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Project-Team ACUMES

Analysis and Control of Unsteady Models for Engineering Sciences

IN COLLABORATION WITH: Laboratoire Jean-Alexandre Dieudonné (JAD)

RESEARCH CENTER
Sophia Antipolis - Méditerranée

THEME
Numerical schemes and simulations

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Project-Team ACUMES

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2. Overall Objectives

2.1. Overall Objectives

ACUMES aims at developing a rigorous framework for numerical simulations and optimal control for transportation and buildings, with focus on multi-scale, heterogeneous, unsteady phenomena subject to uncertainty. Starting from established macroscopic Partial Differential Equation (PDE) models, we pursue a set of innovative approaches to include small-scale phenomena, which impact the whole system. Targeting applications contributing to sustainability of urban environments, we couple the resulting models with robust control and optimization techniques.

Modern engineering sciences make an important use of mathematical models and numerical simulations at the conception stage. Effective models and efficient numerical tools allow for optimization before production and to avoid the construction of expensive prototypes or costly post-process adjustments. Most up-to-date modeling techniques aim at helping engineers to increase performances and safety and reduce costs and pollutant emissions of their products. For example, mathematical traffic flow models are used by civil engineers to test new management strategies in order to reduce congestion on the existing road networks and improve crowd evacuation from buildings or other confined spaces without constructing new infrastructures. Similar models are also used in mechanical engineering, in conjunction with concurrent optimization methods, to reduce energy consumption, noise and pollutant emissions of cars, or to increase thermal and structural efficiency of buildings while, in both cases, reducing ecological costs.

Nevertheless, current models and numerical methods exhibit some limitations:

- Most simulation-based design procedures used in engineering still rely on steady (time-averaged) state models. Significant improvements have already been obtained with such a modeling level, for instance by optimizing car shapes, but finer models taking into account unsteady phenomena are required in the design phase for further improvements.
- The classical purely macroscopic approach, while offering a framework with a sound analytical basis, performing numerical techniques and good modeling features to some extent, is not able to reproduce some particular phenomena related to specific interactions occurring at lower (possibly micro) level. We refer for example to self-organizing phenomena observed in pedestrian flows, or to the dynamics of turbulent flows for which large scale / small scale vortical structures interfere. These flow characteristics need to be taken into account to obtain more precise models and improved optimal solutions.
- Uncertainty related to operational conditions (e.g. inflow velocity in aerodynamics), or models (e.g. individual behavior in crowds) is still rarely considered in engineering analysis and design, yielding solutions of poor robustness.

This project focuses on the analysis and optimal control of classical and non-classical evolutionary systems of Partial Differential Equations (PDEs) arising in the modeling and optimization of engineering problems related to safety and sustainability of urban environments, mostly involving fluid-dynamics and structural mechanics. The complexity of the involved dynamical systems is expressed by multi-scale, time-dependent phenomena, possibly subject to uncertainty, which can hardly be tackled using classical approaches, and require the development of unconventional techniques.

3. Research Program

3.1. Research directions

The project develops along the following two axes:

- modeling complex systems through novel (unconventional) PDE systems, accounting for multi-scale phenomena and uncertainty;
- optimization and optimal control algorithms for systems governed by the above PDE systems.

These themes are motivated by the specific problems treated in the applications, and represent important and up-to-date issues in engineering sciences. For example, improving the design of transportation means and civil buildings, and the control of traffic flows, would result not only in better performances of the object of the optimization strategy (vehicles, buildings or road networks level of service), but also in enhanced safety and lower energy consumption, contributing to reduce costs and pollutant emissions.

3.1.1. PDE models accounting for multi-scale phenomena and uncertainties

Dynamical models consisting of evolutionary PDEs, mainly of hyperbolic type, appear classically in the applications studied by the previous Project-Team Opale (compressible flows, traffic, cell-dynamics, medicine, etc). Yet, the classical purely macroscopic approach is not able to account for some particular phenomena related to specific interactions occurring at smaller scales. These phenomena can be of greater importance when dealing with particular applications, where the "first order" approximation given by the purely macroscopic approach reveals to be inadequate. We refer for example to self-organizing phenomena observed in pedestrian flows [107], or to the dynamics of turbulent flows for which large scale / small scale vortical structures interfere [136].

Nevertheless, macroscopic models offer well known advantages, namely a sound analytical framework, fast numerical schemes, the presence of a low number of parameters to be calibrated, and efficient optimization procedures. Therefore, we are convinced of the interest of keeping this point of view as dominant, while completing the models with information on the dynamics at the small scale / microscopic level. This can be achieved through several techniques, like hybrid models, homogenization, mean field games. In this project, we will focus on the aspects detailed below.

The development of adapted and efficient numerical schemes is a mandatory completion, and sometimes ingredient, of all the approaches listed below. The numerical schemes developed by the team are based on finite volumes or finite elements techniques, and constitute an important tool in the study of the considered models, providing a necessary step towards the design and implementation of the corresponding optimization algorithms, see Section 3.1.2.

3.1.1.1. Micro-macro couplings

Modeling of complex problems with a dominant macroscopic point of view often requires couplings with small scale descriptions. Accounting for systems heterogeneity or different degrees of accuracy usually leads to coupled PDE-ODE systems.

In the case of heterogeneous problems the coupling is "intrinsic", i.e. the two models evolve together and mutually affect each-other. For example, accounting for the impact of a large and slow vehicle (like a bus or a truck) on traffic flow leads to a strongly coupled system consisting of a (system of) conservation law(s) coupled with an ODE describing the bus trajectory, which acts as a moving bottleneck.The coupling is realized through a local unilateral moving constraint on the flow at the bus location, see [76] for an existence result and [61], [75] for numerical schemes.

If the coupling is intended to offer higher degree of accuracy at some locations, a macroscopic and a microscopic model are connected through an artificial boundary, and exchange information across it through suitable boundary conditions. See [67], [95] for some applications in traffic flow modelling, and [86], [91], [93] for applications to cell dynamics.

The corresponding numerical schemes are usually based on classical finite volume or finite element methods for the PDE, and Euler or Runge-Kutta schemes for the ODE, coupled in order to take into account the interaction fronts. In particular, the dynamics of the coupling boundaries require an accurate handling capturing the possible presence of non-classical shocks and preventing diffusion, which could produce wrong solutions, see for example [61], [75].

We plan to pursue our activity in this framework, also extending the above mentioned approaches to problems in two or higher space dimensions, to cover applications to crowd dynamics or fluid-structure interaction.

3.1.1.2. Micro-macro limits

Rigorous derivation of macroscopic models from microscopic ones offers a sound basis for the proposed modeling approach, and can provide alternative numerical schemes, see for example [68], [78] for the derivation of Lighthill-Whitham-Richards [119], [135] traffic flow model from Follow-the-Leader and [87] for results on crowd motion models (see also [109]). To tackle this aspect, we will rely mainly on two (interconnected) concepts: measure-valued solutions and mean-field limits.

The notion of **measure-valued solutions** for conservation laws was first introduced by DiPerna [79], and extensively used since then to prove convergence of approximate solutions and deduce existence results, see for example [88] and references therein. Measure-valued functions have been recently advocated as the appropriate notion of solution to tackle problems for which analytical results (such as existence and uniqueness of weak solutions in distributional sense) and numerical convergence are missing [50], [90]. We refer, for example, to the notion of solution for non-hyperbolic systems [97], for which no general theoretical result is available at present, and to the convergence of finite volume schemes for systems of hyperbolic conservation laws in several space dimensions, see [90].

