

CELL BASED GIS AS CELLULAR AUTOMATA FOR DISASTER SPREADING PREDICTIONS AND REQUIRED DATA SYSTEMS

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ABSTRACT

A method for prediction and simulation based on the Cell Based Geographic Information System(GIS) as Cellular Automata (CA) is proposed together with required data systems, in particular metasearch engine usage in an unified way. It is confirmed that the proposed cell based GIS as CA has flexible usage of the attribute information that is attached to the cell in concert with location information and does work for disaster spreading simulation and prediction.

Keywords: Cellular automata, Geographic information system, Metasearch

1 INTRODUCTION

Satellite data utilizing analysis methods need metadata searches before data retrievals (most countries have adopted the ISO Metadata standard). Although there are some search engines, CS-W as well as OpenSearch, that are standard metadata search engines, there is no unified method for metadata search. In this paper, metadata search is discussed. Meanwhile, the Geographical Information System (GIS) is totally identical to Cellular Automata (CA), which allows predictions and simulations. In this paper, Cell Based GIS as CA (it is referred to CBGISCA hereafter) is proposed.

CA approaches are widely used in disaster spreading simulations such as forest fires (wild fires), flooding, lava flows, landslides, mudflows, etc. CA approaches are simple and easy to develop and obtain spectacular displays or visualization. Especially for forest fire prediction, CA approaches have been used by many researchers to simulate and show fire spreading for some time.

Karafyllidis and Thanailakis (1997) presented a simple CA model to predict the spread of fire in both homogeneous and inhomogeneous forests. This model is simple although it has some additional parameters. Malamud and Turcotte (2000) presented a forest-fire CA model with a program simulating different fire frequencies and spatial and temporal patterns. Hernandez Ecinas, White, del Rey, and Rodriguez Sanchez (2007) presented a new two dimensional CA approach using the hexagonal area of forest and showed the transfer of a fractional burned area under different speeds. The algorithm seems to be more efficient than the conventional one, and it is easily implemented in any computer algebra system, allowing a low computational cost. These above approaches are too simple to show complex forest-fire spreading, such as tree-types, landscape, and wind determination.

Another approach, introduced by Song, Fan, and Wang (2001), presented an improved model of a CA approach. Here tree species, meteorological conditions, and human effects were considered providing generalized “immunity” of a tree from fire. This model improved the previous model with some addition parameters, but it did not show the relationship between trees and the probability of burning. The probability of burning is an important parameter that allows the model to adopt unknown conditions with a simple approach.

In this paper, a new two dimensional CA approach using fire-control probability, wind characteristics, and tree-types is introduced. This approach is simple and easy to develop because it uses phenomenological relationships directly. CA based forest fire prediction requires plenty of attribute data on conditions, wind speed, wind direction, tree species, humidity, air temperature, topological features, etc. On the other hand, GIS has databases that include such attribution data. The proposed CBGISCA consists of 2D cells that represent geographical maps and the aforementioned attribute data. Therefore, CA based simulations can be done effectively with reference to the attribute data. Although this approach is simple, it is an alternate approach to predict the spread of forest fires and shows dangerous areas in the future.

Malamud and Turcotte (2000) presented a simple CA approach using a programmed model. This model consists of a square grid, in which at each time step a tree is randomly dropped on a chosen site. Every $1/f_s$ time steps, a match is randomly dropped (f_s is the sparking frequency). If a tree falls on an unoccupied cell, it is planted. If a match drops on a tree, that tree and all non-diagonally adjacent ones are burned in a fire. The keyword of this approach is sparking frequency.

A very important parameter in forest fire simulation is wind speed. This parameter influences the neighborhood size and sparking probability f_s . The relationship among wind speed, the neighborhood size, and sparking probability, introduced by Sullivan and Knight (2005), is defined. It is the “bubble” convection model of wind speed influences in forest fire simulation because this model assumes that the fire component is a bubble model.

In the following section, the proposed method of a metadata search engine is described, followed by the CBGISCA together with an example of the proposed forest fire propagation method. Simulation results are also described. Concluding remarks with some discussion follow.

2 PROPOSED METHODS

2.1 Metadata search engines

The following metadata search engines are important.

- CS-W OpenSearch is a well known metadata search engine.
- Cadcorp holds metadata in a centralized repository on a geospatial server, GeognoSIS. The repository is accessed through the Open Geospatial Consortium Catalog Server (Web) interface, OGC CS-W.
- OGC CSW Core (OGC, 2007core): this interface is recommended by the GEO/GEOSS.
- OGC CSW ISO Application Profile (OGC, 2007iso): this interface is identified by INSPIRE Implementing Rules (IRs) as the reference for ESDI catalog services.
- OGC CSW ebRIM/EO is an Extension Package (OGC, 2008eo) that is recommended by the GMES/ESA-HMA initiative (<http://earth.esa.int/hma/index.html>).
- OGC CSW ebRIM/CIM (OGC, 2007cim), OGC CSW OpenSearch Extension (OGC, 2008os), and the GENESI-DR (Ground European Network for Earth Science Interoperations – Digital Repositories) (<http://www.genesi-dr.eu/>) catalog interface that is based on it.

