INRIA

INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team BIPOP

Nonsmooth Dynamics and Optimization

Grenoble - Rhône-Alpes

Theme : Modeling, Optimization, and Control of Dynamic Systems

Activity Report

2009

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2. Overall Objectives

2.1. Overall Objectives

Generally speaking, this project deals with nonregular systems, control, modelling and simulation, with emphasis on

- dynamic systems, mostly mechanical systems with unilateral constraints and Coulomb friction, but also electrical circuits with ideal diodes and transistors Mos[1], etc;
- numerical methods for nonsmooth optimization, and more generally the connection between continuous and combinatorial optimization.

[1] metal-oxyde semiconductor

3. Scientific Foundations

3.1. Dynamic non-regular systems

Dynamical systems (we limit ourselves to finite-dimensional ones) are said to be *non-regular* whenever some nonsmoothness of the state arises. This nonsmoothness may have various roots: for example some outer impulse, entailing so-called *differential equations with measure*. An important class of such systems can be described by the complementarity system

$$\begin{cases} \dot{x} = f(x, u, \lambda)\,, \\ 0 \leq y \perp \lambda \geq 0\,, \\ g(y, \lambda, x, u, t) = 0\,, \\ \text{re-initialization law of the state } x(\cdot)\;, \end{cases} \tag{1}$$

where $\perp$ denotes orthogonality; u is a control input. Now (1) can be viewed from different angles.

- Hybrid systems: it is in fact natural to consider that (1) corresponds to different models, depending whether $y_i = 0$ or $y_i > 0$ (y_i being a component of the vector y). In some cases, passing from one mode to the other implies a jump in the state x; then the continuous dynamics in (1) may contain distributions.
- Differential inclusions: $0 \leq y \perp \lambda \geq 0$ is equivalent to $-\lambda \in \mathrm{N}_K(y)$, where K is the nonnegative orthant and $\mathrm{N}_K(y)$ denotes the normal cone to K at y. Then it is not difficult to reformulate (1) as a differential inclusion.
- Dynamic variational inequalities: such a formalism reads as $\langle \dot{x}(t) + F(x(t), t), v - x(t) \rangle \geq 0$ for all $v \in K$ and $x(t) \in K$, where K is a nonempty closed convex set. When K is a polyhedron, then this can also be written as a complementarity system as in (1).

Thus, the 2nd and 3rd lines in (1) define the modes of the hybrid systems, as well as the conditions under which transitions occur from one mode to another. The 4th line defines how transitions are performed by the state x. There are several other formalisms which are quite related to complementarity. A tutorial-survey paper has been published [3], whose aim is to introduce the dynamics of complementarity systems and the main available results in the fields of mathematical analysis, analysis for control (controllability, observability, stability), and feedback control.

3.2. Nonsmooth optimization

Here we are dealing with the minimization of a function f (say over the whole space R^n), whose derivatives are discontinuous. A typical situation is when f comes from dualization, if the primal problem is not strictly convex – for example a large-scale linear program – or even nonconvex – for example a combinatorial optimization problem. Also important is the case of spectral functions, where $f(x) = F(\lambda(A(x)))$, A being a symmetric matrix and λ its spectrum.

For these types of problems, we are mainly interested in developing efficient resolution algorithms. Our basic tool is bundling (Chap. XV of [7]) and we act along two directions:

- To explore application areas where nonsmooth optimization algorithms can be applied, possibly after some tayloring. A rich field of such application is combinatorial optimization, with all forms of relaxation [9], [8].
- To explore the possibility of designing more sophisticated algorithms. This implies an appropriate generalization of second derivatives when the first derivative does not exist, and we use advanced tools of nonsmooth analysis, for example [10].

4. Application Domains

4.1. Introduction

Many systems (either actual or abstract) can be represented by (1). Some typical examples are:

- Mechanical systems with unilateral constraints and dry friction (the biped robot is a typical example), including kinematic chains with slack, phenomena of liquid slosh, etc.
- Electrical circuits with ideal diodes and/or transistors Mos.
- Optimal control with constraints on the state, closed loop of a system controlled by an MPC algorithm[2], etc.

This class of models is not too large (to allow thorough studies), yet rich enough to include many applications. This goes in contrast to a study of general hybrid systems. Note for example that (1) is a "continuous" hybrid system, in that the continuous variables x and u prevail in the evolution (there is no discrete control to commute from a mode to the other: only the input u can be used). Let us cite some specific applications.

