



Activity Report 2011

Team DISCO

Dynamical Interconnected Systems in
COMplex Environments

RESEARCH CENTER
Saclay - Île-de-France

THEME
Modeling, Optimization, and Control
of Dynamic Systems

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Team DISCO

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DISCO is a joint team with Laboratoire des Signaux et Systèmes (L2S) U.M.R. C.N.R.S. 8506, and Supélec, which has been created in January 2010.

1. Members

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2. Overall Objectives

2.1. Objectives

The goal of the project is to better understand and well formalize the effects of complex environments on the dynamics of the interconnections, as well as to develop new methods and techniques for the analysis and control of such systems.

It is well-known that the interconnection of dynamic systems has for consequence an increased complexity of the behavior of the “total” system both in the presence and absence of feedback control loops.

In a simplified way, as the concept of dynamics is well-understood, the interconnections can be seen as associations (by connections of materials or information flows) of distinct systems to ensure a pooling of the resources with the aim of obtaining a better operation with the constraint of continuity of the service in the event of a fault. In this context, the environment can be seen as a collection of elements, structures or systems, natural or artificial constituting the neighborhood of a given system. The development of interactive games through communication networks, control from distance (e.g. remote surgical operations) or in hostile environment (e.g. robots, drones), as well as the current trend of large scale integration of distribution (and/or transport and/or decision) and open information systems with systems of production, lead to new modeling schemes in problems where the dynamics of the environment have to be taken into account.

In order to tackle the control problems arising in the above examples, the team investigates new theoretical methods, develop new algorithms and implementations dedicated to these techniques.

2.2. Highlights

- Silviu Iulian Niculescu obtained the Silver Medal from CNRS in December 2011.
- José Luis Avila Alonso won the Best Poster Price at the 4th DIGITEO Annual Forum.
- Benjamin Bradu won the Best PhD Price of the GDR MACS.

3. Scientific Foundations

3.1. Modeling of complex environment

We want to model phenomena such as a temporary loss of connection (e.g. synchronisation of the movements through haptic interfaces), a nonhomogeneous environment (e.g. case of cryogenic systems) or the presence of the human factor in the control loop (e.g. grid systems) but also problems involved with technological constraints (e.g. range of the sensors). The mathematical models concerned include integro-differential, partial differential equations, algebraic inequalities with the presence of several time scales, whose variables and/or parameters must satisfy certain constraints (for instance, positivity).

3.2. Analysis of interconnected systems

- Algebraic analysis of linear systems
Study of the structural properties of linear differential time-delay systems and linear infinite-dimensional systems (e.g. invariants, controllability, observability, flatness, reductions, decomposition, decoupling, equivalences) by means of constructive algebra, module theory, homological algebra, algebraic analysis and symbolic computation [8], [9], [104], [125], [105], [108].

- Robust stability of linear systems
Within an interconnection context, lots of phenomena are modelled directly or after an approximation by delay systems. These systems might have fixed delays, time-varying delays, distributed delays...

For various infinite-dimensional systems, particularly delay and fractional systems, input-output and time-domain methods are jointly developed in the team to characterize stability. This research is developed at four levels: analytic approaches (H_∞ -stability, BIBO-stability, robust stability, robustness metrics) [1], [2], [5], [6], symbolic computation approaches (SOS methods are used for determining easy-to-check conditions which guarantee that the poles of a given linear system are not in the closed right half-plane, certified CAD techniques), numerical approaches (root-loci, continuation methods) and by means of softwares developed in the team [5], [6].

- Robustness/fragility of biological systems

Deterministic biological models describing, for instance, species interactions, are frequently composed of equations with important disturbances and poorly known parameters. To evaluate the impact of the uncertainties, we use the techniques of designing of global strict Lyapunov functions or functional developed in the team.

However, for other biological systems, the notion of robustness may be different and this question is still in its infancy (see, e.g. [116]). Unlike engineering problems where a major issue is to maintain stability in the presence of disturbances, a main issue here is to maintain the system response in the presence of disturbances. For instance, a biological network is required to keep its functioning in case of a failure of one of the nodes in the network. The team, which has a strong expertise in robustness for engineering problems, aims at contributing at the development of new robustness metrics in this biological context.

3.3. Stabilization of interconnected systems

- Linear systems: Analytic and algebraic approaches are considered for infinite-dimensional linear systems studied within the input-output framework.

