

Calculating the Spread of Wildfires

New Mexico
Supercomputing Challenge
Final Report
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Team 85
Los Alamos Middle School
Seventh Grade

Physics
Programmed in Python

Team Members:

Jonathan Triplett: jonathantriplett522@gmail.com

Ethan Fisk: ethanmfisk@gmail.com

Sponsoring Teacher:

Ellie Simons, Los Alamos Middle School

Mentor:

Dr. Michael Brown, Los Alamos National Laboratory

Executive Summary

Our goal was to create a program that can roughly predict the creation and spread of wildfires using the variables input by the user, such as how many trees there are, the moisture of the trees, and how big the forest is, and we believe we have achieved it.

We started with a simple program that generated a grid and randomly chose which cells around it to ignite. As time progressed, we took into consideration more variables and made our model more accurate. Currently, our program utilizes the variables `treeDensity`, `gridSize`, `loops`, `runs`, `fireRange`, `fuelMoisture`, `branchDiam`, `windSpeed`, `windDir`, and `slope`.

First, the program takes the `branchDiam` and puts it through the function `tries=2*branchDiam+16`, in order to get `tries`, which is inversely proportional to `branchDiam`. Then, it chooses randomly in a Gaussian (normal) distribution which cells to spread to, with the most likely outcome being it spreading to the average of the slope and the wind direction, and the standard deviation of the graph being the wind speed. `Tries` is the number of times it chooses randomly where to spread. If it tries to spread to ground or burned trees, it can't.

Furthermore, our visualization uses six different colors. They are: yellowgreen, forestgreen, yellow, orange, red, black and gray. Yellowgreen is empty ground, forestgreen is trees, yellow is the hottest fire, orange is a midrange fire, and red is the coldest fire.

In conclusion, our model can be used to show the relationship between different variables and how they affect the spread of a fire.

Introduction

We are trying to simulate how wildfires spread by using an agent-based approach; having “cells” that interact with other cells. In addition, we utilized a statistical approach. We created

variables defined by the user like tree moisture or tree density that the program incorporates to predict how the fire will spread. Using this strategy, we can answer questions about how fire spreads, like the effect of increased tree density or the branch diameter on fire spread. We can also find out how these variables affect each other.

Moreover, our model was programmed entirely by us, and is not based on any other software.

Background

Wind

Wind is the largest factor in how determining how wildfires will spread. Wind determines in what direction embers and sparks will fly, and how fast, because sparks and embers are light and can be picked up by the wind. If the wind is heading east, and all other variables are eliminated, then the fire will spread east, because the sparks and embers will blow in that direction.

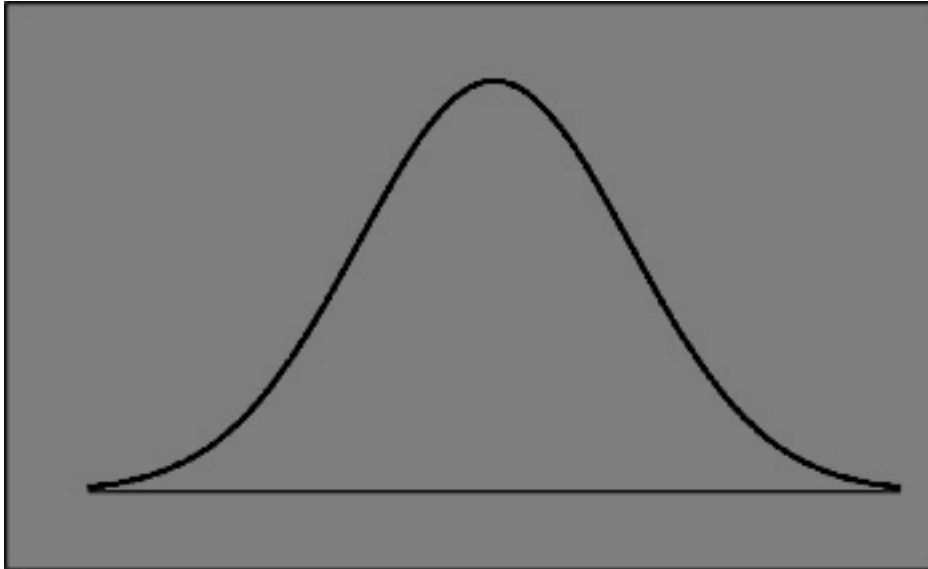
Topography

Contrary to popular belief, fire spreads faster uphill than downhill. If a fire is lit in the bottom of a valley, it will spread faster that if it had been lit at the top of a hill. This is due to the fact that sparks and embers fly through the air before hitting the ground and igniting fuel. If the fire is spreading uphill, it will have to travel a shorter distance through the air, therefore being exposed to the cold air for longer, which will decrease its temperature, also decreasing the likelihood that it will ignite fuel.

