Cellular Automata Based Model of Urban Spatial Growth

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We plan to develop a cellular-automata for simulating future urban growth of a region and emphasize the conditions under which spontaneous growth, such as that which characterizes the regeneration of inner cities and the location of edge cities, can be modelled. To understand the behavior of the urban growth based on the local environment/setups, reserved areas, and other factors that affects the urban growth (about population and construction) expansion, we wish to experiment with various rules of the Cellular Automata.

INTRODUCTION

India has experienced a rapid pace of urbanization in recent years. As the limited land resources in the urban areas diminish, the pressure mounts, which results in an increasing demand for land. This leads to an outward growth of the city thereby transforming the agricultural and forest lands contiguous to the urban areas into built-up areas. This land use land cover conversion is affecting various hydrological and ecological cycles and has become a matter of concern for the climate change, biological and economical sustainability. Thus, there is an urgent need to develop models that can predict future urban growth in accurate manner. These future growth scenarios will help the urban authorities to take preventive measures in a timely manner, for regulating urban growth.

In this report paper we present a handful of models motivated by the aforementioned references and [3]. The paper is organized as follows: First we describe our basic model, the rules and factors taken into consideration. In the next section, we propose several models which are modifications to the basic model for different conditions. Then, we present the results obtained for the models with supporting figures. Finally, the conclusions are presented and references are mentioned.

BASIC MODEL

In this paper, we propose a cellular automata based model for the Urban Spatial Growth. The Urban City is represented by a finite 2 dimensional square matrix, where each square lattice is called a cell. Thus, basically we have 2d array which represents the city. Each cell can have following states.

1. Built-up

Meaning; where already a City is or Construction has already been done.Built-up part has 3 sub parts:

a) Road: Represents road which can be in side or can be outside of the city. We are considering this because distance to road is one of the important factor which can affect the urban growth.

b) City core: Represents some main part of the city which is providing some important resources like market, government offices etc.The exact city core will be hard to define mathematically, but we will try to implement it with some approximations.

c) Normal: Part which is neither road nor a city core, but a normal built up area.

2. Non built up

Area where there is no construction yet, but there is a possibility that it will convert into built up area.

Thus, which built-up area will convert into a built up area; or in other words: what is the probability of particular non-built-up area to convert into built up area is our main point of interest.

3. Restricted

Where there is no chance of construction. That is, it will never convert into the built up area.Like water bodies, government restricted land etc.

Factors affecting how the non-built-up area can convert into a built up area:

1. Physical factors

Physical factor will be measurable, as such how much built up area is there in neighborhood or what is the distance from the nearest road. These factors will be modeled using cellular automata.

2. Social or economic factors

These include the some social factors, like will that particular place be near to his relatives or friends' house or will the place be near to the temple that they visit every day. Some factors such as the neighbors' affluence are also major economic factors that affect the urban growth. This type of factors cannot be measurable nor can be predictable. Hence we will not get into them.

We will only consider the following Physical factors:

1. Contiguous neighborhood.

Signifies how many neighbor cell are in the built- up state. These factor is on the basis of fact that anybody will not make construction in some remote place alone. There must be some already built up area in neighborhood.

2. Distance from Road

Signifies what is the distance of this cell from the nearest cell which is in road stat.This is on the idea that the construction will happen nearer to the roads: a well observed fact.

3. Distance from city core

Signifies what is the distance of this cell from the nearest cell which is in city core stat.This is on the idea that the construction will more likely happen where basic resources or necessities are easily available.

This factor can be questionable as needs can be different for every individual and exact city core is hard to define. But still, it is historically observed fact and also an important factor, so will try to implement it even with some approximate assumptions.

4. Arability of non-built-up area

Signifies how much empty is my neighborhood? Or in other words, how many of the neighbor cells are in the non-built-up stat.

This fact is also questionable as it can be looked as an exact opposite of the first factor (i.e. contiguous neighborhood). Rather it is observed that our built up neighborhood is also not good for new built up. So we will have to consider the effect of both. There should be built up cells in the neighbors, but there shouldn't be too much of them.

Thus, we will first consider each factor separately and then try to combine all of the factors and thereby implement model of Urban Spatial Growth.

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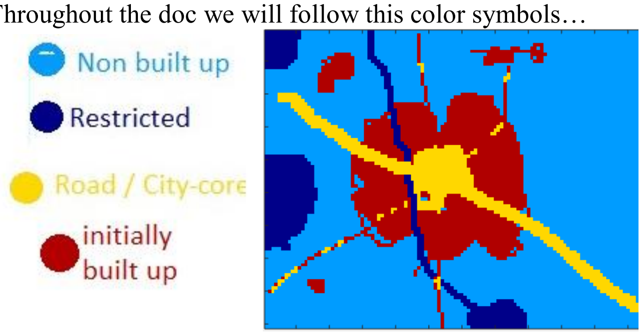


Fig : 2. Here is an example of input image…

* Effect of Contiguous neighborhood and Arability of non built up area.

First we have to define what is neighborhood. For each cell we can take cell which are adjacent to it. This is called 3 x 3 neighborhood.