The OGC seeks comments on City Geography Markup Language (CityGML) V1.1. There are OGC requests for Sensor Planning Server (SPS) 2.0 Reference Implementations. OGC seeks comments on candidate Earth observation profile of coverage standard. OGC seeks comments on the candidate GeoSPARQL standard, the OGC and OpenMI Association to advance computer modeling standards. The OGC seeks participants for its Hydrologic Forecasting Interoperability Experiment. The OGC has completed its Water Information Concept Development Study. The OGC has announced the GEOSS Workshop XLIII: Sharing Climate Information and Knowledge. It would be better if metadata searches be done in a unified way. It is also desired to establish a standard procedure for metadata searches.

2.2 CBGISCA

Because geocoded earth observation satellite data can be represented on geographic maps, GIS representation is effective in such cases. CA, on the other hand, is effective for estimation and prediction phenomena and is based on cells. Therefore, geocoded data can be treated as cell wise data, which results in CBGISCA. Furthermore, GIS works as a neural network, allowing predictions and simulations. In particular, disaster relief and prediction can be done with cellular automata. All the required data for disaster relief and prediction can be represented on cells and can be acquired with Web Map Services: WMS. Meanwhile, the Web Geographical Map (Landscape map→ Landscape object, Land-use map→ Human activity influences), the Forest Map (Forest type→ Tropical Forest, Homogenous Forest, Hot Spots), and the Weather Map (Wind, Season, and Temperature) are also retrieved and downloaded from the service servers through a metasearch. WMS provides geographical map data with the information lossy algorithm while WCS (Web Coverage Service) data is represented as a set of cells. Therefore, CBGISCA uses WCS types of geographical maps, cell based representations of maps rather than WMS.

Raster based GIS consists of cells (grid) while Geo-coded earth observation data is represented on cells. Meanwhile, the data required for simulation and prediction (disaster relief, etc.) is represented on cells. All these data are represented on a cell based GIS and also are used for simulation and prediction as cellular automata.

GIS (ISO Standard) representation of cells, GIS based cellular automata is used for disaster relief and prediction. A metasearch must be done in a unified way. Therefore, a Standard Clearing House System is highly necessary. The consistency of the data quality with space and time as well as among the sensors is a concern.

3 APPLICATIONS OF GIS ON CA FOR FOREST FIRE SIMULATIONS

3.1 Proposed cellular automata on GIS method for forest fire spreading simulation

The proposed method is a two dimensional CA that uses a square grid of sites. The following four parameters are taken into account: tree-types, wind speed and direction, sparking probability, and stooping probability. A number of tree-types with different probabilities for fire are also taken into account.

The proposed forest fire model consists of a square grid of sites of which blank node, tree, and fire are considered to be the status. Some trees around a fire may be fired depending on the sparking probability f_s (Encinas et al., 2007), and also fire may be stopped depending on the stopping probability f_c . The stopping probability f_c is a constant that depends on the tree material and species. Meanwhile, sparking probability is a variable which depends on material (species), wind speed, and wind direction. The tree material (species) parameter shows the possibility of burning. The wind speed parameter defines the size of the neighborhood and shows that the model uses a dynamic neighborhood model. The wild fire propagation direction depends on the wind direction parameter.

The Cellular Automata algorithm for forest fire simulation is represented as follows:

- We begin with a square grid of sites. There are five states:
 $s=1 \rightarrow$ blank node
 $s=2,3,\dots,n+1 \rightarrow$ tree (n different tree types). Malamud et.al (1997) use one type of tree.
 $s=n+2 \rightarrow$ fired
 $s=n+3 \rightarrow$ stopped or completed fired
- We determine the neighborhood (size and shape), depending on wind speed and wind direction, using the Cardioid concept.
- Trees will be fired by the sparking probability f_s if there are fire neighbors.
- Fire will be stopped by the stopping probability f_c .

In the proposed method, we define tree types made of different materials. Each material has a probability of fire that depends on the tree type. Ohgai, Gohnai, Ikaruga, Murakami, and Watanabe (2004) define the simple probability of fire depending on material as the following:

$$S_{ij} = 1, \text{ if wooden} \\ = 0.6, \text{ if preventive wooden} \\ = 0, \text{ if fireproof.}$$

In the CA approach, one of the important parameters is neighborhood rules. The proposed method uses a dynamic neighborhood system depending on wind parameters, wind speed, and wind direction. The number of neighbors depends on wind speed. According to Jirou and Kobayashi (1997) and Ohgai et al. (2004), the relationship between the number of neighbors and wind speed is expressed as Equation (1):

$$D = 1.15 (5 + 0.5 v) \quad (1)$$

where v is wind speed (m/s) and D is the limit of the distance in which the fire can spread.

