

# The Impact of Perception and Wayfinding on Pedestrian Movements

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**Abstract** - When simulating non-trivial scenarios of pedestrian movements it is necessary to model both the small-scale movements to a visible target (operational level) and the process to find and select routes leading to a possibly non-visible destination (tactical level). A huge number of different approaches modelling the operational level of pedestrian movements are already proposed. However, the majority of models of the tactical level are still restricted to shortest path algorithms or similar algorithms determining minimal travel efforts. These approaches assume that pedestrians have unrestricted knowledge about the spatial structure of buildings or facilities and are able to assess lengths and travel times of all possible routes. In fact, in reality the knowledge degree of people differs widely. In addition, wayfinding is a complex process including various tools and strategies which are represented only roughly by minimum-effort calculations. To improve the situation we present modelling approaches representing tools and strategies of human wayfinding and decision making based on evidence from psychological studies and literature. Furthermore, an approach has been created to consider perception in addition to decision making to model wayfinding. In particular, we analyse the consequences and differences appearing in the simulation of complex scenarios when considering more elaborated wayfinding procedures instead of using classic minimum effort calculations. To quantify the consequences and differences we particularly investigate resulting evacuation times. For this purpose we utilize the results of evacuation simulations taken place in the National Gallery of Arts in Washington, D.C.. Comparing the results of simulations considering wayfinding approaches and shortest path calculations we discuss pros and cons, limits, possibilities and the importance of perception and wayfinding models.

**Keywords:** Wayfinding, Pedestrians, Model, Tactical Level, Decision Making, Exit choice decision

## 1. Introduction

Computer simulations of pedestrians' movements are reliable tools to design and assess all kinds of buildings or facilities (e.g. traffic stations, hospitals, stadiums, multifunctional halls and assembly areas). The simulations are used to optimize design and spatial structure to guarantee efficient and safe pedestrians flows during daily traffic and emergency situations. Obviously the modelling of the physical movement (operational level) of pedestrians is essential to represent the crowd's movement patterns realistically. However, it is not sufficient to consider the operational level exclusively. The route or rather exit choice decisions are essential as well and can influence the evacuation process and therefore the evacuation time severely. There may be cases in which the route choice decisions are trivial or have no influence on the outcome, for example if the set-up of the scenario provides only one walkable route or pedestrians have visual access to their final destinations from the start of the evacuation. However, particularly in buildings with an irregular/confusing layout with many unevenly assembled rooms, e.g. museums, schools, universities or hospitals, exit choice decisions and wayfinding can be difficult. Most likely, in these buildings we will find persons who are unfamiliar with the place or even first-time visitors. If, in addition, the signage is insufficient a (direct) route to the outside

cannot always be found immediately. Nevertheless, in several simulations we find shortest path or travel time optimization algorithms to cover the tactical level although these algorithms assume that every pedestrian has complete and global knowledge about the spatial environment and although there are already more realistic approaches to represent wayfinding [5, 17, 8].

In this paper we show how severe the evacuation time can change in realistic scenarios if the simulated pedestrians (agents) are provided with different spatial knowledge degrees instead of comprehensive global knowledge. For this purpose we discuss simulations using a part of the geometry of the National Gallery of Arts in Washington, D.C.. A new wayfinding model [6] allows us to provide agents with different degrees of knowledge, which in addition can be inaccurate or distorted. The wayfinding model is discussed in Section 2 in greater detail.

We show, compare and discuss the results from runs using a minimum effort (in this case shortest path) method, the above mentioned wayfinding model and a simple room exploration method.

### **1.1. Impacts on pedestrians' wayfinding and exit choice decisions (tactical level)**

When regarding evacuation we need to consider that people do not always exit right away. A decision for evacuation may be influenced by conflicting motivation, e.g. helping others or searching for further information (e.g. [23, 12]). After the decision for evacuation, on a tactical level (as opposed to the operational level) a person must decide for one local path (or exit) or an exit strategy.

