Towards the Calibration of Pedestrian Stream Models

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Abstract. Every year people die 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 gain better control over crowd behavior. Simulation of pedestrian streams can help to achieve this goal. In order to be useful, crowd simulations must correctly reproduce real crowd behavior. This usually depends on the actual situation and a number of socio-cultural parameters. In other words, what ever model we come up with, it must be calibrated. Fundamental diagrams capture a large number of the socio-cultural characteristics in a very simple concept. In this paper we represent a method to calibrate a pedestrian stream simulation tool so that it can reproduce arbitrary fundamental diagram with high accuracy. That is, it correctly reproduces a given dependency of pedestrian speed on the crowd density. We demonstrate the functionality of the method with a cellular automaton model.

Keywords: cellular automaton, pedestrian simulation, fundamental diagram, calibration.

1 Introduction

Crowd behavior has gained a lot of interest in the past years, fueled by the insight that mass events with their growing popularity represent a risk for civil security. Overall a comparably large variety of potentially dangerous scenarios is known. The 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) [1] or event-specific [2] (e.g. sports game or religious celebration) characteristics.

To a large extend they all share the same quite general trait that in dense crowds that press towards a certain goal an individual can easily suffocate or be 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 to gain better control over crowd behavior.

Simulation of crowd streams can help to achieve this goal: Simulations allow running through a number of scenarios in a critical situation and thus to find

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adequate measures to improve security. In order to be useful, crowd simulations must correctly reproduce crowd behavior. Primarily, the model must capture the system dynamics, namely the most important mechanisms of interaction. Gradually increasing the details of modeling and comparing simulation results and empirical data has been established as a successful strategy for identifying these mechanisms. While the underlying mechanisms of interaction can be assumed to be quite universal, they depend on a large number of parameters. Especially rather basic or universal rules of interaction cannot be expected to capture every situation and need to be adapted to the scenario of interest. This is a vital issue for practical applications focusing on high-fidelity reproduction of a wide range of scenarios, each characterized by a corresponding set of parameters.

In other words, what ever model we come up with, it must be calibrated. Calibration, in our context, means that the model we use is adapted to specific information from the real world. This information can be extremely varied. Widely known dependencies are for example the basic environmental conditions like structural constraints imposed by the architecture of a surrounding building [3]. Recently also socio-cultural aspects have been investigated [1]. Obviously the range of possible parameters is large and the impact differs from scenario to scenario.

Hence, the first challenge of calibration is to decide where to begin. The present work proposes the use of the so-called fundamental diagram of pedestrian flow as the source of parameters capturing the most relevant parameters characterizing different scenarios. Originating from vehicular highway traffic [4], [5], the diagram describes the function relation between the number of cars on a road section and their velocity. In recent years fundamental diagrams have also been obtained for various other systems based on motile constituents [6], [7], [8].

Among these systems one also finds the empirical fundamental diagram of pedestrian dynamics [9], [6], [10]. The functional relation between the density of pedestrians and walking speed has been measured by several groups. For a detailed survey we refer to [9]. Overall we found clear indication that, indeed, a major number of parameters such as cultural differences are captured. Apparently 'the speed of Indian test persons is less dependent on density than the speed of German test persons'[1].

Besides these effects also a scenario dependence can be expected. In case of counterflowing streams of pedestrians or at a bottleneck, the average walking speed in one direction might also depend on the density of pedestrians moving in the opposite direction [11], [12].

From that it becomes clear, that there is no fundamental diagram that is true for every scenario, culture, location. Simulating crowds in a rail station in, say, Berlin should yield significantly different results from a rail station in Delhi. So 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 fundamental diagram. There are, of course, many more aspects worth investigating. Our choice is to start with the fundamental diagram.

In this paper we represent a method to calibrate a pedestrian stream simulation tool so that it can reproduce any given fundamental diagram. We demonstrate the functionality of the method with a cellular automaton model. Nevertheless, this approach might also be applied in a modified way to models of other classes.

2 A Glance at the Model

Our model of choice is a cellular automaton. This approach allows us to incorporate directly observable interaction in a very simple way. As we focus on application in real scenarios simulation speed, namely faster-than-real-time capability is a major issue. Experience from vehicular traffic [13] or pedestrian dynamics [6], [10] shows that these requirements are usually well met even for large systems. We investigate an area that may be bounded by walls and contain obstacles. Persons are leaving and entering through sources and sinks, namely entrances and exits.

The persons move in one single plane or several planes such as floors. So we may restrict ourselves to two dimensions. We cover the area of interest by cells. In principle, triangular, rectangular and hexagonal cells are possible [10], [14]. Although square cells seem to be the most popular choice, we prefer a hexagonal grid for its two additional 'natural' directions of movement compared to the square grid. Each cell, at each time step, has a state: It is either empty or occupied. A cell can be occupied by a single person. The cell size is chosen to accommodate an average sized European male (in light summer attire and without baggage). Sources and targets of pedestrians as well as obstacles also occupy cells.

