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# APPLICATION OF CELLULAR AUTOMATA FOR MODELING AND REVIEW OF METHODS OF MOVEMENT OF A GROUP OF PEOPLE

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**ABSTRACT**

The article deals with the modeling of the movement of most people. The finite-automaton (FA) model is applied. The analysis of methods of modeling human behavior, including the dependence of density, speed and capacity of various structures on various external parameters. Transition rules for the model of human motion based on the theory of cellular automata are presented. In this work the aim is the strict formalization of rules of transitions that uniquely identify the model. The results of numerical studies are presented.

**Keywords:** *Cellular Automata, Modeling Of Human Movement, Field Model Of Human Movement, FA-Model, FF-Model.*

## 1. INTRODUCTION

Cellular automata are a special case of finite automata. In particular, they are used to model the dynamic behavior of homogeneous media. The behavior of cellular automata is defined in terms of local dependencies. Each cell is a finite state machine, the state of which is determined at the next moment of time by the States of its neighbors in neighborhood. The so-called von Neumann neighborhood (four neighbors located orthogonally to the cell) and Moore neighborhood (four neighbors adjacent diagonally) are usually under review.

The first finite-automaton models (FA-models) the movement of people was based on models of road traffic. The dynamics of such models was mainly deterministic. For instance, bidirectional movement in a long corridor was studied. It was observed that updating the position of the particles occurred sequentially. The particles were given only the direction to move. In case “the desired” cell was occupied by another particle moving in the opposite direction, the particle could randomly choose another unoccupied cell to move. In fact, the motion of particles was considered as the analogue of multilane traffic.

At a later stage, extensions and variations of these models were emerged. For example, various special types of updating the position of the particles, the possibility of reverse motion. The influence of particle shape, other geometries, generalizations for full two-dimensional motion, when the movement of particles is not limited to the nearby cells, the particles can move 2, 3 or 4 cells in one step were observed.

To avoid conflicts between the particles that tried to move to the same position, the update of the position of the particles occurred sequentially [1,2]. Each space cell was assigned points based on its proximity to other particles. The points described “repulsive” interactions, and movement was

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determined by competition between these repulsive forces, and their growth brought the particle closer to the goal.

Now let's review the models:

The Game Of Life John Conway.

The game "Life" was created by John Conway in 1970. It was an embodiment of the idea of two classics of Cybernetics: Alan Turing and John von Neumann. To understand the meaning of this game, you need to go through the main milestones of its history.

The Turing machine, proposed in 1936, is an abstract performer that executes a certain algorithm, moving from one state to another. The idea of Turing was that a control device capable of being in a finite number of States, performing certain algorithms, is able to provide all the sequences of actions used by mankind.

Von Neumann tried to implement the idea of an algorithmic Turing machine using a cellular automaton. A cellular automaton is a regular structure of cells, each of which can be in one of a finite set of States. For the cellular automaton to work, you need to set its initial state and the rules for the transition of cells from one state to another.

The von Neumann machine is a Turing machine capable of reproducing itself. In 1950, von Neumann was able to implement this machine on the space of 200 000 cells, each of which could be in 29 States. The rules of transition of each cell from one state to another depended on the States of four neighboring cells. After the creation of the first von Neumann machine, it was possible to create much simpler implementations (requiring fewer cells and fewer States). To some extent, simplifying von Neumann's machine has become one of the intellectual exercises for Cybernetics. In line with this work and was created described here game. It does not, of course, implement the von Neumann machine, but is a way of studying the properties of cellular automata controlled by simple rules.

Mathematician John Conway in 1970 published in the journal Scientific American (under the heading "Mathematical games", which led the famous popularizer Martin Gardner) description of the game "Life". Its rules are extremely simple (and this, in particular, determines its attractiveness). The game is realized on a plane consisting of square cells. Each cell has eight neighbors (including those with which it touches the corners). Each cell can be in two States: "alive" (occupied, usually shown in black) and "dead" (free, white). To start the game you need to create an initial configuration ("first generation").

Each next generation is determined by the previous one with two rules:

1) a "dead" cell with three "living" neighbors becomes "alive»;

2) a "living" cell with less than two or more than three "living" neighbors becomes "dead".

