Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Master Seminar - Winter Term 2012

Stefan Münchow

Consideration of Social Groups in a Crowd Egress Simulation

Fakultät Technik und Informatik
Department Informatik

Faculty of Engineering and Computer Science
Department of Computer Science

Contents

1 Introduction

Crowd egress simulation has become an important research topic in recent years. Different approaches to simulate crowds were proposed and allow a prediction of evacuation times and overall movement patterns. However, most existing simulation models consider the crowd as a collection of individuals. Latest insights from social psychology show that this approach is doubtable since a crowd is a collection of many smaller social groups that interact with each other. Especially in unfamiliar situations groups have a strong influence on the occupants (Mawson, 2005). It seems that psychological factors have to be considered in evacuation simulation models to create realitic simulation results (Sime, 1995).

The WALK simulation developed at the University of Applied Sciences is a multi-agent based framework for pedestrian simulation. It has the capability to simulate large numbers of agents in various scenarios. Each agent can be equipped with individual and psychological factors. In the future, the artificial intelligence of the agents will be enhanced with socio-psychological factors such as emotions, personality traits and social groups. As a first step towards this, the author's work will focus on incorporating social groups in the WALK simulation framework. The group model to be developed will be based on psychological findings, e.g. the social attachment theory by Mawson (2005) and personal observations of pedestrian movement.

In section 2 basic knowledge from social psychology and existing computer science approaches are summarized. Section 3 describes the preliminary work done in the last terms. In section 4 the goals and the approach of the author's master thesis are defined. Section 5 concludes this work by describing the risks and giving an outlook on further research.

2 Background

In this section relevant psychological theories about groups are explained. They form the basis for the model to be developed. In addition, existing computer science approaches to the modeling of groups are explained.

2.1 Social Groups

A social group "consists of 3 or more people who interact and are interdependent in the sense that their needs and goals cause them to influence each other" (Aronson et al., 2005, p. 254). Whereas 2 people are usually considered to be a "dyad", in this work also associations of 2 people are called "groups". Each member of a group has a role, which is connected with a certain behavior expected from this person. Besides the size of a group there is another important aspect of group composition: the cohesion. It is determined by "qualities of a group that bind members together and promote liking between members" (Aronson et al., 2005, p. 258). The higher the cohesion is, the more the group members stick together. As one would expect, families are the groups with the highest cohesion. Especially in evacuation scenarios this aspect can have a significant influence on the evacuation efficiency.

The presence of group members can have different effects on the individuals. It can lead to arousal which causes a decreased ability to solve complex problems. Alternatively, the presence of group members can have a calming effect as described by the social attachment theory (Mawson, 2005). Moreover, a group's decision making is often strongly influenced by a leader who can be chosen based on different attributes, in case of an evacuation situation these can be age, gender or the familiarity with the environment.

As James (1951) found out group sizes are commonly distributed according to a Poisson distribution. This observation is supported by empirical studies by Moussaïd et al. (2010). Figure 1 shows typical group size distributions observed at public places.

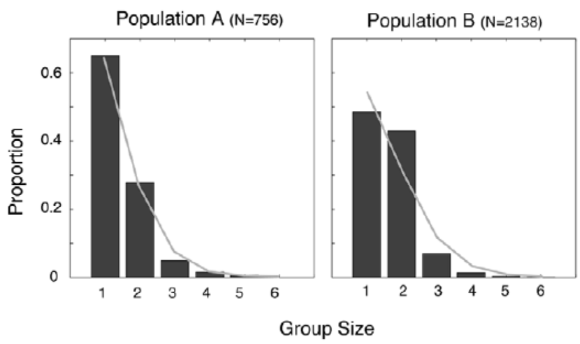

Figure 1: Typical group size distribution at public places (Moussaïd et al., 2010)

Groups greater than 6 people are hardly observed as they tend to split up into smaller subgroups. For this reason, in the following just groups from 2 to 6 people will be considered. The fundamental factors for the group model to be developed are the group size, group cohesion, roles and leadership.

