Land Use Change Modeling in Tehran Using Geo Cellular Automata

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Abstract

In this paper CA[1] urban growth simulation and prediction of Tehran over the last four decades succeeds to simulate specified tested growth years at a high precision level. Some real data layer have been used in the CA simulation training phase such as 1990 while others used for testing the prediction results such as 2001. Next step includes running the developed CA simulation over classified raster data for forty years in a developed .An ArcGIS extention has been developed to defined a set of rules and calibrated based on real urban growth pattern. Uncertainty analysis is performed to evaluate the precision of the simulated results as compared to the historical real data. Evaluation shows promising results represented by the high average accuracies achieved.Some scenarios have been tested and selected a suitable scenario with hight precision. The average precision for the predicted growth images 1975 and 2001 is over 80 %. Modifying CA growth rules over time to match the growth pattern changes is important to obtain accurate simulation. This modification is based on the urban growth relationship for Tehran over time as can be seen in the historical raster data. The feedback obtained from comparing the simulated and real data is crucial in identifying the optimal set of CA rules for reliable simulation and calibrating growth steps.

Keywords: Cellular Automata, GIS,Urban growth,simulation

1 Introduction

Cities and urban development in general emerge from the bottom up andthe spatial order we see in patterns at more aggregate scales can be explained only in this way. The way we simulate such emergence is by representing the basic elements or atoms of the city in two distinct but related ways: through cells which represent the physical and spatial structure of the city and trough agents which represent the human and social units that make the city work [10]. This dissertation will investigate the first way; the cells, which is based on the simulation of the city by using the Cellular Automata (CA) algorithm. CA offer an interesting and innovative approach to the study of urban systems. In recent years there has been a prolific application of CA [7] .This process leads to surprising events to emergent structures not directly obvious of their process but hidden within their mechanism new forms of geometry associated with fractal patterns and chaotic dynamics-all are combined to provide theories that are applicable to highly complex systems such as cities. The employment of CA in urban simulations often entails substantial departures from the original formal structure of CA described by von Neumann, Ulam, Conway, and Wolfram. Although the application of CA to urban systems seems natural and intuitive, this is not in itself sufficient justification for their use [4] .Cellular Automata (CA) can be referred to as one of the Artificial Intelligence (AI) tools[6]. The definition of CA rules is still a research issue, despite the emergence of CA as a powerful visualization tool in urban growth simulation [2]. Urban CA is developed largely through trial and error which makes the CA models essentially heuristic [10].

[1] .Cellular Automata

2 The use of CA Model in urban studies

Most geographical theories are static, assuming that the interactions of their agents take place in a market that remains in a state of equilibrium; this assumption is far from being reasonable,as all cities are continually undergoing changes. This fact makes imperative the use of dynamic models, based on the processes that occur in the territory [9]. The great attraction of CA is the fact that many classes of system dynamics can be simulated through it;another important feature of CA is its ability to give equal weight to the importance of space,time and system attributes[2]. The natural ability that CA have to representcomplex systems with spatial/temporal behaviors from a small set of simple rules and states made this technique very interesting for geographers and urban researchers. CA are intrinsically spatial and they are used to model a wide range of phenomena due to its ability to represent spatial process, from forest fires to epidemics, from traffic simulation to regional-scale urbanization, polycentricism, gentrification, historical urbanization, urban growth, form and location [5]. CA-based modeling also allows the integration of socio-economic and natural systems models in a detailed and realistic way [9]. There are three main classes of urban CA models, for three different purposes, not mutually exclusive, that are a direct result of the exploration of modifications of the formal CA: (1) models designed to explore spatial complexity, (2) models designed to research themes of economical,sociological and geographical areas; and (3) models designed to produce operational tools for planning [5].

3 Tehran CA Urban Growth Simulation

This section describe the design and implementation of CA algorithm to simulate the urban growth of real city namely, Tehran-Iran. The simulation process of a real city will go through many processes starting from analyzing the area of study, data processing,CA algorithm design and implementation and finally evaluation of the simulation results.

3.1 Case Study Area

Tehran city in the center of Iran has been selected for this studyTehran located at latitude 39°N and longitude of 50°W. The fact that Tehran city is the main city in Iran makes it the center of economical development. This result in large urban development over the last four decades. The accelerated urban development raises the need of simulating the growth pattern to help the municipalities in planning the proper distribution of infrastructure services. The social importance of our work is to understand the urban growth pattern over Tehran.

