Modelling Crowd Dynamics in Urban Environments using Multiscale Techniques

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Challenges in crowd dynamics

A major challenge in crowd dynamics is the issue of how a crowd is represented. Showing the crowd as a collection of individuals (an agent-based or *microscopic* approach) does not always respect the emergent properties that are observed when many people gather. On the other hand, modelling a crowd as a fluid (a continuum or *macroscopic* approach) makes it difficult to extract trajectories and other individual properties pedestrians experience. One solution is to combine to two perspective in a hybrid or *multiscale* approach. In that case, one has to take care how microscopic information is translated to the macroscopic perspective and vice versa. For a discussion on how these connections can be made in a mathematical framework, see [2]. An analysis applied to the dynamics of crowds can be found in [3].

Representations on multiple scales

Microscopic representations of crowds can be expressed as a system of ordinary differential equations. In [4], we postulate the following systems, where individual behaviour is a function of environment knowledge. For residents we use a system based on a potential field function Φ (see (3)):

$$\frac{d\vec{x}_{a_i}}{dt} = -v_s(\vec{x}_{a_i}, t) f\left(\nabla\Phi(\vec{x}_{a_i}) - \nabla p(\vec{x}_{a_i}, t)\right), \tag{1}$$

while for *visitors*, we use a Cucker-Smale-like dynamics.

$$\begin{aligned} \frac{d\vec{v}_{b_i}}{dt} &= \sum_{j\in X} (\vec{v}_j - \vec{v}_{b_i}) w_{ij} - \nabla H(\vec{x}_{b_i}, t) + \mathbf{B}_i(t) + g\left(\nabla p\right) v_s\left(\vec{x}_{b_i}, t\right), \\ \frac{d\vec{x}_{b_i}}{dt} &= \vec{v}_{b_i}. \end{aligned} \tag{2}$$

Measuring *crowd pressure*, as a quantity expressing how much individual's desired velocity deviates from the crowd, we can clearly see a qualitative difference in the evacuation progress between the two populations. This illustrates the relevance of incorporating crowd heterogenity in designing evacuation strategies

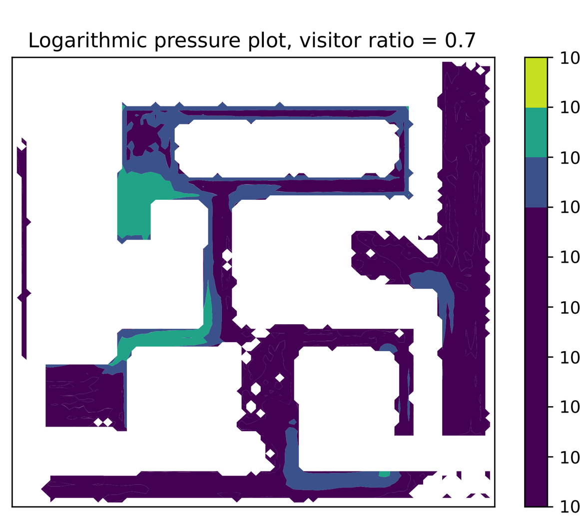

Figure 1. Capturing the pressure in a mix of pedestrian in unknown environments: Lots of searching, but less congestions.

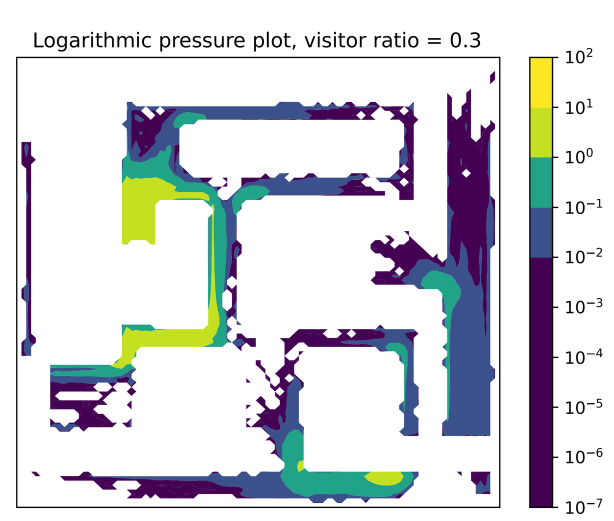

Figure 2. Capturing the pressure in a mix of pedestrian in known environments: efficient use of space, but structural congestions.

Why study crowd dynamics?

The modelling and simulation of crowds poses a challenge that requires more than just a mathematical understanding of how people move from A to B. Cultural, situational and psychological differences have a significant impact on the way pedestrians behave. With society becoming ever more global, understanding the inner working of crowds becomes more and more important, helping us to prevent crowd disasters at a large public event, optimizing flow in traffic situations, or designing evacuation strategies for building structures.

Introduction

This poster showcases contributions in *crowd dynamics* as a result of work done in my project under the supervision of A. Muntean. Crowd dynamics is the term used for describing the behaviour and interaction of groups of people moving in a certain environment. The main goal of crowd dynamics research is to identify the factors that control these dynamics (analysis), and to be able to predict crowd motion in new scenarios (simulation).

