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SIMULATION OF SPATIAL FORM OF URBAN SYSTEMS BY DIFFUSION METHODS (PART 2)

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Abstract: Modeling method for forecasting of social-economic processes in accordance with methodology of applique fractal crystals growth methods in fuzzy attraction potential field was proposed. Impact of model empirical parameters on appearance of fractal structure fluctuations in the form of creating additional aggregation centers was investigated. Computer experiments give a possibility to simulate structures which are well correlated with experimental data received.

Key words: potential of attractiveness, fractal, fuzzy logic, molecular dynamics

The modified model of «accidental rain»

The model of «accidental rain» (AR) was offered by Mardgori Vold and Sazerland (Pietronero L, 1988). In the model of the AR particles move on to the definite accidental trajectories. In paper (Pietronero L, 1988) was shown, that the best concordance with the experiment shows a model in which the clustering center is disposed in the center of the explored region, and particles (candidates on aggregation) begin to move from large distance inward circles. Every particle started from a random point and moved on a random chord, uniting at the collision either with the line of basis, or with a growing cluster. A model AR generates the ramified structures look like ones received by the DLA model.

Less time of computation is basic advantage of AR model against DLA substantially. And Hausdorff-Besicovitch cluster dimension D has the value $D \approx 1.72$ (Pietronero L, 1988).

As our researches showed a classic model AR has the substantial lack, namely: presence of empty regions, in the case of presence of a few clustering centers; a model does not foresee the presence of the potential field which deforms spherical structures. It was offered to remove these lack as follows.

Consideration of a few clustering centers

Lets exist n clustering centers. For every center determines its weight w_i. In case if a settlement has a few attractiveness centers, gravimetric multipliers could be calculated, as the relative quantity of tourists who visited this centers for the definite period of time:

$$w_i = \frac{S_i}{\sum_{i=1,n} S_i}, \qquad (1)$$

where S_i – visitors quantity which visited i th recreation object.

In obedience to an algorithm AR a particle moves on a random chord to one of clustering centers. The clustering center for every particle gets out random appearance depending on the size of the rationed weight w_i. To avoid appearance of empty regions we suggested modifying the aggregation algorithm. On the whole algorithm of joining to the cluster is similar to AR, but after aggregation the copy of particle («transparent particle») is created that continues its motion to the center irresponsive on crystallizing particles. As soon as it gets in a region where there are no aggregated particles in a small radius R (that is a particle got in an empty region) «transparent particle» becomes «ordinary particle» and the accretion algorithm proceeds by a classic rule. How our researches showed the offered method allows to evade the first lack of model AR.

Consideration of the potential field

The potential field deforms the bodies' trajectories. However, in obedience to the theory of the AR particles trajectory remain unchanging during all motion. Therefore we suggested interpreting the potential attractiveness field as the particle aggregation probability potential field. Therefore the potential field of the explored region must be rationed for this purpose. The aggregation probability is determined as the probability of offensive of two independent events, namely the presence of the alongside aggregated particle and the «possibility» of aggregation in the given point from one side of potential field $U(x, y)$. In our computations the authenticity $P_a(x, y)$ found alongside with the moving particle of the aggregated cluster was accepted as 1 if aggregated atom is found in the cell neighboring on a verge with a particle, 0,5 if the aggregated atom is found alongside bias, and 0,01 in other case. Then probability of aggregation of particle is determined as:

$$P(x,y) = U(x,y) \cdot P_a(x,y) \tag{2}$$

The offered method of modification AR indeed allows empty regions being deprived and taking into account influence of the potential field at the design of settlement growth. However calculated fractal front is characterized by the fuzzy structure and presence of a plenty of the isolated aggregation points, which are not experimentally observed.

For the removal of lacks of each considered methods we offer to combine AR and DLA in obedience to the following reasoning: calculate the fractal structure of settlement in obedience to a model AR; select the center of settlement; consider received cluster as only one aggregation center; particles which did not get to the cluster are considered free and continued motion in the potential field in obedience to DLA, aggregated on one cluster. This method gives a possibility to evade the problem of empty regions and calculate correctly front of fractal growth.