Route choice, wayfinding, and orientation are influenced by several psychologically driven factors. In this paper we focus on knowledge in the representation as cognitive map. In addition, the following aspects were found in the literature and in the authors' own field studies (e.g. [10, 15, 13, 22]). These include: spatial affordances, social factors and individual factors like knowledge. Relevant knowledge includes landmarks and generalised knowledge, e.g. layout of office buildings, characteristics of threats requiring evacuation (smoke), location of signage directing to exits. Examples for social factors are leadership and herding behaviour. Individual route choice may be influenced by other pedestrians walking into one direction, appearing to have local knowledge or giving orders. Affordances are qualities of the environment that give sensory information, for example objects, surfaces or places, which are perceived to enable a fulfillment of personal goals [4, 14]. With respect to evacuation, well illuminated spaces, visible exits or escalators leading upstairs not only enable walking there but also attract this behaviour and make it more likely.

Wayfinding is a highly complex cognitive task. It comprises multiple tools (i.a. spatial memories and signs) and strategies (i.a. path searching, route following) that may be utilized sequentially or simultaneously [19, 7]. Wayfinding requires localizing one's own position relative to the desired destination, possibly defining subdestinations (e.g. landmarks, cf. Sec. 1.2), and finally selecting a reasonable route or a direction presumably leading to one's target (exit). In addition, a wayfinder must check continuously, whether he or she is still following the correct route or not, and eventually has to recognize the destination when reaching it [2].

The tools and strategies selected in wayfinding are influenced by knowledge about the current environment and perceived information coming from the environment (e.g. from signs or other people). Even with identical knowledge in a given environment, the strategies and routes in evacuation may still differ between persons due to individual psychological factors [10].

### **1.2. Wayfinding and cognitive maps**

When solving a wayfinding task, people make use of spatial memories gathered from previous visits, generalised information, signs, maps, navigational systems (not yet for indoor purposes) and information from other people (see Sec. 1.1). Spatial memories refer to either cognitive map representation or action-based representation [19].

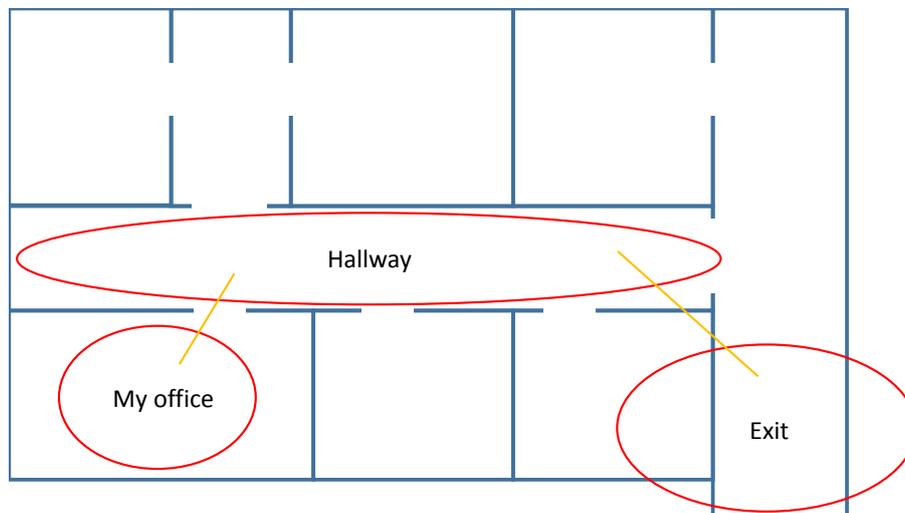
Cognitive map representations built the so-called cognitive map [7, 1, 18] which is the mental representation of a specific spatial environment. This representation incorporates landmarks and their spatial relationships to each other, to the own position and possibly to a destination. Landmarks are essential objects or scenes in the environment which were remembered during previous visits due to their uniqueness or abnormality [7, 1]. The cognitive map is filled with inaccuracies and errors, particularly with respect to metric relations [7, 1]. The map's information content and degree of accuracy depend on the wayfinder's learning capability and number of visits of the regarded environment.

Action-based representations are related to route following. Relying on the route following strategy a wayfinder goes step by step from a subdestination to the next subdestination until he eventually reaches the final one. At each subdestination the wayfinder only knows about the next step. He cannot integrate his or the actual route segment's position into the global frame or rather the whole route [7].

On top of that, due to generalised knowledge, a majority of people possess certain expectation about the spatial set-up of a building or facility [3]. Generalised knowledge is based on experiences with a type of building or facility that may result in individual classifications of their respective layouts. A prototypical train station, for instance, may consist of platforms that are connected by tunnels or bridges. Generalised knowledge is essential for wayfinders especially if they are absolutely unfamiliar with their environment [6].

