

MODELING LAND FEATURES DYNAMICS BY USING CELLULAR AUTOMATA TECHNIQUES

Saturnino Leguizamón

DICYT – Department of Scientific and Technological Research, Universidad de Mendoza,
Aristides Villanueva 773, 5500, Mendoza, Argentina
sleguiza@um.edu.ar

KEY WORDS: snow-cover, cellular automata, remote sensing

ABSTRACT:

The modelling of land features dynamics is an important factor to take into account when it is necessary to quantify or estimate the environmental changes produce by a given phenomena. It is interesting to model, for instance, the amount of water content when a given change of the snow-cover takes place in a given geographical region. The mathematical modelling of such a dynamics is not an easy task because of the many intervening variables and the difficulty which implies the measurement of different parameters. During the last decades, the use of cellular automata (CA) techniques to simulate the behaviour of linear or non-linear systems has been of great interest in the scientific community. This interest owes mainly to the fact that instead of using accurate mathematical formulae, the CA approach depends largely on the relationships among the spatial elements of the feature under study and the assumption of a series of rules that govern such spatial changes. The cell space and the transition rules are the most important factors to be considered in a dynamic model based on the CA approach. The proposed technique is applied also to describe the vegetation changes appearing in a Landsat image of the Mendoza province in Argentina. Considering that the problems of remote sensing analysis are of spatial nature, the use of CA techniques is considered in this paper as one of the most appropriate tools.

1. INTRODUCTION

The knowledge of snow-cover and its dynamics is an important factor to take into account when it is necessary to estimate the water content or to carry out hydrological studies in mountainous regions. The mathematical modelling of such a dynamics is not an easy task because of the many intervening variables and the difficulty which implies their measurements. On the other hand, during the last decades, the use of cellular automata (CA) techniques to simulate the behaviour of linear or non-linear systems is becoming of great interest. This fact is mainly due to the fact that this approach depends largely on local relations and a series of rules instead of precise mathematical formulae.

Although the use of cellular automata is becoming of great interest, few applications in the field of remote sensing are known (Clarke, K. C. et al, 1994). This paper considers the use of the cellular automata (CA) to simulate the dynamics of the snow-cover in a mountainous terrain taking into account important variables in the model, such as slope and insolation. Changes in vegetation cover are also studied in order to estimate its dynamics in front of different factors. While still in the early phases of development, the model provides promising results that encourage the continuation of further studies and experiences with this modern tool in order to obtain complementary and useful information.

2. CELLULAR AUTOMATA, A BRIEF INTRODUCTION

Cellular automata (CA) were originally conceived by John von Neumann and Stanislaw Ulam in the 1940's to provide a formal framework for investigating the behaviour of complex systems (von Neumann, 1966). CA are dynamic systems which are discrete in space and time. They consists of a regular grid of

cells, each of which can be in one of a finite number of k possible states, updated synchronously in discrete time steps according to a local, identical interaction *rule*.

A cellular automata (CA) is an array of "cells", which interact with one another. The arrays usually form either a 1-D string of cells, a 2-D grid, or a 3-D solid.

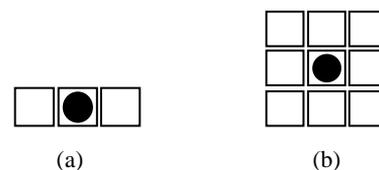


Figure 1. Examples of neighbourhoods used in cellular automata: (a) linear symmetric, (b) neighbourhood of Moore

The essential features of a cellular automaton are:

- its *state*: is a variable that takes different values for each cell. The state can be either a number or a property
- its *neighbourhood*: is the set of cells that interact with the cell in question. In a grid these are normally the cells physically closest to it

A cell' state will change according to a set of *transition rules* that apply simultaneously to every cell in the space. These rules are based on both the current state of the cell under study and also the collective state of its neighbours. Examples of neighbourhoods used in cellular automata can be seen in figure 1.