2.2 Social Attachment Theory

For a long time it was assumed that people in danger tend to react strongly to even mild threats and show selfish, irrational flight behavior. The phrase "panic" is used frequently in this context. In reality this behavior is hardly observed. Instead, the usual reaction of occupants to a threat is to gather with familiar persons and leave the place as a group. Moreover, one can assume that people in danger do not behave irrationally, but show deliberative behavior which is reasonable on the basis of the available information. The social attachment theory by Mawson (2005) assumes that behavior in unknown situations, e.g. a fire alarm in a building, is determined by the following rules:

- Occupants move towards people and places they are familiar with. That means, that occupants gather with their group members and leave through exits which are familiar to them. This is the reason why most people leave a building through the exit they used to enter the place.
- The presence of familiar persons influences the individual's perception of and response to danger the following ways:
  1. When individuals are with familiar persons, the perception of danger causes intense affiliate behavior. They move as a group maintaining proximity with their group members and leave the place together.
  2. When individuals are alone or with strangers, even mild threats can cause flight behavior.

This theory proved to be appropriate in many real situations (Cocking et al., 2009).

2.3 Existing Modeling Approaches

Singh et al. (2009) did empirical observations of group behavior and developed a simulation model based on Helbing's social force model (Helbing und Farkas, 2000) incorporating them. The key observations from the empirical data were:

- When approaching obstacles, most groups or individuals evade to the right, some to the left and only 22% of the groups split up
- Single persons approaching a group rather evade than walk through the group
- If there are multiple obstacles in the way of a group, the group may split up before the first obstacle and will not gather in between 2 following obstacles. The group will gather after all obstacles are avoided
- Persons tend to follow other persons even if they are not within the same social group

The authors defined a group as a maximum of 4 people who move together in the same direction. The social force model was extended by an attractive force of group members and a repulsive force of other groups. Certain group formations are achieved by “formation attraction points”. These are points which are calculated for each occupant relatively to the group neighbor regarding the desired distance and angle between the persons. Each group has a group leader who determines the direction and speed of the group. Followers always move towards their formation attractor point. For the collision avoidance the “nearest point of approach” is calculated for each pair of groups (or pair of groups and individuals).

Qiu und Hu (2010) introduced an agent-based model to show group structures in a pedestrian simulation. The model includes both an intra-group structure and the inter-group relationships. Each agent belongs to exactly one group. Thus, single agents are modeled as a group with just one member. The influence of group members on each other and the influence between groups are defined as matrices with the agents or groups as rows and columns and numerical values between 0 (no influence) and 1 (maximum influence) as the matrix values. An example is shown in figure 2.

ID	Pedestrian_0	Pedestrian_1	Pedestrian_2
Pedestrian_0	N/A	0	0
Pedestrian_1	1	N/A	0
Pedestrian_2	0	1	N/A

Figure 2: Example of an intra-group matrix (Qiu und Hu, 2010)

Agents choose between 3 basic behaviors: Random movement, obstacle avoidance or group maintenance behavior. The movement is inspired by the work of Reynolds (Reynolds, 1999). Each agents uses 2 speed vectors for the group maintenance behavior. The first one is the *aggregation vector*. It points towards the average position of the weighted group members' positions. The second one, the *following vector*, points towards the mean group direction. Group position and group direction are calculated by each agent with regard only to the agents within its visual scope. The group maintenance behavior is triggered when the desired distance between group members is exceeded.

Each group has a leader which is the agent with the smallest id and the only agent in the group who can be influenced by other groups. He follows agents from other groups selected by similarity. For this, the group leader calculates a similarity value for the agents from other groups within his visual range and selects one as the most similar one. In the experiments the authors detected an interesting change in the flow depending on group sizes: With small groups the flow increased, only larger groups decreased the flow.

Moussaïd et al. (2010) focused on the walking patterns which occur in group movement. They collected empirical data about group sizes and their formations at public places and identified recurring patterns: At low densities groups walk abreast in a U-shape opened to the walking direction. With increasing density, the group members get closer together and the group formation becomes a V-shape. The authors came to the conclusion that people in a group move in a way that facilitates communication.

The authors implemented a group model to show this behavior in a simulation based on the social force model. There is an additional attractive force within the group. The center of mass is used as the group center and all agents have a gaze direction that is rotated towards it. This is illustrated in figure 3. Agents choose their position in the group formation in such a way that the angle of the head rotation towards the group center does not become too large. This is achieved by a second force that attracts agents towards the group center. To avoid collisions between the members of a group there is also a repulsive force between them. This simulation model fits the empirical data well. The formations as seen in reality are reproduced in the simulation. Also, the intuitive assumption that groups decrease the evacuation efficiency can be shown. Moreover, it could be seen that the walking speed decreases linearly with group size.