Calculate the next generation makes sense, as long as the field are "living" cells or until the system enters the cycle, repeating one of its previous States. These rules are sufficient to generate a set of patterns (figures) that demonstrate complex behavior. Many designs of the cell are rapidly degraded. Some are stable (such as a square of four adjacent cells). There are "gliders" ("gliders") – patterns that can cyclically change its configuration, moving indefinitely on the plane.

Initially, Conway assumed that a pattern capable of providing an unlimited continuation of the game and an infinitely increasing number of living cells (of course, when using an infinite plane for the game) in this game is impossible. Conway could not prove this claim and offered a prize for his proof or refutation. The award was given to a group of hackers led by bill Gosper: for a year and a half they tried to create a pattern that would reproduce itself, generating other figures. In the jargon used to describe the game "Life" we are talking about creating a "gun", shooting "gliders".

"Gosper's glider gun" became the first pattern capable of existing indefinitely and generating an unlimited number of "living" cells.

Model 1: Blue V. J., Adler J. L.. To simulate the movement of the crowd Blue V.and Adler J. [3] uses cellular automata (CA). The algorithm is used to simulate a crowd that moves in one direction along a track. CA makes a selection of lanes and speed. In this algorithm, pedestrians try to choose a lane that allows them to more freely reach the maximum desired speed. At the first step, each pedestrian looks at whether the adjacent cells are free and whether they are not selected by neighboring pedestrians. In the second step, the pedestrian chooses one of the free lanes (either the current one or one of the adjacent lanes), based on which of the lanes provides more free space for the pedestrian to reach his maximum desired speed. In the third step, the number of moves per unit of time is determined and the pedestrian makes his move. The number of passable cells in the process of movement is determined by the maximum speed of the pedestrian, as well as the free available space.

Model 2: Burstedde C., Schadschneider A.. In [4] Radslider A. and Bursted C., proposed multidirectional model of pedestrian traffic. Any pedestrian can move to one of the 8 adjacent squares at each time step. The proposed ideas were developed in [4,5]. The authors used the minimum number of data concerning pedestrians to simplify the model.

Model 3: Use of rules. Rule-based models introduce special rules of conduct to model the movements and interactions of simple creatures, such as birds, fish, and animals, in the form of herds. This model was later used to simulate pedestrian traffic. Creatures interact on the basis of a certain perception of their environment.

Model 4: Dense crowd. Pedestrians exhibit specific behavior in dense (dense) crowds, such as pushing other pedestrians. In a low density situation, pedestrians change direction to avoid a collision. In dense crowds pedestrians can not be at a sufficient distance from others.

Model 5: The Combination of movement with behavior. In real life, people move towards different goals and perform different actions in the environment. If these factors are not taken into account, the result will be less realistic. Interesting is the work by N. Pelechano [5]. It integrates an additional module PMFserv model of human behavior in the crowd simulation system MACES. This module can influence the decision-making of agents at the micro and macro levels of movement.

Model 6: Group effects. Group effects were studied from different angles. For example, in [6] R. Mousse proposes a crowd model based on the sociological interactions of virtual people (such as common goals and interests) to form emergency crowd behavior. However, this model is mainly focused on relatively rare crowds.

The patterns of movement of people is a microscopic (individual) must play as individual characteristics of the movement of people at low densities crowd flow and mass in high densities. Taking into account the individual properties of the movement of people in the simulation should ensure the implementation of the laws of flow at different densities in different geometries of space (straight path, narrowing) for different types of movement of human flows (fusion, intersection).

From all the various properties inherent in the movement of people, stands out the following minimum:

• The purpose of the movement – to achieve the goal of following;

• Movement of people is a random process. The trajectory of the same person when passing the same route every time let a little, but different from the previous;

• People choose the shortest path to the destination. If the use of the shortest path is not possible, then the person uses an alternative path. That is, when driving a person tries to minimize the length of the path or travel time. Such features of the movement were called strategies of the shortest and fastest way.

The "shortest path" strategy is a strategy in which people move to the goal only by the shortest path.