The first system extensively calculated on computers was the

“Game of Life” (Gardner, 1970). This “game”, invented by John H. Conway, is based on cellular automata theory and uses a two-dimensional square space which is simply a matrix or grid. It was called “Life” because of its analogy with the rise, fall and alternations of a society of living organisms.

The rules proposed by John Conway are:

- A living cell with 4 or more living neighbours, dies for overcrowding
- A living cell with only 0 or 1 living neighbour, dies for isolation
- A dead cell with exactly 3 living neighbour, becomes alive
- All other cells become alive

3. APPLICATIONS OF CA TO SNOW-COVER STUDIES

3.1 Selection of the area of study

In order to demonstrate the usefulness of the CA approach for the estimation of the snow-cover dynamics a mountainous terrain was chosen. To take into account the topographic characteristics of the terrain a Digital Elevation Model (DEM) of the chosen area was needed. To accomplish that goal an elevation data provided by the Shuttle Radar Topographic Mission (SRTM) was downloaded from the web. The DEM image, named S32W070 by NASA, corresponds to a part of Argentina, with the geographical coordinates South 32° and West 070°. The original DEM image was degraded in spatial resolution and corrected from some voids appearing on it. The resulting image (600 x 600 pixels) can be seen in figure 2.

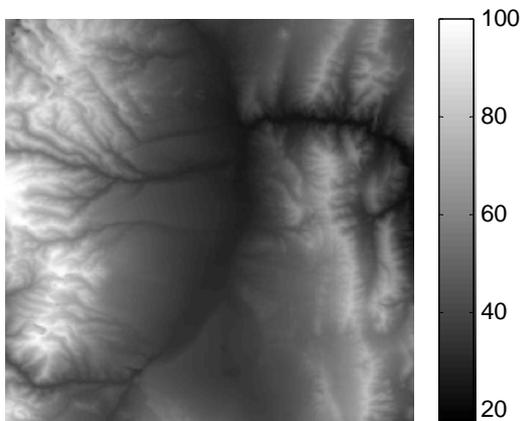


Figure 2. DEM of a mountainous terrain in Argentina (NASA image S32W070, SMTR Mission)

The elevation values, which can also be observed in the bar included in the figure, were arbitrarily assigned and will be mentioned as elevation units; the whiter the colour, the higher the elevation. The altitude of the terrain goes from 20 up to 100 elevation units. A perspective view of the mountain can also be observed in figure 3.

3.2. Generation of the Snowed Area

For considering the study of snow-cover dynamics and in order to simplify some calculations, in this paper we will assume that the lower limit of the snow (the snow-line) is uniform and arbitrarily located at 65 elevation units. In figure 4 we can see

the snowed region of the area of study. The snow-cover is represented in this figure by a binary image; i.e.: white=1 (snow), black=0 (no snow). The area of the snow-cover in its initial value is of 78395 pixels.

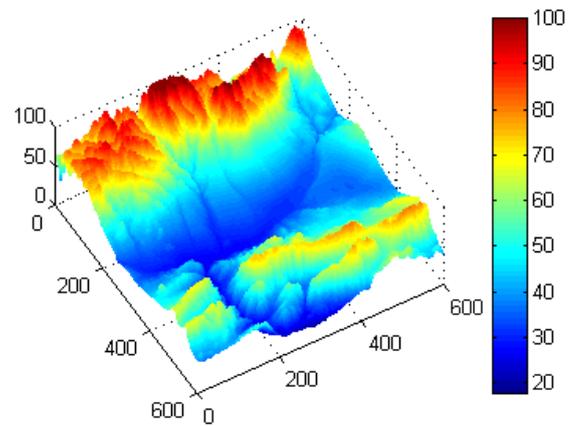


Figure 3. Three-dimensional view of the DEM in figure 2

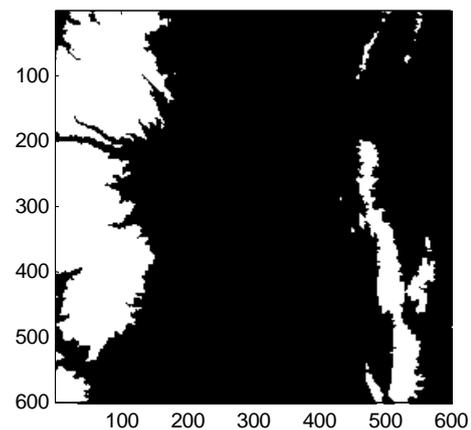


Figure 4. Top view of the snowed region (in white) assuming that the snow-line starts at an altitude of 65 elevation units

