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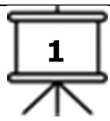
Modelling Forest Fires

Slides/
Worksheets



Note: the symbol ➢ indicates a click in the slides for an element (text or otherwise) to appear.

If a longer settling activity is needed than the question on the slide, hand out Worksheet 1 and let students try the exercise on the reverse side. Tell them not to turn over!

Okay, now that everyone is here, I want you to keep those ideas about what factors might affect forest fires in the back of your head – we'll come back to those later.

Introduction (5 minutes)

Today we are going to look at an area of mathematics known as modelling. This can mean a lot of things in maths; models are used to predict the weather, examine the stock market, calculate how crowds behave and how things move through space, like waves or thrown objects. A mathematical model is usually a set of equations or algorithms, like a computer programme, which can be used to predict real-world behaviour. The better our model, the more accurate predictions.

Today we are going to focus on one specific example – **modelling forest fires**. However, the ideas behind this model can be used to examine a range of different things, such as the spread of disease or bacteria growth. We are going to use one method of modelling today, but there are several other ways to look at things. When you really look at mathematical modelling, the same patterns crop up again and again in different fields of biology, chemistry, physics, epidemiology, economics and in other areas we haven’t even thought of.

Imagine you are looking at a group of rabbits and want to model the population size. If you are watching them constantly and record every new baby rabbit and every time a rabbit dies, this is continuous time. What we will be doing today is looking at time discretely, in steps. It is as if we were only looking at our rabbits once every month and counting the population size then, rather than watching them all the time and looking at how things change, when they change.

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The method for modelling which we are going to use today is called Cellular Automata. This is used in many different areas and can very easily be programmed onto a computer.

- The model is of a fixed grid of cells,
- all of which can be one of a finite number of different states, e.g. Alive or dead, dyed or undyed, 0 or 1.
- There are very simple rules which say what state each cell will be in, according to what its neighbours are doing. The rules are the same for the whole grid. We are going to start looking at this in our first worksheet.
- The green cell is 'active', and all of its neighbours are 'inactive'. Certain rules determine whether a cell becomes active, for example if it is neighbouring an active cell.

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You have a square grid with some black squares.

- We are going to imagine that these are spots of dye on a squared cloth.

The rules for how the dye spreads are given here:

- once something is dyed, the dye is permanent;
- if a square has three or more dyed neighbours, it becomes dyed.
- We are all going to have a go at modelling the spread of the dye.

We will be working in time-steps – for each time-step, we want to know which squares are ABOUT TO BECOME dyed. We need to work them all out, and then it is as if it all happens at once. Then we can move on to the next time-step. Our newly dyed squares won't affect things until that point.

Let's have a look at how it will work.

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Imagine the black squares are dyed. We know that the dye will spread in the next time-step – it will spread to all squares which have three or more dyed neighbours.

? **How many dyed neighbours does each square have?**

- The edge squares are easy: they don't have any dyed neighbours.
- *Go around to each square immediately surrounding the black shape, asking how many dyed neighbours it has. Start with the "1" in row 2, column 3 (16 clicks).*

? - **Which of these squares will become dyed?**

Pupils should identify those with a 3 or 4.

The black squares have already been dyed. The blue squares have been identified as about to be dyed. Have we seen all the ones where the dye will spread from the back squares? Yes – this means it is the end of the time-step.	5
- In the new time-step, both the black and the blue squares are properly dyed, and the dye can spread from both colours. - Where will it go to? *Pupils to identify four squares.* - *4 clicks: Four crosses will appear to show squares which will be dyed.* Remember that the red crosses don't affect things yet, they won't be properly dyed until we move on to the next time-step again. ***Worksheet 1: Spreading Dye.***	6 **Worksheet 1**
## Modelling Forest Fires Activity Cellular automata can be used to model processes such as forest fires in a similar way to the dye; the fire will spread from tree to tree. Again, we need to fit the rules of the model to the real world. Modelling processes like this is useful because it can tell us what might happen, rather than waiting to see; we also want to know how we might stop fires. Different methods can be used to try to stop forest fires, like helicopters dumping a lot of water on the forest or taking out a whole section of trees to remove the fuel so the fire can't spread as easily. But each of these takes time and is costly, so if we can use our models to help work out what might be the most effective, we can try that first. ? **What do we know about how fires spread?** - *1 answer: source of ignition* ? **Can we say that a tree will catch light only if it has a certain number of neighbours already on fire?** *2 clicks.* No – it is more down to chance than that, but the probability of catching light does increase if it has more neighbours burning. We need to introduce probability into the model.	7

