Spatial Non-Cellular Automata

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In the previous segment, we looked at cellular automata models, but we ended with the idea that not all spatial models need to be cellular automata models. And I promised you an example of a model that was not a cellular automata model. And this example goes back a ways to the problem we looked at earlier on elephant contraception.

Suppose we wanted to try and model how different densities of elephants affect the landscape in the Kruger National Park. Remember the whole contraception program in the Kruger National Park was premised on the idea that an elephant density of one elephant per square mile was a useful heuristic. If one challenged that and wanted to start arguing about what an appropriate elephant density is, then, obviously, one would be pushed in the direction of trying to model how elephants interact with and affect their landscape. And to do that, one would have to have some idea of how elephants move over a landscape.

So what we are going to do is create a **non-cellular automata model**, which, in the first instance, just predicts how elephants are going to move over a landscape from one season to the next. And we're going to have a look at how small groups of elephants move over the map.

So, for example, what I have here is, perhaps, a region of the Kruger Park where I have bounded by a river at the bottom and, perhaps, another river at the top. And one might have several large herds of elephants using this region. Perhaps my scale is that each square here is five miles by five miles. Haven't calibrated the scale yet.

The map that we create is a vegetation map for that region. And, as you can see, we have a legend down the side here. So near the river, one might have a mix of riparian forest and riparian grassland. And then further up in the map, one might have different types of vegetation. For example, one might have mopane forests over here. And elephants love mopane trees, and if you have high densities of elephants in mopane forests, they will reduce those trees to bushes that have a maximum production of leaves, and that's what we call "mopane scrub." So perhaps interspersed amongst the forest is mopane scrub. And one could fill in the whole of this vegetation map.

Now what I want to do is think about where my elephants are during a season. I don't want to try and model how the elephants move from day to day or week to week. I want to model how they move from season to season. So what I'm going to do is create little groups of elephants, perhaps five or six elephants in a group, a cow, a daughter and a few calves, perhaps.

And I'm going to assume that for one whole season, they do most of their grazing and eating within one pixel on the block. So I can think of each of those little elephant groups as a kind of pawn distributed on my vegetation map. And at the end of each season, I want to re-distribute those pawns because the elephants are going to have different food preferences from one season to the next.

Now in a cellular automata model, they would only be allowed to move from one cell to a neighboring cell. In practice, a little group of elephants could probably walk from one end of my map to the other in the space of three or four days, or at most, a week. So there's absolutely no point here in having a cellular automata model. Again, notice, if my time-step were different, and I had a time-step of one day, then, perhaps, a cellular automata model might be appropriate. So the type of model you use depends on the scale of your pixels and depends on your time-step.

What I want to do here is, at the end of each season, take all my pawns off the map and re-distribute them appropriately for the next season. And I want to develop an algorithm for doing this.

Now, before we talk about the algorithm I'm going to develop, I want to give you an idea of how one might think about this by looking at something completely different.

Let's suppose that you've just won a raffle, and in that raffle, you have a two-week holiday in one of several destinations of your choice. And this holiday is going to take place in July. And some of your options, or perhaps all of your options, are Alaska, Paris France, the Serengeti, the Antarctic and Dallas.

And I could get some idea of how people might choose where to go by doing a survey of where people would prefer to be in July, or prefer to go for their vacation. And from those survey results, I could come up with a scale of, say, 1 to 10, which tells you what the attractiveness is of each of the holiday destinations in July.

And if you sort of think about how a survey like that might work, you wouldn't want to go to the Antarctic in July. It's mid-winter, right? So that's a 1. You wouldn't want to go to Dallas in July, unless, perhaps, you were interested in spending your life in shopping malls. Paris in July is a bit hot, but Paris is always exciting, so maybe that turns out to be a 5. Alaska in July sounds very exciting. Maybe that's a 9. And maybe Serengeti is also very exciting. So you can see how I could do a survey, convert the results and come up with an attractiveness value for each of my holiday destinations in July.

But suppose the holiday was going to take place, not in July, but in December. Can you see that your results would be very different? The Antarctic might now turn out to be a highly desirable place. Alaska might drop to a highly undesirable place. Christmas in Paris might be quite fun. The Serengeti's always exciting. I don't want to say that Dallas is always unexciting, but Christmas in Dallas might be a great place to go if you live in Minneapolis, so maybe that goes up to a 4.

So you get the idea. You do a survey, and from that, you come up with an attractiveness scale at different times of the year. And that scale is arbitrarily from 1 to 9.

Now how can we use this on elephants? Instead of having Alaska and Paris and Serengeti as your destination, you will have the different vegetation types from your vegetation map in the Kruger Park. And these vegetation types will have different attractiveness, depending on the season. So what you would do is survey your elephants. And suppose season 1 is spring. You would say to the elephants, "Where, in spring, would you most like to be"? And they might say, "Gee, vegetation type 4 is fantastic in spring." And from the results of this survey, you could fill in your numbers. If you then switched to season 2, which is summer, these numbers will change, and so on.

Of course, I'm being facetious when I say you should do a survey of elephants. But if you have scientists who have been carefully studying how elephants use their landscape, they should be able to come up, from their expert opinion, with numbers such as this.

Okay. Now how can we use these numbers to re-distribute the elephants on our map at the beginning of each season? Remember what we decided to do was to take all these little pawns representing small groups of elephants off the map at an end of a season. And now we have to assign them to a new map at the beginning of the next season.

And, in a sense, the way we do this - is we have a vegetation map. From that vegetation map, depending on the season, I can get an attractiveness overlay. So now I have an attractiveness map.

