Visualizing Simulated Room Fires *

Jayesh Govindarajan
Computer Science Dept.

Matthew Ward †
Computer Science Dept.

Jonathan Barnett
Fire Protection Engineering Department

Worcester Polytechnic Institute

Abstract

Recent advances in fire science and computer modeling of fires allow scientists to predict fire growth and spread through structures. In this paper we describe a variety of visualizations of simulated room fires for use by both fire protection engineers and fire suppression personnel. We also introduce the concept of fuzzy visualization, which results from the superposition of data from several separate simulations into a single visualization.

Keywords: Scientific visualization, simulation, fire modeling

1 Introduction

In modern times the emphasis on fire control has focused on understanding and predicting the growth and spread of fires. This has manifested itself in a modern thrust towards performance instead of prescriptive building codes [1]. A key element in this change has been the recent development and availability of computer based fire simulation models. There are two basic types of models in use today, zone and field models.

Zone models divide a room or other space into two homogeneous control volumes: a hot upper layer and a cooler lower layer. Such models are very popular for use in fire reconstruction and have great potential for use as part of decision analysis techniques. A major advantage in using zone models is their ease and speed of execution. This enables their use on typical personal computers. Their main deficiency is that because they divide a space into two homogeneous layers, detailed, location-specific information cannot be ascertained. This is particularly true of spaces with unusual shapes and sizes and where knowledge of localized fluid flow is a critical parameter. For example, the prediction of the operation of a detector near a ceiling beam requires knowledge of the gas temperature and velocity at the detector. Therefore, today's zone models cannot be used for predictions in complex environments. However, for some simple building layouts the appropriate predictions can be performed using zone models such as NIST's model CFAST [2], or the single room model WPI/BRANZFIRE [3].

Field models, also known as computational fluid dynamics (CFD) models, divide the continuum into many homogeneous cells. Such models then solve the fundamental equations of mass, energy and momentum transfer for each cell. CFD models do an excellent job modeling fluid flows and motions between cells. For example, a three-dimensional field model can be used to great advantage in the prediction of fire spread from space to space and for detailed investigations of specific phenomena such as ceiling jets, detector operation and even flame spread on fuel surfaces [4]. Special purpose CFD models for room fire prediction include JASMINE [5] and SOFIE [6]. Other general-purpose CFD models that have been successfully used for fire modeling include FLUENT and TASCflow [7]. Despite the advantages of field models there are three major difficulties. The first is the tedium required developing the model input. Even with automatic mesh generation, a substantial effort is necessary to describe the complex geometries found in buildings and rooms, especially with respect to the description of various objects in a room. Second even with today's fast computers, lengthy computational times are the rule. This often makes sensitivity studies requiring many simulation runs prohibitively expensive. The final problem is interpreting model results. CFD models often contain tens of thousands of cells and generate large volumes of data. This data needs organization, storage and interpretation. As a result, visualization techniques are a critical component for engineering analysis of CFD model results.

2 Visualization Parameters

One aspect of this work involves designing effective visualizations of components of fire simulations for a single room configuration. These visualizations are intended for use by fire researchers and fire fighters. A long-term goal is to investigate connecting a database of simulated fires to the sensors in an actual building, and provide visual depictions of predicted futures (based on retrieving the simulations which best match the fire occurring) in the event of a fire.

Currently, the data to be presented for each time slice of a simulation are: room geometry and content (walls, floor, ceiling, doors, windows, objects in room), sensor data (binary or scalar values at distinct locations), temperature (3D scalar field), location of hot gas layer (scalar value representing height), and time until full room involvement (scalar value). Other data which will be considered for future visualizations include smokiness and gas concentrations (scalar values) and air movement (3D vector field).

There were three visualization configuration variables considered, which together made eight combinations:

Static vs. Dynamic: While it would be intuitive to map simulation time to animation time, in a fire suppression situation a fire fighter may not have sufficient time to view one or more long animations. Thus the fire history and future were encapsulated into a single static scene.

Single vs. Multiple Frames: We can either show a single view of the simulated fire or divide the screen into subimages with multiple views. The loss of detail resulting from subdividing the screen is an issue, as is the time required to study multiple views.

