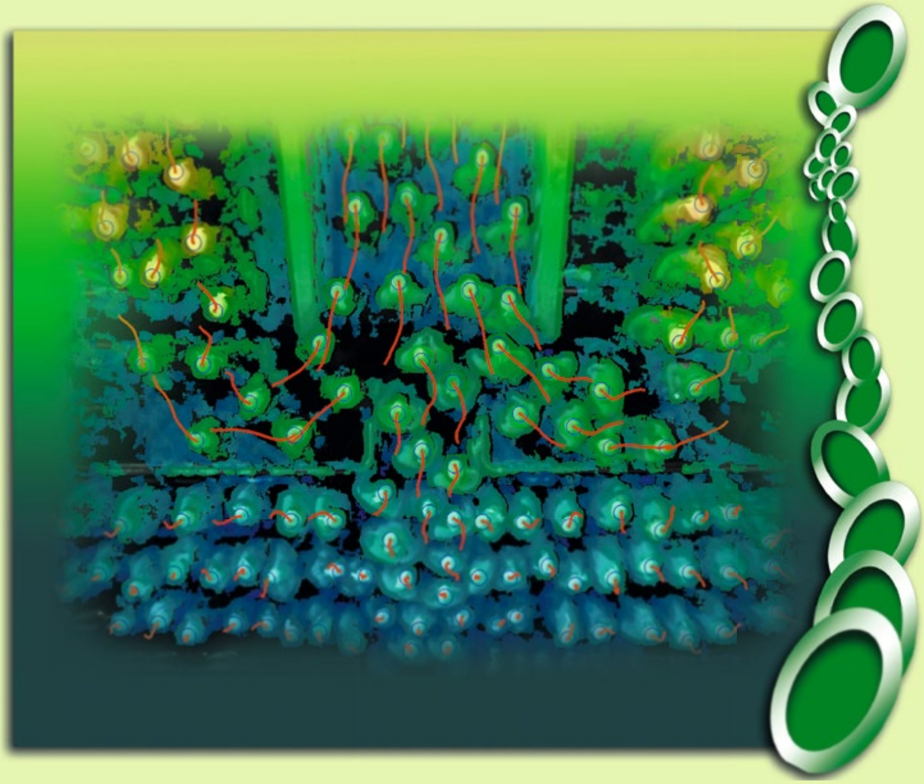
M. Chraibi · M. Boltes
A. Schadschneider · A. Seyfried
Editors

TRAFFIC AND GRANULAR FLOW '13



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Mohcine Chraibi • Maik Boltes •
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Editors
Mohcine Chraibi
Maik Boltes
Armin Seyfried
Jülich Supercomputing Centre
Forschungszentrum Jülich
Jülich
Germany

Andreas Schadschneider
Institut für Theoretische Physik
Universität zu Köln
Köln
Germany

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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	Mohcine Chraibi
Jülich, Germany	Maik Boltes
Köln, Germany	Andreas Schadschneider
Jülich, Germany	Armin Seyfried

Contents

Part I Pedestrian Traffic and Evacuation Dynamics

Part II Highway and Urban Vehicular Traffic

Part III Biological Systems and Granular Flow

Contributors

Vincent Aguiléra Paris-Est University LVMT, Marne-la-Vallée, France

Fernando Alonso-Marroquín School of Civil Engineering, The University of Sydney, Sydney, NSW, Australia

Igor Anufriev St. Petersburg State Polytechnical University, St. Petersburg, Russia

Cecile Appert-Rolland Laboratory of Theoretical Physics, Batiment 210, CNRS UMR 8627, University Paris-Sud, Orsay Cedex, France

B. van Arem Faculty of Civil Engineering and Geosciences, Department of Transport and Planning, Delft University of Technology, Delft, The Netherlands

Chikashi Arita Theoretische Physik, Universität des Saarlandes, Saarbrücken, Germany

Johanna Bamberger Bismarckgymnasium, Karlsruhe, Germany

Stefania Bandini Department of Informatics, Systems and Communications, Complex Systems and Artificial Intelligence Research Center, University of Milano-Bicocca, Milano, Italy