The simulation dynamics themselves follow a specific kind of sequential update scheme. That is, the cells containing persons are updated in the order the persons have entered the scenario from a source.

The core of the model is contained in the 'automaton', that is, the set of rules according to which the cell states are updated when we step one ahead in time. For this, we burrow from physics namely electrodynamics. In principle pedestrians are treated as charged particles, say electrons. So pedestrians are attracted by positive charges, such as exits and repelled by negative charges such as other pedestrians or obstacles.

The forces between pedestrians, targets and obstacles are calculated through a potential field, using the properties of conservative force fields from physics, where the force can be expressed as the gradient of a suitable scalar function: the potential. In this, the model is very similar to any typical cellular automaton model based on potentials as, for example, described in [15], [16], [10], [17], [12], [18], [19] or in the web-published handbook of the TraffGo tool [20]. The pure electron based approach clearly has its limitations when modeling human behavior. For example, humans use what they see in front of them to coordinate their movement. There is no radial symmetry. Hence, our model enriches the basic ideas by a number of sub-models to compensate the most relevant shortcomings. Using the terminology in [10] our model is:

1. Microscopic.
2. Discrete.

3. Deterministic with stochastic aspects.
4. Rule based but potential driven.

In this paper we do not strive to give another complete description of the, very successful, cellular automaton approach based on potential fields. Nor do we intend to describe our particular choice of sub-models. Instead, we want to enhance any such model by an aspect that we think of the utmost importance for useful application: calibration. Hence, we will focus on those model parameters that the calibration algorithm needs.

The model parameter that we will use for calibration is the walking speed. It is directly accessible through experiments and measurements. Each person is generated with an individual speed that the person tries to achieve – and indeed does achieve when the path is free: the free flow velocity [13], [5] or, as we call it, the 'desired velocity'. The distribution of the speeds follows the suggestions in [9]. That is, we assume a normal distribution about some medium desired speed. Some persons wish to go faster, if given the chance, others are slower by habit. The different velocities are made possible by allowing a person to move forward multiple cells per simulation step.

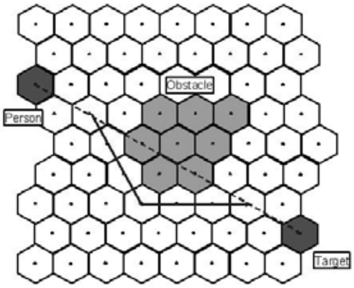

Fig. 1. A cellular automaton based on a grid with hexagonal cells. Pedestrians move from a source to a target avoiding obstacles on the way. We prefer a hexagonal grid over a square grid for its 2 additional 'natural'directions of movement.

3 The Challenge

The simulation results of our model without calibration show that it is suitable to qualitatively reproduce the fact that the denser the crowd, the slower the velocity of each person. That is, people are hindered by each other in their movement. However, in our simulations, they still move too fast compared to well known fundamental diagrams such as the popular diagram described by Weidmann [9]. See Figure 2 and Figure 3. This observation is – or was – shared by others simulation projects. See, for instance, the analysis according to the RIMEA guidelines conducted by [21]: test 4. In addition the simulated pedestrians appear to be 'short sighted'and do not decelerate before they literally 'bump' into a dense crowd.

Results are somewhat improved – at least when we only consider the fundamental diagram according to [9] – when the number of discrete speeds with which a person may move is increased. Please refer to Figure 2 and Figure 3. However, it is impossible to tune the basic model – e.g. by adjusting the repulsive force of indivuduals – so that it reproduces an arbitrary fundamental diagram with satisfactory accuracy on a quantitative level.

4 Solution Strategies

To meet the challenge of reproducing the given fundamental diagram quantitatively we introduce the new concept of deceleration classes. The basic idea is to measure the density of the crowd in the direction in which a person moves and then to adapt the person's velocity to the one suggested by the fundamental diagram of choice. The execution of the idea, however, is a little more complicated because the world of a cellular automaton is discretized through cells. Also, we do not want to loose individual differences in the human behavior.

Measuring the density means to count the number of persons in a reasonable number of cells that lie in the field of vision of a walking person. The field of vision is aligned with the direction in which the person walks. By this we reduce the basically two dimensional problem to the quasi one-dimensional situation for which fundamental diagrams are usually employed. As a result the pedestrians are no longer 'short sighted'but react to congestions ahead of them.

The model is first calibrated such that the mean free flow cell velocity – the average number of cells a person covers per simulation step when the path is free – corresponds to $1.34\frac{m}{s}$ as suggested in [9]. The cell velocities are normally distributed about this mean cell velocity (mcv). We get $2 \cdot mcv - 1$ discrete velocities.

