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The fine-coarse network model for simulating crowd behavior

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The paper covers topics concerning the creation of models and simulators of crowd behavior and their usage in decision support systems. Models and crowd behavior simulators were originally created to understand the phenomena occurring in a real crowd. Due to the complexity of observed processes constructed models only chosen aspects are usually described, while others are being generalized or skipped. Creating a model requires making a choice between descriptions which are constant or discret, deterministic or random, and micro- or macroscopic. The paper introduces a developed model of crowd movement and behavior allowing a simulation of the movement of large masses of crowd in a city agglomeration environment. In model the representation of environment uses a combination of two approaches: coarse network model and fine network model simultaneously. Using a self-made simulator the author conducted experiments showing advantages and effectiveness of implemented model.

Keywords: crowd model, pedestrian behavior, pedestrian movement

1. Main features of the model

Regarding to the main approaches and classifications in crowd modeling main features of our model are:

- the representation of space through a network of cells and a graph
- microscopic approach for the representation of people
- traffic modeling using graph algorithms and potential fields method [3, 4]
- behavior modeling using rule based systems or more complex intelligence models [6].

In the presented model the space is defined on two levels: decision level and operating level.
The figure 1 shows the basic elements of the model, where lines shows possible interactions between elements:

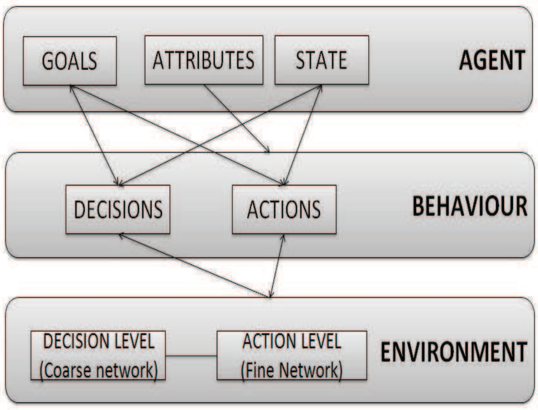


Fig. 1. Basic elements of the model

2. Coarse network

The decision level is represented by network $M^C = \langle N, E, F^C \rangle$ in which every node $n \in N$ responds to logical subarea of model space (e.g.: one compartment, corridor, passage, fragment of large compartment). If there is physical possibility of passing from one to another subarea, then the nodes representing them are connected by an edge $e \in E$ where $E \subseteq \{(n_1, n_2) \in N \times N : n_1 \neq n_2\}$. For nodes and edges the set of functions F^C was defined, from which most important are:

- $f^{NATR} : N \times T \to R, T \subset R_+ \cup \{0\}$, attractiveness – a function describing node's attractiveness of the node as a number of people or medium people congestion in the node at time
- $f^{ECOST} : E \to R_+$, distance – a function describing edge's medium distance between nodes
- $f^{NCAP} : N \to R_+$, capacity – a function describing maximum node capacity (maximum number of people in node)
- $f^{NDIST} : N \times N \times T \to R_+$, route length – a function describing medium length of a route between nodes at time
- $f^{ROUTE} : N \times N \times T \to N$ next node – a function describing the best way (node) of movement between two nodes.

The figure 2 shows an example of the model space and the model on the decision level:

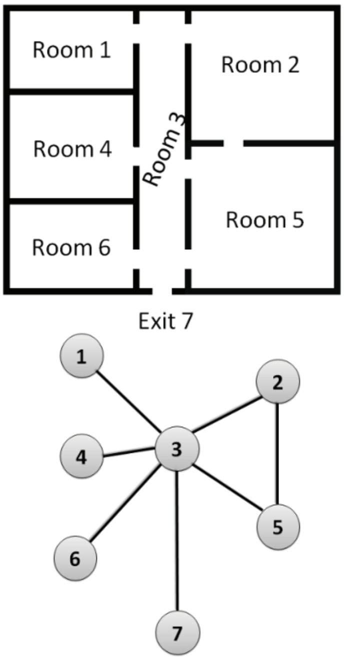


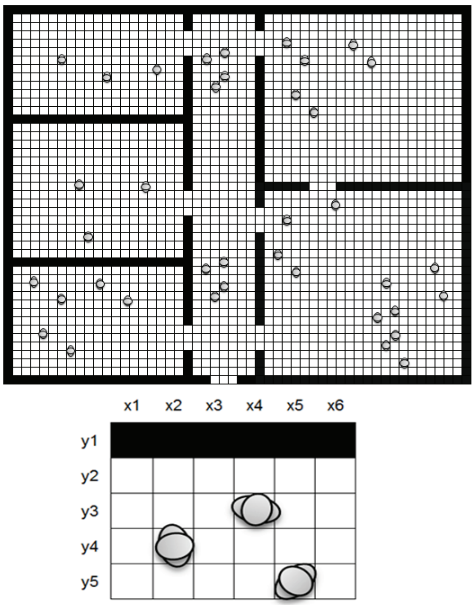
Fig. 2. Model space and the model on the decision level

3. Fine network

At the operating level of the model, the space is represented by a network of cells $M^F = \langle C, D, F^{CF} \rangle$. The space is divided into the adjacent square cells. The size of each cell is the same and it is 0,3 m x 0,3 m. In similar models, which are using a network of cells as a representation of space, the size of the side of the cell is from 0,3 m [1] to 0,5 m (e.g. Exodus [8]). In the model vector $c = \langle i, j \rangle$ represents cell located in the i-th row and the j-th column. Additionally a set *D* of possible directions of movement of person between cells was defined $D = \left\{ < d_x, d_y > \in \{-1,0,1\} \times \{-1,0,1\} \right\}$.

The vector $\langle d_x, d_y \rangle$ described as the direction of movement of person located in cell $\langle i, j \rangle$ means that the person is going to make a move to the cell $\langle i + d_x, j + d_y \rangle$. The set of functions F^{CF} was defined for cells. The most important functions are:

- $f^{CSTATE}: C \to \{0,1,2\}$, state – a function describing the content of the cell; in basic approach 3 possible states of cell are considered: 0 – unavailable, 1 – free, 2 – person
- $f^{PFIELD}: C \times 2^C \to R_+$, potential – a function determining for each cell the distance from it to the selected cells
- $f^{CDIR}: C \times 2^C \to D$, direction – a function determining for each cell the best direction from it to the selected cells
- $f^{CATR}: C \times T \to R_+$ attractiveness – a function affecting the probability of cell being occupied by a person at time
- $f^{CSURR}: C \times R_+ \to 2^C$, surrounding – a function determining a set of cells that are "in field of view" from cell in specified radius.



$$f^{CSTATE}(x2, y4) = 2$$

$$f^{CSTATE}(x3, y3) = 1$$

$$f^{CSTATE}(x5, y1) = 0$$

Fig. 3. Fragment of the model, different states of cells are representing: persons, free space and unavailable space

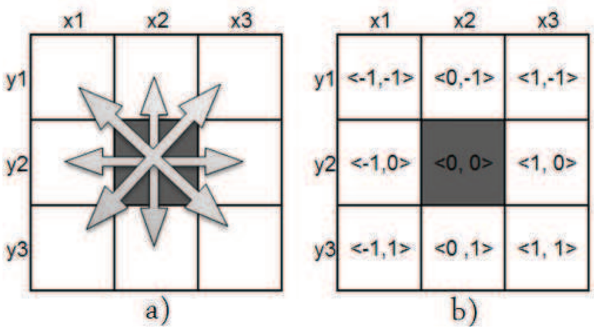


Fig. 4. The assumptions of movement model:
a) 8 possible directions of movement
b) the vectors describing the Direction

The space representations in the model are used on both levels simultaneously. The connection was achieved by assigning the cells of the model at the operating level to the corresponding nodes on the decision level.

