VI Workshop on Mathematical Foundations of Traffic

Traffic Modeling and Management:
Trends and Perspectives

Sophia Antipolis 20-22 March 2013

Book of Abstracts

Inria Sophia-Antipolis Méditerranée

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2. Abstracts of Invited Speakers

WEDNESDAY 20 MARCH, 9:45-10:30

Generic second order traffic flow models (GSOM)

Jean-Patrick Lebaque
IFSTTAR,France

Models of the GSOM (Generic second order modeling) family encompass many current macroscopic traffic flow models. GSOM models extend the classical LWR model, and also the ARZ (Aw-Rascle-Zhang) model. More precisely, in a GSOM model the traffic flow is described by the dynamics of the traffic density and by the dynamics of driver specific quantities. Formally a GSOM model can be expressed as a system of conservation equations with possibly source terms. The driver specific attributes could be destinations, vehicle/driver class, propensity to agressive or conservative driving, or parameters of the fundamental diagram, or any combination of those. Typically a homogeneous GSOM model admits two kinds of waves, kinematic waves (density dynamics) and contact discontinuities (driver attribute dynamics). It follows that the concepts of local trafic supply and demand can be extended to GSOM models. The presentation will first discuss boundary conditions and intersection modelling through the supply/demand approach. The invariance principle, which can be viewed as a self-consistency principle for intersection models, constrains the structure of physically possible models. This question will be discussed in the view of recent work (Flötteröd et al, Jin for instance). It will be shown that internal state nodes provide a general solution to intersection modeling applicable to the GSOM family. Another important issue with GSOM models is (streaming) data assimilation. One way to approach this problem is to use a variational formulation of the model. This program has been recently carried in the case of

LWR models (Claudel and Bayen). In the case of GSOM models the situation is different, since GSOM models are described by systems of conservation laws. It will be shown that a GSOM model needs first to be expressed in lagrangian coordinates, then partially integrated (integration of the driver attribute equations) before it can be recast in a Hamilton-Jacobi form (with respect to lagrangian variables). The resulting variational formulation will be discussed and some of its consequences will be analyzed, notably in terms of numerical schemes.

Wednesday 20 March, 11:00-11:45

Dynamical Phenomena induced by Bottleneck

Ingenuin Gasser
Universität Hamburg, Germany

We consider traffic flow on a ring road and study how the well known solutions for the homogeneous case (no bottleneck) are disturbed by the introduction of a bottleneck. This leads to new dynamical phenomena like different types of coexisting jam like solutions. Mathematically completely different methods than in the homogeneous case have to be used. And in addition an outlook to the open (non ring) road is given.

Wednesday 20 March,11:45-12:30

An investigation of proportionally fair ramp metering

Richard Gibbens
University of Cambridge, United Kingdom

This talk adds to recent work on a ramp metering strategy, proportionally fair metering, inspired by rate control mechanisms developed for the Internet. Specifically, we use simulation results to compare proportionally fair metering with a greedy strategy for a linear network with a series of entry points leading towards a single common destination for all the traffic, such as a radial route towards a city centre. Under our modelling assumptions, the greedy strategy is provably optimal for exogenously determined arrival streams of traffic, but it is unfair, in a certain precise sense, between different entry points and may well have perverse and suboptimal consequences if it influences traffic demand. We further consider a network with parallel roads where flows of traffic may have route choice according to the levels of queueing at the individual entry points. (Joint work with F.P. Kelly)

Wednesday 20 March,14:30-15:15

A Hamilton-Jacobi approach to junction problems in traffic

Régis Monneau
Cermics - ENPC, France

In this talk, we consider first order Hamilton-Jacobi equations posed on a junction, that is to say the union of a finite number of half lines with a unique common point. For the application that we have in mind for traffic flow, the Hamiltonians are naturally discontinuous at the junction point and this creates a challenging difficulty to prove the uniqueness of the solutions. For a suitable notion of viscosity solution, we establish a comparison principle which is our main result. This new result provides a powerful tool to analyse and characterize (uniquely) solutions on junctions.

