Sand on fire: an interactive tangible 3D platform for the modeling and management of wildfires

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Abstract

This paper presents the current development of an interactive tangible 3D platform that is used to conduct wildfire training, incident command and community outreach activities by allowing one to interactively visualize a variety of scenarios on sand tables, based on underlying wildfire, traffic, smoke, rain and incident command models. The platform, which is part of a larger effort to create ambient interactive environments at the Santa Fe Complex, consists of a coordinated camera-projector pair that uses active surface projections to detect physical interaction on an actual sand table. Our hardware and software create simulations on sand surfaces, where the changeable 3D surface is an active part of the simulation. By decoupling the sensing of physical interactivity from the underlying models, our platform is model-agnostic and could be used to visualize fire propagation and evacuation models from a variety of sources. Its value lies primarily in the immediate reactivity of the touchable sand surface, which engages users more intimately than other traditional training and education tools.

Keywords: sand table, interactive, tangible, platform, wildfire modeling, wildfire evacuation, emergency planning, traffic simulation, advanced visualizations, firefighter training.

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1 Background

The City of Santa Fe, New Mexico (USA) faces a wildland fire threat, as do many other communities in the world. In the City there are significant numbers of homes nestled in wild vegetation along narrow roads. Often there is only one ingress/egress to those neighborhoods. Fire Department officials began wondering in 2003 about whether residents would be able to evacuate their homes safely in the event of a fast-moving wildfire, and they began teaching citizens to be ready to evacuate or shelter-in-place depending on the circumstances.

In 2004, Santa Fe City officials initiated a collaboration with agent-based modelers and visualization scientists currently at the Santa Fe Complex and with fire scientists at Anchor Point Group of Boulder, CO to develop models of the interaction between massive but not unrealistic wildfires and traffic as it would exist in an evacuation (the 48,000 acre Cerro Grande Fire, which destroyed over 200 homes in Los Alamos, was visible from Santa Fe). The goals were not only disaster-response planning but also education of citizens and first responders, as shown in fig. 1. City emergency response professionals believe that the ability to visualize a fast-moving fire and its accompanying smoke and their dramatic effect on traffic will serve as an effective educational tool and as a means to illuminate decision-making [1].

Since its beginnings [1], the interactive platform has evolved considerably and has found a variety of applications, including the simulation of boat traffic in the canals of Venice, Italy [2].

More recently (2009) a Santa Fe Complex spin-off company has begun packaging a sand table product (fig. 2) including a series of training tools aimed primarily at firefighting academies [3].

Figure 1: Traditional “table top” exercises used by multi-agency emergency planners.

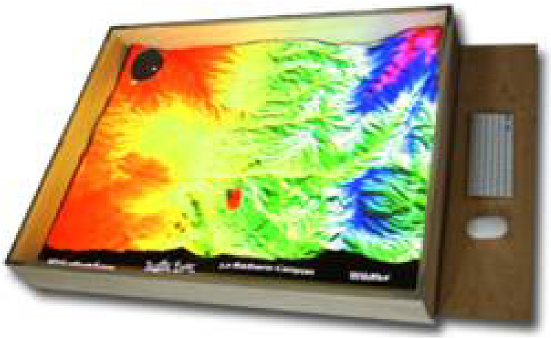

Figure 2: The Simtable system [3].

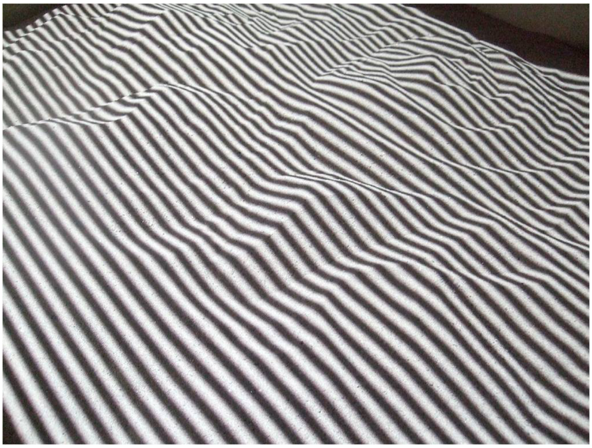

Figure 3: Structured light projected on the sand surface read by a webcam for elevation measurement.

