Abstract: Virtual cities have practically been used in several scenes including 3D games, movies or digital cities on the Internet. We have been developing the system that can generate virtual cities whose cityscape is varied according to local features of land use for each time period. In this paper, we describe the method that makes the features change by using cellular automata. We demonstrate that our method can generate various simulation patterns of land use changes and construct 3D scenes of time-varying virtual cities.

1 Introduction

We have been developing the system to automatically generate virtual cities and simulate urban traffic and pedestrians flow on generated virtual cities[4, 5, 6, 10]. Virtual Cities created on a computer have practically used in various scenes including 3D games, movies, or digital city communities on the Internet[1, 2, 3, 7, 8, 9]. There has been many approaches to generate virtual cities based on maps, CAD data, and pictures of really existent cities[1]. Because these methods cannot generate fictional cities with time-changing, however, it is difficult to apply the method urban planning. In this paper, we propose a method that can simulate land-use change in cities to generate time-varying virtual cities. Our method is based on cellular automata, where interaction among areas to arrange buildings make land-use of each area change.

2 Overview of our virtual city system

2.1 City components

Cities are composed of several artifacts including buildings and roads. We here define the minimum closed area surrounded by roads as a block. Cities can be also regarded as the set of several blocks. In this study, land-use changes by interaction among these blocks. Therefore, we conduct this simulation by using cellular automata where a block is defined as a cell.

We also take account of some properties of roads, by which each block change affects, as shown in Table 1. These properties are given to roads in advance.

2.2 Features of cities

Assuming that a city is the set of blocks and time-varying of the city happens due to changing features of each block, we define the following parameters as the amount of features of the city and blocks.

the economic factor, \( \epsilon(t) \): an economical scale at the \( t \)-th time period, indicating whether the economic condition of the city is booming or not, where \(-1.0 \leq \epsilon(t) \leq 1.0\).

the environmental vector, \( V_i(t) \): the vector, \((l, c, p, d)\), at the \( t \)-th time period for the block, \( i \), where \( l, c \) and \( p \) correspond to the proportion of living, consuming and producing activities, facilitating arranging residence, commerce and labor institutions respectively, where \( 0 \leq l, c, p \leq 1.0 \) and \( l + c + p = 1.0 \).

\( d \) gives how the block, \( i \), is developed, defined as \( d = ta/ba \), where \( ta \) is the total floor areas of all building in the block, \( i \), and \( ba \) is the area size of the block, \( i \).

3 Land-use change simulation

Our simulation method make the environmental vector of each cell change by using cellular automata. Figure 1 gives the algorithm for calculating the environmental vector of the cell, \( i \), for the next generation. Each cell individually fixes the next vector by the algorithm in Figure 1.

(1) select the cell, \( j \in N(i) \)

The cell, \( j \), which has an influence upon the cell, \( i \), is selected with the probability, \( P(j) \), defined as

\[
P(j) = \frac{(d_j)^{k\epsilon(t)}}{\sum_{m \in \mathcal{N}_i} (d_m)^{k\epsilon(t)}},
\]

where \( \mathcal{N}(i) \) is the set of cells adjacent to the cell, \( i \), and \( k \) is the constant value. The selected cell by the equation (1) depends on the economic factor, \( \epsilon(t) \). That is, the cell with higher \( d \) tends to be selected in the economic factor with a higher value, on the contrary, the cell with lower \( d \) tends to be selected in the economic factor with a lower value.

(2) influences on road types

When a part of roads of the cell, \( i \), is special roads such as ones for physical distribution or for commercial use, each value of the environmental vector have some effects.
the develop degree, \( d \)

In Figure 2 it seems to be rather slow to spread influence of road properties. For example, it takes 20 time periods for the influence to reach the entire city. Furthermore, the economic condition is headed for bust, cells near roads become less attractive and start to fall into a decline. In addition, the economic condition is booming up around 0 hour. The larger boom-or-bust degree gives the vector a greater amount of influence of road properties.

### 4 Evaluation

To simulate land-use changes by using our method, we first prepare the 2D road map around Ikebukuro Station in Tokyo, whose area size is a range with 1.4-km sides. The economic factor repeats boom or bust on a 80-time period cycle, as shown in Figure 2.

Figure 3 gives the simulation result. When the economic condition is booming up around 0 ~ 20 time period, a number of cells start to develop and then the influence gradually expands to neighborhood. When the economic condition is headed for bust, cells near roads for commercial use begin to fall into a decline. In addition, it seems to be rather slow to spread influence of economic factor changes to a number of cells.

Figure 4 shows the example 3D scene, where the simulation result of our method is applied to the display module of our virtual city generation system[10].

![Figure 4](https://example.com/figure4.png)  
*Figure 4: The algorithm for calculating the next generation's vector of cell, \( i \).*

in proportion to the absolute value of the economic factor as shown in Table 2. The larger boom-or-bust degree gives the vector a greater amount of influence of road properties.

### 5 Conclusion

In this paper, we have proposed the method to simulate land-use changes for generating time-varying virtual cities. In our method, the block and its features are defined and the features are made change in each time period by using the cellular automata model. We roughly demonstrate that our method can simulate some land-use changes in the real-world road map.

In the real-world city, road properties vary artificially. Our future work consists in expand our method, in which road properties are automatically set. Furthermore, it is important to make the whole system of generation of time-varying virtual cities complete.

### References