The "fast track" strategy is a strategy in which people move to the goal in a fast way: the shortest or alternative (which is not equal to the shortest).

The strategy of the "patient person" - a strategy in which a person can stay in the same place, even if there is a number of free space.

It is assumed that taking into account these properties of motion, the model will reproduce not only the individual, single movement of a person, but also the group dynamics of movement in different spatial situations.

Models based on cellular automata theory are simple, understandable, and contribute to faster computer computation (compared to continuous models).

Despite active research in this area, some challenges remain.

The problem of modeling the movement of people is quite popular. The first model considered is not an individual person's movement, and the change of flow density on the section of track over time (V. M. Predtechensky, A. I. Milinskii, V. V. Kholshevnikov, L. F. Henderson, D. Helbing, R. L. Hugles). Currently, the most interesting models are those that consider the movement of each person: the model of social forces (D. Helbing, P. Molnar, I. Farcas, T. Vicsek, T. Kretz, A. Seyfried) and models based on the theory of cellular automata (V. J. Blue, J. L. Adler, M. Fukui, Y. Ishibashi, G. Malinetsky, M. E. Stepantsov, K. Nishinari, J. Was, A. Kirchner, A. Schadschneider, M. Schreckenberg, S. Bandini) [3], [12], [19].

## 2. CLASSIFICATION OF HUMAN MOVEMENT PATTERNS AND EXAMPLES

Currently, there are quite a number of models of human movement and offered their different classifications [7], [8] – [10]. The most common and frequently used classification is proposed in [18]. Models can be classified according to the following characteristics:

1) microscopic and macroscopic (or individual and in-line [9]). In the first case, each person is considered separately from the others.

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This approach makes it possible to assign individual characteristics to the particles. For example, such as mass, height, age, sex, speed, role in the evacuation process, evacuation exit, etc. In the second case, only the movement of the mass of people with certain homogeneous characteristics (for example, the density of particles and the average speed of movement of the whole group) is considered);

2) discrete and continuous. It is characterized by how time, space, speed of movement and in the model are described.

3) deterministic and stochastic. In deterministic models, in each specific situation, all other things being equal, the model prescribes the same actions to people. However, the movement of people by nature is a random process. Even one and the same person in the same situations can deviate (albeit slightly) from the previous trajectory. The introduction of random elements in the model smooths out the lack of knowledge about the decision-making process of people while driving, especially in emergency cases. The use of stochastic models makes it possible to reproduce and study not only the implementation of evacuation, but the distribution with the allocation of the most popular routes, minimum, maximum and average evacuation time.

It should be noted that models cannot be clearly classified according to the characteristics presented. Some models may include both alternative characteristics. In [9] there are also:

1) behavioral models that take into account not only the movement of particles towards the target (exit), but also other activity (may include different methods of decision-making and actions due to conditions in buildings);

2) partially behavioral models that primarily calculate displacement. The behavior is simulated by introducing a delay distribution of the start of evacuation, the use of individual characteristics of the particles, the effect of smoke;

3) motion models that move particles from one point in space to another. They are used to demonstrate the areas of accumulation of particles, the formation of traffic jams in narrow places.

