Wildfire Spreading Model using a Parallel Implementation of Cellular Automata

Advanced Applied Parallel Programming

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Outline

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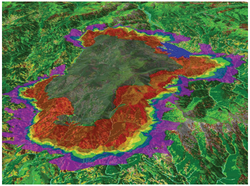

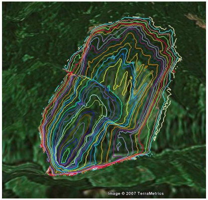

Outline

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

Formalization

Problem

The integration of factors involved on wildfires is costly computationally.

Solution

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Construct a simulation model based on Cellular Automata which it allows decomposing the computations in order to map tasks to threads.

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- A parallel computing approach is introduced to reduce the execution time (more realistic simulations).

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

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

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

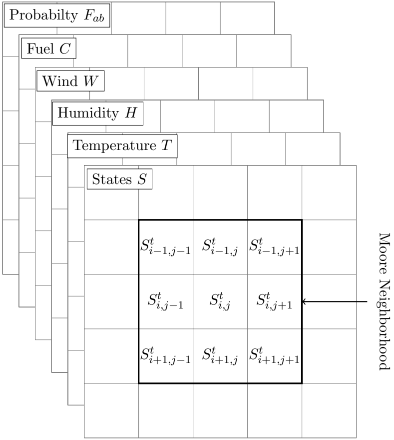

Figure: Discrete World (DW).

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.
- Model evolves in discrete times.

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
    $S_{start:end,\cdot} \leftarrow subSpreading(start, end, S^t, DW)$
  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 $S^t_{start:end,\cdot}$
end procedure

Algorithm

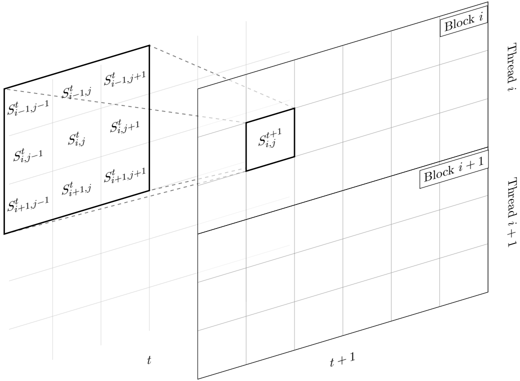

Figure: *SubSpreading* computing a matrix block.

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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 for including 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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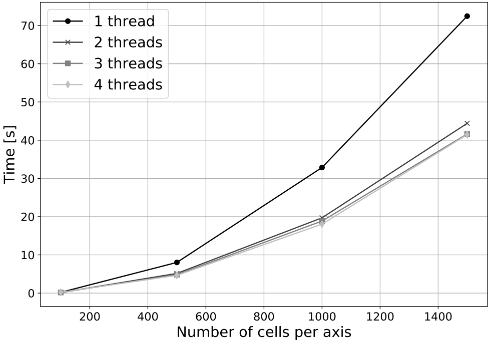

Figure: Threads performance comparison.

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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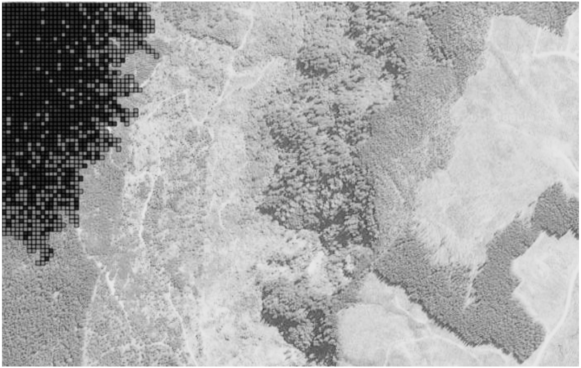

Figure: A portion of map simulated for $N = 1500$, $T = 30°C$, $H = 50\%$, $W_s = 40$ km/hr, $W_d = 90°$, $P = 50$ hPa, $F_{23} = F_{24} = F_{42} = 0.1$.

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- The wildfire dynamics generated with the prototypes are consistent respect to the past events reported by CONAF.
- The complexity of the model exhibits a direct relationship between realism the amount fire factors.

Conclusion

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- According to model features, assign tasks to threads is an effective approach for reducing the execution time.
- Respect to the EDP-based models, the Cellular Automata exhibits a favorable trade-off between the fire factors and the model complexity.

Future Work

- Increase the resolution of the simulated area in order to improve the model approximation.

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- In order to take advantage of computation of several contiguous CA states, implementing a parallel approach based on pipeline.

References I

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