Proposed CAEva Simulation Method for Evacuation of People from a Buildings on Fire

Jacek M. Czerniak, Łukasz Apiecionek, Hubert Zarzycki and Dawid Ewald

Abstract This paper presents practical applications of the cellular automata theory for building fire simulation using the CAEva method. Thanks to the tests carried out using appropriately configured program, realistic results of simulated evacuation of people from the building have been achieved. The paper includes the references to actual fire disasters and provides numbers of their resulting casualties. Using such a kind of predication in civil engineering should increase the fire safety of buildings. Simulations described in this paper seem to be very useful, particularly in case of building renovation or temporary unavailability of escape routes. Using them, it is possible to visualize potential hazards and to avoid increased risk in case of fire. Inappropriate operation of buildings, including insouciant planning of renovations are among frequent reasons of tragic accidents cited by fire brigade information services. Similar problems are encountered by inspectors who assess spontaneous fire accidents or arsons during mas events, where wrong safety procedures or inappropriate attempts to cut costs resulted in tragedy. Thanks to the proposed solutions it shall be easier to envisage consequences of problematic decisions causing temporary or permanent unavailability of escape routes. This is exactly the problem analyzed by this paper. It does not take into account, by the rule, the influence of CO_2 and other gases on evacuation difficulty. The described method has been analyzed using descriptions of real life fires, the participants of which were neither asleep nor asphyxiated with carbon monoxide, while the escape was hindered by fire, room

J.M. Czerniak (✉) · Ł. Apiecionek · D. Ewald
Institute of Technology, Casimir the Great University in Bydgoszcz,
ul. Chodkiewicza 30, 85-064 Bydgoszcz, Poland
e-mail: jczerniak@ukw.edu.pl

Ł. Apiecionek
e-mail: lapiecionek@ukw.edu.pl

D. Ewald
e-mail: dawidewald@ukw.edu.pl

H. Zarzycki
Wroclaw School of Applied Informatics "Horyzont", ul. Wejherowska 28,
54-239 Wroclaw, Poland
e-mail: hzarzycki@horyzont.eu

K.T. Atanassov et al. (eds.), *Novel Developments in Uncertainty Representation and Processing*, Advances in Intelligent Systems and Computing 401,
DOI 10.1007/978-3-319-26211-6_27

layout as well as stress and number of the event participants. The results achieved for such conditions are approximate to the actual (reallife) outcomes, which proved the method to be correct.

1 Introduction

Cellular automata are classified to one of IT branches, namely to artificial intelligence. They include a network of cells, each of which is characterized by some specific state and a set of rules. Change of a current state of a given cell is the outcome of the above mentioned properties and interrelations with the neighboring cells. The theory of cellular automata was first introduced by an American scientist of Hungarian origin, John von Neumann. He showed, among other things, that even simple machines are characterized by reproduction ability; that feature was previously regarded as a fundamental feature observed in living organisms [7–9, 16, 18]. For many years cellular automata had been subject to theoretical studies only. With the development of computers and software, optimizing methods based on that attitude have been more and more frequently studied and implemented in practice. Thanks to their versatility, cellular automata are applied in many real life fields, such as: biology, physics, mathematics and in different fields of IT, such as cryptography or computer graphic.

1.1 Application of Cellular Automata

Cellular automata have been applied in practice. One of the examples of such applications is the simulation of the traffic, where specifically defined cellular automaton controls the street traffic. The traffic is controlled basically at the specific segment of a given traffic intensity [1, 11]. This applies for example to traffic intensity control in highways of the Ruhr in Germany. The monitoring centers designed especially for that purpose collect data from selected sections of highways. Then the data is analyzed and used to prepare shorttime simulations of the traffic intensity using cellular automata [2, 3]. Web sites of that project include statistical information about performed studies on behavior of drivers who were prewarned about possible traffic problems [1, 3, 9] that might occur over several following hours [6, 12]. Demographic simulations for a given region are among other examples of cellular automata applications. The aim of such simulations is to generate the structure showing the size of population at a given area in a way to create a map of forecasted population density [4]. Simulations of this type can be based on the wellknown “Game of Life” [14]. This is possible, because following some modifications of the algorithm, it can count life occurring in observed cells. Implementations of other automata include image processing, generation of textures, simulation of waves, wind as well as the program CAEva (Cellular Automata simulation of Evacuation) developed also for