In this framework, we plan to investigate and make use of measure-based PDE models for vehicular and pedestrian traffic flows. Indeed, a modeling approach based on (multi-scale) time-evolving measures (expressing the agents probability distribution in space) has been recently introduced (see the monograph [72]), and proved to be successful for studying emerging self-organised flow patterns [71]. The theoretical measure framework proves to be also relevant in addressing micro-macro limiting procedures of mean field type [98], where one lets the number of agents going to infinity, while keeping the total mass constant. In this case, one must prove that the *empirical measure*, corresponding to the sum of Dirac measures concentrated at the agents positions, converges to a measure-valued solution of the corresponding macroscopic evolution equation. We recall that a key ingredient in this approach is the use of the *Wasserstein distances* [143], [144]. Indeed, as observed in [126], the usual L^1 spaces are not natural in this context, since they don't guarantee uniqueness of solutions.

This procedure can potentially be extended to more complex configurations, like for example road networks or different classes of interacting agents, or to other application domains, like cell-dynamics.

Another powerful tool we shall consider to deal with micro-macro limits is the so-called **Mean Field Games (MFG)** technique (see the seminal paper [118]). This approach has been recently applied to some of the systems studied by the team, such as traffic flow and cell dynamics. In the context of crowd dynamics, including the case of several populations with different targets, the mean field game approach has been adopted in [57], [58], [80], [117], under the assumption that the individual behavior evolves according to a stochastic process, which gives rise to parabolic equations greatly simplifying the analysis of the system. Besides, a deterministic context is studied in [131], which considers a non-local velocity field. For cell dynamics, in order to take into account the fast processes that occur in the migration-related machinery, a framework such the one developed in [74] to handle games "where agents evolve their strategies according to the best-reply scheme on a much faster time scale than their social configuration variables" may turn out to be suitable. An alternative framework to MFG is also considered. This framework is based on the formulation of -Nash- games constrained by the **Fokker-Planck** (FP, [48]) partial differential equations that govern the time evolution of the probability density functions -PDF- of stochastic systems and on objectives that may require to follow a given PDF trajectory or to minimize an expectation functional.

3.1.1.3. Non-local flows

Non-local interactions can be described through macroscopic models based on integro-differential equations. Systems of the type

$$\partial_t u + \mathrm{div}_{\mathbf{x}} F(t, \mathbf{x}, u, W) = 0, \qquad t > 0,\ \mathbf{x} \in \mathbb{R}^d,\ d \geq 1, \tag{1}$$

where $u = u(t, \mathbf{x}) \in \mathbb{R}^N$, $N \geq 1$ is the vector of conserved quantities and the variable $W = W(t, x, u)$ depends on an integral evaluation of u, arise in a variety of physical applications. Space-integral terms are considered for example in models for granular flows [45], sedimentation [52], supply chains [101], conveyor belts [102], biological applications like structured populations dynamics [125], or more general problems like gradient constrained equations [46]. Also, non-local in time terms arise in conservation laws with memory, starting from [73]. In particular, equations with non-local flux have been recently introduced in traffic flow modeling to account for the reaction of drivers or pedestrians to the surrounding density of other individuals, see [53], [60], [64], [99], [139]. While pedestrians are likely to react to the presence of people all around them, drivers will mainly adapt their velocity to the downstream traffic, assigning a greater importance to closer vehicles. In particular, and in contrast to classical (without integral terms) macroscopic equations, these models are able to display finite acceleration of vehicles through Lipschitz bounds on the mean velocity [53], [99] and lane formation in crossing pedestrian flows.

General analytical results on non-local conservation laws, proving existence and eventually uniqueness of solutions of the Cauchy problem for (1), can be found in [47] for scalar equations in one space dimension ($N = d = 1$), in [65] for scalar equations in several space dimensions ($N = 1$, $d \geq 1$) and in [41], [66], [70] for multi-dimensional systems of conservation laws. Besides, specific finite volume numerical methods have been developed recently in [41], [99] and [116].

Relying on these encouraging results, we aim to push a step further the analytical and numerical study of non-local models of type (1), in particular concerning well-posedness of initial - regularity of solutions, boundary value problems and high-order numerical schemes.

3.1.1.4. Uncertainty in parameters and initial-boundary data

Different sources of uncertainty can be identified in PDE models, related to the fact that the problem of interest is not perfectly known. At first, initial and boundary condition values can be uncertain. For instance, in traffic flows, the time-dependent value of inlet and outlet fluxes, as well as the initial distribution of vehicles density, are not perfectly determined [59]. In aerodynamics, inflow conditions like velocity modulus and direction, are subject to fluctuations [105], [124]. For some engineering problems, the geometry of the boundary can also be uncertain, due to structural deformation, mechanical wear or disregard of some details [82]. Another source of uncertainty is related to the value of some parameters in the PDE models. This is typically the case of parameters in turbulence models in fluid mechanics, which have been calibrated according to some reference flows but are not universal [137], [142], or in traffic flow models, which may depend on the type of road, weather conditions, or even the country of interest (due to differences in driving rules and conductors behaviour). This leads to equations with flux functions depending on random parameters [138], [141], for which the mean and the variance of the solutions can be computed using different techniques. Indeed, uncertainty quantification for systems governed by PDEs has become a very active research topic in the last years. Most approaches are embedded in a probabilistic framework and aim at quantifying statistical moments of the PDE solutions, under the assumption that the characteristics of uncertain parameters are known. Note that classical Monte-Carlo approaches exhibit low convergence rate and consequently accurate simulations require huge computational times. In this respect, some enhanced algorithms have been proposed, for example in the balance law framework [123]. Different approaches propose to modify the PDE solvers to account for this probabilistic context, for instance by defining the non-deterministic part of the solution on an orthogonal basis (Polynomial Chaos decomposition) and using a Galerkin projection [105], [114], [120], [146] or an entropy closure method [77], or by discretizing the probability space and extending the numerical schemes to the stochastic components [40]. Alternatively, some other approaches maintain a fully deterministic PDE resolution, but approximate the solution in the vicinity of the reference parameter values by Taylor series expansions based on first- or second-order sensitivities [132], [142], [145].

Our objective regarding this topic is twofold. In a pure modeling perspective, we aim at including uncertainty quantification in models calibration and validation for predictive use. In this case, the choice of the techniques will depend on the specific problem considered [51]. Besides, we plan to extend previous works on sensitivity analysis [82], [121] to more complex and more demanding problems. In particular, high-order Taylor expansions of the solution (greater than two) will be considered in the framework of the Sensitivity Equation Method [54] (SEM) for unsteady aerodynamic applications, to improve the accuracy of mean and variance estimations. A second targeted topic in this context is the study of the uncertainty related to turbulence closure parameters, in the sequel of [142]. We aim at exploring the capability of the SEM approach to detect a change of flow topology, in case of detached flows. Our ambition is to contribute to the emergence of a new generation of simulation tools, which will provide solution densities rather than values, to tackle real-life uncertain problems. This task will also include a reflection about numerical schemes used to solve PDE systems, in the perspective of constructing a unified numerical framework able to account for exact geometries (isogeometric methods), uncertainty propagation and sensitivity analysis w.r.t. control parameters.

3.1.2. Optimization and control algorithms for systems governed by PDEs

The non-classical models described above are developed in the perspective of design improvement for real-life applications. Therefore, control and optimization algorithms are also developed in conjunction with these models. The focus here is on the methodological development and analysis of optimization algorithms for PDE systems in general, keeping in mind the application domains in the way the problems are mathematically formulated.