4.2. Computational neuroscience

Modeling in neuroscience makes extensive use of nonlinear dynamical systems with a huge number of interconnected elements. Our current theoretical understanding of the properties of neural systems is mainly based on numerical simulations, from single cell models to neural networks. To handle correctly the discontinuous nature of integrate-and-fire networks, specific numerical schemes have to be developed. Our current works focus on event-driven, time-stepping and voltage-stepping strategies, to simulate accurately and efficiently neuronal networks. Our activity also includes a mathematical analysis of the dynamical properties of neural systems. One of our aims is to understand neural computation and to develop it as a new type of information science.

4.3. Electronic circuits

Whether they are integrated on a single substrate or as a set of components on a board, electronic circuits are very often a complex assembly of many basic components with non linear characteristics. The IC technologies now allow the integration of hundreds of millions of transistors switching at GHz frequencies on a die of 1cm^2. It is out of question to simulate a whole such IC with standard tools such as the SPICE simulator. We currently work on a dedicated plug-in able to simulate a whole circuit comprising various components, some modelled in a nonsmooth way.

4.4. Walking robots

As compared to rolling robots, the walking ones – for example hexapods – possess definite advantages whenever the ground is not plane or free: clearing obstacles is easier, holding on the ground is lighter, adaptivity is improved. However, if the working environment of the system is adapted to man, the biped technology must be preferred, to preserve good displacement abilities without modifying the environment. This explains the interest displayed by the international community in robotics toward humanoid systems, whose aim is to back man in some of his activities, professional or others. For example, a certain form of help at home to disabled persons could be done by biped robots, as they are able to move without any special adaptation of the environment.

[2] model predictive control

4.5. Optimization

Optimization exists in virtually all economic sectors. Simulation tools can be used to optimize the system they simulate. Another domain is parameter *identification* (Idopt or Estime teams), where the deviation between measurements and theoretical predictions must be minimized. Accordingly, giving an exhaustive list of applications is impossible. Some domains where Inria has been implied in the past, possibly through the former Promath and Numopt teams are: production management, geophysics, finance, molecular modeling, robotics, networks, astrophysics, crystallography, ...Our current applicative activity includes: the management of electrical production (deterministic or stochastic), the design and operation of telecommunication networks.

4.6. Computer graphics Animation

A new application in Bipop is the simulation of complex scenes involving many interacting objects. Whereas the problem of collision detection has become a mature field those recent years, simulating the collision response (in particular frictious contacts) in a realistic, robust and efficient way, still remains an important challenge. Another related issue we began to study is the simulation of heterogeneous objects such as granular or fibrous materials, which requires the design of new high-scales models for dynamics and contacts; indeed, for such large systems, simulating each interacting particle/fiber individually would be too much time-consuming for typical graphics applications. Finally, our current activity includes the shape control of simulated objects, which is of great importance in the field of artistic design, for the making of movies and video games for example. Such problems typically involve constrained optimization.

5. Software

5.1. Nonsmooth dynamics: Siconos

Participant: Vincent Acary.

In the framework of the European project Siconos, Bipop was the leader of the Work Package 2 (WP2), dedicated to the numerical methods and the software design for nonsmooth dynamical systems. The aim of this work is to provide a common platform for the simulation, modeling, analysis and control of abstract nonsmooth dynamical systems. Besides usual quality attributes for scientific computing software, we want to provide a common framework for various scientific fields, to be able to rely on the existing developments (numerical algorithms, description and modeling software), to support exchanges and comparisons of methods, to disseminate the know-how to other fields of research and industry, and to take into account the diversity of users (end-users, algorithm developers, framework builders) in building expert interfaces in Python and end-user front-end through Scilab.

After the requirement elicitation phase, the Siconos Software project has been divided into 5 work packages which are identified to software products:

1. *Siconos/Numerics* This library contains a set of numerical algorithms, already well identified, to solve non smooth dynamical systems. This library is written in low-level languages (C,F77) in order to ensure numerical efficiency and the use of standard libraries (Blas, Lapack, ...)
2. *Siconos/Kernel(Engine + Front-End)* The Engine is an object-oriented structure (C++) for modeling and simulation of abstract dynamical systems. The Front-End is the driver interface of the Engine thanks to two types of API's. The first one is an API in C++, interfaced in Python for scripting uses. The second API, in C, will be interfaced with Scilab for a more user-friendly platform.
3. *Siconos/Analysis* This part is devoted to the stability and bifurcation analysis of nonsmooth dynamical systems.
4. *Siconos/Control* This part is devoted to the implementation of control strategies of non smooth dynamical systems.
5. *Siconos/*IMSE The final product is an Integrated modeling and Simulation Environment dedicated to applied nonsmooth problems.

Further informations may be found at http://siconos.gforge.inria.fr/

5.2. Humanoid motion analysis and simulation

Participant: Pierre-Brice Wieber.