3.2 Data Preparation

The data that has been used for the urban growth simulation included three historical satellite images covering a period of Fourthy years. These raw images include one 60 m resolution MSS image (1975) and four 30 m resolution TM images (1990 and 2001). The images are geometrically rectified to the same projection of Universal Transverse Mercator (UTM) zone 39N. Projected images are registered to spatially fit over each other using a second order polynomial transformation function and 15 well defined control points. Registration errors are very small represented by values far less than one pixel.

3.3 The Classification of Sattellite Images

After the images were geometrically rectified and registered spatially to each other, the next step to prepare the images as inputs to the CA simulation algorithm is image classification. Six classes are defined based on maximum likelihood classification system (1976):water, road, commercial, Green area where land has been covered by forest area, residential areas and Non_Urban areas. Commercial and residential classes will be combined after the simulation as one class called urban.Ground reference data sources including orthophotographs classification maps are used for identifying the land cover classes and for training and testing data collection. Maximum likelihood classification method is used for supervised classification. Classification precision report is prepared for each classified image using the testing data to check the quality of classification. Results indicate high precision level of classification above 75%.

3.4 Implementation of CA algorithm in GIS Environment

In this section we will discuss the detailed process of design and implementation of CA algorithm in ArcGIS 9.2 programming environment to simulate the urban growth in Tehran over forty years.
At the first the oldest classified image 1975 is selected as an input for CA urban simulation. For each growth simulation step, a new empty achromatic raster image with the same size as the input classified image (1975) of 526*526 pixels is created that is presented in Fig.1. A 3x3 Moore neighborhood is used in the simulation process. The updated center pixel is determined as a function of current state of center pixel and the states of the neighborhood pixels. The output image of one growth step is used as input for the next growth step to have accumulative urban growth. Ground truth images 1990 is used for training to calibrate the CA rules and growth step while ground truth images of 2001 ise used for testing purposes only. The simulated CA image for the first ground truth (1990) is obtained after running the CA algorithm using different scenarios of CA rules and growth steps to accumulate the growth to this date. Growth step and CA rules are calibrated through testing the scenarios results' by comparing them to the ground truth of image 1990 and select the growth step and CA rule with minimum simulation error. Once the calibrated step and CA rules are obtained, they are used to run the simulation to predict the growth for year 2001.

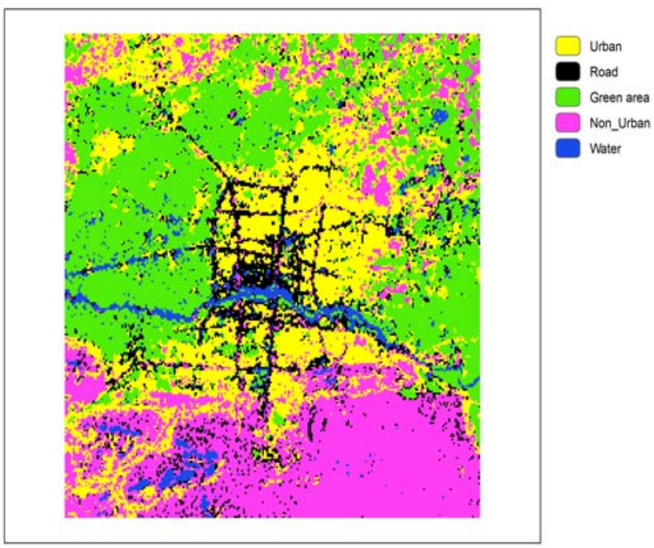


Fig. 1. Tehran ground truth for 1975

Many scenarios are tested to tune the CA rules and investigate the precision of them and now we will only mention here the two scenarios used for rules which have got the highest precisio to run the simulation from 1975 to 1990 for the updated rules .

Scenario 1:

1. IF tested pixel under consideration is water, THEN no growth is allowed at this pixel.
2. IF tested pixel under consideration is road, THEN no growth is allowed at this pixel.
3. IF tested pixel under consideration is residential OR commercial (Urban), THEN keep this pixel the same without any change.
4. IF center pixel under consideration is (Green Area) AND there are 4 Urban pixels in the neighborhood, THEN change center pixel to Urban .

Scenario 2:

1. IF tested pixel under consideration is water, THEN no growth is allowed at this pixel.

2. IF tested pixel under consideration is road, THEN no growth is allowed at this pixel.
3. IF tested pixel under consideration is residential OR commercial (Urban), THEN keep this pixel the same without any change.
4. IF center pixel under consideration is (Green Area) AND there are 3 Urban pixels in the neighborhood, THEN change center pixel to Urban

The simulated image is evaluated base on equation (1),(2) and (3) and compared to the 1990 ground truth image for updating the rules. Table 1 and Table 2 summarizes the comparison between simulated and ground truth of 1990 images for scenario 1 and scenario 2 and Fig.2 shows Tehran ground truth and CA simulated images for 1993 base on scenario 2.