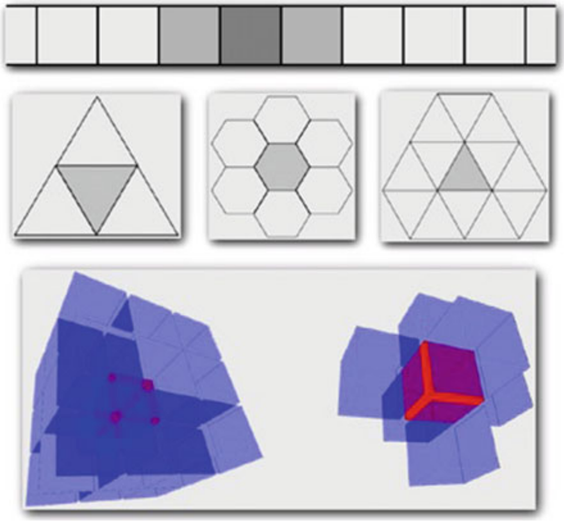

Fig. 1 Types of grids: 1D, 2D, 3D [*source* [5]]

the purposes of this study. The aim of the proposed algorithm is to simulate escape of people from the building on fire with a given number of exits and fire sources [5, 13, 15, 19].

1.2 The Grid of Cellular Automata

A grid or a discrete space, where cellular automata evolution takes place is totally built of identical cells. All the cells must be surrounded by the same number of neighbors and must be characterized by the same number of states. There are three structural factors which significantly influence the grid form and, as a consequence, the behavior of the entire cellular automaton [2, 9, 16]

- the size of a space depends on the magnitude of the studied problem, the examples of which are shown in Fig. 1 (grid 1D, 2D, 3D);
- regularity condition, which requires complete filling of the grid with identical cells;
- the number of neighbors (dependent on both the above factors).

2 Forecasting the Fire Hazard

Fire is an element against which man is often helpless, especially when the fire breaks out inside rooms. Thus the designs of residential, commercial or other public buildings must meet complicated firesafety requirements. Width of corridors, number of escape exits and permissible number of persons which can stay in a room at the same time significantly influences safety of people inside. Obviously, it is not sufficient to include escape exists in the plan, but the door must be unlocked too. Casualties in many fires were caused by locked emergency exits [10, 17, 19]. Recently, there were many disasters caused by fire in buildings, e.g. the fire of the hotel in Kamień Pomorski (PL) with 23 casualties (where emergency exit turned out to be locked) or the fire of hypermarket in Nowy Targ (PL), caused probably by welding works inside. Another example is the fire of a block of flats in Koluszki (PL), were one person died. When designing buildings, architects meet requirements of binding firesafety standards, but this is often insufficient to avoid a tragedy. Additional simulation studied could help to solve that problem. Moreover, even the best architectural design cannot prevent fire if a building is incorrectly operated. It is not rare to encounter renovation plans ignoring the fact that escape routes or some exits from a building would be temporarily unavailable during the renovation. From the statistical point of view, fire hazard increases during renovation works. The program CAEva is an implementation of the CAEva method, the pseudocode of which is shown below. It has been developed in order to test escape of people from a building as a result of fire hazard. It allows comparison of different simulation results and development of appropriate conclusions. The program has been implemented in the C++Builder environment, which is an objectoriented programming tool in Windows environment and is available free of charge at the AIRlab web site. Using the program it is possible to draw a board of any size including the plan of a singlestorey building, to locate people inside and to indicate the place of fire. The board consists of the grid of cells. Each cell can assume only one of the following states: fire, wall, person, person on fire or an empty cell. Figure 2 shows the diagram of states for a single cell in the fire simulation automaton.

