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Fire spread simulation using cellular automata in forest fire

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Abstract. Forest fires are adverse events both economically and mentally. Triggers of fires are complex variables so that the spread of fire to date has not been predicted. Modeling is one solution to study the process of spreading fire. The Cellular automota was used to simulate the spread of fire in forest fires. Simulations carried out with simulations carried out by varying the value of burnability. burnProbability is a value that shows the probability of a tree burning. The value of burnability used is 10%, 20%, 30%, 40%, 50%, 60%, 70% and 80%. From each burnProbability value, the percentage of forest that is burned is calculated. The simulation was carried out for 17 iterations for each burnProbability value. The results of the average is the greater the value of burnProbability, the greater the percentage of burned forest. When the burnProbability value of 80% of the burned forest is almost entirely, it is 97.23183%.

1. Introduction

Forest fires are natural events that can occur naturally or intentionally. Natural factors are usually caused by high temperatures and the presence of minerals such as coal, oil or natural gas and triggered by the friction of branches and dry tree branches, while the intentional factor is humans who intentionally burn forests[1]. Until now, the spread of fire during forest fires cannot be predicted with certainty, because there are many variables in the trigger factors of fires. The trigger factors that play a role in the process of fires are fuel, humidity, wind, and slope of the land or slope [2]. Forest fires often occur in Indonesia, especially during the dry season. Fires that have occurred in Indonesia have a detrimental effect if they are not properly anticipated. In 1997 during the Elnino disaster, forest fires burned around 25 million hectares of forest land around the world, and Indonesia in 1997 was the country that experienced the most severe forest fires [1].

Model is a representation of a real system. Complex system studies can be carried out using modeling [3]. Forest fires are one example of a complex problem. The spread of fire and smoke is a complex phenomenon caused by chemical reaction and physical processes [3]. The computational method is progressing, so that the problem of the distribution of fire can be modeled. Cellular Automata is a computational method that can be used to model the phenomenon of forest fires[4]

Basically, there are two types of computational simulation methods used for the spread of fire and smoke: a) the Computational Fluid Dynamics (CFD) modeling method that resolves the basic equations of physical processes and clams [5]; and b) Celullar Automata (CA) which is a modeling method based on probabilitic transition rules between states [6][7].

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2. Cellular Automata

Cellular automata are dynamic systems operating discrete in space and time, on a uniform, regular lattice and characterized by "local" interactions. Cellular Automata were invented by the mathematician Stanislaw Ulam and were used by J. von Neumann, followed by A.W. Burks and E. F. Codd, to solve problem of the non-trivial self-reproduction in a logical system [8]. A cellular automata is defined by a grid with start states and set of rules for state transitions.

Generally, cellular automata consist of four elements, which could be considered as a tuple (X, S, N, f):

a) X are cells which are objects in any dimensional space, we can call this cellar space. In cellar space, each cell has the form $x=(x_1, x_2, x_3, .., x_m)$,where m is the dimension of the space. All cells have some forms of neighborhood.
b) S is a nonempty finite set of automaton states. Each cell can take on only one state at any one time from a set of states, $s \in S$. Strict CA also requires state variables to be discrete.
c) Neighborhood Template N - the state of any cell depends on the states and configurations of other cells in the neighborhood n of that cell. In two-dimensional space, there are two well-known templates, von Neumann or 5 cell neighborhood.
d) f is state transition function rule [9]

3. Forest model

The area of spreading fire in the forest is modeled with a 17x17 size matrix. Representation of forest models as shown in Figure 1. Each cell represents the conditions that occur in it. Possible circumstances are having values 0, 1 and 2. Each value indicates the condition of the tree in the cell. A value of 0 (Empty) represents that the cell is empty or there are no trees in it. The value of 1 (Tree) represents that in the cell there is a tree that is not burned. The last possibility is the value 2 (Burning) which represents that the cell contains a burning tree.