## 2. The Cognitive Map Approach

In this section, we discuss a wayfinding (route choice) model which represents the evaluation and implementation of partial and inaccurate spatial information. This reflects the application of the concept of the human cognitive map [6]. In consequence, agents make their exit choice decisions based on information in their individual modeled cognitive maps. A modeled cognitive map incorporates knowledge about a specific number of landmarks including information about their positions relative to each other [6]. By assessing its cognitive map, an agent tries to find a route to a near final exit. It prefers to use landmarks as subgoals if they are connected with the final destination in the cognitive map (My Office → Hallway → Exit (in Fig. 1)). In case no landmarks are connected with the final destination (or if routes via connected landmarks cause severe detours), the agent directly tries to find the final destination by heading in the direction of this exit [6]. In order to take into account the inaccuracy of the cognitive map, the location of landmarks or destinations are represented as ellipses instead of zero-dimensional points in the representation of the cognitive map [6]. That means that the exact position of a landmark is not clear but supposed somewhere within the ellipse. For more and detailed information about the modelled mechanisms and implementations of the cognitive map approach readers are referred to [6].



**Fig.1.** The cognitive map approach: Ellipses (red) represent the inaccurate location of landmarks in the cognitive map. Connections between landmarks are marked by orange lines. The spatial structure in the background is not part of the cognitive map. It is shown to see the map in the spatial context.

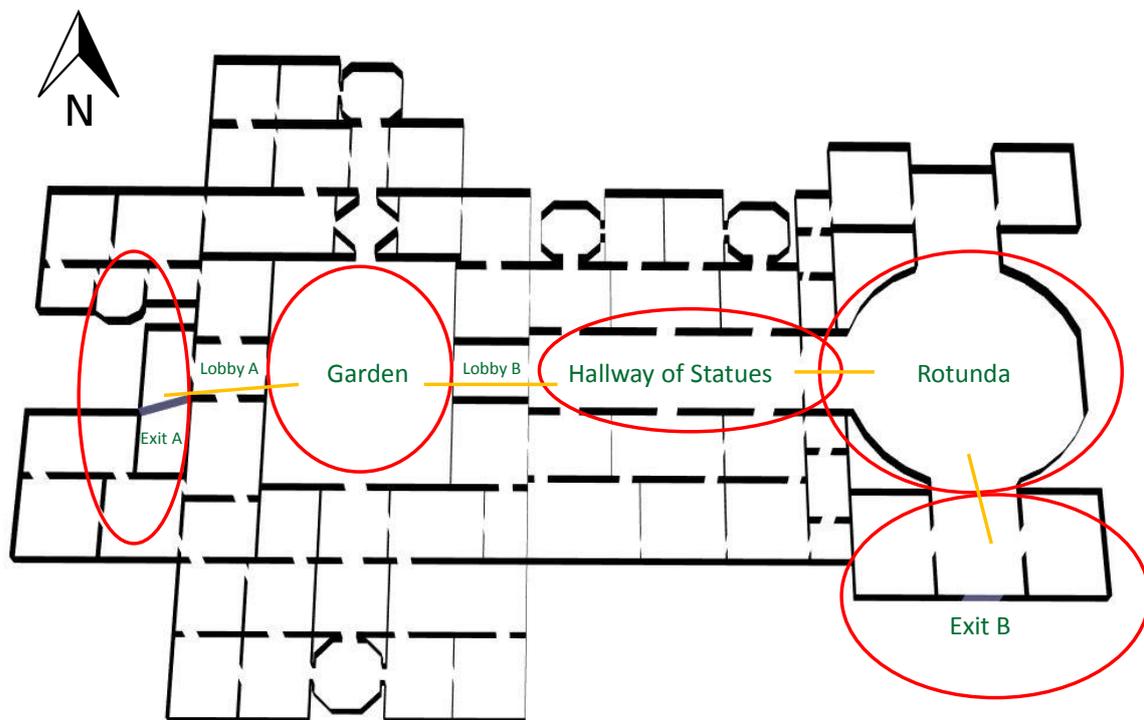
### 2.1. Perceptual Abilities and Generalised knowledge

Beside the information in their cognitive maps agents are provided with perceptual abilities and generalised knowledge (see Sec. 1.2). We assume that pedestrians are able to know in which type of building they currently are located [6]. We further assume that a majority expects buildings (particularly e.g. office buildings, hotels, schools and hospitals) to have circulation areas (e.g. corridors, lobbies, entrances) and that circulation areas are the best choice to move efficiently from origin to destination within the building [6].

