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Modeling pedestrians' interest in locations: A concept to improve simulations of pedestrian destination choice

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ABSTRACT

Large environments that are designed for travel, leisure, and for everyday life – such as transport hubs, amusement parks, and shopping centers – feature different locations that are frequently visited by pedestrians. Each visit is evoked by one's motivation to engage in some kind of activity at a certain location. By means of modeling the pedestrians' interests in locations with the aid of computer simulations, it is possible to forecast the occupancy at locations by utilizing sophisticated pedestrian destination choice models. In the field of pedestrian dynamics research, location preference modeling is not common, but it is all the more rare to include a psychological grounding into such choice models. Here we show that our psychologically inspired and mathematically defined model to describe pedestrians' interests in locations is able to improve the exactness of pedestrian destination choice models. The interest function model is based on the psychological concept of goal-related memory accessibility and on fundamental coherences found in pedestrian-related data that is measurable at locations. We validated the interest function model and our results provide evidence that our approach improves the simulation fidelity regarding occupancy forecasting. Because the interest concept is designed as a framework that can be coupled to existing microscopic pedestrian simulators, it can be used in most pedestrian destination choice models to describe pedestrian visiting preferences. Consequently, the reliability of the occupancy predictions of pedestrian simulations can be enhanced by integrating the interest function model into choices models.

1. Introduction

Pedestrian simulations aim to predict pedestrian movement behavior in different environments. Decision makers can identify dangerous situations and increase pedestrian safety by evaluating the prediction models' simulation results. We describe these results as macroscopic pedestrian performance indicators. An important indicator is the pedestrian flow that describes the throughput of pedestrians in time and space between two locations [58], e.g., a route connected by two junctions. The pedestrian flow decreases with an increasing number of pedestrians [52]. Additionally, the flow changes if the geometric layout of the surroundings impedes walking [42]. Another important indicator is to be seen in high pedestrian densities [50]. A well-known tragic example in which high pedestrian densities played a key factor is the Love Parade disaster [28]. In contrast to the macroscopic indicators, microscopic indicators account for people's walking properties such

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as the position, the direction and the velocity. Hence, it is the microscopic pedestrian walking behavior that leads to macroscopic pedestrian-related performance indicators. Therefore, microscopic pedestrian computer simulations are used to forecast macroscopic performance indicators [1,16,36,56,60].

In our work, we focus on a specific macroscopic factor: the number of visitors at a location over time, in other words, the location's occupancy. This time dependent value ultimately describes the pedestrians' visiting patterns at a location, which is a macroscopic indicator for capacity caps and safety issues [50,57]. The occupancy emerges due to microscopic behavior of pedestrians comprising repeated stays at locations and travel among locations. Hence, chains of destination choices describe a complex visiting process. In the literature, this process is referred to as *trip chain* [46], *multipurpose trip* [15], *plan* [25], or *spatial sequential choice* [23]. In pedestrian dynamics, the selection of the next location to visit is defined as *strategic behavior* [30] and is also known as *destination choice* or *goal selection*. In general, a pedestrian selects a destination to visit because he/she prefers to engage in an activity on offer at that location over another activity. Thus, choice of destination includes a range of motivational properties, which guide and drive pedestrian behavior.

One issue in contemporary pedestrian dynamics research is that there are only very few models of pedestrian destination choice that takes psychological factors into account. Because modeling pedestrian behavior is essentially about modeling human behavior, we believe that introducing a psychologically grounded methodology to model pedestrians' location preferences will improve destination choice models. We approach this research gap by proposing a new framework to model pedestrians' interests in form of a mathematical function. The theoretical groundings of the interest function model are the psychological concept of goal-related memory accessibility and the fundamental coherences found in measurements of pedestrians visiting locations. Drawing on computer simulations, we can show that the interest function model is valid as stand-alone concept. Additionally, we are able to improve an existing task queuing destination choice model [53] with the interest function model and provide evidence that the approach outperforms the widely used origin–destination matrix approach on a multi-location simulation scenario. The results provide evidence that applying the interest function model improves pedestrian occupancy forecasts by improving destination choice simulations.

The remainder of this paper is structured as follows. In Section 2, we present contemporary strategic behavioral modeling approaches and related work. Section 3 begins with a recapitulation of the necessary psychological groundings, followed by a mathematical description of the interest functions framework. Additionally, the regeneration of the occupancy at a location is explained. The validation of the interest function framework for a single location concludes Section 3. In Section 4, we show how to integrate the model into existing microscopic models of pedestrian behavior. Furthermore, we present and evaluate results of interest-based pedestrian computer simulations for multiple locations. The paper closes with a discussion about challenges in Section 5 and concluding remarks in Section 6.

2. Related work

The concept of categorizing pedestrian behaviors as strategic, tactical, and operational behavior is an accepted approach in pedestrian dynamics [14,30,31]. Strategic behavior describes destination choice and models sequencing activities – while tactical models depict the pedestrians' navigation behavior by defining an approximated walking route that starts at the pedestrian's current position and ends at a certain destination. Operational models relate to the manner of walking to the next visible intermediate navigation node, adjoining the walking route and interacting with other pedestrians and obstacles along the way.

The history of strategic pedestrian behavioral research is well summarized by Timmermans et al. [55]. Early approaches to model strategic behavior were driven by attempts to assess the efficiency of shopping malls [15]. However, many strategic pedestrian behavioral models are application-independent, and the most widely used generic approach is the origin–destination matrix (OD matrix) concept. An OD matrix is a Markov chain model [55] that describes the probability of visiting a destination if a pedestrian is at a specific origin location. The model is time-invariant and quite easy to apply. Nonetheless, the OD matrix approach is difficult to apply in larger application scenarios [14] and is still being studied [20,34]. In addition, more sophisticated approaches have been developed in recent years [16,19,25,30]. The research highly related to our work are the need-based approach of Arentze and Timmermans [7] and the potential attractivity measure concept of Danalet et al. [17]. Both models are original approaches, but based on other grounds than those of the interest function model. Hence, we provide a new perspective to this branch of research.

In general, psychology-based concepts receive increasing attention in pedestrian dynamics research. Approaches considering human psychology and cognitive abilities are already established in operational models [32,45,47] and tactical models [10,37,38]. Even if rare, there are examples for psychologically enhanced strategic pedestrian behavioral models [35,41,59,61].

The development of computationally implementable models regarding human cognition, behavior, and decision making is nowadays highly advanced [11,29,54]. For example, the adaptive control of thought (ACT) by Anderson [3] is widely used in different variations and has been continuously improved. Balke and Gilbert [8] presented an in-depth survey about models and architectures of human decision making for social simulations. One of the main drawbacks of many of these highly advanced models and architectures is that they are not designed for strategic pedestrian behavior modeling. However, there are exceptions – such as work of Pelechano et al. [48] and Wijermans et al. [61].

Despite different approaches and modeling paradigms for strategic behavior, a surprising void was identified in most strategic models. Often, the destination choice is modeled based on a change in motivation, desire, urge, drive, or will –