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Towards automatic and robust adjustment of human behavioral parameters in a pedestrian stream model to measured data

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ABSTRACT

People die or get injured at mass events when the crowd gets out of control. Urbanization and the increasing popularity of mass events, from soccer games to religious celebrations, enforce this trend. Thus, there is a strong need to better control crowd behavior. Here, simulation of pedestrian streams can be very helpful: Simulations allow a user to run through a number of scenarios in a critical situation and thereby to investigate adequate measures to improve security. In order to make realistic, reliable predictions, a model must be able to reproduce the data known from experiments quantitatively. Therefore, automatic and fast calibration methods are needed that can easily adapt model parameters to different scenarios. Also, the model must be robust. Small changes or measurement errors in the crucial input parameters must not lead to disproportionally large changes in the simulation outcome and thus potentially useless results. In this paper we present two methods to automatically calibrate pedestrian simulations to the socio-cultural parameters captured through measured fundamental diagrams. We then introduce a concept of robustness to compare the two methods. In particular, we propose a quantitative estimation of parameter quality and a method of parameter selection based on a criterion for robustness. We discuss the results of our test scenarios and, based on our experience, propose further steps.

1. Introduction

Larger and larger pedestrian crowds can be observed daily in so-called critical infrastructures such as subways and railway stations, at airports, in shopping malls and high rise buildings, and at different mass events. This phenomenon entails problems of comfort and safety that become more and more pressing. Potentially dangerous scenarios range from environmental disasters to terrorist attacks. Each scenario comes with its own scale (building, housing block or city), cultural (e.g. India or Germany) (Chattaraj et al., 2009) or event-specific (Johansson et al., 2007) (e.g. sports game or religious celebration) characteristics. To a large extent they all share a quite general trait. In a dense crowd pressing towards a certain goal an individual can easily suffocate, be crushed or trampled to death. And of course there is always the need to evacuate people as fast as possible. Without being complete this illustrates the need for adequate and well-organized crowd management.

Today, crowd management is usually done by careful planning. Emergency plans are based on previous experience. However, experience is limited to events that have already happened and have been recorded in some way. It cannot cover any future scenarios. Fortunately, mathematical models and simulation tools can provide virtual experience where real experience is missing. Simulations allow a user to run through a number of scenarios and to observe the outcome. Decisions for a large variety of emergencies can be based on this.

This leads us to the fundamental question: When does a mathematical model correctly reproduce reality? In our case, we demand that the model captures the system dynamics, namely the most important mechanisms of crowd interaction. Increasing the details of modeling gradually and comparing simulation results of different model approaches and empirical data has been established as a successful strategy for identifying these mechanisms (Kneidl et al., 2010; Hamacher and Tjandra, 2002). The information contained in measurements usually is extremely varied. Widely known dependencies are for example the basic environmental conditions like structural constraints imposed by the architecture of a surrounding building (Predtechenskii and Milinskii, 1969). Recently socio-cultural aspects have been investigated (Chattaraj et al., 2009). Obviously the range of possible parameters is large and the impact differs from scenario to scenario.

The present work relies on the use of the so-called fundamental diagram of pedestrian flow to capture the most relevant characteristics of different scenarios. Originating from vehicular highway traffic (Greenshields, 1935; May, 1990), the diagram describes the functional relation between the number of cars on a road section

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and their velocity. In recent years fundamental diagrams have also been obtained for various other systems based on motile constituents (Chowdhury et al., 2005). The functional relation between the density of pedestrians and walking speed has been measured by several groups. For a detailed survey we refer to (Weidmann, 1992), for publicly available samples to www.ped-net.org. Overall we found clear indication that, indeed, a major number of parameters such as cultural differences are captured. For example, the speed of Indian test persons is apparently less dependent on density than the speed of German test persons (Chattaraj et al., 2009).

In short, we propose, to calibrate our model to measured relationships between density and flow in an attempt to qualitatively and quantitatively reproduce real situations. Ideally, before running a simulation, we would obtain a fundamental diagram – or a collection of such diagrams – that is suitable for the scenario we are interested in. Then we would calibrate our model, so that it reproduces the phenomenon expressed through the density-flow relationship.