Simulated agents are hence able to perceive the type of adjacent areas and will prefer circulation areas if available [6]. If no circulation area is in sight and the cognitive map cannot provide any helpful information the agent heads to the nearest door. For that purpose it has been provided with the ability to estimate the Euclidean distances within the actual room. The approach to model generalised knowledge (incl. perception) can be combined with the above mentioned cognitive map approach. Using this combination, agents will prefer circulation areas taking them closer to their targets. For more information about the implementation of generalised knowledge and the combination with the cognitive map approach see [6].

### 3. Case study

With the help of the following case study we show how severely the evacuation time can be influenced by pedestrians' knowledge degrees and used strategies. The case study comprises a set of simulated evacuation scenarios taking place in the virtual representation of a real building, namely the National Gallery of Arts (museum). To simplify the case study's scenario we make use of the west part of the gallery's West Building. Fig. 2 shows the scenarios' spatial structure.



**Fig.2.** In the background: The spatial structure (ground plan) of the west part of the National Gallery of Arts' West Building visualized in JuPedSim [11]. Exits and selected rooms are marked (green). In the foreground: Red Ellipses represent landmarks in the modelled cognitive map which serves as a template. The cognitive maps used in the simulation cases are modifications of this map. Orange lines represent spatial connections between landmarks.

The spatial structure provides two exits. One on the west side and one on the south-east side. Both exits are marked in Fig. 2. In particular, this building has been chosen as it incorporates lots of choice points: A majority of rooms or enclosed areas are directly connected to multiple adjacent rooms. The average interconnection density (ICD) [21] is about 2.55 options per choice point. The majority of the rooms has a similar size and shape as they serve as exhibition space. There are only few circulation areas, e.g. corridors or lobbies and these can only be found in the middle axis of the spatial structure (see Fig. 2).

### 3.1. Parameter setting and initial and boundary conditions

We position two agents in each of the 69 rooms at the start of the evacuation simulation. In consequence, in total 138 agents have to be evacuated. The positions of the agents within the rooms are determined randomly.

The physical movement (operational level of pedestrian modelling) is simulated by using the Collision-Free Optimal Velocity Model by [9]. The model parameters are kept constant for every agent and in every simulation. The parameters' values can be seen in Tab. 1.

Table 1: Model parameters used for the simulation cases.

Parameter	Desired velocity $v_0$ [m/s]	Time gap $T$ [s]	Wall strength $a_{wall}$ [m] (cut by circle of $D=0.2$ m)	Ped strength $a_{ped}$ [m] (cut by circle of $D=0.2$ m)	Relaxation time $\tau$ [s]
Value	1.34	1.0	5.0	5.0	0.5

The simulations were executed using the framework Jülich Pedestrian Simulator (JuPedSim) [11].

### 3.2. Routing models

For the simulation of the tactical level, e.g. the agents' doorway and exit choice decisions, we used various routing models:

#### A – Global shortest path

For each agent, the shortest path between the agent's initial position and the nearest located final exit is calculated in advance. The calculated path is kept during the whole agents' journey or rather is not changed dynamically. The routing model assumes that pedestrians have accurate and complete knowledge about the spatial structure of the scenario and can accurately evaluate path lengths within the structure.

#### B – Cognitive map approach

Agents are provided with inaccurate knowledge about selected parts of the scenario's spatial structure. This knowledge is represented by the cognitive map modelling approach which is described in Sec. 2.

Each agent is provided with a unique variation of the cognitive map shown in Fig. 2. The cognitive map of agents with a high knowledge degree has all the landmarks and connections shown in Fig. 2. Besides, shapes and sizes of the ellipses representing landmarks are only slightly modified. Agents with a minor and less accurate knowledge degree are provided with a part of the original landmarks and possibly no connections between them. In addition, shapes and sizes of the ellipses are highly modified.

