Wildfire Spreading Model using a Parallel Implementation of Cellular Automata

Advanced Applied Parallel Programming

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INTRODUCTION

- Wildfires are one of the most harmful phenomena in Chile.

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- Fires may start by varied reasons, ranging from reckless human behavior to extreme weather and environmental conditions.
- Around 50000 hectares are burnt yearly, and in certain occasions up to 100000 hectares (CONAF, 2013).
- Fire spreading dynamics has gathered large attention from the scientific community.
- Wildfires are modelled using continuous or discrete models, or a combination of both.

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   - Formalization
   - Solution

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To 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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- The fire model was constructed integrating environmental factors, forest fuel, topography with a discrete model based in Cellular Automata (CA) which interact and evolve in discrete time steps.

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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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- **Cellular Automata**

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- **Cellular Automata**
    - Spatial Dimension: We used a 2D spatial dimension based on a grid of size $M \times N$. Each cell is located over the grid in positions (i, j).

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  - Neighborhood: This CA model use the Moore Neighborhood, defined as

$$N^M_{(i_0, j_0)} = \{(i, j) : |i - i_0| \leq r, \ |j - j_0| \leq r\}. \qquad (1)$$

  for a cell (i_0, j_0) in a radius $r = 1$.

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

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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.
Formally, we define the transition as

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

where functions f are defined by

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

$$E = \frac{a \ C \ T \ W_s}{H \ P}. \tag{3}$$

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

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

  where N_b is the number of burning state neighboring cells.

  Then, f_{12} is computed by

$$f_{12} = \alpha \ E + \beta \ p(N_b). \tag{5}$$

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

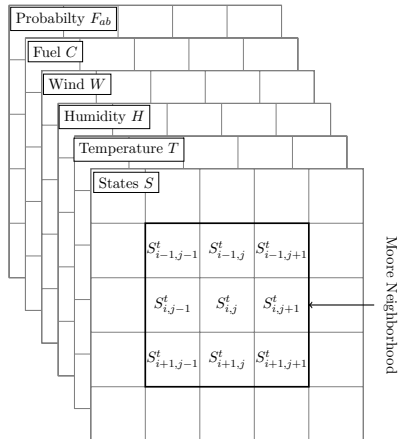INTRODUCTION
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FIGURE: Discrete World.

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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.

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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.

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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

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Algorithm 2 Spreading Algorithm

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procedure SPREADING(S^t, DW)

    $N \leftarrow$ number of columns 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**

            $end \leftarrow$ number of rows in DW.

        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

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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 **??** with S^t and DW.

        end for

    end for
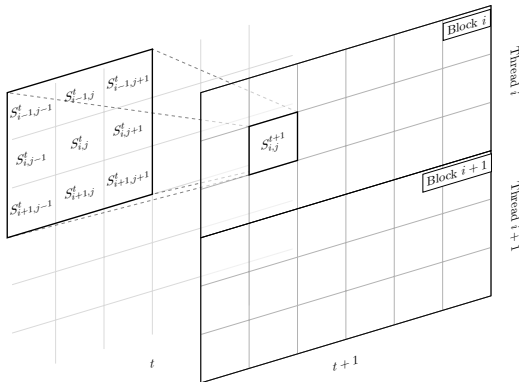
    return $S^t_{i,j}$

end procedure

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FIGURE: *SubSpreading* computing a matrix block.

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EVALUATION

- Using a square grid of size $N \times N$ and defining the maximum number of discrete times T_{max} we estimate a computational complexity of $O(T_{max} \cdot N^2)$.

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- Using a square grid of size $N \times N$ and defining the maximum number of discrete times T_{max} we estimate a computational complexity of $O(T_{max} \cdot N^2)$.

- 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 $O(N^3)$.

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- Using a square grid of size $N \times N$ and defining the maximum number of discrete times T_{max} we estimate a computational complexity of $O(T_{max} \cdot N^2)$.
- 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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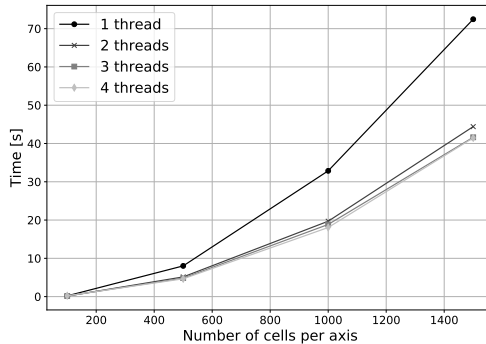
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FIGURE: Threads' performance comparison.

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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

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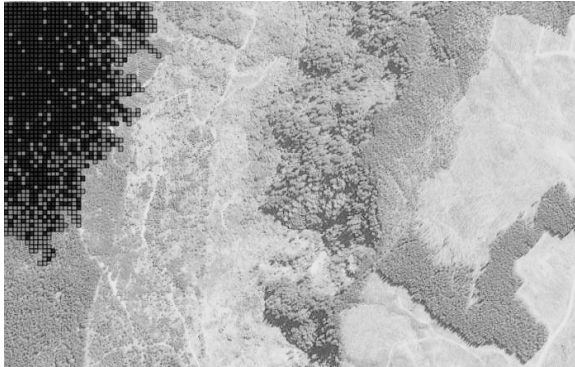
FIGURE: piece of map simulated for $N = 1500$, $T = 30°C$, $H = 50\%$, $W_s = 40$ km/hr, $W_d = 90°$, $P = 50$ hPa, $F_{23} = F_{24} = F_{42} = 0.1..$

VALIDATION/DISCUSSION

- The wildfire dynamics generated with the prototypes are consistent with what CONAF has observed in past devastating wildfires occurring in Chile

CONCLUSION

- 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.

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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 $t + 1$.

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

References I

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`incendios-forestales-en-chile/`. Online; accessed 25
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