Single vs. Multiple Simulations: Scientists wish to study the effect of changing simulation parameters on the resulting simulated fire. Also, as simulations may predict diverse futures for the fire, it is important to provide fire suppression personnel with best, worst,

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†Contact: WPI CS Department, 100 Institute Rd., Worcester, MA 01609 USA, matt@cs.wpi.edu, (508) 831-5671.

and average case scenarios from simulations matching actual sensor events. Thus we need to consider methods of superimposing data from multiple simulations into a single visualization. We refer to the resulting image as a *fuzzy* visualization, as the true behavior of a fire is predicted to fall within the range of simulated values.

3 Prototype Visualizations

There are eight configurations of visualizations of the simulated fire data considered to date. Examples of each, along with their strengths and weaknesses are presented below. Full scale images, as well as animations, can be viewed at the project web site `http://mavis.wpi.edu/~firedb/`. In preliminary evaluations by potential users, it was interesting to note that while researchers were interested in the use of slices through the 3D field to gain an understanding of the temperature gradients, fire suppression personnel preferred 3D isotherms, thus sacrificing detail for what they perceived as a more intuitive representation.

Dynamic Scene, Single Frame, Single Simulation (DSSFSS): This animation (see Fig. 1) was intuitive to interpret. Sensors are indicated as glyphs along the ceiling, with their state indicated by color. The top of the glyph shows the actual sensor state and the bottom indicates the state as predicted by the simulation. The hot gas layer is projected onto two walls, using color to differentiate hot gas from cool gas. Temperature is represented by either colored slabs or multiple nested isosurfaces, with transparency used to provide views of the inner (hotter) isotherms.

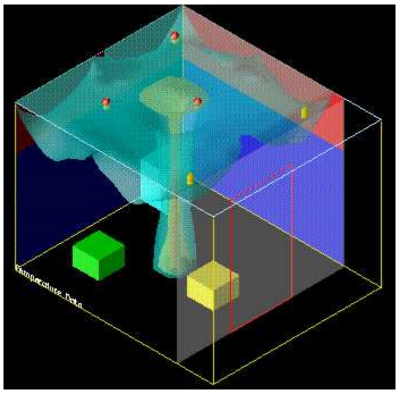

Figure 1: Time slice of single frame, single simulation visualization, showing three nested isotherms, sensors, hot gas layer, and objects in the room.

Static Scene, Single Frame, Single Simulation (SSSFSS): A significant challenge was to generate a single image capable of conveying values at multiple time steps (see Fig. 2). The position of the hot gas layer plotted against time was shown on the back and left walls of the room, with a grid to help quantify changes in height over time. Nested isosurfaces or contours on slices can be used to show the location of a single isotherm at different time steps. Various options to show sensor state over time in a single glyph, using either color, size, or shape encoding, are being evaluated.

Dynamic Scene, Multiple Frame, Single Simulation (DSMFSS): With multiple frames we can separate the individual isotherms into separate frames (see Fig. 3, color plates), or use one frame to show the DSSFSS case and show air flow as a field of arrow glyphs in a second frame. Alternatively, we can show advanced frames (e.g., time plus 5 minutes, time plus 10 minutes) to allow easy assessment of the rate and direction of fire growth.

Static Scene, Multiple Frame, Single Simulation (SSMFSS): For a static scene, the most appropriate use of multiple frames is

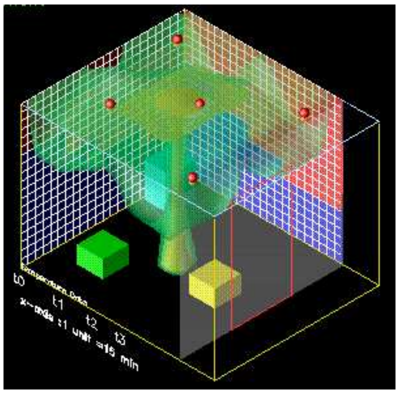

Figure 2: Static view of single frame, single simulation visualization. Isotherms represent current time plus offsets of one and two minutes. Location of hot gas layer over time is plotted on back walls, starting with current time.

to show different time periods in different frames. Four time steps appears to provide adequate detail for useful analysis.

Dynamic Scene, Single Frame, Multiple Simulations (DSSFMS): For multiple simulations we use nested, translucent isosurfaces to show multiple fields, this time resulting from multiple simulations (see Fig. 4). This provides a mechanism for comparison, although it can lead to confusion in interpretation. The location of the hot gas layer and the time until full room involvement are each scalar values, and thus we can color or shade the areas of the clock (Fig. 5) or walls proportional to the number of simulations which agree on a given state at the given location/time. This helps separate outliers from the dominant predicted values.