Modeling of clustering and fluctuation

Empiric indexes of this theory are particle mass and environmental resistance coefficient. Mass m in physics is a measure of body sluggishness. I.e. than greater mass of the body, the less influence of the potential field on it. Mass reduction results in the acceleration increase towards potential field maximal gradient (fig.1). That is more lightweight particles gravitate to the roads while heavy particles will be aggregated on the crystallization centers. While complex social structures prognostication, such as settlements, mass can be interpreted as investment possibility measure for certain object (sanatorium, hotel, office, cottage etc.) or infrastructure (supermarket, shop, booth etc.). Environmental density β can be interpreted as an investment assistance measure for a region. On fig.2 the forecast fractal structures are resulted in such approaching: crystallization center is located in the center of the examined region; crystallization center is crossed by a direct horizontal road. In an experiment particles were used with the masses $m = 0.1$ (fig.2.a) and $m = 0.01$ (fig.2.b). Viscid friction coefficient is $\beta = 0.0001$. From figures evidently, that a fractal structure formed by particles with the masses $m = 0.01$ is more prolate along a road than structure formed by particles with the masses $m = 0.1$. Consequently,

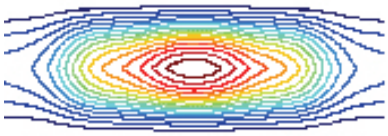

Figure 1. Potential field of attractiveness in approaching: Center-road

they confirm our hypothesis in relation to interpretation particles mass. I.e. investment powerful objects gravitate to the attractiveness centers and transport paths are considerably influence small and middle business objects. Environmental viscidity plays a substantial role at fractal growth. While coefficient β is increasing (region investment assistance is reducing) absolute speed of the particles are diminishing and a geometrical form of growing fractal will, mainly, be determine by the potential field gradient (29 – part 1) and poorly depend on initial particles velocities. A maximal gradient change is directed to the road therefore the particles motion trajectory on the initial stage of fractal growth can be described as attenuated vibrations athwart to the road with the gradual moving of particle to the attractiveness center (fig.3.a). From figure evidently, that vibration amplitude for lightweight particles goes out more quickly, unlike heavy (fig.3.b). I.e. the motion trajectory for particles with greater mass will have chaotic hesitating character which will be determine by casual initial conditions. The lightweight particles motion trajectory is poorly depends on initial velocity and mainly determine by the initialization coordinate.

While fractal simulation by 100 000 particles with the masses $m = 0.1$ in an environment with a viscid friction a structure which repeats a form of potential field appears (fig.4.a). An interesting effect is observed at a fractal simulation with lightweight particles. Amount of particles which move along a road due to mentioned features for particles motion with such mass at approaching to the aggregation center grows sharply. There is a situation which reminds «congestion» on motorways. Such fluctuation results in the particles aggregation in these areas. As a result, on certain distance from the aggregation center the additional aggregation area appears (fig.4.b). Similar effect is observed in cities and district centers neighborhoods where along the roads summer residence with missing center of attractiveness for development emerges.

Figure 2 Fractal in approaching: Center-road when $\beta = 0.0001$, a) $m = 0.1$, b) $m = 0.01$

Figure 3 Motion trajectory of the particle in the potential field center-road when $\beta = 0.001$, a) $m = 0.01$, b) $m = 0.001$

A difference between received fractal structures is an instrument for determination external and internal structures of obtained crystals.

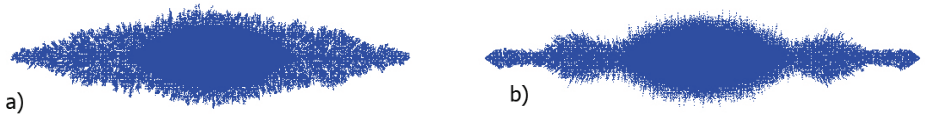

Figure 4 Fractal in approaching: Center-road when $\beta = 0.001$, a) $m = 0.1$, b) $m = 0.01$

Let us assume that N types of business or infrastructure elements exist, which are described by the masses m_i, $i = 1 \div N$ and relative amount p_i. Types N and their amount can be obtained from statistical data, cluster analysis or expert estimations. Ukrainian economic situation define that size of region investment assistance is greater for large business. I.e. then the capital increasing the amount of barriers for the business conduction diminishes. The following supposition was used: viscid friction size is inversely proportional to the mass of particle: $\beta_i \sim 1/m_i$.

Fractal growth is simulated in obedience to Diffusion-limited aggregation (DLA) with such approaching:

- the index i of particle mass m_i selected randomly depending on the size of relative amount p_i; amount β_i is determined;

- an aggregation takes place on particles with the masses equal or greater than mass of mobile particle. I.e. investment powerful objects oust small business.

Computer experiment

For model approbation we have conducted experiment in which fractal structure of settlements Sudak-Noviy Svit, Novoselitsya, Kitsman' was simulated.