In the recent years, the Youla-Kučera parametrization (which gives the set of all stabilizing controllers of a system in terms of its coprime factorizations) has been the cornerstone of the success of the H_∞ -control since this parametrization allows one to rewrite the problem of finding the optimal stabilizing controllers for a certain norm such as H_∞ or H_2 as affine, and thus, convex problem.

A central issue studied in the team is the computation of such factorizations for a given infinite-dimensional linear system as well as establishing the links between stabilizability of a system for a certain norm and the existence of coprime factorizations for this system. These questions are fundamental for robust stabilization problems [1], [2], [8], [9].

We also consider simultaneous stabilization since it plays an important role in the study of reliable stabilization, i.e. in the design of controllers which stabilize a finite family of plants describing a system during normal operating conditions and various failed modes (e.g. loss of sensors or actuators, changes in operating points) [9]. Moreover, we investigate strongly stabilizable systems [9], namely systems which can be stabilized by stable controllers, since they have a good ability to track reference inputs and, in practice, engineers are reluctant to use unstable controllers especially when the system is stable.

- Nonlinear systems

The project aims at developing robust stabilization theory and methods for important classes of nonlinear systems that ensure good controller performance under uncertainty and time delays. The main techniques include techniques called backstepping and forwarding, constructions of strict Lyapunov functions through so-called "strictification" approaches [3] and construction of Lyapunov-Krasovskii functionals [4], [5], [6].

- Predictive control

For highly complex systems described in the time-domain and which are submitted to constraints, predictive control seems to be well-adapted. This model based control method (MPC: Model Predictive Control) is founded on the determination of an optimal control sequence over a receding horizon. Due to its formulation in the time-domain, it is an effective tool for handling constraints and uncertainties which can be explicitly taken into account in the synthesis procedure [7]. The team considers how multiparametric optimization can help to reduce the computational load of this method, allowing its effective use on real world constrained problems.

The team also investigates stochastic optimization methods such as genetic algorithm, particle swarm optimization or ant colony [10] as they can be used to optimize any criterion and constraint whatever their mathematical structure is. The developed methodologies can be used by non specialists.

3.4. Synthesis of reduced complexity controllers

- PID controllers

Even though the synthesis of control laws of a given complexity is not a new problem, it is still open, even for finite-dimensional linear systems. Our purpose is to search for good families of “simple” (e.g. low order) controllers for infinite-dimensional dynamical systems. Within our approach, PID candidates are first considered in the team [2], [36].

- Predictive control

The synthesis of predictive control laws is concerned with the solution of multiparametric optimization problems. Reduced order controller constraints can be viewed as non convex constraints in the synthesis procedure. Such constraints can be taken into account with stochastic algorithms.

Finally, the development of algorithms based on both symbolic computation and numerical methods, and their implementations in dedicated Scilab/Matlab/Maple toolboxes are important issues in the project.

4. Application Domains

4.1. Modeling and analysis of Acute Myeloid Leukemia

In collaboration with the BANG project-team at INRIA Paris-Rocquencourt, the DRACULA team at INRIA Grenoble - Rhône-Alpes, the COMMANDS project team at INRIA Saclay-Île-de-France, INSERM, Cordeliers Research Center and St Antoine Hospital, Paris, we consider the modeling and control of Acute Myeloid Leukemia (AML).

The main goal of this project is the theoretical optimization of drug treatments used in AML, with experimental validation in cell cultures, aiming at proposing efficient therapeutic strategies in clinic.

We work on an discrete maturity-structured model of hematopoiesis introduced in [98]. In this model, several generations of cells are considered and, for the first time, the cell cycle duration is assumed to be distributed. At each level, the population of immature cells are divided into two subpopulations: proliferating and non proliferating cells. Physiological phenomena of re-introduction from the non proliferative into the proliferative subpopulation is modeled in the team as a nonlinear dynamical interconnection between the two sub-populations, and input-output tools seem to be useful in this context [35].

4.2. Control of continuous bioreactors

We study problems of coexistence or regulation of species of micro-organisms in bio-reactors called chemostats.