2 The interactive tangible 3D platform

The platform consists of a physical sandbox, a computer projector, and a web camera coordinated by an operating system software. The webcam is used to sense human computer interactions and, in combination with the projector, to perform two "*structured light*" scans in order to establish:

1. a correspondence from camera pixels to projector pixels and
2. the height of the sand in real time (fig. 3).

The elevation scan allows the platform to provide visual feedback to users to guide them as they reconstruct a specific landscape based on topographic maps.

The platform’s operating system detects interactions within the camera's field of vision and uses Open Sound Control (OSC) protocols to communicate with separate modeling applications running on the platform. Another spinoff of the Santa Fe Complex is developing an application programming interface (API) that will allow any programmer to write applications for the many other potential uses of the platform [4].

Current applications of the platform [3] are designed to react to laserpointers, whereas laboratory versions can also react to hand or facial gestures and can incorporate physical fiducials to represent various types of interactions, as was done with the Venice Traffic Table [2].

The 3D elevation detection algorithms based on the *structured light* approach, our platform allows a user to select a geographical area in Google Earth and follow color cues to form the elevation map in the sand.

Digital Elevation Models (DEMs) are loaded from a seamless dataset which provides 10 meter resolution DEMs for the US and 30 meter resolution DEMs for locations outside of the US. Data can also be loaded from geoservers supporting the Web Mapping Service (WMS) and Web Feature Service (WFS) protocols. DEM files can be loaded from local government sources if higher resolutions are needed. It is often the case that local governments have higher resolution files resulting from LIDAR surveys or other sources.

Once a DEM is loaded, the Simtable scans the current height of the sand for comparison and colors the sand red where sand needs to be removed and colors green where sand needs to be placed. This “sculpt by color” allows users to quickly form an area of interest in less than 20 seconds.

Further realism is added to the sand table by projecting hill shading onto the slopes. A user interface element of a yellow sun depicted in 8 allows the user to change the direction of the sun and thus modify the hill shading.

Moreover, our platform provides a “flyto” feature that translates a laserpointer position on the sand table to latitude and longitude and to then fly to that location in Google Earth on a second screen. Fire scenarios that include historical progression maps can be loaded for post-mortem “lessons learned” review exercises (fig. 4).

There are important tradeoffs in different approaches to wildfire modeling. The biggest is the tradeoff of predictive accuracy for real-time feedback. As the initial uses for the Simtable have been for training and community outreach, we developed the CA approach as it allows users to get immediate interaction instead of waiting hours for a single fire to be simulated.

The Simtable is “modeling agnostic” in that it supports an application programming interface (API) to run user-supplied models that would take the elevation of the sand as an input. More sophisticated models can be loaded that add features like wind models that are terrain-sensitive and fire models that generate their own weather.

The platform can incorporate a variety of models, employing a number of underlying algorithms, as illustrated in the following section of this paper.