The settlements were chosen because of a presence in them brightly expressed summer residence buildings (fig.5 – fig.7). The geographical features of these settlements are:

- Sudak-Noviy Svit – located by the sea, has a considerable historical-cultural legacy and only one approach road (fig.5);
- Novoselitsya is a district center; there is two motor-car roads located under an acute angle to each other; a summer residence settlement appeared only on one of approach road (fig.6).
- Kitsman' is a district center; basic attractiveness centers are located in a city center; the road of state value hasn't many turns and crosses the center of city (fig.7).

Potential field was calculated using entry parameters of fuzzy model with Sugeno fuzzy inference algorithm. As entry parameters we use distances to the historical-cultural centers, administrative objects, roads and distance by a road to the nearest object and geometry of seashore (Sudak-Noviy Svit). Relief features were not taken into account.

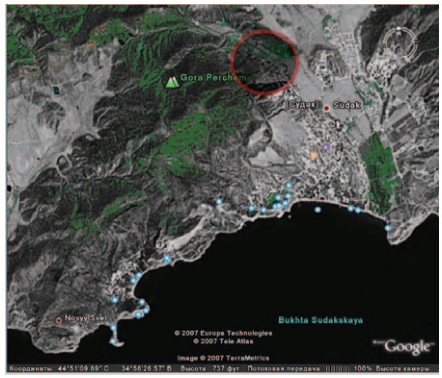

Figure 5 Picture from space: Sudak-Noviy Svit

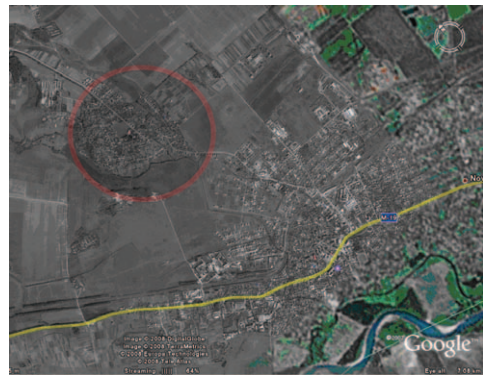

Figure. 6 Picture from space: Novoselitsya

Figure 7 Picture from space: Kitsman'

Calculations were carried out by the modified DLA method with such approaching: initial velocity of particle selected randomly; mirror border terms were used. I.e. crossing the verge of probed area a particle appeared from an opposite side keeping all other run-time indexes. During an experiment particles were used with the masses $m_1 = 1;\ m_2 = 0.1;\ m_3 = 0.01$. A relative amount are $p_1 = 0.1;\ p_2 = 0.2;\ p_3 = 0.7$. The viscid friction coefficient is $\beta_1 = 10^{-5}$, $\beta_2 = 10^{-4}$, $\beta_3 = 10^{-3}$.

In the process of Sudak-Noviy Svit region research obtained fractal consisted close to 74 000 aggregate particles. General structure of obtained fractal displays all features of the simulated region (fig.5, fig.8). Fractal growth at this region simulation reminds the projection of physical crystal growth on a plane. The basic objects of attractiveness are located coast-wise and near a road. As evidently from fig.8, the limitations account hinders fractal growth in the sea area.

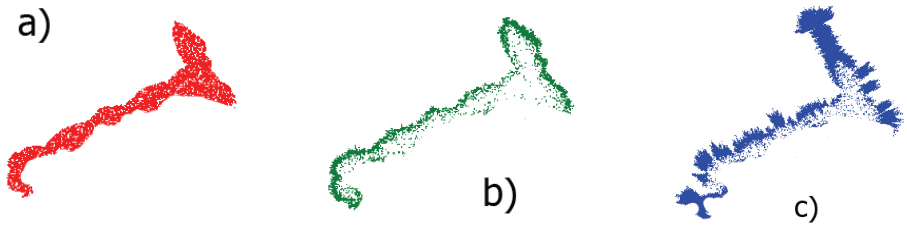

Figure 8. Fractal structure segments of Sudak and Noviy Svit: a) $m = 1$, b) $m = 0.1$, c) $m = 0.01$

Figure 8 shows infrastructure segmentation of the probed region. From figure evidently that the more expensive infrastructure aggregates from particles $m = 1$ located along a coastline and surrounds the basic historical-cultural centers of Sudak-Noviy Svit. I.e. overtakes an area which more attractive. The middle class infrastructure is located very close to the expensive elements and makes a small layer compared to the expensive elements of infrastructure despite the initial amount of aggregate particles with mass $m = 0.1$ exceeds twice aggregate particles with $m = 1$. Evidently absorption of middle business by the large business. Penetration of middle class elements in the area with expensive infrastructure is insignificant despite small business. The elements of small business with masses $m = 0.01$ are located on considerable distance from the basic attractiveness centers and gravitate to the road. From fig.8.c evidently, that this segment overtake both the surrounding villages outskirts for the probed region and «leaks» between the expensive elements of infrastructure. An alike picture is indeed observed, especially on resorts, where small shops and booths are located on the most prestige and expensive areas near-by a sea or centers of attractiveness.