In [37], we have studied a competition model between an arbitrary number of species in a chemostat with one limiting substrate and including both monotone and non-monotone growth functions, distinct removal rates and variable yields. The dilution rate and the substrate input concentration were chosen as positive constants. We have shown that only the species with the lowest break-even concentration survives, provided that additional technical conditions on the growth functions and yields are satisfied. The proof relies on the construction of a Lyapunov function

In [62], we studied chemostat models in which the species compete for two or more limiting substrates. First we considered the case where the nutrient flow and species removal rates and input nutrient concentrations are all given positive constants. In that case, we use Brouwer degree theory to give conditions guaranteeing that the models admit globally asymptotically stable componentwise positive equilibrium points, from all componentwise positive initial states. Then we used the results to develop stabilization theory for controlled chemostats with two or more limiting nutrients. For cases where the dilution rate and input nutrient concentrations can be selected as controls, we prove that many different componentwise positive equilibria can be made globally asymptotically stable. This significantly extends the existing control results for chemostats with one limiting nutrient. We demonstrate our methods in simulations.

4.3. PVTOL Aircraft

In [20] and [51], we applied the technique of backstepping and of construction of strict Lyapunov functions to solve a tracking problem for the celebrated aircraft model PVTOL (Planar Vertical Takeoff and Landing). It is a benchmark dynamics for an aircraft moving in a vertical plane that contains the important features needed to design controllers for real aircraft. The controllers are the thrust out of the bottom and the rolling moment controller. The main challenges are that the thrust controller must remain nonnegative and that the system is underactuated. We overcame these challenges through a change of variables that transforms the PVTOL tracking dynamics into a chain of three subsystems and then applying asymptotic strict Lyapunov function methods and bounded backstepping. Relative to the PVTOL model literature, the significance of our PVTOL work was (a) the global boundedness of our controllers in the decoupled coordinates, (b) their applicability to cases where the velocity measurements are not available, by using an observer, (c) the positive lower bound on the thrust controller, (d) our allowing a very general class of reference trajectories, and (e) our use of ISS to certify good performance under actuator errors, which would not be possible using LaSalle invariance or nonstrict Lyapunov functions.

5. Software

5.1. YALTA

Participants: David Avanessoﬀ [correspondent], Catherine Bonnet, André Fioravanti [UNICAMP, correspondent].

The YALTA package is dedicated to the study of classical and fractional systems with delay in the frequency-domain. Its objective is to provide basic but important information such as, for instance, the position of the neutral chains of poles and unstable poles, as well as the root locus with respect to the delay of the system. The corresponding algorithms are based on recent theoretical results (see, for instance, [14] and [112]) and on classical continuation methods exploiting the particularities of the problem [113], [18]. Some refinements have been included this year in order to deal with systems with tricky numerical behaviour. The YALTA package will be available in the first semester of 2012.

5.2. OreModules

Participants: Alban Quadrat [correspondent], Daniel Robertz [Univ. Aachen], Frédéric Chyzak [INRIA Rocquencourt, Algorithms Project].

The OREMODULES package [106], based on the commercial Maple package Ore_algebra [107], is dedicated to the study of linear multidimensional systems defined over certain Ore algebras of functional operators (e.g., ordinary or partial differential systems, time-delay systems, discrete systems) and their applications in mathematical systems theory, control theory and mathematical physics. OREMODULES is original because it combines the recent developments of the Gröbner bases over some noncommutative polynomial rings [115], [117] and new algorithms of algebraic analysis in order to effectively check classical properties of module theory (e.g., existence of a non-trivial torsion submodule, torsion-freeness, reflexiveness, projectiveness, stably freeness, freeness), it gives their system-theoretical interpretations (existence of autonomous elements or successive parametrizations, existence of minimal/injective parametrizations or Bézout equations) [121], [120], [105] and it computes important tools of homological algebra (e.g., (minimal) free resolutions, split exact sequences, extension functors, projective or Krull dimensions, Hilbert power series). The abstract language of homological algebra used in the algebraic analysis approach carries over to the implementations in OREMODULES: up to the choice of the domain of functional operators which occurs in a given system, all algorithms are stated and implemented in sufficient generality such that linear systems defined over the Ore algebras developed in the Ore_algebra package are covered at the same time. Applications of the OREMODULES package to mathematical systems theory, control theory and mathematical physics are illustrated in a large library of examples. The binary of the package is freely available at <http://wwwb.math.rwth-aachen.de/OreModules/>.