Marc Barthelemy Institut de Physique Théorique, CEA, CNRS-URA 2306, Gif-sur-Yvette, France

Somayyeh Belbasi University of Zanjan, Zanjan, Iran

Johannes Brügmann Fakultät für Physik, Universität Duisburg-Essen, Duisburg, Germany

Martins Brics Institute of Physics, Rostock University, Rostock, Germany

Marek Bukáček Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Prague, Czech Republic

Jonathan Busch School of Civil Engineering, The University of Sydney, Sydney, NSW, Australia

Alexander P. Buslaev MADI, MTUCI, Moscow, Russia

Antonia Chechina Keldysh Institute of Applied Mathematics RAS, Moscow, Russia

Tao Chen Institute of Public Safety Research, Tsinghua University, Beijing, China

T. Chmura Nottingham University, Nottingham, UK

Keechoo Choi Department of Transportation Engineering, TOD-based Sustainable Urban Transportation Center, Ajou University, Suwon, Korea

Natalia Churbanova Keldysh Institute of Applied Mathematics RAS, Moscow, Russia

Luca Ciandrini DIMNP UMR 5235 CNRS, and Laboratoire Charles Coulomb UMR 5221 CNRS, Université Montpellier II, Montpellier Cedex, France

Julien Cividini Laboratoire de Physique Théorique d'Orsay, Bâtiment 210, Université Paris-Sud 11, Orsay Cedex, France

G. Costeseque Université Paris-Est/Ecole des Ponts ParisTech/CERMICS, Marne la Vall ee Cedex 2, France

Université Paris-Est/IFSTTAR/GRETTIA, Marne-la-Vallée Cedex 2, France

Matthias Craesmeyer Institut für Theoretische Physik, Universität zu Köln, Köln, Germany

Luca Crociani Department of Informatics, Systems and Communications, Complex Systems and Artificial Intelligence Research Center, University of Milano-Bicocca, Milano, Italy

Winnie Daamen Faculty of Civil Engineering and Geosciences, Department of Transport and Planning, Delft University of Technology and NS Stations, Netherlands Railways, Delft, The Netherlands

Felix Dietrich Munich University of Applied Sciences, München, Germany

Technische Universität München, Garching bei München, Germany

Ning Ding Center for Intelligent and Networked Systems, Tsinghua University, Beijing, China

Li-Yun Dong Institute of Applied Mathematics and Mechanics, Shanghai University, Shanghai, China

Dorine C. Duives Delft University of Technology, Delft, The Netherlands

Christian Eilhardt University of Cologne, Institute of Theoretical Physics, Köln, Germany

Takahiro Ezaki Department of Aeronautics and Astronautics, School of Engineering, The University of Tokyo, Tokyo, Japan

Japan Society for the Promotion of Science, Tokyo, Japan

M. Ebrahim Foulaadvand University of Zanjan, Zanjan, Iran

M. Fukui Nakanihon Automotive College, Sakahogi, Japan

Marion Gödel Munich University of Applied Science, Munich, Germany

Yuan Gao Center for Intelligent and Networked Systems, Tsinghua University, Beijing, China

Michael Gauß Fernstudienzentrum – Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Anna-Lena Geßler Bismarckgymnasium, Karlsruhe, Germany

Ralph Germ Technische Universität Dresden, Dresden, Germany

Bernat Goñi Ros Faculty of Civil Engineering and Geosciences, Department of Transport and Planning, Delft University of Technology, Delft, The Netherlands

Andrea Gorrini Information Society Ph.D. Program, Department of Sociology and Social Research, University of Milano-Bicocca, Milano, Italy

David Greenwood Faculty of Engineering, University of Bristol, Bristol, UK

Samer H. Hamdar Department of Civil and Environmental Engineering Academic Center, School of Engineering and Applied Science, The George Washington University, NW Washington, DC, USA

Peter Heitzelmann Bismarckgymnasium, Karlsruhe, Germany

P. Hemmerle Daimler AG, HPC: 059-X832, Sindelfingen, Germany

Gerhard Hermanns University of Duisburg-Essen, Duisburg, Germany

B. Herz Universitat Pompeu Fabra, Barcelona, Spain

Jeroen van den Heuvel Faculty of Civil Engineering and Geosciences, Department of Transport and Planning, Delft University of Technology and NS Stations, Netherlands Railways, Delft, The Netherlands

