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. Alternatively, you might be planning to start a fire and 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 the 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 that, 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 10 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 burnt 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 is 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." 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 squares the fire spreads to. 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 is 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 were sufficient fuel in the susceptible patch to keep the fire going.

So for the first simple model, everything really comes down to the fuel loads 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. 0 means there's nothing you can do that would ever make that square burn. It is desert. It's not going to burn. 1 means, wink at it and it will 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. My random number generator is Dana who is sitting at my side here. And the way she is going to generate random numbers is by a somewhat old-fashioned way. Dana, do you want to show us how you flip a coin?

Are you ready?
Yes.
That one didn't work.
Tails.
Very good!

Okay. So we're now ready to do a simulation. Dana is going to flip coins and I'm going to work with my model over here. I've got two possible replicates, and basically each square on the map could be either burning, susceptible, burnt, or unburnt.

I'm going to simplify things by representing burning with a hatch like that. And I'm going to suppose lightning has struck my central square and spread out, and that square is burning. The way my simulation is going to work is that in term of my rook model, these four squares are susceptible. Instead of writing a little S, I'm just going to put a little cross in the corner to show which squares are susceptible. So that square is susceptible. That square is susceptible. That is. And that is. Once I've defined my susceptible squares, I can suppose that this central square has burnt.

And I'm going to represent burnt by just hatching both ways. So now I've got to decide whether each of the susceptible squares caught a light while that central square was burning. And the way I'm going to do it, since the flammability is .5, is say if a random number is heads, or less than .5, it's going to burn. Otherwise, it won't burn. The question is, which of these squares should I choose first? Since I might be working on a time step of five years and I have no idea which way the wind might be blowing at the time at which this particular square was burning. I'm just going to choose them at random, and that randomness of choice on my part represents an odd puff of wind in this direction, which could equally change in the next few minutes to a puff of wind in that direction.

So I'm going to start off with this square, and Dana is going to flip a coin, and remember heads means it burns, tails means it doesn't. Go ahead, Dana.
Tails.
Tails. So that didn't burn. It's no longer susceptible. It's still unburnt. I'm now going to pick that square.
Tails.
This fire isn't going anywhere. Let's pick that square next.
Heads.
Okay. That's heads. So that is now burning. Because it's burning, those three neighbors become susceptible. That's burnt. So it can't burn again. Once I've marked the three neighbors as susceptible, I can mark that square as burnt. Let's try this square next.
Heads.
So that is burning as well. Because it's burning, that's susceptible, that's susceptible - notice this was already susceptible. And that's burnt. Since I've marked the susceptible neighbors, I can mark that as burnt.

Let's move to this square.
Heads.
I guess I've put that in the wrong direction, but you get the idea. Now something interesting happens. This square is susceptible. That square is susceptible. And this square that was susceptible and didn't burn has become susceptible again. It's as though the fire has turned around with the wind and put that square in danger again.

Well, let's look at that square.
Tails.
Tails. It didn't burn. Let's look at this one.
Heads.
That one is burning. By the way, I should have marked that as burnt. That's burning. So this is susceptible and that is susceptible, and that is burnt.

Let's go back to that square.
Tails.
So that didn't burn. This square?
Heads.
Is burning. So that is susceptible. That is susceptible. That's burnt.

Let's go to this square.
Tails.
Not going to burn. This square?
Tails.
This square.
Heads.
It's burning. So this square has another chance to burn. Let's do that one.
Heads.
Burning. Notice this square now has another chance again to burn, and so does that. Let's try this square.
Heads.
Heads. So that's burning. Susceptible, susceptible and burnt.
Let's try this one.
Heads.
Burning, susceptible, susceptible, burnt.
Let's try that one.
Tails.
Not burning. That one?
Tails.
Not burning.
Tails.
Not burning.
Heads.
That one's burning. Only one square becomes susceptible.
Tails.
Tails. Not burning. Let's try this one.
Tails.
Not burning. So notice that the fire has pretty well burnt itself out in this area. We've got three left to test. Let's try this.
Tails.
That's not going to burn. That?
Tails.
It's not going to burn.
Tails.
And that didn't burn.
So at this point our fire has burnt itself out, and when I talk about the fire footprint on this particular landscape, the hatched areas are my fire footprint. And notice as fires burn it's a fairly realistic sort of footprint. It has burnt out some areas and missed other areas. The total area burnt is . . . 11 squares.

If I were to do another replicate, which I won't, then I could count how many squares burnt on this replicate. And if I did enough replicates, I could get a size frequency histogram for burning fires on that particular landscape if the flammability of the landscape is 0.5.

Well, we've gone through this using Dana as an analog computer, but in practice, of course, if we're going to do many replicates, we want to speed it up. So we need to put it on a real computer. So the next step is to show you a model that does exactly the same thing on a larger landscape with different flammabilities.

Well, we now have a real random number generator. Thanks to Dana for being the analog. What I'm going to do here is have a computer map that is 25 by 25 squares. And I can set my flammability to 0.5, as we did with the coin flipping.

We run the model, and I think you can see here's the central square where the fire started, and this is a particular example of how that fire might have spread. If we count the squares, 206 burnt in that replicate. Don't worry about what goes on - on this side of the screen.

If we want to do another replicate, we run the model again, and that time we only burned 22 squares. Run it again, and if I click a number of times, you get some idea of the range of fire footprints that we could get on that landscape if the flammability is 0.5.

What I'm going to do next is change the flammability to .6. And we will now get a feel for what the difference is between a flammability of 0.5 and 0.6. I'm going to run the model. And I think you can eyeball the fact that even though there was one example there where the fire didn't spread at all, that .6 is qualitatively different from 0.5. You're much more likely to burn nearly the whole map with a flammability of 0.6.

Well, we've seen 0.6 and 0.5. What happens if we go backwards? I'm now going to look at 0.4. And again, I think you can see that this is qualitatively different from both 0.5 and 0.6.
And then if I run down to a flammability of 0.2. Again there are times where only one other square burns or when no squares burn at all.

If you had been watching those figures, one could draw a histogram of how many squares burnt how frequently for each of the flammability figures. So if we imagine a diagram like this where we have total area burnt along one axis and frequency along another. I think what we've seen for 0.2 is that our frequency looks something like that. Whereas for 0.6, it looked something like that. With maybe 0.5 looking like that. And 0.4 looking like that.

A diagram like this, and of course, we are dealing here with a homogeneous landscape. But nevertheless, a diagram like this, if you had any fire records from a real landscape could enable you to calibrate what you mean by a flammability of 0.2 or 0.4 or 0.5 or 0.6.

So this is a plausible model to use. Suppose, however, that we knew there was a wind blowing in a particular direction, at the time of the year when fires were most likely to burn? If we wanted to represent a prevailing wind like that, we could perhaps increase flammabilities ahead of the wind and reduce flammabilities behind it. And that might be a simple enough fix to represent wind direction.

The only thing we haven't done with this model is look at what happens if you have a heterogeneous landscape, and we are going to have one last look at another model in which we do that.