# GENERIC TOOL FOR MODELING AND SIMULATION OF FIRE PROPAGATION USING CELLULAR AUTOMATA

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Abstract : In spite of their simplicity, Cellular Automata ( CA ) have a great potential for being used in modeling various natural phenomenon. CA receive widespread interest among researchers from diverse field to learn and use them in their application domain. Although CA can be used in diverse application domain, researchers usually develop CA model for their specific problems domain despite universality is the true nature of CA. In this research, we attempt to develop a tool to model and simulate CA. This is a general purpose tool that can be used to develop various CA based model. As a starting point, this tool will be implemented to modelling and simulating fire propagation. In consequence, literature study was conducted on some related research of fire propagation model to get the generic aspect from that models. The generic aspect then implemented into software artefact as a generic tool. In the end, the tool will be tested to implement rules from related research. The test result shows that with the same construction, the tool can implement various rules and fire propagation models.

Keywords : modeling; simulation, cellular automata, fire propagation

## Introduction

Toward understanding of natural phenomenon, researchers from diverse field use a variety of method to model the phenomenon into simple mathematical model. It aims to study and predict the behavior of the phenomenon. Most of natural phenomenon are propagation phenomenon such as fire, swelling, gas propagation which are part of complex systems. This phenomenon can be viewed as a propagation cells in space which is same as the concept of cellular automata (CA)[1].

CA are mathematical model for complex natural systems containing large numbers of simple identical components with local interaction. CA can be seen as a uncomplicated spatial model which decentralized, composed of individual component that is called as cell. The cell can interact each other limited to the local interaction among cell. Each of this individual cell has a state that changes over time depends on its neighborhood cell. The overall structure of CA can be viewed as a parallel processing device. However this simple structure will produce a complex pattern when it is iterated several times[2]. According to this, CA model does not only provide a mathematical model but it also provides a visual model through simple spatial model.

In order to modeling widely diverse application areas, researchers have struggled to establish simpler and more practical architecture of CA based on the logical concept of universality [2]. Universality defines as the property which is able to perform different tasks with the same underlying construction by simply being programmed in a different way[3]. Until the present time, there are some researches about CA and its implementation in various field (e.g., physics, chemistry, biology and ecology ) [4]. But, researchers from distinct field have intuitively described CA dynamics with problems in their own field , without necessarily being aware the capabilities of universality in CA [2].

In this research, we develop a tool to model and simulate CA. Based on the concept of universality, this tool can create different model with the same construction just by running the model in a different rule. By using this tool, the researchers can create various simulation model without being aware to rebuild the component for each model. For starting point this tool will be tested to modeling fire propagation from various research[5]–[7].

## Cellular Automata

1. *Basic Component of CA*

CA are mathematical idealizations of physcal systems in which space and time are discrete, and physcal quantities take on a finite set of discrete values[8].

The four components of CA are :

1. Cellspace

Cellspace is an environment of CA that consists of cells on which the CA is computed . Usually, the shape of cells is equal in size and shape that can be present as triangles, squares or hexagons. The grid can be one dimension (e.g., elementary CA), two dimension (grid) or even higher.

1. State

Each cell has its own state which is has its own color or value. The number of state possibilities is typically finite . For example in binary automaton, e.g., Game of Life[9], there is two states available : "alive" and "dead" ( otherwise referred to as “on” and “off”).

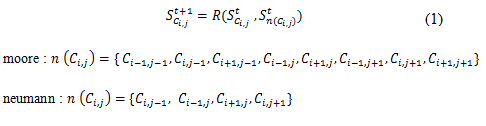
1. Neighborhood

Neighborhood in CA are composed by a cell and its adjacent cells that also have a role to determine the evolution of state of that cell. Neighborhood in one dimensional CA consist of a cell and its two adjacent cells (in the right and left ). In two dimensional CA there are two types of neighborhood : von Neumann neighborhood and Moore neighborhood. Von neumann neighborhood consist of a cell and the four adjacent cells (north, east, south and west) whereas moore neighborhood consist of the previous five cells and the four diagonal cells (north-east, south-east, south-west and north-west).

Neighborhood in CA can be implemented in different range. Range of 1 means that only the nearest cells are considered as neighbor. In range of *n*, all of the cells in radius of *n* from a certain cell considered as neighbor of that cell.