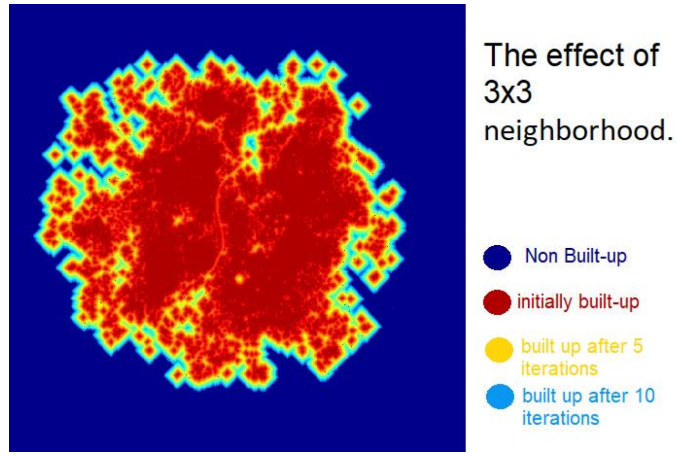


Fig : 3

We can see that we got almost like a boundary of cells around the existing cells in each iteration, which is not more practical.

After performing some experiments and doing some reading we made a decision that 3 x 3 neighborhood is not suitable here, rather 5 x 5 or 7 x 7 is better. As suggested in reference reading we got **7 x 7 neighborhood**.

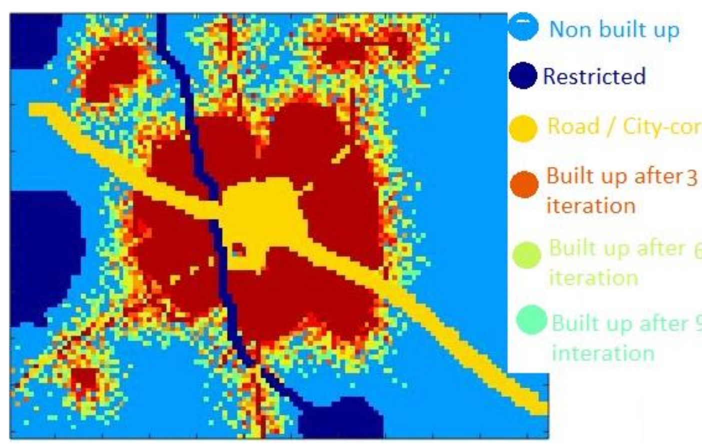


Fig : 4. Effect of 7 x 7 neighborhood.

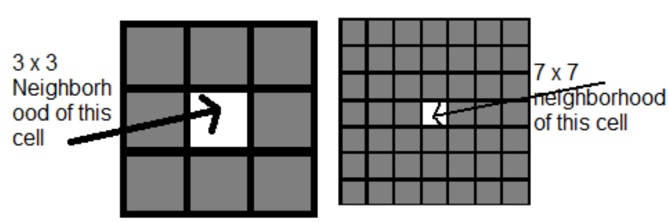


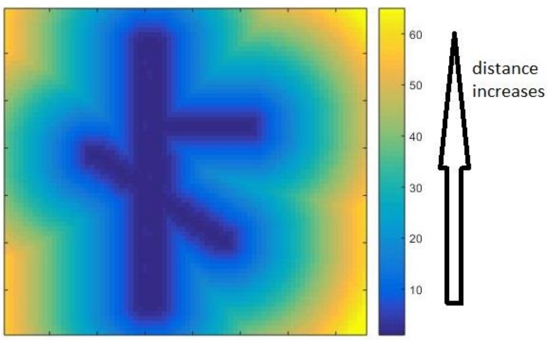
Fig : 5.
7 x 7 is better than 3 x 3 or 5 x 5 for our purpose.

** Effect of distance from city core and distance from road.*

First, for each cell we will calculate the distance from nearest cell which is in road or city core.

We fist define this distance as simple Euclidian distance.

$$d = ((x1-y1)^2 + (x2-y2)^2)^{(1/2)}$$ Fig : 6



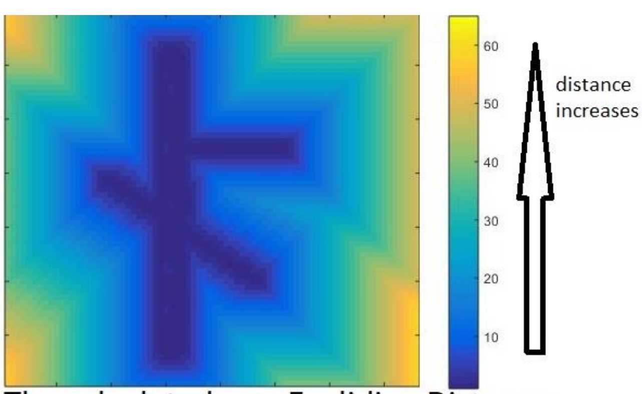
The Calculated Eclidian Distance

Now we have got the distances. But this is not the best equation for our purpose.