Random Distributions

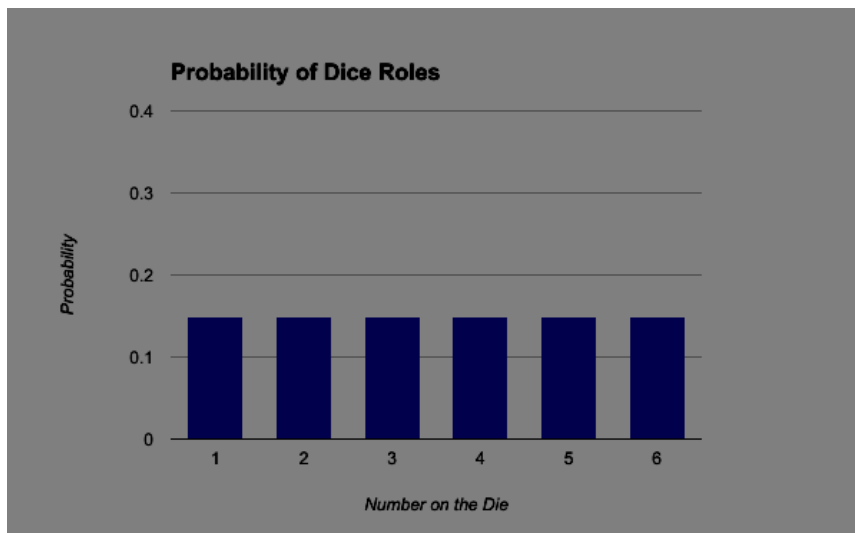
In our program, we used two different random distributions, Gaussian (Normal), and uniform. A Gaussian or normal distribution is when the data appears to follow a bell shaped

curve, with the most likely outcome being the middle one, and the least likely outcomes being the two outer ones. Examples of gaussian distributions are heights, test scores, and weights. A gaussian distribution is shown in Figure [1].



[1]. Source: GlobalSpec. Retrieved from <http://www.globalspec.com/reference/69565/203279/11-5-the-normal-gaussian-distribution>

A uniform distribution is where there is an equal chance of any outcome. Examples include dice rolls, or picking marbles from a container (assuming there is an equal amount of each type). An example is shown in Figure [2].



[2] Source: Ethan Fisk

Description

Cells

In our program, there is a grid made of cells. A cell is the space in which one tree can reside. There are five different possible states for each cell. They are 0, 1, 2, 3, 4, 5, and 6. 0 is empty ground, and so does not burn, although fire can spread over it. 1 is a tree, which can catch fire. At the beginning of the program, the grid is entirely made of 0s and 1s, except for a single cell in the center. 2 is the hottest fire, which, as it runs out of fuel, will become cooler and cooler, moving from 2 to 3 to 4, which is the coldest fire. After a 4 fire burns out, will become a 5, which is burned ground. Nothing can spread to 5, but fire can spread over it.

At first, these were our only states, but we began to experience problems with fire trying to spread outside the grid. Our solution was to make a seventh state called 6, which is a wall on the outside of the grid, equal in thickness to the fireRange. Nothing can spread to it, which solves our problem.

Variables

Our program uses the variables `treeDensity`, `gridSize`, `loops`, `runs`, `fireRange`, `fuelMoisture`, `branchDiam`, `windSpeed`, `windDir`, and `slope` (all defined by the user) in order to calculate how the fire will spread. `treeDensity` is the ratio of tree cells to total cells, expressed as a whole percent. The denser the forest becomes, the more the fire will spread. `gridSize` is the side length of the grid, in cells. The grid is always a square. `Loops` is the number of iterations in each run, and `runs` is how many times the program is run. `fireRange`, based on the `windSpeed`, is the distance a fire can spread, in cells. `fuelMoisture`, usually about 50%, is the percentage of the trees that is water, the drier the trees, the more the fire will spread. `branchDiam` is the thickness, in centimeters, of the branches on the fuel. The thinner the branches, the more the fire will spread. An example is with grass. Grass is very thin, and so spreads very fast. Compare this with large trees like sequoias and redwoods, which have much thicker branches, making them spread less.

