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Towards TransiTUM: A generic framework for multiscale coupling of pedestrian simulation models based on transition zones

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Abstract

Existing pedestrian dynamics models differ in computational effort and their ability to authentically describe human movement behaviour. Hybrid approaches combine different models to speed up simulation time and to improve the results of the simulation. Current hybrid approaches can only combine a specific set of models. It is not possible to independently change the coupled models from the hybrid approach. Furthermore, transition of pedestrians between the different models is only possible at specific entry points. TransiTUM overcomes these issues and can combine any model if provided a certain set of parameters, which are common in pedestrian dynamics (e.g., pedestrians' positions, velocities). In this paper, the coupling of mesoscopic and microscopic scales is presented.

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1. Introduction

Pedestrian dynamics simulations can be divided into three different types (microscopic, mesoscopic and macroscopic) by their spatial resolution. In macroscopic models the scenario is reduced to a network of nodes and edges. The calculation itself is based on aggregated parameters of human crowds and not on the behaviour of individual pedestrians (Shiwakoti and Nakatsuji, 2005). Therefore, these kinds of pedestrian dynamics models are computationally efficient for the price of low spatial resolution. Many macroscopic models draw from the theory of fluid mechanics. For example, Henderson (1974) adopted the gas kinetic Boltzmann transport equation to describe the motion of crowds. The Lighthill-Whitham-Richards (LWR) model (Lighthill and Whitham, 1955a,b; Richards, 1956) and its variants (Hughes, 2003; Kachroo, 2009) are based on the continuity equation of fluid dynamics. These approaches are often simplified to one spatial dimension to reduce the complexity of the problem (Colombo and Rosini, 2005; Hartmann and Sivers, 2013). The second important kind of macroscopic simulations is the network flow model. These models calculate the smallest amount of time pedestrians need to exit a given network scenario (Burkard et al., 1993; Tjandra, 2003).

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Mesoscopic models, which are carried out by cellular automatons (Blue and Adler, 2001), have typically a finer spatial resolution associated with increasing computational effort. Therefore, the complete scenario needs to be split up into a regular grid. Each cell of the grid has an equal size and contains one or zero persons (Schadschneider et al., 2009). In pedestrian dynamics, unit cells have rectangular (Varas et al., 2007; Ji et al., 2013) or hexagonal (Hartmann, 2010) shapes. Both geometries have advantages and disadvantages (Birch et al., 2007). A finite set of rules routes the pedestrians locally, according to its boundary conditions, through the scenario (Schadschneider, 2001; Ji et al., 2013). Since the spatial resolution is restricted by the size of the unit cell, the pedestrians move cell-wise to their targets. This motion behaviour causes artefacts in comparison to pure euclidean movement (Köster et al., 2011).

Microscopic models simulate pedestrians, similar to cellular automatons, as discrete singular objects. However, the simulation scenario is in continuous space. For this reason, the spatial resolution is only limited by computational accuracy. Many microscopic models, like the social force (Helbing et al., 2002) or the centrifugal model (Yu et al., 2005), are based on physical principles. In these concepts, each object in the scenario has its own potential. The superposition of all forces controls the equations of the motion of crowds. Another microscopic approach is the use of utility maximisation (Hoogendoorn and Bovy, 2004). It is based on the assumption that each pedestrian locally optimises his or her walking behaviour by choosing the route with the least effort. Since an improvement in spatial resolution increases the computational effort, scenarios with large crowds can not be simulated by very detailed models in reasonable time. Usually, good simulation accuracy can be achieved even though only a small part of the total scenario is simulated in detail, while the remaining parts are calculated roughly. Furthermore, some models are more suitable to reproduce special pedestrian dynamic phenomena than others (Duives et al., 2013). In both cases, it is necessary to simulate different parts of the scenario with different pedestrian dynamic models. Since persons can exceed the borders between coupled models, transition rules have to be applied to ensure a coherent transition.

Various hybrid models exist, which carry out these tasks. Anh et al. combine a LWR-model with an agent based Leader-Follower approach to simulate evacuation behaviour on a road network. The straight parts of the streets are calculated by the macroscopic model and the cross-section, in which the pedestrians choose their next target, are simulated in the microscopic scale. Chooramun et al. (2012) designed a concept in which three scales are coupled into one hybrid model to investigate large area evacuations. The models are encapsulated in compartments (e.g., rooms) and connected by small local transition regions (e.g., doors). A coupling of two scales is presented by Xiong et al. (2010). They simulated multiple partitions of a corridor with a microscopic and a macroscopic models. Transition cells are defined on the shared borders of unequal model types.

Current hybrid models have two common weaknesses. The transition of pedestrians between coupled models is limited on elected regions of the boundary (e.g., doors, cross-sections). Therefore, a transition is not possible on the whole border of a model. This approach is sufficient for restricted scenarios (e.g., road networks, buildings) in which the transition can simply happen on local nodes (e.g., cross-sections, doors), but it is inadequate for settings on open areas (e.g., public events). In these scenarios, persons can enter a region from any direction. Therefore, the whole border of a coupled model has to be able to transmit pedestrians to adjacent models. Another weak point of state-of-the-art hybrid modelling is the inflexibility of exchanging the combined models. There is no broad framework which supplies a method to connect arbitrary pedestrian dynamic models. Therefore, we develop TransiTUM, a generic transition framework based on transition zones. In the following we propose a first approach to solve the mentioned problems (see Figure 1a) for the coupling of a cellular automaton and a microscopic model.

2. Composition of the transition framework

The proposed transition framework couples a more detailed model with a more coarse model. The scenario is separated by these models into two independent parts. Each model has knowledge solely about components of the setting which are inside its own layer. The transition framework itself knows about all layers of the scenario. If pedestrians approach the border of their current scale they get transmitted by TransiTUM to the adjacent scale. Therefore, a shared set of parameter has to be assigned to the pedestrians. The minimum set contains the current velocity $\vec{v}_i$, the next target $\vec{z}_i$, the diameter $d_{ped,i}$ and the current position $\vec{o}_i$ for each pedestrian P_i. The index i flags pedestrians in the microscopic model, while the index j flags pedestrians of the mesoscopic model. Additionally, a global peak speed v_{max} and the duration of time steps for each scale (Δt_{ds}, Δt_{cs} respectively) is necessary. These parameters are sufficient for successful transformations. The coupled models export parameters after each simulation time step. TransiTUM reads and modifies this data to enforce the transition of pedestrians. Before the next simulation step, the models import