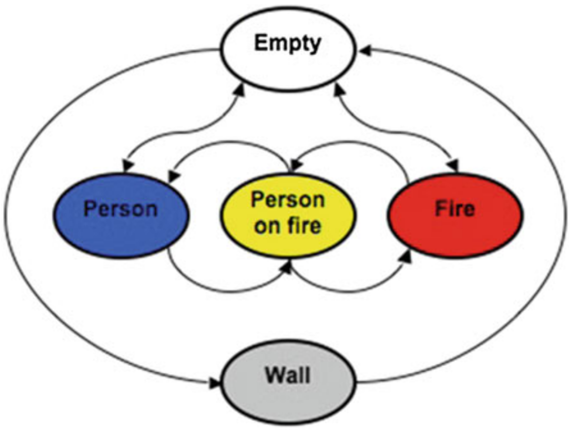

Fig. 2 Diagram of cell states

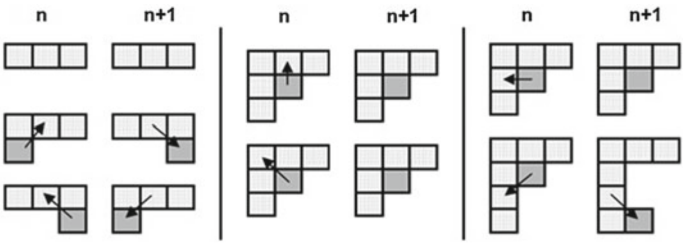

Fig. 3 Boundary conditions (rebound from the grid edges)

2.1 Boundary Conditions

The discrete space, where different evolution of cellular automata take place includes d-dimensional, theoretically infinite grid. As a grid of that type cannot be implemented into a computer application, it is represented in the form of a finite table. Thus it is necessary to set boundary conditions at the grid borders, i.e. at the table limits. The set of basic conditions is shown in Fig. 3. Those conditions are analogous for the rotation by 90°, so they were skipped as trivial ones.

The following rules were used for the simulation of the cell motion in the wall direction:

- straight motion—unchanged state of a cell,
- diagonal motion—state of a cell changes into empty one, angle of incidence equals the angle of rebound and, as a consequence, the state of a cell in the mirror image shall change into the state of the cell that initiated the motion,

motion conditions:

- motion is possible if a target cell is in the empty state. Otherwise the cell shall not change the state,
- the attempt of the motion of the cell in "person" state to the cell in "fire" state increases the number of burns of the initiating cell.

A special case is an attempt of the motion from the corner of the board. Rebound in three initiating directions does not change the state of a cell and the attempt of the motion in the remaining five directions may cause such change. It should be also noted that motion rules and conditions apply to the cells in the "person" state as well as in the "fire" state. The fields to which motion cannot be made are cells in "wall" state. Rebound conditions occur at the edge of the cellular automata grid, which constitutes a barrier from which moving virtual objects rebound (in visual sense). Those conditions are used to simulate encased empirical spaces. Figure 4 shows seven consecutive phases of cell generations visualizing rebound of objects from the grid edges.

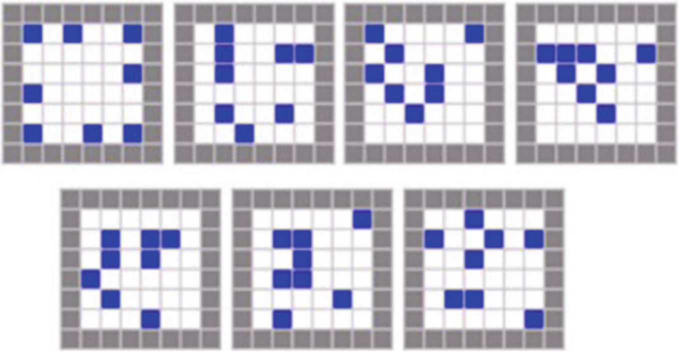

Fig. 4 Sample seven steps of the evolution

2.2 Transfer Function

Evolution of cellular automata takes place in discrete time determining consecutive processing cycles. Each discrete moment $t = \{0, 1, 2, n\}$ is used for updating the state of individual cells, thus each automaton is a dynamic object over time. In every iteration, the transfer function can process (calculate) all the cells in the grid one by one according to specific rules. Each processed cell receives its new state based on calculation of its current state and states of the neighboring cells. Transfer rules and the state space as well as defined neighborhood are inherent elements of the cellular automata evolution process.