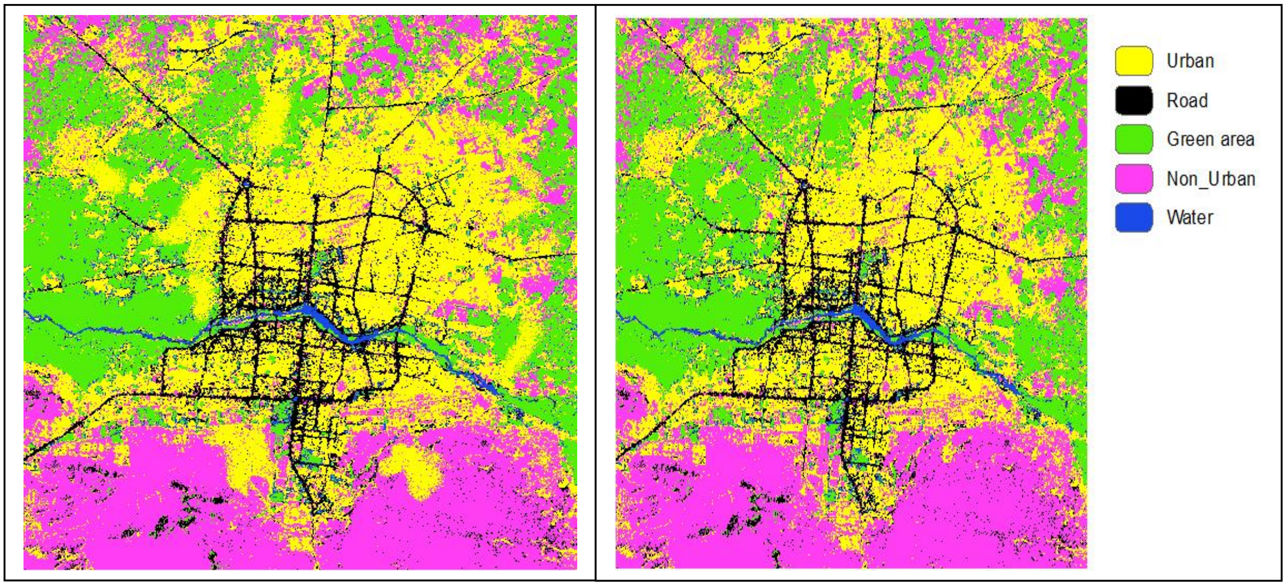
Urban= (Commercial + Residential) **(1)**
Error = (Urban_simulated) - (Urban_real) **(2)**
Precision (%) = 100- abs ((Urban_simulated) - (Urban_real)/(Urban_real)* 100%) **(3)**

Table 1. Scenario 1 CA simulation evaluation results of year 1990

Region	1990 Ground Truth (Urban)	1990 simulated (Urban)	Error	Precision(%)
Tehran	95616	120571	24955	73.90

Table 2. Scenario 2 CA simulation evaluation results of year 1990

Region	1990 Ground Truth (Urban)	1990 simulated (Urban)	Error	Precision(%)
Tehran	95616	106301	24955	88.82



