

Modelling Forest Fires

Masterclass:

Additional Information

Introduction to modelling as a concept, and why we do it.

Modelling, in maths, is the process of describing a system or phenomenon using mathematical concepts. Models can be used to solve problems and make predictions and can be made simple or complex depending on the number of factors taken into account. We use mathematical models because they allow us to make logical predictions about a future event under different conditions, so that preparations can be made. For example, this Masterclass focuses on modelling forest fires. We need to be able to predict a likely rate and direction that a fire will spread in, in order to fight the fire and minimise the damage caused.

A mathematical model can be classified as:

- Linear or non-linear – a linear model generally describes a scenario wherein as one factor increases/decreases, another does the same. A non-linear model generally describes chaotic phenomena, and is harder to build
- Static or dynamic – a dynamic model changes over time, whereas a static model describes a steady-state regardless of time
- Discrete or continuous – this describes how the factors involved are seen. For example, time may be modelled as continuous, or in discrete time steps, as seen in cellular automata
- Deterministic or probabilistic – a deterministic model means that for a given start point and assumed factors, the outcome will always be the same. A probabilistic model is where chance takes effect, creating potentially different outcomes

There are several other ways to classify a model, described in more detail here: <https://www.turito.com/learn/math/mathematical-modeling>

Real-World Mathematical Modelling

Modelling has numerous real-world applications, and wider uses for modelling are being found constantly.

A major example is using models to predict the spread of disease. During the peak of the COVID-19 pandemic in 2020-21, models were used to track the progression of the disease. These models were highly complex but allowed scientists to calculate the 'R number' for the disease. R value was a measure of how many people would become infected by one infectious person. If R was above 1, then every infectious person would spread COVID-19 to 1.1 people (in other words, every 10 people would infect 11 people), thus the disease would

spread. If R was below 1, then the disease would regress, and eventually stop. The models used to calculate R also allowed scientists to tweak certain conditions to see how R might change under different circumstances. If no action had been taken by governments, R for COVID-19 would have been roughly 3, and the disease would spread exponentially. Mathematically modelling allowed scientists to advise governments as to how to minimise COVID-19's R value, leading to the regression of the disease.

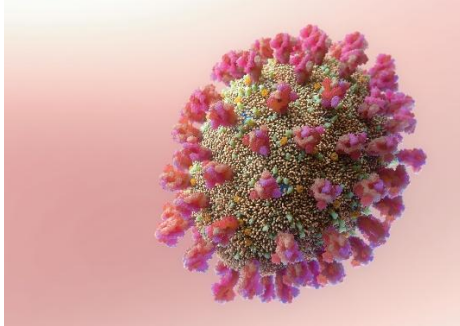


Image: ISO-FORM LLC

Mathematical modelling is used for many, many more purposes, and across a wide variety of industries. Just a few examples include:

- Determining stability of bridges, buildings and roads
- Predicting weather, including storms and hurricanes
- Predicting earthquakes and other natural disasters
- Making business decisions to maximise efficiency and profit
- Analysing economic data
- Developing technology e.g., fingerprint/facial recognition, artificial intelligence

Cellular Automata

A cellular automaton (plural; cellular automata) is a model in which cells in a regular grid are considered to be in 'neighbourhoods' with their surrounding cells. Cellular automata use discrete time-steps to model phenomena over time. The state/condition of cells in a neighbourhood at a given time-step will dictate the state of their neighbouring cells at the next time-step. Different sizes/shapes of neighbourhood can exist – in this Masterclass, we look at immediately surrounding cells in a 2D plane, called a Moore neighbourhood. However, the 'neighbours' could also be the cells in a cross like in the image below, called a von Neumann neighbourhood. Since cellular automata can also exist in 3 dimensions, 3D neighbourhoods can also be considered in such models.

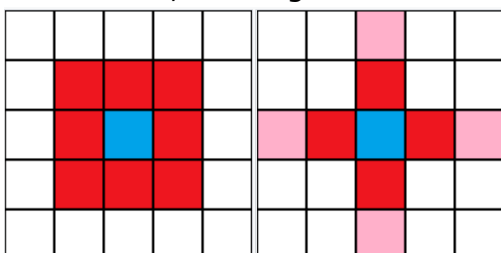


Image: Wikipedia. Left is a Moore neighbourhood; right is a von Neumann neighbourhood.

In this masterclass, cellular automata are used to model the spread of forest fires. In real life, cellular automata have many more uses, including:

- Modelling development of cancer, e.g., tumours and metastatic invasion
- Modelling large-scale chemical reactions
- Representing magnets and changes in magnetic ability (Ising model)
- Procedural generation of terrain in video games

Zuse's Theory, put forward in 1969 by German computer scientist Konrad Zuse, proposes that the entire universe is effectively a singular cellular automaton!

Factors Affecting Forest Fires

Many factors can influence the spread of forest fires – some of which are discussed in the Masterclass. This is a non-exhaustive list of factors that can change the likelihood of a fire starting, or spreading, within a forest ecosystem.

- Weather
 - Temperature – naturally, fires are more likely in warmer weather
 - Humidity – fires are more likely in dry weather
 - Wind speed – fires will spread more quickly in high winds
 - Precipitation – fires are less likely in rain
- Fuel
 - Flammable species – trees such as eucalyptus, cypress and pines are more flammable than others
 - Density – forests with trees closer together will spread fire more quickly
 - Surface vegetation – brush and bracken will quicken spread of fire between trees
 - Dead or dying trees – these are drier and thus will catch fire more easily. This could be due to plant disease outbreaks, or low suitability of the tree species for the environment
- Human
 - Human activity – forests with increased sources of ignition e.g., event sites, camp sites, many visitors and car parks are more likely to set fire
 - Response – delays in prediction, mitigation, detection and response increase fire risk and spread. Thus, remote forests are more at risk
- Geography
 - Soil – dry/drought-prone soil will increase fire spread
 - Land – south-facing forests and forests on slopes are at increased risk of fires



Image: NARA & DVIDS Public Domain Archive

California in the United States is particularly prone to forest fires, having experienced on average eight thousand fires a year since the year 2000. This exceptionally high number of forest fires can be attributed to several factors. Key recent examples include 2017 and 2020 wildfire seasons, as well as the January 2025 fires.

California often experiences hot and windy weather, and frequent prolonged droughts. Although there have been records of forest fires in the area since the 1850s, climate change has intensified this weather and made forest fires worse in the 21st Century. Fires are typically ignited in these forests by lightning and carried by high winds. Furthermore, old and poorly maintained electrical transmission cables running through the forests can also ignite trees.

Historically, native Californians would set small, controlled fires to keep the total fuel in the forests low, such that a singular massive, devastating, uncontrollable fire would be less likely. However, conservation efforts have prevented the use of controlled fires as a mitigation tactic.