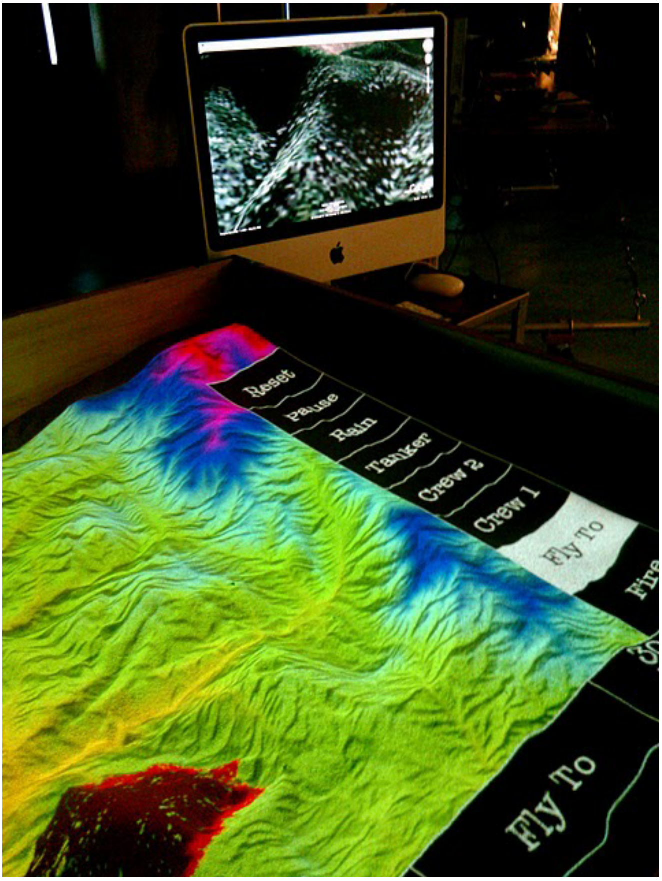

Figure 4: “Fly To” mode allows users to point to a location on the sand table and fly to that location on a separate first-person monitor, displaying the Google Earth terrain at the chosen location.

3 Forest fire applications on the platform

Our tangible interactive 3D platform can be used in a variety of contexts [1, 2]. The following sections illustrate how the platform is being applied in the real world for the training of firefighters and first responders, with the goal of improving the coordination among public safety agencies in the event of a major forest fire [3].

In this context, there are three main phenomena and activities that our platform allows to concurrently model for the training of first-responders and other emergency personnel in the containment and management of a wildfire:

1. The spreading of the wildfire
2. The evacuation dynamics
3. The firefighting strategy

3.1 Wildfire spreading model

Our platform can incorporate a variety of fire spreading models. The current application [3] trains wildland firefighters by simulating actual fire behavior, which spreads downwind, and uphill over mountain slopes, variably combusting vegetation fuel it finds in its path.

The table currently ships with a custom cellular automata (CA) model [3]. Fires can be interactively "started" on the sand table using either a physical cigarette lighter or a laserpointer. Ignited cells spread to neighboring cells in a probabilistic discrete event simulation. Fire spread rates are configurable as matrices in external .csv textfiles. Current matrices are draw from BehavePlus [5] for given temperatures, relative humidities, wind, slope and fuel types. When a fire ignites in a cell, the probability of a neighboring cell igniting depends on the wind, the elevation difference and the spread rate of the fuel type in that cell. Simply speaking, a cell is more likely to ignite if it is downwind and uphill from an already burning cell and it will combust more or less rapidly depending on its prevailing vegetation cover.

3.2 Evacuation dynamics

The wildfire evacuation model explores the interaction of two complex systems; a traffic model and a wildfire model. Combining two models with different time steps and architectures is a challenge in agent-based modeling, especially when the models are directly affecting each other. Cars blocking roads in an emergency evacuation could hinder fire crews preventing them from reaching the fire. This would cause the fire crew's attack on the fire to be hampered by the dynamics of the traffic model with a resulting change in fire model behavior as compared to an ideal fire attack (i.e. one with immediate fire crew presence). As the fires most likely to affect Santa Fe would be fast moving (up to 5 km/hour), we assume that only fires where the initial attack was unable to control the fire would rise to the level of evacuation. Thus this model can be considered the worst-case situation of no fire attack allowing the assumption that fire dynamics are independent of the traffic dynamics. This leaves the fire model free to be run independently of the traffic model and to serve as input to the traffic model. Below we detail the traffic model GIS inputs and traffic behavior including the wildfire model impact on the traffic model.

