

Agent Based Simulation of Pedestrian Movement in Urban Environments

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Abstract

New urban planning approaches increasingly focus on pedestrians as key actors of urban planning concepts. Simultaneously, ongoing scientific analysis of pedestrian movements on public footpaths and squares provides new opportunities to explain the behaviour of individual passers-by, providing the street a computational component. Nevertheless, there is a lack of simulation tools for pedestrian movement in urban outdoor environments, especially for urban planning purposes. Therefore, an agent based tool simulating pedestrian movement, using the social force model, was implemented. Using common spatial data formats like ESRI Shapefile and GeoJSON, the tool is capable to create agents for a chosen part of a city, in which a simulation of the pedestrian movements can be performed. The tool developed in this work is particularly suited for the simulation of planning scenarios in small urban units such as pedestrian zones, neighbourhoods or development areas.

Keywords: pedestrian movement, agent based models, social force model, urban modelling, open data, urban planning

1 Introduction

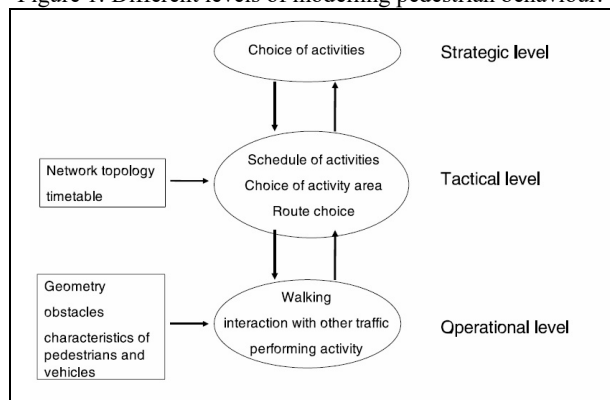
The impact of pedestrians on the shape of a city starts already with the first urban structures: the development of early road networks in settlements and cities was primarily formed by the everyday routines of the local people, and also the size and spread of pre-industrial cities was limited to less than one million inhabitants by the maximum walking distance of the people (Batty 2018). With the industrial revolution and the upcoming motorized traffic, an explosive urban growth was made possible, while the relevance of pedestrians in urban planning dropped significantly, resulting in mission statements of urban development focussing on car-friendly cities and supporting the process of suburbanization. Starting with the revitalization of inner cities in Europe during the 1990s, pedestrians regained interest within urban development, culminating in the Time Square's transformation into a pedestrian-friendly zone in the centre of Manhattan in 2009 (Hass-Klau 2015).

Meanwhile, the scientific cooperation of traditional urban researchers and computer scientists enables new explorations of pedestrians and their behaviour on public footpaths and squares, giving the street a computational component and providing new opportunities to explain the behaviour of individual passers-by (Filomena and Verstegen 2018; Torrens 2016). Nevertheless, due to an own survey based on Meinert et al. (2019), most of the pedestrian simulation tools are built for evacuation scenarios and pedestrian flows in crowded infrastructures, e.g. metro stations, leaving a gap for simulating pedestrian movement in urban outdoor environments, especially for planning purposes. The work of this paper reacts to this and develops a prototype tool to simulate individual, agent-based pedestrian movements in a small-scale urban environment, based on findings and contributions in the research fields of urban simulation.

2 Related Work

Modelling pedestrian dynamics is a very complex task and should consider three different levels of behaviour, as shown in figure 1 (Schadschneider et al. 2009; Hoogendoorn and Bovy 2004). At the strategic level, the pedestrians decide which activities are set to their agenda. At the tactical level, pedestrians have to schedule their activities and choose the best route to fulfil their agenda. Finally, the operational level describes the actual process of walking, and the behaviour of the pedestrians to avoid collisions with obstacles or other pedestrians.

Figure 1: Different levels of modelling pedestrian behaviour.



Source: Schadschneider et al. 2009.

