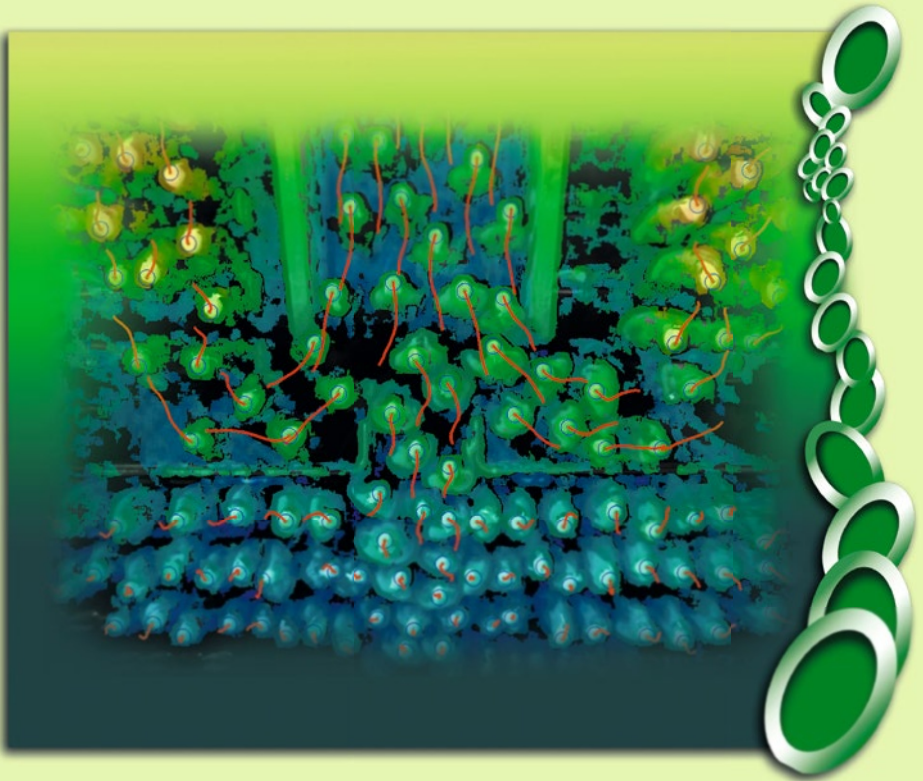


M. Chraibi · M. Boltes
A. Schadschneider · A. Seyfried
Editors

TRAFFIC AND GRANULAR FLOW '13



 Springer

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Mohcine Chraibi • Maik Boltes •
Andreas Schadschneider • Armin Seyfried
Editors

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Foreword

For its tenth edition, the international conference “Traffic and Granular Flow” (TGF) returned to the location of the very first meeting held in 1995. From 25 to 27 September, 2013, 105 international researchers came again together at the Forschungszentrum Jülich.

The purpose of the TGF’13 is bringing together international researchers from different fields ranging from physics to computer science and engineering to stimulate the transfer between basic and applied research and to discuss the latest developments in traffic-related systems.

In 1995 the TGF was probably the first conference with this objective. The workshop was attended by about 130 participants from 14 countries. My colleagues – D. E. Wolf and M. Schreckenberg – and I conceived the workshop to facilitate new ideas by considering the similarities of traffic and granular flow. To develop a unified view of flow instabilities like traffic jams or clogging of a hopper by powder was a purpose of the international workshop. Traffic as well as Granular Flow have both intriguing conceptual analogies. Traffic jams can be described by the same equations as density waves in granular pipe flow, and efficient simulation tools like cellular automata have been developed along similar lines in both fields, just to name two examples.

I am pleased to see that after so many years the field of traffic and granular flow is still progressing and that numerous problems could be solved by new facilities. Nevertheless, we are facing plenty of new challenges in these research fields. In 2013 the international conference covers a broader range of topics related to driven particles and transport systems. Besides the classical topics of granular flow and highway traffic, its scope includes data transport (Internet traffic), pedestrian and evacuation dynamics, collective motions in biological systems (swarm behaviour, molecular motors, social insects, etc.), complex networks and their dynamics (transportation network, Internet, epidemics, social networks, etc.) and intelligent traffic systems.