3.3. Reduction of the Snow Considering Topography

In this section we present a CA approach to calculate the dynamics of the snow-cover during a given elapsed time. Starting from a given initial time and with a fixed snowed region, such as that represented by the white colour in Fig. 4, the snow-cover will suffer a reduction of its surface owing to different situations. In our case we will consider that the reduction of the snow-cover is due to the smelting because of the temperature, therefore the higher temperatures are found at lower levels, beginning from the bottom, and that the magnitude of this reduction is affected by the altitude of the terrain, i.e.: the higher the altitude the lower the temperature and, consequently, less reduction of the snow. We will also assume that the snow-reduction process will take place in 20 time units.

In order to apply the CA theory we need to define, or choose a working neighbourhood and a set of rules. In our case the CA neighbourhood will be a Moor block of cells (3x3), such as that showed in Fig.1. The working image, named S, is that of the initial snowed region (Fig.4). After applying the snow reduction

process by means of the CA approach we will obtain the output image which will be named R.

To consider the influence of the topography we have to use the information provided by the DEM of the area under study. As it was previously said, at higher elevations the environmental temperature is lower than that at lower elevations; therefore, the snow reduction rate will be lower at higher altitudes compare to that occurring at lower altitudes. To take into account that situation, the snow cover will be arbitrarily divided in 3 levels of altitude which are named region 1, (the lower) region 2 and region 3 (the highest).

Having at hand all the set of data we can state the CA approach as follows:

Given the neighbourhood

$$N=[S(i-1,j-1), S(i-1,j), S(i-1,j+1), S(i,j-1), S(i,j+1), S(i+1,j-1), S(i+1,j), S(i+1,j+1)]$$

and assuming that our neighbourhood is in a snowed region (then $\sum(N) \neq 0$), we propose the following rules:

- if the snow is in Region 1, $T=5$
- if the snow is in Region 2, $T=4$
- if the snow is in Region 3, $T=3$

then, if $\sum(N) \leq T$, $R(i,j)=0$

where T is a given threshold.

As a result of this operation, and after 20 steps (or time units) we obtain the snowed region which can be seen in figure 5.

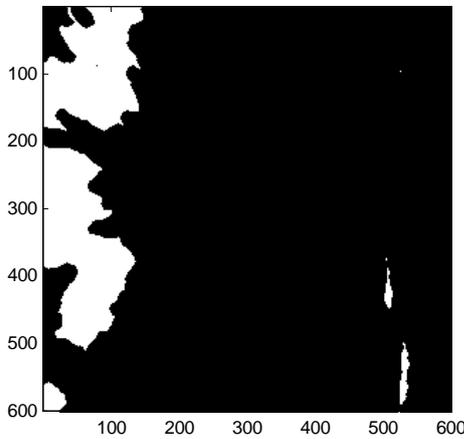


Figure 5. Representation of the remaining snow after 20 time units, taking into account the effect of the elevation data provided by the DEM

In figure 6 we can observe the evolution of the snow-reduction process; and therefore, its dynamics.

3.4. Reduction of the Snow Considering Insolation

To take into account the effect of the insolation in the reduction of the snow-cover area we need to generate the illuminated area. The illuminated area can be seen in figure 7. In that figure we assume that the insolation of the surface owes to the presence of the sun located, at the moment of the observation, in the East (right side of the image), and at an elevation of 45 degrees.

