

A Model of Wildfire Propagation Using the Interacting Spatial Automata Formalism

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“How (ceaselessly) heaven revolves! How (constantly) earth abides at rest! And do the sun and moon contend about their (respective) places? Who presides over and directs these (things)? Who binds and connects them together? Who is it that, without trouble or exertion on his part, causes and maintains them? Is it, perhaps, that there is some secret spring, in consequence of which they cannot be but as they are? Or is it, perhaps, that they move and turn as they do, and cannot stop of themselves?”

— Zhuangzhi, 4th century BC [1]

Abstract

In this thesis, I address the modelling and computer simulation of spatial, event-driven systems from a computer science perspective. Spatially explicit models of wildland fire (wildfire) behaviour are addressed as the specific application domain. Wildfire behaviour is expressed as a formal model and the associated simulations are compared to existing models and implementations. It is shown that the *interacting spatial automata formalism* provides a general framework for modelling spatial event-driven systems and is appropriate to wildfire systems. The challenge addressed is that of physically realistic modelling of wildfire behaviour in heterogeneous environments. Heterogeneous environments are natural and agricultural landscapes that vary spatially in fuel distribution, topography and meteorological conditions. Simulations of wildfire are important because they have the potential to save human lives and offer economic and environmental advantage through real-time prediction of fire spread and risk analysis. Many existing simulation models have known limitations in their ability to describe accurately known fire behaviour such as the shapes of fire fronts and the acceleration of spreading fires. The challenge of building physically realistic models of wildfire behaviour is to capture this behaviour.

The use of an interacting spatial automata formalism is a unique contribution to the science of fire modelling and simulation. Interacting spatial automata are specified using the *Circal process algebra* as a specification language, taking advantage of the rigour of the formalism's methods of abstraction and composition. This is significant because it allows a user of the formalism to build hierarchical models

of interacting components using locally determined timing, both of which are important features of the spatial structure of a natural landscape system. A new approach, creating discrete and hierarchical landscape patches, allows for the modelling of isotropy — that is, the circular spread of fire in calm, flat and homogeneous environments. Together, the hierarchical and irregular properties of the structure form an approximate model for the patchiness of real landscapes of fuel distributions. The introduction and use of this structure is novel for both wildfire modelling and generalised cellular automata methods.

A significant feature of the interacting spatial automata formalism that is useful in models of complex systems is the interaction-centric nature of the specification. Using Circal as a specification language, the formalism models the conduits through which interactions occur (connections) between components (cells) as explicit interactions using labelled events. The structure of an interacting spatial automaton extends the structure of generalised cellular automata, typically used to create discrete models of spatial systems. Using labelled connections between sets of cells, rather than just pairs, the formalism is better suited to building neighbourhood-based mechanisms of propagation. Many current models do not incorporate the influence of a neighbourhood (the geometry of the fire front local to an unburnt volume of fuel, for example), but rather determine the propagation of fire using only point information. Whilst neighbourhood-based influence of behaviour is common to cellular automata theory, its use is very rare in existing models of wildfire models.

In this thesis, I present the modelling technique and demonstrate its applicability to wildfire systems via a series of simulation experiments, where I reproduce known spatial wildfire dynamics. I conclude that the interacting spatial automata formalism is appropriate as a basis for constructing new computer simulations of wildfire spread behaviour. Simulation results are compared to existing implementations, highlighting the limitations of current models and demonstrating that the new models are capable of greater physical realism.

Preface

This work was completed in the years 2003 to 2006 at the University of Western Australia in Perth, Western Australia. Chapter 6 is an extended and updated version of an experiment-based paper published by Springer as a part of the Sixth International conference on Cellular Automata for Research and Industry October 25-27, 2004; a conference in Amsterdam that marked the one-hundredth anniversary of von Neumann's birth.

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Complex systems science is an inherently multidisciplinary field of research. I acknowledge the researchers of complex systems, who discover patterns in nature, discover novel ways of reproducing them in computer simulations and have the unenviable job of attempting to communicate their ideas and results in simple ways, despite the complexity of their subject. The best science is the kind that is simple enough to be understood by a diversity of people.

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