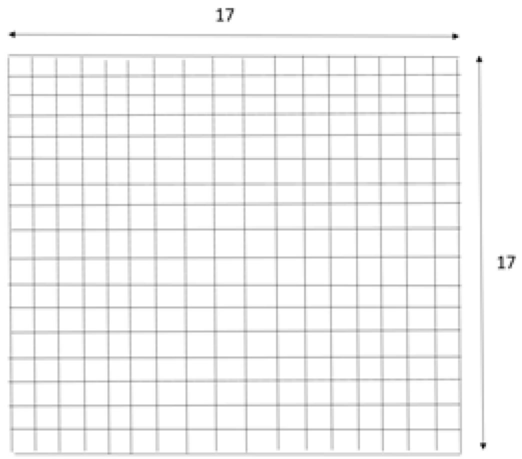


Figure 1. Cell representation in 17x17 size matrices

The initial condition of the system has 2 opportunities, namely probTree and probBurning. The opportunity for a tree to be located in a cell is expressed by probTree, while probBurning states the chance for a tree to burn if there is a tree in the cell. So the presentation of the tree that burned at the beginning of the simulation was stated by probBurning

4. Neighborhood Von Noumann

Neighboring cells in 2-dimensional form are represented using Von Neymann Neighborhood. A neighbor cells are cells that are located in the North, South, West and East and these cells. One cell has four neighbors. As shown in Figure 2. one cell has North, South, West and East neighbors.

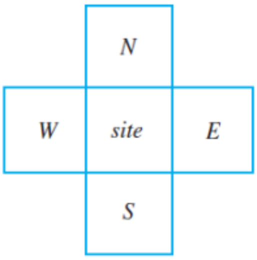


Figure 2. Von Neumann Neighborhood's representation of a cell.

The rule for the spread of fire based on Von Noumann Neighborhood is that trees can burn when their neighbors burn. If a cell is worth 0 (Empty) at time t, then at time t + 1 the cell also remains worth 0 (Empty). If a cell is worth 1 (Tree) at time t, then when t + 1 tree in the cell can burn or not at time t + 1, this depends on the neighboring cell there is fire or not. Cells that have a value of 2 (Burning) represent that in the cell loading the burning tree at time t will always burn out, so that at time t + 1 the cell will be worth 0 (Empty).

5. Periodic Boundary Condition

The spread of fire has rules that can be applied to every cell, including cells whose position is at the matrix boundary. Cells located in the first and last row, the first and last columns must also be burned. This is contrary to Von Neumann Neighborhood's rule because cells located at the matrix boundary have no neighbors. So to overcome the problem of the rules of spread, it is necessary to add one or two cells at each boundary called the boundary expansion.

In Figure 3 shows the geometry built on the model. Area A is the observation area which is a 17x17 sized matrix. Area B is the area used in the simulation. Region C is the area used for Periodic Boundary Condition. The area of the Periodic Boundary Condition as shown in Figure 4. Conditions that occur in cells located at the boundary of the matrix will affect the conditions that are at the boundary of the matrix that is located across. Iteration is done 17 times.

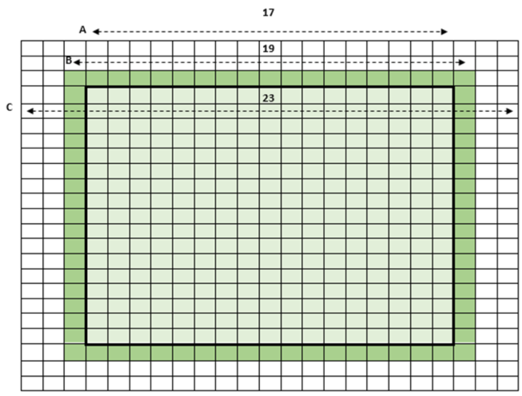


Figure 3. Model Geometry

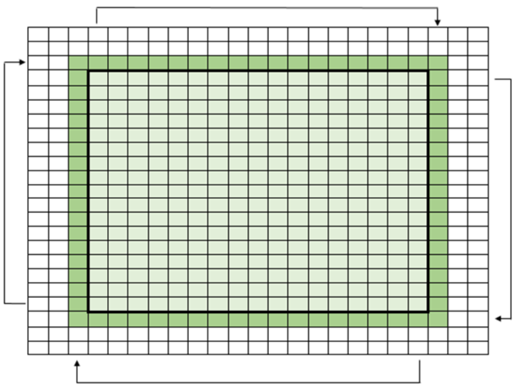


Figure 4. Periodic Boundary Condition

The location of the neighbors of each cell is shown in Figure 5. If a cell with coordinates (i, j) then the cell has 4 for the neighbor. The East neighbor is in the coordinate (i, j + 1), the South neighbor is at the coordinate (i + 1, j), the West neighbor is at the coordinate (i, j-1) and the North neighbor is at the coordinate (i -1, j). The fire spreading algorithm can be shown as in Figure 6.