Main collaborators for this work include E. Cirillo (La Sapienza), M. Colangeli (University of L'Aquila), H. Duong (University of Warwick), A. Jalba (TU Eindhoven) and T. Thieu (GSSI). More details can be found in published works.

Simulation and visualisation

Simulation of crowd dynamics is not only a mathematical challenge, but also a computer-scientific one. Especially for large crowds, one needs to take care that suitable algorithms and data structures are used. If one wants to run a simulation interactively, this becomes even more important. Using simulation as an aid in evacuation situations creates a desire for efficiency over accuracy: one wants to evaluate a large number of potential scenarios fast. As such, multiscale representations can also be of help in visualisation. This research topic is closely linked to the automated evaluation of crowd evacuation status; how can smart cameras decide the level of crowdedness and anticipate possible hazardous situations?

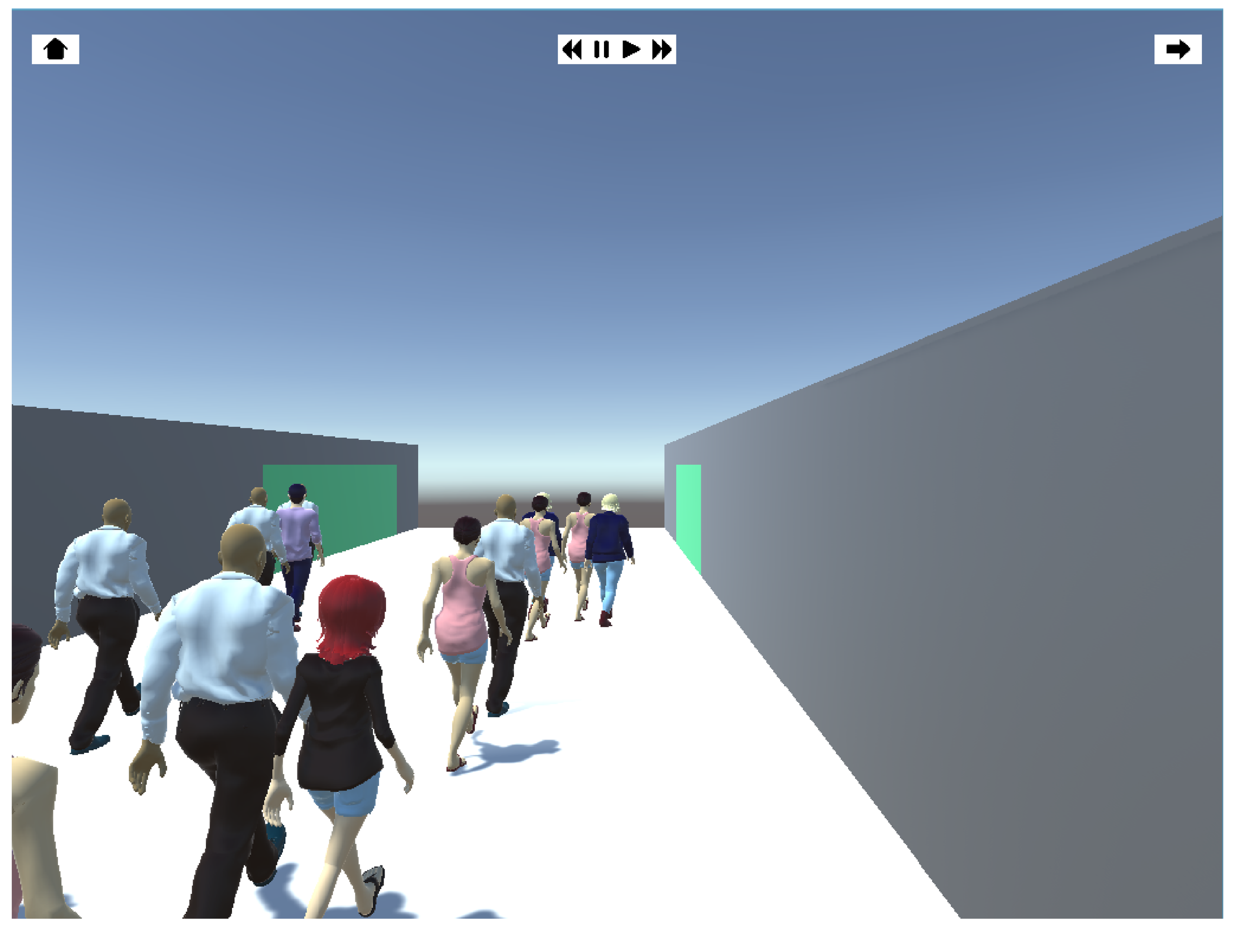

Figure 3. A 3D view of an evacuation in a built structure, extension of Mercurial.