3.1.2.1. Sensitivity VS adjoint equation

Adjoint methods (achieved at continuous or discrete level) are now commonly used in industry for steady PDE problems. Our recent developments [134] have shown that the (discrete) adjoint method can be efficiently applied to cost gradient computations for time-evolving traffic flow on networks, thanks to the special structure of the associated linear systems and the underlying one dimensionality of the problem. However, this strategy is questionable for more complex (e.g. 2D/3D) unsteady problems, because it requires sophisticated and time-consuming check-pointing and/or re-computing strategies [49], [100] for the backward time integration of the adjoint variables. The sensitivity equation method (SEM) offers a promising alternative [81], [110], if the number of design parameters is moderate. Moreover, this approach can be employed for other goals, like fast evaluation of neighboring solutions or uncertainty propagation [82].
Regarding this topic, we intend to apply the continuous sensitivity equation method to challenging problems. In particular, in aerodynamics, multi-scale turbulence models like Large-Eddy Simulation (LES) [136] , Detached-Eddy Simulation (DES) [140] or Organized-Eddy Simulation (OES) [55], are more and more employed to analyse the unsteady dynamics of the flows around bluff-bodies, because they have the ability to compute the interactions of vortices at different scales, contrary to classical Reynolds-Averaged Navier-Stokes models. However, their use in design optimization is tedious, due to the long time integration required. In collaboration with turbulence specialists (M. Braza, CNRS - IMFT), we aim at developing numerical methods for effective sensitivity analysis in this context, and apply them to realistic problems, like the optimization of active flow control devices. Note that the use of SEM allows computing cost functional gradients at any time,

which permits to construct new gradient-based optimization strategies like instantaneous-feedback method [112] or multiobjective optimization algorithm (see section below).

3.1.2.2. Multi-objective descent algorithms for multi-disciplinary, multi-point, unsteady optimization or robust-design

n differentiable optimization, multi-disciplinary, multi-point, unsteady optimization or robust-design can all be formulated as multi-objective optimization problems. In this area, we have proposed the *Multiple-Gradient Descent Algorithm (MGDA)* to handle all criteria concurrently [83] [84]. Originally, we have stated a principle according which, given a family of local gradients, a descent direction common to all considered objective-functions simultaneously is identified, assuming the Pareto-stationarity condition is not satisfied. When the family is linearly-independent, we dispose of a direct algorithm. Inversely, when the family is linearly-dependent, a quadratic-programming problem should be solved. Hence, the technical difficulty is mostly conditioned by the number m of objective functions relative to the search space dimension n. In this respect, the basic algorithm has recently been revised [85] to handle the case where $m > n$, and even $m \gg n$, and is currently being tested on a test-case of robust design subject to a periodic time-dependent Navier-Stokes flow.

The multi-point situation is very similar and, being of great importance for engineering applications, will be treated at large.

Moreover, we intend to develop and test a new methodology for robust design that will include uncertainty effects. More precisely, we propose to employ MGDA to achieve an effective improvement of all criteria simultaneously, which can be of statistical nature or discrete functional values evaluated in confidence intervals of parameters. Some recent results obtained at ONERA [129] by a stochastic variant of our methodology confirm the viability of the approach. A PhD thesis has also been launched at ONERA/DADS.

Lastly, we note that in situations where gradients are difficult to evaluate, the method can be assisted by a meta-model [148].

3.1.2.3. Bayesian Optimization algorithms for efficient computation of general equilibria

Bayesian Optimization -BO- relies on Gaussian processes, which are used as emulators (or surrogates) of the black-box model outputs based on a small set of model evaluations. Posterior distributions provided by the Gaussian process are used to design acquisition functions that guide sequential search strategies that balance between exploration and exploitation. Such approaches have been transposed to frameworks other than optimization, such as uncertainty quantification. Our aim is to investigate how the BO apparatus can be applied to the search of general game equilibria, and in particular the classical Nash equilibrium (NE). To this end, we propose two complementary acquisition functions, one based on a greedy search approach and one based on the Stepwise Uncertainty Reduction paradigm [92]. Our proposal is designed to tackle derivative-free, expensive models, hence requiring very few model evaluations to converge to the solution.

3.1.2.4. Decentralized strategies for inverse problems

Most if not all the mathematical formulations of inverse problems (a.k.a. reconstruction, identification, data recovery, non destructive engineering,...) are known to be ill posed in the Hadamard sense. Indeed, in general, inverse problems try to fulfill (minimize) two or more very antagonistic criteria. One classical example is the Tikhonov regularization, trying to find artificially smoothed solutions close to naturally non-smooth data.

We consider here the theoretical general framework of parameter identification coupled to (missing) data recovery. Our aim is to design, study and implement algorithms derived within a game theoretic framework, which are able to find, with computational efficiency, equilibria between the "identification related players" and the "data recovery players". These two parts are known to pose many challenges, from a theoretical point of view, like the identifiability issue, and from a numerical one, like convergence, stability and robustness problems. These questions are tricky [42] and still completely open for systems like e.g. coupled heat and thermoelastic joint data and material detection.

4. Application Domains

4.1. Active flow control for vehicles

The reduction of CO2 emissions represents a great challenge for the automotive and aeronautic industries, which committed respectively a decrease of 20% for 2020 and 75% for 2050. This goal will not be reachable, unless a significant improvement of the aerodynamic performance of cars and aircrafts is achieved (e.g. aerodynamic resistance represents 70% of energy losses for cars above 90 km/h). Since vehicle design cannot be significantly modified, due to marketing or structural reasons, active flow control technologies are one of the most promising approaches to improve aerodynamic performance. This consists in introducing micro-devices, like pulsating jets or vibrating membranes, that can modify vortices generated by vehicles. Thanks to flow non-linearities, a small energy expense for actuation can significantly reduce energy losses. The efficiency of this approach has been demonstrated, experimentally as well as numerically, for simple configurations [147]. However, the lack of efficient and flexible numerical models, that allow to simulate and optimize a large number of such devices on realistic configurations, is still a bottleneck for the emergence of this technology in an industrial context. In particular, the prediction of actuated flows requires the use of advanced turbulence closures, like Detached Eddy Simulation or Large Eddy Simulation [96]. They are intrinsically three-dimensional and unsteady, yielding a huge computational effort for each analysis, which makes their use tedious for optimization purpose. In this context, we intend to contribute to the following research axes:

- *Sensitivity analysis for actuated flows.* Adjoint-based (reverse) approaches, classically employed in design optimization procedure to compute functional gradients, are not well suited to this context. Therefore, we propose to explore the alternative (direct) formulation, which is not so much used, in the perspective of a better characterization of actuated flows and optimization of control devices.
- *Hierarchical optimization of control devices.* The optimization of dozen of actuators, in terms of locations, frequencies, amplitudes, will be practically tractable only if a hierarchical approach is adopted, which mixes fine (DES) and coarse (URANS) simulations, and possibly experiments. We intend to develop such an optimization strategy on the basis of Gaussian Process models (*multi-fidelity kriging*).

