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The dynamic of an urban cellular automata in a 3-D spatial pattern

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Abstract

The cellular automata method is a useful tool for analyzing discrete spatio-temporal dynamics. However, the method holds a disadvantage due to the difficulty of representing variation of density and mix of the land uses. To overcome this obstacle, I have proposed an approach based on a 3-D spatial pattern. This rule of dynamics is similar to that utilized by White, Engelen e Uljee (1997). In order to demonstrate the results related to the use of a 2- and 3-D pattern, the paper sets out the proposed model and the experiments which were carried out within specific theoretical contexts. Conclusions are drawn on the utility of the present approach.

Introduction

A cellular automata dynamic is usually based on a one or two dimensional spatial pattern. But when this method is utilized to analyze the urban spatial dynamic, it is difficult to include important parameters, such as variation of density and the mix of land use. Although this obstacle can be overcome by using a set of continuous variables related to the cell (Semboloni, 1999), the current paper proposes a different approach based on a 3-D spatial pattern. This approach has already been used to study "game of life" in a 3-D spatial pattern (Bays, 1988). In the current situation, the rules proposed by White, Engelen and Uljee (1997) will be adapted to a 3-D spatial pattern.

When the third dimension is included, it is possible to vary density while maintaining discrete variables. A varying density produces results that are quite different from those obtained with constant density. To demonstrate these differences, the paper includes the results of the model and a comparison of clusters that occur when using 2 or 3-D spatial patterns.

AC dynamic in a 3-D spatial pattern

Spatial pattern is conceived as a cubic grid. Each cell of this grid takes 7 states: commerce (1), industry (2), housing (3), vacant (4), river (5), railway (6), and road (7).

A cell in a state that ranges 1-3 is considered as a built cell. In this case, the states are related to the activity that is carried out within each building. Three indexes identify a cell c_{ijk}. The first two indexes i and j, relate to the position on the plane; the third one, k, represents height of the cell if the cell is built, or, otherwise stated, the floors number of the building as follows: $k = 1$ represents the ground floor, $k = 2$ the first floor of the building and so on. Only a cell with $k = 1$ may take states ranging from 5-7.

Obviously a cell with $k > 1$ cannot be built if the underlying cell is not already built. Building cost is related to each cell and changes with k. In addition for each activity, there is also a cost that is related to the floor level on which the activity occurs. In the latter case, if cost increases sensibly with the increasing of k, then built cells with $k > 1$ will become rare.

The method for assigning states to cells is similar to that proposed by White, et al. (1997). Each cell is potentially capable of changing from state p to a state q with $1 \leq p \leq 4$ and $1 \leq q \leq 3$. This potential can be calculated using equation 1. States are assigned by beginning with the maximum potential and continuing until the global quantity of each state, exogenously established, has been reached. The potential ability of transformation from state p to state q in cell c_{ijk} is calculated using the following equation:

$$P_{p,q} = vs_{ijk}(1 + \sum_{r,d} m_{q,r,d} I_d) + H_p - C_k - F_{q,k}, \quad (1)$$

where:

$P_{p,q}$: transition potential from state p to state q in cell c_{ijk};

$m_{q,r,d}$: weight connected to the cells in state r at distance d from c_{ijk} in relation to state q;

$I_d = 1$ if he state of the cell distant d from c_{ijk} is equal to r, $I_d = 0$ otherwise;

H_q: inertia parameter, $H_q > 0$ if $q = p$, otherwise $H_q = 0$;

C_k: building cost for a cell at floor k in case $p = 4$;

$F_{k,q}$: cost related to performing activity q in floor k;

s_{ijk}: difficulty to build in relation to the slope of ground , $0 < s_{ijk} < 1$;

v: disturbance factor, $v = 1 + [-ln(rand)]^\alpha$.

Results of experiments

Simulation has been performed within a theoretical context during 100 iterations. To do this, first the global quantity of each activity is established at each iteration. Then, the model calculates the spatial distribution. In this experiment, the parameters $m_{q,r,d}$ are based on those established by White, et al.(1997); they are shown in figure 1. The maximum number of floors is 10. Parameters C_k and $F_{k,q}$ as shown in table 1.

