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Assignment 6c
15 December 2018

A Fire Propagation Algorithm

for Demonstrating Natural Fire Spreading Behaviors

Introduction

Scholars have been studying the complex relationship between humans and nature for decades. This relationship serves an integral part in shaping the culture of many regions around the world. For instance, because the Mekong river intersects a large section of Can Tho, Vietnam, people in this part of the world prefers floating markets, a unique way of trading and selling produce in boats that migrates along the Mekong's body, over the conventional on-land markets. In Japan, Mount Fuji is a symbolistic mountain representing a sacred site for Shinto practitioners due to its positioning relative to the Sun and its majestic appearance. These examples illustrate the influence of nature on humanity; however, the relationship between human and nature is not merely one-sided. The complexity stems from the fact that the human-nature relationship is reciprocal. Humanity has also attempted to impact nature in various ways. According to Clark Erickson, the pre-Columbian peoples in the Bolivian Amazon domesticated their surroundings through adjusting soils, building earthworks, and altering drainage, which often times increased the biodiversity of the region (2006: 237). Among the technologies that they utilized for landscape domestication, fire proved to be one of the most powerful resources. Stephen Pyne claimed that once the genus *Homo* acquired the ability to initiate and stop fire, the earth has gradually been transformed in different ways (1998: 64). Pyne defined anthropogenic fire as mean of altering landscapes by humans to serve specific needs. He claims that "anthropogenic fire is as much a cultural artifact as chopping stones and skyscrapers" (Pyne 2002: 70). Studying human-induced fire and its traces – the conditions of the altered landscape – can give us clues about the local people and their culture. For instance, a group of Israeli researchers reported new findings showing evidence of human-controlled fire dating back to over 790,000 years (Balter 2004: 663). Archaeologists and historians use this conclusion to explain the history of early signs of human colonization in Europe and other northern latitudes. Peola Villa, a researcher at the University of Colorado, believes that the colder climate in these regions is tied to the use of fire (Balter 2004: 665). Anthropogenic fire – fire that is intentionally formed by humans -- has been used to alter the environment by enhancing agricultural practices, increasing biodiversity, raising the availability of game animals (Erickson 2006: 237). Pyne highlighted the ways the indigenous peoples in Australia and California reshape whole landscapes with fire, including promoting vast grasslands and allowing biome to be perpetuated (1998: 77). Native Americans set fires in California's coast ranges and valleys to eliminate brush, enhance grass, and drive game and grasshoppers (Anderson 2014: 1).

Often portrayed in the media as a natural disaster, fire on a large-scale typically carries a negative connotation for the public and the government. In this project, I present a computer algorithm that demonstrate the behaviors of fire spreading in Unreal Engine, a popular game engine widely used to develop games and simulation in the computer graphics industry. In addition, I hope to promote a positive perception of fire, especially anthropogenic fire, through discussions on how native peoples in the Bolivian Amazon have used fire to enhance their everyday lives.

Background

Fire-making Techniques

Before matches and mechanical methods of fire-making, a more labor-intensive technique was used. The technique involves a platform on which a stick-like device is hand-span to generate friction between the bottom of the device and the platform and thus releasing hot dust particles. The Guarayú of eastern Bolivia use the shaft of their arrows as a drill (Figure 1). Dust particles then falls onto a tinder placed underneath the apparatus, which ignites the fire. (Métraux 1948: 434). This technique widely used across regions not only within the Bolivian Amazon but also throughout the world. Producing fire with a fire drill is a time-consuming process and therefore, people preferred to go through considerable trouble to preserve existing fire (Anderson 2014: 5).

Anthropogenic Fire in the Bolivian Amazon

Fire contributes towards many practices of native people in the Bolivian Amazon and reveals important insights about cultural practices in the region. The Mojo took full advantage of fire in food acquisition by burning grass to drive game animals toward ambushes and heating their blowguns over fire to straighten them (Métraux 1948: 412, 417). The Cayuvava used fire in a ritual in which offerings consisting of animal meats were placed on trays around a fire (Métraux 1948: 427). The Sirionó used fire to keep undesirable insects like mosquitoes away (Métraux 1948: 457). For this project, I am focusing on anthropogenic fire and examining how inhabitants in the Bolivian Amazon region use burning to maintain savannas to encourage biodiversity, removing dead grass to provoke new grasses for valuable game (and for grazing livestock today), and keeping forests at bay (Erickson 2006: 250).