4.2. Vehicular and pedestrian traffic flows

Intelligent Transportation Systems (ITS) is nowadays a booming sector, where the contribution of mathematical modeling and optimization is widely recognized. In this perspective, traffic flow models are a commonly cited example of "complex systems", in which individual behavior and self-organization phenomena must be taken into account to obtain a realistic description of the observed macroscopic dynamics [106]. Further improvements require more advanced models, keeping into better account interactions at the microscopic scale, and adapted control techniques, see [56] and references therein. In particular, we will focus on the following aspects:

- *Junction models.* We are interested in designing a general junction model both satisfying basic analytical properties guaranteeing well-posedness and being realistic for traffic applications. In particular, the model should be able to overcome severe drawbacks of existing models, such as restrictions on the number of involved roads and prescribed split ratios [69], [94], which limit their applicability to real world situations. Hamilton-Jacobi equations could be also an interesting direction of research, following the recent results obtained in [111].
- *Data assimilation.* In traffic flow modeling, the capability of correctly estimating and predicting the state of the system depends on the availability of rich and accurate data on the network. Up to now, the most classical sensors are fixed ones. They are composed of inductive loops (electrical wires) that are installed at different spatial positions of the network and that can measure the traffic flow, the occupancy rate (i.e. the proportion of time during which a vehicle is detected to be over the loop) and the speed (in case of a system of two distant loops). These data are useful / essential to calibrate the phenomenological relationship between flow and density which is known in the traffic literature

as the Fundamental Diagram. Nowadays, thanks to the wide development of mobile internet and geolocalization techniques and its increasing adoption by the road users, smartphones have turned into perfect mobile sensors in many domains, including in traffic flow management. They can provide the research community with a large database of individual trajectory sets that are known as Floating Car Data (FCD), see [108] for a real field experiment. Classical macroscopic models, say (hyperbolic systems of) conservation laws, are not designed to take into account this new kind of microscopic data. Other formulations, like Hamilton-Jacobi partial differential equations, are most suited and have been intensively studied in the past five years (see [62], [63]), with a stress on the (fixed) Eulerian framework. Up to our knowledge, there exist a few studies in the time-Lagrangian as well as space-Lagrangian frameworks, where data coming from mobile sensors could be easily assimilated, due to the fact that the Lagrangian coordinate (say the label of a vehicle) is fixed.

- *Control of autonomous vehicles.* Traffic flow is usually controlled via traffic lights or variable speed limits, which have fixed space locations. The deployment of autonomous vehicles opens new perspectives in traffic management, as the use of a small fraction of cars to optimize the overall traffic. In this perspective, the possibility to track vehicles trajectories either by coupled micro-macro models [76], [95] or via the Hamilton-Jacobi approach [62], [63] could allow to optimize the flow by controlling some specific vehicles corresponding to internal conditions.

4.3. Concurrent design for building systems

Building industry has to face more and more stringent requirements, including energy performance, structural safety and environmental impact. To this end, new materials and new technologies have emerged [115] to help the construction firms meet these requirements. At the same time, many different teams or firms interact, most of the interaction being of non-cooperative nature. The teams involved in construction have different goals, depending on which stage they operate. Indeed, the lifetime of a building goes through three stages: construction, use and destruction. To each of these phases correspond quality criteria related in particular to:

- Safety: structural, fire, evacuation, chemical spread, etc.
- Well-being of its occupants: thermal and acoustic comfort.
- Functionality of its intended use.
- Environmental impact.

These stages and criteria form a complex system, the so-called building system, whose overall quality (in an intuitive sense) is directly impacted by many heterogeneous factors, such as the geographical location or the shape or material composition of some of its components (windows, frames, thermal convectors positions, etc.) It is obvious that the optimization process of these settings must be performed at the "zero" stage of the project design. Moreover, the optimization process has to follow a global approach, taking into account all the concurrent criteria that intervene in the design of building systems.

The application of up-to-date concurrent optimization machinery (games, Pareto Fronts) for multiphysics systems involved in the building is an original approach. With our industrial partner, who wishes routine use of new high performance components in the construction of buildings, we expect that our approach will yield breakthrough performances (with respect to the above criteria) compared to the current standards.

The research project relies on the ADT BuildingSmart (see software development section) for the implementation of industrial standard software demonstrators.

4.4. Other application fields

Besides the above mentioned axes, which constitute the project's identity, the methodological tools described in Section have a wider range of application. We currently carry on also the following research actions, in collaboration with external partners.

- **Modeling cell dynamics.** Migration and proliferation of epithelial cell sheets are the two keystone aspects of the collective cell dynamics in most biological processes such as morphogenesis, embryogenesis, cancer and wound healing. It is then of utmost importance to understand their underlying mechanisms.

Semilinear reaction-diffusion equations are widely used to give a phenomenological description of the temporal and spatial changes occurring within cell populations that undergo scattering (moving), spreading (expanding cell surface) and proliferation. We have followed the same methodology and contributed to assess the validity of such approaches in different settings (cell sheets [103], dorsal closure [44], actin organization [43]). However, epithelial cell-sheet movement is complex enough to undermine most of the mathematical approaches based on *locality*, that is mainly traveling wavefront-like partial differential equations. In [89] it is shown that Madin-Darby Canine Kidney (MDCK) cells extend cryptic lamellipodia to drive the migration, several rows behind the wound edge. In [130] MDCK monolayers are shown to exhibit similar non-local behavior (long range velocity fields, very active border-localized leader cells).

Our aim is to start from a mesoscopic description of cell interaction: considering cells as independent anonymous agents, we plan to investigate the use of mathematical techniques adapted from the mean-field game theory. Otherwise, looking at them as interacting particles, we will use a multi-agent approach (at least for the actin dynamics). We intend also to consider approaches stemming from compartment-based simulation in the spirit of those developed in [86], [91], [93].

- **Modeling cardio-stents.**

  Atherosclerosis or arterial calcification is a major vascular disease, caused by fatty deposits on the inner walls of arteries. Angioplasty techniques propose several solutions to remedy this pathology. We are interested in those which consist in introducing a metallic stent, to crush the lipid plaques, and ensure permanent enlargement of the damaged arterial wall. The implementation of such an element is accompanied by an immune reaction of the arterial walls, which is manifested by an accelerated proliferation of cells within the so called media, which highlights two major risks: restenosis, and thrombosis . One promising technique is to introduce a "Drug Eluting Stent", which is a metallic stent coated with a polymer layer containing an antiproliferative drug to slow the proliferation process, in order to improve the functioning of the stent. Our major objective in this part is to setup and develop the mathematical modeling and computational tools that lead to the effective estimation of the Fractional Flow Reserve [128], which is a promising new technique to help the cardiologists take decisions on stent implantation.

- **Game strategies for thermoelastography.** Thermoelastography is an innovative non-invasive control technology, which has numerous advantages over other techniques, notably in medical imaging [122]. Indeed, it is well known that most pathological changes are associated with changes in tissue stiffness, while remaining isoechoic, and hence difficult to detect by ultrasound techniques. Based on elastic waves and heat flux reconstruction, thermoelastography shows no destructive or aggressive medical sequel, unlike X-ray and comparables techniques, making it a potentially prominent choice for patients.

  Physical principles of thermoelastography originally rely on dynamical structural responses of tissues, but as a first approach, we only consider static responses of linear elastic structures.
  The mathematical formulation of the thermoelasticity reconstruction is based on data completion and material identification, making it a harsh ill posed inverse problem. In previous works [104], [113], we have demonstrated that Nash game approaches are efficient to tackle ill-posedness. We intend to extend the results obtained for Laplace equations in [104], and the algorithms developed in Section 3.1.2.4 to the following problems (of increasing difficulty):
  - Simultaneous data and parameter recovery in linear elasticity, using the so-called Kohn and Vogelius functional (ongoing work, some promising results obtained).
  - Data recovery in coupled heat-thermoelasticity systems.
  - Data recovery in linear thermoelasticity under stochastic heat flux, where the imposed flux is stochastic.
  - Data recovery in coupled heat-thermoelasticity systems under stochastic heat flux, formulated as an incomplete information Nash game.

- Application to robust identification of cracks.