While there has been a lot of research in the fields of pedestrian simulation, implementing the operational level, and pedestrians interacting with urban environment through agent

based modelling, implementing the tactical and operational level, there are only a very few approaches to implement all of the three levels of pedestrian dynamics at the same time. Therefore, the simulation tool implemented in this work has to combine findings of two research fields: Pedestrian simulations, and agent based models of pedestrians.

2.1 Pedestrian simulations

In comparison to the simulation of motorized traffic, pedestrians are not bound to lanes or sidewalks. Instead of abstracting the movements to a one dimensional road network as done with cars in many traffic simulations, one has to consider that pedestrians not only move in two dimensions, but use sidewalks, squares, lawns and open spaces, and cross streets nearly everywhere. However, modelling the operational level of pedestrian dynamics is often based on variations of models from physics, which can be classified into three categories due to their different spatial resolution: macroscopic, microscopic and mesoscopic (Ijaz et al. 2015; Schadschneider et al. 2009). Macroscopic models, such as fluid-dynamic and gas-kinetic approaches, simulate only an abstract behaviour of a large crowd, resembling fluid and gas-kinetic motions in physics. By contrast, microscopic models focus on the detailed behaviour of the individual pedestrian, using rule-based or force-based approaches. In rule-based models, the focus is set on the pedestrians' intrinsic behaviour, implementing a decision-making based on predefined rules, often justified from psychology, according to the current situation, the neighbourhood and the agenda of the individual pedestrian. Therefore, force-based models emphasize an extrinsic behaviour of pedestrians, as if their motion is the subject of external forces from other pedestrians and the surrounding infrastructure. Finally, mesoscopic models are using in-between approaches, combining elements of microscopic models with macroscopic ones, e.g. by assigning individual behaviour to a small group of people and simulating the whole group as a single entity.

2.2 Pedestrians in agent based models

As shown by Batty (2005), agent based modelling is a popular approach in the field of urban simulation, as it is the only way to account for the diversity of local movements in urban systems. Pedestrian simulations in urban environments are possible in all scales of the city. Therefore, agent based models provide a suitable tool for comprehensive interactions, simulating actions on the micro level and measuring their results at the macro level (Filomena and Verstegen 2018), e.g. by analysing everyday movements of commuters over the whole city (Batty 2018) or the route of shoppers in pedestrian zones and shopping centres (Haklay et al. 2001). For the latter, agent based modelling has gathered commercial value as well as a predictive tool to price different shopping locations due to the frequency of passers-by (Torrens 2016; Batty 2005).

Beside pedestrians as actors in urban systems, recent research approaches in agent based pedestrian models focus on the spatial cognition of agents for routing and orientation purposes (Filomena and Verstegen 2018), which is part of

tactical level of pedestrian behaviour and can be connected to the research field of pedestrian routing. Routing through open spaces in turn is part of the wayfinding algorithms which have to be implemented in the pedestrian simulation models using microscopic approaches, like rule-based and force-based models.

3 Simulation tool

The aim is to build a simulation tool implementing all levels of pedestrian behavior at the same time. The tool should not focus on a specified area or city, but provide a general approach to urban simulation on the micro level by providing basic pedestrian movement scenarios and a simple data input interface, using common spatial data formats like ESRI Shapefile, GeoJSON and CSV. The concept of the tool is therefore based on general ideas of urban simulation, while the actual implementation resembles functions of pedestrian simulation and agent based modelling tools.