Designed as part of this investigation, *Mercurial* ([5]) is an open-source prototype framework for crowd dynamics that uses multiscale simulation techniques to predict crowd flow, and provide microscopic 2D (Figure 4), 3D (Figure 3) and macroscopic (Figure 2) visualisations. Mercurial is designed with the following goals in mind:

1. **Scalability**. Simulations work for large numbers of agents. By using multiscale techniques, pair-pair interactions can be computed in computationally less expensive ways.
2. **Continuum and agent-based quantities**. Both trajectories as well as densities and velocity fields are computed as the simulation progresses. These can be used in decision mechanisms for evacuation managers.
3. **Modularity**. Mercurial is written in Python, with modules being wherever possible agnostic of each other, allowing for easy extension and customisation.

Crowd navigation in complex environments

The interaction between crowds and the environment accouns for a large part of their behaviour. When modelling this, one needs to take into account various situation-dependent parameters like range of sight, distance to walls, and pedestrian knowledge of their environment. One option of creating smooth but direct paths to the exit which respect the environment, is by computing a potential field function,i.e., solve an eikonal equation:

$$\begin{aligned} \|\Phi(\vec{x})\|^2 &= u(\vec{x}) \text{ for } \vec{x} \in \Omega, \\ \Phi(\vec{x}) &= 0 \text{ for } \vec{x} \in E, \\ \partial_n \Phi(\vec{x}) &= 0 \text{ for } \vec{x} \in \partial\Omega, \end{aligned} \tag{3}$$

where Ω represents the walkable space (and $\partial\Omega$ the interface with any obstacles) and E represents the exit. Here $u(x)$ is a marginal walking cost. Another important modelling aspect is describing pedestrian-pedestrian interaction. By applying a system such as presented in (1) or (2), the model can be used for practical applications. In Figure 4 and Figure 5, we illustrate how pedestrian location affects their evacuation time. This framework is elaborated on in [1].

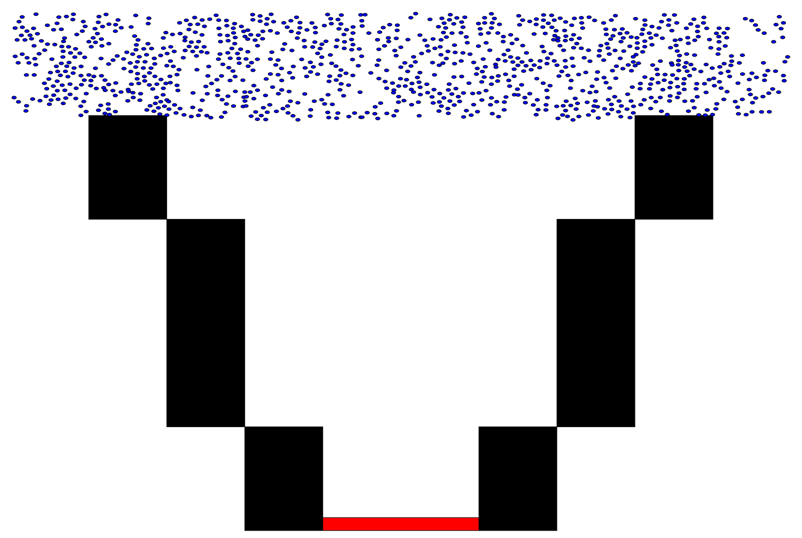

Figure 4. Evacuation scenario leading to congestions.

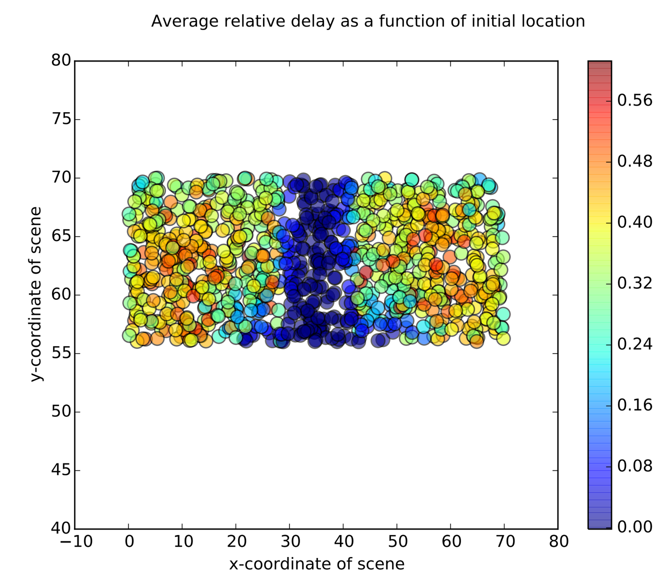

Figure 5. Relative delay as a function of initial position.

Future steps

As next steps, we plan to rigourously investigate the links between microscopic and macroscopic representations. Some steps have been made in [2], but more is to be explored, especially when the individual behaviour is considerably more complex. Furthermore, the propagation of information throughout crowds has a significant effect on their dynamics, although it is a difficult phenomenon to validate. More investigation is needed to see how information propagation can be modelled.

Published work

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Master's thesis, Technische Universiteit Eindhoven, 2016.

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Fire Technology, 55(2):415–436, 2018.

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Python framework for building, running and post-processing crowd simulations.