The first model of the movement of people was macroscopic and described the changes of the density of people and their speed in time. Usually macro models are deterministic and continuous. In the macroscopic approach, several directions are distinguished. Models based on hydrodynamics and molecular kinetic theory: L. F. Henderson [11], D. Helbing [12], R. L. Hughes [13]. The most problematic place of these models is the inability to correctly describe the flow of people at low densities [12], that is, in areas with developed (complex) internal infrastructure (for example, lecture and auditorium, classrooms, shopping halls, etc.). Models of domestic norms for determining the calculated values of fire risk: simplified analytical model of human, simulation-stochastic model of human flow. All escape routes are divided into elementary areas. Then on each elementary site the homogeneous human flow with the characteristics (density, speed, intensity of movement) is considered and there is a time of movement on an elementary site. Not take into account such properties of the flow such as flow coating, re-formed, decompression of the stream. Also, the macro models include the first-order flow model [15] (based on the fundamental diagram); the Bruno model [16] (based on the mass conservation equation, taking into account the properties of human movement, but the direction of movement is assigned in advance); the Colombo-Rosini model [17] (based on the LWR model of road traffic [18], [19], can be used to simulate panic situations, but only unidirectional traffic is considered). With the development of computer technology, microscopic models have become the most popular. In [20], [21] a Social-force model was proposed in which interactions between individual particles were carried out through the use of the idea of social force or social field [22]. It refers to deterministic continuous models. In relation to the dynamics of the movement of people, social force represents the influence of the environment (other people, infrastructure) and changes the speed of the particle (distinguish between the desired and actual speed). This force is responsible for the amount of acceleration of each particle. The movement of particles occurs according to the equation of the 2nd Newton's law. Since such an equation of motion takes place for each particle, we are actually dealing with a huge system of related equations. The model of social forces is widespread and remains one of the priority directions of development of models of human movement [23], [24]. A particular analogue of the model of social forces is the model of optimal speed [25]. It does not take into account the physical interactions of people, but only the deviation from the desired speed due to the presence of other people on the way, while the influence of "ahead" of standing people is expressed more strongly. In [26] − a model based on magnetic forces, where particles and their targets are considered as poles of the opposite sign. Micro models are also models based on the theory of cellular automata.

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Software products (including commercial) are developed on the basis of models of human movement. The set of capabilities and features of any program is determined primarily by the basic mathematical model, but the computer program itself can be filled with certain functionality useful to the user, but not directly related to the calculation of evacuation and the quality of the result. The choice of software is based on the tasks to be solved by the user. The works [8], [9] reflect the state of Affairs in the field of software products for the calculation of evacuation, implementing a particular mathematical model. Such programs are used to demonstrate areas of particle accumulation, Queuing, and congestion in bottlenecks within the building in question. Behavior is modeled by setting specific responses to an individual or group environment. The program can use different delay time of evacuation, set individual characteristics of people (speed, density, etc.), take into account the conditions of visibility, especially the choice of people evacuation routes, conditions of awareness, individual evacuation scenarios (instructions, roles). Unfortunately, in most cases directly mathematical model of evacuation is a black box for the user, because the software product is commercial. The conducted studies [27] confirm that, despite the extensive useful functionality of the program, testing on simple examples as a straight corridor, a room with one exit gives, for example, a weak dependence of the evacuation time on the flow density. Part of this state of Affairs is a consequence of the fact that at the moment has not yet formed a universal database of tests evacuation models. As a rule, modelers test models at their own discretion, checking the reproduction of some phenomena peculiar to the movement of people, and missing others.

One of the important components of ensuring normal life in cities is the question of the safety of movement of people in a limited space and a large number of other moving people. Thus, residents of modern cities are often faced with the problem of traffic in the crowd when using public transport, in underground passages, turnstiles and escalators of the subway. There is also a serious problem in evacuating people from buildings in case of emergency.

Since the actual experiment is expensive, and sometimes the experimental data can only be the results of an emergency that has already occurred, sometimes with a tragic outcome, there is a need for computer simulations of the movement of people, for example, to determine the best geometry of the space where people are expected to congregate, or to determine the time of evacuation.

In the mathematical modeling of situations in which people are active, there is a problem that a complete mathematical description of the behavior of a single person at this stage of development of science is not possible, because its actions are determined by a very large number of factors, both rational and irrational.

However, the behavior of a large group of people in a standard (not emergency) situation is predictable and well described in a probabilistic way. Here the law of large numbers works: even if one person for some reason decides to act non-trivial, his actions will have very little impact on the movement of the group as a whole.

In the last few years, a lot of research has been devoted to modeling human movement. The analysis of existing works, even not exhaustive, shows that the main research is carried out using the following two approaches: continuous and discrete.

The approach is based on the fact that the movement of people is described by a system $N$ (number of people) of differential equations (the movement of an individual is subject to Newton's second law with a complex right-hand side, taking into account the forces of human interaction with other people and obstacles). Such models allow to take into account the mass and speed of an individual. On average, it takes $O(N^2)$ computing operations for one time step.

The discrete approach assumes discretization of space and unification of physical parameters of people involved in the movement, but differs in transparency of decision-making rules at each time step. One time step in a discrete model requires $O(N)$ operations.