The HuMAnS toolbox offers tools for the modelling, control and analysis of humanoid motion, be it of a robot or a human. It is a C/C++/Scilab/Maple-based set of integrated tools for the generation of dynamical models of articulated bodies with unilateral contact and friction, their simulation with an event-driven integration scheme, their 3D visualization, the computation of stability measures, optimal positions and trajectories, the generation of control laws and observers, the reconstruction of movements from different sensing systems.

5.3. Optimization

Participant: Claude Lemaréchal.

Essentially two possibilities exist to distribute our optimization software: library programs (say Modulopt codes), communicated either freely or not, depending on what they are used for, and on the other hand specific software, developed for a given application.

The following optimization codes have been developed in the framework of the former Promath project. They are generally available at http://irabot.inrialpes.fr/raweb.html; M1QN3 is also distributed under GPL.

5.3.1. Code M1QN3

Optimization without constraints for problems with many variables ($n \geq 10^3$, has been used for $n = 10^6$). Technically, uses a limited-memory BFGS algorithm with Wolfe's line-search (see Chap. 4 of [2] for the terminology).

5.3.2. Code M2QN1

Optimization with simple bound-constraints for (small) problems: D is a parallelotope in R^n. Uses BFGS with Wolfe's line-search and active-set strategy.

5.3.3. Code N1CV2

Minimization without constraints of a convex nonsmooth function by a proximal bundle method (Chap. XV of [7], Chap. 9 of [2]).

5.3.4. Modulopt

In addition to codes such as above, the Modulopt library contains application problems, synthetic or from the real world. It is a field for experimentation, functioning both ways: to assess a new algorithm on a set of test-problems, or to select among several codes one best suited to a given problem.

5.4. Simulation of fibrous materials

Participants: Florence Bertails-Descoubes, Gilles Daviet, Florent Cadoux.

The goal of the MECHE ADT, started in September 2009 and planned for 2 years, is to develop a software for simulating the dynamics of assemblies of thin rods (such as hair), subject to contact and friction. This software combines a panel of well-accepted models for rods (ranging from reduced coordinates to maximal coordinates models, and including models recently developed by some members of the group) with classical as well as innovative schemes for solving the problem of frictious contact (incorporating the most recent results of the group). The aim of this software is twofold: first, we would like to compare and analyse the performance of nonsmooth schemes for the frictious contact problem, in terms of realism (capture of dry friction, typically), robustness, and computational efficiency. This study will be conducted onto the different rod models that are available in the software. Second, such a software will help us understand the behaviour of a fibrous material (such as hair) through virtual experiments, thanks to which we hope to identify and understand some important emergent phenomena. In the past, such fibrous materials have been seldom studied (though many applications have come out those years - e.g. cosmetology and computer graphics), and we believe that numerical simulation will give to us some important hints on how to model such a system macroscopically.

An associate engineer, Gilles Daviet, have been hired in September 2009 to work full-time on the MECHE project.

6. New Results

6.1. Modeling

6.1.1. Simulation of electrical circuits as nonsmooth dynamical systems

Participants: Vincent Acary, Olivier Bonnefon, Bernard Brogliato.

DC-DC converters are usually difficult to simulate with classical tools like SPICE because of the highly nonlinear behaviour of some components and the frequent occurrence of intrinsically generated switching events.

The simulation of such circuits modelled as nonsmooth systems has been successfully achieved with a clear advantage over several SPICE simulators and a simulator belonging to the hybrid modelling approach [31].

6.1.2. Simulation of spiking neuronal networks

Participant: Arnaud Tonnelier.

The numerical simulation of neural networks requires special attention to reproduce accurately the firing times of spiking neurons, while allowing efficient simulation of large networks. Event-driven strategies have become increasingly popular since they allow the simulation of spiking neural networks exactly, with a computational cost similar to classical time-stepping schemes. Previous works were limited to linear integrate-and-fire neurons. In [42] we extend event-driven schemes to a class of nonlinear integrate-and-fire models. Results are presented for the quadratic integrate-and-fire model with exponential synaptic currents.

The development of an event-driven simulation algorithm has to be done case by case. In [28] we propose a generic technique, *voltage-stepping schemes*, that is based on a discretization of the voltage state-space of individual neurons. The new simulation strategy defines a local event-driven method inducing an implicit activity-dependent time stepping scheme. Long time-steps are used when the neuron is slowly varying, whereas small time-steps are used in periods of intense activity. Our method is illustrated on nonlinear integrate-and-fire models. The efficiency of voltage-stepping schemes for the numerical simulation of spiking neural networks has been assessed in [36].

6.1.3. Neural dynamics

Participant: Arnaud Tonnelier.