- **Constraint elimination in Quasi-Newton methods.** In single-objective differentiable optimization, Newton's method requires the specification of both gradient and Hessian. As a result, the convergence is quadratic, and Newton's method is often considered as the target reference. However, in applications to distributed systems, the functions to be minimized are usually "functionals", which depend on the optimization variables by the solution of an often complex set of PDE's, through a chain of computational procedures. Hence, the exact calculation of the full Hessian becomes a complex and costly computational endeavor.

  This has fostered the development of *quasi-Newton's methods* that mimic Newton's method but use only the gradient, the Hessian being iteratively constructed by successive approximations inside the algorithm itself. Among such methods, the Broyden-Fletcher-Goldfarb-Shanno (BFGS) algorithm is well-known and commonly employed. In this method, the Hessian is corrected at each new iteration by rank-one matrices defined from several evaluations of the gradient only. The BFGS method has "super-linear convergence".

  For constrained problems, certain authors have developed so-called *Riemannian BFGS*, e.g. [133], that have the desirable convergence property in constrained problems. However, in this approach, the constraints are assumed to be known formally, by explicit expressions.

  In collaboration with ONERA-Meudon, we are exploring the possibility of representing constraints, in successive iterations, through local approximations of the constraint surfaces, splitting the design space locally into tangent and normal sub-spaces, and eliminating the normal coordinates through a linearization, or more generally a finite expansion, and applying the BFGS method through dependencies on the coordinates in the tangent subspace only. Preliminary experiments on the difficult Rosenbrock test-case, although in low dimensions, demonstrate the feasibility of this approach. On-going research is on theorizing this method, and testing cases of higher dimensions.

- **Multi-objective optimization for nanotechnologies.** Our team takes part in a larger collaboration with CEA/LETI (Grenoble), initiated by the Inria Project-Team Nachos, and related to the Maxwell equations. Our component in this activity relates to the optimization of nanophotonic devices, in particular with respect to the control of thermal loads. We have first identified a gradation of representative test-cases of increasing complexity:
  - infrared micro-source;
  - micro-photoacoustic cell;
  - nanophotonic device.
  These cases involve from a few geometric parameters to be optimized to a functional minimization subject to a finite-element solution involving a large number of dof's. CEA disposes of such codes, but considering the computational cost of the objective functions in the complex cases, the first part of our study is focused on the construction and validation of meta-models, typically of RBF-type. Multi-objective optimization will be carried out subsequently by MGDA, and possibly Nash games.

5. New Software and Platforms

5.1. MGDA

Multiple Gradient Descent Algorithm
KEYWORDS: Descent direction - Multiple gradients - Multi-objective differentiable optimization
SCIENTIFIC DESCRIPTION: The software provides a vector d whose scalar product with each of the given gradients (or directional derivative) is positive provided a solution exists. When the gradients are linearly independent, the algorithm is direct following a Gram-Schmidt orthogonalization. Otherwise, a sub-family of the gradients is identified according to a hierarchical criterion as a basis of the spanned subspace associated with a cone that contains almost all the gradient directions. Then, one solves a quadratic programming problem formulated in this basis.

https://hal.inria.fr/hal-01139994 https://hal.inria.fr/hal-01414741
FUNCTIONAL DESCRIPTION: The utilization of the platform can be made via two modes : – the interactive mode, through a web interface that facilitates the data exchange between the user and an Inria dedicated machine, – the iterative mode, in which the user downloads the object library to be included in a personal optimization software.

- Participant: Jean-Antoine Désidéri
- Contact: Jean-Antoine Désidéri
- URL: http://mgda.inria.fr

5.2. Igloo

Iso-Geometric anaLysis using discOntinuOus galerkin methods
KEYWORDS: Numerical simulations - Isogeometric analysis
SCIENTIFIC DESCRIPTION: Igloo contains numerical methods to solve partial differential equations of hyperbolic type, or convection-dominant type, using an isogeometric formulation (NURBS bases) with a discontinuous Galerkin method.
FUNCTIONAL DESCRIPTION: Igloo is composed of a set of C++ libraries and applications, which allow to simulate time-dependent physical phenomena using natively CAD-based geometry descriptions.

- Author: Régis Duvigneau
- Contact: Régis Duvigneau

5.3. BuildingSmart

BuildingSmart interactive visualization
KEYWORDS: Physical simulation - 3D rendering - 3D interaction
SCIENTIFIC DESCRIPTION: The aim of the BuildingSmart project is to develop a software environment for the simulation and interactive visualisation for the design of buildings (structural safety, thermal confort).
FUNCTIONAL DESCRIPTION: The main task of the project is to study and develop solutions dedicated to interactive visualisation of building performances (heat, structural) in relation to the Building Information Modeling BIM framework, using Occulus Rift immersion.
NEWS OF THE YEAR: Demo movies are available from Youtube (see web site)

- Participants: Régis Duvigneau, Jean-Luc Szpyrka, David Rey and Clement Welsch
- Contact: Abderrahmane Habbal
- URL: http://youtu.be/MW_gIF8hUdk

6. New Results

6.1. Macroscopic traffic flow models on networks

Participants: Guillaume Costeseque, Nikodem Dymski, Paola Goatin, Nicolas Laurent-Brouty, Giulia Piacentini, Florent Berthelin [COFFEE, Inria], Antonella Ferrara [U Pavia, Italy], Simone Göttlich [U Mannheim, Germany], Oliver Kolb [U Mannheim, Germany].

In [38], we propose a new mathematical model accounting for the boundedness of traffic acceleration at a macroscopic scale. Our model is built on a first order macroscopic PDE model coupled with an ODE describing the trajectory of the leader of a platoon accelerating at a given constant rate. We use Wave Front Tracking techniques to construct approximate solutions to the Initial Value Problem. We present some numerical examples including the case of successive traffic signals on an arterial road and we compare the solution to our model with the solution given by the classical LWR equation in order to evaluate the impact of bounded acceleration.

The internship of Giulia Piacentini focused on traffic control via moving bottleneck of coordinated vehicles [35]. The possibility of properly controlling a moving bottleneck to improve the traffic flow was considered. The traffic is represented by means of a macroscopic model able to take into account the interactions with the bottleneck. This latter interacts with the surrounding flow modifying the traffic density and the flow speed profiles. An optimal control problem is stated by using the speed of the moving bottleneck as control variable. Specifically in this paper the MPC (Model Predictive Control) approach is used in order to get a fuel consumption reduction when the traffic is congested due to the presence of a fixed bottleneck on the highway. In addition we have demonstrated that no increase of the travel time is caused by the control application. The concept illustrated in this paper suggests a future innovative traffic control approach. Indeed the prospective of exploiting special vehicles with manipulable speed to control the traffic flow is particularly attractive given the expected increasing penetration rate of autonomous vehicles in traffic networks in future years.

In collaboration with S. Göttlich and O. Kolb, we studied macroscopic traffic flow models on a road network [36]. More precisely, we consider coupling conditions at junctions for the Aw-Rascle-Zhang second order model consisting of a hyperbolic system of two conservation laws. These coupling conditions conserve both the number of vehicles and the composition of traffic through the junction. The proposed Riemann solver is based on assignment coefficients, multi-objective optimization of fluxes and priority parameters. We prove that this Riemann solver is well posed in the case of special junctions, including 1-to-2 diverge and 2-to-1 merge.

In the setting of Florent Berthelin's secondement, we rigorously proved the convergence of the micro-macro limit for particle approximations of the Aw-Rascle-Zhang equations with a maximal density constraint [4]. The lack of BV bounds on the density variable is supplied by a compensated compactness argument.

6.2. Non-local conservation laws

Participants: Felisia Angela Chiarello, Paola Goatin, Elena Rossi.