Within the creation of every cognitive map (by altering the original map), a landmark is omitted by the probability of  $P_L$ .  $P_L$  has been set to 30 % for the regarded case studies. In case a landmark has been omitted the related connections are also left out. However, by a certain probability  $P_C$  (here set to 20%), new direct connections between the landmarks which had been connected to the omitted landmark are established. Both centres and expansions  $a$  and  $b$  of the ellipses are modified making use of a Gaussian distribution. For the shifting of the centres  $(p_x, p_y)$ , we use a distribution with a standard deviation of  $a/5$  (for  $p_x$ ) and  $b/5$  (for  $p_y$ ) respectively ( $p_x, p_y$  as mean value). The expansions of the ellipses are altered with the help of a Gaussian distribution with a standard deviation of  $a/3$  ( $a$ ) and  $b/3$  ( $b$ ) (each  $a, b$  as mean values). Using these variations, many different reasonable maps are created. As a minimum, every agent's cognitive map comprises an ellipse representing one of the final exits.

In addition to the evaluation of their cognitive map knowledge, the agents remember and re-recognize rooms they already have been in. Those rooms are avoided by an agent in case it has to search for the exit [6].

The cognitive map approach implicates the premise that pedestrians' knowledge degrees varies widely but can be represented by the above mentioned variations. Furthermore, it is assumed that the cognitive map approach can at least represent parts of the cognitive processes involved in the wayfinding progress realistically.

### C – Room exploration

In this model, the agents do not possess knowledge about the building’s spatial structure (empty cognitive map) at the start of the simulation. Hence, here it is assumed that all pedestrians have not remembered any spatial information during their actual visit or possible earlier visits of the building. They have to explore the rooms to find an exit eventually. The agents avoid rooms they already explored.

### D – Room exploration by using circulation areas (using generalised knowledge)

In principle this routing procedure is identical to the room exploration. However, now the agents prefer to proceed via circulation areas, e.g. hallways and lobbies, when searching an exit. The preferred circulation areas (Rotunda, Lobby A, Lobby B, Garden, Hallway of Statues) are marked in Fig. 2. Here, we start from the premise (beside the premises mentioned in Model C) that pedestrians have generalised knowledge about the fact that they will find an exit more efficiently via circulation areas.

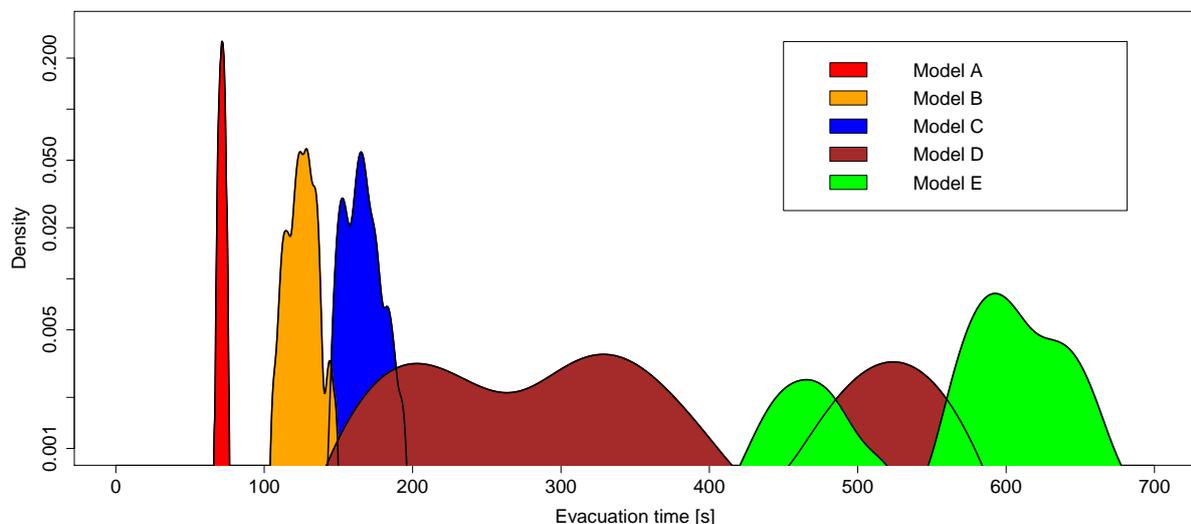
### E – Cognitive map approach in combination with generalised knowledge

The model is a combination of models B and D. Hence, agents are simultaneously provided with a certain degree of knowledge about the explicit spatial set-up (cognitive map) and are able to distinguish between circulation and common areas (generalised knowledge).