4. Pedestrians

In the developed model, each person has its own:

- characteristics (average and maximum speed, maximum energy level, obedience, knowledge of the surroundings)
- state (position, speed, energy)
- the objectives to be achieved (to leave the building, to escape the room).

In the implemented simulator the person is represented by an agent who makes decisions and performs actions with consideration of a set of characteristics, states, the objectives to be achieved and the state of the environment.

5. Movement

The movement of agents in the model is executed in two stages:

- in the first stage the agent decides where it is going to move (considering the objective it wants to achieve). In this stage the route between the nodes is set with use of the space model on decision level and f^{ROUTE} function. In basic approach graph – network algorithms are used for setting the shortest route (e.g.: Dijkstra, A^*). During the route setting where functions f^{NATR} and f^{ECOST} are used the congestion in node may have influence on cost of movement between the nodes. Additionally it is possible to consider the probability of the agents' familiarity of surroundings for setting the incomplete and approximate routes
- in the second stage, the agents' route is set on the operating level using functions: $f^{CDIR}, f^{CATR}, f^{CPURR}$. In this stage, the potential field method (function f^{PFIELD}) was used for setting the direction of movement to any node in accordance with rule: for every node $n \in N$ potential values are determined only for cells assigned to the nodes adjacent to node *n*.

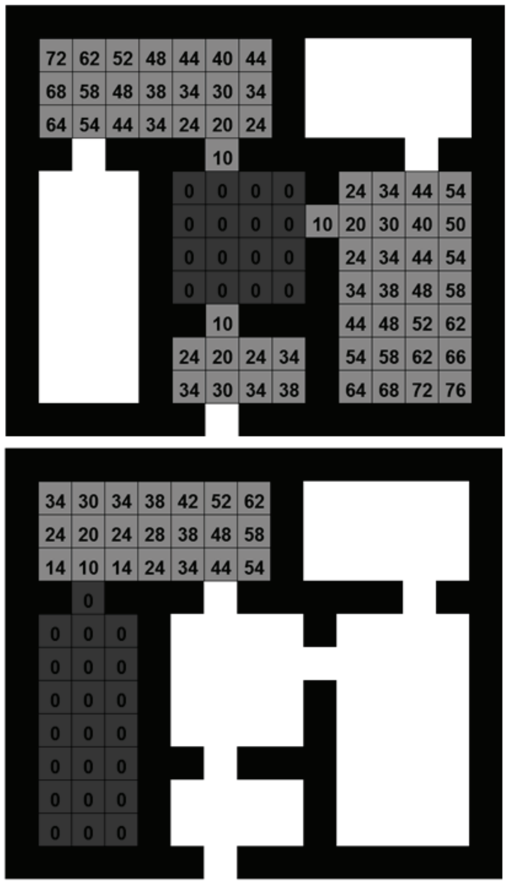


Fig. 5. Potential field method – target nodes (dark grey color), nodes for which potentials describing the distance from target nodes are determined (light grey color)

Apart from potentials also the cell's attractiveness (function f^{CATR}) has the influence on the final direction of movement of agent. In addition it was assumed that the "best" direction of movement is chosen with certain probability. In the model, the agent will move not only to find itself in a cell with the lowest (highest) potential, but also will select the most attractive cells. In the model, the attractiveness of the cell is determined using functions f^{CPURR} and f^{CSTATE} in accordance with assumptions:

- the most attractive cell doesn't change the direction of movement
- the cells located near walls and around other agents are less attractive
- the cells located in the route of movement of other agent are less attractive.