We can **introduce probability** into the model very easily.

- Let's assume that, in normal conditions, each tree has a 1/3 chance of catching light from one burning neighbour.

If a tree has more than one burning neighbour, it can catch light from <u>any</u> of them. We need to apply the probability for <u>each</u> neighbouring tree which is already burning.

- We can model this on our grid.
- Each cell represents a tree, and has two possible states: normal or burning. We can incorporate the probabilities using dice; we can roll once for every burning neighbour a tree has. The probability of catching light is 1/3, so a tree will catch light if we roll a 5 or a 6.

Tree D has one burning neighbour, so we roll once. Tree E has two burning neighbours, A and B – it could catch fire from A, or from B, or from both (but we don't worry about it catching fire from both as one spark will do). This means we need to roll the dice twice, once for catching fire from A and once for catching fire from B. If either roll is a 5 or 6, E catches fire.

Tree F has three burning neighbours. How many times do we need to roll?

Three. If any roll is a 5 or 6, F catches fire.

Can you see how E and F are more likely to catch light?

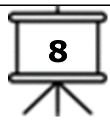
We are going to model this process in the next worksheet. We need to follow the same sort of method as with the spreading dye – we need to look at each square carefully to work out which have a chance of catching fire. For each tree, we need to work out how many burning neighbours it has, and therefore how many times we need to roll the dice to see if it does actually catch fire.

Let's work through an example…

Example *– show on board or visualiser. Get a volunteer to be your 'dice roller'. If you can, use different colours and different patterns to fill the squares in each time-step.*

- *Start with a grid – 5x5 works fine, or you can make it bigger. Colour in the middle square – this is your burning tree in time-step 0.*

- *Using a new colour, put a dot in each of the 'trees' (squares) immediately surrounding your coloured square to show that these have a possibility of burning. They will burn with probability 1/3 in this example – get the students to shout out two numbers to look for on the six-sided die, if those numbers are rolled then the tree you are checking will catch fire.*



- *Choose a starting point (one of the dotted squares) to check; does the tree catch fire? Get your dice roller to roll the die and see. If yes, colour it in in the colour/pattern for time-step 1; if not, move to the next dotted tree. You need to check all the dotted trees once and only once.*

- *When you get your first burning tree: when checking the next tree (likely adjacent), ask how many times you need to roll the dice. Students to shout out the answer – should be once. Remind them that the tree you have coloured in is not on fire yet, so fire cannot spread from there; it will only be on fire at the end of the time-step. To make it easy to do, you are using a different colour/pattern for each time-step, and you need to ignore any trees with the colour/patterns that you are using.*

- *Once you have got back to your starting point, tell the students that this is the end of time-step 1, and all those trees you have just coloured in are now on fire.*

- *Switch to a new colour, and put a dot in any trees which can now catch fire; remind the students that any trees which already had a dot can still catch fire, just because it didn't burn in the first time-step doesn't mean it won't this time around.*

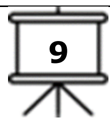
- *Choose a tree to check which has more than one burning neighbour. Get the dice roller to roll once; does it catch fire? If not, ask the students if you need to roll again. If it catches fire first time, either talk about what would have happened if it hadn't (i.e. needing to check again), or move round the shape systematically until you get to another tree with more than one burning neighbour that you'll need to check multiple times. Remember that the number of times you need to check (assuming the tree does not initially catch fire) is the number of burning neighbours.*

- *Once you've illustrated the 'multiple burning neighbours' scenario, you can move on – you don't need to finish the time-step.*

❓ **What different weather conditions would affect our model?**

[Ideas from students – give a little thinking time and ask for hands up, or get them to chat to the person next to them briefly first if they are particularly quiet. Explain that we're just sticking to really simple weather conditions at the moment, e.g. how dry and wet it is (see next slide for what we'll be looking at). Any other ideas, tell them to keep that for later – we will come back to them!]