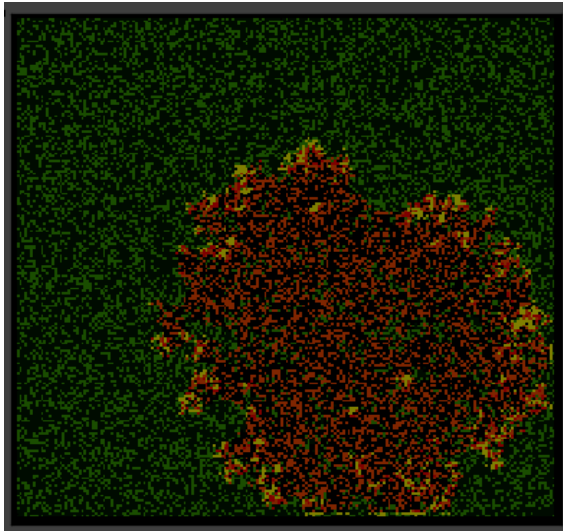
`windSpeed` and `windDir` are the speed and direction of the wind. We made a simplification and assumed that they are both constant. `Slope` is a list, and contains two numbers, which are the slope of the x-axis and the slope of y-axis. If the slope is positive, then there is a higher chance of spreading in that direction, and if the slope is negative, the inverse is true.

How the Fire Spreads

First, the program takes the branchDiam and puts it through the function $\text{tries} = 2 * \text{branchDiam} + 16$, in order to get tries, which is inversely proportional to branchDiam. Then, it chooses randomly in a Gaussian (normal) distribution which cells to spread to, with the most likely outcome being it spreading to the average of the slope and the wind direction, and the standard deviation of the graph being the wind speed. Tries is the number of times it chooses randomly where to spread. If it tries to spread to ground or burned trees, it can't.

Visualization

In our visualization, 0 is yellowgreen, 1 is forestgreen, 2 is yellow, 3 is orange, 4 is red, 5 is black, and 6 is grey. This follows reality, with yellow being the hottest fire, then orange, then red, and burned fuel have a scorched black color. The grey cells are “walls” that we put around the grid to keep it from spreading out of bounds (causing an error)



A fire after 50 iterations, with a forest density of 70%, no wind, a flat landscape, 2 centimeter thick branches, and a tree water content of 50%

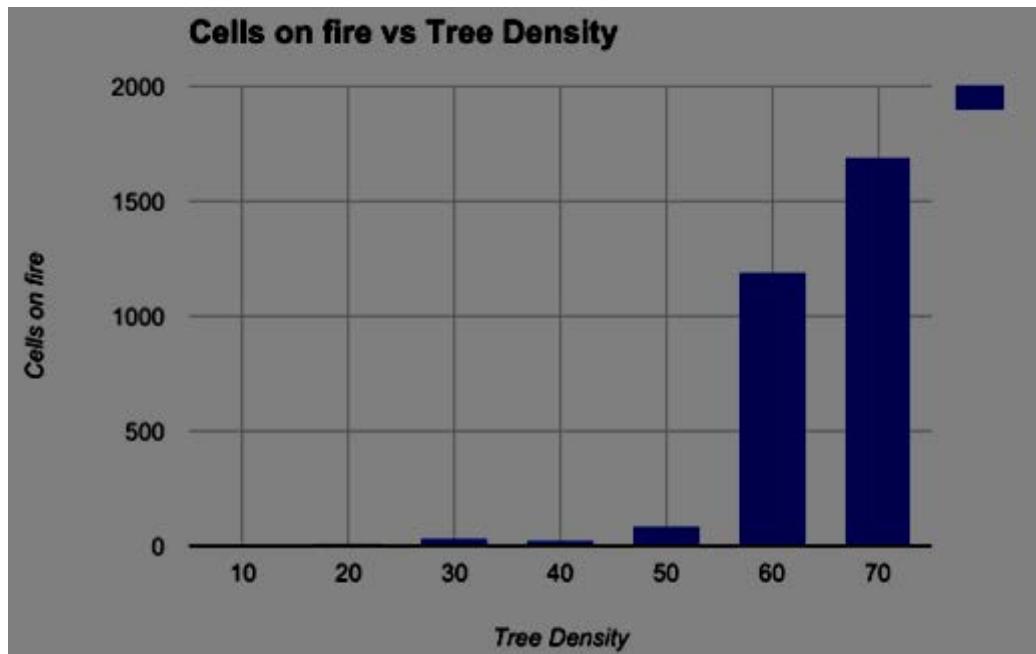
However, the program only makes a visualization on the last iteration. This is because, if it were to print out all of the iterations a a graph, in some cases it would print out hundreds of figures. To make the program more manageable, we had it just print out the numbers until the last iteration.