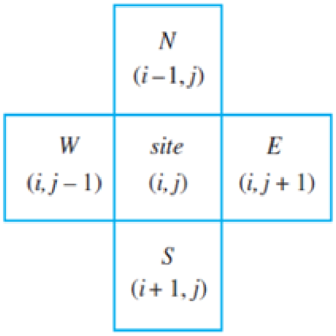


Figure 5. The cell Neighborhood geometry

```
Inisialisasi:
    EMPTY = 1 ; TREE = 2; BURNING = 3;          ← States
    N = 17                                      ← grid length and weight
    T = 17                                      ← total iteration
    forest(N,N);                                ← matriks (forest)
    forest(:,:) = TREE                          ← initial state
    forest(9,9) = BURNING                       ← fire source (9,9)
        burnProbability = 0.8                   ← burn probability (0.1,0.2,…,0.8)
    t = 0                                       ← initial condition t

while t < T

    for j = 2 to N-1
      for i = 2 to N-1
        site = forest(i,j)

        if site == EMPTY
              nextStep(i,j) = EMPTY
        elseif site == BURNING
              nextStep(i,j) = EMPTY
        else
          if NORTH==BURNING or EAST==BURNING or SOUTH==BURNING or WEST==BURNING
              if rand() < burnProbability
                     nextStep(i,j) = BURNING
              else
                     nextStep(i,j) = TREE
              end
          else
              nextStep(i,j) = TREE
          end
        end

      end
    end
    forest = nextStep

    Do Periodic Boundary Conditions             ← Periodic Boundary Conditions
    t = t+1
End

Count the burning area                          ← Percentage the burning area
terbakar
Plot matriks forest                             ← Plot matriks
```

Figure 6. Fire spreading algorithm

6. Results and Discussion

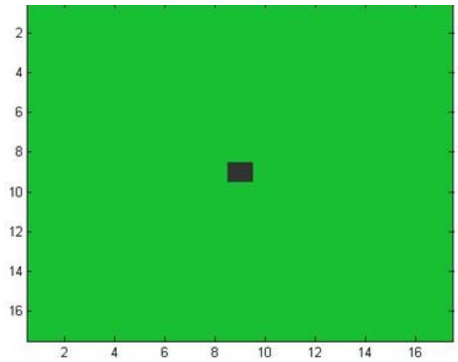
After the model was formed, simulations of the spread of fire in forest fires were conducted using the Cellular Automata method. Simulation is done by varying the value of burnProbability. burnProbability is a value that shows the probability of a tree burning. The value of burnProbability used is 10%, 20%, 30%, 40%, 50%, 60%, 70% and 80%. From each burnProbability value, the percentage of forest that is burned is calculated. The simulation was carried out for 17 iterations for each burnProbability value.

Figure 6(a) is a simulation result for the spread of fire with a 10% burnProbability value. It can be seen that the tree burned a little and only near the source of the fire. The percentage of burning forest with a 10% burnProbability value is 0.34602%. Figure 6(b) is the result of a fire spread simulation with a 20% burnProbability value. There are also not many burning trees, but more than Figure 6(a). The percentage of burning forest with a 20% burnProbability value is 0.69024%.

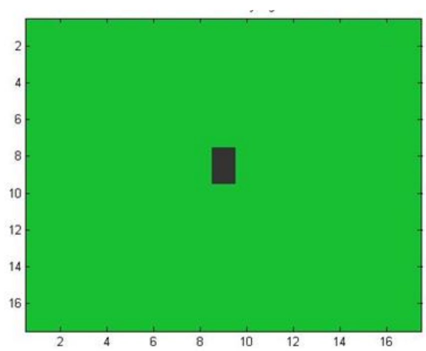
Figure 7(a) is a simulation result for the spread of fire with a 30% *burnProbability* value. It appears that more trees are burning. The percentage of forest burned with a 30% *burnProbability* value is 1.0381%. Figure 7(b) is the result of simulating the spread of fire with a 40% burnProbability value. Trees that burn more when compared to 30% burnProbability. The percentage of forest burned with 40% burnProbability is 0.3841%.

Figure 8(a) is a simulation result for the spread of fire with a 50% burnProbability value. It is seen that the trees that burn more and more when compared to before, but the location tends to be around the fire source which is located in the center of the matrix. The percentage of burning forest with a 50% burnProbability value is 8.3045%. Figure 8(b) is the result of a fire spread simulation with a 60% burnProbability value. The more burned trees and the direction they spread. The percentage of burned forest with a 60% burnProbability value is 74.0484%.