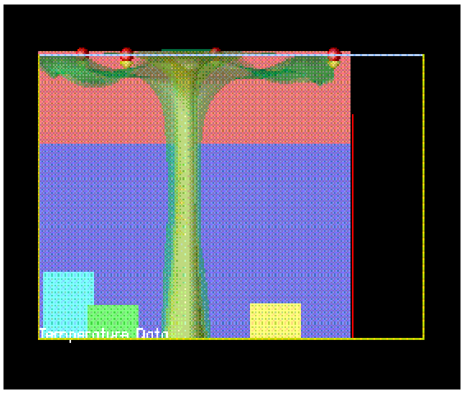

Figure 4: Time slice of single frame, multiple simulation visualization, with nested isotherms from three simulations. Densest area is where simulations agree that the temperature is greater than or equal to the threshold.

Static Scene, Single Frame, Multiple Simulations (SSSFMS): For scalar values, such as height of the hot gas layer, one can use a shaded plot on the back wall, with time represented from left to right and the simulation values combined as in the DSSFMS case (Fig. 5), Some nestings of isosurfaces are possible, but we found stacked slices of time-dependent contour lines (one slice per simulation) was easier to interpret, as long as the number of simulations is relatively small. Figure 6 shows the expansion of a single isotherm over time (time coded by color) as predicted by four different simulations.

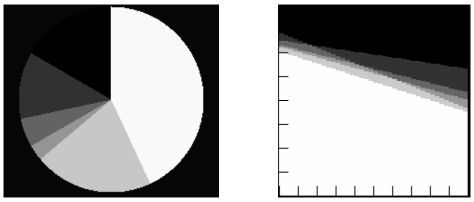

Figure 5: Examples of fuzzy visualization of a scalar value over multiple time frames. The left image shows the time until Full Room Involvement. Darkest region indicates all simulations predict at least 10 minutes until FRI, while majority predict approximately 20 minutes. The right image shows the location of hot gas layer over time, showing multiple simulations superimposed.

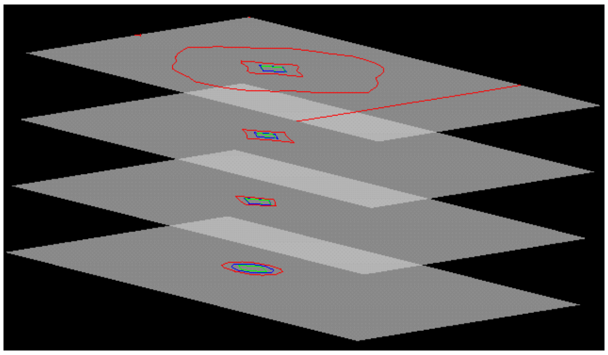

Figure 6: Four stacked simulations showing a slice of an isotherm as it changes over time. Color corresponds to time.

Dynamic Scene, Multiple Frame, Multiple Simulations (DSMFMS): The simplest solution to this configuration is to use separate frames for each simulation. The number of simultaneously displayed simulations will be limited by the screen size and the desired level of detail.

Static Scene, Multiple Frame, Multiple Simulations (SSMFMS): Here we employ the SSSFSS methods and use different frames for each simulation (Fig. 7, color plates), or we use the DSSFMS methods and use multiple frames to convey different time slices.

4 Related Work

Visualization of 3-D scalar fields has been a common theme in the field of visualization, though more often the focus has been a single scalar value at a given location rather than multiple values. Hong et. al. [8] mixed scalar and vector fields in the visualization of a fire simulation, developing incremental update techniques to enhance performance and interactivity. Rushmeier et. al. [9] used ray casting and line integration to render fires in pools of liquid fuel. The results of thousands of simulations were averaged together to get a final value for each location. Treinish [10] created visualizations consisting of multiple views of the atmosphere, employing redundant mappings and both juxtapositioning and superimpositioning methods. Finally, Pajon and Tran [11] display multiple scalar fields derived from geological exploration and modeling by either rapidly switching between each of the scalar fields or combining two or three scalar fields via color coding or color and elevation on 2-D slices of the field.

