Excellent approach to modeling urban expansion by Fuzzy Cellular Automata – Agent Base Model

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Abstract:

Recently, the interaction between humans and their environment is the one of important challenges in the world. Land-use/cover change (LUCC) is a complex process that includes actors and factors at different social and spatial levels. The complexity and dynamics of urban systems make the applicable practice of urban modeling very difficult. With the increased computational power and the greater availability of spatial data, micro-simulation such as the agent based and cellular automata simulation methods, has been developed by geographers, planners, and scholars, and it has shown great potential for representing and simulating the complexity of the dynamic processes involved in urban growth and land use change.

This paper presents Fuzzy Cellular Automata in Geospatial Information System and remote Sensing to simulated and predicted urban expansion pattern. These FCA-based dynamic spatial urban models provide an improved ability to forecast and assess future urban growth and to create planning scenarios, allowing us to explore the potential impacts of simulations that correspond to urban planning and management policies. A fuzzy inference guided cellular automata approach. Semantic or linguistic knowledge on Land use change is expressed as fuzzy rules, based on which fuzzy inference is applied to determine the urban development potential for each pixel.

The model integrates an ABM (agent-based model) and FCA (Fuzzy Cellular Automata) to investigate a complex decision-making process and future urban dynamic processes. Based on this model rapid development and green land protection under the influences of the behaviors and decision modes of regional authority agents, real estate developer agents, resident agents and non- resident agents and their interactions have been applied to predict the future development patterns of the Erbil metropolitan region.

Key Word: Fuzzy Cellular Automata, Agent - Base, Enhancement, Urban Expansion.

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1. Introduction:

Understanding urban land use change is a crucial prerequisite for effective urban planning. This holds for growing and expanding cities, a well-studied process. Cities play a crucial role in our lives, providing habitats for over half of the world's population [2, 3]. However, understanding such systems is extremely complex as they are composed of many parts, with many dynamically changing parameters and large numbers of discrete actors interacting within space. Understanding the urban growth process is very important in the urban planning, urban management, and policymaking process [5,7,10]. Through a better understanding of the mechanism of urban development process, the urban planner and manager could be able to reduce the risk of making wrong or bad decisions and enhance the effectiveness of new plans. Researches set up many models and invent many assistant tools to get a better understanding of the urban expansion phenomena. With the help of models, which are the simplified or abstracted representation of the real city, researchers and urban planners are trying to study the urban development process thoroughly [2,8,11]

The aim of the project in which the presented modeling study is embedded is to develop management strategies for the shrinking town Erbil to become more model-efficient. In this research, new CA model will be developed and implemented to study the urban growth and urban form changing process in Erbil city, Kurdistan region, IRQ. The approach is applied to model the growth of the city over a period of 40 years from 1980 to 2020.Master plans will be translated into the model structure to regulate the model developing as it was in the real world guiding the urban development. After implementation of the CA – ABM model, it will generate some urban form scenarios and thus being assessed to check its usability of being used as an assistant tool for urban planning.

Since Erbil city's development varied very much in four periods, from the start of 1980s to the start of 1990s and from the start of 2000s to the end of 2012s, in spatial pattern and temporal aspect, to present the two different periods of development, the CA - ABM model will use different parameter setting for the two periods.

2. Study area

Erbil City is located in the north of Iraq. Erbil Province borders Turkey to the north and Iran to the east. Erbil composes with both Dahuk and Sulaymaniyah, the area run by the Kurdistan Regional Government (KRG). The City of Erbil is the capital of both Erbil Province and the KRG (OCHA and UNAMI, 2009). Mountains predominates the landscape towards the north east of the province; the relief in the southern part is rather plain, whilst the middle section is more undulated. Erbil City located 316 km north of Bagdad and 80 km west of Mosul, and has road networks to Mosul to the west, Tikrit and Baghdad to the south-east, and the frontier of Iran to the north-west. Urban life at Erbil City can be dated back to at least 6000 B.C. and it is one of the oldest continuously inhabited cities in the world. Erbil City was a major trading center on the route between Baghdad and Mosul, a vital role that it still plays today with significant road networks to the outside world. The chosen study area is bounded by the coordinate from 405662.457926 m to 414992.977578 m easting and from 3999003.137635 m to 4009674.249192 m northing, in zone 38N according to UTM cartographic coordinate system (Fig. 1). The population density of Erbil municipality and Erbil District is 135.5 (persons/krn") and 472.9 (persons/krrr') respectively. Population growth in urban areas has a direct influence on the use of land, transportation, education, recreational, and places enormous need for housing and infrastructure (Bhaskaran et al., 2010).

