# Wildfire Spreading Model using a Parallel Implementation of Cellular Automata

## Advanced Applied Parallel Programming

Daniel San Martín

Departamento de Informática
Universidad Técnica Federico Santa María

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# Outline

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

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- 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

## Problem

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

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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.
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

# Solution

- 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.

# Solution

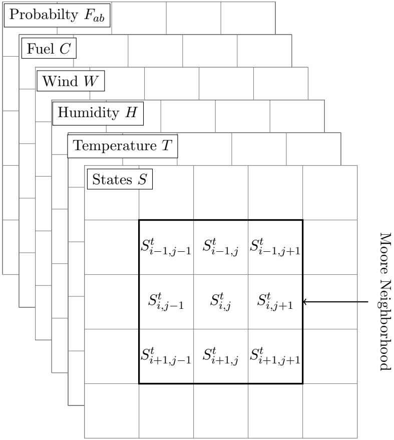


Figure: Discrete World.

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- 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 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**

# 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 **??** with $S^t$ and $DW$.
    **end for**
  **end for**
  **return** $S^t_{i,j}$
**end procedure**

# Algorithm

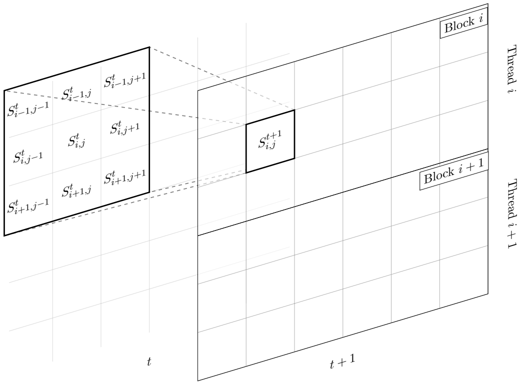


Figure: *SubSpreading* computing a matrix block.

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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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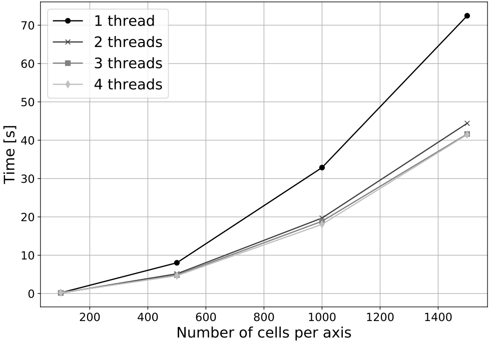


Figure: Threads' performance comparison.

# 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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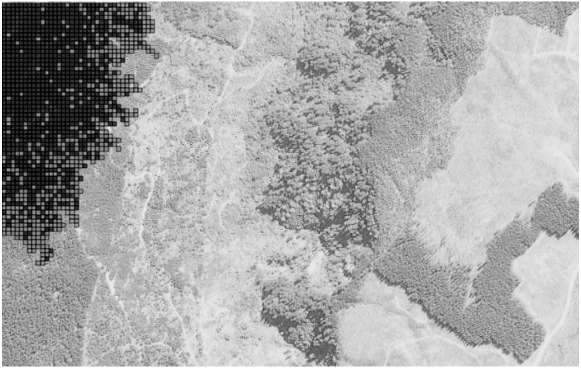

Figure: piece of map simulated for $N = 1500$, $T = 30°\text{C}$, $H = 50\%$, $W_s = 40$ km/hr, $W_d = 90°$, $P = 50$ hPa, $F_{23} = F_{24} = F_{42} = 0.1$..

# 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 $t + 1$.
- 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.