Poul G. Hjorth Department of Applied Mathematics and Computer Science, Technical University of Denmark, Kongens Lyngby, Denmark

Ingmar Hofsäß PTV Group, Karlsruhe, Germany

Serge P. Hoogendoorn Faculty of Civil Engineering and Geosciences, Department of Transport and Planning, Delft University of Technology and NS Stations, Netherlands Railways, Delft, The Netherlands

Pavel Hrabák Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Prague, Czech Republic

Tsumugi Ishida Department of Complex Systems Science, Nagoya University, Nagoya, Japan

Mayuko Iwamoto Graduate School of Advanced Mathematical Sciences, Meiji University, Tokyo, Japan

Anders Johansson Faculty of Engineering, University of Bristol, Bristol, UK

David de Jong Delft University of Technology, Delft, The Netherlands

Roxana Josens Instituto de Fisiología, Biología Molecular y Neurociencias, FCEN – UBA, Pabellon II, Ciudad Universitaria, de Buenos Aires, Argentina

Gerta Köster Munich University of Applied Sciences, München, Germany

Rene Kahlmeyer Bismarckgymnasium, Karlsruhe, Germany

Jevgenijs Kaupužs Institute of Mathematical Sciences and Information Technologies, University of Liepaja, Liepaja, Latvia

Institute of Mathematics and Computer Science, University of Latvia, Riga, Latvia

Boris S. Kerner Physik von Transport und Verkehr, Universität Duisburg-Essen, Duisburg, Germany

Arne Kesting TomTom Development Germany GmbH, Berlin, Germany

M. Kikuchi Cybermedia Center, Osaka University, Toyonaka, Japan

Ekaterina Kirik Institute of Computational Modelling SB RAS, Akademgorodok, Krasnoyarsk, Russia

Sarah Klein Universität des Saarlandes, Saarbrücken, Germany; Laboratory of Theoretical Physics, Batiment 210, University Paris-Sud, Orsay Cedex, France

Victor L. Knoop Faculty of Civil Engineering and Geosciences, Department of Transport and Planning, Delft University of Technology, Delft, The Netherlands

Florian Knorr Fakultät für Physik, Universität Duisburg-Essen, Duisburg, Germany

Micha Koller IT-Designers GmbH, Esslingen am Neckar, Germany

Sara Korn Bismarckgymnasium, Karlsruhe, Germany

Valery V. Kozlov Steklov Mathematical Institute, Russian Academy of Sciences, Moscow, Russia

Milan Krbálek Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Prague, Czech Republic

Tobias Kretz PTV Group, Karlsruhe, Germany

I.N. Kulkov University of Duisburg-Essen, Duisburg, Germany

Bharat Kunwar University of Bristol, Bristol, UK

Valentina Kurtc St. Petersburg State Polytechnical University, St. Petersburg, Russia

Sylvain Lassarre IFSTTAR GRETTIA, Marne-la-Vallée, France

Jean-Patrick Lebacque Université Paris-Est/IFSTTAR/GRETTIA, Champs sur Marne, Marne la Vall ee Cedex 2, France

Karsten Lehmann PTV Group, Karlsruhe, Germany

Zhi-Yang Lin Institute of Applied Mathematics and Mechanics, Shanghai University, Shanghai, China

Hans van Lint Delft University of Technology, Delft, The Netherlands,

Siuming Lo Department of Civil and Architectural Engineering, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong SAR

Celia Lozano Facultad de Ciencias, Departamento de Física, Universidad de Navarra, Navarra, Spain

Xue Hao Lu Jing Ye High School, Shanghai, China

Robert Lubaś Department of Applied Computer Science, AGH University of Science and Technology, Kraków, Poland

Peter B. Luh Department of Electrical and Computer Engineering, University of Connecticut, Storrs, CT, USA

Wei Lv State Key Laboratory of Fire Science, University of Science and Technology of China, Hefei, China

Alma R. Méndez Department of Applied Mathematics and Systems, Universidad Autónoma Metropolitana (Cuajimalpa), Alvaro Obregón, México

