

NUMB3RS Activity: Making "Fireprints" **Episode: "Scorched"**

Topic: Modeling the spread of fire

Grade Level: 10 - 12

Objective: Students will model the spread of a fire using a single variable, with the opportunity to consider and appreciate how complex such a model can be.

Time: 30-45 minutes (if done individually, see "Alternate Use of Activity")

Materials:

- Graphing calculator
- Two colored pencils (preferably red or orange, and black)

Introduction

A spreading fire can be thought of as a dynamic process, where at each tick of the clock the fire spreads according to certain rules. To model a real fire, the number of variables to consider is tremendous. For example, in a forest or brush fire, some of these variables are the density of the "fuel," humidity, initial temperature, and wind direction and speed.

In this activity, students will compress all of the above into a single variable, namely a probability that the fire will spread across a unit of distance, shown as cells on a grid. By using slightly different probabilities, students can produce burn patterns (one type of "fireprint") with different characteristics.

Discuss with Students

In "Scorched," Charlie and Larry discuss how different arsonists approach fires differently. This means that every fire could be different, not just in terms of the arson method, but in the whole character of the fire. According to Larry, "What we're talking about is a fingerprint for fires," or as Charlie puts it, a "fireprint."

The model in this activity uses a square grid, where each cell in the grid could represent a single tree, area of brush, etc. Starting with an initial set of cells set on fire (by coloring them red), students use a random number generator to determine if a burning cell ignites each of its horizontal and vertical (not diagonal) neighbors. In each iteration, a cell can be in one of three states: unburned (white), burning (red), or burned (black). A burning cell burns for only one iteration, then is colored black to mean it is totally burned. Once a cell is burned, it cannot reignite. By the procedure on the student page, each iteration consists of examining all neighbors of burning cells to decide if they become ignited, and then coloring all of the previously burning cells black.

Students should work on a fire in pairs; one student will determine whether cells ignite, and one will do the coloring. The probabilities used by students should vary between 0.4 and 0.6 (see "Extensions" for more about why this range is important). Have groups use a die to randomly select from these probabilities (based on the number the die lands on): 1 = 0.40; 2 = 0.45; 3 = 0.50; 4 = 0.50; 5 = 0.55; 6 = 0.60.

Alternate Use of Activity

Students can also do this activity individually and outside of class. The author has an applet that simulates the activity (listed under "Extensions"). If this is a more desirable approach to the topic, then use the procedure below, with no more than 10–15 minutes of class time needed:

1. Distribute copies of the student page to the entire class, and introduce students to the topic.
2. Review the procedure for generating the model, as it appears on the student page.
3. Point out the directions for the alternate activity as listed on the student page.
4. The questions on the student page apply to both versions of the activity.

Student Page Answers: *Student models – a good place to see extra samples is to generate them using the author's applet on the Web, discussed in "Extensions."* **1.** *The greater the probability, the more area will be burned.* **2.** *Both very low and very high probabilities will produce smooth edges; low because the fire burns out quickly, and high because the fire burns out of control.* **3.** *The probabilities for northern and southern neighbors would stay the same, the probabilities for the western neighbors would be less, and the probabilities for the eastern neighbors would be greater.* **4.** *Terrain, humidity, density, initial temperature, type of fuel, drafts, exposed surface area, etc.*

Name: _____

Date: _____

NUMB3RS Activity: Making "Fireprints"

To help identify an arsonist, Charlie Eppes is faced with the huge task of mathematically determining a "fireprint." He must use over 600 variables to describe the characteristics of a set fire. This activity considers one such characteristic, the burn pattern that a fire leaves once it is out.

Work with a partner. One of you will determine which cells get ignited, and the other will color the results. The grid on the next page will serve as a model for a fire, with each cell representing a tree, area of brush, etc. Roll a die to determine the probability you will use for your model: 1 = 0.40; 2 = 0.45; 3 = 0.50; 4 = 0.50; 5 = 0.55; 6 = 0.60. Record this probability in the space on the next page.

Procedure:

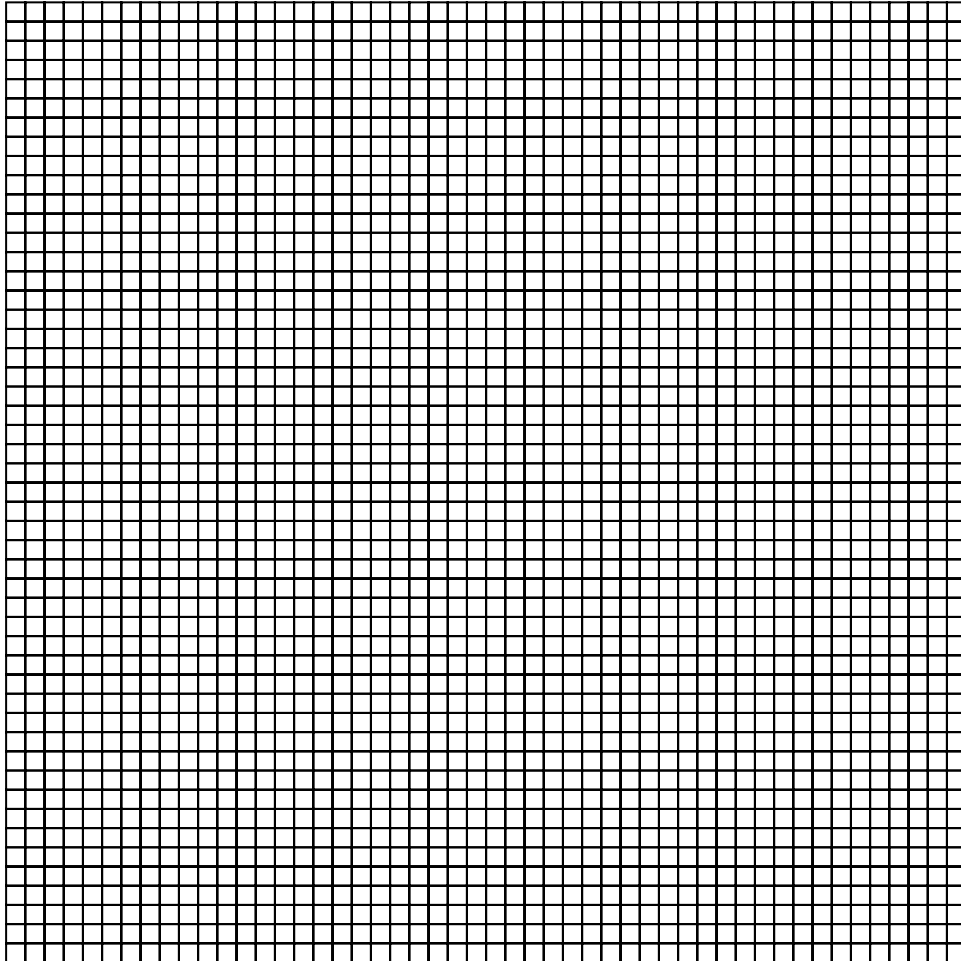
1. On your graphing calculator, press MATH, PRB, Rand to create a generator of random numbers between 0 and 1.
2. In the center of the grid below, color in an irregular block of 5–10 cells red to show the start of the fire.
3. Starting at the top of the fire and going clockwise:
 - a. Select the horizontal or vertical neighbor of a burning cell.
 - b. Press ENTER on the calculator to get a random number.
 - c. If the random number is *less than or equal to* your assigned probability, color the neighbor cell red.
 - d. Move to the next neighbor cell and repeat steps b and c. If a non-burning cell has more than one burning neighbor, test it for each burning neighbor separately unless it starts burning.
 - e. When you have tested all neighbors of a burning cell, color the original burning cell black to show that it has completely burned.
 - f. Continue around the edge of the fire until you return to the top.
4. Repeat step 3 until:
 - a. No new cells are ignited (meaning the fire has burned itself out), or
 - b. A cell is ignited that is at the edge of the grid. If this happens, color all of the remaining burning cells black.

Once all student teams have finished their models, compare other students' models to yours. Be sure to take note of the probabilities that other students used for their models. See if you can discover a relationship between the probabilities used and the shape and size of the resulting burn patterns.

Note: if you are doing this activity by yourself outside of class, you should use the applet at: <http://dimacs.rutgers.edu/~cbiehl/fire.html>

1. Open the applet on the web site.
2. Follow the procedure above for the pencil and paper version of the activity, but use all of the probabilities at least once.
3. In order to make observations, remember to stop the fire if it reaches the edge of the "field."

Use the grid below to draw your fireprint.



Probability used: _____

Use the fireprint you created and the other fireprints you have analyzed to answer the following questions.

1. One of the ways to describe a fire by its burn pattern is the total area burned. How is the burned area affected by the probability used to model the spread?
2. Another way to characterize the severity of a fire is by how smooth or irregular the edge of the burn pattern is. How would using a very low probability be similar to a high probability when examining the edge of the burn pattern?
3. Suppose you wanted to repeat this model but wanted to add another variable, namely wind. If you wanted your model to include wind blowing from *west to east*, how would this change your procedure for determining if a burning cell's neighbors catch fire?
4. Suppose you wanted to model an actual fire. Name as many other variables as you can that you would have to be able to mathematically account for in your model. (Compare your list to Charlie's when you watch "Scorched.")

The goal of this activity is to give your students a short and simple snapshot into a very extensive mathematical topic. TI and NCTM encourage you and your students to learn more about this topic using the extensions provided below and through your own independent research.

Extensions

Introduction

This activity represents a simple view of a very complex problem. Fire models have become a powerful research and training tool for firefighters, fire protection engineers, and environmentalists. Models can be used to simulate a fire in a single room, a whole building, an entire city, or over large areas of brush and woods (as in the western United States). In order for researchers and engineers to develop better tools for fighting fires, it is important for them to understand the chemistry, physics, and mathematics behind how fires spread.

For the Student

Research based on the model used in the activity has shown that there is a "critical" range of probabilities for generating "interesting" burn patterns, namely between 0.4 and 0.6. Very low and very high probabilities produce smooth-edged burn patterns. However, in the critical range, the burn patterns are more complex. As an extension to this activity, students can explore the "fractal" properties of these burn patterns. For a more detailed investigation of the fractal properties of forest fire burn patterns, as well as the underground percolation patterns of oil spills, see Mathematics Teacher magazine (published by NCTM), Volume 91 #8 (November 1998) and Volume 92 #2 (February 1999). Visit the website below to either purchase the article or ask your teacher to download it if they are an NCTM member.

http://my.nctm.org/eresources/article_summary.asp?URI=MT1999-02-128a&from=B

Additional Resources

The author of this activity has created an applet for this fire model. In this model, you can also include wind and build firebreaks as the fire spreads. Visit:

<http://dimacs.rutgers.edu/~cbiehl/fire.html>

For an example of a "Growth and Burn" model, see Albert Schueller's model at:

<http://schuelaw.whitman.edu/JavaApplets/ForestFireApplet/>

This applet runs over a longer period of time, and shows how trees grow back after a forest fire.

For more information on the types of models used as well as the mathematics and science required to develop them, see the article "Computer Fire Models" by Anthony D. Putorti, Jr., Fire Safety Engineering Division, Building and Fire Research Laboratory, National Institute of Standards and Technology. It is available at: **http://www.interfire.org/res_file/firemod.asp**