Wildfire Spreading Model using a Parallel Implementation of Cellular Automata

Advanced Applied Parallel Programming

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Outline

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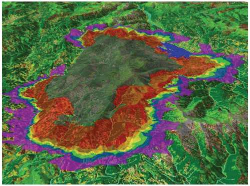

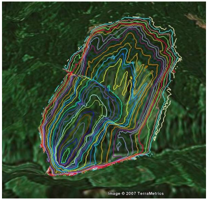

Outline

1. Introduction
2. Problem
   - Formalization
   - Solution
3. Results
   - Evaluation
   - Validation/Discussion
   - Conclusion
   - Future Work

Formalization

Problem

Build a suitable model to be incorporated into a video-game-based simulator to allow assessment of decision making during wildfire combat involving different agencies which are part of the response system in Chile.

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- To include the dynamic component, it was necessary to enhance the computation of the model with parallel computing techniques.

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- **Topography**: It influences over the two above factors, the fuel and weather, modifying or altering them.

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  - Transition Function: $F : DW \rightarrow S$ where,

Solution

DW is a discretized world that contains states S, temperature T, humidity H, wind speed W_s and direction W_d, fuel C and the probability threshold of change from state a to b F_{ab}. All this variables are matrices with values between 0 to 1.

Solution

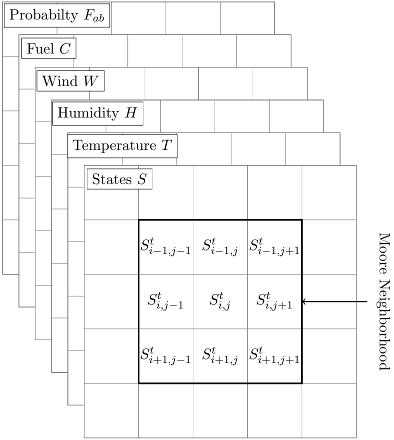

Figure: Discrete World DW.

Solution

Formally, we define the transition as

$$S_{i,j}^{t+1} = \begin{cases} 2, & \text{if } S_{i,j}^{t} = 1 \text{ and } f_{12} \geq F_{12} \\ 2, & \text{if } S_{i,j}^{t} = 4 \text{ and } f_{42} \leq F_{42} \\ 3, & \text{if } S_{i,j}^{t} = 2 \text{ and } f_{23} \leq F_{23} \\ 4, & \text{if } S_{i,j}^{t} = 3 \text{ and } f_{24} \leq F_{24} \end{cases}, \tag{2}$$

where functions f are defined by

Solution

- Function f_{12}:
  - The environmental factors E:

$$E_{i,j} = \frac{W_{d_{i,j}}\ C_{i,j}\ T_{i,j}\ W_{s_{i,j}}}{H_{i,j}\ P_{i,j}}. \tag{3}$$

  - The burning states of neighborhood $p(N_b)$:

$$p(N_b)_{i,j} = \frac{N_b}{8}, \tag{4}$$

  where N_b is the number of burning state neighboring cells.

  Then, f_{12} is computed by

$$f_{12} = \alpha\ E_{i,j} + \beta\ p(N_b)_{i,j}. \tag{5}$$

- Functions f_{23}, f_{24}, f_{42} are random values between 0 and 1 and F_{23}, F_{24}, F_{42} are threshold parameters.

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- The development of the algorithm needs to perform a tessellation of the area to be simulated, where each cell represents the state of a square portion of the terrain.
- The model works with a world discretized by layers (DW), where each layer contains the information of the components described before.

Algorithm

Algorithm 1 Main Algorithm

$S^0 \leftarrow$ Initialize cell's states.
$DW \leftarrow$ Initialize discrete world.
for $t = 0$ to T_{max} **do**
  $S^{t+1} \leftarrow spreading(S^t, DW)$
end for

Algorithm

Algorithm 2 Spreading Algorithm

procedure SPREADING(S^t, DW)
  $N \leftarrow$ number of rows in DW
  for $i = 0$ to $N_{threads} - 1$ **do**
    $delta \leftarrow N/N_{threads}$
    $start \leftarrow i \cdot delta$
    if $i = N_{threads} - 1$ **then**
      $end \leftarrow N$
    else
      $end \leftarrow (i + 1) \cdot delta$
    end if
    $S \leftarrow subSpreading(start, end, S^t, DW)$
  end for
  for $i = 0$ to $N_{threads} - 1$ **do**
    Thread's join
  end for
  return S
end procedure