Jian Ma National United Engineering Laboratory of Integrated and Intelligent Transportation, School of Transportation and Logistics, Southwest Jiaotong University, Chengdu, PR China

Reinhard Mahnke Institute of Physics, Rostock University, Rostock, Germany

Xu Mai State Key Laboratory of Fire Science, University of Science and Technology of China, Hefei, PR China

Andrey Malyshev Institute of Computational Modelling SB RAS, Akademgorodok, Krasnoyarsk, Russia

Christian Marschler Department of Applied Mathematics and Computer Science, Technical University of Denmark, Kongens Lyngby, Denmark

Takashi Matsuoka Graduate School of Advanced Mathematical Sciences, Meiji University, Tokyo, Japan

Dinesh Mohan Transportation Research and Injury Prevention Programme, Indian Institute of Technology New Delhi, New Delhi, India

J.D. Muñoz Universidad Nacional de Colombia, Bogotá, D.C., Cundinamarca, Colombia

Marcin Mycek Department of Applied Computer Science, AGH University of Science and Technology, Kraków, Poland

A. Nakayama Faculty of Science and Technology, Meijo University, Nagoya, Japan

Ryosuke Nishi National Institute of Informatics, Tokyo, Japan

JST, ERATO, Kawarabayashi Large Graph Project, Tokyo, Japan

Katsuhiro Nishinari Research Center for Advanced Science and Technology, The University of Tokyo, Tokyo, Japan

Kazumichi Ohtsuka Research Center for Advanced Science and Technology, The University of Tokyo, Tokyo, Japan

L.E. Olmos Universidad Nacional de Colombia, Bogotá, D.C., Cundinamarca, Colombia

Gaurav Pandey Transportation Research and Injury Prevention Programme, Department of Civil Engineering, Indian Institute of Technology New Delhi, New Delhi, India

Daniel R. Parisi Instituto Tecnológico de Buenos Aires, de Buenos Aires, Argentina

Saira Saleem Pathan Fraunhofer Institute for Factory Operation and Automation, Magdeburg, Germany

T. Pitz Rhine-Waal University of Applied Sciences, Kleve, Germany

Egor Popel Siberian Federal University, Krasnoyarsk Krai, Russia

Jakub Porzycki Department of Applied Computer Science, AGH University of Science and Technology, Kraków, Poland

Lingqiao Qin Department of Civil and Environmental Engineering Academic Center, School of Engineering and Applied Science, The George Washington University, NW Washington, DC, USA

Álvaro Ramírez-Gómez Escuela Técnica Superior de Ingeniería y Diseño Industrial, Universidad Politécnica de Madrid, Madrid, Spain

K. Ramchandra Rao Department of Civil Engineering, Indian Institute of Technology New Delhi, New Delhi, India

Hubert Rehborn Daimler AG, HPC: 059-X832, Stuttgart, Germany

Shahreena Rhasbudin Shah Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands

Klaus Richter Fraunhofer Institute for Factory Operation and Automation, Magdeburg, Germany

Michel Roussignol Paris-Est University LAMA, Marne-la-Vallée, France

Zeinab Sadjadi Department of Theoretical Physics, Saarland University, Saarbrücken, Germany

Qi Hao Sang Jing Ye High School, Shanghai, China

Ludger Santen Department of Theoretical Physics, Saarland University, Saarbrücken, Germany

Andreas Schadschneider Institut für Theoretische Physik, Universität zu Köln, Köln, Germany

W.J. Schakel Faculty of Civil Engineering and Geosciences, Department of Transport and Planning, Delft University of Technology, Delft, The Netherlands

Michael Schreckenberg Fakultät für Physik, Universität Duisburg-Essen, Duisburg, Germany

M. Reza Shaebani Department of Theoretical Physics, Saarland University, Saarbrücken, Germany

Shrikant Sharma Buro Happold, Bath, UK

A. Shibata Computing Research Center, High Energy Accelerator Research Organization (KEK) & Graduate University for Advanced Studies (Sokendai), Tsukuba, Japan

Kenichiro Shimura Research Center for Advanced Science and Technology, The University of Tokyo, Tokyo, Japan