3. Data / software used

The following data and software were used in the framework of this study:

3.1 Satellite data

LANDSAT Enhanced Thematic Mapper (ETM) data in digital format were preferred over other satellite data due to the availability of three near- to mid-infrared bands, extremely useful for terrain and lineaments analyses. Furthermore, as LANDSAT ETM provides eight co-registered spectral channels (one panchromatic with 15 m spatial resolution, six bands ranging from visible to mid-infrared with 30 m spatial resolution, and one thermal band with 60 m spatial resolution), this permitted a large spectrum of band combinations, useful in visual interpretation of different features. In view of the LULCC of the study, LANDSAT ETM data were selected as acquired in the different years, to evidential features (vegetation, soil changes) related to the occurrence of environmental changes by too much vegetation. Six LANDSAT scenes fully covered the study area, but another four were also available, acquired in different months and/or years. The LANDSAT data used in the study are listed in below table.

Table 1: Erbil's LANDSAT data

Path	Row	Date of acquisition
168	36	20/06/1984
168	36	15/06/1990
168	36	10/06/2000
168	36	25/06/2010

Erbil's Available Data and Pre-processing
The list of available data includes:

- Urban Land Cover for 1990, 2000 and 2010
- Land Cover Map (LCM) classification for 1990, 2000 and 2010
- Classified Road Network for 1990, 2000 and 2010
- DEM

3.2 Software
The following software we will use:

For geo – referencing and general image processing we must work with ENVI 4.8. We work with ERDAS 10 for visual analysis and interpretation IDRISI for operating CA Modeling and ArcGIS 9.3 for GIS data acquisition, analysis and presentation.

4. Methods and Materials:

Prediction of Urban Growth and Land Use Change using CA Transition Rule

A suitability map was used to estimate the annual demand of land for urban development depending on the historical growth of Erbil city. The evolution of a cell was determined by the suitability value and the number of cell that were developed. The cells were then calculated to establish how many cells had attained a particular state of a time transition rule [1,4,9]. Cell are allocated to a particular state by selecting them from the set of available (the cells which can undergo transition) cells that are spread over the city [29].

$$u_{i,j}^{t+1} = f(u_{i,j}^{t}, \Omega_{i,j}^{t}, S_{i,j}^{t}) \quad (1)$$

Where,

$u_{i,j}^{t+1}$ = the state of the cell at row i and column j at time t+1;

$u_{i,j}^{t}$ = the state of the cell at row i and column j at time t;

$\Omega_{i,j}^{t}$ = the development of cells within the neighborhood of the cell at row i and column j; and,

$S_{i,j}^{t}$ = the suitability score for the cell at row i and column j for urban development.

In the above equation, the function f is formulated using IF, THEN and ELSE statements as shown in Equation 1. The repeated application of this rule produced a complex spatial pattern.

IF ($S_{i,j}^{t} * \Omega_{i,j}^{t} \geq$ threshold value); (2)

Then $u_{i,j}^{t+1}$ = urban;

Else $u_{i,j}^{t+1}$ = non-urban.

The knowledge base is represented as linguistic "IF…THEN" rules, connecting hypotheses to conclusions through a certainty factor. The most frequently used inference engines are classified into the stages of aggregation, implication and accumulation. Aggregation returns the fulfillment of the hypothesis for every rule individually [29]. Implication combines aggregation's result to the rule's certainty factor (CF) resulting to the degree of fulfillment for each rule's conclusion. Finally accumulation corresponds to compromising different individual conclusions into a final result.

Fuzzy logic with CA could design a useful framework for modeling and simulate the urban growth dynamics [11,20,6]. Fuzzy Cellular Automata Urban Growth Model (FCAUGM) is generally capable of simulating and predicting the complexities of urban growth. Trends and characteristics of an urban environment was shown in perfect style by this method because, one of the novelties of this model is the design and development of a set of transition rules based on fuzzy set theory rather than probability theory [1,29,8,10].

To simulating Erbil urban Growth Model (EUGM) in this mode we could replicate realistically the spatial dynamics and processes of urban growth, several transition rules were developed. These are classified in four stages: **a)** by identifying spatially-based factors, **b)** by creating “driving forces” for urban growth, **c)** by identifying and using Erbil's transportation Network shape and **d)** by creating optimum scale factor for Erbil's Developed Pixels (EDP). In Erbil's FCAUGM by using Fuzzy Logic, urban variables that consist of partially factors overlapping qualitative fuzzy sets. Each fuzzy set is described by a linguistic variable familiar to its quality while quantitative (numerical) information is appointed to the proper fuzzy sets by the correspondent membership function.

