Australian Bushfire CRC Fire Simulation Model

George Milne, P.J. Johnston, J. K. Kelso

School of Computer Science and Software Engineering, University of Western Australia
Research Challenge:

- “better” simulations: more physically realistic
- “faster” simulations: complete simulation runs in a few minutes
- trade off: accuracy versus performance
- all simulations are abstractions / approximations of real world
Bushfire simulation - components
<table>
<thead>
<tr>
<th><strong>Cell based simulation</strong></th>
<th><strong>Fire line propagation</strong></th>
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<tbody>
<tr>
<td>Both methods are valid</td>
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<td>Landscape is divided into small pieces, usually of equal area that represent the fuel, topography and fire state (unburnt, burning or burnt) through time.</td>
<td>The position of the burning front is propagated through time.</td>
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<td>Cell approach has traditionally had difficulty producing realistic fire shapes.</td>
<td>Fire line propagation can be inefficient because of the need to propagate the entire fire front at regular short intervals.</td>
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<td>Complex algorithms are required for handling the situation where different parts of the fire front converge.</td>
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Irregular grids remove grid bias

- All simulation models are an abstraction of the physical world
- Regular grids have traditionally been used because of the ease of data import and computer programming
- Regular grids introduce bias aligned with the grid orientation which is the same everywhere.
- Irregular grids also introduce bias but the bias is different at each location and over a moderate sized region, cancel out.
- A more sophisticated computational model is required to implement irregular grids.
PROGRAM A : BushfireCRC Fire Simulation Model

Regular grid

Irregular grid
Fire spread by propagation delay

1. Each cell/patch has approximately 6 neighbours

2. When a patch is ignited, the patch’s fuel type, moisture, wind speed and direction and the appropriate fire behaviour model are used to calculate the head fire rate of spread

3. The distance and direction to each neighbour determine the time it takes to ignite each neighbour from the current patch.
Patch states

1. At any given time, each patch is in one of the three states: unburnt, burning or burnt.

2. Ignition changes the state of unburnt patches that contain fuel to burning (e.g. a patch that contains only water remains unburnt).

3. When a patch is ignited, ignition of each of its unburnt neighbours is scheduled.

4. A patch remains burning from the time of ignition for a period equal to the diameter of the patch divided by the rate of spread.

5. Burnt cells cannot be re-ignited.
Each patch has
- location
- fuel characteristics (static)
- fuel moisture (dynamic)
- neighbour list (distance & direction)
Efficiency

1. The BushfireCRC fire simulator is a *Discrete Event Simulator*.
2. Instead of propagating the entire fire front at given time steps, the ignition of each patch occurs in a time-ordered sequence.
3. The number of ignition events for a simulation is proportional to the number of patches involved regardless of the fuel or weather.
4. A fire front simulator advances the entire fire front at each time step. The time step must be chosen small enough that the fastest moving part of the fire is accurately modelled. Rates of spread can vary by a factor of at least 100 (e.g. head fire versus backing fire), so much of the fire front is advanced in many small steps when a single step should suffice.
5. A fire front simulator also needs to check for overlap of converging fire fronts, whereas the cell approach simply ignores the attempted ignition of an already burning patch.
A Discrete Event Simulator steps from event to event
Mt Cooke Fire, WA, 9-11 January 2003
(courtesy of Department of Environment and Conservation, WA)