## 3.3. Results of the case study – Comparison between routing models

For each of the above discussed routing models 1000 simulations of the case study’s scenario were executed. For the runs that use routing model B or rather E different, randomly created variations of cognitive maps were utilized (in each run each agent has its own randomly created unique map, see Section 3.2 B). The distributions of the simulated evacuation times are shown in Fig. 3 and 4. Fig. 3 depicts the overall evacuation times whereas Fig. 4 depicts the time when 95 % of the agents have been evacuated for each of the simulation cases.

In the simulation cases making use of Model B and C, the evacuation time is noticeably influenced by a small part (about 5 %) of the agents that need much more time compared to the others. That is because in many cases a part of the agents makes the wrong decision in the room Hall of Statues. Instead of proceeding to Lobby B or the Rotunda they head to the rooms at the north and south site of the Hallway. Using Model B, this behaviour is shown particularly if agents presume Exit A to be more in the west than it is. Once inside the rooms at the north and south side of the hallway, they keep looking for the exit by exploring several adjacent rooms. It takes a certain time until they return to the Hallway and proceed to the Rotunda. If the journeys of some agents already have been quite long until they proceed to the wrong room in the Hallway, the overall evacuation time increases severely.



**Fig.3.** Distribution (kernel density estimation) of evacuation times using the discussed routing models.

These last 5 percent of the agents are therefore “responsible” for the evacuation times from ca. 450 to ca. 580 seconds (Model B) and from ca. 550 to ca. 680 seconds (Model C) (see Fig. 3 and 4). Figs. 3 and 4 and Table 2 show that, as expected, the evacuation time increases when the knowledge degree of the agents decreases. Also the variability of the evacuation times is increasing with decreasing knowledge degrees. Particularly when using Model B, a relatively high variability had been expected due to the fact that not only the agents’ starting positions but also the information degree (in their cognitive maps) had been altered remarkably. However, the evacuation times of the runs with Model C show a relative high variability as well, although here only the agents’ starting positions had been changed within the runs. This phenomenon results from the fact that the starting position is decisive for the selection of the first doorway.

Table 2: Mean and standard deviation of the evacuation times.

	Model A	B	C	D	E
Mean [s]	71.5	351.3	640.0	164.5	126.1
Deviation from Model A [%]	-	391.3	795.1	130.1	76.4
Std [s]	1.5	127.3	140.3	10.0	8.2
Mean 95% [s]	63.9	160.3	405.9	141.8	106.3
Deviation 95% from Model A [%]	-	150.9	535.2	122.0	66.4
Std 95% [s]	1.3	25.1	32.4	3.6	4.3

The selection of the doorway itself it obviously decisive for the continuing journey, for example if an agent heads to a doorway facing away from the rooms in the middle axis of the gallery. Please note that in every case the evacuation times (also the times when 95 % are evacuated) very much depend on the route choice or rather the progress of the search of a small group of agents, in some cases possibly only one single agent, since no congestion occurs at any time or place in the simulation.

