Spatial Cellular Automata

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Recorded: March, 2011

Terri has now shown you how to put a fire-spread model in a non-homogeneous landscape onto a spreadsheet. There are two points to be made about what she did. The first is, don't be confused about how she used a random number generator. She just used that as a shortcut to create a non-homogeneous flammability map. One could equally as easily have actually taken real data and entered them into each pixel on the map.

But I say, Terri showed you how to develop a fire model because her model isn't quite the same as the one that I described in the previous lecture. Can you figure out what the difference is?

PAUSE the video: Take a few moments to think about how the spreadsheet fire model is different from the spatial fire models lecture.

You'll notice that after putting in the flammability on the map, she chose a threshold. Choosing a threshold is somewhat like spinning one single random number. And in a sense, she used that one random number for every susceptible cell on the map; whereas, you will recall that we generated a new random number whenever we considered a susceptible cell. She could've done exactly what I did on the spreadsheet, but it would have just been a little bit more difficult to follow.

Before we leave fire models, there's one more thing we could've done. So far, we have chosen to ignore wind. And you remember the reason we had was that the wind might change from one day to the next, from one hour to the next, and we were looking at a time of the year when we couldn't really specify exactly where the winds were blowing unless we knew that there was a high probability of a prevailing wind in a specific direction. And suppose we knew that, and suppose we knew that that prevailing wind went from, for example, left to right across our map. We could do something very simple by, for example, increasing the flammability of cells ahead of the wind and reducing the flammability of cells behind the wind. And in that way, we could probably simulate the effect of a prevailing wind.

I want to leave the fire model now because it isn't a typical spatial model. Why do I say that? We were interested here in the pattern. We didn't care how that pattern evolved over time. That wasn't one of our objectives. We just wanted to get a footprint. Normally, in spatial models, one's looking at a map at time T and how it evolves or changes into a map at time T plus 1. This is almost like a salami tactics model or any type of model on a spreadsheet where you know how far you've got with your variables or what their values are at time T. And what you are now trying to do is predict how it's going to change to time T plus 1. The difference here is that the whole map changes.

And what I'm going to show you is how a type of model can be developed for going from time T to time T plus 1. And this type of model is called a "**cellular automata**" model.

Let's have a look at our maps. On the left, I have a map at time T. On the right, I have a map that I am trying to generate at time T plus 1. Now, each pixel in my map at time T will contain information. And, typically, that information would be one of a number of states. For example, if we're looking at a landscape, those states might be forest, meadow, bush land, desert.

If we're looking at the spread of a disease, we might have a square that's infested, non-infested and no longer infested. So I'm going to represent those states just by numbers. So I'm just going to put numbers. Suppose I have four states, and I happen, at time T, to have some numbers in it that happen to look like that. I won't fill in the rest.

What I want to do is model how the map is going to look at time T plus 1. And I'm going to do that one cell at a time. And the first rule is that the map at time T plus 1 is entirely predictable from the map at time T. So, for example, if I start filling in the values across here, the values I've put in at time T plus 1 will not influence the values in the cells that I still have to address.

For example now, suppose I'm going to be looking at this cell, and I want to predict its value, its state. What I'd do is I'd go back to my map at time T, and I'd find the equivalent cell on my map at time T. And it happens to be in state 3. In cellular automata, the value that we're going to have here will depend on the value at time T as well as the values in its immediate neighbors. And if I'm looking at the rook model, my immediate neighbors would be that square, that square, that square and that square. So I would have an equation, or a set of rules, or some way, an algorithm, of predicting what number between 1 and 4 to put in this cell, based on the fact that I've got a 1, 4, 2 and 1 in the neighbors and a 3 in the center cell. Suppose, in this case, it gives me a 2. And, as I say, I can then generate the rest of the pattern, or the rest of the values in the cells at time T plus 1 entirely from looking at the cells at time T. And that is how my model would develop.

As I said, this is called a “cellular automata” model. And there are two rules that you need to follow:

[1] The first rule is that the map at time T plus 1 depends only on the map at time T. And then if you think about it, it is a rule that we’ve been using in most of our modeling. When we’re projecting a population forward from time T to T plus 1, we didn’t go back and look at what it was at time T minus 1. We always did it one step at a time from the value at the beginning step.

[2] The second rule, though, is more restrictive. It says, “You can calculate the state of any cell at time T plus 1 from the states of the corresponding cell on the map at time T and its immediate neighbors.” And you can decide whether those immediate neighbors on a rook model or on a queen model.

Well, what I’d like you to do now is to think of examples where you might be able to apply cellular automata models. When do you think you could use this kind of paradigm?

<u>PAUSE the video</u>: Write down some examples of where you could apply cellular automata models.

I’m not sure what examples you thought of, but for example, hydrological models would fit a cellular automata approach very well. Spread of a crop disease, perhaps. Dave Tilman at the University of Minnesota has done a lot of work on a completely different scale of competition between prairie grasses. If you had a cellular automata model where each cell was just the size of one grass tuft, you could apply his theoretical rules to see how the distribution and biodiversity of prairie grasses might change from one season, or from one summer season to the next. So these are examples of where you could use cellular automata models.

Now cellular automata models are, in fact, the prevailing paradigm in spatial models. And one might wonder why this is the case. And the answer is, somehow or other, it became a habit. But do we really need to confine ourselves to cellular automata models? Look back at the examples you thought of and ask yourself whether you were compromising yourself. What do I mean by “compromising yourself?” Were you taking some kind of spatial process and forcing it into the cellular automata mold because that is the only mold you have seen? This is one of the cardinal sins of modeling, taking something that doesn’t fit into a particular modeling approach and forcing it into it.

What is so reprehensible about trying to force something into a cellular automata model? Well if you think about it, remember we had two conditions. It's the second condition that says that you can predict the value of a cell at time T plus 1 entirely from the corresponding cell at time T and its immediate neighbors. That could be very restrictive.

For example, if you were looking at Dave Tilman's work with prairie grasses, you would be saying that seeds could spread in a cellular automata model only from the grass tuft to its immediate neighbors. We know that's not true. And it might be very important that in particular grass species, they have the ability to disperse their seeds over much larger distances. So there's no reason to restrict yourself to do that.

Or suppose you had a pine beetle epidemic in a forest. If you were using a cellular automata model, you would have to say that in a time-step, the epidemic could never spread more than one patch away. That, again, might turn out to be unnecessarily restrictive.

So what we need to do is generalize the idea of cellular automata models. And, basically, a spatial model is a game that you can play on a map. You can set up a set of rules to tell you exactly how to get to the map at time T plus 1 from the map at time T. And, provided those rules fit the problem, and you've designed a good model world, there's no reason at all why you should stick to cellular automata models.

So what I'd like you to do now is to think about examples where you might want to develop a spatial model but where it wouldn't be a cellular automata model. And in the next lecture, I'm going to show you one such example.

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