Sullivan and Knight (2005) use the bubble concept while we use the “Cardioid” concept for definition of the influence of wind direction on the neighborhood system. This is the proposed model in the CA approach for forest fire simulation. This is an original method which differs from the Sullivan and Malamud models. The new limit of the distance in which fire can spread is represented as Equation (2):

$$D^* = D (1.5 + \cos (d)) \quad (2)$$

where d is wind direction, D is the limit of the distance that is written in equation 1, and D^* is the new limit of distance of fire can spread.

Figures 1 and 2 show how the wind parameters determine the neighborhood system in our approach. In these figures we have two variables, r and α . The first parameter is wind speed r that relates to wind speed. The second parameter is wind direction α .

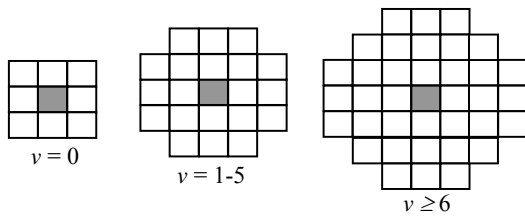


Figure 1. Neighborhood size depends on wind speed

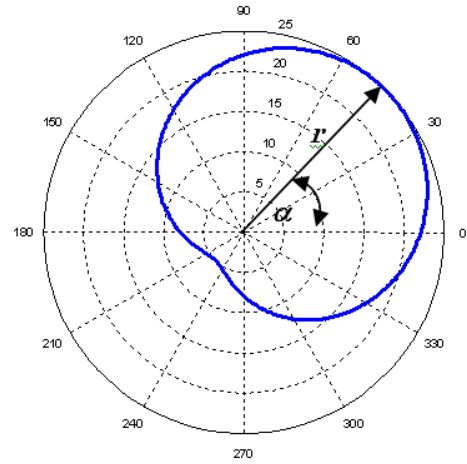


Figure 2. The Cardioid concept for wind influence

3.2 Simulation results

In this simulation three tree-types with different probabilities of fire are set. The probability is randomly selected. The other input parameter is density, the number of trees in the observation area. We selected a density of around 0.6-1. Figure 3 shows the simulation results in 40 unit time steps with different densities. This simulation uses two probability functions: sparking probability f_s and stopping probability f_c . The number of fired areas, which depends on sparking probability and stopping probability, are shown in Figure 4. A different combination of f_s and f_c has different joint points at the number of trees and the number of fired areas.

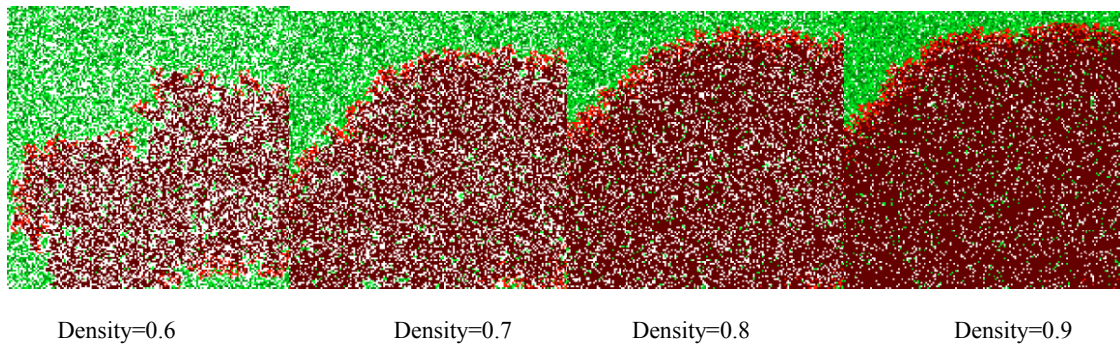


Figure 3. Simulation results on different density

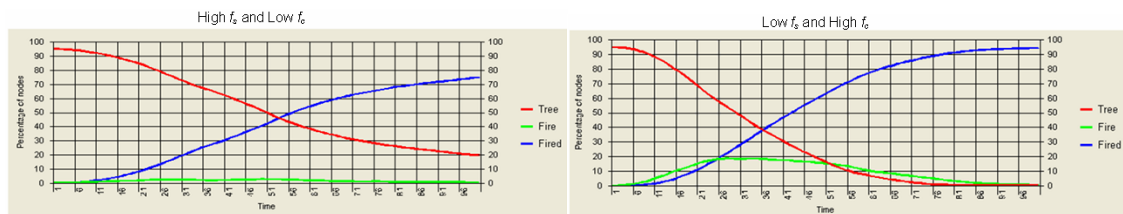


Figure 4. The number of fired area depends on f_s and f_c .

4 CONCLUSIONS

In conclusion, we make the following recommendations:

- GIS (ISO Standard) representation of cells should be used.
- GIS based cellular automata is appropriate and should be used for disaster relief and prediction.
- Metasearch must be done in a unified way. Therefore a Standard Clearing House System is definitely required.

- The consistency of the data quality with space and time as well as among the sensors is a concern.

In particular, the proposed CBGISCA allows the flexible use of attribute data that are required for disaster prediction with reference to geographical location information. Also, the prediction results can be represented in a GIS display superimposed with other attribute data. Therefore, it is easy to check the validity of prediction results.

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