Influences on Fire Behaviors

The behaviors of a fire and the surrounding environmental conditions can define the way the fire impact an ecosystem. For instance, in rain forest regions, extreme drought periods generate the perfect biomass conditions for burning. Increasing the contrast between wet and dry conditions increase the vigor of the fire regime (Pyne, 1998: 65). The quantity and type of burning agents, such as dry grass, also contributes to the intensity of the fire. The more intense and durable the fire, the more landscape impacted.

Data and Tutorials

This project focuses on the realistic visualization of fire appearance and behavior. My research consists of examining photographs and videos of fire spreading in different environment settings such as savannas, forests, and open fields of the Bolivian Amazon (Figures 2 – 4). These photographs show the scope and characteristics of anthropogenic fire, smoke, and effects on the vegetation such as color desaturation over time (Figure 5). I used specific photographs to understand the agents used to feed the fire (Figure 3) and estimate the scope of the fire to propagate the burning agents needed to trigger and carry the fire (Figures 2 and 4).

I also viewed drone videos of landscape burning, such as the sugar cane burning in Blak Tatu on Youtube, for details about the dynamic burning process and fire behavior. These visual resources aided the process of designing the look of the fire, including the generation of smoke, the color intensity and saturation, and impact on coloration and size of the vegetation. I also collected data on duration based on specific plant types, locations, and weather, but I decided not to apply this information in the project design because the plants were not native to the Bolivian

Amazon. In addition, I decided to speed up the fire propagation so actual fire life-time would not be needed.

To prepare for the project, I learned Unreal Engine with the help of the course's teaching assistants. Unreal Engine provides premade foliage and a fire effect that resembles real fire. Unreal Engine's website has comprehensive, easy-to-follow documentation for its interface and features. I also learned Blueprints, an alternative to C++, for defining the behaviors of the objects inside of the scene with a visual scripting interface instead of an integrated development environment. Due to prior experience with Unity, another popular game engine, I quickly become familiar with Unreal Engine.

Process

Models and Testing Elements

I utilized the foliage and fire effect inside Unreal Engine to test my propagation algorithm. For rapid prototyping, I modeled a small, generic terrain with varied elevations and a water body using the landscape painting and sculpting tools in Unreal (Figure 6). I made the decision not to prototype with the summer intern project's landscape because the of the large size.

Influencing Factors

The impacting conditions that I decided to include in the algorithm are the positioning of the burning agents – defined as the elements that carry the fire like dry grass and the type of the burning agents. Due to time constraints, I was not address other natural elements like wind direction and intensity, humidity, and weather conditions that impact fire dynamics.

The Algorithm

After using various tutorials on Unreal objects, effects, and Blueprints manipulations, I decided on two potential executions of the algorithm. The first method is terrain-dependent, which involves the x and y coordinates of the terrain and the positions of the combustible objects (savanna grass). Starting from the ignition point of the fire, the algorithm would search for the surrounding coordinates and determines whether a burnable object exists at that location and spread the fire to locations intersecting with burnable objects. The problem with this method is that we do not know the direction in which the burnable object exists, the algorithm would have to start at an arbitrary adjacent coordinate. In the worst case, checks all eight adjacent coordinates before finding one that contains a burnable object. In addition, generating coordinates for a landscape is easy, as landscapes can vary in resolution (or subdivisions). A simple vertex-based coordinate allocation system would result in potentially millions of coordinates for a large-scale landscape, further increasing the runtime of the algorithm. The second method is collision-based, which is a common concept in game design. This method requires each fire carrier to define a collision boundary. For each burnable object that falls within the collision boundary of the object(s) on fire, the fire would spread to those objects. The algorithm is then repeated on the newly burned objects.

I decided to proceed with the latter method due to its flexibility and terrain-independent quality. I could test the algorithm without having to create an initial terrain. Furthermore, the collision-based algorithm is more efficient using the well-developed Unreal collision detection feature. Furthermore, the algorithm can trivially recognize non-flammable objects such as water bodies and wet plants.

The chosen method required each burnable object to comprise of three subcomponents: a foliage object, a collision object, and a fire effect (Figures 7 – 8). The foliage object represents the appearance of the object. The collision object serves as the backbone of the algorithm. The fire effect is triggered as the object gets set on fire. to define the shape of the collision boundary, I chose a circle for simplicity purpose. The ideal collision boundary is one that most closely aligns with the outline of the burnable object. To determine which objects are flammable, I added a tag, which represents a particular object quality, to all objects that should catch on fire during the fire spread (Figure 9).

