways to each string at each step.



So is it conceivable that the ultimate model for our universe could be based on a multiway system? At first one might not think so. For our everyday impression is that our universe has just one definite history, not some kind of whole collection of different histories. And assuming that one is able to look at a multiway system from the outside, one will immediately see that different paths exist corresponding to different histories.

But the crucial point is that if the complete state of our universe is in effect like a single string in a multiway system, then there is no way for us ever to look at the multiway system from the outside. And as entities inside the multiway system, our perception will inevitably be that just a single path was followed, corresponding to a single history.

If one were able to look at the multiway system from the outside, this path would seem quite arbitrary. But for us inside the multiway system it is the unique path that represents the thread of experience we have had.

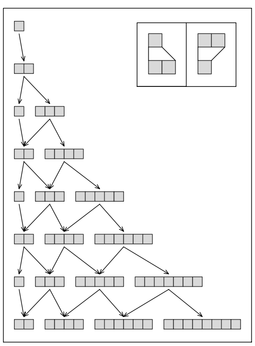
Up until a few centuries ago, it was widely believed that the Earth had some kind of fundamentally unique position in space. But gradually it became clear that this was not so, and that in a sense it was merely our own presence that made our particular location in space seem in any way unique. Yet for time the belief still exists that we—and our universe—somehow have a unique history. But if in fact our universe is part of a multiway system, then this will not be true. And indeed the only thing that will be unique about the particular history that our universe has had will be that it is the one we have experienced.

At a purely human level I find it rather disappointing to think that essentially none of the details of our existence are in any way unique, and that there might be other paths in the multiway system on which everything would be different. And scientifically it is also unsatisfying to have to say that there are features of our universe which are not determined by any finite set of underlying rules, but are instead in a sense just pure accidents of history associated with the particular path that we have happened to follow in a multiway system.

In the early parts of Chapter 7 we discussed various possible origins for the apparent randomness that we see in many natural systems. And if the universe is described by a multiway system, then there will be an additional source of randomness: the arbitrariness of the path corresponding to the history that we have experienced.

In many respects this randomness is similar to the randomness from the environment that we discussed at the beginning of Chapter 7. But an important difference is that it would occur even if one could in effect perfectly isolate a system from the rest of the universe. If in the past one had seen apparent randomness in such a system there might have seemed to be no choice but to assume something like an underlying multiway system. But one of the discoveries of this book is that it is actually quite possible to generate what appears to be almost perfect randomness just by following definite underlying rules.

And indeed I would not expect that observations of randomness could ever reasonably be used to show that our universe is part of a multiway system. And in fact my guess is that the only way to show this with any certainty would be actually to find a specific set of multiway system rules with the property that regardless of the path that gets followed these rules would always yield behavior that agrees with the various observed features of our universe.



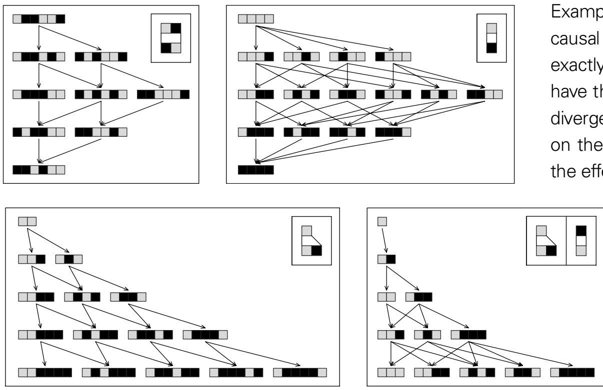
A multiway system in which strings of any length can be generated—but in which only specific sequences of lengths actually occur on any path.

At some level it might seem surprising that a multiway system could ever consistently exhibit any particular form of behavior. For one might imagine that with so many different paths to choose from it would often be the case that almost any behavior would be able to occur on some path or another. And indeed, as the picture on the left shows, it is not difficult to construct multiway systems in which all possible strings of a particular kind are produced.

But if one looks not just at individual strings but rather at the sequences of strings that exist along paths in the multiway system, then one finds that these can no longer be so arbitrary. And indeed, in any multiway system with a limited set of rules, such sequences must necessarily be subject to all sorts of constraints.

In general, each path in a multiway system can be thought of as being defined by a possible sequence of ways in which the replacements specified by a multiway system rule can be applied. And each such path in turn then defines a causal network of the kind we discussed in the previous section. But as we saw there, certain underlying rules have the property that the form of this causal network ends up being the same regardless of the order in which replacements are applied—and thus regardless of the path that is followed in the multiway system.

The pictures below show some simple examples of rules with this property. And as it turns out, it is fairly easy to recognize the presence of the property from the overall pattern of multiway system paths that occur.



Examples of multiway systems in which the causal network associated with every path is exactly the same. All such multiway systems have the property that every pair of paths which diverge at a particular step can converge again on the following step. The first rule shown has the effect of sorting the elements in the string.

If one starts from a given initial string, then typically one will generate different strings by applying different replacements. But if one is going to get the same causal network, then it must always be the case that there are replacements one can apply to the strings one has generated that yield the same final string. So what this means is that any pair of paths in the multiway system that diverge must be able to converge again within just one step—so that all the arrows in pictures like the ones above must lie on the edges of quadrilaterals.

Most multiway systems, however, do not have exactly this property, and as a result the causal networks that are obtained by following different paths in them will not be absolutely identical. But it still turns out that whenever paths can always eventually converge—even if not in a fixed number of steps—there will necessarily be similarities on a sufficiently large scale in the causal networks that are obtained.

At the level of individual events, the structure of the causal networks will typically vary greatly. But if one looks at large enough collections of events, these details will tend to be washed out, and regardless of the path one chooses, the overall form of causal network will be essentially the same. And what this means is that on a sufficiently large scale, the universe will appear to have a unique history, even though at the level of individual events there will be considerable arbitrariness.

If there is not enough convergence in the multiway system it will still be possible to get stuck with different types of strings that never lead to each other. And if this happens, then it means that the history of the universe can in effect follow many truly separate branches. But whenever there is significant randomness produced by the evolution of the multiway system, this does not typically appear to occur.

So this suggests that in fact it is at some level not too difficult for multiway systems to reproduce our everyday perception that more or less definite things happen in the universe. But while this means that it might be possible for there to be arbitrariness in the causal network for the universe, it still tends to be my suspicion that there is not—and that in fact the particular rules followed by the universe do in the end have the property that they always yield the same causal network.

Evolution of Networks

Earlier in this chapter, I suggested that at the lowest level space might consist of a giant network of nodes. But how might such a network evolve?

The most straightforward possibility is that it could work much like the substitution systems that we have discussed in the past few sections—and that at each step some piece or pieces of the network could be replaced by others according to some fixed rule.

The pictures at the top of the facing page show two very simple examples. Starting with a network whose connections are like the edges of a tetrahedron, both the rules shown work by replacing each node at each step by a certain fixed cluster of nodes.

This setup is very much similar to the neighbor-independent substitution systems that we discussed on pages 83 and 187. And just as in these systems, it is possible for intricate structures to be produced, but the structures always turn out to have a highly regular nested form.