Table 1: Values assigned to the building cost C_k and to the cost $F_{k,q}$ related to the performing of the activity q on floor k.

k	C_k	$F_{k,1}$	$F_{k,2}$	$F_{k,3}$
1	10	0	0	0
2	9	2	10	5
3	8	2	10	5
4	10	2	10	5
5	14	2	10	5
6	19	2	10	5
7	26	2	10	5
8	35	2	10	5
9	45	2	10	5
10	60	2	10	5

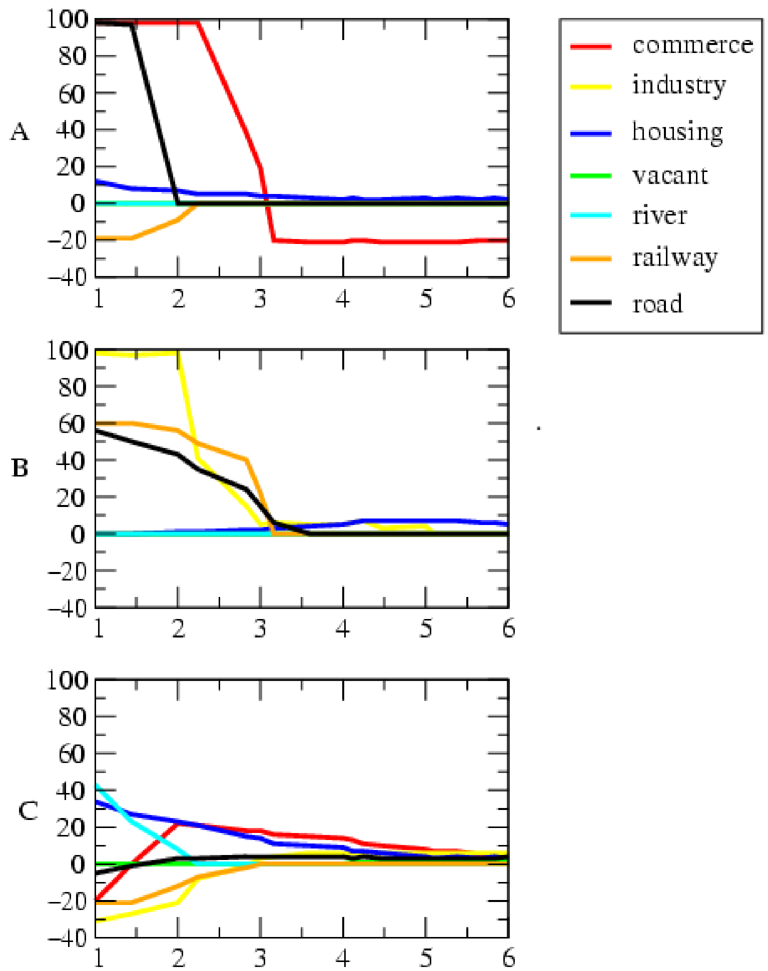

Figure 1: Variation of weights $m_{q,r,d}$. Graph A: X axis, distance (d), Y axis, weight of cell in state r (states are listed in the legend) in connection with commercial activity ($q = 1$). Graph B: Y axis, weight of cell in state r in connection with industrial activity ($q = 2$). Graph C: Y axis, weight of cell in state r in connection with residential activity ($q = 3$).