Procedural Methodology

Procedural programming refers to a series of routines or subroutines that is carried out during the execution of a program. The routines let users input certain criteria to influence the outcome of program. This project takes advantage of procedural techniques to quickly generate and propagate fire. Alternative methods would require manual placement of fire and altering object behaviors based on their interaction with the fire, which can be tedious. In addition, Unreal Engine automatically resets the scene to its initial state (pre-burning) when user presses the stop button. Other modeling software such as Maya would require the user to manually reset the state of the objects, which can be time-consuming.

Iterations and Challenges

Although the algorithm was executed without coding, the procedure of repeated testing, which is important in programming to ensure efficiency and accuracy. I began experimenting on two small shrubs in two scenarios 1) overlapping and non-overlapping. Once the algorithm works on the two individual plants, I began to place multiple plants in a randomized fashion in clustering (densely populated), sparse, and no-overlapping groups to test for edge cases.

After I have successfully implemented the propagation aspect of the algorithm, I replicated realistic behaviors of the elements in the scene. The plant objects instantaneously disappeared after they were caught fire, so I added to the Blueprint a cluster of nodes to slowly decrease the size of the objects based on time (Figure 12). When I scaled the plants, I noticed that the larger plants were decreasing in size at an exponential rate (Figure 13). To resolve this, I incorporated the size of the objects into the subroutine so that the size reduction part of the algorithm depends on both time and object size. Larger objects should now reduce size more slowly. To test whether the algorithm can recognize objects that are non-flammable such as bodies of water, I added a lake and placed it next to the cluster of plants after I populated the landscape with the plant objects (Figure 14). The lake did not burn because I did not give it a flammable tag.

User Flexibility

Taking advantage of a characteristic of procedural generation, I designed the Blueprints so that certain characteristics of the fire and the objects can be edited easily to achieve different behaviors (Figures 10-12). Users can change the plant type by editing the foliage element of the object and altering the intensity and life-time of the fire for specific environments. Finally, users can add flammable tags to objects that they want to burn.

Results

After experimentation and prototyping, I created a fire propagation algorithm that can be applied to diverse landscapes populated with different object types, which can be easily edited and adapted to specific research projects and for demonstration purposes. For example, to show how the indigenous peoples of the Bolivian Amazon used fire to domesticate landscapes, we can transfer the algorithm to the summer research intern landscape, in a savanna and add collision spheres and flammable tags to the objects that occupy that landscape.

To demonstrate the propagation, I set the spreading and burning time of the fire and the objects to a small value. I manually defined the starting location of the fire to the level Blueprint – the master Blueprint that defines the behaviors of the current scene such as camera placements, player position, and timer initiation. Finally, I recorded the fire spreading from a bird-eye view, for the audience to observe the dynamic and complex spreading of the fire on the landscape (Appendix 1).

Conclusions

As Pyne stated, "the fire-mediated relationship between humans and the earth is fantastically complex" (1998: 69). For decades, native peoples have taken a proactive stance in reshaping the landscape, employing powerful technologies and resources like fire. Anthropogenic fire would lead to new earthworks, greater biodiversity, improved soil conditions for agriculture, and increased availability of game animals.

Although scholars have attempted to describe the human-fire relationship through various written and verbal communications, few have considered using visualizations of that relationship using traditional art, comics, narration, computer graphics, modeling, interactive digital storytelling, games, simulation, and animation. Visualizing complex fire characteristics and how they evolve over time is the most effective way to study and present the phenomenon.

Although the main goal of the project is to produce a procedural fire propagation, I wished to integrate the algorithm into a diverse set of environments to illustrate the flexibility of the algorithm. The algorithm could be easily adapted to different types of setting with varied vegetation and elevation. Due to time constraints, I was unable to create multiple landscapes for the class demonstration. A possible future project would be to bring the algorithm into different types of environment with unique objects to observe how they interact with each other. Another project involves populating the scene with people. Instead of simply initiating the fire from a random point, the user can animate a human to start and monitor the fire. This extension can be applied to a research project on anthropogenic fire. An application to the summer research intern project of 2018 is to develop an animated short or virtual reality user mode so viewers to observe the fire in close proximity, which is not possible due to safety reasons in real life.

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Appendix 1

Animation Video 1: Size-independent decreasing subroutine (online link).

Animation Video 2: Fire does not spread to non-overlapping objects (online link).

Animation Video 3: Fire propagation demonstrated on landscape (online link).