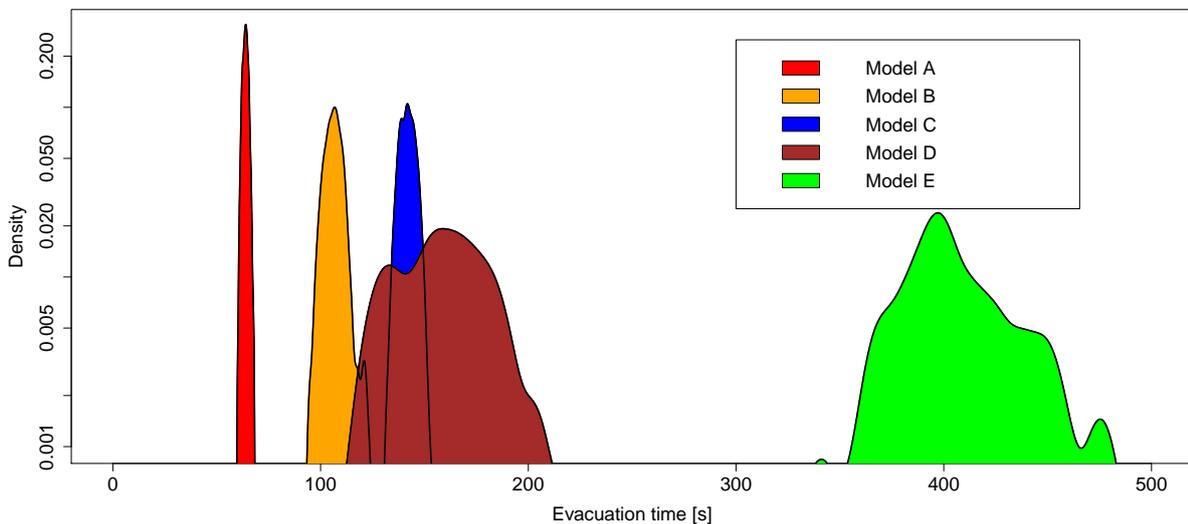


Fig.4. Distribution (kernel density estimation) of times when 95% of pedestrians are evacuated. The routing models discussed in this paper are used.

Furthermore Figs. 3 and 4 and Table 2 show the importance of generalised knowledge (in this case the differentiation between functional and circulation areas). The mean value and the standard deviation of the evacuation time using Model D (only generalised knowledge) is even lower compared to runs in which the agents are provided with explicit spatial information (in their cognitive maps). As expected, compared to Model D a combination of generalised and explicit spatial knowledge leads to lower evacuation times.

However, here, the evacuation times' mean value still deviates remarkably (76.4 % and 66.4 % respectively) from the mean value of the runs using Model A (see Tab. 2). As expected, the evacuation times and particularly the evacuation times of 95 % of the runs using Model C (no information at all) are noticeably higher (350 - 500 s) compared to all other models (60 - 200 s) (See Figs. 3 and 4 and Tab. 2).

## 4. Summary and Conclusions

In this paper we showed the impact of various routing models on the evacuation time of a realistic scenario. For this purpose we used a (global) shortest path algorithm, a cognitive map approach that provide the agents with different degrees of spatial knowledge and a simple room exploration method. The resulting evacuation times vary widely. Even if the agents are provided with either cognitive map representations and generalised knowledge the evacuation times differs by ca. 75% from the global shortest path model.

The combination of the cognitive map approach and the implementation of generalised knowledge (Model E) is still an inaccurate representation of real human cognitive processes involved in the wayfinding or decision making tasks. I.a. the model neither comprises the evaluation of signs nor the evaluation of information from other human beings (i.a. herding effects). Action-based representations are not modelled either.

Additionally, the agents' cognitive maps are modifications of one single map. The landmarks of this map have been determined by the authors based on information from the ground plan exclusively. Possibly real visitors of the gallery remember more, less or even completely different objects. Thus, their cognitive maps may look different and might not be appropriately represented by a modification of the mentioned map which serves as a template.

In consequence, we are faced with two factors which determines the quality of a simulation using the cognitive map approach remarkably. The first factor is related to the question if the agents implement a certain representation of knowledge properly or rather behave realistically in case of specific cognitive map representations. The second factor comprises the determination of the representations. Which landmarks are mainly remembered in a certain situation, for example in unfamiliar museums? To which extent do the knowledge degree vary, for instance regarding first time visitors of a museum? Both factors are decisive and need to be investigated.

However, the assumption that pedestrians possess inaccurate, varying and incomplete spatial knowledge is reliable [7, 1], especially compared to the assumptions that underlie shortest path calculations. Nevertheless it's not our intention to claim one of the approaches to be a significant better model for the tactical level of pedestrian simulations. Instead we want to demonstrate solely the large, decisive, possibly negative impact on the duration of an evacuation indicating the necessity for such a research approach. In consequence we will invest more resources into the investigation of wayfinding itself and its underlying mechanisms and into the modelling of wayfinding processes in pedestrian simulations. Our future work comprises the further development of the shown exit choice decision model in terms of including the modelling of all strategies and tools and their collaboration involved in wayfinding tasks. In addition, the model will in the future consider factors that influence the exit choice decision related to sensory input, for example the recognition of jams or smoke propagation [16].

## Acknowledgements

This research is funded by the Deutsche Forschungsgemeinschaft (DFG) contract No. GZ:SE 17894-1 and by the German Ministry for Education and Research (BMBF) contract No. 13N13266 (project ORPHEUS).

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