“I Smell Smoke…”
Otero County Forest Fires

New Mexico Supercomputing Challenge

Final Report

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SCC Team 8

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Abstract:

Cloudcroft is a town nestled in the mountains of Lincoln National Forest with only a few exits and a high likelihood of a fire. Our challenge was to model the spread of a fire in Cloudcroft and the egress of the populace in such an event. Our model will include a variety of scenarios, including initial location of the fire, time of day, and the readiness of the populace. At this time, our experimental results are incomplete, but we are moving to completion and will present results and conclusions at that time.

The Problem:

Cloudcroft is located in the northwestern area of the Sacramento Ranger District of Lincoln National Forest. It is served by county highway 82 and state highway 244. These constitute three of the four exits, the other exit leading deeper into the forest itself. This exit, state highway 130, poses the threat of leading evacuees deeper into the woods when the fire is bound to consume that area also.

Figure 1: A is Cloudcroft in this image.

Once started, many factors contribute to the growth or diminishing of a fire. Wind will aid the spread of the fire in all cases depending on which way the wind blows. If rain is falling, it may be much easier for a fire team to extinguish the fire depending on how much rain is falling. If lightning and thunder accompany the rain (as is often the case), it may be possible for another fire to spring up from the lightning and join the other fire, creating more burned surface area. Cloudcroft is a very mountainous land, and recalling that fires will burn upwards faster than down, the fire can overtake a mountain ridge faster than it can take over a valley descending downhill. Density of vegetation can also make or break a forest fire. If there is naught but grass in a meadow, a fire will be hindered by this, but if there is a cluster of old trees, some of which can be dead, the fire will blaze up and have more energy to spread. Sudden breaks in the amount of fuel available can create a barrier for a fire. One such example is a road. Finally, depending on when the Forest Service and Fire Department are informed of the fire, a fire may be combatted at any stage of growth by the Public Safety Departments (PSD). As Cloudcroft has multiple exits, if the fire obscures one, the people can quickly find another way. Evacuees are as often as not going to “turn on the radio” and take the safest way out the first try.

Background and Research:

In the 2011 to 2012 school year, the Artesia High School Team created a model of Artesia in the event of a gas leak at the Navajo Refinery. The model was nicely done, and we made it to within one step of being a finalist team; however, last year's model did not have many dynamics added to it, such as wind, density, and additional behaviors. This year, we took the model to a new level with a similar problem: fires in Cloudcroft. Due to the crunch on time, we shifted our focus to the dynamics of fires rather than the evacuation.

In Artesia, the likelihood of a gas leak contaminating the city was far more probable than the chances of a fire. In addition, the gas could be guaranteed to come out of one singular location: the Navajo Refinery. Artesia is quite large in comparison to Cloudcroft, and the certainty of the origin of the gas leak can prove advantageous when evacuating a large town. Cloudcroft has a different set of problems.

The probability of a fire igniting in the forests surrounding the Cloudcroft area is likely. During its history, the city of Cloudcroft has declared six states of emergency due to fires- more than any other disaster in Lincoln National Forest. Over time, the chances of a forest fire become inevitable, and when that fire does start, it can be started anywhere, and by a variety of causes, the most frequent of which is lightning during a rainstorm.

We chose to focus more on the dynamics of fires as opposed to evacuation behaviors for the subject of our problem. Aware that many people perceived us as taking on two problems at the same time, it was necessary to clarify our primary problem. Another part of the choice was the sudden realization that not much time remained to successfully assemble both concepts into one model. Typically it is expected that a team only faces down one problem at a time. While the egress model used in the 2012 final project by our team last year focused on evacuation, we found that there may be more lucrative information and dynamics in modeling a fire.

Approach:

The first step we took was in the direction of understanding the mechanics of the program we chose to use. NetLogo, our chosen program, utilizes various agent sets: there are the mobile agents (turtles), the immobile agents (patches), and in between these two layers, we have the drawing layer. This type of layout is ideal for agent-based models and patch-agent interface.