➢ So far, we have been talking about normal conditions – not too wet, not too hot – and we said that the probability of a tree catching fire from one burning neighbour is 1/3.



- **How would we take a drought into account?** *[Ideas from students]*

- This would make it easier for trees to burn, so would raise the probability of it happening – for example to 5/6.

- **How would we take wet weather or floods into account?** *[Ideas from students]*

- This would make it harder for trees to burn, so would lower the probability of it happening – for example to 1/6, or even 1/10 if it was extremely wet!

We discussed how you could roll the dice once for each burning neighbour and if any of the rolls started a fire, your tree would burn. For the tree in position 1, you have one burning neighbour, so you would roll once. Tree 2 has two neighbours, so roll twice; same for trees 3, 4 and 5. Tree 6 has three burning neighbours so you would roll three times.

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Worksheet 2

You are going to explore the effects of different conditions with this model on your problem sheets. Read the instructions carefully. You will also need to discuss some questions in your groups, and we will talk about these after your worksheet.

Worksheet 2: Forest Fires *(30-40mins)*

IMPORTANT: As with the spreading dye, you are looking at where the fire will spread to. Those new trees don't start burning until you have gone through every tree in your grid which already has burning neighbours to see if they will catch light.

[25-30 mins gone; worksheet 30-40 mins, then break (or put break time during the worksheet time). They can carry on with their worksheets during the break if they want to. After worksheet 1 and the break you should have 70-80 minutes left.]

Ensure all students have worksheet 1 – there is one per group of (up to) 4, and they will each have a double-sided page with a different probability to check. Each group of 4 will also need coloured pencils and three six-sided dice and one 10-sided die. If you don't have any dice, get them to use folded bits of paper, or a phone app if some of them have phones. If you don't have 10-sided dice, adjust the probabilities on the worksheet and slides (remember to test!).

If they finish looking at their condition once, it is important to do it again to see if the pattern is similar – because chance is involved, it probably won't be! Encourage them to either repeat the same condition again or swap with another person in their group.

- *[Click to show first two lines]* All of you should have had a go at modelling the spread of a fire in an orchard.

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Worksheet 3

Look at what happened with the different conditions within your group and discuss between you – in a minute I'll come round and ask each group for one interesting thing they noticed about how the fires spread. It might be a comparison between conditions, or an interesting thing with one of the conditions.

- *Give discussion time of a few minutes, then ask from one idea from each group.*
- *Lead a short discussion about what the students found and the patterns they noticed – can also ask for hands up if different things happened, e.g., did any of them fill in their grids within X time-steps? Did any have a lone unburnt tree for several time-steps? Did any of them have fires which went off in particular directions? Did any not fill in their grids? What conditions were each of these things for? Talk/ask about whether they will all have got the same/similar patterns, given chance was involved. They may have some really interesting thoughts about what they have noticed.*

So far we have looked at a very simple model for how a fire might spread. We are going to spend the rest of the session looking at how to improve this and make it more realistic.

- **What else could we include – what might affect the spread of a fire, or affect how it behaves?**

- *Give thinking/discussion time; if you want to go round every group, go in the opposite direction to before, or ask for hands up. It's likely that lots of students will want to contribute ideas. Remind them that some of them had ideas from earlier.*
- *Write them on the board – simplify things so they can use them as ideas for adapting their own models, e.g., "wind direction", "wind speed", "types of trees", etc.*

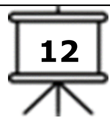
- In Worksheet 2 we will look at incorporating some of these factors to make our models more realistic.