1. Rule

Rule determines the transition of a cell state and its neighborhood from one discrete time step to another. It applies to all cell and occurs in parallel. The state transition formulation can be represented as



Where *R* is rule, *S* is state, *t* is time or timestep , *C* is Cell and *n* represents neighborhood . So that, state of a cell at time step t+1 determined by rule that acts upon state of a cell and its neighborhood at time step t.

1. *Basic Implementaion*

The basic implementation for simulating CA uses two arrays of cell : the first one contains the global configuration at the current time step. Moreover, the second one refers to the result after the transition rule is applied. In every time step, all cells are scanned and after all cells have been computed, the result of the computation in the second array is copied into the first array and the time advances to the next time step. This process is repeated over time.

We assume a grid in size *n* x *n* which means the scanning process needs *n2* amount of time to scan all cells at every time step. The scanning process should be focused on the cell that has a potential to change its state on the next time step. The basic principles to predict whether a cell possibly change state or not in a next time step are exposed in [10].

The CA are often simulated on a finite size of cell space. Because we can't scan all cells on an infinite cell space in a finite amount of time. But the problem with the finite size of cell space is the cells at the edge of cell space is lack of neighbors. Based on [11], the three ways to overcome this problem are :

1. Edges remain constant. Never evaluate the cells at the edge and their state is always constant ( e.g., 1 or 0 ). This is the simplest and easiest solution.
2. Toroidal cell space. Taping the left with the right edge of cell space. Also, taping the top with the bottom edge of cell space.This can be visualized as a doughnut shape of cell space.
3. Edges have different neighborhoods and rules. Defining a different kind of neighborhoods and rules for the edge of cell space. This solution will make the system more complex.

## Fire Propagation Modeling with Cellular Automata

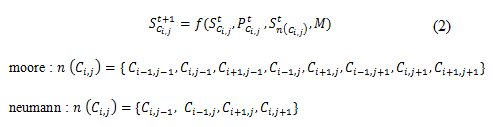
Basically three factors that influences the fire propagation, namely fuel, heat and oxygen. In CA, fire propagation phenomena must be emulated by constructing some appropriate rules. So as to create a fire propagation by using the technique of CA, the probability formulation of fire spreading in the transition rules usually revolve around that three main factors.

Some research about modeling fire propagation using CA in [5]–[7], [12]–[14] use distinct both rules and parameters. In forest fire modeling, to determine the possibility of fire to spread in an area, the researchers in [5] use the ignition probability from neighbour cells, researchers in [6] use the parameter of wind condition and vegetation characteristics and researchers in [7] use the vegetation cells distribution across the lattice, the chance of a burning cell become burnt, and the chance of burning cell spread to a neighbouring vegetation cell. Moreover, in city fire spreading simulation, the researchers in [12], [13] use the fire spreading judgement index to calculate the probability of fire spread among the lattice. In this research we attempt to find the basic aspect to modeling fire propagation using CA from various previous reserach [5]–[7], [12]–[14]. So, based on that basic aspect we can create a generic tool that can modeling various fire propagation.

## Analysis of basic aspects on CA Model

Based on Wolfram [4], The four basic components of cellular automata are : cellspace, state, neighborhood and rules. These are mandatory components to modeling using cellular automata. To create a model based on cellular automata, the researchers need to adjust these components based on their specific problems. Moreover, In modeling natural or physical phenomenon, a cell is not only has a state but also properties. For example, in fire propagation modeling on urban areas, the building condition is composed of building material, floor area and height that represent the characteristic of building[12]. These factors affect the probability of fire to spread across the building. Besides the cell properties, the result of simulation is also affected by environmental factors (e.g., weather or wind direction and velocity such in [6][15]) that is model properties. In contrast with cell properties that affect local cell, model properties affect all the cells in the lattice. Since both of these properties affect the result of the simulation especially on both natural and physical phenomenon simulation, we include those properties into state transition formulation.