We chose NetLogo for several reasons. Last year's model operated using NetLogo, and it is efficient to maintain a consistent format with codes and interfaces. NetLogo is very capable in that it can simulate anything from forest fires to the logistic spread of a disease. In addition, NetLogo can accept and adapt to a variety of data sources. We found the GIS data extension to be most relevant to use in our model.

GIS data utilizes various methods of storing data about terrain and the location of events on terrain. Some files come as ".shp" files, which are essentially shapes. Some of these shapes are borders, and others are dots to indicate the origin of an event, such as the starting point of a fire. Other files serve as the powerhouse of a certain set of data. These files are spreadsheet oriented and are called ".dbf" files. Files also come in ".PRJ" files, which project a set of coordinates across the display. There are many more types of files used in GIS, but these types proved to be the most crucial to our model.

Once all the GIS data was gathered and dissected into its understandable parts, we moved into building the model itself. In order to optimize the aspect of the forest, we incorporated the factors of fire spread (topography, density, etc.) into a map of Cloudcroft, including roads. We focused primarily on the area surrounding the main Cloudcroft village, in the northern part of the Lincoln National Forest.

It was relatively easy to implement a generic Google map of Cloudcroft into the model. Using the printing tool ImageJ, we successfully took a snapshot of the Google map, and, after manipulating the coordinates, we created a map of Cloudcroft. From there, we moved on to matching the coordinates of the GIS data to the coordinates of the area photographed.

Once the map was in place, we used the GIS data to program each patch with a set of numbers, indicating its density of vegetation and height of vegetation. The spreading fire can thus interrogate this data set to ascertain the values of its factors, primarily density and height. This provides a more authentic representation of the forests of Cloudcroft.

The Model:

The model utilizes many aspects of NetLogo, some of which we did not know could happen. When NetLogo uses the GIS extension, it looks into multiple files and will not continue if one of the files is missing. In addition, it senses modified data and cannot open it unless it is the original file. The model is extremely meticulous in this aspect, and also in the manner of displaying GIS data.

The model uses stochastic cellular automata to propagate the fire. A system of probability is defined below:

- At time *t*, the cell is in either of two states: burning or not burned.
- At time *t* + 1, the state of each cell is updated, as follows:
- If the cell is burning at time *t*, then fuel is consumed in the [*t*, *t* + 1) interval. If the fuel is completely exhausted during that interval, then the state of the cell is changed to "burnt-out".

- If the cell is not burning at time *t*, and no neighboring cell at time *t* is burning, then the state of the cell at time *t* + 1 is not burning.
- If the cell is not burning at time *t*, and N nearest neighbors are burning at time *t*, and M next-nearest neighbors are burning at time *t*, then the probability of the cell burning at time *t* + 1 is as follows:
- $1 - [(1-p)^N + \left(1 - \frac{p}{2}\right)^M]$, where p is the probability of fire propagation from a burning cell to a nearest-neighbor non-burning cell in a unit time.
- The probability that the cell will not be burning at time *t* + 1 is as follows:
- $[(1-p)^N + \left(1 - \frac{p}{2}\right)^M]$

For simplicity and ease of modeling, we assumed all turtles were vehicles. This would be the equivalent of gathering all the people of a family into a car before the fire strikes Cloudcroft. This also allows us to focus more on the fire dynamics while not completely ignoring the evacuation aspect.

With the evacuation, the turtles can follow one of two paths of decisions, or “flood fills”: their instinct or the prudent instructions of “the radio in the car”. Choosing the instinct may not always lead to safety, but choosing to listen to the radio may lead a turtle in the direction opposing the fire. Using two different flood fill dynamics, one of which has the right information and the other of which has some faulty information, the agents may be influenced to make irrational decisions in their egress.

Model Verification:

At the moment, we are not completely done with the model implementation phase. Part of this is due to the loss of two team members. In addition, several events were going on during the months leading up to the final due date.