FCAUGM model gives the evaluation closer to the complex reality of Erbil's expansion patterns. Assignment of the weights to the different indicators can be taken into consideration in an environmental impact using fuzzy logic, in order to obtain a significant homogeneity and objectivity. Direct employment of fuzzy logic lies in the way knowledge is captured, i.e. by employing man-made rules. The construction of a manual, expertly guided rule-base is a complex task due to the presence of a high number of inter-dependent variables.

Table 2: The factors and scores effect of the transition rule

Suitability factors	
High Suitable	4
Suitable	3
Moderate Suitable	2
Less Suitable	1
Unsuitable	0
Land use Factors	
Urban land	4
Exclusive land	0
Non – urban Land	1
Green areas	0
Other land use	0

5. Conclusions:

Effective and efficient planning of an urban environment requires information about growth trends and patterns amongst other important information. Many urban growth models have been developed over the years and have been used in the developed countries for forecasting growth patterns. In the developing country however, there have very few studies showing the application of these models and how they perform differently. Erbil City is located in the north of Iraq. Erbil Province borders Turkey to the north and Iran to the east. Erbil composes with both DUHOK and SULYMANIEH, the area run by the Kurdistan Regional Government (KRG). According to the plan of Erbil, parameters such as distance from transport networks, distance from residential areas, distance from the green spaces, urban density, and elevation used to urban growth simulation in FCA model.

Some of its characteristics (fixed driving factors, neighborhood filter rules, etc.) may complicate its application and lower the quality of reconstructions. The best results were achieved when moderate changes were considered. The quality of reconstructions was poorest when periods or classes with exceptionally high or low variability of land-use were considered. The application of historical and archeological data for calibration and validation of reconstructions is desirable if realistic reconstructions of the development of the cultural landscape are expected. Based on following suggestions we could design best model to simulate Erbil city.

1. In this method the problem was about low resolution (30m) property of Landsat images which makes the classification difficult. Moreover beside the properties of the Landsat image the study area which includes many heterogeneous areas make the classification with Landsat images difficult. Erbil city's development varied very much in two periods, from the start of 1980s to the start of 1990s and especially from the start of 2000s to the end of 2012s (social - economical parameters are very important), in spatial pattern and temporal aspect, to present the two different periods of development, the CA - ABM model will be useful rather than CA model because, agents have strong effected on Erbil's urban model.

2. Transportation network in Erbil has circle form. CA model couldn't completely simulate the rules of transportation network, because; as I said before after 2000s Erbil has shown rapid expansion based on agents.
3. In this method the problem was about low resolution (30m) property of Landsat images which makes the classification difficult. Moreover beside the properties of the Landsat image the study area which includes many heterogeneous areas make the classification with Landsat images difficult.
4. A few policy scenarios for baseline development, rapid development and green land protection under the influences of the behaviors and decision modes of regional authority agents, real estate developer agents, resident agents and future agents and their interactions must be apply to predict the future development patterns of the Erbil metropolitan region.

10. References:

[1]: Al- Ahmadi ,K , See, L, , A ,& Hogg, J. (2008).Calibration of a fuzzy cellular automata model of urban dynamics in Saudi Arabi Ecological Complexity.(2008), doi:10.106/j.ecom.2008.09.004a .

[2]: Almeida, C.M., B.S. (2008).Using neural networks and cellular automata for modeling intra-urban land-use dynamics. International Journal of Geographical Information Science, 22(9), 943 963

[3]: An, L., 2012. Modeling human decisions in coupled human and natural systems: Review of agent - based models. Ecol. Modell. 229, 25–36.

[4]: Arsanjani, J.J., Helbich, M., Vaz, E.D.N., 2013. Spatiotemporal simulation of urban growth patternsusing agent-based modeling: The case of Tehran. Cities32, 33–42.

[5]: Batty, M. (2005).Cities and Complexity Understanding Cities with Cellular Automata Agent-based Models and, Mass., MIT Press.

[6]: Benenson, I. and P. M. Torrens, 2004. Geosimulation: Agent-based Modeling of Urban Phenomena. John Wiley and Sons, Ltd, London.

[7]: Brown, D. G., S. E. Page, R. L. Riolo, et al., forthcoming. Agent-based and Analytical Modeling to Evaluate the Effectiveness of Greenbelts. Environmental Modelling & Software

[8]: Brown, Daniel G., Riolo, Rick, Robinson, Derek T., North, M., and William Rand (2005) "Spatial Process and Data Models: Toward Integration of Agent-Based Models and GIS" Journal of Geographical Systems, Special Issue on Space-Time Information Systems 7(1): 25-47

[9]: Chen, Q., Mynett, A. E. (2003).Effects of cells size and configuration in cellular automata-based prey-predator modeling Simulation Modeling Practice and Theory, 11, 609-625.