Wednesday 20 March, 16:30-17:15

MILP-based estimation and control of first order conservation laws: applications to transportation engineering

Christian Claudel
KAUST, Saudi Arabia

This talk describes a new framework for solving control and estimation problems in systems modeled by scalar conservation laws with convex flux, with applications to highway traffic flow estimation and control. Using an equivalent

Hamilton-Jacobi formulation, we show that the be solution to the original PDE can be written semi-analytically. Using the properties of the solutions to HJ PDEs, we prove that when the data of the problem is prescribed in piecewise affine form, the constraints of the model are mixed integer linear. This property enables us to identify a class of transportation engineering problems (control, estimation, fault detection, user privacy analysis) that can be solved exactly using MILPs.

THURSDAY 21 MARCH, 09:00-09:45

Traffic light control on road networks

Simone Göttlich
Universität Mannheim, Germany

Traffic flow phenomena can be described by a continuous traffic flow network model incorporating constraints for optimal traffic light switchings in time. The focus is on the discussion of the extended traffic model and the derivation of a suitable optimization framework to determine the optimal switching points. In fact, the model can be related to mixed-integer programming models that allow for Branch and Bound based optimization procedures. To ensure feasibility and to reduce the computational effort of large-scale instances, there is evidently need for suitable heuristics.

THURSDAY 21 MARCH, 9:45-10:30

Traffic monitoring with smartphones

Daniel Work
University of Illinois at Urbana-Campaign, U.S.

The recent and rapid growth smartphones is dramatically changing how traffic is monitored on our roadways. In addition to providing a significant increase in sensor coverage, data from these devices also poses new challenges in traffic modeling and data assimilation for the next generation of traffic management systems.

In the first part of the talk, I will describe the problem of estimating model parameters from GPS data, which is a critical but cumbersome task. A poorly calibrated model leads to erroneous estimates in data–poor environments, and limited forecasting ability. I will present a method for calibrating flow model parameters for a discretized scalar conservation law using only velocity measurements. The method is based on a Markov Chain Monte Carlo technique, which is used to approximate statistics of the posterior distribution of the model parameters. Numerical experiments highlight the difficulty in estimating jam densities, and provide a new approach to improve performance of the sampling through re-parameterization of the model.

I will also describe a new approach to monitor traffic with cell phones, known as TrafficTurk. Inspired by Amazon's Mechanical Turk for crowd sourcing human intelligence tasks, TrafficTurk enables large-scale traffic sensor deployments to improve coverage during extreme congestion events. The system has been deployed for sporting events in Urbana-Champaign, and in New York following Superstorm Sandy.

Thursday 21 March, 11:00-11:45

Forecasting and control of Traffic systems: a network system view

Carlos Canudas de Wit
GIPSA-Lab, Grenoble, France

The Grenoble Traffic Lab (GTL `http://necs.inrialpes.fr/pages/reseach/gtl.php`) initiative is a real-time traffic data center (platform) intended to collect traffic road infrastructure information in real-time with minimum latency and fast sampling periods. This lecture includes several aspects on modeling, forecasting and control of traffic systems, which are applied to the GTL. In this presentation, we first review main conservation models which are used as a basis to design physical-oriented forecasting & control algorithms. In particular we underline fundamental properties like downstream/upstream controllability and observability of such models, and present a new network set-up for analysis. Then we present advances in traffic forecasting using graph-constrained macroscopic models which substantially reduce the number of possible affine dynamics of the system and preserve the number of vehicles in the network. This model is used to recover the state of the traffic network and precisely localize the eventual congestion front. The last part of the talk we discuss issues on density balancing control, where the objective is to design the homogeneous distribution of density on the freeway using the input flows as decision variables. The study shown, that a key-stone for the design of the balanced states is a necessary cooperation of ramp metering with the variable speed limit control.