The quadratic integrate-and-fire model (QIF) with adaptation is commonly used as an elementary neuronal model that reproduces the main characteristics of real neurons. In [29], we introduce a QIF neuron with a nonlinear adaptive current. This model reproduces the neuron-computational features of real neurons and is analytically tractable. It is shown that, under a constant current input, chaotic firing is possible. In contrast to previous studies, the neuron is not sinusoidally forced. We show that the spike-triggered adaptation is a key parameter to understand how chaos is generated.

Precise spatiotemporal sequences of spikes are observed in many neural systems and are thought to be involved in the neural processing of sensory stimuli. In [26] we examine the capability of spiking neural networks to propagate stably spatiotemporal sequences of spikes. We derive some analytical results for the wave speed and show that the stability of simple waves is determined by the Schur criteria. The transmission of a sequence of several spikes is related to the existence of stable composite waves, i.e. the existence of stable spatiotemporal periodic traveling waves. We show that the stability of composite waves is related to the roots of a system of multivariate polynomials.

6.1.4. Modeling and simulation of mechanical rods

Participant: Florence Bertails.

In Bertails's PhD thesis, a new dynamic model for an elastic rod was presented: the Super-Helix model, which stands for one of the most promising models for simulating non-stretchable rods that can bend and twist. However, this model suffers from a quadratic complexity in the number of discrete elements, which, in the context of interactive applications, makes it limited to a few number of degrees of freedom – or equivalently to a low number of variations in curvature along the mean curve.

In our recent work [13], we overcome this limitation by proposing a new, recursive scheme for the dynamics of a Super-Helix, inspired by the popular algorithm of Featherstone for serial multibody chains. Similarly to Featherstone's algorithm, we exploit the recursive kinematics of a Super-Helix to propagate element inertias from the free end to the fixed end of the rod, while the dynamics is solved within a second pass traversing the rod in the reverse way. Besides the gain in linear complexity, which allows us to simulate a rod of complex shape much faster than the original approach, our algorithm makes it straightforward to simulate tree-like structures of Super-Helices, which turns out to be particularly useful for animating trees and plants realistically, under large displacements. We are now looking at modeling contact and friction of thin rods with rigid objects.

6.1.5. Multiple impacts modelling

Participant: Bernard Brogliato.

The so-called Darboux-Keller approach for modelling simple impacts, is extended to the case of multiple impacts in [22] and [27], following the impact law introduced in [38] [44]. A distributing law that accounts for the elasticity law is found, and combined with Stronge's energetic coefficient. Careful comparisions are made with experimental results found elsewhere in the physics and mechanical engineering literature on granular media, which show the validity of the model. Coulomb's friction into the model in [22] and [27].

6.1.6. Hair dynamics

Participants: Florence Bertails-Descoubes, Florent Cadoux, Vincent Acary.

In the case of hair dynamics, we have shown in [14] that optimization-based methods such as the approach by Alart and Curnier [35], little known in the computer graphics literature, outperform classical schemes of computer graphics (typically, penalty-based approaches) for solving the frictious contact problem, both in terms of realism and robustness.

6.2. Optimization

6.2.1. Nonsmooth analysis of spectral sets

Participant: Jérôme Malick.

Spectral sets are sets of matrices that depend only on the constraints on the eigenvalues: S is a spectral set if $S = \lambda^{-1}(C)$ with C a subset of $\mathbb{R}^n$. A spectral set S inherits from properties of the underlying set C, such as convexity. We prove in [30] that the spectral sets associated to smooth manifolds in $\mathbb{R}^n$ (having some local symmetry) are themselves manifolds in the space of matrices. This result looks simple but generalizes several useful particular cases, and was extremely difficult to prove: we brace together tools from nonsmooth analysis, differential geometry, group theory and spectral analysis.

6.2.2. Semidefinite programming and applications

Participant: Jérôme Malick.

Many problems in Control and Combinatorial Optimization have modelizations as semidefinite optimization problems; but as for numerical resolution, this approach is limited by the performances of semidefinite optimization solvers that often run into numerical trouble when the sizes of problems get large. We contribute in solving partly this for 2 particular cases :

- Using a standard convex analysis algorithm (proximal algorithm) we develop in [23] a new algorithm for solving semidefinite optimization problems in presence of a very large number of constraints (and a small number of variables). Our approach turns out to be very efficient, as it outperforms all known methods for some combinatorial problems such as Lovász' number.

- We propose in [19] a new approach by projection to solve semidefinite feasibility problems - as for exemple computing SOS decomposition of Lyapunov polynoms. This natural, geometric idea is as simple as efficient : we release a short Matlab software implementing this idea, and as shown in [19], it is competitive for solving those semidefinite feasibility problems with more evoluated reliable tools (as SeDuMi).