Here and in previous works, the author provides a model of discrete probability of human motion in space with a given geometry, based on the theory of cellular automata.

## 3. FIELD MODEL OF HUMAN MOVEMENT

Manuscripts must be in English (all figures and text) and prepared on Letter size paper (8.5 X 11 inches) in two column-format with 1.3 margins from top and .6 from bottom, and 1.25cm from left and right, leaving a gutter width of 0.2 between columns.

The field model Floor Field (FF) is widely used. It is based on the use of so-called fields [28] for modeling the driving force and interaction with other particles. In the model two fields were used: dynamic and static. These fields have the same discrete structure as the space through which particles move in FA-models. The dynamic field corresponds to a virtual trace, which is created by the movement of particles and affects the movement of others. It has its own dynamics, namely dispersion and forgetting. A static field or distance field does not change over time, it is a kind of map of the area where each cell contains the inverse distance to the nearest exit, taking into account all fixed obstacles. The field does not depend on the presence or absence of particles in the area under consideration. The value increases as you approach the output.

The transition probabilities for all particles depend on the values of the fields $S$ and $D$ in the neighboring cells. The formula for calculating the probabilities is designed so that the greatest probability is given to the directions with the highest field values. The influence of both fields on the particle motion is controlled by constants $k_S$ and $k_D$ respectively. The greater the value the more directional the movement to the exit and the shorter the path the particles choose. With a strong attachment to the dynamic field, that is, with an increase, there is an increasingly pronounced "crowd" behavior when individuals try to follow others.

The classical formula of transition probabilities (for example, towards $\varphi$) has the following form:

$$\rho_\varphi = Norm^{-1} e^{k_D D_\varphi} e^{k_S S_\varphi} (1 - f_\varphi)\omega_\varphi$$

where $Norm$ – a normalizing factor (the sum of all transition probabilities), $k_s, k_D$ – model parameters, $S_\varphi, D_\varphi$ – values of static and dynamic fields in the cell towards $\varphi$. The $f_\varphi$ value specifies whether the cell is occupied or empty. If $f_\varphi = 0$, the cell is empty, and if $f_\varphi = 1$, the cell is occupied. The $\omega_\varphi$ value indicates the presence $(\omega_\varphi = 1)$ or absence $(\omega_\varphi = 0)$ of the wall and other fixed obstacles. Moving to a occupied cell or cell related to an obstacle is prohibited. The particle can remain in the same place only when all adjacent cells are occupied or belong to obstacles.

The transition rules are arranged as follows: a static field is calculated, the dynamic field at the initial time has a zero value, for each particle and for each direction of movement the transition probabilities are determined and on the basis of the obtained distribution of possible directions where the direction for movement is selected. If the model uses synchronous updating of the position of particles, then there are conflicts associated with the fact that several particles can claim one cell [29]. After resolving such conflicts, the particles are moved to new positions, and the dynamic field is updated.

Currently, the dynamic field $D$ is not practically taken into account in the modeling $(k_D = 0)$. However, the idea of using the $S$ distance field to model the driving force was a significant improvement over other models and made it easy to reproduce the directional movement of people.

Many specific models have been developed based on the FF approach. Analysis of the work shows that FF-models differ in the following features:

1) space discretization method, cell size and shape;
2) neighborhood pattern;
3) the speed of the particles (moving into one cell or several);
4) the calculation method of $S$ field ;
5) FA operation modes, synchronous or asynchronous;
6) the calculation method of transition probabilities;
7) transition rules;
8) method of conflict resolution.

The opposite field distances are mostly used in FF-models, i.e. the values of the fields increase when approaching the exit. Moreover a synchronous mode of operation is generally used in FF-models. All particles move to new positions at the same time. In this mode, there are conflict situations when two or more particles claim one cell. Asynchronous mode eliminates the occurrence of conflict situations. In this case, the particles to be moved are commonly chosen randomly [28].