When a person is surrounded by a dense crowd on the way to the chosen target, which lies in the direction of the lowest potential, the person's speed is adapted: More precisely, each person's desired velocity is temporarily reduced. Note that it still depends on the availability of a free path, whether the person can really achieve this new desired velocity. The number of cells by which the desired velocity of an individual is reduced for a certain density also depends on the original free flow velocity of the person, so that we maintain the individual differences in the walking speed. In our approach, the speed reduction depends on the density and free flow velocity. The dependency is expressed in a set of rules that involve artificial calibration parameters. Since the model's world is partitioned in cells the densities are discrete too. We therefore speak of density classes and, accordingly, of 'deceleration classes' to denote the calibration parameters that we introduced in the rules. Now, the deceleration classes must be tuned according to the fundamental diagram. This means, the model can be calibrated.

The impact of the calibrated deceleration classes on the simulation results is evident in Figure 4. We achieve an excellent fit with the fundamental diagram we used for calibration (taken from [9]).

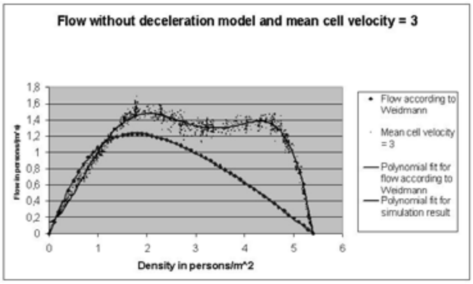

Fig. 2. Uncalibrated flow: without decleration model. The basic model does not correctly reproduce the dependency of the velocity on the density in a crowd.

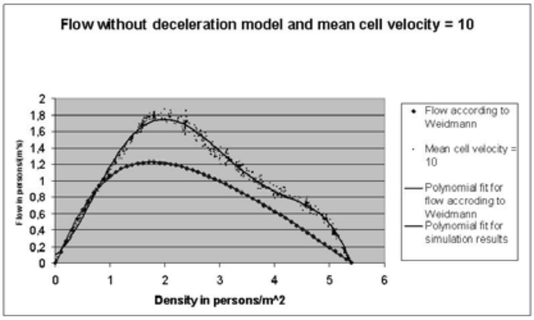

Fig. 3. Uncalibrated flow: without decleration model. The basic model does not correctly reproduce the dependency of the velocity on the density in a crowd. Increasing the number of possible velocities improves the results qualitatively, but does not allow to tune the model to an arbitrary fundamental diagram.

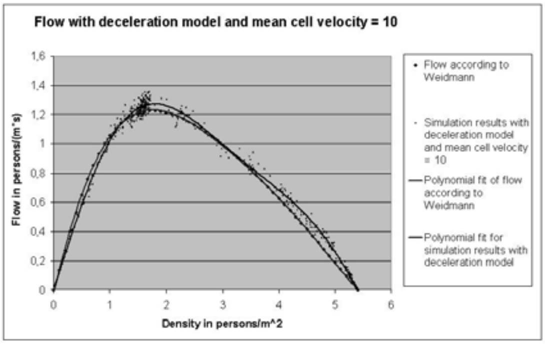

Fig. 4. Calibrated flow: with deceleration model. Introducing the deceleration model allows calibration. Parameters are tuned to an excellent fit with the fundamental diagram.

5 Conclusion

In this paper we discuss a first step towards the calibration of pedestrian stream models based on scenario specific fundamental diagrams. We consider the fundamental diagram as a behavioral model that aggregates a multitude of socio-cultural and even scenario dependent parameters. Ultimately, the differences in – say gender, nationality, fitness dependent on day time – find their expression in the way people walk as individuals and surrounded by a crowd. The walking speed is the crucial parameter. It depends on the density.

Thus, we do not need to identify each socio-cultural parameter of which, as a rule, we cannot quantify the influence anyway. Instead we feed the appropriate fundamental diagram into the simulation. In a learning phase, we adjust the way people slow down when they are walking in a crowd until the particular fundamental diagram is faithfully reproduced by computer simulations of our model.

To illustrate our calibration approach we have chosen a potential-based cellular automation model. We suggested so-called deceleration classes in this cellular automaton model to slow down persons when they approach a crowd on their way to a chosen target. We demonstrated that the calibrated deceleration classes are suitable to obtain a very good fit to a given fundamental diagram.

In an ideal set up, each scenario would have its own fundamental diagram. We therefore believe that the sort of calibration suggested here, is absolutely necessary to tune a simulation model to the scenario of interest. Clearly the number of measured fundamental diagrams currently available to the researcher is very limited. However, with new methods to gain data, such as video analysis or radio technologies, this deficiency may soon be overcome and it will become necessary to devise methods to automatically calibrate a simulation tool.

Robustness of our calibration, that is, sensitivity to variations and errors in the data is another vital issue. Furthermore, we will strive to refine and enlarge our method according the insight we expect from the increasing number of empirical fundamental diagrams.

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