6.2.3. Advances on alternating projections theory

Participant: Jérôme Malick.

Alternating projections are simple and efficient methods to solve feasibility problems (that is to find a point in the intersection of several sets); they are widely used in engineering sciences. One striking example is to design "tight frames" [43]; there are many other applications in image processing, "compress sensing" in particular.

In several successful applications, linear convergence is observed, but not explained by the theory which focuses on alternating *convex* projections - whereas these applications require projections onto nonconvex sets.

Our paper [37] proves linear convergence of the method under very mild assumptions, namely that the intersection is *strong* (i.e. essentially "linearly regular"). Note that convexity is not necessary to get the local convergence result. The proof of these results rely heavily on tools from nonsmooth geometry [40].

6.2.4. Frictional contacts

Participants: Vincent Acary, Florent Cadoux, Claude Lemaréchal, Jérôme Malick.

We have designed a new algorithm to compute the Coulomb friction forces in a nonsmooth mechanical system; see [34]. The algorithm is hierarchical: in an inner stage, the sliding velocities are fixed and the corresponding forces are computed as solutions of a second-order cone program (a simple quadratic programming problem when the dimension is 2); in this formulation, the sliding velocities then have to satisfy a system of nonlinear equations, which is solved by a Newton method in the outer stage.

This approach has been implemented and compared with other ones, in particular [35] which we also improved by inserting a stabilizing device.

6.2.5. Proximal algorithm for smooth functions

Participants: Marc Fuentes, Claude Lemaréchal, Jérôme Malick.

This research was motivated by the minimization of a smooth but ill-conditioned function f, such as presented in [39]. For this, the proximal approach consists in constructing the sequence $x_{k+1} = p(x_k)$, where $p(x)$ minimizes the function $p \mapsto f(p) + \frac{1}{2}|p - x|^2$. Unless f is simple enough, actual implementations require a stopping rule for the internal minimization algorithm computing $p(x_k)$. The rationale for most such rules is to guarantee $|x_{k+1} - p(x_k)| \leqslant \varepsilon_k$, where ε_k is essentially pre-assigned. We propose in [17] a rule based on a sufficient decrease $f(x_k) - f(x_{k+1})$, applicable when f is differentiable. We prove convergence of the resulting algorithm and illustrate it on some test-problems from the CUTEr library.

6.3. Control

6.3.1. Observer design

Participant: Bernard Brogliato.

The general problem of state observation for nonsmooth dynamical systems, or hybrid dynamical systems, remains largely open, in particular for systems whose trajectories may jump. In [16], [18] solutions are proposed for the design of asymptotic observers for various classes of nonsmooth systems (differential inclusions, complementarity systems). The problem of "closing the loop" (the separation principle) is also solved in particular cases.

6.3.2. Trajectory tracking

Participants: Bernard Brogliato, Tran Anh Tu Nguyen.

In these works [25], [24] the problem of extending the so-called passivity-based controllers to Lagrangian systems with unilateral constraints is considered. The first work [25] treats fully actuated rigid systems. The second work [24] deals with the case when joint flexibilities are present. This is thought to be quite important since impacts are likely to excite vibrational modes and possibly destabilize the closed-loop system. We first derive a suitable stability criterion, then we design a switching control algorithm and numerical simulations are performed with the Moreau's time-stepping scheme of the SICONOS platform.

6.3.3. Optimal control

Participant: Bernard Brogliato.

The problem of quadratic optimal control with state inequality constraints is studied in [15], where the Pontryagin's necessary consitions take the form of a linear complementarity system (LCS). We take advantage of the formalism of the higher order Moreau's sweeping process [32], that is a distribution differential inclusions, to analyze this LCS. The work of ten Dam on the geometrical analysis of the positive invariance of systems with inequality state constraints is also used. Both frameworks allow us to better study the qualitative properties of the optimal trajectories.

6.3.4. Digital sliding mode control

Participants: Vincent Acary, Bernard Brogliato.

The problem of difital sliding mode controllers is a long-standing issue not yet satisfactorily solved. We propose in [12] ideas which are inspired from the numerical methods of contact mechanics [1] and which permit a) to suppress the numerical chattering, b) to obtain a smooth stabilization on the sliding surfaces. The work is continued together with Yury Orlov in more general cases where the system is acted upon by disturbances and a disturbance estimation is added.

6.4. Software development

6.4.1. Meche toolbox

Participants: Florence Bertails, Gilles Daviet, Florent Cadoux.

The main functionalities developed in 2009 for the MECHE software are:

The main functionalities developed in 2009 for the MECHE software are:

- The development of two rods models (added to Super-Helix rod model), namely the implicit mass-spring model [33] and the CORDE model [41]

- The development of a bunch of methods for solving the incremental problem for frictious contact, including several variants of [35], as well as the new algorithm described in [34].