5 Summary and Conclusions

In this paper we've presented an overview of fire modeling and simulation and presented several strategies for visualizing simulation output for analysis by fire researchers and fire suppression personnel. The concept of a fuzzy visualization, namely the result of superimposing multiple predicted data sets in a single visualization, was introduced, and examples of visualizing several fuzzy data types were shown. Our on-going research is focused on assessing these visualizations with different target audiences and developing alternatives to meet their needs and expanding the visualizations to include multiple room fires and building-level overviews of fire histories and predicted futures. Finally, we would like to explore alternate methods for combining scalar fields, such as the texture based methods described in [12]. We anticipate the results of our research will be valuable for understanding the complexities of fire growth and selecting effective strategies for the suppression of fires in the modeled spaces.

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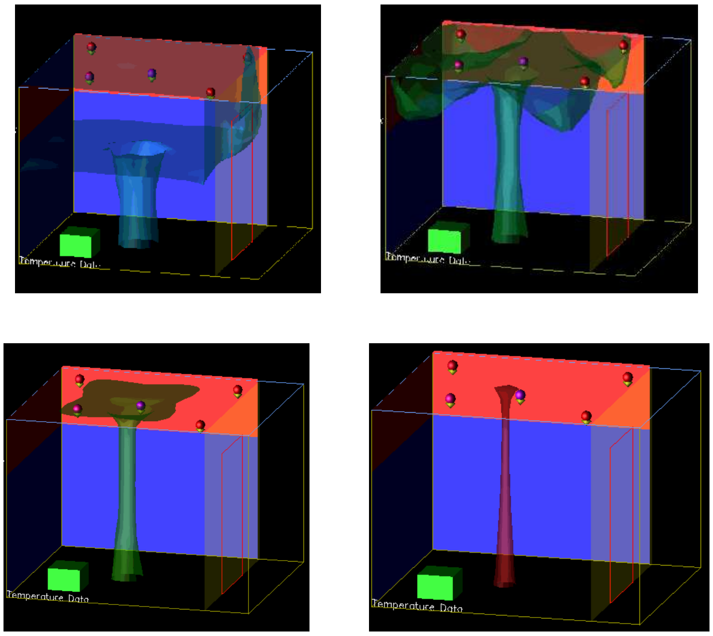

Figure 3: Time slice of multiple frame, single simulation visualization, showing four different isotherms (note heat escaping through door in first frame).

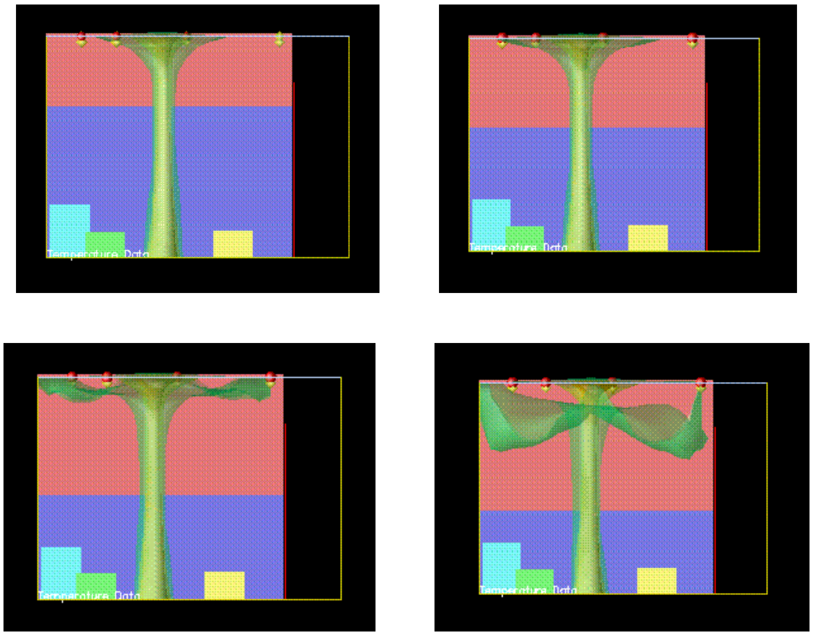

Figure 7: Static scene of multiple frame, multiple simulation visualization, with one frame per simulation and nested isosurfaces showing a single temperature at distinct time steps.