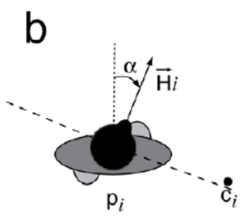

Figure 3: Occupant with gazing direction H_i and the group center c_i (Moussaïd et al., 2010)

Köster et al. (2011) developed a group model based on a cellular automaton approach. Similar to Moussaïd et al. (2010) the main focus was on the group formations that arise. The cellular automaton consists of hexagonal cells. Potential fields are used to model the attraction or repulsion between agents and obstacles. To model the group formation, repulsive forces between group members are turned off. In addition, each group has a leader, who is always the occupant nearest to the exit and creates an attracting field for the group members. All group members approach the same exit and move with the same walking speed. To avoid the loss of group members, agents slow down with increasing distance to the last occupant, meaning the one who is farthest from the exit. Moreover, the walking speed is influenced by the angle between group members.

The strength of the agents' wish to communicate is configured by a numerical parameter. By this, the communication can be turned of completely, e.g. when the group reaches a bottleneck. The authors performed a classroom egress experiment to collect empirical data. Students were assigned to groups of different sizes and got the task to evacuate the classroom as quickly as possible together with their group members. The results show that the evacuation time increases with the average group size. The presented simulation model is able to reproduce the empirical data for this scenario.

3 Preliminary Work

In this section preliminary work of the last terms is summarized.

3.1 Agent Framework

Since there is no single accepted theory which describes behavior of people in crowds it is necessary to experiment with different agent implementations. To use the WALK simulation as a testbed for various experiments, a flexible and modular agent framework was developed. Thereby, it is possible to realize components of the agent in various ways and to deploy them to the system.

The resulting agent architecture is shown in figure 4. The agent passes through 4 phases in each reasoning cycle: In the *perception phase* the environment is perceived. The result is information about obstacle and agent positions and other environmental conditions, e.g. occurring alarms and threats. In the *interpretation phase* facts known by the agent (stored in the working memory) are aggregated and new facts are created. This is done by an arbitrary number of *evaluation phases*, e.g. for knowledge, social and emotional evaluation. Afterwards, all facts stored in the working memory are used by the *decision making phase*. In this phase the agent chooses the next goal to pursue and creates a plan for it. The *action phase* always takes the next action of the currently performed plan and tries to execute it. All subcomponents and even phases, especially the interpretation phase, are optional and can be replaced easily by alternative realizations.

Currently, there is just a simple agent who gets a specified target position at simulation startup and always chooses the goal to move towards this target. If the agent reaches the target position, he is removed from the simulation. The path finding is done by an A* search algorithm on a graph representation of the environment, which creates a sequence of waypoints the agent approaches. For the steering between 2 waypoints potential fields are used. At that, waypoints have an attracting potential and agents a repulsive one. In addition, agents periodically check if they got stuck by calculating the distance they traveled in the last n time steps towards the exit and calculate their path again if necessary.

3.2 Measurement Areas

To measure all relevant data the simulation system was extended by *measurement areas*. These are areas which are defined for each scenario and track relevant values for the specified area in each simulation step. The different types of measurement areas are explained in the following:

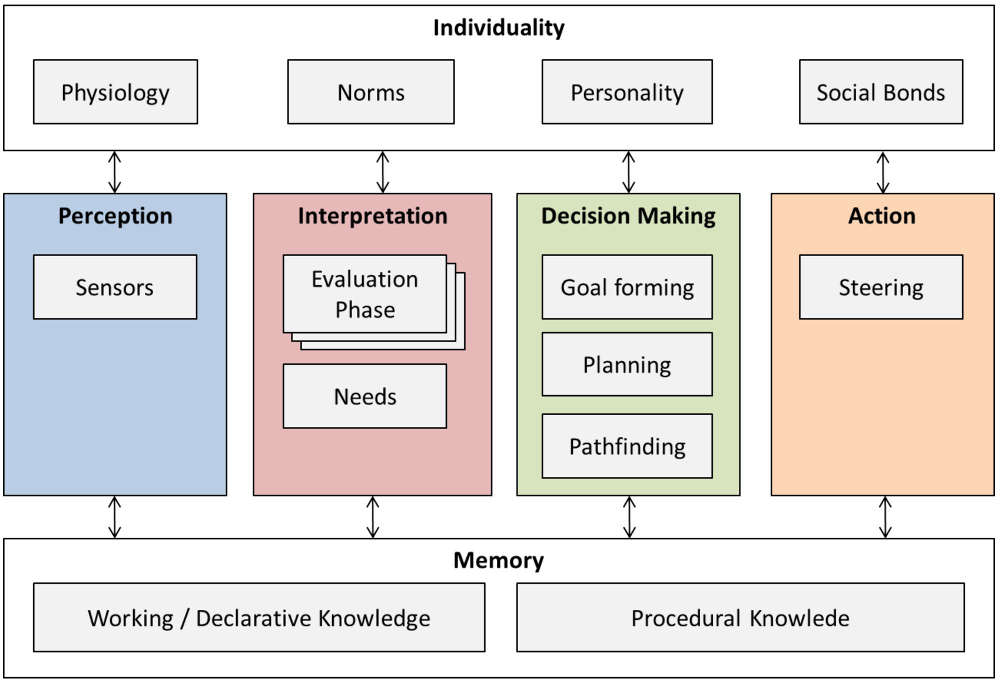

Figure 4: The WALK agent architecture

Agent count Counts the number of agents that passed the area in a simulation run

Density Counts the number of agents which are situated in the area at the current simulation step and calculates the density by dividing it by the area size

Average walking speed Tracks the average walking speed of the agents moving within the specified area by comparing their current position with the position in the last simulation step

All values are logged to a file. In addition, the simulation keeps track of the number of agents which are in the simulation. When the last agent reaches the target and is removed from the simulation, the overall evacuation time is logged.

4 Goal Setting

Many authors investigated the relation between the average group size and the evacuation time (see section 2.3). However, besides the average group size there is another important factor which has not been analyzed in detail: the group cohesion. In the author's work the relation between social group size and group cohesion to the evacuation time will be examined.

4.1 Hypotheses

The consideration of group cohesion in addition to the average group size leads to some assumptions regarding the predicted evacuation times and average walking speed. These are as follows:

Increased group size and cohesion lead to increased evacuation time
Evacuation times predicted by a simulation model regarding social groups are higher than predicted by simulation models ignoring them. It can be expected that many small groups do not affect evacuation time significantly and that predicted evacuation times increase with larger groups. Furthermore, evacuation times will increase the more, the higher the group cohesion is. Groups with a low cohesion will split up and not affect the evacuation efficiency much whereas groups with a high cohesion will significantly increase evacuation time.

High density reduces the impact of social groups on evacuation time
At a high level of density the effect of considering groups in the model is minimal. If agents in the simulation are not able to move towards their group members and are just forced to “flow” with the crowd it does not matter if they are in groups or alone. Presumably, many groups with high cohesion will increase evacuation time even at high densities since they try hard not to split up. In other cases the evacuation time will not be affected significantly.

4.2 Approach

To examine the hypotheses stated above a sensitivity analysis of the system is performed. In order to do so, basically 4 work steps are carried out:

1. Validation of the basic system ignoring social factors by comparison with empirical data. The basic simulation system has to be valid before additional influencing factors are incorporated. This ensures that changes in evacuation times result from the deployed group model and not from changes to or errors of the basic simulation platform.

2. Development of a multi-agent-based group model. It will consider psychological theory on the one hand and also existing model approaches on the other hand. The ideas of Qiu und Hu (2010) and Moussaïd et al. (2010) will be a good starting point for this.

3. Validation of the group model by comparison with empirical data. This is necessary to ensure that the group model describes the reality adequately before further experiments are performed.

4. Performance of experiments. Assuming a valid agent model they are conducted to examine the hypotheses stated above.

While step 1 is a preliminary work to ensure a valid base system, steps 2 and 3 are vital for the quality of the research results. They will be performed iteratively. The group model is implemented, validated and adjusted repeatedly until the simulation results are satisfactory.

4.2.1 Validation

To validate the basic simulation model the evacuation of a movie theater is simulated and compared with empirical results of an evacuation exercise presented in Klüpfel (2003). In this exercise 100 persons were evacuated out of a movie theater. To track each person, they wore hats with numbers on it. As a result, the overall evacuation time and the individual evacuation time and exit choice of each person were recorded. The scenario is described exactly in Klüpfel (2003) with the environment geometry and the initial distribution of occupants. It is used to validate the basic WALK simulation system with simple agents ignoring social groups. Therefore, the evacuation times predicted by the simulation are compared to the empirical data. The scenario and the realization in WALK are shown in figure 5.