However, there is another requirement that must be fulfilled to make a crowd simulation an effective tool for, say, security staff especially during a crisis. It must be several times faster than real time even in a complex scenario. Here we have a short-term prediction tool in mind that would allow the user to go through decision alternatives based on the current situation. The work of this paper stems from a research project where a major railway station is observed and a demonstrator for such a short term prediction device is being investigated. The required high simulation speed for the simulation can be achieved, even on off-the-shelf hardware, with a cellular automaton model. Another thing we observed almost immediately is that the type of travellers and hence the walking behavior strongly varies with the time of the day. Changes may occur within minutes, e.g. after the last commuter train has arrived. Rush hour passengers are very different from sight-seers or football fans. The latter behave very differently before the game when most of them are still sober and after the game when the alcohol level in the blood is high. It appears, at this moment, still impossible to gain density-flow relationships in real time with the video extraction techniques progressing slower than the authors hoped. Therefore, in this paper, we still rely on published data to show quantitative differences in the density-flow relationship for, say, rush hour traffic and “normal” traffic such as are available through www.ped-net.org. The differences we see in the published data are very significant. Once the video techniques catch up, on-line measurements should replace data from literature. And calibration should be done to the measured data. Calibration, however, must not reduce the availability of the tool. For the calibration this entails that it be both automatic and sufficiently fast not to slow down the simulation in progress.

But still, automatic and fast calibration is not sufficient. Calibration must also be robust. That is, small changes in the parameter sets must not cause changes in the simulation results that lead to a different interpretation of the results. We must expect such changes from measurement errors and the continuous change of the scenario itself through a changing population each time life measurements are fed into the model to do short range predictions. Very sensitive reaction to those differences entails the risk of producing useless output. Sensitive reaction might of course be an inherent characteristic of an instable model or, indeed, an instable phenomenon. To our knowledge, mathematical stability of pedestrian stream models has not been proved so far, but is inherently assumed – or hoped for – by modelers such as ourselves. We believe that the relationship between density and flow is a function changing with the characteristics of the population in the area of observation which in turn changes with time. Each experimental measurement is fully valid for perhaps only a number of minutes and a parameter set calibrated according to the data is only optimal for that period. We presume that, at the next moment, it has slightly shifted from the true optimal set. Only if the choice of parameters is a robust one, the differences in the simulated results will also be small. See Fig. 1 for an illustration of the concept.

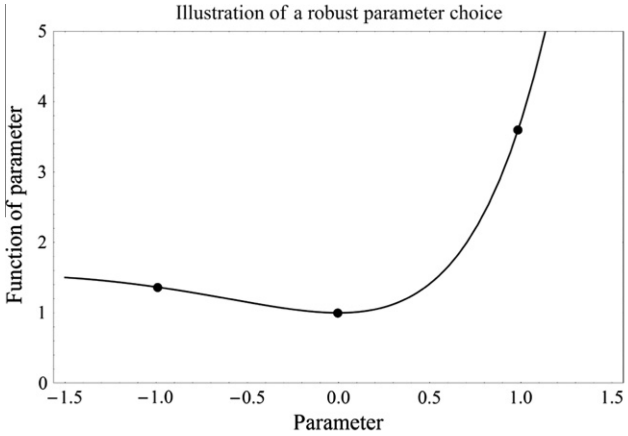

Fig. 1. Illustration of robust parameter choices and the use of sensitivity studies to obtain robust choices. The circle in the middle indicates the position of a minimum of a function depending on some parameter. If the parameter deviates from the optimum to the left, the function values change little. All parameter choices left of the optimum, induced by e.g. a small error, are robust. Deviations to the right lead to much bigger changes in the function. These parameter choices are not robust. Disturbing the parameter from the optimum identifies robust choices.

Thus we look at a triple challenge: to automate calibration, to make it just as fast as the simulation itself and to ensure a robust parameter choice. Recent progress in calibrating pedestrian stream models has encouraged the authors to face the challenge. According to (Hoecker and Milbracht, 2009; Klein et al., 2009; Johansson et al., 2007; Nagel and Schreckenberg, 1992) calibration can be achieved in principal. However, up to now, automatic algorithms have been discussed for social force models, only. In this paper we present two approaches to automate calibration for a cellular automaton model and introduce a new quantitative criterion to measure the robustness of each calibration. It turns out, that the optimal calibration parameter sets derived by the two methods do not only differ in how well the subsequent simulations capture the measured phenomenon, but also in how sensitive the simulation model reacts to small changes in the parameter sets. We call a parameter set derived from a calibration more robust than another if the same systematic changes in the parameter set lead to smaller changes in the simulation outcome. This sensitivity study leads us to an additional decision criterion for the optimal choice of parameters.

Our paper is organized as follows. The next section will shortly introduce our cellular automaton model. Then the automatic calibration and a method to select a robust parameter set are described and results are presented. A discussion of the limitations of the present state of the art and on potential next steps concludes the paper.

2. A glance at the model

We choose a cellular automaton model for two reasons. First, we are interested in large-scale pedestrian simulation in a fraction of real time. Cellular automaton models for vehicular traffic or pedestrian dynamics have proven to show faster-than-real-time speed even for large systems (Schadschneider et al., 2009; Burstedde et al., 2001). Furthermore, cellular automata provide an intuitive representation of interactions between entities that can be incorporated in a very simple way. The number of approaches to