Once executed, the program displays main screen ready to draw the building plan and to arrange individual elements inside. Once the board is drawn and all the components are arranged there, one can start configuration of fire and people parameters and setting of the group effect.

Fire parameters:

- fire goes out alone, if the number of neighbors is less than 1,
- fire goes out from overpopulation, if the number of neighbors is more than 3,
- new fire is generated when the number of neighbors is at least 3,
- but not more than 4.

Parameters of people:

- probability that a person goes towards the exit 50,
- number of burns resulting in death 5,
- group effect On/Off.

The Fig. 5 shows the result of the program after creating 50 generations of evolution. There are points in the screen simulating people escaping towards the exit and the propagating fire. All the events are recorded in the table of statistics. They include: number of people remaining within the board, saved from and died in fire or by crushing. That data shall be used to draw conclusions from experiments.

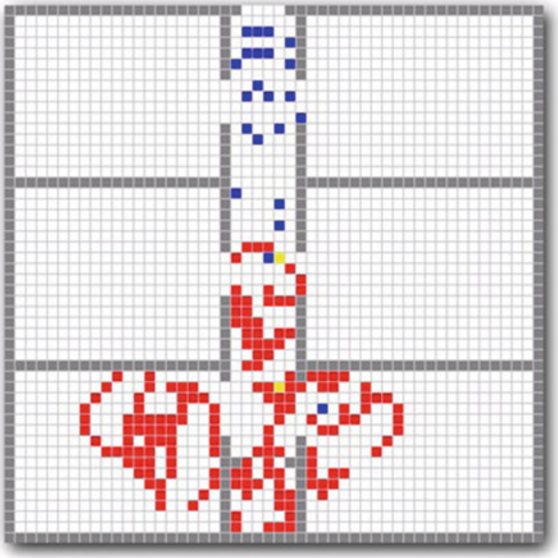

Fig. 5 The result of the program after creating 50 generations of evolution

The test including simulation of a building on fire was based on certain rules and relations. Setting of the following parameters, selection of versions and inherent rules altogether make up an environment influencing the mortality rate of people during fire of a building for the proposed simulations:

- layouts of the building floors, including the number and location of doors,
- distribution of defined number of people inside the building at specified places,
- setting the fire parameters:
  - fire goes out alone, if there are less than one neighbor,
  - fire goes out because of overpopulation, if there are more than 3 neighbors,
  - new fire is generated when there are at least 3 neighbors, but not more than 4.
- setting of the parameters for people (live cells):
  - number of burns resulting in death is by default set to 5,
- location of the fire source on the board:
  - specifying the probability, with which people go towards the exit (four options): 25, 50, 75, 100 %,
  - specifying whether people go towards the exit in groups (two options): with or without a group effect.

3 The Experiment

The authors assumed in the experiment that three boards are always used with the same arrangement of walls as well as location of fire and people, but with different number of doors (1 to 3). The board pl_1drzwi_ogień1 shown in Fig. 6 is provided with only one exit from the building and includes seven rooms, where 70 blue points simulating people were located and the fire was set using red points (lower left corner of the board). The remaining two boards pl_2drzwi_ogień1 and pl_3drzwi_ogień1 differ from each other in the number of doors. In the board pl_2drzwi_ogień1 there are two doors and in the board pl_3drzwi_ogień1 there are three doors (Fig. 6).