Algorithm

Algorithm 3 Sub-spreading Algorithm

procedure SUBSPREADING($start, end, S^t, DW$)
  $N \leftarrow$ number of columns in DW.
  for $i = start$ to end **do**
    for $j = 0$ to N **do**
      Compute $S^t_{i,j}$ using equation (2) with S^t and DW.
    end for
  end for
  return $S^t_{i,j}$
end procedure

Algorithm

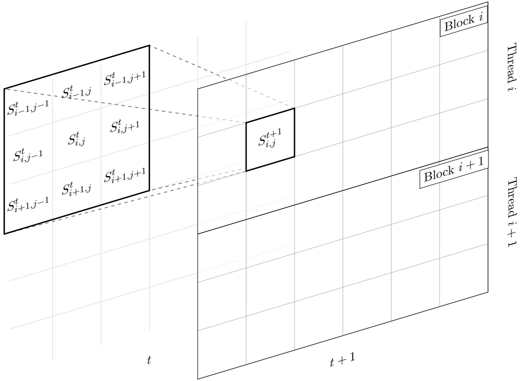

Figure: *SubSpreading* computing a matrix block.

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- If we choose $T_{max} << N$ the complexity is about $O(N^2)$, but it may change a lot if $T_{max} \sim N$ increasing the complexity to $O(N^3)$.
- This is the main motivation of to include the use of threads in the computing of the model.

Evaluation

The experiments were made using a fixed $T_{max} = 50$, for 1 to 4 number of threads, repeating the simulations 10 times per N.

Table: Summary of the average times in seconds.

Threads	$N = 100$	$N = 500$	$N = 1000$	$N = 1500$
1	0.198	8.023	32.861	72.464
2	0.135	5.147	19.695	44.407
3	0.163	4.825	18.852	41.626
4	0.220	4.650	18.055	41.458

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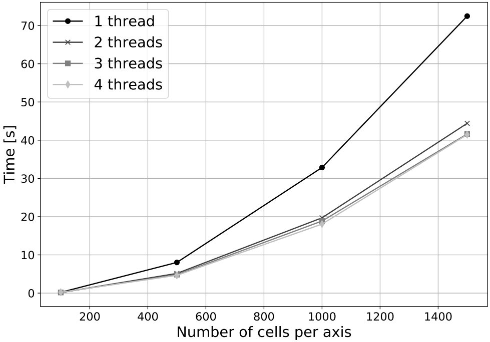

Figure: Threads' performance comparison.

Evaluation

Table: Speedups results.

Threads	$N = 100$	$N = 500$	$N = 1000$	$N = 1500$
2	1.47	1.56	1.67	1.63
3	1.21	1.66	1.74	1.74
4	0.90	1.73	1.82	1.75

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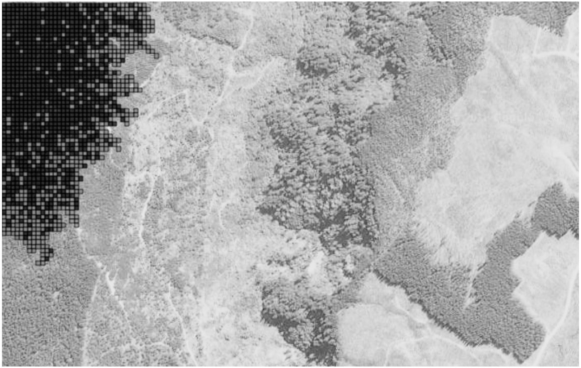

Figure: piece of map simulated for $N = 1500$, $T = 30°\mathrm{C}$, $H = 50\%$, $W_s = 40$ km/hr, $W_d = 90°$, $P = 50$ hPa, $F_{23} = F_{24} = F_{42} = 0.1$..

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- The main problem with wildfire models based on differential equations is the computational cost associated with the resolution of the system of equations.
- The complexity of the models is related to the realism and dynamism they have.

Conclusion

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- The incorporation of parallel techniques allows the model to compute enough states in discrete times to show a qualitatively realistic result for the specialists' requirements.
- The use of multithreads is a good strategy to apply to this problem given the characteristics of the discrete world and the independence of states between the times t and $t + 1$.
- Model complexity is smaller in comparison to the classical methods based on differential equations.

Future Work

- Work with more solid components, or finer granularity in some cases, for the core characteristics of the wildfire dynamics, such as the topographic and fuel components.

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- Use a parallel architecture of the pipeline type, taking advantage of the refresh rate in the interface of the simulator.

References I

CONAF (2013). Incendios forestales en chile. http://www.conaf.cl/incendios-forestales/incendios-forestales-en-chile/. Online; accessed 25 November 2017.