Jan Sieber College of Engineering, Mathematics and Physical Sciences, University of Exeter, Exeter, UK

Isabella von Sivers Munich University of Applied Sciences, München, Germany

Weiguo Song State Key Laboratory of Fire Science, University of Science and Technology of China, Hefei, PR China

Jens Starke Department of Applied Mathematics and Computer Science, Technical University of Denmark, Kongens Lyngby, Denmark

Yūki Sugiyama Department of Complex Systems Science, Nagoya University, Nagoya, Japan

Kohta Suzuno Graduate School of Advanced Mathematical Sciences, Meiji University, Tokyo, Japan

Shin-ichi Tadaki Department of Information Science, Saga University, Saga, Japan

Yohei Taniguchi Department of Advanced Interdisciplinary Studies (AIS), Graduate School of Engineering, The University of Tokyo, Tokyo, Japan

Alexander G. Tatashev MTUCI, MADI, Moscow, Russia

Akiyasu Tomoeda Meiji Institute for Advanced Study of Mathematical Sciences, Meiji University, Tokyo, Japan

CREST, Japan Science and Technology Agency, Tokyo, Japan

Antoine Tordeux Paris-Est University LVMT, Marne-la-Vallée, France

Marina Trapeznikova Keldysh Institute of Applied Mathematics RAS, Moscow, Russia

Martin Treiber Technische Universität Dresden, Dresden, Germany

Daishin Ueyama Graduate School of Advanced Mathematical Sciences, Meiji University, Tokyo, Japan

R.M. Velasco Department of Physics, Universidad Autónoma Metropolitana (Iztapalapa), Iztapalapa, México

Giuseppe Vizzari Department of Informatics, Systems and Communications, Complex Systems and Artificial Intelligence Research Center, University of Milano-Bicocca, Milano, Italy

Aral Voskamp Faculty of Civil Engineering and Geosciences, Department of Transport and Planning, Delft University of Technology and NS Stations, Netherlands Railways, Delft, The Netherlands

Hai L. Vu Delft University of Technology, Delft, The Netherlands,

Jarosław Wąs Department of Applied Computer Science, AGH University of Science and Technology, Kraków, Poland

Femke L.M. van Wageningen-Kessels Delft University of Technology, Delft, The Netherlands

Zhi Jie Wang Jing Ye High School, Shanghai, China

Hans Weber Department of Physics, Luleå University of Technology, Luleå, Sweden

Xiaoge Wei State Key Laboratory of Fire Science, University of Science and Technology of China, Hefei, China

S.C. Wong Department of Civil Engineering, The University of Hong Kong, Pokfulam, Hong Kong

Daichi Yanagisawa College of Science, Ibaraki University, Bunkyo, Mito, Ibaraki, Japan

Marina V. Yashina MTUCI, MADI, Moscow, Russia

T. Yosida Nakanihon Automotive College, Sakahogi, Japan

Guan Zong Yuan Jing Ye High School, Shanghai, China

S. Yukawa Department of Earth and Space Science, Osaka University, Toyonaka, Japan

Thomas Zaksek Fakultät für Physik, Universität Duisburg-Essen, Duisburg, Germany

Hui Zhang Institute of Public Safety Research, Tsinghua University, Beijing, China

Peng Zhang Institute of Applied Mathematics and Mechanics, Shanghai University, Shanghai, China

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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C. Appert-Rolland (✉)
Laboratory of Theoretical Physics, CNRS UMR 8627, University of Paris-Sud, 91405 Orsay Cedex, France
e-mail: Cecile.Appert-Rolland@th.u-psud.fr

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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,ξ)	
Cellular automata *FHP Model* [10]	Cellular automata *Nagel-Schreckenberg model* [11]	Cellular automata *Floor Field model* [12]	Cellular automata *Langmuir kinetics* [13]
Continuous PDEs Conservation of mass and momentum *Navier-Stokes Eqs*	Continuous PDEs Conservation of mass + fundamental diagram $j(\rho)$ *LWR Model* [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 know – 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 features 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

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

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 $\rho_\pm$ 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 ± 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

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

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 ± pedestrians. The function $p(\rho_\pm, \rho_\mp)$ can be determined from experimental measurements.