The methods of conflict resolution are discussed in the works of A. Kirchner, K. Nishinari and A. Radslider [30]. The main idea is as follows. With the probability of one of the particles, which is randomly selected from all the candidates, it is allowed to move to the disputed cell, the rest remain in place. This allows us to describe the effect of the difficulty of movement between the particles. The parameter can be interpreted as some kind of local pressure between particles. If the value is close to one, then the neighboring particles

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can greatly interfere with each other to reach the desired cells. The value is called the friction parameter. In the simplest case, when a conflict situation occurs, one particle is randomly selected to move, the rest remain in the same places [29,30]. The formula for the calculation of transition probabilities is the most variable part of the patterns of human movement.

Some more precise definitions concerning FA-models are presented as follows [28].

The cellular automaton is generally determined by a set of cells densely filling the discrete $D$-dimensional space. The couple $<i, j>, (0 < i < N, 0 < j < M)$ corresponds to the cell, the lower left corner, which has the given coordinates [8]. We believe that in each point, $\varphi(i, j) -$ potential is set which reflects some field, acting on people. The potential can be set by means of a continuous function $\varphi(x, y)$. Subsequently we discretize the function. As usual, the potential can be associated with the "field strength" in the grid node:

$$E_{ij}^{x} = \varphi(i, j+1) - \varphi(i, j-1),$$

$$E_{ij}^{y} = \varphi(i+1, j) - \varphi(i-1, j).$$

The next step is to set the probabilities of the object moving to neighboring cells.

First, we define the neighborhood pattern. For example, if transfer is possible in four directions (horizontally and vertically), the pattern of the neighborhood is represented as the form:

| | | |
|---|---|---|
| | $(i-1j)$ | |
| $(i, j-1)$ | $(i, j)$ | $(i, j+1)$ |
| | $(i+1j)$ | |

With the movement of the particle it can be associated (associate) a random $\sigma$ variable. In this case, formula $\sigma = u_{ij-1} + u_{ij+1} + u_{i-1,j} + u_{i+1,j}$ is presented where the other values

$$\rho_1 = \frac{u_{ij-1}}{\sigma}, \quad \rho_2 = \frac{u_{ij+1}}{\sigma}, \quad \rho_3 = \frac{u_{i-1j}}{\sigma},$$

$$\rho_4 = \frac{u_{i+1j}}{\sigma}$$

treated as the probability of the transition of the object to the left, right, down and up, respectively, obviously $\sum_{i=1}^{4} \rho_i = 1$.

Review of only four areas does not mean a serious limitation. Transitions in diagonal directions can be easily performed [30]. The direction of particle motion is determined on the basis of transition probabilities in each direction for each particle at each discrete time step and a set of transition rules [31,32].

Methods of setting potentials. The traditional scheme of step-by-step computations for a discrete approach based on CA theory is as follows [35,36]. First, the transition probabilities are calculated, in accordance with this, the directions of movement for each particle are selected, then the conflicts are resolved if two or more particles were contenders for one cell, and the movement itself.

If $i_0 j_0 -$ some point, you can set the potential that takes the maximum value at this point having the form of "caps". The cap can be set using the normal distribution:

$$f(x, y) = \frac{1}{\sigma_x \sigma_y \sqrt{2\pi}}$$

$$e^{-\frac{(x-\mu_x)^2}{\sigma_x^2} * \frac{(y-\mu_y)^2}{\sigma_y^2}}$$

A special case is commonly considered $\sigma_x = \sigma_y, \mu_x = \mu_y$.

In our opinion, it is more interesting to consider the functions studied in the fuzzy logic of the Zad [33,34]. For example, the function defining a fuzzy number.

A fuzzy number is a normalized and convex fuzzy $A$ set defined on the set of real numbers $\mathbf{R}$, i.e. for the $\mu_A(x)$ membership function of which is performed:

1) $\max_{x \in \mathbf{R}} \mu_A(x) = 1$, fuzzy number normalized;

2) $\mu_A(\lambda x_1 + (1-\lambda)x_2) \geq \min(\mu_A(x_1); \mu_A(x_2))$, the number of convex.