F.A. Chiarello's PhD thesis focuses on non-local conservation laws. As a first result, we proved the well-posedness of entropy weak solutions for a class of scalar conservation laws with non-local flux arising in traffic modeling. We approximate the problem by a Lax-Friedrichs scheme and we provide L^∞ and BV estimates for the sequence of approximate solutions. Stability with respect to the initial data is obtained from the entropy condition through the doubling of variable technique. The limit model as the kernel support tends to infinity is also studied. See [33].

6.3. Crowd motion modeled by Fokker-Planck constrained Nash games

Participants: Alfio Borzí [Univ. Wurzburg], Abderrahmane Habbal, Souvik Roy [Univ. Wurzburg].

Fokker-Planck-Kolmogorov (FPK) equations are PDEs which govern the dynamics of the probability density function (PDF) of continuous-time stochastic processes (e.g. Ito processes). In [48] a FPK-constrained control framework, where the drift was considered as control variable is developed and applied to crowd motion.

In [13] a new approach to modelling pedestrians' avoidance dynamics based on a Fokker–Planck (FP) Nash game framework is presented. In this framework, two interacting pedestrians are considered, whose motion variability is modelled through the corresponding probability density functions (PDFs) governed by FP equations. Based on these equations, a Nash differential game is formulated where the game strategies represent controls aiming at avoidance by minimizing appropriate collision cost functionals. The existence of Nash equilibria solutions is proved and characterized as a solution to an optimal control problem that is solved numerically. Results of numerical experiments are presented that successfully compare the computed Nash equilibria to the output of real experiments (conducted with humans) for four test cases.

6.4. Solving with games the coupled problem of conductivity or obstacle identification and data recovery

Participants: Abderrahmane Habbal, Rabeb Chamekh [PhD, LAMSIN, Univ. Tunis Al Manar], Marwa Ouni [PhD, LAMSIN, Univ. Tunis Al Manar], Moez Kallel [LAMSIN, Univ. Tunis Al Manar], Nejib Zemzemi [Inria Bordeaux, EPI CARMEN].

Based on previous successful attempts [104], [113] to tackle ill posed inverse problems a Nash games, we consider two developments :
The first one is related to joint obstacle shape/location and data recovery. We consider a game theory approach to deal with a geometric inverse problem related to the Stokes system. The problem consists in detecting an obstacle in a flow from incomplete measurements on the boundary of a domain. The approach that we propose deals simultaneously with the reconstruction of the missing data and the identification of one or more objects immersed in a viscous and incompressible fluid flow. The solution is interpreted in terms of Stackelberg-Nash equilibrium between both problems. We develop a new obstacle detection algorithm and we consider different numerical situations to illustrate the efficiency and robustness of the method.
The second one is dedicated to the electrocardiography inverse problem. The difficulty comes from the fact that the conductivity values of the torso organs like lungs, bones, liver,...etc, are not known and could be patient dependent. Our goal is to construct a methodology allowing to solve both the data completion (heart electrical signal recovery) and conductivity identification at the same time.

6.5. The Kalai-Smorodinski solution for many-objective Bayesian optimization

Participants: Mickael Binois [Univ. Chicago], Victor Picheny [INRA, Toulouse], Abderrahmane Habbal.

Bayesian optimization methods are efficient to find solutions of multi-objective problems under very limited budgets of evaluation. An ongoing scope of research in multi-objective Bayesian optimization is to extend its applicability to a large number of objectives.

We have proposed in [127] a novel approach to solve Nash games with drastically limited budgets of evaluations based on GP regression, taking the form of a Bayesian optimization algorithm. Experiments on challenging benchmark problems demonstrate the potential of this approach compared to classical, derivative-based algorithms.

Regarding the harsh many-objective optimization problems, the recovering of the set of optimal compromise solution generally requires lots of observations while being less interpretable, since this set tends to grow larger with the number of objectives. We thus propose to focus on a choice of a specific solution originating from game theory, the Kalai-Smorodinski solution, that possesses attractive properties [22] [19]. We further make it insensitive to a monotone transformation of the objectives by considering the objectives in the copula space. A tailored algorithm is proposed to search for the solution, which is tested on a synthetic problem.

6.6. Isogeometric analysis

Participants: Régis Duvigneau, Asma Azaouzi [ENIT], Maher Moakher [ENIT].

We develop high-order isogeometric solvers, based on CAD representations for both geometry and solution space, for applications targeted by the team, in particular convection-dominated problems. Specifically, we investigate a Discontinuous Galerkin method for compressible Euler / Navier-Stokes equations, based on an isogeometric formulation: the partial differential equations governing the flow are solved on rational parametric elements, that preserve exactly the geometry of boundaries defined by Non-Uniform Rational B-Splines (NURBS), while the same rational approximation space is adopted for the solution [34].

Recent extensions concern the capability to capture discontinuities in the solution, local refinement strategies by splitting algorithms [25] and high-order sensitivity analysis [24].

This topic is partially studied in A. Azaouzi's PhD work [21], [27], supervised by R. Duvigneau and M. Moakher.

6.7. Sensitivity equation method for hyperbolic systems

Participants: Régis Duvigneau, Camilla Fiorini [UVST], Christophe Chalons [UVST].

While the sensitivity equation method is a common approach for parabolic systems, its use for hyperbolic ones is still tedious, because of the generation of discontinuities in the state solution, yielding Dirac distributions in the sensitivity solution.

To overcome this difficulty, we investigate a modified sensitivity equation, that includes an additional source term when the state solution exhibits discontinuities, to avoid the generation of delta-peaks in the sensitivity solution. We consider as typical example the one-dimensional compressible Euler equations. Different approaches are tested to integrate the additional source term: a Roe solver, a Godunov method and a moving cells approach [20], [26], [32]. This study is achieved in collaboration with C. Chalons from University of Versailles, in the context of C. FIorini's PhD work.

6.8. Classification algorithms in Bayesian optimization

Participants: Régis Duvigneau, Matthieu Sacher [Ecole Navale], Frédéric Hauville [Ecole Navale], Olivier Le Maître [CNRS-LIMSI].

A Gaussian-Process based optimization algorithm is proposed to efficiently determine the global optimum for expensive simulations, when some evaluations may fail, due to unrealistic configurations, solver crash, degenerated mesh, etc. The approach is based on coupling the classical Bayesian optimization method with a classification algorithm, to iteratively identify the regions where the probability of failure is high.

The method is applied to the optimization of foils and sails in the context of racing yachts [14], [18], [23], [28], in particular for the America's Cup in collaboration with Groupama team. This work is part of M. Sacher's PhD work at Ecole Navale.

6.9. Multifidelity surrogate modeling based on Radial Basis Functions

Participants: Jean-Antoine Désidéri, Cédric Durantin [CEA Leti, University Côte d'Azur], Alain Glière [CEA Leti], Justin Rouxel [CEA Leti].

Multiple models of a physical phenomenon are sometimes available with different levels of approximation. The high fidelity model is more computationally demanding than the coarse approximation. In this context, including information from the lower fidelity model to build a surrogate model is desirable. Here, the study focuses on the design of a miniaturized photoacoustic gas sensor which involves two numerical models. First, a multifidelity metamodeling method based on Radial Basis Function, the co- RBF, is proposed. This surrogate model is compared with the classical co-kriging method on two analytical benchmarks and on the photoacoustic gas sensor. Then an extension to the multifidelity framework of an already existing RBF-based optimization algorithm is applied to optimize the sensor efficiency. The co-RBF method does not bring better results than co-kriging but can be considered as an alternative for multifidelity metamodeling [9].