- The integration of several frictious contact algorithms (partly taken from the Siconos platform, and partly developed for that purpose) into the available rods models

- The development of collision detection schemes in-between rods and between rods and external objects (dynamic planes, spheres and meshes)

- The improvement of time performance through code optimization

- The handling of import files (mesh + motion) and export files (for rendering in 3DS Max) in collaboration with L. Boissieux (SED)

6.4.2. Platform development: Siconos

Participants: Vincent Acary, Olivier Bonnefon.

The main achievements for the Siconos platform are

- *Siconos/Kernel*. Improvements and enhancements of
  - Modeling part: new NewtonEuler Dynamical systems;
  - Example library: example library with Optimal control example and Relay Systems
- Improvements and extensions of the documentation.

7. Contracts and Grants with Industry

7.1. Industrial contracts

ANR Cheveux: Modeling and dynamic simulation of hair in the context of feature films production. Partners: Neomis Animation SARL, BeeLight SARL, Institut Jean Le Rond d'Alembert (UPMC-CNRS), Inria (Bipop, Evasion and Artis).

ANR Saladyn: Numerical tools for simulating dynamics systems in mechanics; Partners: INRIA Bipop, LMGC Montpellier, EdF, Schneider Electric.

EdF: Documentation of the `noisedf` software

L'OREAL: "Contrat d'étude" planned for 2009-2010, for adding extended functionalities to the hair simulation software transfered in 2006 (F. Bertails-Descoubes)

7.2. Other grants

– ANR Saladyn, programme COSINUS.
– ANR Multiple Impact, programme BLANC.
– FUI Romeo.
–ANR Cheveux, programme .
–ANR VAL-AMS, programme SETIN.
– ASSOCIATE TEAM: SHARE, Simulation of virtual Humans and Animals interacting with Realistic Environments, with theuniversity of Vancouver.

8. Dissemination

8.1. PhD Theses

– Thesis of F. Cadoux, université Joseph Fourier Grenoble, November 2009.

8.2. Software

– M2FC1 (a code for nonsmooth-nonconvex optimization) sent to Mentor Graphics (design of robust analog circuits).

8.3. Animation of the scientific community

B. Brogliato is:
– Member of the International Program Committee of ICINCO 2009, IFAC ADHS 2009.

F. Bertails has been a reviewer for
– ACM SIGGRAPH since 2007
– Eurographics since 2005
– ACM Solid and Physical Modeling Symposium since 2008.

She has been a member of the national SPECIF PhD award boarding since 2007.

8.4. Teaching

– ENSIMAG: J. Malick, F. Cadoux, F. Bertails-Descoubes: “Numerical Optimization”, 54h and 64h respectively).
– Université de Limoges, laboratoire XLIM: B. Brogliato (master 2 recherche Math. Appl., 15h)
– INPG, laboratoire GIPSA lab: B. Brogliato (master 2 recherche Automatique, 15 h)
– Université de Peking (PKU): B. Brogliato (cours master et doctorants, 18h).
– UFR IMA, UJF Grenoble 1, (V. Acary, lectures on â Mathematical models for physicsâ, 56h in Master 2)

8.5. Invitation of specialists

– Y. Orlov (CICESE Mexico), one month;
– R. Bridson (University of British Columbia), one week;
– M. van de Panne (University of British Columbia), one week;

8.6. Participation to conferences, seminars

– Conference on Scientific Computing Conference in honour of E. Hairer’s 60th birthday 17-20 June 2009 (2 participants)
– 12th Seminar "NUMDIFF" on Numerical Solution of Differential and Differential-Algebraic Equations 14 - 18 September 2009 (1 participant)
– XIXeme Congrès FranÃ§ais de Mécanique, 24–28 August 2009 (2 participants)
– Colloque en l’Honneur des 60 ans de Michelle Schatzman, 8/9 décembre 2009 (1 participant)
– 7th Euromech Solid Mechanics Conference ESMC2009, Lisbon, September 7-11 (1 particiapnt)
– First International Colloquium on Non-Linear Dynamics of Deep Drilling Systems, 12-13 March 2009, Château de Colonster, université de Liège, Belgique. (1 participant)
– European Control Conference, Budapest, 23-26 August (1 participant)
– Congrès de la SMAI, 2009 (1 participant)

9. Bibliography

Major publications by the team in recent years

[1] V. Acary, B. Brogliato. *Numerical Methods for Nonsmooth Dynamical Systems: Applications in Mechanics and Electronics*, Lecture Notes in Applied and Computational Mechanics, vol. 35, Springer Verlag, 2008.