Verification and Validation

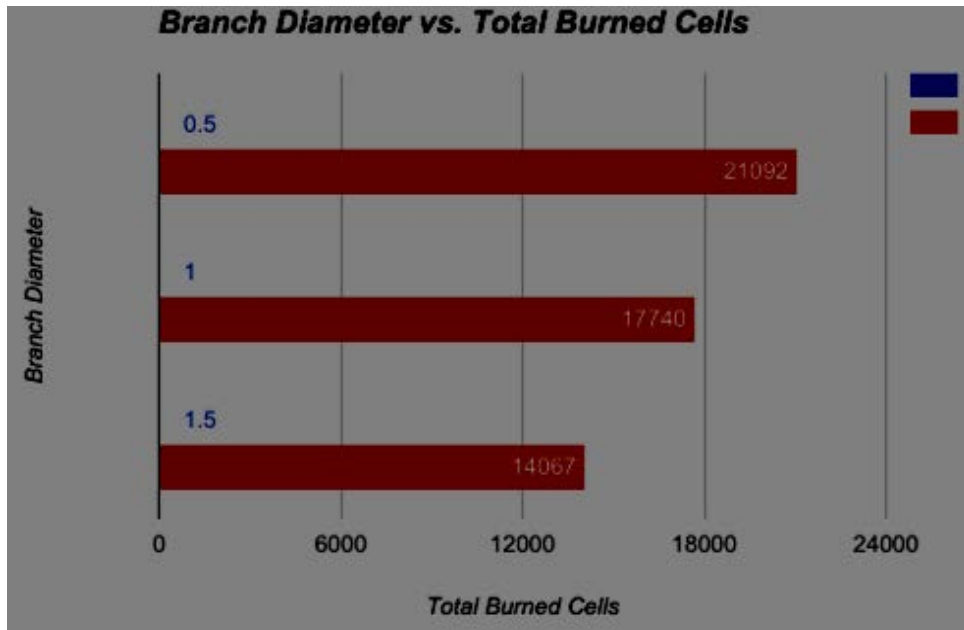
We verified and validated our model our model by testing all our variables. When we set the wind to go a certain direction, the fire spreads that direction, just like in reality. In addition, when we have larger branch diameters, then the fire spreads more slowly, just like in reality. Furthermore, when we increase the fuel moisture, the fire does not spread as well, just like in reality. In our visualization, we use correct fire colors, ie. the coldest fire is red, and then orange, then yellow. This is the hottest wildfires get (except for perhaps large conflagrations), but past this fire turns white and then blue.

Moreover, fire needs three things to light. They are oxygen, fuel and heat. Oxygen is not modeled in our program, but the fire needs fuel (this is why empty ground cannot light on fire), and heat, which is why fires turn black and stop burning if they become too cold.

Results



This is a graph of the total burned cells compared to the tree density. With this you can see that the amount of flames really spikes around 60, probably because it catches easier and easier the more trees there are, and soon it reaches a turning point. We were unable to run it past 70, as our computers ran out of memory. We believe this is a bug in our program, or just that we are using inefficient coding practices, but we are unsure. We hope to fix it in the future.



This figure shows the relationship between branch diameter and burned tree cells. The thinner the branches, the more the fire will spread. In addition, the increase of burned cells appears to be linear.

Conclusions

In conclusion, our model can be used to show the relationship between different variables and how they affect the spread of a fire. The variables include treeDensity, gridSize, loops, runs, fireRange, fuelMoisture, branchDiam, windSpeed, windDir, and slope. In addition, our results validate our model by showing that it accurately predicts how fire spreads based on different variables.

Furthermore, our most significant achievement was successfully creating a model that predicts how a wildfire will spread using different variables, which in our present model include branch diameter, fuel moisture, forest density, wind speed, wind direction, the topography of the landscape, the forest size, and the fire spread range, which were goals we outlined in our proposal.

In the future, we hope to talk more with Dr. Michael Brown and improve the accuracy of our model.

Acknowledgements

We would like to thank Ellie Simons, for originally recruiting us into the Supercomputing Challenge. In addition, we would like to thank Dr. Michael Brown for giving us valuable insight and helping us to make our model more accurate, and to Laurie Triplett, for administering many of our meetups and giving us encouragement.

Citations

Gaussian Distribution Graph: Global Spec. Retrieved from

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“A Mathematical Model for Predicting Fire Spread in Wildland Fuels” by Richard C. Rothermel. 1972. U.S. Forest Service.

“A Great Aridness: Climate Change and the Future of the American Southwest” by William deBuys. 2011. Oxford University Press.

Dr. Michael Brown, LANL, personal communication.

Our Current Source Code

<https://github.com/MTN-GEARS/Hotshots/blob/master/Final%20Code>