### Details on Fire Conditions and Fire Behaviour

1. **Origin** - Lightning strike at about 9:50 pm on 9th January 2003 on top of steep rocky hill top, 1km south of Millars Log Road
2. **About 30 Hectares burnt in about 8 hours overnight within steep, and inaccessible terrain.**
   Rate of Spread about 80 m/hr with 3 - 4 metre flames.
3. **Fire rapidly accelerates after 8:00am driven by hot, dry NW winds 30 Km/hr. Rate of Spread ranges from 500-1000 m/hr burning in 15 year old fuels.**
4. **Fire crosses power line at 12:20 pm on 10th January 2003, moving at 2500 m/hr, 15-25 metre flames, and spotting about 1-2km ahead of main fire.**
   Air temperature 35°C, Minimum Relative Humidity 20%, Fuel Moisture 3%.
5. **Complete defoliation resulting from fire intensity of about 75,000 kw/hr in 17 year old Jarrah fuels.**
6. **New fire resulting from spot fire about 8 km downwind from main head fire.**
7. **Fire intensity reduced from 75,000 to about 15,000 kW/hr as fire moves out of 17 year old into 7 year old fuels. Note the reduced level of defoliation & scorched evident on satellite image.**
8. **Spot fires blown into the 3 year old patchy prescribed burn were allowed to burn out to tracks at low intensity.**
9. **Fire driven by westerly winds moves from 10 year old fuels into 23 year old fuels with a subsequent increase in fire intensity.**
10. **At 5:00am on 11 January 2003, headfire (10 m flame height) runs into 5 year old fuels and is dramatically reduced in intensity and rate of speed. Ground forces undertake successful direct attack on headfire.**
MOUNT COOKE FIRE, WESTERN AUSTRALIA 9 - 11 JANUARY 2003

Details on Fire Conditions and Fire Behaviour

1. Origin - Lightning strike at about 9:50 pm on 9th January 2003 on a hilltop south of Millars Dam Road.
2. Area burned - About 100 hectares burned in about 8 hours, mostly within a 10-km radius of the origin.
3. Rate of spread - 45 to 50 km/h, burning in 15-year-old forests.
4. Fire behaviour - Spotting occurred at 10:20 pm on the morning of 10th January, burning at 250 km/h.
5. Fire intensity - About 75,000 kW/h per hectare.
6. Consequences - No loss of life or property.

Fire behaviour was dominated by spotting and uncontrolled spread.

1. Fire intensity was reduced to about 5,000 kW/h.
2. Spots from the fire were burning at a rate of 30 km/h.
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18. Fire behaviour was dominated by spotting and uncontrolled spread.
Simulation of Mt Cooke fire: Input data

- Northern Jarrah fuel type with fuel loads calculated from time since previous fire (Red book)
- Surface Moisture Content versus time (calculations by L. McCaw, DEC)
- Wind speed versus time from weather station away from fire ground multiplied by a single scale factor
- Wind direction inferred from fire shape.
- Ignition at 4 am 10 Jan, plus spot fire at 12 noon
- Topography
Simulation with observed wind speed x 1.25
Simulation with observed wind speed x 1.3
PROGRAM A: BushfireCRC Fire Simulation Model

Simulation with observed wind speed x 1.3, and all fuel 15 years old
Regular grid
8 neighbours

Irregular grid
Lessons learnt from simulation of Mt Cooke fire

• Each simulation took around 1 second to run for patches of approx. 250 m diameter
• A small increase in wind speed causes a large increase in area burnt
• Reduced fuel load due to prescribed burns contained the fire on the northern flank
• The BushfireCRC simulator reproduces fire spread with slight modification of input data
• Red book possibly under-predicted ROS for this fire?
Conclusions

1. Simulator is fast
2. Irregular grid provides accurate fire shapes
3. Initial validation is promising
4. Rapid simulation allows us to consider applications involving multiple simulations allowing for the uncertainty in the input data (forecast weather, fuel moisture model, fire behaviour model, probabilistic spotting model)
5. Further development required on user interface, data import, inclusion of spot fire model
UWA Bushfire Simulator: approach we would like to take.

- use an underlying heat transfer mechanism
- generate, transport, consume heat quanta
- occurrence of discrete heat transfer events between discrete landscape patches
- burning patches generate heat
- unburned neighbours consume heat

heat then transferred from hot to cold (2nd Law)
Why this Approach?

- mechanism underpinned by physics of thermodynamics
- builds on our modelling and simulation experience with *interacting concurrent systems*
- allows for development of tractable mechanism for fire/atmosphere interaction
- computational efficiency via *discrete event simulation*

But .............