1990 simulated 1990 Ground truth

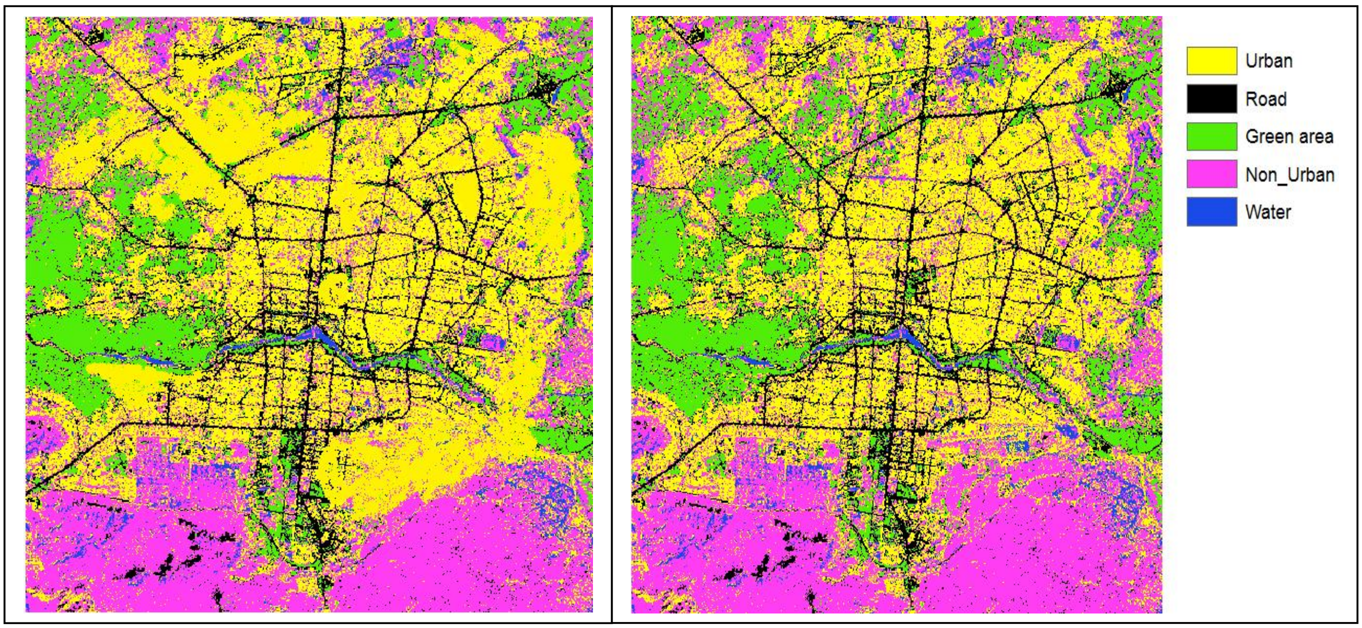
Fig. 2. Tehran ground truth and CA simulated images for 1990 base on Scenario 2

Due to the good results achieved by scenario 2, we decided to go with scenario 2 to simulate the growth from 1990 to the year 2001. Scenario 2 is used as well to continue the simulation to predict growth for year 2001 based on the same rules. Table 3 summarizes the urban growth prediction evaluation results based on scenario 2 for year 2001 and Fig.3 shows Tehran ground truth and CA simulated images for 1993 base on scenario 2.

Table 3. Scenario 2 CA simulation evaluation results of year 2001

Region	2001 Ground Truth (Urban)	2001 simulated (Urban)	Error	Precision(%)
Tehran	103070	117560	14490	85.90

The precision achieved for the predicted year 2001 of 85.90% is encouraging for such long term prediction of 11 years interval.. Based on the CA simulation strategy we used to predict 2001, future prediction of Tehran urban growth can be simulated. Such prediction will help municipalities identify the future growth trend and design the sustainable infrastructure plans to accommodate such trend.



2001 Simulated 2001 Ground Truth

Fig. 3. Tehran ground truth and CA simulated images for 2001 base on Scenario 2

Conclusion

To conclude, it is worth noting that urban models span both theory and practice and that their rationale depends on developing new theory as well as their use in policy-making and planning. This tends to confuse and conflate their development as the same class of model is often used for both. Traditional land use models are the most applied and the most parsimonious,and are still the dominant model used in practice. This is largely because they attempt to be comprehensive in simulating location and interaction,land use and transport. But in this they sacrifice detail and process. They are largely non-dynamic and in a world where change is to the fore, this limits their applicability. The rise of more micro-dynamic CA models clearly attempts to meet this challenge and in-so-far as these models are being applied, they tend to concern more particular processes in cities such as segregation, housing market policies, pedestrian movement and related behaviours. What has happened however is a broadening of styles and model types. It is worth noting too that at the edge of this domain, there are many computer methods, in GIS for example, that in some circumstances might be considered as ‘models’ which blur into the model types reviewed here.

CA urban growth simulation and prediction of Tehran city over the last Four decades succeeds to simulate specified tested growth years at a high precision level however the interval time of satellite images of has got stronge effect on predicate percision. Some ground truth images have been used in the CA simulation training phase such as 1990 while 2001 used for testing the prediction results . Calibrating the CA growth rules is important through comparing the simulated images with the real ground truth to obtain feedback. An important notice is that CA rules need also to be modified over time to adapt to the urban growth pattern. The evaluation method used on region basis has its advantage in covering the spatial distribution component of the urban growth process.This investigation shows that Tehran has got a noticeable growth in urban area and it can be anticipate that the rate of urban growth will be more rapid rather than previous years .

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