

**School of Biological Sciences**

**ASSESSMENT COVER SHEET AND TEMPLATE**

**Section A** – to be completed by the student

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| Student Number | **2228202** | | |
| Programme | MSc Bioinformatics | | |
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**Abstract**

Cellular automata such as Conway’s game of life provide computational tools to experiment with biological hypotheses (Caballero et al., 2016).

The forest fire model is a simulation applying the Von Neumann neighbourhood rule (Kari, 2005), through a triplet of python functions which replicate the dynamic rate of fires and tree growth in a forest. A steady state has been achieved by testing the different model parameters lighting rate (f) and growth rate (p). Additional rules have simulated the emergence of a tree with the evolutionary advantage of fire resistance and consistent burning at the edges. This model while still in its beta phase provides a framework for testing different probability simulations using python numpy arrays while visualising time series results and animations.

**Method**

**Initialise state**

This function creates a 2D numpy array of random ones and twos that will be used as the first state in the simulation.

**Update state**

Will update any numpy array with the forest fire simulation rules and is the main function within this system. The approach taken is to use for loops to enumerate over each index of the array and apply the 4 rules when each condition is met.

All of these rules are applied on a per index basis and use multiple numpy functions within the enumerative loop.

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| Rules | Description |
| 1 | Burnout, an if statement was used with a numpy enumerate. |
| 2 | The Von Neumann neighbourhood rule is applied via directional indexing in a 2D numpy array. +/- 1 to a row (x) or column (y) |
| 3 | Lightning strike using numpy random function. The probability ratio is assigned by a float. |
| 4 | Tree growth using numpy random function. The probability ratio is assigned via a float. |

**Edges**

Within rule 2 edges of the array have to be accounted for, an index cannot be outside the maximum or minimum threshold. The edges have been set to empty when this condition is met to stop error messages.

**Run simulation**

Calls on the above two functions and iterates over a defined number of steps, saving the history of each time-step.

To collect the history of each timestep lists and the append function have been used due to their more flexible and efficient appending properties when compared to numpy arrays. The history list is converted to a 3D numpy array resulting in a visually convenient 2D array for each step or index.

**Results**

A steady state has been achieved by changing the edges rule to 3 instead of 1 or 2. This allows for enough fires to consistently spread throughout the forest.

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| **Figure 1**. – Comparing cells proportions in a steady state  A steady state has been achieved when f = 0.001 and p = 0.05. |

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| **Figure 2. – Extinction of trees**  Testing the growth rate at zero and lightning still occurring is sufficient for the trees to become extinct. |

**Comparing growth and lightning rates**

The forest fire simulation allows for the effect of growth and lightning rate on tree and fire proportions overtime to be monitored. The increase in fire rate correlates with a larger drop in trees (figure 1).

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| **Figure 3.** – Forest fire animation  The animation provides a visualisation of fire spreading throughout the forest. |

**Adding in a new rule.**

When adding in a competitor tree with fire resistant properties it is possible to observe how these two species compete with each other under their respective selection pressures. The hypothesis that a fire resistant tree will thrive within this simulation is a reasonable assumption that can be experimented on and is evidenced in figure 4.

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| **Figure 4** Adding in a tree competitor.  This figure confirms the alternative hypothesis that the original tree species (3) will become a less abundant species in the forest. |

The new species of tree is under pressure by corporate mining operations while the original tree is at risk of lightning and burning.

**Discussion**

A low lightning probability of 0.001 and a higher growth of 0.05 results in a sufficient steady state, with tree proportion falling dramatically in the initial phase. A successful cellular automata using the Von Neumann neighbourhood has been created that can dynamically compare probabilities of a range of rules. This computation has confirmed it is feasible to add in extra parameters and rules by appending new numbers.

Other probability ratios of growth and lightning have been experimented with (see jupytr lab appendix) and the dimensions of the grid are important in visualising the spread of the fire.

It would be interesting to develop a more robust collection of data at different probabilities. The simulation in its current form, while repeatable is in separate snap shots executed in jupyter labs. A better approach would be to try and create more functions to systematically generate the visualisations to avoid repetition of outputs. Creating an aggregate of all the different results into a summary level data frame grouped by input parameters would allow for a better comparison of growth and lightning rate. Furthermore, comparing basic descriptive statistics for different categories and making inference and predictions on the states at n =10000 would infer the forest fire models predictive effectiveness. A future analytical approach would be to create general linear models from the simulated data. Additional biological hypotheses could then be applied, such as seasonal time periods such as summer and the probability of fires. The simulation would then be improved at estimating causal relationships between the variables of interest.

**References**

Caballero, L., Hodge, B. & Hernandez, S. 2016. Conway's “Game of Life” and the epigenetic principle. *Frontiers in cellular and infection microbiology,* 6**,** 57.

Kari, J. 2005. Theory of cellular automata: A survey. *Theoretical computer science,* 334**,** 3-33.