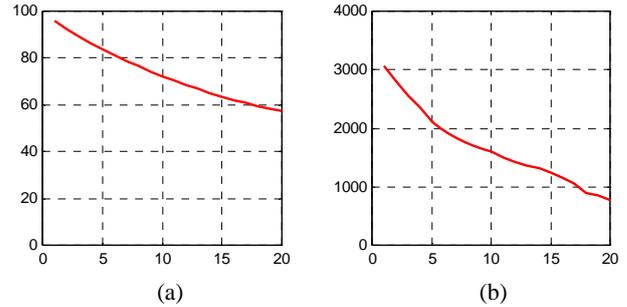


Figure 6. Snow reduction by altitude of the soil: (a) percentage of extracted area of snow vs. time units, (b) extracted area of snow vs. time units

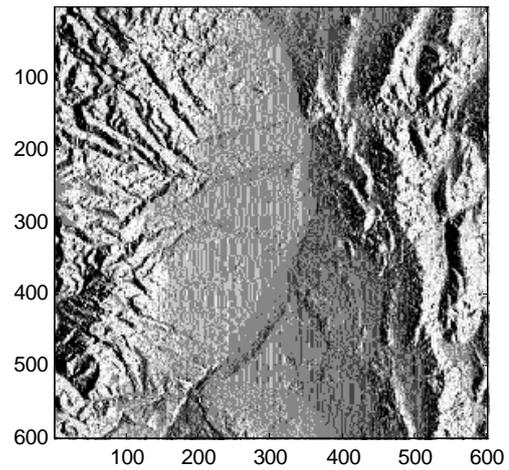


Figure 7. Image of the area of study illuminated by the sunlight coming from the East with a Sun elevation of 45°

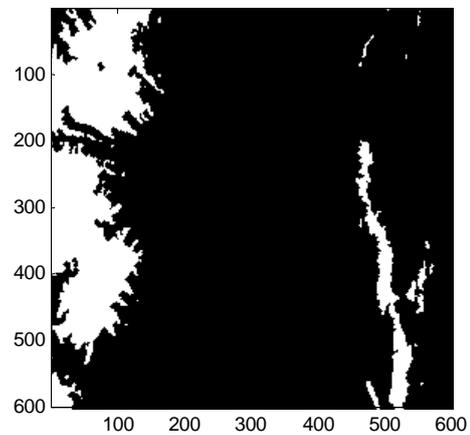


Figure 8. Remaining snowed area after 20 time units, taking into account the effect of the insolation of the area of study

The working image S is that of the snowed region (Fig.4) and the resulting image is named R. The insolation values (IL) of the illuminated area range from 0 to 0.95. For that reason we apply a rule similar to that considered in the previous case, with the difference that now we will use only two regions: lower IL and higher IL with the limit value $IV=0.6$. Therefore the CA approach is as follows:

Given the neighbourhood

$$N=[S(i-1,j-1), S(i-1,j), S(i-1,j+1), S(i,j-1), S(i,j+1), S(i+1,j-1), S(i+1,j), S(i+1,j+1)]$$

the proposed rule is:

$$\begin{aligned} &\text{if } IL < 0.6, T=3 \\ &\text{if } IL \geq 0.6, T=6 \end{aligned}$$

then, if $\sum(N) \leq T, R(i,j)=0$

As we can observe, the threshold T allows the change of the dynamic rate in the snow reduction. This is possible thanks to the use of more pixels in the neighbourhood. The result of the snow reduction is shown in Fig. 8, where the more insolated area suffers a remarkable reduction of snow. Figures 9a and 9b show the dynamic of that reduction during a period of 20 time units.

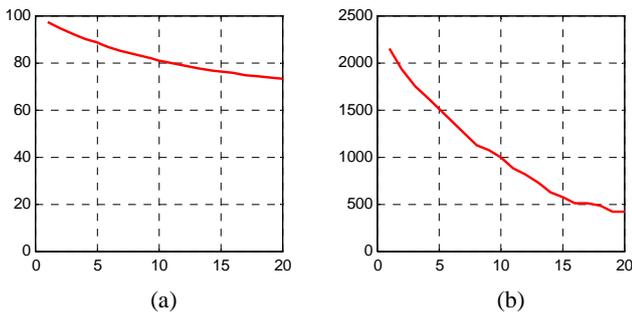


Figure 9. Snow reduction by insolation: (a) percentage of extracted area of snow vs. time units, (b) extracted area of snow vs. time units

4. APPLICATIONS OF CA TO VEGETATION STUDIES

4.1 Selection of the Area of Study

The procedure used in the dynamic study of snow-cover can also be used in the dynamics of some changes occurring in the vegetation. Changes can obey different causes. In this case we are interested in studying the evolution of changes due to the advance of subterranean water which cause the damage of the vegetation. This phenomenon is taking place in some parts of the Mendoza province in Argentina.