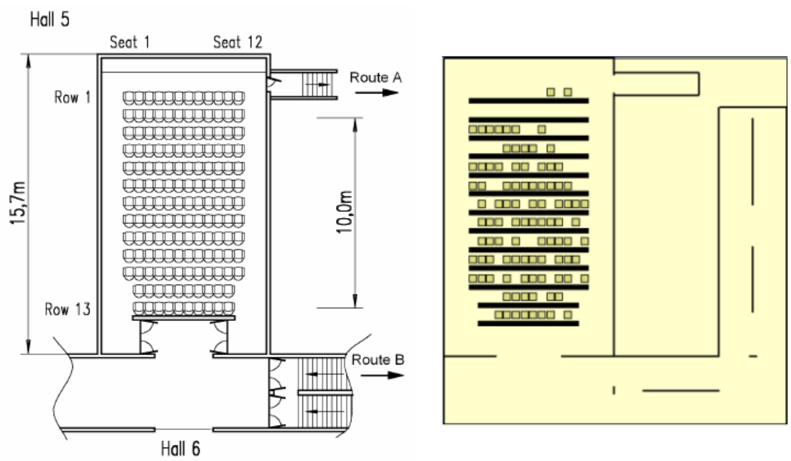

Figure 5: Movie theater scenario

To validate the group model a class room egress experiment from Köster et al. (2011) is reproduced with the group simulation model and compared to the empirical data. The cohesion value is assumed to be high in this case as the students were instructed to stay together. The measured evacuation times dependent on the average group sizes are compared to the values observed in the exercise. This will give a clue about the realism of the group model. This validation step will be performed multiple times since the group model is likely to need some improvements that become clear after each simulation run. The scenario is illustrated in figure 6.

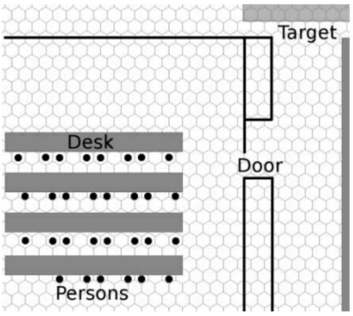

Figure 6: Classroom egress scenario (Köster et al., 2011)

4.2.2 Experiments

Assuming a valid group model additional experiments are performed. The scenarios used are representative for common situations in crowd evacuation and are taken from Brunner et al. (2009):

- A bottleneck through which many persons enter another room
- A big room which many persons want to leave through different exits

In the first step the group structure is varied in different simulation runs from only individuals to many large groups. Also, the cohesion within groups is modified from low cohesion (e.g. acquaintances) to high cohesion (e.g. families). The influence of the average group size and cohesion on the average walking speed and the overall evacuation time is measured. The used simulation settings are shown in table 1 whereby each “x” marks a simulation setting.

Average Group Size	Cohesion Level		
	low	mid	high
1		x	
2	x	x	x
3	x	x	x
4	x	x	x
5	x	x	x
6	x	x	x

Table 1: Experimental settings for the first test series

In the second step, densities are altered by modifying the initial agent count. The influence of the density on the impact of considering social groups in the simulation is rated by measuring the average walking speed and the overall evacuation times. For this analysis just settings with only individuals and groups of 5 persons are used. The experiments to be performed are shown in table 2 whereby each “x” marks a simulation setting.

Average Group Size	Cohesion Level			Density		
	low	mid	high	low	mid	high
1		x		x	x	x
5	x			x	x	x
5		x		x	x	x
5			x	x	x	x

Table 2: Experimental settings for examination of group influence at different densities

In the experiments all relevant measures (evacuation time, average walking speed, density) are recorded by measurement areas as described in 3.2. The expected results were described in section 4.1.

5 Risks & Outlook

As Zhou et al. (2010) pointed out the validation of pedestrian simulation systems is a great challenge. The parameters of the simulation system are calibrated based on single scenarios. This enhances the danger to fit them just to one scenario and loose generality. The author tries to avoid this by using 2 different scenarios for validation and 2 scenarios for the experiments. By this, the danger to loose generality should be minimized. Another risk is the complexity of the topic. The modeling of groups in the simulation touches many areas of artificial intelligence, e.g. pathfinding, knowledge representation and planning. The author tries to use simple and pragmatic solutions for aspects which are not directly related to the research topic. Still, there are some aspects that potentially can not be solved sufficiently without further investigation on the topic.

In the following months, the author will realize the group model and perform the experiments described in this paper. If the resulting model will match the expectations and create realistic group behavior, the WALK platform will have done a great step towards a mature simulation system. There are some aspects that could be subject to further research. In the author's work only fixed groups, which existed from the start of a simulation, will be considered. In some situations groups can form spontaneously. This phenomenon could be examined by means of simulation. Moreover, it would be interesting to examine the influence of personality traits and emotions on the behavior of the crowd.

