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A BUSHFIRE EVACUATION PLANNING SERVICE UTILISING MULTIPLE SIMULATION SYSTEMS

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INTRODUCTION

Bushfires cause environmental destruction, property damage, and loss of life in many parts of the world. Examples include recent disasters in Australia, such as the 2009 bushfires in Victoria [1], and in the US with both the 2003 and 2007 fires in Southern California [2]. In addition, population growth and urban sprawl has given rise to communities where a large proportion of the population underestimate their risks. Therefore, enabling emergency services to better understand, plan, and prepare for such disasters is of great importance in mitigating the associated dangers. To this end, modelling the risk caused by bushfires on the population and environment has been a focus of research in recent years.

The behaviour of people during bushfires is a very important factor. People react differently as the emergency unfolds, and exhibit a variety of actions. Their awareness (e.g., the access to warning messages and danger reports), beliefs (e.g., on the defendability of their homes and the extent of the fire), evacuation behaviours and priorities (e.g., the need to save their pets and valuables), and consequently, their response to such events have a bearing on the overall outcomes of an evacuation within the affected region. This disparity in behaviours has a direct influence on the evacuee exposure risk.

MODELLING A BUSHFIRE EVACUATION

Multiple approaches have been proposed around modelling and simulation of bushfire evacuation scenarios aimed at better understanding the risks associated with them. However, many of the prior techniques are significantly simplified representations of reality.

In this talk we present a modelling and simulation approach that accounts for multiple dynamic factors affecting bushfire evacuation scenarios. A diagram of the core modelling components is shown in Figure 1. Our primary interest in this work is the safety of people. It follows that our modelling and risk assessment approach focusses on the movement of people and their proximity to threats.

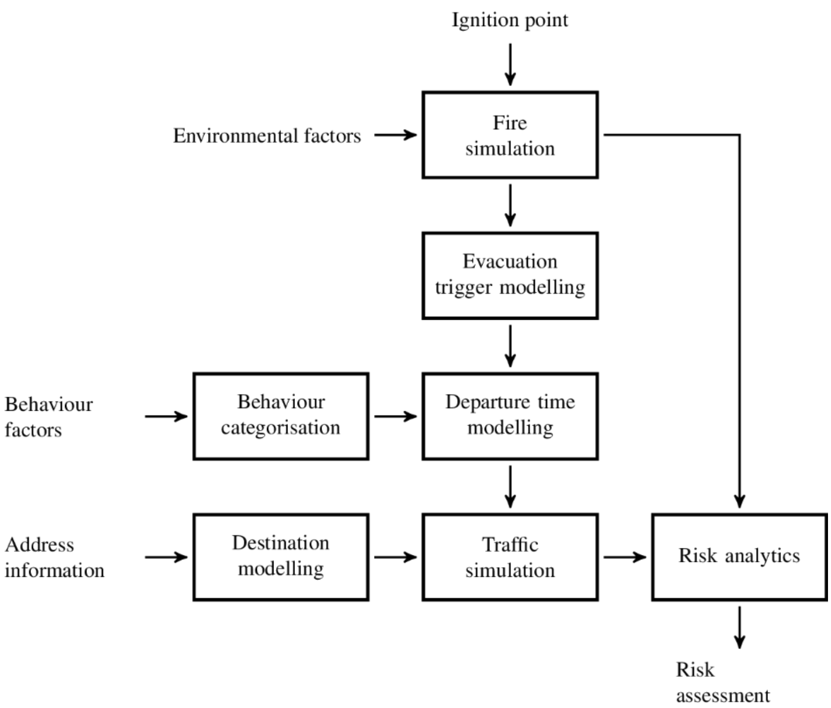

Figure 1: Modelling flow diagram

A *bushfire simulator* has been implemented following the cellular automata model for forest fire spread prediction proposed and validated by Alexandridis et al. [3]. In particular, our simulator captures the effects of the type and density of vegetation, wind speed and direction, ground elevation, and spot fires. In addition, the simulator includes models of the Fire Danger Index (FDI) and fire suppression efforts.