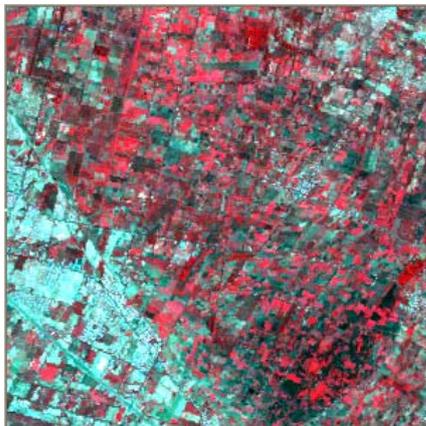


Figure 10. Subset of a Landsat image (bands 432, 300 x 300 pixels), of a cultivated area in the province of Mendoza .

Figure 10, which is part of a Landsat image, shows quite clear the damage of the vegetation caused by subterranean water. It is

shown in dark areas.

4.2 CA Approach to the Dynamic Study of the Damage

In order to identify clearly the vegetation changes in the region we perform an unsupervised classification task to the given image.

After the classification we select from the classified image all pixels corresponding to vegetation. The result of this operation is shown in figure 11 which is a binary image (black=0, white = 1).

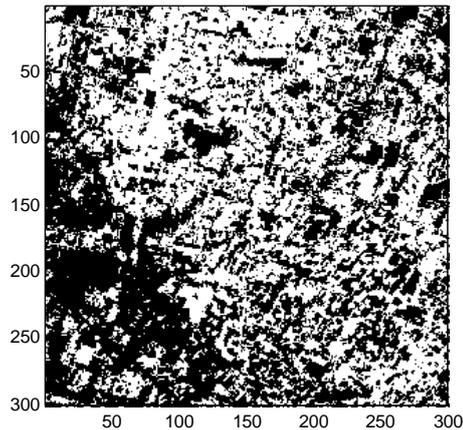


Figure 11. The regions in white (pixel value=1) indicate the presence of vegetation. In black (pixel value=0) shows areas with no vegetation

The CA neighbourhood used in our procedure will be the same used in the previous experiences, i.e.: Moore neighbourhood. The working image, named S , is the one shown in figure 11. Now, we can state the CA approach as follows:

Given the neighbourhood

$$N=[S(i-1,j-1), S(i-1,j), S(i-1,j+1), S(i,j-1), S(i,j+1), S(i+1,j-1), S(i+1,j), S(i+1,j+1)]$$

and assuming that our neighbourhood is in a vegetated region (then $\sum(N) \neq 0$), we propose the following simple rule:

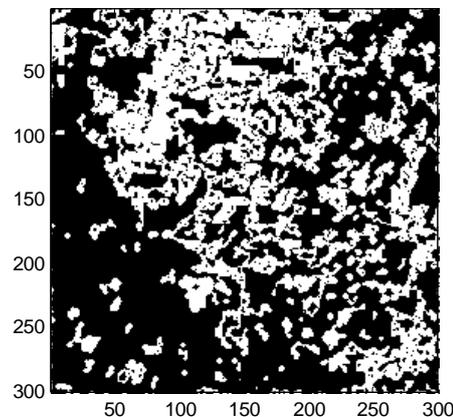


Figure 12. Resulting image of the reduced vegetated area after 10 time units and a threshold $T=3$.

For a given threshold value T ($2 < T < 8$)

$$\text{if } \sum(N) \leq T, R(i,j)=0$$

where R is the resulting vegetated area. This operation can be performed in a given number of steps (number of time units).

