Research Statement
of Benedetto Piccoli

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FLOWS ON NETWORKS.

Recently a theory of conservation laws on complex networks was developed and applied in different domains as: vehicular traffic (see 2 and 39 of Publications List), data networks (52) and supply chains (60).
The mathematical framework consists in conservation laws (or systems of conservation laws) on a network, modelled as a topological graph. The dynamics on arcs is thus determined while that on nodes needs to be defined. The only conservation through the node is not sufficient to determine a unique solution, thus various additional rules were considered, depending on the physics of the system under consideration. In particular, for vehicular traffic the following two rules were used:
(A) fluxes distribute on outgoing roads according to fixed coefficients;
(B) the through flux is maximized (respecting rule (A)).
The first rule exresses driver preferences, while the second one is an "entropy" type condition. For data networks the order of the two rules is inverted, since packets can be more easily re-directed on the network. The theory was devloped proving existence of weak entropic solutions on complex networks both for vehicular and data traffic, using a wave-front tracking algorithm and innovative variation estimates. It is interesting to notice that Lipschitz continuous dependence from initial conditions is true only for data networks (see 39 for a counterexample for vehicular traffic). The latter result was obtained using a generalized Finsler structure on L^1: a methodology proposed by Bressan and then used to prove uniqueness of weak entropic solutions to systems of conservation laws and Lipschitz continuous dependence from initial data (see 22).
The models used for supply chains consist either in coupled Ode-Pde systems (see 56) or in systems of conservation laws on networks (see 60). In both cases existence results were

obtained, while Lipschitz continuous dependence was proved for the ode-pde case, see 56. The research program moved forward proposing numerical methods for conservation laws on networks, in particular for determining the load on large networks encountered in applications (see 44, 47). The latter methods were then applied to various portions of real urban networks for the city of Rome and Salerno in collaboration with the Rome agency for mobility (ATAC spa) and the City Hall of Salerno. In particular we treated the case of a complicate traffic circle, namely the Re di Roma square (see Figure 1 left), and the whole Salerno network cosisting of 1500 arcs (see Figure 1 right). All simulations are done using GIS data, see also www.iac.cnr.it/˜ bretti/TrafficNumericalSolutions.html

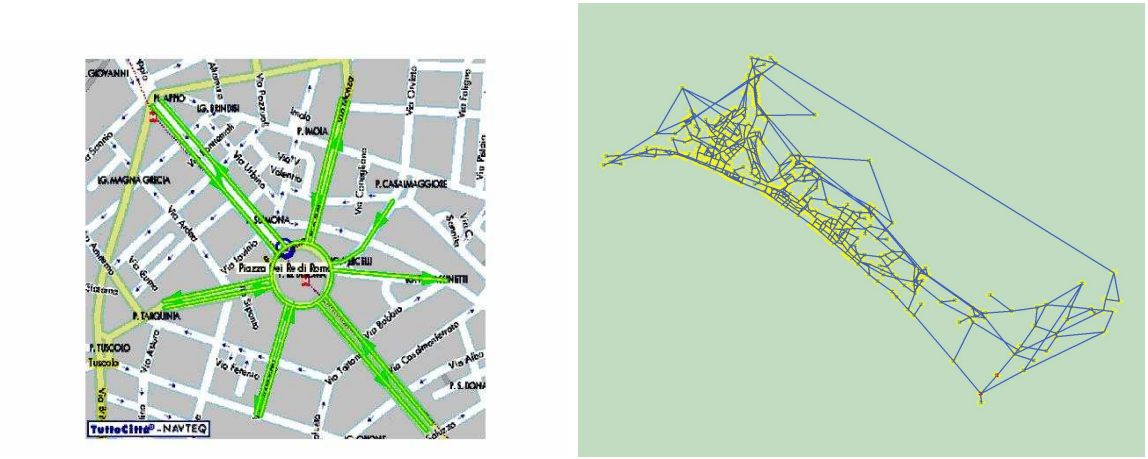

Figure 1: Simulation results for Re di Roma square in Rome (left) and the whole urban network of Salerno (right).

Future directions.

