Ecosystem Spatial Models: Fire

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Spatial models can be fun. And to show how much fun they can be, we're going to try to develop a very, very simple fire model.

Now there are lots of fire models out there. Most of them have very specific purposes. So, for example, you might have a model to use for planning on how to control a fire that is currently burning. Or, alternatively, you might be planning to start a fire and to control a prescribed burn. In other words, you might have a fire-behavior model. Both of those models assume that you know the conditions at the time and on the day that you are burning or dealing with a fire that is burning. In other words, you would know things like the humidity and the wind direction and various other factors that might vary from minute to minute or hour to hour.

We're going to try to develop a very simple model with a very different purpose. The assumption we're going to make is that we have a landscape model, something that looks like this, where each square represents a patch that may be a square mile or a square kilometer but something quite large. We're going to assume that a particular square is burning. In other words, we might have a situation where lightning hit here, and the fire spread over the square.

What do I mean by "burning?" I would mean what a GIS person would use to classify that square as burning. There's fire over more than half of it, perhaps.

And the question we're going to ask is, "If nobody does anything to suppress it, will that fire spread to any of its neighbors?" The purpose of the model is that we might have some kind of ecosystem model, and we might be running that ecosystem model on a time-step of a year or even five years or ten years. And what we want to create using this fire model is a fire footprint that is the kind of fire footprint you might have got during that time- step if fires had burned at, perhaps, at the worst time for fires during each season.

So how might we go about doing something like that? Well, I mentioned the first thing we were going to do was ask whether the fire spread to any of its neighbors. The first thing we need to do is to define what we mean by "neighbors." And for people who work with spatial models, there are two types of definitions of neighbors.

The first over here is called the “rook” model. In this case, the central square has only four neighbors. The more complicated model is one in which the central square has eight neighbors, and that is known as the “queen” model for reasons that are obvious to anybody who plays chess. The queen model is usually a much more realistic model to use, but to simplify what we are going to be doing here, we are going to use a rook model. And the way we are going to use the rook model is to say, “If that central square there is burning, then all of the neighbors are susceptible in the sense that they could catch fire.” I’m going to put a little “s” in there for “susceptible.”

We then have to decide which--and perhaps more than one of those squares--which of those square the fire spreads to. And we need to think about how we might go about doing that.

Now I said if one had a fire model where one knew the specific time and day at which the fire was burning, you could take into account humidity and wind direction and things like that. But here, we don’t know when the fire’s going to be burning. So it follows that the wind could be blowing in any direction, and we can’t talk about wind direction unless, perhaps, we know that in that particular area at the time of year when fires are most likely, that there is a prevailing wind in a particular direction, perhaps something like the Santa Ana winds in California. But let’s suppose, for the moment, there is no prevailing wind direction.

The question then is, “What is going to determine whether or not a neighbor catches fire?” Does it depend on the intensity of the fire in the square that’s already burning?

Well, in deciding an issue like that, we need to look at scale. If our scale is of the order of a square kilometer or square mile for each patch, then the intensity of fire in the burning square might cause the fire to spread in the first few meters into the next patch but would be unlikely to sustain it, unless there was sufficient fuel in the susceptible patch to keep the fire going.

So for the first simple model, everything really comes down to the fuel load, or flammability of the susceptible patch. Well, how are we going to define that fuel load, and what might it depend on? It could depend on the soil type. It could depend on the vegetation that’s growing there. And it might depend on slope, for example.

Whatever it is, let’s introduce a flammability scale of 0 to 1. Zero means there’s nothing you can do that would ever make that square burn. It is desert. It’s not going to burn. One means, wink at it, and it'll burst into flames. And, obviously, somewhere between 0 and 1, one has different levels of flammability.

Now, for the purpose of showing how we might develop an algorithm to start and spread a fire, we're going to assume the flammability is .5. And the reason for choosing it to be .5 will become obvious when I introduce you to my random number generator.

Let me introduce you to my assistant, Pam. Pam is a high-tech analog random number generator. Pam has a coin, and she can spin it, and heads means that the square is going to burn, and tails means the square will not burn.

So let's start a fire on a landscape and see how it evolves.

Here we have a landscape, and we also have a code on the right-hand side. A blank square means unburnt. When it is burning, I'm going to hash it like that. When it's burning, the neighbors become susceptible, and I'm going to put a little cross in the square. And I'm also going to say that the burning square is now burnt out, so that's a double hatch.