THURSDAY 21 MARCH, 11:45-12:30

Modeling and controlling traffic congestion and propagation in large-scale networks

Nikolas Geroliminis
École polytechnique fédérale de Lausanne, Switzerland

This talk tackles the problem of modeling and optimization in large-scale congested traffic networks with an aggregated realistic representation of traffic dynamics and route choice and multiple modes of transport. Realistic modeling and efficient control of transportation systems remains a big challenge, due to the high unpredictability of choices of travelers (in terms of route, time and mode of travel), the uncertainty in their reactions to the control and the spatiotemporal propagation of congestion, the lack of coordinated actions coupled with the limited infrastructure available. While there is a vast literature of congestion dynamics, control and spreading in one-dimensional traffic systems with a single mode of traffic, most of the analysis at the network level is based on simplistic models or simulation, which require a large number of input parameters (sometimes unobservable with existing data) and cannot be easily solved in real time. We model the dynamics of a heterogeneously congested urban network with multiple centers of congestion as a set of interconnected regions with low scatter aggregated relationships between network flux and density. Optimal control methodologies can identify the inter-transfers among regions to maximize the system output, as expressed by the number of trips ending in the regions. These control policies can change the spatial distribution of congestion in such a way that the network outflow increases. The validation of the modeling methodologies and the traffic management schemes are conducted in various and complex city structures scenarios using data from field experiments advanced micro-simulations.

THURSDAY 21 MARCH, 14:30-15:15

Effective Dyamic Speed Limit Control approaches

Serge Hoogendoorn
Technische Universiteit Delft, Netherlands

Variable Speed Limits have been deployed with moderate success. While some of the approaches have turned out to be effective, many shown very limited or even adverse results, in particular with respect to motorway throughput. We argue that this is mainly due to the limited use of the state-of-the-art in traffic flow theory, which points clearly into directions in which solutions should be sought. In this presentation, we will briefly review the key traffic flow phenomena that actually lead to the principles of traffic management. Based on these principles, we show how dynamic speed limits can be effectively and successfully deployed to improve motorway throughput. In particular, we show a novel approach to suppression shockwaves (wide moving jams) using Variable Speed Limits called Specialist. We discuss the underlying traffic flow theoretical principles, and the resulting method. We discuss its application in simulation, as well as the results of a successful pilot study performed on the A12 motorway in the Netherlands. Furthermore, we discuss the sensitivity to the compliance of the road users on the speed limits shown on the variable message signs. The final part of the talk discusses future applications when instead of using variable message signs, cooperative approaches using in-car deployment are being proposed.

THURSDAY 21 MARCH,16:30-17:15

Various possibilities for solving Riemann problems at junctions.

Mauro Garavello
Università Milano Bicocca, Italy

In this talk we present various possibilities for solving Riemann problems at junctions (or intersections). From a mathematical point of view an intersection is represented by a finite number of incoming and outgoing roads, while roads are described by a bounded real interval. In each road a macroscopic-type traffic model is considered. The choice of the solution at junctions is clearly related to the geometry of junctions and to the traffic model considered. In this way, it is possible to describe several different situations: intersections governed by traffic lights, roundabouts, bottlenecks, toll gates. Also the coupling between different traffic models can be treated in this setting.

For each solution, we analyze all the mathematical properties related to it with particular emphasis to existence and well posedness of solutions to the Cauchy problem on a network.

Friday 22 March, 9:00-9:45

A fresh look at the role of the fundamental diagram in traffic flow

Michael Zhang
University of California, Davis, U.S.

The fundamental diagram of traffic flow, depicting bi-variate relations between flow rate (or headway), density (or spacing) and vehicular speed, underpins almost every aspect of traffic science: it embodies, in an average sense, driver behavior that separates traffic "particles" or "fluid" from other physical particles and fluids, forms the foundation of many transportation engineering applications such as highway capacity analysis, and shows up in almost every form of traffic models—microscopic car-following, macroscopic fluid-like, and mesoscopic gas-kinetic models— hence also permeates into dynamic traffic assignment as well. It is thus understandable that tremendous effort has been devoted to the study of this subject, in the name of traffic stream models, since the pioneering work of Greenshields. Models of all shades and color, from linear to exponential, smooth to discontinuous, single-valued to set-valued, have been proposed to describe traffic stream characteristics, yet a consensus seems still lacking as to what forms the fundamental diagram should adopt and what basic properties and boundary conditions it must possess and satisfy. In this talk, I attempt to summarize what we know about the fundamental diagram, critique on its properties, and in particular, set forth a few benchmark tests to screen out fundamental diagrams that are clearly wrong or inadequate. I also point out several pitfalls to avoid in the study of traffic stream models, and examine some of the consequences of fundamental diagrams with particular properties in the study of traffic dynamics, such as instability and stop-and-go waves.