6.10. Descent algorithm for nonsmooth stochastic multiobjective optimization

Participants: Jean-Antoine Désidéri, Quentin Mercier [ONERA Châtillon, University Côte d'Azur], Fabrice Poirion [ONERA Châtillon].

An algorithm for solving the expectation formulation of stochastic nonsmooth multiobjective optimization problems is proposed. The proposed method is an extension of the classical stochastic gradient algorithm to multiobjective optimization using the properties of a common descent vector defined in the deterministic context. The mean square and the almost sure convergence of the algorithm are proven. The algorithm efficiency is illustrated and assessed on an academic example [12].

6.11. Hessian transfer for multilevel and adaptive shape optimization

Participants: Badr Abou el majd [Hassan II University Casablanca], Jean-Antoine Désidéri, Abderrahamane Habbal, Ouail Ouchetto [Hassan II University Casablanca].

We have developed a multilevel and adaption parametric strategies solved by optimization algorithms which require only the availability of objective function values but no derivative information. The key success of these hierarchical strategies refer to the quality of the downward and upward transfers of information. In this paper, we extend our approach when using a derivative-based optimization algorithms. The aim is to better re-initialize the Hessian and the gradient during the optimization process based on our construction of the downward and upward operators. The efficiency of this proposed approach is demonstrated by numerical experiments on an inverse shape model [1].

7. Partnerships and Cooperations

7.1. Regional Initiatives

7.1.1. Collaboration with Venturi group

In the context of UCA partnerships, a collaboration with Venturi group has been initiated by R. Duvigneau and A. Habbal, concerning the aerodynamic optimization of a Formula-E vehicle and the multi-disciplinary modeling of an electric polar vehicle. This collaboration funded two internships (N. Abettan and A. Guincestre).

7.2. European Initiatives

7.2.1. FP7 & H2020 Projects

7.2.1.1. TramOpt

Title: A Traffic Management Optimization platform for enhanced road network efficiency

Programm: H2020

Duration: Mai 2017 - Octobre 2018

Coordinator: Inria

Inria contact: Paola Goatin

Building on the advances of the ERC TRAM3 project, the TRAMOPT PoC project aims are twofold:

- developing a robust prototype to allow real-life testing and deployment of a novel traffic control Decision Support System (DSS) based on a software platform for road traffic management including variable speed limits, ramp-metering and re-routing policies. This DSS is intended for public and private traffic managers to increase freeway network performances (e.g. congestion and pollution reduction);
- assessing the exploitation perspectives through a dedicated market study evaluating the added value of TRAMOPT over existing solutions and identifying the best business approach to foster uptake and commercialization of our technology.

7.3. International Initiatives

7.3.1. Inria International Labs

Inria@SiliconValley

Associate Team involved in the International Lab:

7.3.1.1. ORESTE

Title: Optimal REroute Strategies for Traffic managEment

International Partner (Institution - Laboratory - Researcher):

University of California Berkeley (United States) - Electrical Engineering and Computer Science (EECS) (EECS) - Alexandre M. Bayen

Start year: 2015

See also: http://www-sop.inria.fr/members/Paola.Goatin/ORESTE/index.html

This project focuses on traffic flow modeling and optimal management on road networks. Based on the results obtained during the first three years, we aim at further develop a unified macroscopic approach for traffic monitoring, prediction and control. In particular, we aim at investigating user equilibrium inference and Lagrangian controls actuations using macroscopic models consisting of conservation laws or Hamilton-Jacobi equations.

7.3.2. Inria International Partners

7.3.2.1. Informal International Partners

- University of Brescia, Information Engineering (R.M. Colombo: http://rinaldo.unibs.it/)
- University of Mannheim, Scientific Computing Research Group (SCICOM) (S. Göttlich: http://lpwima.math.uni-mannheim.de/de/team/prof-dr-simone-goettlich/)
- University of Rutgers - Camden, Department of Mathematical Science (B. Piccoli: https://piccoli.camden.rutgers.edu/)

7.4. International Research Visitors

7.4.1. Visits of International Scientists

- A. Borzi (August 2017, Univ. Wurzburg) : Existence of Nash equilibria for deterministic and stochastic differential games.
- S. Roy (September 2017, Univ. Wurzburg) : Fokker-Planck constrained Nash games and Infinite Dimensional Hamilton-Jacobi equations.
- T. Liard (September 2017, Rutgers University - Camden): well-posedness of traffic control problems by autonomous vehicles.
- A. Keimer (October 2017, UC Berkeley): modeling and well-posedness study for Dynamic Traffic Assignement.

7.4.1.1. Internships

- G. Piacentini (March-July 2017, University of Pavia): traffic control by autonomous vehicles..

7.4.2. Visits to International Teams

7.4.2.1. Research Stays Abroad

- N. Laurent-Brouty visited UC Berkeley for 1 month in May 2017

8. Dissemination

8.1. Promoting Scientific Activities

8.1.1. Scientific Events Organisation

8.1.1.1. General Chair, Scientific Chair

- P. Goatin is member of the the scientific committee of the annual seminar CEA-GAMNI *"Numerical fluid-mechanics"*.
- J.-A. Désidéri and A. Habbal had organized and chaired the 27th IFIP TC7 Conference on System Modeling and Optimization (Sophia Antipolis, June 29 - July 3, 2015). As a result, they jointly chaired with L. Bociu (North Carolina University) the reviewing panel that elaborated the book of revised contributions edited by Springer [29].

8.1.1.2. Member of the Organizing Committees

- P. Goatin was member of the organizing committee of the Indam *"Transport Modeling and Management: Vehicles and Crowds"*, Roma (Italy), March 2017.
- R. Duvigneau and A. Habbal organized a minisymposium *PDE-Constrained Optimization, Control and Games: New Models and Methods - Part I and II* at the SIAM Conference on Optimization, May 22-25, Vancouver BC (Canada).

8.1.2. Scientific Events Selection

8.1.2.1. Member of the Conference Program Committees

- A. Habbal is member of the the scientific committee of the 8th Conference on Trends in Applied Mathematics Tunisia-Algeria-Morocco TAMTAM 2017, May 10-13, Hammamet (Tunisia).

8.1.3. Journal

8.1.3.1. Member of the Editorial Boards

- P. Goatin is member of the Editorial Board of *Networks and Heterogeneous Media*.

8.1.3.2. Reviewer - Reviewing Activities

- J.-A. Désidéri has made reviews for the *International Journal of Information Technology & Decision Making*, *Comptes Rendus de l'Académie des Sciences*, and *Algorithms*.
- R. Duvigneau is a reviewer for the following international journals : Computers & Fluids, International Journal for Numerical Methods in Fluids, Computer Methods for Applied Mechanical Engineering, Computer Aided Geometric Design, Applied Mathematics & Mechanics, Engineering Optimization.
- P. Goatin is reviewers for the following international journals: Acta Applicandæ Mathematicæ ; African Journal of Mathematics and Computer Science Research; Algorithms; Annales de l'Institut Henri Poincaré (C) Analyse Non Linéaire; Applied Mathematics and Computation; Computer-aided Civil and Infrastructure Engineering; Discrete and Continuous Dynamical Systems; European Journal of Operational Research; IEEE Transactions on Automatic Control; IEEE Transactions on Intelligent Transportation Systems; International Journal of Dynamical Systems and Differential Equations; Journal of Computational Physics; Journal of Flow, Turbulence and Combustion; Mathematical Models and Methods in Applied Sciences; Mathematics of Computation; Networks and Heterogeneous Media; New Journal of Physics; Nonlinear Analysis Ser. B: Real World Applications; SIAM Journal of Mathematical Analysis; SIAM Journal of Applied Mathematics; SIAM Journal of Numerical Analysis; SIAM Journal on Scientific Computing.
- A. Habbal is reviewer for the following international journals: Applied Mathematics (AM), Scientific Research Publishing ; Journal of Structural and Multidisciplinary Optimization ; Journal of Math. Model. Nat. Phenom. ; International Journal of Mechanical Sciences ; Modern Applied Science ; Asian Journal of Control ; Applied Mathematics and Computation ; Computer Methods in Applied Mechanics and Engineering ; Bulletin of Mathematical Biology ; Journal of Pure and Applied Functional Analysis ; Int. Journal of Mathematical Modeling and Numerical Optimization; Numerische Mathematik; Journal of Differential Equations; EMS Surveys; AMS reviews.