Initial explorations in modeling intersections were prototyped in NetLogo [11] with the road network modeled as a graph with nodes and edges. As an aside, our team continues to find NetLogo invaluable as a powerful rapid prototyping environment for agent-based models while it remains approachable to domain experts that don't normally identify themselves as coders. As the number of cars in the traffic model increased up to 70,000 and the GIS components grew in importance, development was transitioned to pure Java.

Agent-based models typically consist of agents interacting with each other in an environment. In general an environment may consist of cells in a grid with a topology of four or eight neighbors or a network (graph) topology. The traffic model's environment is constrained to the topology of the streets of Santa Fe as input in a GIS shapefile. The shapefile consists of shapes called polylines, shapes that are made up of a number of piecewise linear segments, and is a description of the ‘center line’ of the streets of Santa Fe. From this information a road network is built. Roads consist of multiple lanes proceeding from a directional distance of zero at one end to the total length of the road at the other. Each road has at least one lane that has directionality and a distance of zero at one end of the road proceeding to the length of the road at the other (fig. 5).

Depending on the number of lanes and whether the road is one-way, roads may have lanes beginning at both ends of the road. The cars exist on lanes that meet at intersections and can pass from one lane to another at intersections based on the connectivity of the intersection. Lanes that enter an intersection are connected to lanes that exit that intersection.

Car agents are aware of their neighbors sharing a lane, a road, or an intersection. Cars are not aware of their absolute positions in space such as elevation or north or east location as they exist at a distance along a lane in this world of roads and intersections. Cars are aware of their neighbors in this space, avoid collisions, accelerate and decelerate, and turn at intersections following a mixture of local rules while seeking a destination.

Predetermined sets of origins and destinations are defined in the model. At the beginning of a model run cars are assigned a destination and an origin location based on the real locations of homes in Santa Fe from another GIS data file. Destination points may include an evacuation center or road that leads out of town and can conceivably be extended to various other destinations, such as area hotels.

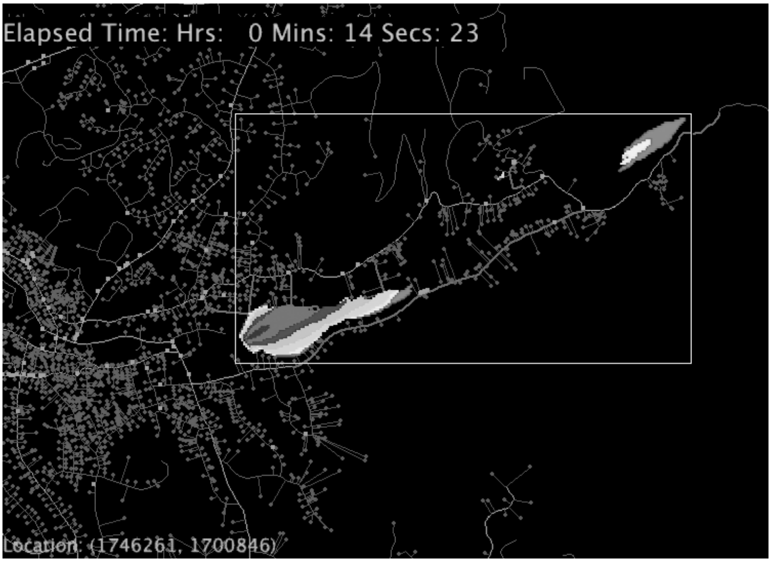

Figure 5: Agent-based traffic evacuation.

All intersections in the model are informed of the distance to destination points through an initial "*flood-fill*" from these points. This technique is useful when there are only a handful of possible destinations; however, it is memory and CPU-intensive for a large number of points.

This evacuation model is not so much concerned with the destination as with the dynamics of leaving the evacuated areas. Careful selection of evacuation points allows us to produce realistic sets of local routes out of the evacuated area. From that point, cars follow a set of local rules choosing particular routes at intersections according to the capacity of roads, their distance to the goal as determined by the flood fill, with aversion to changing roads too often, and a certain amount of random noise that we refer to as the 'tourist factor' that serves to give drivers an incomplete knowledge of the roads. Added to the above is general aversion to driving on or near roads that are near active fires. Possible further work in the social modeling of the evacuees would be necessary to determine where in particular populations would drive to, including friends and family homes, hotels, and other locations outside of the evacuated area. We focused, however, on areas which we knew would be challenging to evacuate in the event of an aggressive crown fire. The body of research produced by Cova *et al.* provides good background and many valuable techniques for characterizing relative neighborhood evacuation risk [6–10].