Assumed *P* is cell properties and *M* is model properties, if we include both properties into Eq.(1) :



If cell *C* composed of state ( *S* ) and properties ( *P* ) and the state and properties of cell *C* will change on the next time step, so :



So, in order to create a generic tool that can create a various model CA, the tool should be fulfill the following capabilities :

1. Providing a feature for user to create a custom cellspace, save and reuse the cellspace. So it can be use in other projects.
2. Capabilities to manage a list of state. This feature provide access for users to add or delete states in model.
3. Providing a feature for user to define a custom rule for model that they made
4. Providing a feature for users to choose which neighborhood that they use in their model
5. Providing an access for user to use and define model properties. For example : in fire propagation modeling , the user can include wind condition into their model since this properties can affect the behaviour of fire spreading

## Software Architecture

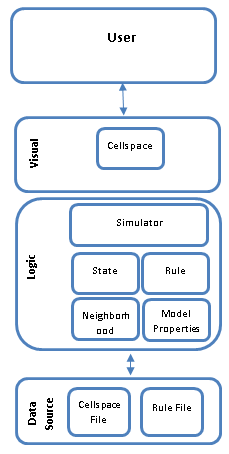


Figure 1 Software Architecture

Figure 1 shows the architecture of tool that we develop in this research. For processing and computation, we use Java programming language (Java SE) and for GUI and visualization of simulation we use Java Swing and Processing programming language [16]. This tool consist of six modul, the six moduls are :

1. Cell space

The main capabilities of this modul is being able to create cellspace from image, create manually or generate grid randomly. To create a cellspace from image, this component transforms pixels from image into array of cells and color from the image as a property of cell. In short , this component manages the creation of cellspace and the properties of each cells.

1. Rule  
   This modul receives and compiles the rule which is made by user. It also integrates that rule into main program. We use Java Compiler from Java programming language to compile the rule that user made.
2. State

This module stores a list of state to be used in a simulation model. Given this module, users can add or delete a state to be used in the simulation model.

1. Neighbourhood

This module provides the facility for users to define the type of neighborhood that will be used in modeling CA. By default the two types of neighbourhood namely moore and von neumann.

1. Model Properties

This module provides the facility for users to define the value of model properties. This modul contains the variables associated with a model on a specific domain. For now, this module contains the settings of the wind condition used in fire propagation model.

1. Simulator

This is the core of tool that integrates all the previous component. It controls which cell will be processed, what kind of neighborhood will be used and how many iteration will be done, etc. Generally, it acts as a simulator which controls the entire simulation process.

## Fire Spreading Application

In this research, The tool will be tested to create fire propagation model using transition rule presented in [5]–[7]. Dimension of cellspace that we use are 200 x 150 (30,000 cells) and 400 x 300 (120,000 cells). The data that we use as cellspace in this testing is available at[17].

1. ***Fire Spreading Model Proposed by Quartieri et al. (2010)***

In this model, the ignition probability of a cell depends only on the number of burning cell in its neighborhood. The type of neighborhood that used in this model is moore neighborhood. As shown in figure 2, three fire point have been chosen as initial conditions. After 30 time steps, as shown in figure 3, the fire shaped roughly circular like the pattern of fire spreading without wind condition which occur int the real world

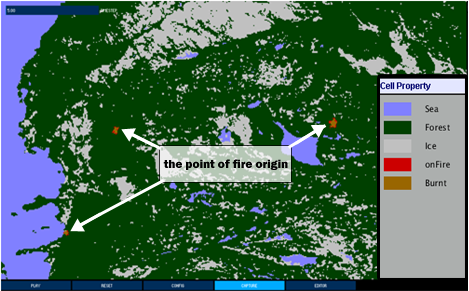


Figure 2 Simulation result after 5 time steps with three initial burning cells

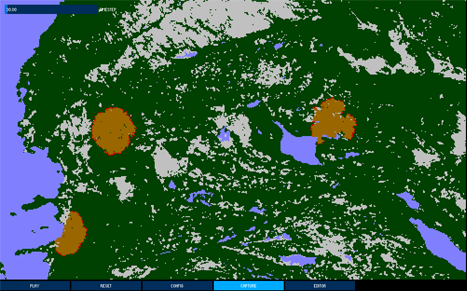


Figure 3 Simulation result after 30 time steps

1. ***Forest Fire Spreading Model Proposed by Bodrozic et al. (2006)***

In this model, Bodrozic et al. on [6] use parameter of vegetation characteristics and wind conditions as a factor that affect the behaviour of fire propagation. There are two types of vegetation in this model : forest with probability of burning 70% and short grass/vineyard with probability of burning 30%.