3.1 Conceptual design

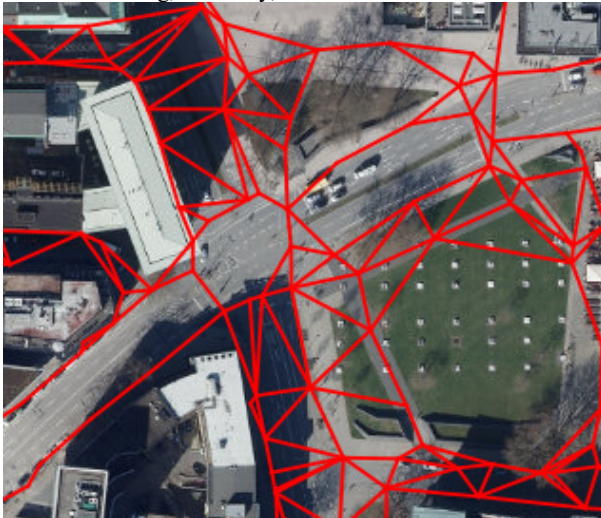
The tool developed here focuses on smaller urban units, so most of the pedestrians in this areas are entering and leaving the simulation zone during their daily routine. Therefore, these points of entering and leaving the simulation system are defined by introducing the concept of "gateways": Gateways are locations in the city where people become active pedestrians, e.g. stations of public transport or parking lots (Batty 2005; Haklay et al. 2001). Gateways are a core feature of urban simulation, and both scenarios of the simulation tool implemented in this work depend on the existence of this spots in the simulation area. In the standard scenario of the tool, agents start and finish their movements at one of these gateways, while walking to the given waypoints in between. A second scenario analyses the reachability of a chosen location by simulating the movements of a given number of pedestrians, starting from the nearest gateways and walking towards the target location.

In agent based modelling, agents are defined as systems that sense their environment and act on it in pursuit of an own agenda (Franklin and Graesser 1997). In comparison to the three levels shown in figure 1, sensing the environment is mainly part of the operational level, while acting in pursuit of an own agenda is more linked to the tactical and strategic levels. Therefore, agent based pedestrians have to (1) take care of the activities surrounding them, especially boundaries and other agents, and (2) follow a given set of properties working as an agenda, e.g. some locations to reach, a certain velocity the agent wants to walk with, and an wayfinding heuristic to the next destination on his list.

As stated before, orientation and navigation of pedestrians in urban environments is subject to recent research. In this work, a network-based approach for orientation and wayfinding, based on Open Street Map data of streets, footpaths and traffic lights, is used. This common wayfinding heuristic is stated by Benenson and Torres (2004): pedestrians, who do not see their next destination, establish intermediate nodes and move from one to another. The nodes

of the network are point representations of the common walkable areas (footways, pedestrian zones, cross-walks, etc.), while the lines solely work as edges for the implementation of shortest path algorithm used for finding intermediate nodes. Figure 2 shows an example of such a generated network of a part of Hamburg, Germany, where the nodes are placed on footpaths and only those connections are allowed, that are in a line of sight between points and do not cross a four-lane-road outside of official crossings.

Figure 2: Generated routing network for part of the city of Hamburg, Germany, based on data from OSM.



Source: Google Satellite (Background image)

The operational level, and therefore the actual computation of pedestrian movements, is implemented with the social force model as stated by Helbing et al. (2005). As mentioned before, the social force model, as the most common force-based model, is based on the idea that the actual pedestrian movement behaviour is influenced by external forces, which change the direction and velocity of the pedestrians. With combining the agent characteristics with an operational pedestrian simulation, the tool is able to generate pedestrians who follow their individual agenda, but also avoid collisions on the individual level and create pedestrian jams on the aggregate level.

3.2 Implementation

While the conceptual design of the tool is based on general research findings of pedestrian motion and agent based modelling, the architecture of the tool also adopts basic concepts of research contributions of urban simulation. First, as introduced in the STREETS model of Haklay et al. (2001), there is a separation between the pre-processing part of the simulation – generating agents and the physical environment of the simulation – and the actual computation of the pedestrian movements. Second, as implemented in the multi-agent simulation toolkits MASON (Luke et al. 2005) and GAMA (Grignard and Drogoul 2017), the visualization part is