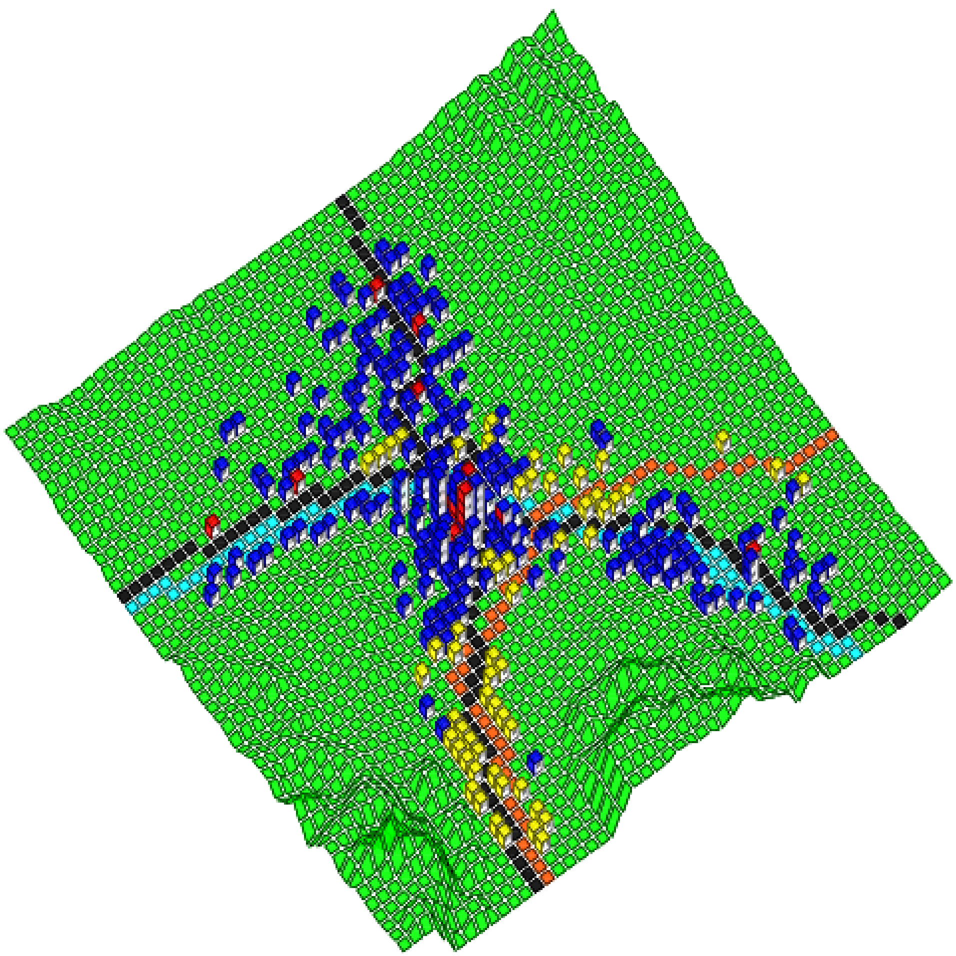

Figure 2: Axonometric view of the cluster after 50 iterations.

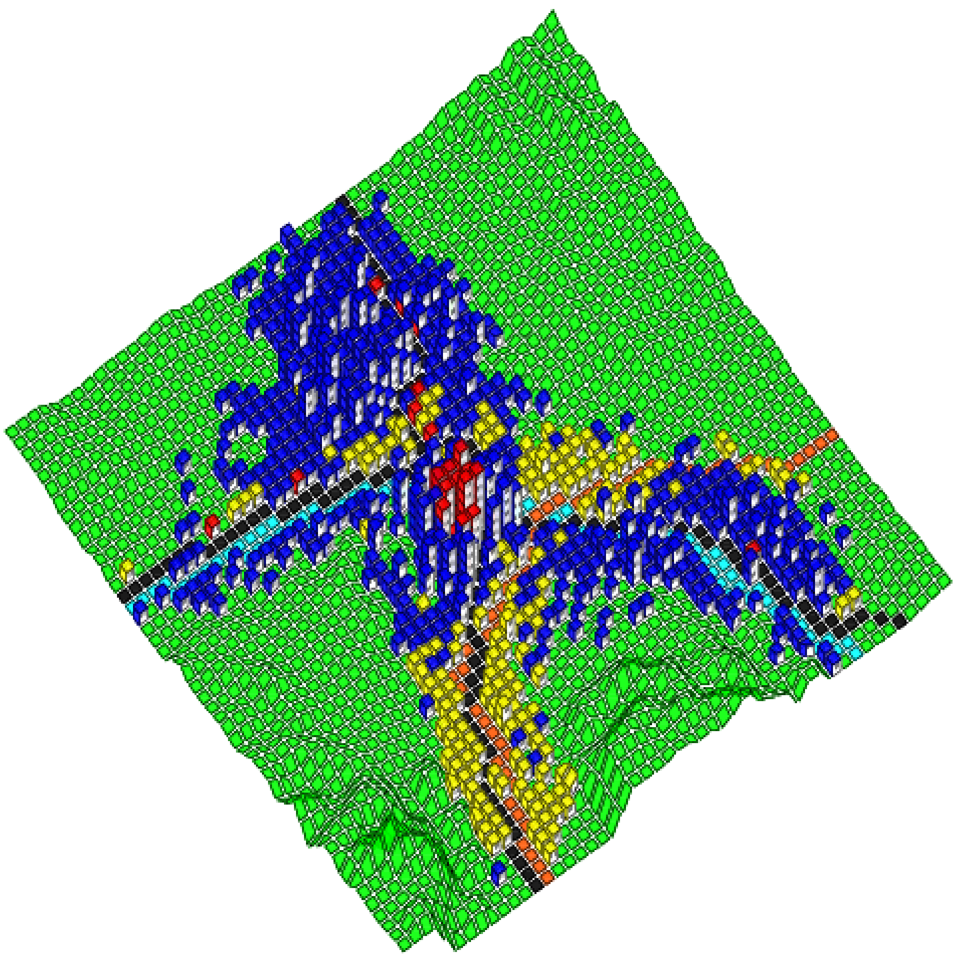

Figure 3: Axonometric view of the cluster after 100 iterations.