[2] J. Bonnans, J. Gilbert, C. Lemaréchal, C. Sagastizábal. *Numerical Optimization*, Springer Verlag, 2003.

[3] B. Brogliato. *Some perspectives on the analysis and control of complementarity systems*, in "IEEE Trans. Automatic Control", vol. 48, n^o 6, 2003, p. 918-935.

[4] B. Brogliato. *Nonsmooth Mechanics*, Springer Verlag, 1999, 2nd edition.

[5] B. Brogliato, R. Lozano, B. Maschke, O. Egeland. *Dissipative Systems Analysis and Control*, Springer Verlag, London, 2007, 2nd edition.

[6] B. Brogliato, S. Niculescu, P. Orhant. *On the control of finite-dimensional mechanical systems with unilateral constraints*, in "IEEE Trans. Automatic Control", vol. 42, n^o 2, 1997, p. 200-215.

[7] J.-B. HIRIART-URRUTY, C. LEMARÉCHAL. *Convex Analysis and Minimization Algorithms*, Springer Verlag, Heidelberg, 1993, Two volumes.

[8] C. LEMARÉCHAL. *Lagrangian relaxation*, in "Computational Combinatorial Optimization", M. JÜNGER, D. NADDEF (editors), Springer Verlag, 2001, p. 115-160.

[9] C. LEMARÉCHAL, F. OUSTRY. *Semi-definite relaxations and Lagrangian duality with application to combinatorial optimization*, n^{o} 3710, Inria, 1999, http://hal.inria.fr/inria-00072958, Rapport de Recherche.

[10] C. LEMARÉCHAL, F. OUSTRY, C. SAGASTIZÁBAL. *The $\mathcal{U}$-Lagrangian of a convex function*, in "Trans. AMS", vol. 352, n^{o} 2, 2000, p. 711-729.

Year Publications

Doctoral Dissertations and Habilitation Theses

[11] F. CADOUX. *Optimisation et analyse convexe pour la dynamique non régulière*, Univ. Joseph Fourier, Grenoble, 2009, Ph. D. Thesis.

Articles in International Peer-Reviewed Journal

[12] V. ACARY, B. BROGLIATO. *Implicit Euler numerical scheme and chattering-free implementation of sliding mode systems*, in "Systems and Control Letters", 2009, submitted, provisionally accepted.

[13] F. BERTAILS. *Linear Time Super-Helices*, in "Computer Graphics Forum", vol. 28, n^{o} 2, 2009.

[14] F. BERTAILS, F. CADOUX, V. ACARY. *FIBERS: simulating the Fine Interaction Between Entangled RodS*, in "Transactions on Graphics", 2009, submitted, conditionally accepted.

[15] B. BROGLIATO. *Some results on optimal control with unilateral state constraints*, in "Nonlinear Analysis, Theory, Methods and Applications", vol. 70, 2009, p. 3626-3657.

[16] B. BROGLIATO, W. HEEMELS. *Observer design for Lur'e systems with multivalued mappings: a passivity approach*, in "IEEE Transactions on Automatic Control", vol. 54, n^{o} 8, August 2009, p. 1996-2001.

[17] M. FUENTES, JÉRÔME. MALICK, C. LEMARÉCHAL. *Practical inexact proximal algorithms for smooth optimization*, in "Computational Optimization and Applications", 2009, submitted.

[18] W. HEEMELS, M. CAMLIBEL, J. SCHUMACHER, B. BROGLIATO. *Observer-based control of linear complementarity systems*, in "Int. Journal of Robust and Nonlinear Control", 2009, submitted.

[19] D. HENRION, J. MALICK. *Projection methods for conic feasibility problems: applications to polynomial sum-of-squares decompositions*, in "Optimization Methods and Software", December 2009.

[20] K. KIWIEL, C. LEMARÉCHAL. *An inexact conic bundle variant suited to column generation*, in "Mathematical Programming", vol. 119, n^{o} 1, 2009, p. 177-206.

[21] C. LEMARÉCHAL, A. OUOROU, G. PETROU. *A bundle-type algorithm for routing in telecommunication data networks*, in "Computational Optimization and Applications", vol. 44, n^{o} 3, 2009, p. 385-409.

[22] C. LIU, Z. ZHAO, B. BROGLIATO. *Frictionless multiple impacts in multibody systems: Part II. Numerical algorithm and simulation results*, in "Proceedings of the Royal Society A, Mathematical, Physical and Engineering Sciences", vol. 465, n^{o} 2101, 2009, p. 1-23.

[23] J. MALICK, J. POVH, F. RENDL, A. WIEGELE. *Regularization Methods for Semidefinite Programming*, in "SIAM Journal on Optimization", vol. 20, n^{o} 1, 2009, p. 336-356, http://dx.doi.org/10.1137/070704575.

