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Visualization Blackboard

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Visualization of Wildfire Simulations

Newspaper headlines constantly remind us of the human and property losses we suffer from wildfires, severe storms, earthquakes, and other natural disasters. These disasters cost the United States hundreds of lives and billions of dollars annually. Scientists at Los Alamos National Laboratory are developing computer models to predict the evolution of such disasters. Predicting the course of these events in faster than real time permits developing management strategies to minimize their adverse consequences. Presently, the complexity of models that forecast crises requires the advanced computing systems available at Los Alamos. In the near future, these models will be adapted for use in planning, training, and operational situations, but will still require advanced computing systems to run.

In the initial phase of this crisis-forecasting project, scientists are developing computer models to predict the spread of a wildfire. These models will simulate both fire behavior and the local and regional weather conditions that affect a fire. To complement the modeling effort, Los Alamos researchers are partnering with Los Angeles County Fire Department, United States Forest Service, and Kennedy Space Center personnel who provide real-world wildfire expertise and fire measurements.

Fire behavior is highly dependent upon winds, temperatures, and moisture. It is crucial to predict these weather parameters over the small regions where they directly affect a fire. Weather conditions in these small regions are driven by dynamic weather patterns such as cold fronts and high-pressure systems that develop over much larger geographic areas. The Regional Atmospheric Modeling System (RAMS),[1] originally developed at Colorado State University, predicts these variable weather patterns.

The RAMS model uses measurements from weather stations all over the United States to predict winds, temperatures, and moisture into the near future. RAMS then accurately translates this information into increasingly smaller geographical areas. Weather predictions from RAMS in the vicinity of a fire are used by the high-resolution model for strong gradient applications (Higrad) to accurately simulate weather variables across the fire line.[2] To model the interactions between winds and fire, Higrad has been combined with a simple fire behavior model (Behave) from the US Forest Service. This combined modeling system (Higrad/Behave) is the first step in predicting the actual progress and heat release of a wildfire.[3] Two fires have been simulated using this combined model: the July 6, 1994, South Canyon fire near Glenwood Springs, Colorado and the October 22, 1996, Calabasas fire near Malibu, California.

Approach

Scientists will use visualization of the simulation results to assess the simulation's quality. Eventually fire fighting personnel will use the results as a visual forecast of a fire's evolution. When visualizing the wildfire simulation, both the scientists and the fire personnel want the results to look as realistic as possible without compromising scientific accuracy. Realism is considered important because the visualization will be used to study the evolution of previous fires, train personnel on how to respond to a fire, and eventually generate a visual forecast of a new fire. In addition, a realistic depiction helps simplify the scientist's job of visually comparing the results of the simulation to the ground truth data (some of which are currently based on photographs and videotapes).

The Higrad/Behave model produces three main data fields: temperature and winds over a $128 \times 128 \times 101$ volume at 10-meter resolution, and burn region data over the topography's surface. In addition, local topography data was available for the two test simulations. As a first approach we used a mesh to represent topography and multiple isosurfaces of the temperature data. Figure 1 shows the results of the visualization for the South Canyon fire.
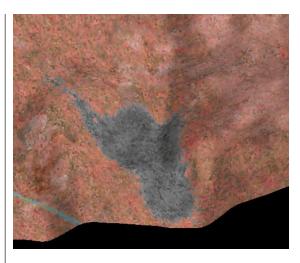
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1 Temperature-based isosurface results.

2 Close-up of texture-mapped topography.

3 Composited volume-rendered and texture-mapped result.

While the scientists found these results reasonable, the fire officials had difficulty understanding the nonphotorealistic representation. To make the visualization more realistic, we replaced the temperature isosurfaces with two volume renderings and texture mapped the topography.[4] The two volume-rendered results used different transfer functions to depict smoke and fire based on temperature values. The topography texture maps are based on actual textures extracted from photographs and videos of the fire regions. As the fire progresses, the burn region data serves to modify the colors of the original texture map to a darkened grayscale. In addition, random patches of the original texture map introduced into the burn region simulate small areas missed by the fire.