1) Irrigation channels and gas pipelines. The dyamics of irrigation networks and gas networks are similar to the case considered above, with obvious differences. Some results are available both for gas pipelines and irrigation channels, however a consistent complete theory is still to be developed.

2) Control and optimization of network flow. The control variables correspond to the distribution coefficients and priority parameters of traffic at nodes of the network. Unfortuntely the I/O maps are not continuous in general. The performance can be measured by different functionals as: total flux, average speed and average travelling time. Partial results were obtained in 59, 73.

3) Pedestrian flow models. Since almost twenty years microscopic models are available for pedestrian motions (by Helbing, Hoogendorn and others). More recently macroscopic models were proposed (Colombo-Rosini, Bellomo-Dogbe). A time-evolving measures approach was proposed in 84, which permits to address in an efficient way the theoretical and numerical problems showing up with boundary conditions for conservation laws in two

dimensions. The modelling aspects will be futher addressed in particular referring to internal forces and turbulent regimes. We aim also at studying the optimization of evacuations manouvers by shape optimization of obstacles.
We report a simulation test for the flow of three groups of pedestrians through a narrow corridor starting from a larger area. This is the typical situation encountered in metro stations at train arrivals. In Figure 2 we report the desired velocity field to exit the area and three time shots of density evolution.

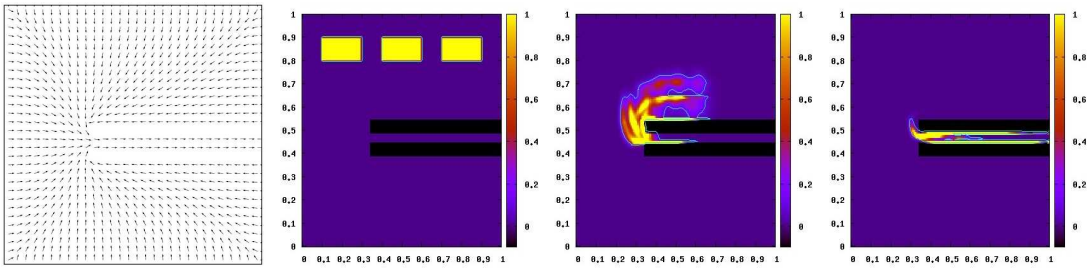

Figure 2: Simulation results for pedestrian flow through a narrow passage. From left to right: desired velocity field, initial condition, interaction at corridor entrance, flow through corridor.

STOCHASTICS AND CONTROL

The interplay between stochastics and control was present in various recent research lines, mainly with two perspectives: Either of using advanced stochastic methodologies to address efficiency and robustness of control strategies for complex systems; or of designing control algorithms for systems with highly stochastic feautures. To the first group it belongs the research devoted to stochastic algorithms for control performances (see 120) and to the second one the mathemtical finance problem of Public Debt Management (see 37). In the following we illustrate some research lines describing also future directions.

Ongoing research and future directions.

1) Stochastic algorithms for testing control performances. Stochastic simulations constitute an efficient method when addressing performance analysis of control algorithms. Our main application was to automotive control see 80. We aim at obtaining theoretical results for the case of hybrid systems, designing advanced Monte Carlo methods and using Chernoff bounds for probabilistic estimates. Partial results were obtained in 77.

2) MPC methods for portfolio optimization and Public Debt management. In 37 it was proposed the use of Model Predictive Control methods to design efficient Markov controls for public bonds issuance. The same techniques were explored in 111 for the case of portfolio optimization. We aim at developing systematically this technique also with the use of stochastic optimization intermediate steps.

3) Optimal deployment of sensors over complicated domains. F. Bullo and collaborators developed a theory for optimal deployment of sensors for suveillance of areas, usually modelled as convex regions of the plane. We adapted the theory to the more difficult case of networks (see 82) under the assumption of simplified sensors features. We aim at addressing the more general case of not omnidirectional sensors and improve the performance of the optimization algorithms. A comparison will be done with classical approaches for resources allocation problems.

4) Optimal control methods for HIV treatments. Optimal control methodologies were used to improve cancer immunotherapy effects (see 48) and for parameters fitting. In collaboration with Ospedale Spallanzani of Rome we are treating the case of optimal farmacological treatments for HIV infected patients. The main problem is early detection of drug resistance due to virus mutations, partial results were obtained in 71.