In response to the fire progression, several types of events are modelled and serve as evacuation triggers to the population. *Warnings* are sent out on a per-area basis, i.e., whenever the fire front is projected to impact an area the residents of that area are sent a warning of the estimated time-to-impact. There is also the *fire visible* event, which may trigger people to evacuate when they can see the fire.

Behaviour modelling captures the kinds of events people will respond to, i.e., what makes them leave, the timing of their departure, their vehicle use (people per vehicle) and destination selection (shelters, evacuation routes).

We use an agent-based *traffic simulator* to predict the movement of vehicles (and thus people) in each scenario. The particular simulator we use, SUMO, falls into the *microscopic* category in that individual vehicle dynamics are modelled explicitly. The simulator receives a set of *origin-destination-time* triples, one for each vehicle. It then computes a route for each vehicle before simulating their movements and interactions.

RISK EVALUATION

With the detailed results of the simulators we use, it is possible to derive more granular risk predictions. Specifically, we approximate the danger to a person by considering their proximity to the threat. We previously introduced a technique for computing the exposure count for an area or population. The basics of which follow.

We calculate the distance between a point $p \in \mathbf{R}^2$ and a threatened area $X_t \subset \mathbf{R}^2$ as $d(p, X_t) = \inf\{ f(p, a) : a \in X_t\}$, where f is the euclidean distance between two points. Both the threat and the position of each person will vary over time. We then define the *person-threat distance* (shown diagramatically in Figure 2) at time t as: $\xi_{it} = d(p_{it}, X_t)$ where p_{it} is the location of person i at time t. We obtain a minimum person-threat distance as $z_i = \min_t \xi_{it} T$. The *exposure count* for a population Q in a given scenario is the total number of people who were within some distance δ of the threat at some point in time, computed as:

$$E_Q = \Sigma H(\delta - z_i) \quad (1)$$

where $H(x) = 0$ if $x < 0$ otherwise $H(x) = 1$.

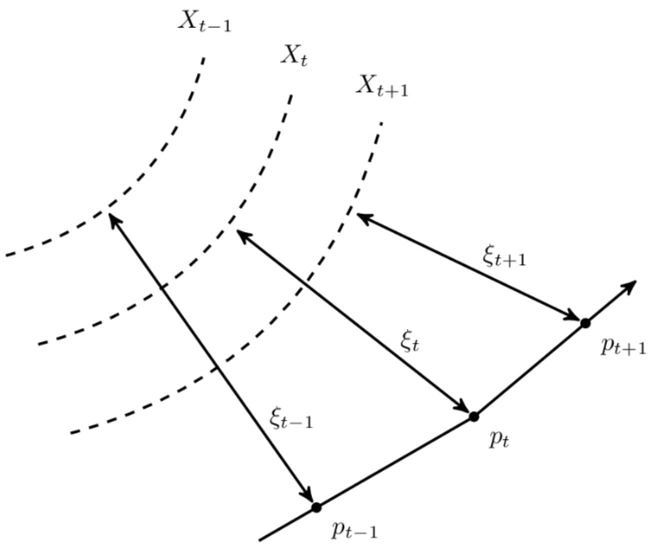

Figure 2: Person-threat distance. Note that in this figure we use $t - 1$ to denote 'the previous time-step' and omit the person index i for simplicity.

INTEGRATION PLATFORM

The internal design follows a Service Oriented Architecture (SOA) approach. The modelling, simulation and analytics components are each exposed as separate REST-based (Representational State Transfer) services. Data and execution flow is controlled by a workflow manager service, an orchestrator and a data-service. This separation into multiple web-services improves the ease and efficiency of development, testing, deployment, maintenance and scalability of the system.