Figure 2 shows a close-up of the resulting texture-mapped topography, which is then composited with the results of the volume-rendered temperature field. Figure 3, from the Calabasas fire simulation, shows the composited results. In this picture, the fire colored yellow shows the hottest range (340 degrees Kelvin and above), followed by orange (327 to 339 degrees) and red (315 to 326 degrees). The gray-colored smoke occupies the temperature range 300 to 325 degrees.

Implementation and results

We had a time frame of a month and a half to produce videos for the two simulated wildfires. Therefore we wanted to use an existing package to quickly create the visualization. We picked IBM's Visualization Data Explorer (DX), which supplies a full collection of visualization tools and allows for quick program prototyping and creation.[5] DX provides the functionality to volume render in software and texture map in hardware. However, it currently does not support the compositing of software and hardware rendering. Due to time constraints, and a closed implementation of the DX renderer, we were forced to compute a blending-based composite. In general we found that although a single tool—such as a stand-alone volume renderer—might provide better functionality for a specific operation, it was valuable to have a complete collection of tools designed to work together.

Performance is a key concern for this project's future because all results—both the visualization and the simulation—must be computed in faster than real time. To improve performance, we used the Symmetric Multiprocessor (SMP) version of DX. This version exploits data-parallelism within the modules of the data flow network. That is, a module's data is partitioned to multiple processors and multiple threads process the data. The implementation requires 27 seconds to render one second of real-time (simulated) data on 24 processors of a Silicon Graphics Origin 2000. Additional performance improvements will be critical to the future success of the project.

Figure 4 shows the progression of the South Canyon fire over five-minute time intervals. The entire animation sequence contains 1,250 frames and covers 20 minutes of simulated time accelerated 30 times faster than real time. Both the simulation and the resulting visualization accurately portray how the fire evolved in real life. Strong winds, produced by a large-scale weather system, are evident (blowing from the lower left to the upper right). These winds caused the fire to rapidly climb the canyon and tragically take the lives of 14 fire fighters.

For the two simulated fires the scientists are currently analyzing the results in a qualitative manner, since the real-world data for comparison consists of video and summarized personal accounts of the fire's spatial and temporal behavior. In the near future scientists will compare their results to the output of the Airdas system, an airborne scanning instrument designed to record information about a fire.[5] The system includes detectors for fuel condition assessment and fire temperature measurements. The data from this system will let the scientists quantitatively assess the results of their simulation.

Future work

The Higrad/Behave model currently runs slower than real time, and the scientists are working to improve its performance. They want to obtain results at least five times faster than real time to make the simulation useful as a predictive tool. To produce visualization results in faster than real time, we're experimenting with hardware-based volume rendering. In addition, we plan to look at new visualization algorithms that will let the scientists visually compare Airdas and simulation data.

Finally, we're studying how to effectively handle the remote delivery of visualization results to fire personnel at the actual location of the fire. ∎
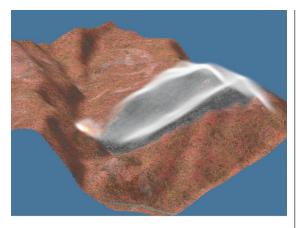
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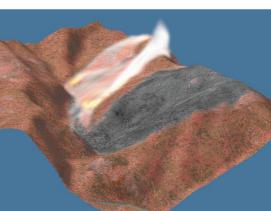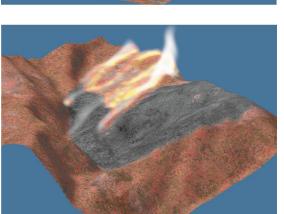
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4 The progression of the South Canyon Fire over time.

Video on the Web

To see video showing the Calabasas Canyon, California and South Canyon, Colorado fires simulated over time, go to

http://computer.org/cga/cg1998/extras/g2019x.htm

The South Canyon fire simulation covers a total time of 20 minutes and is shown at a speed 30 times faster than the simulation time. The Calabasas fire simulation time covers 68.5 minutes, shown 30 times faster than the simulation time.