## 4. RESEARCH ON THE BEHAVIOR OF REAL CROWDS

It provides a review and analysis of many field observations of the behavior of real crowds, including the study of the dependence of the density, the speed of the crowd and the capacity of various structures on various external parameters. Fluctuations in the speed of participants in the crowd depend on many reasons, it is difficult to obey the exact calculation. The value and the physical data of the person, and different personal circumstances are demonstrated [38,39]. Therefore, when assessing the speed of movement, it is inevitable to resort to averages, which can be considered reliable if they are established on the

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basis of statistical methods. To a large extent, the speed of movement depends on the density of the human mass. The higher the density, the slower the movement. In the first developed model there is a possibility of 2D-animation (Fig. 1). The following model uses 3D animation (Fig. 2). The figure shown in the schematic shows the crowd, there is an increase in the density of the crowd in the area adjacent to the exit of the hall. As it can be seen from this figure, even with the quiet movement of the crowd there is a congestion.

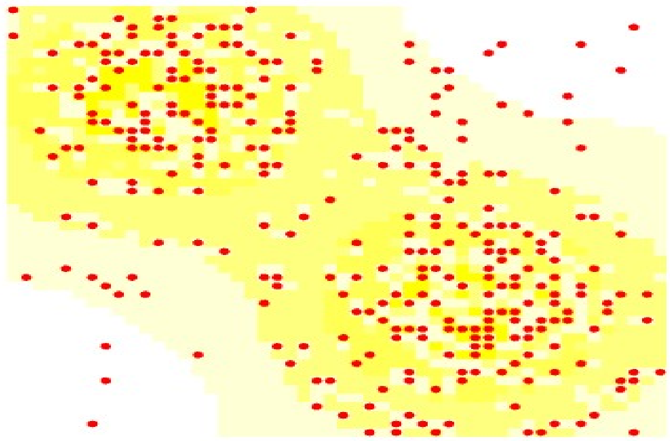

*Figure 1: 2D-schematic representation of the crowd*

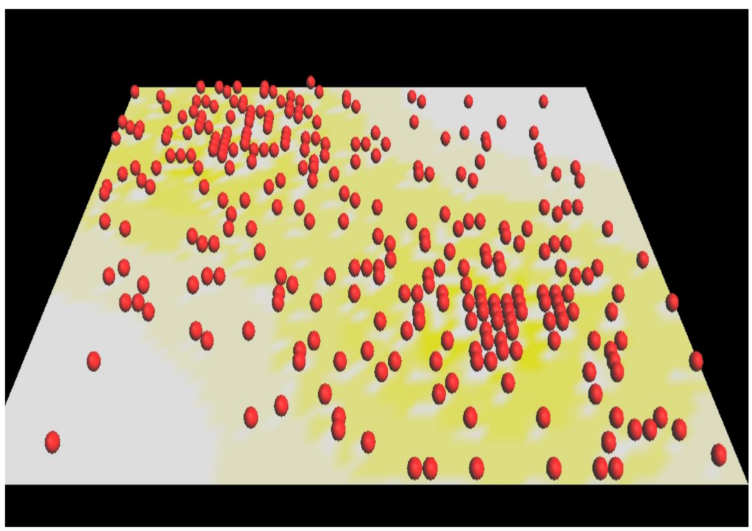

*Figure 2: 3D - schematic representation of the crowd*

It is not possible to obtain the parameters of the movement of people in emergency conditions, thus, for these purposes it is necessary to resort to the use of either conditions of approach close to emergency, or methods of extrapolation of data obtained under normal conditions.