[10]: Crooks, A.T. (2006), 'Exploring Cities using Agent-Based Models and GIS', in Sallach, D., Macal, C.M., and North, M.J. (eds.), Proceedings of the Agent 2006 Conference on Social Agents: Results and Prospects, University of Chicago and Argonne National Laboratory, Chicago, IL, Available at

[11]: Dietzel, C., Herold, M., Hemphill, J.J., Clarke, K.C., 2005. Spatio-temporal dynamics in California's Central Valley: Empirical links to urban theory. Int. J. Geogr. Inf. Sci. 19, 175–195.

[12]: Edmonds, B., Moss, S., 2005. From KISS to KIDS - An 'anti-simplistic' modelling approach, in: Davidsson, P and Logan, B and Takadama, K (Eds.), Multi-agent and multi-agent-based simulation. Springer, Berlin, Germany. pp. 130–144.

[13]: Gaube, V., Remesch, A., 2013. Impact of urban planning on household's residential decisions: An agent-based simulation model for Vienna. Environ. Model. Softw. 45, 92–103.

[14]: Gilbert, N., 2004. Agent-based social simulation : dealing with complexity. Complex Syst. Netw. Excell. 9, 1–14.

Grimm, V., Revilla, E., Berger, U., Jeltsch, F., Mooij, W.M., Railsback, S.F., Thulke, H.-H., Weiner, J., Wiegand, T., [15]: DeAngelis, D.L., 2005. Pattern-oriented modeling of agent-based complex systems: lessons from ecology. Science 310, 987–91.

[16]: Huang, Q., Parker, D.C., Filatova, T., Sun, S., 2014. A review of urban residential choice models using agent-based modeling. Environ. Plan. B Plan. Des. 40, 1–29.

[17]: Lanes, S. Andres M. Garcia, David Miranda, Rafael. Cellular automata models for the simulation of real-world urban processes: A review and analysis. Landscape and Urban Planning 96 (2010) 108–122

[18] L. Wang, H. Hu, X. Zheng, J. Deng and G. Ning, “Study on LUCC Based on Vector Date Source Using the CA-Markov Model,” 2010. www.ieee.org

[19]: J. J. Arsanjani, M. Helbich, W. Kainz and A. D. Boloorani, “Integration of Logistic Regression, Markov Chain and Cellular Automata Models to Simulate Urban Expansion,” International Journal of Applied Earth Observation and Geoinformation, Vol. 24, 2012, pp. 265-275.

[20]: J. R. Eastman, “IDRISI Selva, Guide to GIS and Image Processing,” Clark Lab, Clark University, Worcester, 2013.

[21]: Moreno, N. & Marceau, D. J. (2007).Performance assessment of a new vector-based geographic cellular automata model .Proceedings of the International conference on Geo-Computation, 3 - 5 September 2007.Maynooth, Ireland.

[22]: Moreno, N. (2008a). : a vector-based geographic cellular automata model allowing geometrical transformations of objects. Environment and Planning B: Planning and Design, vol. 35.

[23]: Moreno, N. (2008).A vector-based geographical cellular automata model to mitigate scale sensitivity and to allow objects’ geometric transformation, University of Calgary, 20266.104

[24]: Schwarz, N., Haase, D., Seppelt, R., 2010. Omnipresent sprawl? A review of urban simulation models with respect to urban shrinkage. Environ. Plan. B Plan. Des. 37, 265–283.

[25]: Torrens, P.M. (2014) “Animating peoplescapes in urban models”. In GeoComputational Analysis and Modeling of Regional Systems, S. Dragićević & J.-C. Thill, J.-C. (Eds.) New York: Springer. Forthcoming.

[26]: Torrens, P.M. (2014) “Geographical agents in three dimensions”. In Geocomputation: A Practical Primer, Singleton, A. & Brunsdon, C. (Eds.) London: Sage (in press; book is here)

[27]: Torrens, P.M. (2014). "High resolution space-time processes for agents at the built–human interface of urban earthquakes", International Journal of Geographical Information Science, 28(5): 964-986

[28]: X. Li and A. G-O. Yeh,―Neural-network-based cellular automata for simulating multiple land use changes using GIS, Geographical Information Science, vol. 16, no. 4, pp. 323-343, Nov. 2010.

[29]: Yan .L. (2009).Modeling urban development with geographical information systems and cellular automata. CRC Press

[30]: Voinov, A., Seppelt, R., Reis, S., Nabel, J.E.M.S., Shokravi, S., 2014. Values in socio-environmental modelling: Persuasion for action or excuse for inaction. Environ. Model. Softw. 53, 207–212.