The results of performed experiments using CAEva program as regards the behavior of people at the moment of fire outbreak in building are presented in Table 1. Results of the experiments have been classified considering the group effect and probability with which people go towards the emergency exit. 8 tests were performed for each board and obtained numerical results of the tests concerned people, who:

- died in the fire,
- were crushed in the crowd,
- were saved from the fire.

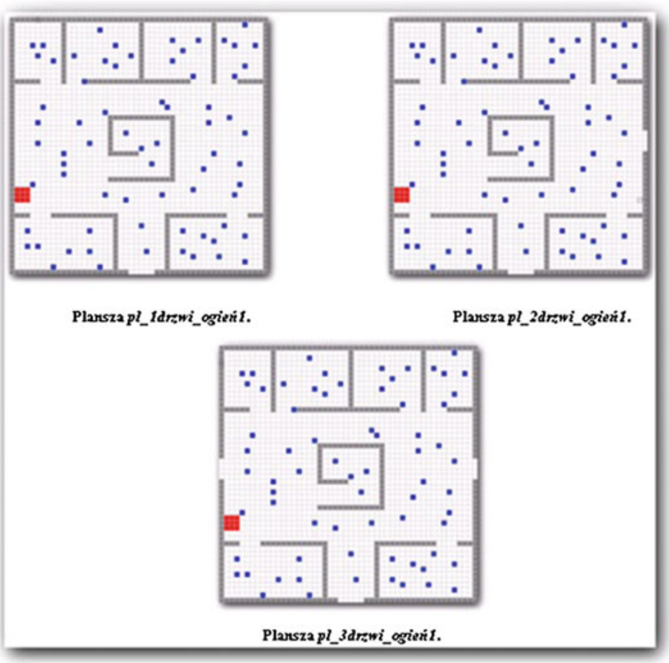

Fig. 6 Sample boards of the building

Table 1 Mortality rate of people as a result of fire

Building plans	Group effect					
	Yes			No		
	Probability that people go towards the exit			Probability that people go towards the exit		
	25 %	50 %	75 %	25 %	50 %	75 %
	Number of people die/crushed/saved from the fire					
bd_1door_fire1	64/0/6	47/0/23	9/3/58	65/0/5	38/0/32	11/0/59
bd_2doors_fire1	38/0/32	24/0/46	7/0/63	40/0/30	21/0/49	5/0/65
bd_3doors_fire1	43/1/26	24/0/46	9/0/61	39/1/30	18/0/52	11/0/59
bd_1door_fire2	57/0/13	24/2/44	3/0/67	58/0/12	16/0/54	2/0/68
bd_2doors_fire2	40/0/30	3/0/67	1/0/69	31/0/39	10/0/60	0/0/70
bd_3doors_fire2	28/0/42	1/0/69	0/0/70	23/0/47	5/0/65	0/0/70
bd_1door_fire3	59/0/11	25/2/43	1/2/67	56/0/14	16/1/53	1/0/69
bd_2doors_fire3	50/0/20	12/1/57	7/0/63	53/0/17	13/0/57	7/0/63
bd_3doors_fire3	42/0/28	3/0/66	0/0/70	41/0/29	5/0/65	0/0/70

The mortality rate depends on the place of the fire outbreak. If the fire blocks any room, then people staying there are not able to escape and to reach the exit even if they go towards the exit with 100 % probability. The group effect used in the program does not necessarily help in escape of people from a building. It can cause crowd as people are looking for other people to form groups and thus crushes can occur. When a person does not have any direction when he/she could move he/she is crushed. Figures 7 and 8 show the number of saved people who went towards the exit with the probability of 50 and 75 %.