As was said it is possible to reach the coast by approach road. From fig.8.c evidently that aggregating center formed by lightweight particles on an entrance to the probed region. As evidently from fig.5 and fig.8.c theoretically obtained aggregation center well correlates with this summer residence settlement with respect to distance to the coast and size. The differences in form can be explained by the territorial limitations accounting.

The obtain fractal structures of Novoselitsya (41 000 aggregate particles) (fig.9) and Kitsman' (30 000 aggregate particles) (fig.10) are repeated basic features of internal structure, which was observed for a region Sudak-Noviy Svit. I.e. the elements of large business take most investment attractive territories, ousting middle business. The elements of small business and private houses from one

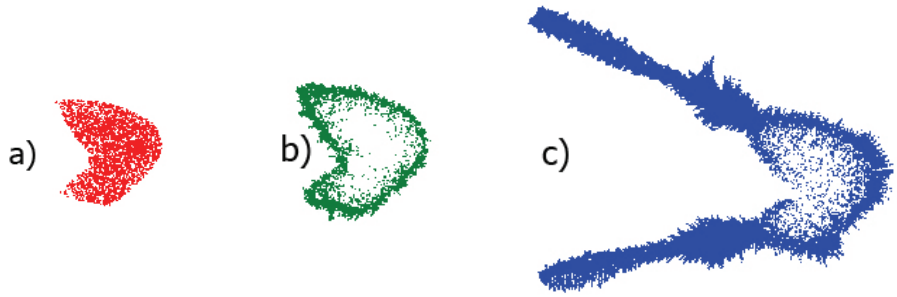

Figure 9. Fractal structure segments of Novoselitsya: a) $m = 1$, b) $m = 0.1$, c) $m = 0.01$

Figure 10. Segments of fractal structure of Kitsman': a) $m = 1$, b) $m = 0.1$, c) $m = 0.01$

side gravitate to the roads and removed from a center, forming summer residence settlements and actively penetrate through the elements of large business.

From fig 9.c evidently that obtained fractal structures forecast formation of the two new aggregation centers in a direct closeness from the settlement center. When compared to fig.6 evidently, that the overhead center of aggregation in size and form repeats this summer residence settlement. However a lower center doesn't have the real analogues. It can testify to the potential attractiveness of this territory for development. And it is scientific soil for planning and development strategy of this region.

Fig.10.c represents clearly expressed summer residence settlement formation on the edge of the city with the clearly expressed peak in the place of road turn. As evidently from figure 7 such features of settlement geometrical structure is indeed observed on snapshots from space. Fig.7 testifies that on certain distance from a district center exists another settlement. On figure 10.c in this area indeed there is a bulge of fractal structure. Consequently this territory has a potential

attractiveness for development. It resulted in an origin of new settlement in mentioned neighborhood. And now for this region real structure simulation it is needed to take into account this new settlement centers of attractiveness.

Similarity of theoretical structures and obtained segments with experimental structures confirms correctness of the offered prognostication and segmentation method and is foundation for subsequent theoretical and practical researches.

Conclusions

The algorithm of fractal growth calculation is presented in the fuzzy potential field by the « accidental rain».

Influence of the model empiric parameters on the form of cluster which grows is investigated. Empiric parameters values at which fluctuations in growth of cluster have place were defined. That results in appearance of the new aggregation centers. This mechanism was explained and proved.

During computer calculations we received fractal structures which well conform to experimental information. It confirms supposition that a crucial role in formation of settlements is played by a present infrastructure, namely: roads and present attractiveness centers.

Received segments are confirmed basic economic features of present infrastructure.

It is showed that the aggregation centers formed due to fluctuations repeat basic characteristics of the real summer residence settlements with respect to form and location.

Good correlation of experimental and computational data leads to adequacy of the offered methodology and allows to use it for subsequent prognostication both geometrical form and internal structures of settlements. Research and analysis of new aggregation centers emerging is scientific soil for planning the strategy of region development.

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