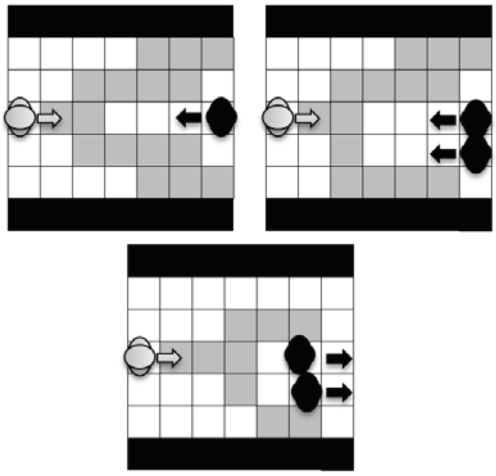


Fig. 6. The most attractive cells (light grey color) for the agent (grey color) in different situations

This approach of movement modeling allows for the consideration of dynamic changes in the model environment without the necessity of re-designation of the potentials. Changes in model environment like fire or door blockage influence only change in movement between the nodes.

6. Behavior

One of the most important elements of described model is the module responsible for agent behavior. Behavior modeling is executed by constructing decision making network on basis which the agent's behavior is determined. An example of simplified decision making model for evacuees can be described by rules:

- if the agent knows the route to exit – it will choose the shortest route
- if the agent doesn't know the route to exit – it will follow other agents
- if the agent stands for certain time in congestion – it will again choose the shortest route without taking into consideration the crowded node
- if the agent is located near the place of hazard – it will find the route without the dangerous nodes.

Of course, there can be much more rules, what on one hand, can improve the appropriateness of behavior of agents but on the other hand affects the computational complexity.

7. Experiments

In second experiment presented model was used to simulate building evacuation with information system . In addition to the rules from section 6 for the purpose of carrying out experiments, taking into account of the information system there was one more rule added: if the agent is located in the information node – it will with a certain probability change the direction of movement according to the one proposed by the information system.

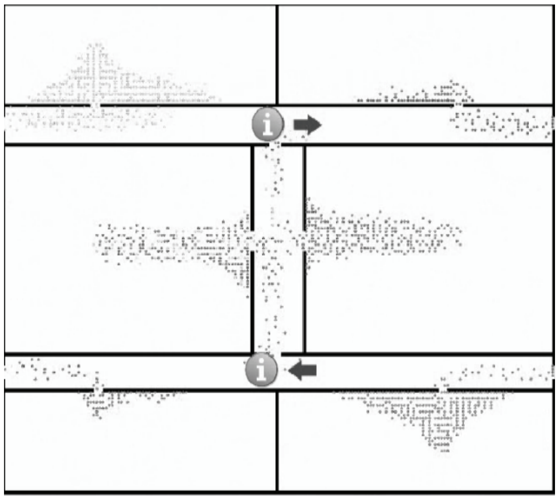


Fig. 7. Simulation of building evacuation with information system (red arrows shows best directions)

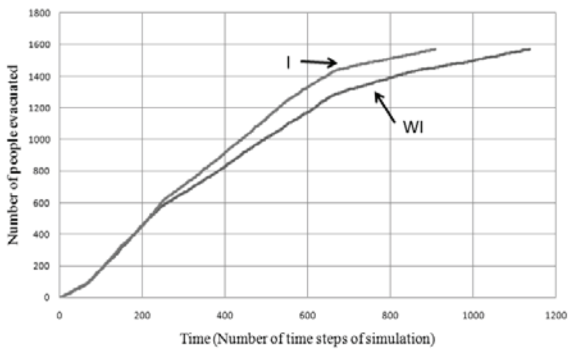


Fig. 8. Number of people that escaped from building in time: with information system (I), without information system (WI)

In second experiment implemented model was used for simulations:

- different number of pedestrians leaving single room

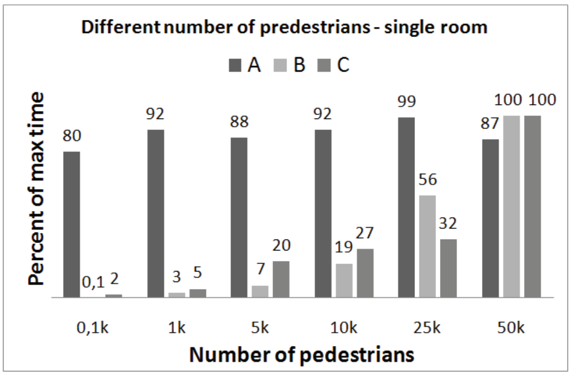


Fig. 9. Different number of pedestrians and times needed for: A – build environment (100 = 5 s), B – build crowd (100 = 20 s), C – simulation (100 = 800 s)

- large number of pedestrians leaving building with different complexity

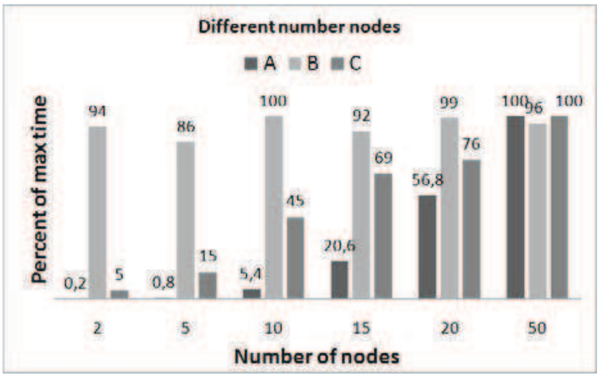


Fig. 10. Different number of nodes and times needed for: A – build environment (100 = 623 s), B – build crowd (100 = 10 s), C – simulation (100 = 750 s)

- pedestrians responds to different congestions in building.

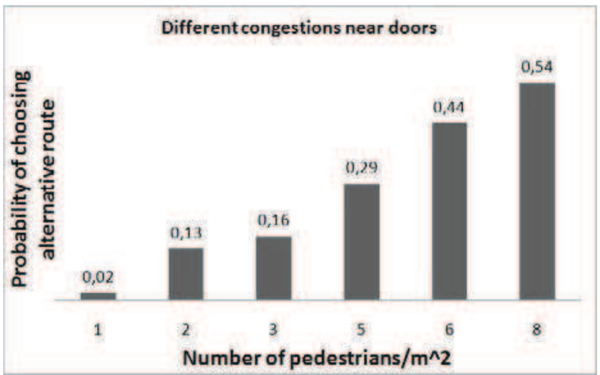


Fig. 11. Different congestions near doors and probability of choosing alternative route

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Symulacja zachowania tłumu z użyciem modelu otoczenia opartego o graf i sieć komórek

M. KAPAŁKA

Referat obejmuje zagadnienia związane z tworzeniem modeli i symulatorów zachowania tłumu oraz ich wykorzystaniem jako narzędzi wspomagających w procesach podejmowania decyzji. Modele i symulatory zachowania tłumu zaczęły powstawać jako próba odpowiedzi na pytanie, jakie zjawiska zachodzą w rzeczywistym tłumie. Konstruowane modele zazwyczaj opisują szczegółowo, ze względu na dużą złożoność zjawisk zachodzących w rzeczywistości, tylko wybrane elementy, a pozostałe są uogólniane lub pomijane. Tworząc model, dokonuje się wyboru w zależności od przeznaczenia między opisem ciągłym a dyskretnym, deterministycznym a stochastycznym oraz mikro- a makroskopowym. W pracy przedstawiony został własny model przemieszczania się tłumu, pozwalający na symulację przemieszczania się dużych grup w warunkach aglomeracji miejskiej. W pokazanym modelu przestrzeń reprezentowana jest przy użyciu dwóch podejść równocześnie: sieci komórek i grafu. Autor wykonał z użyciem skonstruowanego symulatora eksperymenty, pokazując zalety i efektywność modelu.

Słowa kluczowe: model tłumu, zachowanie jednostki, ruch jednostki