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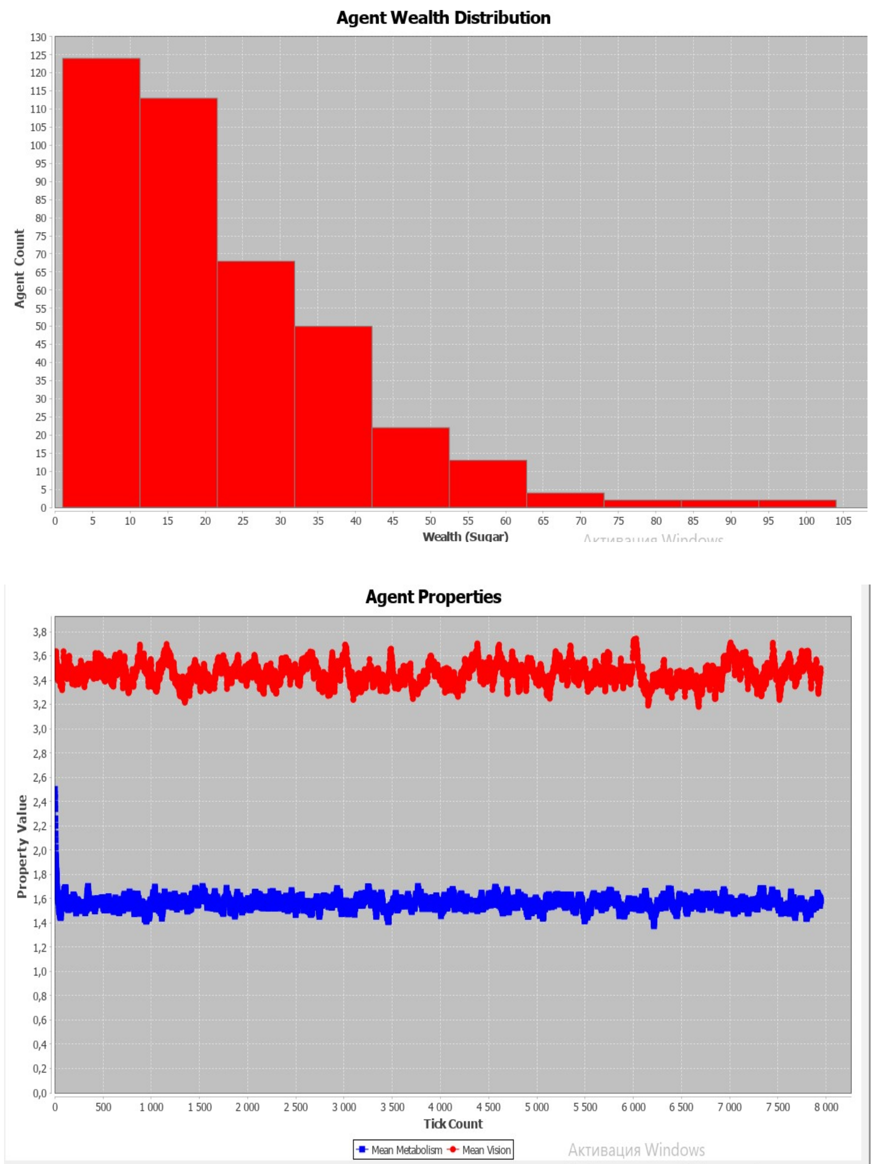


*Figure 3-4: Dependence of speed on density of the crowd*

In the figures 3 and 4 the dependence of speed on the density of the crowd are presented. The above data of field observations of crowd behavior are of great practical value and will be used in the future to test the proposed model of crowd behavior for its compliance with real crowds

## 5. CONCLUSION

The paper deals with a discrete approach to modeling the movement of people in different spatial situations. The model is constructed using the theory of cellular automata, is stochastic, but the transition probabilities are calculated so that the motion is reproduced from random to strictly directed.

The patterns of movement of people is a microscopic (individual) must play as individual characteristics of the movement of people at low densities crowd flow and mass in high densities. Considering the individual properties of the traffic in the simulation needs to enforce the laws of traffic flow at different densities in different geometries of space (direct path, narrowing, potowatomi) for different types of traffic flows (merging, crossing). Models based on cellular automata theory are simple, understandable, and contribute to faster computer computation (compared to continuous models). Despite active research in this area, some challenges remain. Existing CA-models of human

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movement are poorly formalized (especially transition rules). Description of the model is carried out, as a rule, in verbal form. Whereas the mathematical description allows to interpret the model unambiguously and facilitates the program implementation. The distance field in FF models is used explicitly, which imposes certain restrictions on the linear dimensions of the computational domain.

The direction of motion is considered as a random variable and is determined on the basis of transient probabilities.

The transition to new positions is carried out through the rules of transitions according to the selected directions of movement. The following ideas of other scientists were used in the construction of the model. The idea of the distance field to the output of S and the exponential form.

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