Figure 9(a) is a simulation result for the spread of fire with a 70% burnProbability value. It is seen that more and more trees are burned and spread throughout the forest. The percentage of forest burned with a 70% burnProbability value is 91.3495%. Figure 9(b) is the result of a fire spread simulation with an 80% burnProbability value. More and more trees are burned and almost all of the forest is burned. The percentage of burned forest with a 20% burnProbability value is 98.6159%. Of all the BurnProbability, which has the largest percentage of burning forest, the value is 80%. The greater the burnProbability, the more the forest will burn. This is because the more likely a tree is burning.

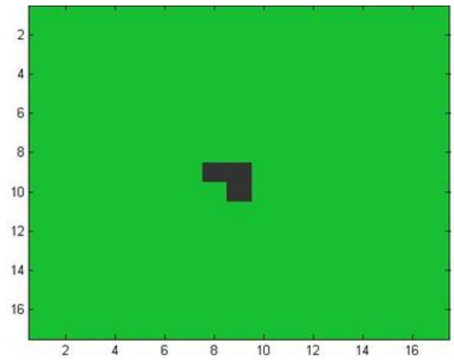


(a)

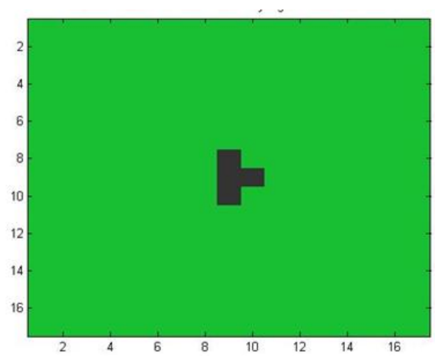


(b)

Figure 6. Fire spread simulation (a) *burnProbability* 10% (b) *burnProbability* 20%



(a)



(b)

Figure 7. Fire spread simulation (a) *burnProbability* 30% (b) *burnProbability* 40%

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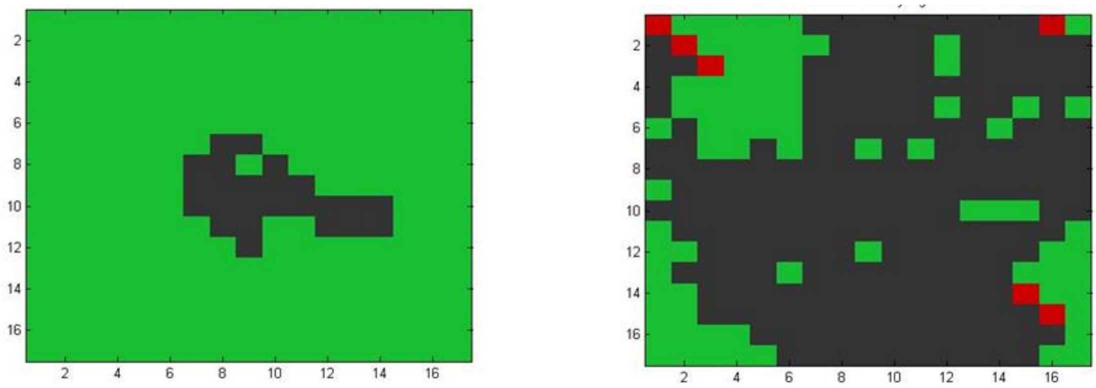
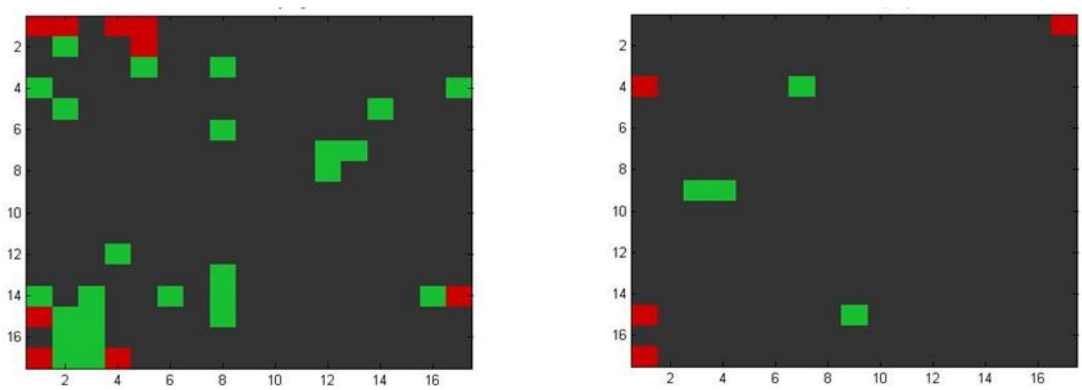