We have, however, in the process of creating this model, eliminated some possibilities. We are going to assume that no person leaves his or her car and begins running into the forest, so we will not worry about people trampling each other. We will also assume that each turtle will escape the forest with an equal likelihood, and that no roadblocks have been placed around all the roads, which would create a “no-win” scenario.

Results:

The current model loads the GIS data overlaying a map of Cloudcroft, showing the primary roads of exit in white and yellow on the map. After an hour of tinkering with coordinates, we pinned down the area where Cloudcroft is on the map, and overlaid it with the

GIS map, taking note of the stunning match. We also have a model that simulates fire spread and a model that simulates evacuation behavior in small spaces, the former of which will be implemented into the model and the latter of which will only contribute a small amount of code. A list of values will be assigned to each patch, indicating the factors necessary for a fire.

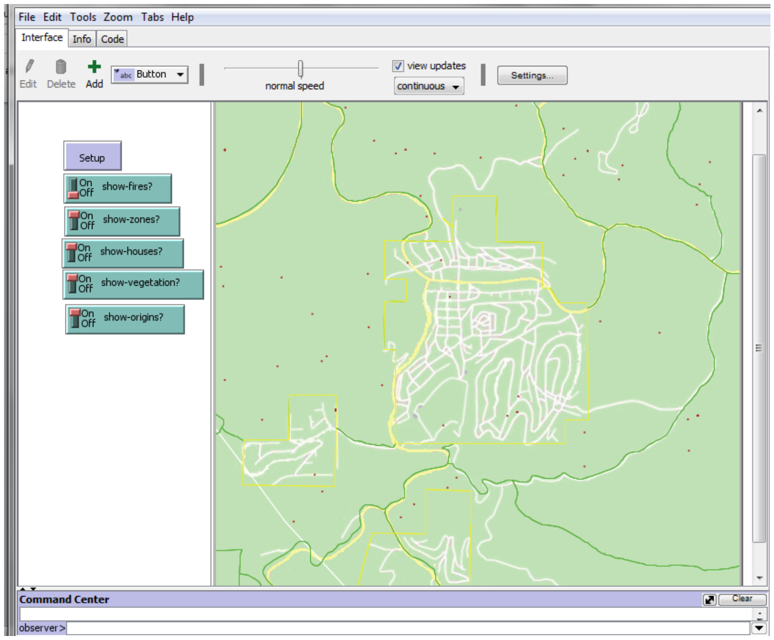

Figure 2: The faint yellow lines and dark green lines are the GIS data overlaying the map.

Conclusions:

Cloudcroft, nestled within the mountains, is bound to be hit by a fire. When that happens, the people are likely not to panic, but rather enter their vehicles as instructed and flee before the fire strikes. The fire's growth is influenced by several factors, including density and topography, and may fizzle out before there is reason to panic. On the other hand, it may grow to become ferocious and drive people into a back road.

Based on our research, we can conclude that a fire hitting Cloudcroft itself in the Lincoln National Forest area is highly probable, but we cannot back that up until test runs and experiments are conducted.

Software, References, and Other Products:

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Most Significant Achievement:

Our most significant achievement was, simply put, making it through the year without collapsing completely. We lost many team members of vital support during the year and faced down an impending doom without surrendering. Delays and disturbances served to frustrate our mission and confound our minds, but we managed to pull through.

Aside from surviving, we gained valuable information on computing and programming. At the beginning of the 2012 to 2013 school year, we wondered at the world of NetLogo and stammered at the thought of creating a model as fully fledged as the previous year's model. With the aid of our mentors, we began to comprehend what we could do in NetLogo and the other facets needed to solve the problem we faced this year.

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We are greatly thankful to our mentors, Nick Bennett and Josh Trujillo, for aiding us in our moment of need and delivering vital information in time of crisis. We thank our main teacher, Mr. Randall Gaylor, for his patience and sacrifice of time to ensure our success. Thanks also go to Mr. Jose Quiroz, for his support in driving us to and from our destinations.