[24] C. MORARESCU, B. BROGLIATO. *Passivity-based switching control of flexible-joint complementarity mechanical systems*, in "Automatica", 2009, in press.

[25] C. MORARESCU, B. BROGLIATO. *Trajectory tracking control of multiconstraint complementarity Lagrangian systems*, in "IEEE Transactions on Automatic Control", 2009, in press, scheduled for June 2010.

[26] A. TONNELIER. *Transmission of precise spike timings in neural networks*, in "SIAM J. Appl. Dyn. Syst", 2009, submitted.

[27] Z. ZHAO, C. LIU, B. BROGLIATO. *Planar dynamics of a rigid body system with frictional impacts. II. Qualitative analysis and numerical simulations*, in "Proceedings of the Royal Society A, Mathematical, Physical and Engineering Sciences", vol. 465, n^{o} 2107, 2009, p. 2267-2292.

[28] G. ZHENG, A. TONNELIER, D. MARTINEZ. *Voltage-stepping schemes for the simulation of spiking neural networks*, in "Journal of Computational Neuroscience", vol. 26, n^{o} 3, 2009.

[29] G. ZHENG, A. TONNELIER. *Chaotic solutions in the quadratic integrate-and-fire neuron with adaptation*, in "Cognitive Neurodynamics", vol. 3, n^{o} 3, 2009.

Other Publications

[30] A. DANIILIDIS, A. LEWIS, JÉRÔME. MALICK, H. SENDOV. *Locally symmetric manifolds lift up to spectral manifolds,*, 2009, submitted.

References in notes

[31] V. ACARY, O. BONNEFON, B. BROGLIATO. *Time-stepping numerical simulation of switched circuits with the nonsmooth dynamical systems approach*, in "IEEE Transactions on Computer Aided Design of Intergrated Circuits and Systems", 2009.

[32] V. ACARY, B. BROGLIATO, D. GOELEVEN. *Higher order Moreau's sweeping process: Mathematical formulation and numerical simulation*, in "Mathematical Programming", vol. 113, n^{o} 1, 2008, p. 133-217.

[33] D. BARAFF, A. WITKIN. *Large Steps in Cloth Simulation*, in "Computer Graphics Proceedings, Annual Conference Series", 1998, p. 43-54.

[34] F. CADOUX. *An optimization-based algorithm for Coulomb frictional contact*, in "Esaim Procs.", 2008, to appear.

[35] A. CURNIER, P. ALART. *A generalized Newton method for contact problems with friction*, in "J. de Méc. Théor. et Appl.", vol. suppl. 1 to 7, 1988, p. 67-82.

[36] G. GHAITH KAABI, G. ZHENG, A. TONNELIER, D. MARTINEZ. *Simulation de réseaux de neurones intègre-et-tire non linéaires par discrétisation du potentiel*, in "Deuxième conférence française de Neurosciences Computationnelles Neurocomp08, Marseille : France", 2008.

[37] A. LEWIS, R. LUKE, JÉRÔME. MALICK. *Local convergence of nonconvex averaged and alternating projections*, in "Foundations of Computational Mathematics", 2008, to appear.

[38] C. LIU, Z. ZHAO, B. BROGLIATO. *Frictionless multiple impacts in multibody systems. I: Theoretical framework*, in "Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences", vol. 464 (2100), 2008, p. 3193-3211.

[39] P. MARÉCHAL, A. RONDEPIERRE. *A proximal approach to the inversion of ill-conditioned matrices*, in "Comptes-rendus de l'académie des Sciences", 2009, to appear.

[40] R. ROCKAFELLAR, R.-B. WETS. *Variational Analysis*, Springer Verlag, Heidelberg, 1998.

[41] J. SPILLMANN, M. TESCHNER. *CORDE: Cosserat Rod Elements for the Dynamic Simulation of One-Dimensional Elastic Objects*, in "ACM SIGGRAPH / Eurographics Symposium on Computer Animation, San Diego", August 3-4 2007.

[42] A. TONNELIER, H. BELMABROUK, D. MARTINEZ. *Event-driven simulations of nonlinear integrate-and-fire neurons*, in "Neural Computation", vol. 19, 2007, p. 1-13.

[43] J. TROPP, I. DHILLON, R. HEATH, T. STROHMER. *Designing structured tight frames via in alternating projection method*, in "IEEE Transactions on Information Theory", vol. 51, 2005, p. 188-209.

[44] Z. ZHAO, C. LIU, B. BROGLIATO. *Energy dissipation and dispersion effects in granular media*, in "Physical Review E - Statistical, Nonlinear, and Soft Matter Physics", vol. 78, n^{o} 3, 2008.