As shown in figure 4, three fire points have been chosen as initial conditions. One of the fire points is located near the grass field (rightmost). The simulation result after 30 time steps (figure 5), shows that the fire propagates among the forest is faster than in the grass because of the burning probability of forest is higher than grass.

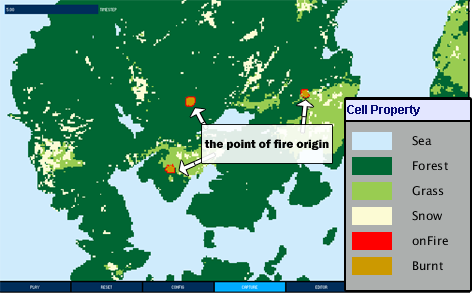


Figure 4 the three fire points as initial condition

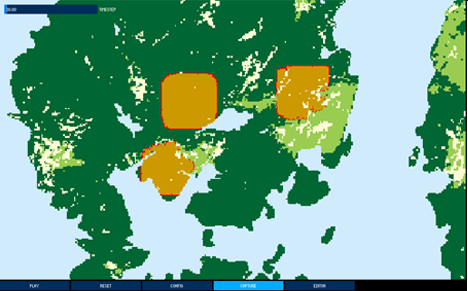


Figure 5 The simulation result after 30 time steps

1. ***CA Model For Wildland Fire Spread Dynamic Proposed by Almeida and Macau (2011)***

In this model, there are three factors that affect the behaviour of fire to spreads : First, the vegetation cells distribution across the lattice (D). Second, the chance of a burning cell become burnt (B). Third, the chance of burning cell spread to a neighbouring vegetation cell (I).

As shown in the figure 6, we implemented a different parameter values to see changes in the behavior of fire spreading. From the result of implementation shows that although all the simulation result are in the same time steps, the fire spreads in dissimilar behaviour.

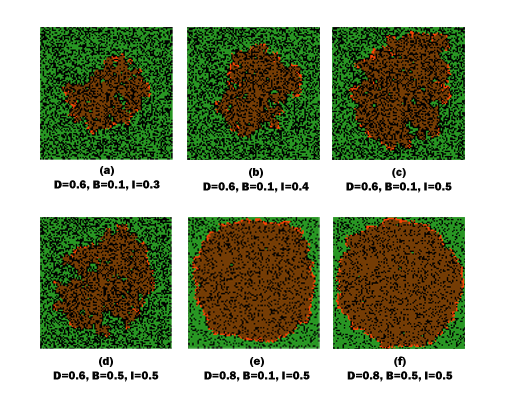


Figure 6 Implementation of fire spread dynamic with different parameter values

From this experiment, we conclude that in a heterogeneous vegetation environment the level of burning cell remain burning (B) increase the influence of fire to spreads but in a heterogeneous vegetation environment that has more fuel, the variable of fire spreading probability (I) has a bigger influences than the variable of fire resistance (B) to cause fire spreading in a wider area.

## Conclusion

In this paper the authors develop a generic tool to modeling and simulating fire propagation from various previous research. We attempt to find the basic aspect to modeling fire propagation using CA from various previous reserach. So, based on that basic aspect we can create a generic tool that can modeling various fire propagation. The tool consist of six main modul : grid generator, state, neighborhood, rule, model properties and cellular automata as a simulator. Subsequently, The tool tested to create fire propagation model using transition rule presented in related research.

From the results of the testing shows that with the same construction, the tool can create different models and implements distinct transition rule. Although some of the simulation result do not exactly match visually with the result obtained by related researchers, but there are similarities of fire behaviour. The main cause that make the difference in simulation result is due to the probability factor involved in the transition rule.

For future work, we attempt to improve the capabilities of this tool by adding some new features (e.g. neighborhood creator) so this tool can create a more complex model. Instead of fire propagation model, we attempt to develop various model using this tool since all the CA based model consist of same component (cellspace, rule, state, neighborhood). To achieve this goal, we need to explore all the related research about CA based model.

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