8.1.4. Invited Talks

- P. Goatin: Workshop "Current topics in kinetic theory", Warsaw (Poland), March 2017.
Invited talk: *"Non-local macroscopic models of traffic flow"*.
- A. Habbal: Univ. Wurzburg Chair of Mathematics (Scientific Computing) Mathematical Colloquium, Wurzburg, April 2017.
Invited talk: *Modeling avoidance dynamics by FP-constrained Nash games*
- P. Goatin: Barcelona Mathematical Days, Barcelona (Spain), April 2017.
Session "Progress in Transport Phenomena".
Invited talk: *"Non-local conservation laws arising in traffic modeling"*.
- P. Goatin: 2016-17 Warwick EPSRC Symposium, Warwick (UK), May 2017.
Workshop "Emerging PDE models in Socio-Economic 'Sciences".
Invited talk: *"Moving bottlenecks in traffic flows"*.
- J.-A. Désidéri & A. Dervieux: Journées Scientifiques Inria, Sophia Antipolis, 14-16 June, 2017: Invited talk: 50 ans de calcul scientifique: le point de vue de numériciens des fluides (*50 years of scientific computing: the viewpoint from CFD-ers*).

- P. Goatin: ICERM Topical Workshop “Pedestrian Dynamics: Modeling, Validation and Calibration”, Providence, RI (USA), August 2017.
Invited talk: *“Macroscopic modeling and simulation of crowd dynamics”*.

8.1.5. Research Administration

- P. Goatin is member of BCP (“Bureau du Comité des Projets”) at Inria Sophia Antipolis Méditerranée.
- R. Duvigneau is member of CDT (“Comité Développement Technologique) at Inria Sophia Antipolis Méditerranée.
- R. Duvigneau is member of CSD (“Comité Suivi Doctoral) at Inria Sophia Antipolis Méditerranée.
- R. Duvigneau is responsible for the Immersive Space Committee at Inria Sophia Antipolis Méditerranée.

8.2. Teaching - Supervision - Juries

8.2.1. Teaching

Master: Advanced Optimization, 40.5 hrs, M2, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (J.-A. Désidéri, R. Duvigneau).

Master: Conservation laws and finite volume scheme, 30 hrs, M2, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (P. Goatin).

Master: Multidisciplinary Optimization, 22.5 hrs, joint *Institut Supérieur de l’Aéronautique et de l’Espace* (ISAE Supaéro, "Complex Systems") and M2 (Mathematics), Toulouse (J.-A. Désidéri).

Licence: Summer Project in Mathematical Modeling, 36 hrs, L3, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (A. Habbal).

Master: Numerical Methods for Partial Differential Equations, 66 hrs, M1, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (A. Habbal and R. Duvigneau).

Master: Modeling strategies for e-Formula races, M1 Students Project, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (A. Habbal).

8.2.2. Supervision

PhD in progress : Cédric Durantin, *Meta-modelling for the optimization of nanophotonic devices*, October 2014. Supervisors : J.-A. Désidéri and A. Glière (CEA LETI).

PhD in progress : Quentin Mercier, *Multicriterion optimization under uncertainties : the stochastic multiple gradient approach. Application to aerelasticity*, October 2015. Supervisors : J.-A. Désidéri and F. Poirion.

PhD in progress : Sosina Mengistu-Gashaw (EURECOM), *Mobility and connectivity modelling of 2-wheels traffic for ITS applications* , March 2015. Supervisors: P. Goatin and J. Härri (EURECOM).

PhD in progress: Rabeb Chamekh, *Game strategies for thermo-elasticity*, Jan 2015, Supervisors: A. Habbal, Moez Kallel (LAMSIN, ENIT, Tunis)

PhD in progress: Marwa Ouni, *Solving inverses problems in fluid mechanics with game strategies*, October 2016, Supervisors: A. Habbal, Moez Kallel (LAMSIN, ENIT, Tunis)

PhD in progress: Kelthoum Chahour, *Modeling and optimal design of coronary angioplastic stents*, Nov 2015, Supervisors: A. Habbal, Rajae Aboulaich (LERMA, EMI, Rabat)

PhD in progress: A. Azaouzi, *isogeometric analysis methods for hyperbolic systems*, ENIT (Tunisia) / University of Nice - Sophia Antipolis, Oct. 2013, supervisors: R. Duvigneau and M. Moakher (ENIT).

PhD in progress: M. Sacher, *advanced methods for numerical optimization of yacht performance*, Ecole Navale , Oct. 2014, supervisors: R. Duvigneau, O. Le Maitre (LIMSI), F. Hauville and J.-A. Astolfi (Ecole Navale).

PhD in progress: C. Fiorini, *Sensitivity equation method for hyperbolic systems*, Univ. Versailles, Oct. 2014, supervisors: R. Duvigneau, C. Chalons (Univ. Versailles).

PhD in progress : Nicolas Laurent-Brouty (ENPC), *Macroscopic traffic flow models for pollution estimation and control*, September 2016. Supervisor: P. Goatin.

PhD in progress : Felisia Angela Chiarello (Université de Nice Sophia Antipolis), *Conservation laws with non- local flux*, October 2016. Supervisor: P. Goatin .

PhD in progress : Nikodem Dymski (Maria Curie Sklodowska University & Université de Nice Sophia Antipolis), *Conservation laws in the modeling of collective phenomena*, October 2016. Supervisors: P. Goatin and M.D. Rosini (UMCS).

PhD defended on November 2017: Boutheina Yahyaoui, *Validation of mecano-chemo-biological models for cell sheet wound closure*, Jan 2013, Supervisors: A. Habbal, Mekki Ayadi (LAMSIN, ENIT, Tunis)

8.2.3. Juries

- P. Goatin was member of the committee of P. Grandinetti's PhD thesis *"Control of large-scale traffic networks"*, Université de Grenoble, September 11th, 2017.
- A. Habbal was member of the committee of F. Kpadonou *Optimisation de forme et anisotropie par une méthode isogéometrique-polaire* , Université de Versailles et Saint-Quentin, August 31, 2017.

8.3. Popularization

- J.-M. Loubes and P. Goatin, *"La prédiction dans les transports"*, Les Big Data à découvert, CNRS Editions (2017), pp. 124-125.
- Press article: *Les mathématiciennes ont de plus en plus confiance*, La Tribune, May 2017. Portrait of P. Goatin by L.J. Baudu.
- P. Goatin gave the talk *"Le trafic routier en équations"* at Luxembourg University and at Lycée Aline Mayrisch du Luxembourg on October 5, 2017, as part of the conference cycle *"La Recherche au féminin"* organized by the French Institute of Luxembourg.
- Web Press articles : *On a Collision Course with Game Theory* about the Royal Society Proceedings paper [13] in https://phys.org/news/2017-09-collision-game-theory.html and in http://www.sciencenewsline.com/news/2017092714240040.html

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