FRIDAY 22 MARCH, 9:45-10:30

Moving bottlenecks within the three representation of traffic flow: an overview of numerical issues

Ludovic Leclercq
Université de Lyon, IFSTTAR / ENTPE, LICIT, France

Accounting for moving bottlenecks are now a common feature for traffic flow models because this permit to represent multiple situations: impact of slow vehicles on the surrounding traffic, impact of lane-changers with bounded acceleration,... Theoretical foundations for incorporating moving bottlenecks in first order (LWR) model have been presented fifteen years ago ([1], [2]). Lots of numerical methods have then been proposed to cope with this problem but most remained unsatisfactory until the recent introduction of the variational theory. This paper proposes an historical overview of such methods. The first discretize the moving boundary condition in order to match the constraints with the classical rectangular numerical grid. The second extend the Godunov scheme with non-rectangular cells on both sides of the moving boundary conditions. The third take benefit from the variational theory and assimilate moving bottlenecks to shortcuts. This last category leads to efficient numerical scheme that can be exact and/or grid-free with some particular assumptions on the fundamental diagram. Recent developments in the traffic flow theory have shown the connections between the expressions of the LWR model between the three 2-dimensional coordinate systems arising in the space of vehicle number, time and distance. Numerical issues related with the introduction of moving bottlenecks will be discussed in all the three coordinate systems in order to emphasize similarities and differences.

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FRIDAY 22 MARCH, 11:00-11:45

A general phase transition model for traffic flow on networks

Sebastien Blandin
IBM Research Collaboratory, Singapore

An extension of the Colombo phase transition model is proposed. The congestion phase is described by a two-dimensional zone defined around a standard fundamental diagram. General criteria to build such a set-valued fundamental diagram are enumerated, and instantiated on several standard fluxes with different concavity properties. The solution of the Riemann problem in the presence of phase transitions is obtained through the design of a Riemann solver, which enables the construction of the solution of the Cauchy problem using wavefront tracking. The free-flow phase is described using a Newell-Daganzo fundamental diagram, which allows for a more tractable defini- tion of phase transition compared to the original Colombo phase transition model. The accuracy of the numerical solution obtained by a modified Godunov scheme is assessed on benchmark scenarios for the different flux functions constructed.

3. Abstracts of Contributed Speakers

Wednesday 20 March,15:15-15:35

Road junction modelling using a scheme based on Hamilton-Jacobi equation

Guillame Costeseque
Université Paris-Est, Ecole des Ponts ParisTech, CERMICS, France and
Université Paris Est, IFSTTAR, GRETTIA, France

In this talk, we present the study of first order Hamilton-Jacobi (HJ) equations posed on a "junction", that is to say the union of a finite number of half-lines with a unique common point. We allow the Hamiltonians to be discontinuous through the junction point. We adopt the framework presented and developed in [2]. Indeed this paper allows us to get the existence and the uniqueness of the solution to the HJ equations under suitable assumptions. In order to solve such a model, we propose a numerical scheme which is closely related to the classical Godunov scheme as it was expressed for traffic flow modelling in [3]. We prove two main results. The first one is gradient and time derivatives estimates for the numerical scheme. The second one is the convergence of the numerical solution to the solution of the HJ problem. We then apply these results to the traffic case and we briefly compare them to those obtained by a classical approach (see e.g. the book [1]) for the very seminal first order LWR model [4,5].