5.3. Stafford

Participants: Alban Quadrat [correspondent], Daniel Robertz [Univ. Aachen].

The STAFFORD package of OREMODULES [106] contains an implementation of two constructive versions of Stafford's famous but difficult theorem [132] stating that every ideal over the Weyl algebra $A_n(k)$ (resp., $B_n(k)$) of partial differential operators with polynomial (resp., rational) coefficients over a field k of characteristic 0 (e.g., $k = \mathbb{Q}, \mathbb{R}$) can be generated by two generators. Based on this implementation and algorithmic results developed in [128] by the authors of the package, two algorithms which compute bases of free modules over the Weyl algebras $A_n(\mathbb{Q})$ and $B_n(\mathbb{Q})$ have been implemented. The development of the STAFFORD package was motivated by the problem of computing injective parametrizations of underdetermined linear systems of partial differential equations with polynomial or rational coefficients (the so-called *Monge problem*), differential flatness, the reduction and decomposition problems and Serre's reduction problem. To our knowledge, the STAFFORD package is the only implementation of Stafford's theorems nowadays available. The binary of the package is freely available at <http://wwwb.math.rwth-aachen.de/OreModules/>.

5.4. QuillenSuslin

Participants: Alban Quadrat [correspondent], Anna Fabiańska [Univ. Aachen].

The QUILLEN-SUSLIN package [110] contains an implementation of the famous Quillen-Suslin theorem [130], [133]. In particular, this implementation allows us to compute bases of free modules over a commutative polynomial ring with coefficients in a field (mainly \mathbb{Q}) and in a principal ideal domain (mainly \mathbb{Z}). The development of the QUILLEN-SUSLIN package was motivated by different constructive applications of the Quillen-Suslin theorem in multidimensional systems theory [110] (e.g., the Lin-Bose conjectures, the computation of (weakly) left/right/doubly coprime factorizations of rational transfer matrices, the computation of injective parametrizations of flat linear multidimensional systems with constant coefficients, the reduction and decomposition problems, Serre's reduction problem). To our knowledge, the QUILLEN-SUSLIN package is the only implementation of the Quillen-Suslin theorem nowadays available. The binary of the package is freely available at <http://wwwb.math.rwth-aachen.de/QuillenSuslin>.

5.5. OreMorphisms

Participants: Alban Quadrat [correspondent], Thomas Cluzeau [ENSIL, Univ. Limoges].

The ORE MORPHISMS package [109] of OREMODULES [105] is dedicated to the implementation of homological algebraic tools such as the computations of homomorphisms between two finitely presented modules over certain noncommutative polynomial algebras (Ore algebras), of kernel, coimage, image and cokernel of homomorphisms, Galois transformations of linear multidimensional systems and idempotents of endomorphism rings. Using the packages STAFFORD and QUILLEN-SUSLIN, the factorization, reduction and decomposition problems can be constructively studied for different classes of linear multidimensional systems. Many linear systems studied in engineering sciences, mathematical physics and control theory have been factorized, reduced and decomposed by means of the ORE MORPHISMS package. The binary of the package is freely available at <http://www-sop.inria.fr/members/Alban.Quadrat/OreMorphisms/index.html>.

5.6. JanetMorphisms

Participants: Alban Quadrat [correspondent], Thomas Cluzeau [ENSIL, Univ. Limoges], Daniel Robertz [Univ. Aachen].

The JANET MORPHISMS package is dedicated to a new mathematic approach to quasilinear systems of partial differential equations (e.g., Burger's equation, shallow water equations, Euler equations of a compressible fluid) based on algebraic analysis and differential algebra techniques [44]. See Section 6.2. This package computes symmetries, first integrals of motion, conservation laws, study Riemann invariants... The JANET MORPHISMS package is based on the Janet package (<http://wwwb.math.rwth-aachen.de/Janet/>).

5.7. PurityFiltration

Participant: Alban Quadrat [correspondent].

The PURITYFILTRATION package, built upon the OREMODULES package, is an implementation of a new effective algorithm obtained in [97], [77], [76] which computes the purity/grade filtration [102], [103] of linear functional systems (e.g., partial differential systems, differential time-delay systems, difference systems) and equivalent block-triangular matrices. See Section 6.1. This package is used to compute closed form solutions of over/underdetermined linear partial differential systems which cannot be integrated by the standard computer algebra systems such as Maple and Mathematica. This package will soon be available.