So what I'm going to do on this landscape is I'm going to start a fire in the central square. So I start a fire, and that means major lightning strike, and that square is now burning. Because it's burning, my four rook neighbors each have a little "x" in them. They are susceptible. And I'm now going to mark that as burnt, and test each of these four squares to see whether or not they catch fire.

So, Pam, if you could spin the first coin.

PAM: Heads.

STARFIELD: It comes up heads, which means that that square is now burning. And the second?

PAM: Tails.

STARFIELD: Tails. So that didn't burn. No longer susceptible. And the next, please?

PAM: Tails.

STARFIELD: That one didn't burn. And again.

PAM: Heads.

STARFIELD: And this one is burning. Because these two squares are burning, I'm now going to look at their neighbors and mark them as susceptible. So that top one is now susceptible. That is susceptible on two counts, but it doesn't matter. It's still just susceptible. That is susceptible. That cannot be susceptible because it's burnt already. This will be susceptible, and that will be susceptible.

So we now have one, two, three, four, five susceptible squares, and we've got to test to see whether the fire spreads to them. So, Pam, if we could have a random number generated?

PAM: Heads.

STARFIELD: Heads. That one's burning. And again?

PAM: Tails.

STARFIELD: That one doesn't burn. Again?

PAM: Heads.

STARFIELD: That one is burning.

PAM: Tails.

STARFIELD: That one doesn't burn.

PAM: And tails.

STARFIELD: And tails. By the way, I'm going around in a clockwise direction here, but in fact, what I'm trying to model is a kind of random process where the wind could be changing. And so I could really choose the susceptible squares at random.

Now I'm not going to go on with this, but what I need to do is the two that were originally burning, I forgot to mark as burnt. And now I need to take the two new ones that are burning and mark their neighbors as susceptible. And I would keep on until the fire burnt out. And when the fire burnt out, I could count the squares and record the pattern and look at the furthest distant square that burnt or any other information that I wanted to collect from this simulation.

So you could see how this works. And, basically, the steps in the process is that you have some fires that are burning on the map. You mark in all your susceptible squares. You then change the burning squares to burnt. You then test all the susceptible squares, which means generate a random number and compare that with the flammability. And then you mark the new burning squares. And you keep on going until the fire burns out.

Well it would be nice to look at a landscape that is still homogeneous but which can have random numbers that are other than .5, and it would be nice to look at how this works on a larger landscape. So I'm going to thank Pam, my analog random number generator, and I'm going to switch to a program written in an old version of Visual Pascal, and we'll see how the model works on a much larger landscape.

So here we have a grid that is 25 squares by 25 squares. And, as you can see, the center square has a fire raging in it. What we can do is choose the flammability. And I'm going to start now with a low flammability of .15. And we click on Run the model, and nothing happens. That fire did not spread. We click on Run the model again. That fire didn't spread. And again, and we had that pattern. And let's do two more. Nothing happened. And just by watching those simulation, you get a sense of what a flammability of .15 means.

Let's now change the flammability to .3. And if we run the model, and again, and again, and again, and again, you see that .3 is qualitatively different from .15.

Let's now go to .45. And we run the model again, and we'll run it again, and again, and again, and once more. And we get a sense of what .45 means.

And .6 is a pyromaniac's delight. And let's run the model a few more times, and you can see that, virtually, your whole landscape burns. And notice, by the way, that there are little pockets of unburnt pixels within this huge burnt area, and that is pretty realistic.

So what we have now is a model to generate the kind of fire footprint that we set out to generate in the first place. If we did many replicates at different values for the flammability, we'd be able to draw histograms that look rather like this.

I want to plot frequency versus the total area burnt. And if you recall, when we had a flammability of .15, very often, nothing burnt at all, and occasionally, a few other squares burned. So our histogram would look something like that. And I could mark that as 0.15.

On the other hand, when we went up to a flammability of .6, we had huge areas burning most of the time. So our histogram would probably look something like that.

And in between, we had .3, which was probably like that.

And we had .45, which was probably something like that.

Now if you had a homogeneous landscape, and you had data over a large number of years on the frequency and extent of fires, you could probably calibrate the flammability of that vegetation type by comparing it to a diagram that looked something like this.

Well, so far, we've been talking about homogeneous landscapes, but obviously, this model could work equally well on a non-homogeneous landscape. And what Terri is now going to do on a spreadsheet is create a non-homogeneous landscape, start fires in it and see how they spread.

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