PDES FOR IMAGES

Beside the problems involving networks mentioned in the first paragraph, Pde methodologies were recently used for image analysis. Using evolutive equations through scales, some approximation results were obtained for wavelet transforms of signals and images, then used for denoising and compression, see 72.
We aim at extending this approach for detection of instantaneous frequency, with special focus on radar signals.

Academic, istitutional and industrial collaborations.

1) Piaggio Research Center in Pisa. There is an ongoing collaboration since 1998 with the research center "E. Piaggio" in Pisa (www.piaggio.ccii.unipi.it). The main research theme focuses on advanced control methods for robotic applications. B.P. is a member of the center, is delivering seminars and PhD courses and is supervising with A. Bicchi (the Center Director) 1 PhD student and 1 Post-Doc student. IAC and Piaggio center participated jointly to the HYCON project of FP6 (2004-2008).

2) University of Salerno. There is a strong collaboration since 2001 with the University of Salerno and related Institutions : Moma (a spin-off, www.momanet.it), CRMPA (research center, www.crmpa.it) and CEMSAC (research consortium, www.cemsac.it). The main research topics are control theory and traffic flow on networks. Various national and international collaborative projects were developed. Recently 4 PhD students and 3 Post-doc students were supervised in collaboration. A CRMPA section was opened at IAC and directed by B.P.

3) U. California at Berkeley, CCIT and Nokia. In 2008 a collaboration started with Berkeley on a project run jointly with CCIT and Nokia. The thematic is traffic monitoring by mobile phone GPS data. An experiment was run by Berkeley with Nokia in San Francisco area (see lagrange.ce.berkeley.edu/media/media-coverage.html) and then the IAC group was contacted for the theory developed on networks. Two Berkeley students visited IAC for some months working on modelling and numerical aspects. Berkeley and CCIT take part in the ITN EU Project "Reckon" (under evaluation) coordinated by B.P.

4) Italian Ministry of Economy and Finance. Since 2002 a collaboration is ongoing between IAC and Ministry of Economy and Finance on the thematic of Public Debt Management, under the direction of B.P. (modelling) and M. Bernaschi (software). More precisely the main topic is the modelization of the interest rates evolution and the optimization of issuances of public bonds. The project was financed by the Ministry on yearly basis and by an Italian Project FIRB 2003.

5) A.T.A.C. A collaboration started since 2006 with ATAC (the Rome public transportation company www.atac.roma.it). The thematic is that of vehicular traffic monitoring, modelling and simulation. Experiments were run on parts of Rome urban network: Muro Torto boulevard, Re di Roma square and Lungotevere area. An official agreement is under signature between C.N.R. and ATAC.

6) Parades. Since 2002 a collaboration started with Parades (www.parades.rm.cnr.it) on the thematic of control methodologies for automotive control. The collaborative research activity is giving rise to various papers and the supervision of two students. A further research activity on exhaust system was developed also with Magneti Marelli (www.magnetimarelli.com).

7) Elasis. Recently a collaboration started with Elasis (www.elasis.com), the second biggest research center of Fiat group (more than 1000 employees). The thematic is that of

traffic modelling with particular focus on the usage of telematic data and safety issues. Elasis is full partner in the recent ITN EU project "Reckon" (under evalution) coordinated by B.P.

8) Selex - Sistemi Integrati. In 2008 a collaboration started with Selex spa (www.selex-si.com) on the thematic of sensors deployment and flow control on airports. Selex is a company of Finmeccanica and has around 3000 employees. A joint italian research project on modelling detection of stochastic signals with radars is under evaluation.

9) Italdata. A collaboration with Italdata (Siemens group, www.italdata.it) started in 2003. The thematic is traffic modelling and path optimization over loaded networks. The main project is the italian ICT project "Goethe" (total budget 1 MEUR).

10) Vu LOG. Vu LOG (www.vulog.com) is a spin-off of INRIA of Sophie-Antipolis (France) taking part in EU ITN project "Reckon", coordinated by B.P., as full partner with main thematic measurements of car C02 emissions.

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