Supercomputing is one of the instruments in traffic and granular research, and Forschungszentrum Jülich, as one of the largest national centre for supercomputing and part of PRACE, is proud to play an important role in security research. In

the Jülich Supercomputing Centre, a division focuses on models of self-driven systems with applications in civil security and traffic planning. Experiments are performed and methods of data capturing are refined to support the developments of reliable models usable for security-related applications. In combination with high performance computing, we are able to tackle challenges in the simulation of large systems using high fidelity models.

I would like to thank the entire Organizing Committee and the Scientific Committee of the conference for their intensive and excellent work.

Jülich, Germany
September 2013

Achim Bachem

Preface

In its tenth edition, “Traffic and Granular Flow” returned to the location of the very first conference held in 1995 at Forschungszentrum Jülich in Germany. The conference took place from 25 to 27 September 2013 and was organized in cooperation with the Institute for Theoretical Physics, University of Cologne, and the Jülich Supercomputing Centre of the Forschungszentrum Jülich.

Originally initiated to disseminate new ideas by considering the similarities of traffic and granular flow, TGF’13 covered a broad range of topics related to driven particle and transport systems. Besides granular flow and highway traffic, its scope includes data transport, pedestrian and evacuation dynamics, intercellular transport, swarm behaviour and collective dynamics of other biological systems.

One hundred five international researchers from different fields ranging from physics to computer science and engineering came together to discuss the state of the art developments. The stimulating atmosphere has facilitated many discussions and several new cooperations have been initiated.

A special thank goes to all colleagues who helped behind the scenes in the organization of the conference, especially Erik Andresen, Matthias Craesmeyer, Christian Eilhardt, Kevin Drzycimski, Stefan Holl, Ulrich Kemloh, Gregor Lämmel, Wolfgang Mehner, Daniel Salden, Bernhard Steffen, Antoine Tordeux and Jun Zhang.

The organizers gratefully acknowledge the financial support from the German Federal Ministry of Education and Research (BMBF) within the program Research for Civil Security, grant number 13N12045.

The conference series will continue and the next conference will be held in Delft (the Netherlands) in 2015.

Jülich, Germany
Jülich, Germany
Köln, Germany
Jülich, Germany

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Part I
Pedestrian Traffic and Evacuation
Dynamics

Modeling of Pedestrians

Cecile Appert-Rolland

Abstract Different families of models first developed for fluid mechanics have been extended to road, pedestrian, or intracellular transport. These models allow to describe the systems at different scales and to account for different aspects of dynamics. In this paper, we focus on pedestrians and illustrate the various families of models by giving an example of each type. We discuss the specificities of crowds compared to other transport systems.

1 Introduction

What is the common point between fluids, cars, pedestrians or molecular motors? Though they are quite different and evolve in systems of very different sizes, they all result into flows, and they all obey simple conservation laws. As a result, the families of models that have been developed in the past to describe fluids at different scales have also been adapted to describe highway traffic [1], crowds [2] or axonal transport [3, 4] (Table 1).

Let us consider first macroscopic models: At large scales, individuals are not visible anymore, and the state of the system can be characterized by locally averaged density and velocity. For fluids, Navier-Stokes equations express the conservation of mass and of momentum.

For road traffic, mass conservation is still relevant, and provides a first equation relating density and velocity. However, as vehicles are in contact with the road, momentum is not conserved. A second relation must be provided to close the equations. The simplest way is to give the (possibly data-based) fundamental diagram, relating the flow of vehicles and the density. The resulting model is a so-called first order model, a prominent example being the LWR model [14, 15]. The more sophisticated second-order models [16, 17] express the fact that the adjustment of flow to density may not be instantaneous but rather takes place within a certain

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Table 1 Correspondence of model families, for four different physical systems: fluids, road traffic, pedestrian traffic and intracellular traffic. We mention a few models (with their reference) as prominent and/or historical examples of a given model type. The scale at which the system is described increases as one goes down in the table

Fluids	Road traffic	Pedestrians	Molecular motors
Molecular dynamics [5, 6] $m \mathbf{a} = \sum \mathbf{f}$	Car-following [7–9] $a(\Delta V, \Delta x)$	Ped-following	Molecular dynamics $m \mathbf{a} = \sum \mathbf{f}$
Kinetic theory $P(v, x, t)$	Kinetic theory $P(v, x, t)$	Kinetic theory $P(v, x, t, \xi)$	
Cellular automata <i>FHP Model</i> [10]	Cellular automata <i>Nagel-Schreckenberg model</i> [11]	Cellular automata <i>Floor Field model</i> [12]	Cellular automata <i>Langmuir kinetics</i> [13]
Continuous PDEs Conservation of mass and momentum <i>Navier-Stokes Eqs</i>	Continuous PDEs Conservation of mass + fundamental diagram $j(\rho)$ <i>LWR Model</i> [14, 15]	Continuous PDEs Conservation of mass and ...	Continuous PDEs Open system: balance of fluxes

relaxation time. The second relation between density and velocity is then a second partial differential equation.