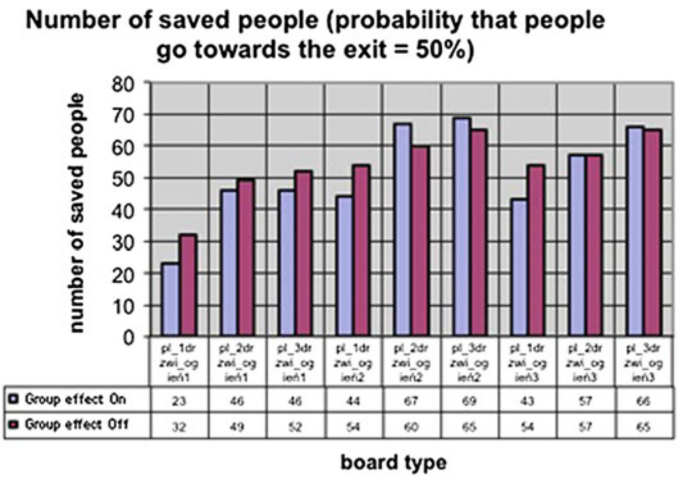

Fig. 7 Probability that people go towards the exit = 50 %

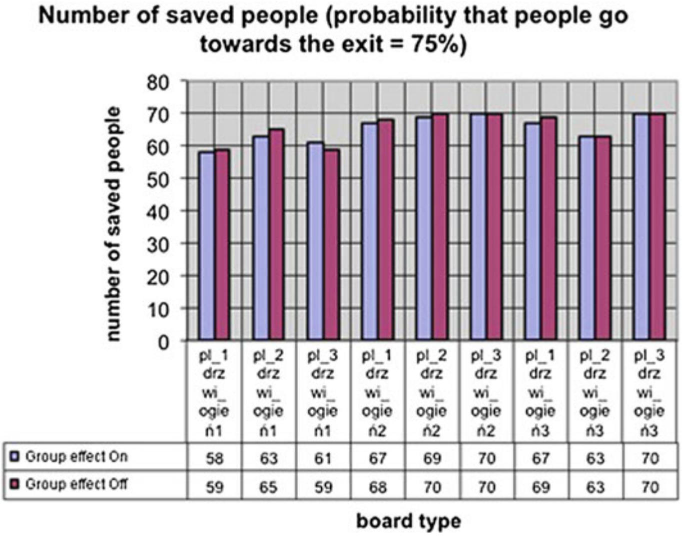

Fig. 8 Probability that people go towards the exit = 75 %

4 Conclusions

It is extremely difficult to simulate real fire inside a building. Behavior of people during fire can be stochastic and unpredictable. Authors of this study managed to present simulation of the escape of people from a building by means of cellular automata, the implementation of which was used in the study.

Following appropriate configuration of the program using the probability with which a person goes towards exit, setting the fire parameters and selecting proper option for the group effect one can draw the following conclusions:

Number of people saved from fire thanks to the group effect is comparable to the result without the group effect. The results differ depending on the type of the board and location of fire, but they are essentially very similar to each other.

When group effect is used in the program, the number of people who die as a result of crushing is larger than when no group effect is used. This happens when a person is not able to move in any direction. This is due to the fact that simulated individuals gathering in groups create areas of high density which results in death as a consequence of crushing.

In the implementation used for the experiments, people who go towards the exit way with 100 % probability are most likely to survive. To be realistic about the observations of people escaping from a building on fire, about their stress and the constantly increasing fire intensity, more probable value of probability with which they escape shall optimally be below 75 %. Hindrances that affect the decision making process during evacuation include, among others, limited visibility smoke resulting from combustion of flammable materials, high temperature and toxic gases. It is obvious here that no person would be able to pass the shortest way 100 % probability under such conditions during evacuation.

Number of doors on the board of the program is of high importance for the escape route. The more emergency exits the higher chance for people inside a building to escape and save.

Simulations of the presented experiments confirm the thesis that insouciant or unlawful blocking of escape routes inside buildings may result in tragic consequences at each stage of the building operation. Personnel responsible for fire safety and structural safety inspections may apply such tools to justify their decisions that sometimes could seem too strict. To make the simulation even more realistic, it is worth considering the option of automatic change of the parameter of the program related to the probability with which a person goes towards an exit. It is commonly known fact that the analysis of underlying causes and conditions of disasters show that the probability of survival decreases with the passing of time. Thus future experiments should take into account this fact.

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