When you build a model, you start really simply and build up the complexity to reflect the real-world, so you're going to start with just ONE thing to add in to your model. If this works well, you can add in a second thing, test it works, and so on.

You can choose something from on the board, come up with your own idea, or if you are stuck there are also some ideas on the sheet. To put something in your model you will need some instructions that someone else or a computer can follow – these might be written out or explained with a diagram. Being able to put together simple instructions is the basis of computer programming. Computers are very good at doing simple things very quickly, but they are stupid. You need to give them idiot-proof instructions.

There are lots of questions on the sheet to help you think about how to put your idea into a model, but you don't have to answer them; there are also some grids for you to try it out on. At the front we have a selection of different dice for you to borrow if you wanted to try out different probabilities. You can work in your groups, in pairs or individually. Make sure you are starting with the real-world situation and making a model from that, not just going "this would be a good thing to do with the dice" and not having an actual situation it links to. ***Worksheet 3: Your Adaptations*** - *Put out a section of dice; if working with an older group than Year 9 or have lots of extra time in your scheduled workshop, you could also have different paper (e.g., hexagonal or triangular grids). Go round and talk to the students; check what they are including, and how they are including it. Make sure this makes sense (e.g., wind direction would affect the probabilities of trees relative to the burning tree, not give a different probability for one half of the grid). Check all understand and are happy working on their models.* - *Stop 10 minutes before the end (longer with a very large group) and go round the room asking the students what they added into their model – go round the room in the opposite order to when you asked for feedback on worksheet 1. Tell the students to keep it brief – e.g., "wind direction" rather than explaining how, though for some ideas a bit of explanation might be required. If you're tight on time you can also ask for hands up to show who else used a common idea.* Many of you chose different ideas to incorporate into your models, and even those who chose to look at the same thing did it in different ways. If we were to put everything all of you had done together into one big model, it would be a much better representation of how the fire might spread in the real world – and we could use that to help us work out where fires might go, if people were likely to be in danger, and what might work to stop them. As there is chance involved, a model is only an estimate of what might happen – we need to repeat it hundreds or thousands of times to get a good picture of the most likely outcomes and patterns for the real-world conditions we are facing. You'll see this with a weather forecast – it will give you what the probability of rain is, but can't tell you for certain whether it will rain and when it will start or stop.	

End of session – recap



We have only scratched the surface of what you can do today.

- Even the models we have been looking at can be applied to a range of different populations – you just have to be careful to make sure your model fits with the real-world situation.
- As I said at the beginning, the forest fire model is often used to examine the spread of disease.

This picture shows one model of a disease spreading, with the probabilities in the model linked to how the disease can infect people.

We can also model animal patterns with very similar ideas. This type of shell has a very complicated pattern – yet it can be modelled with the simple rules of cellular automata. This picture shows how; the set of rules is called 'Rule 30' (it was named by Steven Wolfram). You start with one single square of pigment and lay out each time step line-by-line, according to a set of rules of when the next square will be coloured. This fits with how shells grow – they lay out material along one edge and build it up strip by strip. When Wolfram examined this rule, he found that the pattern produced was very similar to that on the shell. Many other shell patterns can be modelled by similar rules.

- Look at: Nicky Case and John Conway's "Game of Life"

If you would like to explore these ideas more, you can look into using different types of mathematics to model things like populations, animal migration, the weather, disease spread, cancer growth, etc.

- To play more with Cellular Automata, there is a great game called "The Game of Life" which you can find on the internet or as a smartphone app.

This used simple rules about when cells will die or when new cells will be born (become alive) and it can give you really different behaviours depending on your starting patterns. There is a smartphone app which also allows you to change the rules and investigate what will happen.

Nicky Case has put together a very similar model of a forest fire to the one we have been playing with, programmed in Python. You can change the variables to experiment with different conditions and the effect this has. You can also edit the code.