For pedestrians also, the mass conservation equation must be completed to provide a closed set of equations. However, the complexity is increased by the fact that pedestrians, first, walk in a two-dimensional space, and, second, do not necessarily all go in the same direction.

Within cells, intracellular transport also involves some “walkers”, i.e. some molecules equipped with some kind of legs that perform stepping along some cylindrical tracks called microtubules. In contrast with human pedestrians, these so-called molecular motors do not only walk along microtubules, they can also detach from the microtubules, diffuse around, and attach again. Thus, if one considers the density of motors on the microtubule, even mass conservation is not realized any more. The equations that determine the evolution of density and velocity must then rather express some balance of fluxes between different regions of the system.

In the same way as various macroscopic models can be proposed for all these systems, there are some equivalents of molecular dynamics or of cellular automata approaches that have been developed for road, pedestrian or intracellular traffic.

In most cases, for a given physical system, different types of models have been proposed independently to account for the behavior of the system at different scales, leading to large families of models. In some cases however, it is possible to relate the models at the different scales and to understand how the macroscopic behavior can emerge from the individual dynamics.

In this paper, we shall focus on pedestrian modeling, and give an example for each family of models. Part of this work (Sects. 2, 3, and part of 4) was performed in the frame of the interdisciplinary PEDIGREE project [18]. The teams involved are presented in Table 2.

Table 2 The PEDIGREE Project involved four French teams listed below

Laboratory	IMT	INRIA	CRCA	LPT
Team leader	P. Degond	J. Pettré	G. Theraulaz	C. Appert-Rolland
Participants	J. Fehrenbach	S. Donikian	O. Chabiron	J. Cividini
	J. Hua	S. Lemercier	E. Guillot	A. Jelić
	S. Motsch		M. Moreau	
	J. Narski		M. Moussaïd	

The work of Sect. 5 was performed as part of the master and PhD of Julien Cividini, in collaboration with H. Hilhorst.

2 Ped-Following Model

Fluids can be described at the level of molecules, by taking into account all the interaction potentials between atoms in a more or less refined way, as is done in molecular dynamics simulations [5,6]. When vehicles or pedestrians are considered, two main difficulties arise. First the interaction potential is not known – actually the interaction cannot in general be written as deriving from a potential. Second, the interaction is in general highly non-isotropic, and does not depend only on the position but also on the velocity and on the target direction of each individual.

In road traffic, cars naturally follow lanes. This feature greatly simplifies the problem. Each car has a single well-defined predecessor on its lane. Apart from lane changes, a car driver can only adjust its speed. He will do so depending on the conditions in front (distance, velocity, acceleration of the predecessor). Actually several cars ahead could be taken into account (and indeed some empirical studies [19] have shown that a driver may take into account several of its leaders). But still, there is a clear hierarchy among the leaders, given by their order in the lane.

In pedestrian traffic, individuals evolve in a two-dimensional space, and may interact with several pedestrians at the same time, without a clear hierarchy. Besides, the combination of interactions is in general not a simple sum of one-by-one interactions. However, there are situations where the flow is organized in such a way that it is quasi one dimensional.

For example in corridors, all pedestrians mostly go in the same direction. Even if two opposite flows are considered, it is known that some lanes are formed spontaneously, and within each lane the flow is again quasi one dimensional and one directional.

The way pedestrians follow each other is even more clear when pedestrians walk in a line. Such a configuration can be met for example in very narrow corridors. It has been realized in several experiments [20–22], in order to study how pedestrians react when they can only adjust their speed. One may then wonder how the acceleration of a pedestrian is related to the distance, velocity, acceleration of

its predecessor, and how the behavior of a pedestrian differs from the one of a car. However, in order to evaluate the following behavior of a pedestrian, one needs to be able to track at the same time, and on long enough time windows, the trajectory of both the pedestrian under consideration and its predecessor.