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Wednesday 20 March, 15:40-16:00

BML model with open boundary conditions

Julien Cividini

Laboratoire de Physique Théorique,Université Paris-Sud and CNRS, France

A cellular automaton model for road traffic in cities has been formulated by Biham,Middleton and Levine in the 90s [1]. In this BML model each group of cars is represented by a particle. Each particle has a preferred direction having a preferred direction, say east or north, and is allowed to move in that direction on a square lattice modeling the streets of the city. The only interaction between the cars is simple exclusion, i.e. each site of the lattice can be occupied by at most one particle. This model has been widely studied on a torus. A jamming transition occurs for high enough particle density, in which case particles form a global jammed cluster. Below this transition, particles have been observed to self- organize into a diagonal pattern propagating with the flow. In this talk I will generalize this model to open boundary conditions by simulating a crossing between two perpendicular entrance lanes, and intro- duce mean-field equations meant to describe this system at low density [2]. A linear stability analysis of the equations will provide an explanation for the formation of the diagonal pattern on the torus. In the open system particles will be shown to self-organize not exactly into diagonals but into 'chevrons', a slightly tilted pattern whose angle depends on the position. This property will be shown to emerge from the equations as well. Although there is no full analytical explanation for this effect, I will provide a simple picture of it by isolating the dominant propagation modes of the particles. Numerical simulations prove that the observed chevrons are fairly close to this picture.

References

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Wednesday 20 March, 17:15-17:35

Pedestrians crossing the streets

Raul Borsche
University of Kaiserslautern, Germany

In urban traffic the paths of pedestrians and cars often intersect. We present a simple approach for the coupling of existing pedestrian and traffic flow models. Different behaviors of both interactors are modeled by appropriate coupling functions. Several numerical examples show the influence of the coupling conditions and simulate situations of daily experience.

Wednesday 20 March, 17:40-18:00

How can macroscopic models reveal self-organization in traffic flow?

Emiliano Cristiani
Istituto per le Applicazioni del Calcolo "M. Picone", Consiglio Nazionale delle Ricerche, Italy

In this talk we propose a new modeling technique for vehicular traffic flow, designed for capturing at a macroscopic level some effects, due to the microscopic granularity of the flow of cars, which would be lost with a purely continuous approach. The starting point is a multiscale method for pedestrian modeling, recently introduced in Cristiani et al., Multiscale Model. Simul., 2011, in which measure-theoretic tools are used to manage the microscopic and the macroscopic scales under a unique framework. In the resulting coupled model the

two scales coexist and share information, in the sense that the same system is simultaneously described from both a discrete (microscopic) and a continuous (macroscopic) perspective. This way it is possible to perform numerical simulations in which the single trajectories and the average density of the moving agents affect each other. Such a method is here revisited in order to deal with multi-population traffic flow on networks. For illustrative purposes, we focus on the simple case of the intersection of two roads. By exploiting one of the main features of the multiscale method, namely its dimension-independence, we treat one-dimensional roads and two-dimensional junctions in a natural way, without referring to classical network theory. Furthermore, thanks to the coupling between the microscopic and the macroscopic scales, we model the continuous flow of cars without losing the right amount of granularity, which characterizes the real physical system and triggers self-organization effects, such as, for example, the oscillatory patterns visible at jammed uncontrolled crossroads.
(Joint work with Benedetto Piccoli and Andrea Tosin).

Thursday 21 March, 15:15-15:35

An easy-to-use numerical approach for simulating traffic flow on networks

Maya Briani
Istituto per le Applicazioni del Calcolo "M. Picone", Consiglio Nazionale delle Ricerche, Italy

In this talk we present a new simple model for traffic flow on networks based on the LWR model. Starting from the model proposed in [1], we derive a system of conservation laws with space-dependent and discontinuous flux, each of which describes the evolution of a population of drivers with a unique origin-destination pair. The main advantage of this formulation is that junctions actually disappear, so that a unique mathematical theory can be applied for the whole network, i.e., there is no need to manage junctions separately as in the classical theory [2]. To avoid the excessive increase of the equations of the system, a modified version of the model is also proposed, in order to deal with large networks. Surprisingly, if the equations are numerically approximate by means of the Godunov scheme, the resulting algorithm *automatically* maximizes the flux at junctions, thus selecting a reasonable solution of the problem. Numerical examples for small- and medium-scale networks are provided, aiming at showing the simplicity of the algorithm.

(Joint work with Emiliano Cristiani).