Results at steps 50 and 100 are shown in figures (figure 2 and 3). Color legend of areas: ground (green), roads (black), railways (orange), and river (magenta). Commercial buildings (red), industrial (yellow), and housing (blue). Activities located in a set of cells that are defined by the constant i e j may vary with k. In order to show this aspect, while the right side of the building remains white, the left side reflects the color which is appropriate to the activity carried out in the floor. The roof color is related to the most frequent activity in the building block.

Differences between 2 and 3-D

In order to consider the effects of three-dimensional parameters, $F_{k,q}$ has been varied by multiplying it by a coefficient f ranging 0.5-2.5. If this coefficient is higher than 2.5, only cells with $k = 1$ are built and, in essence, the resulting cluster will be two-dimensional. If the coefficient is lower than 0.5, cells with $k = 10$ are built.

To adequately examine this problem, the coefficient f, from 0.5 to 2.5., has been varied during a set of one hundred experiments. The resulting clusters have been evaluated by using three indicators:

1. number of built cells;
2. standard deviation of the location of cells around its centroid;
3. concentration of activities calculated by using the average number of the cells having the same activity of the central cell and located in the eight bordering cells.

The results of these experiments, in relation to the established indicators, are shown in figure 4. By increasing the coefficient f, it is possible to increase both the number of built cells and the standard deviation. In such conditions, the activities tend to be more and more dispersed unless industrial activity, because its related cost ($F_{k,q}$) increases sensibly when $k > 1$ (see table 1). On the other hand, the concentration of activities decreases with the increasing of the coefficient.

Clearly, important differences exist in the resulting clusters. These differences depend on the variation of density that are obtained by using the third dimension. Thus, it can be stated that the third-dimension modifies crucial characteristics of the clusters.

Further developments

The model can be upgraded by introducing a further cost characteristic - urban code - in the equation 1. By introducing this element, it is possible to to establish an interaction between the user and the model, and to experiment with a possible evolution path of the cluster in relation to urban plans.

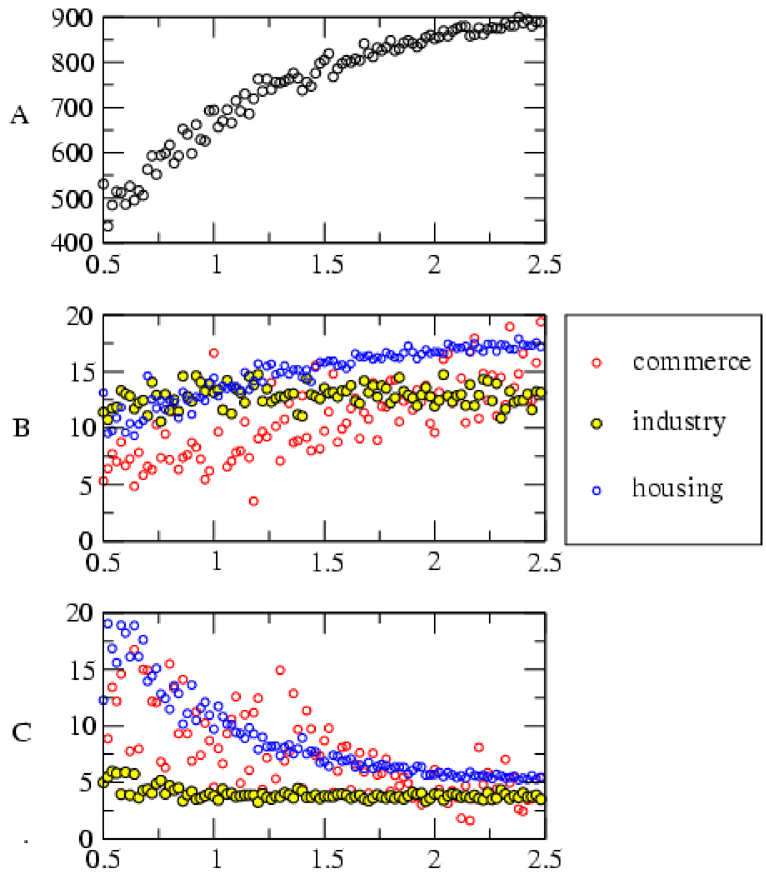

Figure 4: The variation of indicator Y axis, as a function of the variation of coefficient f Y axis. Graph A, built cells; graph B, standard deviation; graph C, average number of cells having the same activity of the central cell and located in the eight bordering cell.

Conclusions

A spatial dynamic within a three-D space has been proposed. The results obtained by varying parameter controlling height of buildings have been compared. In conclusion when a three-dimensional model is applied to an urban context, the results are more realistic. In addition with a 3-D model it is possible to represent the a crucial aspect of urban development within a cluster: variation of density. Furthermore, with this method it is possible to compare results that have been obtained by using coupled map lattices and cellular automata.

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