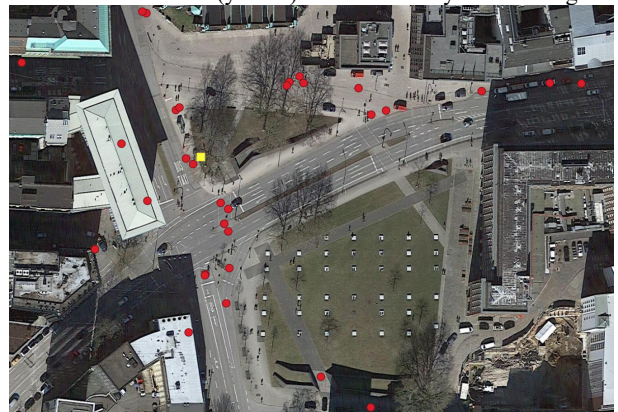
separated from the computation. Therefore, the architecture of the tool consists of three different modules, responsible for pre-processing, computation and visualization of the pedestrian movements respectively.

Starting the simulation tool within a given bounding box, the pre-processing module generates the whole simulation environment, built on given layers of buildings, water bodies and other obstacles. Furthermore, agents are created and placed at gateways, semi-randomly distributed due to the number and types of the gateways found in the simulation area. With all starting parameters set, the pedestrian movements are computed in the simulation module, which contains an adapted version of the crowd simulation tool developed by Meinert et al. (2019). During the simulation, the actual positions of the pedestrians are streamed as GeoJSON-files, providing an interface for visualization purposes and database handling, which is implemented in the visualization module.

3.3 Application

As a first application, a museum wants to discuss where to place a new information board on a central square in Hamburg, Germany, based on the movements of passers-by. Therefore, the tool is connected to a CityScope, an HCI system for public participation and decision-making (Noyman et al. 2017). While the bounding box of the simulation is taken from the extent of the background map shown on the CityScope, users can set the target of the pedestrians by placing a colour-coded brick on the interactive CityScope display table, sending the coordinates to the simulation tool via a Web Application Messaging Protocol (WAMP) service. While running the simulation, the positions of the pedestrians are streamed in opposite direction via the WAMP service, allowing a real time visualization of the simulated pedestrian movements on the CityScope display table, as shown in figure 3. With the information provided by the tool, the museum is now able to analyse the pedestrian movements not only in terms of frequency, but also regarding the heading of the pedestrians and their possible recognition of other museum services provided in the surrounding area.

Figure 3: Simulated Pedestrians (red) passing a planned information board (yellow) in the inner city of Hamburg.



Source: Google Satellite (Background image)

4 Discussion

The implemented tool implements all levels of pedestrian motions, using an agent based approach for setting the pedestrians and a simulation based on the social force model for the actual pedestrian movement computation. Using the most common geospatial data formats and geodata available as open data, the tool developed in this work can easily simulate pedestrian movements in all urban environments, but due to the conceptual design, it is best suited for the simulation of planning scenarios in small urban units.

With the two scenarios developed by now, the architecture of the tool allows advancements for special research questions with small efforts. This contributes to the ongoing cooperation between traditional urban researchers and computer scientists, with the possibility to expand the simple agents with attributes from the findings of urban scientists exploring pedestrian behaviour on the streets. As done in the STREETS model of Haklay et al. (2001), it would be also possible to extend the agents properties with socio-economic data of the simulated area. Research findings thereby does not have to be on a qualitative research level, so e.g. movement profiles generated from mobile telephone data, GPS-tracking mobile applications or camera observations can be used for generating and optimizing the routing network needed for the actual pedestrian movement simulation module. A different approach for pedestrian routing could be implemented with a dynamic version of a shortest path finding between the pedestrian waypoints, using one of the algorithms compared by Hahmann et al. (2018).

5 Conclusion

The work in this paper accounted for the increasing role of pedestrians in urban planning and developed a tool to simulate their movements in an urban environment. First, a logic was implemented to create a simulation environment, based on given data of buildings, roads and stations of public transport, which can be easily imported from open geodata sources. Then, pedestrian movements were computed with the social force model approach, while the actual positions of the pedestrians were streamed to the visualization module, which can be adapted to the special requirements of the user.

The tool developed in this work is particularly suited for the simulation of planning scenarios in small urban units such as pedestrian zones, neighbourhoods or development areas, and can be established as a new approach to support decision-making in urban planning.

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