References

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Thursday 21 March, 15:40-16:00

On the Micro–Macro Limit in Traffic Flow

Elena Rossi
Dip. di Matematica e Applicazioni, Università di Milano–Bicocca, Italy

We investigate the relations between a macroscopic LWR model and a microscopic follow-the-leader model for traffic flow. In particular, we establish a relation between the macro- and the microscopic variables, showing that the two descriptions are to some extent specular [3]. Then, we prove that solutions to the microscopic model tend to those to the macroscopic ones in a sort of kinetic limit, i.e., as the number of individuals tends to $+\infty$, following [2]. This result is then extended to the case of several populations, referring to the macroscopic model in [1] and to the natural multi–population analogue of the microscopic one.

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Thursday 21 March, 17:15-17:35

A PDE-ODE model for a junction with ramp buffer

Maria Laura Delle Monache
Inria Sophia Antipolis-Méditerranée, France

We consider the Lighthill-Witham-Richards traffic flow model on a junction composed by one mainline, an onramp and an offramp, which are connected by a node. The onramp dynamics is modeled using an ordinary differential equation describing the evolution of the queue length. The definition of the solution of the Riemann problem at the junction is based on an optimization problem and the use of a right-of-way parameter. The numerical approximation is carried out using Godunov scheme, modified to take into account the effects of the onramp buffer. We present the result of some simulations and check numerically the convergence of the method.
(Joint work with Jack Reilly, Samitha Samaranayake, Walid Krichene, Paola Goatin and Alexandre M. Bayen).

Thursday 21 March, 17:40-18:00

Queueing process with excluded-volume effect

Chikashi Arita
Institut de Physique Théorique, CEA Saclay, France

The simplest queueing model is of the so-called M/M/1 type, where customers stochas- tically enter the system, and leave the system at one server. When we (pedestrians) make a queue, we can proceed if there is a space in front of us. However this excluded-volume effect of queues is neglected in the usual queueing process. I introduced a simple extension of the M/M/1 queueing model with the excluded-volume effect (”exclusive queueing process”, EQP) by imposing a new boundary condition on the asymmetric exclusion process [1]. The usual queueing process converges if the injection rate is smaller than the extraction rate. On the other hand the injection rate cannot be larger than the maximal current of the asymmetric exclusion process for convergence of the EQP, i.e. “the queue itself is a bottleneck”. The EQP also has rich mathematical properties. Its stationary state can be written in a matrix product form [1, 2]. For a special case the EQP has an exact dynamical solution [4]. The talk also includes recent numerical results which provide nontrivial physical properties [3, 5, 6].

References

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Friday 22 March, 11:45-12:05

Kinetic ODEs modeling vehicular traffic in time and space

Andrea Tosin
IAC-CNR, Italy

In this talk I present a mathematical model of vehicular traffic based on the methods of the generalized kinetic theory, in which the space of microscopic states (position and velocity) of the vehicles is genuinely discrete. While in the recent literature discrete-velocity kinetic models of car traffic have already been successfully proposed, this is, to the authors' knowledge, the first attempt to account for all aspects of the physical granularity of car flow within the formalism of the aforesaid mathematical theory. Thanks to a rich but handy structure, the resulting model allows one to easily implement and simulate various realistic scenarios giving rise to characteristic traffic phenomena of practical interest (e.g., queue formation due to roadworks or to a traffic light). Moreover, it is analytically tractable under quite general assumptions, whereby fundamental

properties of the solutions can be rigorously proved.
(Joint work with Luisa Fermo).

FRIDAY 22 MARCH, 12:10-12:30

Two–Phase and Micro–Macro Descriptions of Traffic Flow

Francesca Marcellini
Dip. di Matematica e Applicazioni, Università di Milano – Bicocca, Italy

We present two frameworks for the description of traffic, both consisting in the coupling of systems of different types. First, we consider the 2-phase model [1, 3], where a scalar conservation law is coupled with a 2×2 system. Then, we present the coupling of a micro- and a macroscopic models, the former consisting in a system of ordinary differential equations and the latter in the usual LWR conservation law, see [2, 4]. A comparison between the two different frameworks is also provided.

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