The fire model output consists of eight raster files of which the "Time of Arrival" (TOA) and "Flame Length" (FML) files are currently used as input to the traffic model. The TOA file consists of a geographic area covered by a grid of pixels. Pixel values are either the fractional hour that fire first enters that pixel or "–1" if no fire ever entered the area. Shape files generated from wildfire simulations were imported into Google Earth Pro (http://earth.google.com/) so that they could be shared with citizens of Santa Fe as .kmz layers. The Pro version of Google Earth is only required to generate the .kmz files from .shp files. The .kmz files are then distributable to end-users with the free version of Google Earth.

The traffic model takes this information as input and sorts fire points according to the time of the start of fire at each location. As the traffic model reaches the time when a fire first appears, that point is added to a set of current fires and roads that are near these fires are impacted as are roads that are located downwind of the fire. These points last for a certain time based on the estimate of duration of fire given the fuels at that location, before they are removed from the list. This information is made available to nearby roads, which can then be queried by cars traveling on these roads for deciding whether to turn at an intersection. Finding fire or smoke on a road, the car will avoid that road.

3.3 Firefighting strategies

The platform herein described is capable of not only simulating the spreading of fire and the evacuation of people, but it can also play out operational firefighting strategies that can be used to train fire crews.

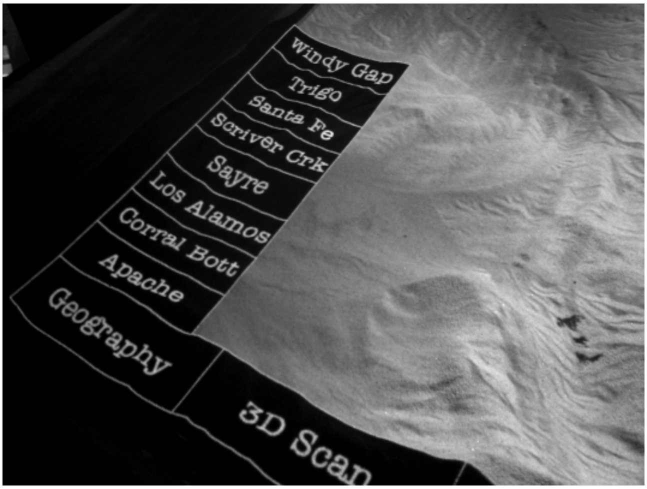

Figure 6: Historical fires menu.