Such an experiment has been realized in the frame of the PEDIGREE project [18]. Pedestrians were asked to walk as a line, i.e. to follow each other without passing [23]. Their trajectory was circular, in order to avoid boundary effects. The motion of all pedestrians was tracked with a high precision motion capture device (VICON) [24]. As a result, the trajectories of all pedestrians were obtained for the whole duration of the experiment (from 1 to 3 min).

Various combinations of the dynamic coordinates of the predecessor have been tested against the acceleration a of the follower. It turned out that the best correlation was obtained [23, 25] for the relation

$$a(t) = C \frac{\Delta v(t - \tau)}{[\Delta x(t)]^\gamma} \quad (1)$$

where v is the velocity of the predecessor, and Δx the distance between the predecessor and its follower.

One important difference with car traffic is the time delay τ introduced in the velocity: While the follower is able to evaluate quite instantaneously the position of his predecessor, he needs some time delay τ to evaluate his velocity.

Another difference with car traffic is the ability of pedestrians to flow even at very large local densities [26]. In the aforementioned experiment, the velocity was still of the order of 1 or 2 dm/s at local densities as high as 3 ped/m. This can be achieved thanks to the ability of pedestrians to keep walking even at very low densities: they can reduce the amplitude of their steps almost to zero while still keeping a stepping pace almost constant [27].

In contrast to cars, pedestrians can also take advantage of any space left by the predecessor, synchronizing partially their steps as was observed in previous experiments [20]. Surprisingly, this synchronization effect is also observed for pedestrians walking at a larger distance [27], probably as a result of the tendency of pedestrians to synchronize with external rhythmic stimuli [22].

Here we have presented a model for one-dimensional pedestrian flows. In general, pedestrians move in a two-dimensional space, and various agent based models have been proposed which we shall not review here.

3 One-Dimensional Bi-directional Macroscopic Model for Crowds

At the other extreme, when seen from a distance, crowds can be described as continuous fluids. As mentioned in the introduction, one important difference with fluids is that pedestrians have a target – which may not be the same for all of them.

A simple configuration is met in corridors: the flow is quasi one-dimensional, but pedestrians can walk in both directions. There is thus a need to distinguish two densities ρ_{\pm} of pedestrians, one for each walking direction. Each density obeys a conservation law:

$$\begin{aligned}\partial_t \rho_+ + \partial_x(\rho_+ u_+) &= 0, \\ \partial_t \rho_- + \partial_x(\rho_- u_-) &= 0,\end{aligned}$$

where u_{\pm} is the locally averaged velocity of pedestrians going in the \pm direction.

Two other relations are needed to determine the four unknown densities and velocities. This is achieved by writing two other differential equations for the momentum [28, 29]

$$\begin{aligned}\partial_t(\rho_+ u_+) + \partial_x(\rho_+ u_+ u_+) &= -\rho_+ \left(\frac{d}{dt}\right)_+ [p(\rho_+, \rho_-)], \\ \partial_t(\rho_- u_-) + \partial_x(\rho_- u_- u_-) &= \rho_- \left(\frac{d}{dt}\right)_- [p(\rho_-, \rho_+)],\end{aligned}$$

in which, by analogy to the pressure in fluid mechanics, the interactions between pedestrians are described by a term $p(\rho_{\pm}, \rho_{\mp})$. There is however a major difference with fluid mechanics: following [17], the derivative

$$(d/dt)_{\pm} = \partial_t + u_{\pm} \partial_x \quad (2)$$

is taken in the referential of the walking pedestrians, and not in the fixed frame as for fluids. Indeed, pedestrians react to their perception of the surrounding density as they see it while walking.

The term $p(\rho_{\pm}, \rho_{\mp})$ is actually not a pressure as in fluid mechanics, but rather a velocity offset between the achieved velocity u_{\pm} , and another quantity w_{\pm} which, as it is conserved along each pedestrian trajectory, can be interpreted as the desired velocity that the pedestrian would have if he was alone. In other words,

$$\begin{aligned}u_+ &= w_+ - p(\rho_+, \rho_-) \\ -u_- &= w_- - p(\rho_-, \rho_+)\end{aligned}$$

where w_{\pm} are Riemann invariants

$$\begin{aligned}\partial_t w_+ + u_+ \partial_x w_+ &= 0 \\ \partial_t w_- + u_- \partial_x w_- &= 0\end{aligned}$$

conserved along the trajectories of \pm pedestrians. The function $p(\rho_{\pm}, \rho_{\mp})$ can be determined from experimental measurements.