(a) (b)

Figure 8. Fire spread simulation (a) *burnProbability* 50% (b) *burnProbability* 60%



(a) (b)

Figure 9. Fire spread simulation (a) *burnProbability* 70% (b) *burnProbability* 80%

Each *burnProbability* value is simulated 10 times. The simulation results for each BurnProbability are shown in Table 1. Furthermore, the value is calculated on average as shown in Table 2. From the results of the average it can be seen that the greater the value of burnProbability, the greater the percentage of burned forest. When the burnProbability value of 80% of the burned forest is almost entirely, it is 97.23183%.

Table 1. Table of percentage of forest fires

Trial	***burnProbability***							
	10%	20%	30%	40%	50%	60%	70%	80%
1	0.34602	0.69204	0.34602	11.4187	3.1442	51.9031	87.8893	98.2699
2	0.34602	0.34602	0.34602	7.2664	41.5225	82.3529	91.3495	96.1938
3	0.34602	2.4221	6.5744	1.7301	11.0727	65.7439	93.4256	98.2699
4	0.34602	2.4221	2.0761	1.7301	41.5225	64.7059	94.4637	98.9619
5	0.34602	1.7301	1.0381	0.34602	12.8028	73.7024	89.6194	97.2318
6	0.34602	1.7301	0.34602	3.4602	0.346	77.8547	78.8927	96.1938
7	0.34602	2.7682	3.4602	9.3426	53.3633	79.2388	92.3875	95.1557
8	0.34602	1.3841	3.4602	0.96204	20.4152	57.7855	94.4637	98.2699
9	0.34602	0.34602	1.0381	0.96204	17.301	65.0519	83.045	95.1557
10	0.34602	0.34602	0.34602	1.0381	3.4602	68.8581	93.7716	98.6159

Table 2. The average forest burned for each burnProbability value.

burnProbability	**The average percentage (%)**
10%	0.34602
20%	1.41868
30%	1.903118
40%	3.82563
50%	20.49504
60%	68.71972
70%	89.9308
80%	97.23183

7. Conclusion

From this research it can be seen that the higher the BurnProbability, the more trees are burned. That is because the possibility of the tree burning is getting bigger. Cellular Automata can be used to simulate the process of spreading fire in forest fires. For further research real data will be used to validate its performance.

References

[1] A. I. Febriandhika, F. Ramdani, and A. N. Rusydi, “Pengembangan Sistem Simulasi Perkiraan Penyebaran Api Pada Gunung Arjuno Kawasan Tahura R . Soerjo Menggunakan Tangible Landscape,” *J. Pengemb. Teknol. Inf. dan Ilmu Komput. Univ. Brawijaya*, vol. 3, no. 2, 2019.
[2] R. C. Rothermel, “How to Predict the Spread and Intensity of Forest and Range Fires,” *USDA For. Serv. Gen. Tech. Rep.*, p. 161, 1983.
[3] A. Muzy, E. Innocenti, A. Aiello, J.-F. Santucci, and G. Wainer, “Cell-DEVS quantization techniques in a fire spreading application,” pp. 542–549, 2003.
[4] I. K. A. Thanailakis, “A model for predicting forest fire spreading using celullar automata,” *Ecol. Modell.*, vol. 99, no. 1, pp. 87–97.
[5] Dr N. Gobeau;Dr x.x. Zhou, “Evaluation if CFD to Predict Smoke Movement in Complex Enclosed Spaces,” .
[6] A. Ohgai, Y. Gohnai, S. Ikaruga, M. Murakami, and K. Watanabe, “Cellular Automata Modeling For Fire Spreading As a Tool to Aid Community-Based Planning for Disaster Mitigation,” *Recent Adv. Des. Decis. Support Syst. Archit. Urban Plan.*, pp. 193–209, 2005.
[7] D. I. Curiac, O. Banias, C. Volosencu, and D. Pescaru, “Cellular Automata Based Simulation for Smoke and Fire Spreading in Large Buildings,” no. 0.
[8] X. Li and W. Magill, “Modeling fire spread under environmental influence using a cellular automaton approach,” *Complex. Int.*, vol. 8, pp. 1–14, 2000.
[9] L. Bodrožić, D. Stipaničev, and M. Šerić, “Forest fires spread modeling using cellular automata approach,” *... Split. Dep. Model. ...*, 2006.