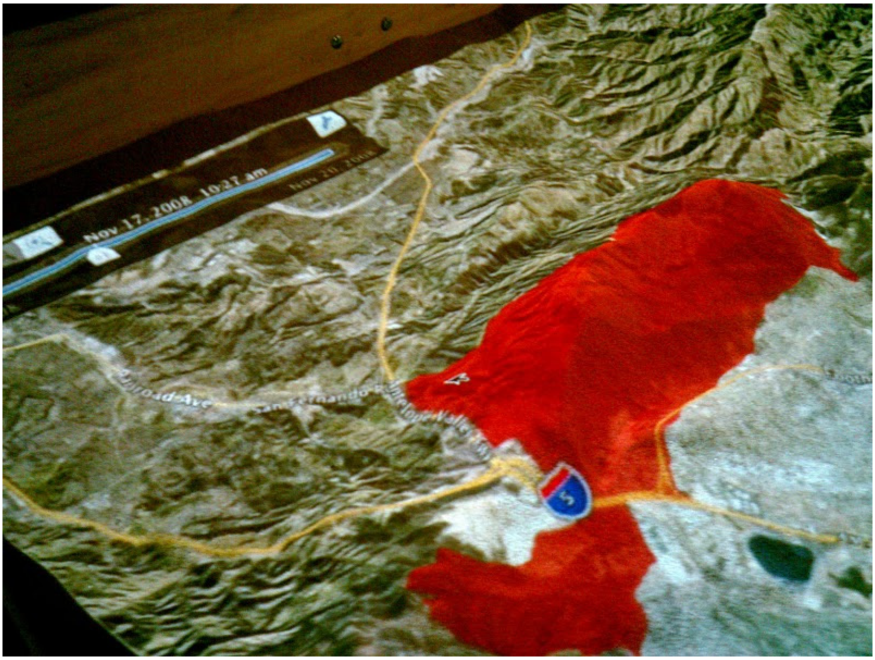

Figure 7: Historical fire progression example (Sayre Fire, 2008).

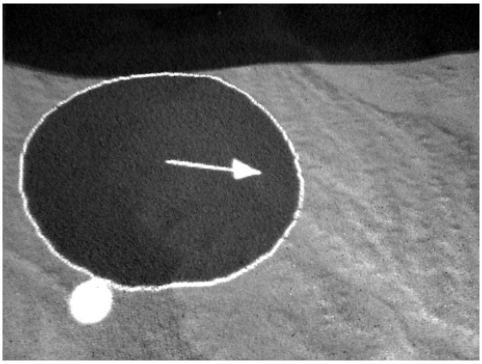

Figure 8: Interactive wind vector and sun location interface.

Figure 6 shows how our platform allows trainers to select eight "famous" wildfires and their corresponding topologies, to provide real-life scenarios on which firefighters can hone their skills.

Once a specific wildfire is selected, our platform displays a color-coded image of the terrain, suggesting where the users need to add or remove sand to conform it to the selected wildfire's terrain. The user can re-scan the surface to iteratively reproduce the terrain with the best approximation required for the training session (fig.7).

GIS layers, such as vegetation fuel, roads, and buildings can be interactively loaded on to the sand to affect fire behavior during a training session.

While the simulation is running, firefighter trainers are able to manipulate the strength and direction of the wind shown in fig. 8. Changing the wind, instantly affects the fire's behavior, thus requiring a quick reaction on the part of the trainees.

The latest version of the Simtable [3] supports the deployment of two types of crews (type 1 and type 2) who can clear fire lines along a fire's path to slow its spread and protect sensitive populated areas. The system simulates the production rate (in "chains per hour") of the two types of crews as they manually create the fire line. To make the strategies even more realistic the system also allows the use of flying "tankers" to airdrop fire retardants over specific locations again in an effort to slow the spreading of a wildfire.

All of these tools for the training of firefighters leverage the flexibility and adaptability of our platform.

4 Conclusions

The interactive tangible 3D platform can support a variety of models and interactions for the visualization of the spreading of forest fires, of the consequent evacuations of local inhabitants, and of a variety of strategies that can be employed to suppress the fires. It allows hands-on training of firefighters on historical fires and can simulate real firefighting actions, such as the clearing of fire lines by ground crews and the dropping of fire retardants using airplanes.

The decoupling of the interface from the underlying models allows flexibility for both the choice of interactivity (laserpointer, fiducials, hand gestures, face tracking, etc.) and the choice in sophistication of the fire spreading and traffic evacuation models and will also permit the inclusion of proprietary models or open-source tools developed in the community, thanks to a planned Application Programming Interface (API).

The realistic accuracy of the terrain model visualizations, including the fly-to views on Google Earth, as well as the tangible nature of the sand table – which had already extensively proven itself in traditional firefighting training – engage the users more profoundly and are likely to bring about measurable benefits in the quality of the training that the firefighters receive.

The platform can also be used to educate citizens about how to react when a fire hits closer to home. Being able to show one's own house on the sand table makes our platform a much more effective public outreach tool, which has many more applications above and beyond the modeling and management of forest fires.

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