And imagine all my family groups lining up to be assigned to where they're going to be spending the next season. And the first group comes along, and you say to them, "Where would you like to be?" And they say, "The best place on the map." And what you would then do is assign them randomly to one of the squares with the highest attractiveness on the map.

Now as soon as you have a new group in that square, it's not quite as attractive to other elephants because there are already elephants grazing there. So what you would do is have some rule for how the attractiveness drops off, depending on the number of little groups that are using that pixel. So you would update your overlay. And then along would come the next group of elephants. And in that way, you would continue to assign the elephants to different places in the map. That could be a very effective, non-cellular automata way of distributing your elephants.

Okay. Now this would not be very exciting for more than four seasons because nothing is changing on our vegetation map. But this is just part of a story where ultimately what we want to do is think about how the vegetation in a pixel might change, depending on the number of elephants that are utilizing that pixel at different times of the year.

So what we now want to do is add to this a component of, within pixel models, where the number of elephants, the time of the year, perhaps rainfall and perhaps fire are going to affect the vegetation type. And the way you could do this would be to have, perhaps, three or four frame-based models. And those frame-based models could run inside each pixel.

So now what we have been talking about as vegetation type is really the frame that you happen to be in in that pixel. And when I say "several frame-based models," for example, one would have one model for vegetation in the riparian zone and another model for vegetation, for example, in the mopane lowlands. So you would break the region in the vegetation map up into a number of three or four-type different areas where the vegetation responds in different ways to elephants and rainfall.

And now you have the potential to do something very exciting because what you have is a sort of circular situation where the vegetation, as we've seen, determines how the elephants move across the landscape from one season to the next. Depending on how the elephants move, the vegetation might, over time, over several years, change. Each time the vegetation changes, the elephants are going to distribute themselves in a different way. And that is, then, again going to change the way in which the vegetation changes.

So, for example, you could have pixels where there is forest that is highly desirable to elephants. That forest gets wiped out over a number of years and converted into a grassland. The elephants move elsewhere at the time of year that they would've been in the forest. And, in due course, that forest re-generates. But it can only do that if the number of elephants in the landscape is relatively low. If the number of elephants is much higher, if we go to increased densities, then it is possible that some elephants will, in a sense, be forced to use the grassland and prevent re-generation of forest where they would much prefer to have had the forest or to have moved to another pixel with forest if there had been one.

So I think you can see how you can get a fantastically-interesting interaction from a very simple spatial model, which, in this case, is how elephants move from one season to another, and from some very simple frame-based models, which look at how elephant, rain and fire affect the vegetation. And from that combination of simple models, you can get some very interesting results.

So what we are now looking at is a combination of spatial models and frame-based models. We can call these "**Ecosystem Models**." And I'm going to show you another example in a moment.

The combination of frame and elephant movement that I've described in the previous section in the Kruger Park has never been implemented as a model. A very rough prototype was developed just to see how it might work. But what I'm going to talk about now is a model that has been developed and has been extensively used.

The model takes place in the north of Alaska, where there's a lot of concern about how climate change might affect the vegetation, in particular, how forests might move north into areas that are currently tundra north of the Brooks Range in Alaska, and also, how the changes in vegetation and climate might change the probability of large fires in Interior Alaska.

And a code has been developed that is a combination of a spatial model and a frame-based model. The pixels are of the size of one or two miles to a side, and the time-step is about five years. Things happen slowly in Alaska.

And the model works as follows. For the spatial aspect, at the beginning of each time-step, one has a distribution of vegetation across the landscape. The vegetation corresponds to frames in a frame model, and the vegetation could be tundra. It could be an evergreen forest. It could be a deciduous forest. It might even be a dry grassland, somewhat like the steps in the north of Russia.

Depending on the vegetation and the climate, we have a fire-spread model. We pepper the landscape with lightning. On the basis of where lightning hits and what type of vegetation we have, we decide whether or not that lightning is actually going to set alight that whole pixel. And if it does, we then apply the fire-spread model that we described right at the beginning of this module. In fact, the fire-spread model was developed precisely for that purpose.

Then, once we know which squares or pixels are burnt, we are in a position to use frame models inside each pixel to decide whether the vegetation has changed or to keep track of variables that we'll determine in due course, whether the vegetation changes. And these frame models can also refer to maps because part of the story might depend on how close seed sources are to that particular pixel.

This code is called ALFRESCO. ALFRESCO stands for Alaskan Frame Based Ecosystem Code.

And you can find references to a large number of papers and to reports at a website at the University of Alaska Fairbanks. Dr. [Scott] Rupp has been the person who's been developing most of this work.

http://www.frames.gov
http://www.frames.gov/documents/catalog/alfresco_users_guide_v2_0_3.pdf

What is fascinating in these applications is, first of all, that interaction between, again, a spatial model--in this case, mainly the fire story--and frame-based models, which look at how vegetation changes, depending on the climate. So here you have an interaction where fires change the landscape. Obviously, the landscape can change fires. If you get a very large fire, you might reset the landscape in particular ways. And it might be a large time before that landscape changes to the point at which it is likely to have another large fire. So you get some really interesting and very often counter-intuitive consequences out of this combination.

Now not only do you have the spatial-fire model affecting the frame-based vegetation model, but you have different scenarios for climate change coming into the story as well. So you now have a three-dimensional, if you like, mix. And that fairly simple combination of models produces some very interesting results with practical implications to, for example, fire management in Interior Alaska.

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