Because if you look at how we define neighborhood Fig : 5, All the cell adjacent to the current cell should be at distance 1. But here the diagonal ones will be at 1.4142.

So we have to define the distance in a new way which is as following.

$$d = \max (| x1 - y1 | , | x2 - y2 |)$$ Fig : 7



The calculated non-Euclidian Distance

Considering this distance is natural for this model. So with having this type of distance, let's look at its effect on urban growth.

Fig : 8. Effect of distance to road factor.

Now, as we can see that non-built up areas near the road will have the high probability into converting into the city than areas which are far from city core and road.

More constructions happening near the city is very natural and well observed fact practically.

$$p = 1 - \text{dist(this)}/ \max(\text{dist})$$

So if the distance is zeros (road itself) than probability of converting into built up will be 1 (which any ways the road). Then as distance increases, p decreases. And finally *distance(this cell) = max (dist)* and *p = 0*; thus implying no room for new construction.

- * Combining both the effects

Now we will combine all the effects for building a final model.

Let's say probability included with the first factor (neighborhood) is p1, and with the second factor (distances from the road etc) is the p2.

We can assign weights w1 and w2 (real positive numbers) with them and final probabilities will like.

$$P = w1 * p1 + w2 * p2.$$

There can be a lot debate on what is the w1 and w3 should be or could be. But after having a lot of experimenting we arrive at the result that values of w1 and w2 are completely based on ***local practical factors;*** and cannot be defined theoretically.

We finally set w2 = 0.1 and w1 = 0.5 based on our experiments and results.

Let’s look at the final version of output.

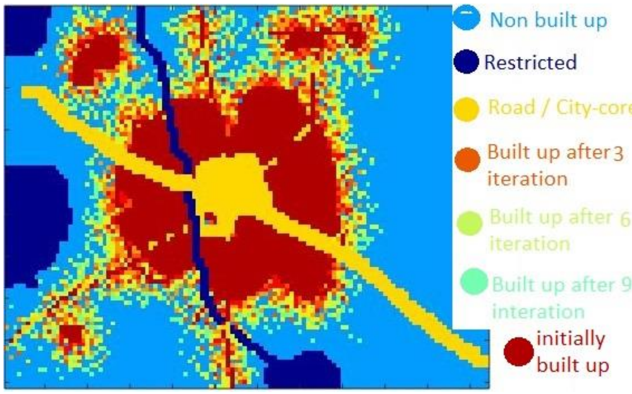


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Fig : 9.

As one can see we have got the new built up cells based on all the above mentioned factors.

This model can be illustrated more clearly through videos.

Conclusion:

In developing countries like India, there is an urgent need for sustainable urban development. At present most of the decision making in urban development is done on intuition basis and in ad-hoc manner. Models such as the one proposed here, which simulate urban growth realistically, can be operated as an urban planning tool to build projected growth scenarios and answer “what-if” type questions. The model proposed in this study can be used as a planning tool for developing alternative scenarios and the urban planner can take more rational and scientific decisions by looking at the various scenarios generated thus providing a scientific basis for implementing a decision.

Our model can still be considered primitive and there are always lots of room for more improvements through experimenting and deeper analysis. But it matches closely to the approximate results drawn from the Google Earth.

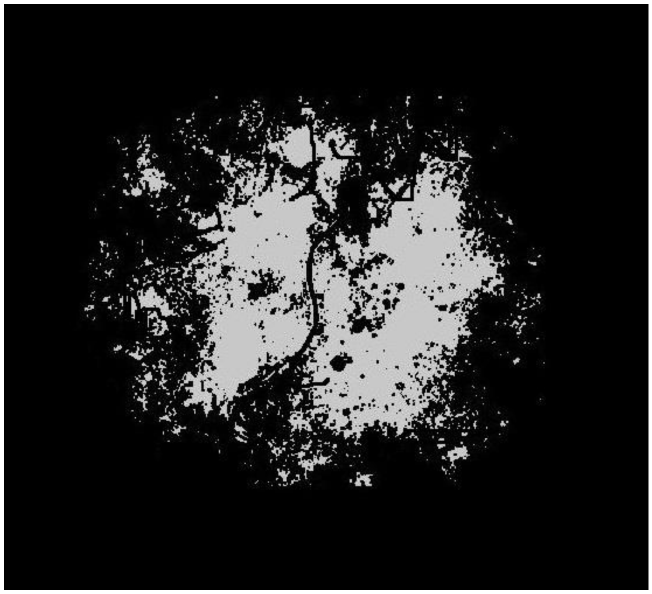

Fig: 10

Modeling of growth of Ahmedabad City using our code.

It actually matches pretty close with growth of the actual city.

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[1] Sandeep Maithani, “Cellular Automata Based Model of Urban Spatial Growth”, Springer (2011)

[2] John Lahiti, “Urban Growth Modeling using Cellular Automata”, ITC (March 2008)

[3] Khalid Al-Ahmadia, Alison Heppenstall, Linda Seeb and Jim Hogg, “Urban Growth Dynamics”, Semantic Scholar (2007)