References

[Aronson et al. 2005] ARONSON, Elliot ; TIMOTHY, Wilson ; AKERT, Robin M.: *Social Psychology*. Seventh Ed. Upper Saddle River, NJ : Prentice Hall, 2005. – ISBN 9780138144784

[Brunner et al. 2009] BRUNNER, U ; KIRCHBERGER, H ; LEBEDA, C: RiMEA-Richtlinie für Mikroskopische Entfluchtungsanalysen 2.2. 1. (2009). – URL http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Richtlinie+für+Mikroskopische+Entfluchtungsanalysen#1

[Cocking et al. 2009] COCKING, C. ; DRURY, J. ; REICHER, S: The psychology of crowd behaviour in emergency evacuations: Results from two interview studies and implications for the Fire and Rescue Services. In: *Irish Journal of Psychology* (2009), S. 1–31. – URL http://www.psihq.ie/IJPVol30No1-4.pdf#page=64

[Helbing und Farkas 2000] HELBING, D ; FARKAS, I: Simulating dynamical features of escape panic. In: *Nature, Vol. 407, pp. 487-490,* 407 (2000), September, Nr. 6803, S. 487–90. – URL http://www.ncbi.nlm.nih.gov/pubmed/11028994http://papers.ssrn.com/sol3/papers.cfm?abstract_id=947685. – ISSN 0028-0836

[James 1951] JAMES, John: A preliminary study of the size determinant in small group interaction. In: *American Sociological Review* 16 (1951), Nr. 4, S. 474–477. – URL http://www.jstor.org/stable/10.2307/2088278

[Klüpfel 2003] KLÜPFEL, H: A cellular automaton model for crowd movement and egress simulation. (2003). – URL http://duepublico.uni-duisburg-essen.de/servlets/DerivateServlet/Derivate-5477/Disskluepfel.pdf

[Köster et al. 2011] KÖSTER, Gerta ; SEITZ, Michael ; TREML, Franz: On modelling the influence of group formations in a crowd. In: *Contemporary Social ...* (2011), Nr. December 2011, S. 37–41. – URL http://www.tandfonline.com/doi/abs/10.1080/21582041.2011.619867

[Mawson 2005] MAWSON, AR: Understanding mass panic and other collective responses to threat and disaster. In: *Psychiatry: Interpersonal and biological processes* (2005). – URL http://guilfordjournals.com/doi/pdf/10.1521/psyc.2005.68.2.95

[Moussaïd et al. 2010] MOUSSAÏD, M ; PEROZO, Niriaska ; GARNIER, Simon: The walking behaviour of pedestrian social groups and its impact on crowd dynamics. In: *PloS one* 5 (2010), Nr. 4, S. 1–7. – URL http://dx.plos.org/10.1371/journal.pone.0010047

[Qiu und Hu 2010] QIU, Fasheng ; HU, Xiaolin: Modeling group structures in pedestrian crowd simulation. In: *Simulation Modelling Practice and Theory* 18 (2010), Nr. 2, S. 190–205. – URL http://dx.doi.org/10.1016/j.simpat.2009.10.005http://www.sciencedirect.com/science/article/pii/S1569190X09001555. – ISSN 1569-190X

[Reynolds 1999] REYNOLDS, CW: Steering behaviors for autonomous characters. In: *Game Developers Conference. http://www. red3d. com/ . . .* (1999). – URL http://www.red3d.com/cwr/steer/gdc99/

[Sime 1995] SIME, JD: Crowd psychology and engineering. In: *Safety Science* 21 (1995), Nr. March 1993, S. 1–14. – URL http://www.sciencedirect.com/science/article/pii/0925753596810113

[Singh et al. 2009] SINGH, Harmeet ; ARTER, Robyn ; DODD, Louise ; LANGSTON, Paul: Modelling subgroup behaviour in crowd dynamics DEM simulation. In: *. . . Mathematical Modelling* 33 (2009), Nr. 12, S. 4408–4423. – URL http://dx.doi.org/10.1016/j.apm.2009.03.020http://www.sciencedirect.com/science/article/pii/S0307904X09000808. – ISSN 0307-904X

[Zhou et al. 2010] ZHOU, Suiping ; CHEN, Dan ; CAI, Wentong ; LUO, Linbo: Crowd modeling and simulation technologies. In: *. . . Computer Simulation (. . .* 20 (2010), Oktober, Nr. 4, S. 1–35. – URL http://portal.acm.org/citation.cfm?doid=1842722.1842725http://dl.acm.org/citation.cfm?id=1842725. – ISSN 10493301