An emphasis was placed on the composability and replaceability of services. To this end, all services are exposed through a standardized interconnect and designed around the abstract concept of a *job*. Also, a common framework was implemented and used across all services to handle job management, request processing and validation, data inputs and outputs.

New capabilities can be easily integrated into the system, and there is flexibility in the choice of modules (e.g., a different behaviour modeller service). More importantly, this is done with minimal impact to the REST interfaces of other services. We also achieve loose-coupling of components within the system by restricting links between components based on their data outputs and requirements, instead of pre-specified hard dependencies. This affords further flexibility and composition ease.

The workflow manager service is responsible for reactively driving the sequence of computations. It is charged with calling the various modelling, simulator and analytic services in the correct order, and ultimately informing the UI once computation is complete. An orchestrator manages a registry of services within the service composition system, and subscriptions to data-event notifications from other components. Finally, a data-service stores and serves all simulation outputs as they are generated.

USER INTERFACE

In order for this advanced modelling approach to be of practical value, it needs to be accessible to the people and organisations who must develop plans and make decisions to prepare for bushfire evacuations. Accordingly we have developed a web-based interface through which users can configure, execute and inspect evacuation scenarios. The user interface was built with the following objectives in mind:

- usable by a general audience with ten minutes of training,
- single click execution of full scenario simulation, and
- results should be returned within five minutes.

This interface is of value both during the planning activities carried out by emergency management organisations, and during community engagement campaigns. The use of dynamic visual scenario examples is a highly effective means of communicating the nature of the risk faced by residents. Accordingly, this tool helps to raise awareness and instigate greater responsibility among at-risk communities.

EXAMPLE USAGE

To further demonstrate the capabilities of our tool we now present a typical usage story.

1. User *A* opens the bushfire evacuation planning service in a standard web browser and sees the *scenario configuration* page. Here *A* can:
    - create and position one or more fire ignition points,

- create and position shelters, and adjust their radius of attraction (residents within the radius may then evacuate to the shelter),
- set environmental conditions (wind speed and direction, fire danger index), and
- inspect the local population distribution.

2. Once *A* has defined the initial conditions for a *scenario*, a simulation *job* can be submitted. This job enters a queue before the simulation begins under the guidance of the workflow manager service.

3. Upon completion of the job, a notification is delivered to *A* that the scenario results are ready for inspection

4. User *A* navigates to the results page for the newly completed scenario. Here *A* is presented with a regional break-down of the scenario outcomes. For each region there are estimates of the number of exposures and the time to evacuate for both local and through traffic.

5. On this page there is also time slider, which allows *A* to see the fire progression and the traffic conditions evolving over time. For the traffic, road segments are coloured according to the average speed of vehicle travelling over them within the current interval.

6. For each region more detailed statistics are also available. This includes a histogram of vehicle departures, and exposure counts. The histogram shows when people are leaving and often provides insight into the behaviour of evacuees. *A* can also see the number of shelter users originating from each region.

7. At any time *A* can configure alternate scenarios or variations on existing ones. In this way comparisons can be made and the impact of different factors can be assessed.

CONCLUSIONS

In this paper we have described a bushfire planning service for investigating the outcome of bushfire evacuation scenarios. The model builds on previous approaches by adding dynamic evacuation triggers (warnings and visibility) as determined by an evolving bushfire simulation.

The actions of evacuees have a dependency on their respective locations, relative to the threat, thereby enabling greater location sensitivity.

In addition, the combination of a microscopic traffic simulator with a dynamic fire spread simulator underpins the exposure count metric, which provides a direct estimate of the threat to a population in an evacuation scenario.

Finally, the approach we present is enabled by a model composition architecture. This architecture supports the seamless integration of modelling and simulation components in a way that is both efficient and scalable.

The work we have described is part of the *IBM Evacuation Planner* which is a decision support system targeted at emergency service personnel and community engagement groups. The system is currently designed for use in the planning stages of bushfire emergencies. Future work will consider the additional challenges of ingesting live data and generating real-time predictions.

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