The resulting image of the proposed operation is shown in figure 12 for a threshold $T=3$ and 10 time units. In figure 13 we can see the changes produced in the vegetation area during 10 time units and for a threshold of $T=3$.

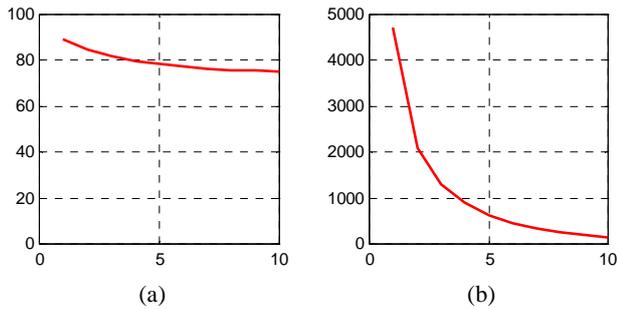


Figure 13. Reduction of vegetation for $T=3$. (a) percentage of extracted area of vegetation vs. time units, (b) extracted area of vegetation vs. time units

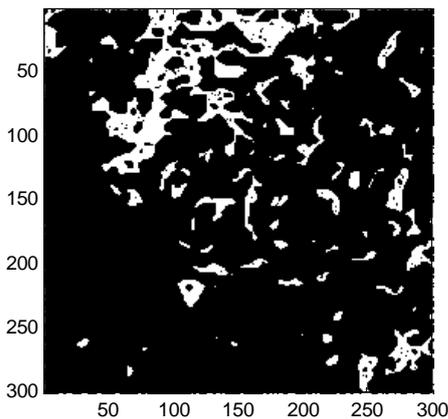


Figure 14. Resulting image of the reduced vegetated area after 10 time units and a threshold $T=4$.

The same process is performed for the same image but using a threshold of $T=4$. The resulting image reduced in the vegetation area can be seen in Fig. 14.

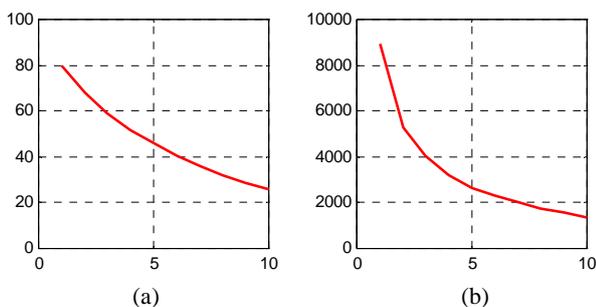


Figure 15. Reduction of vegetation for $T=4$. (a) percentage of extracted area of vegetation vs. time units, (b) extracted area of vegetation vs. time units

Fig 15 shows the dynamic behaviour of the process when we apply a threshold of $T=4$ and the process occur during 10 time units. It is important to observe that different values of the threshold T produce different speed in the vegetation changes.

5. CONCLUSIONS

The present paper demonstrates the practical use of cellular automata (CA) to carry out studies of snow-cover and vegetation dynamics. This modern tool shows enough flexibility to simulate the changes produced in different features of the environmental landscape. The first part of the paper faces the problem of snow-cover dynamics in mountainous regions. To that end the information provided by digital elevation models (DEMs) and other factors such as insolation is of useful interest.

The proposed technique here presented is still in the early phase of development, therefore, the applications were carried on real models of the terrain but subjected to assumed behaviours. The results, however, are promising to continue further studies aiming at complementing those obtained by complicated and not always accurate mathematical models.

References

- Clarke, K. C. *et al.* (1994), *A Cellular Automaton Model of Wildfire Propagation and Extinction*. In: *Photogrammetry Eng. & Remote Sensing*, vol. 60. No. 11, p. 1355-1367.
- Gardner, Martin (1970). *The Fantastic Combination of John Conways's New Solitaire Game "Life"*, *Scientific American* 223:4, pp. 120-123
- von Neumann, John (1966), *Theory of Self-Reproducing Automata*, University of Illinois Press, Champaign, Illinois.