5.8. AbelianSystems

Participants: Alban Quadrat [correspondent], Mohamed Barakat [Univ. Kaiserslautern].

The ABELIANSYSTEMS package is an implementation of an algorithm developed in [97], [77], [76] for the computation of the purity/grade filtration [102], [103] in the powerful homalg package of GAP 4 dedicated to constructive homological algebra methods, and developed by Barakat (University of Kaiserslautern) and his collaborators (<http://homalg.math.rwth-aachen.de/>). This package both supersedes the existing PURITYFILTRATION package which uses the non-efficient Maple Gröbner basis computation (see Section 5.7), and the original homalg procedure which computes purity filtration by means of time-consuming spectral sequences. Using the homalg package philosophy, the ABELIANSYSTEMS package can be used for the computation of the purity filtration of objects in different constructive abelian categories such as sheaves over projective varieties as demonstrated in the homalg package called Sheaves (see <http://homalg.math.rwth-aachen.de/>).

5.9. SystemTheory

Participants: Alban Quadrat [correspondent], Thomas Cluzeau [ENSIL, Univ. Limoges], Markus Lange-Hegermann [Univ. Aachen], Mohamed Barakat [Univ. Kaiserslautern].

The SYSTEMTHEORY package is a homalg based package dedicated to mathematical systems. This package, still in development, will include the algorithms developed in the OREMODULES and OREMORPHISMS packages. It currently contains an implementation of the OREMORPHISMS procedures which handle the decomposition problem aiming at decomposing a module/system into direct sums of submodules/subsystems.

6. New Results

6.1. Algorithmic study of linear functional systems

Participants: Alban Quadrat [correspondent], Thomas Cluzeau [ENSIL, Univ. Limoges].

In [77], [76], [97], it is shown that every linear functional system (e.g., PD systems, differential time-delay systems, difference systems) is equivalent to a linear functional system defined by an upper block-triangular matrix of functional operators: each diagonal block is respectively formed by a generating set of the elements of the system satisfying a purely i -codimensional system. Hence, the system can be integrated in cascade by successively solving (inhomogeneous) i -codimensional linear functional systems to get a Monge parametrization of its solution space [129] [89]. The results are based on an explicit construction of the grade/purity filtration of the module associated with the linear functional system. This new approach does not use involved spectral sequence arguments as is done in the literature of modern algebra [102], [103]. To our knowledge, the algorithm obtained in [77], [97] is the most efficient algorithm existing in the literature of non-commutative algebra. It was implemented in the PURITYFILTRATION package developed in Maple (see Section 5.7) and in the homalg package of GAP 4 (see Section 5.8).

Given a linear multidimensional system (e.g., ordinary/partial differential systems, differential time-delay systems, difference systems), Serre's reduction aims at finding an equivalent linear multidimensional system which contains fewer equations and fewer unknowns. Finding Serre's reduction of a linear multidimensional system can generally simplify the study of structural properties and of different numerical analysis issues, and it can sometimes help solving the linear multidimensional system in closed form. In [17], Serre's reduction problem is studied for underdetermined linear systems of partial differential equations with either polynomial, formal power series or analytic coefficients and with holonomic adjoints in the sense of algebraic analysis [102], [103]. These linear partial differential systems are proved to be equivalent to a linear partial differential equation. In particular, an analytic linear ordinary differential system with at least one input is equivalent to a single ordinary differential equation. In the case of polynomial coefficients, we give an algorithm which computes the corresponding linear partial differential equation.

In [45], we give a complete constructive form of the classical Fitting's lemma in module theory which studies the relation between equivalences of linear systems and isomorphisms of their associated finitely presented modules. The corresponding algorithms were implemented in the OREMORPHISMS package (see Section 5.5).

6.2. A new approach to classes of quasilinear PD systems

Participants: Alban Quadrat [correspondent], Thomas Cluzeau [ENSIL, Univ. Limoges], Daniel Robertz [Univ. Aachen].

Many partial differential systems appearing in mathematical physics, engineering sciences and mathematical biology are nonlinear. Unfortunately, algebraic analysis and D -module theory, which were successful for the algorithmic study of linear partial differential systems, cannot consider nonlinear PD systems. This project aims at developing a generalization of the algebraic analysis approach to certain classes of quasilinear partial differential systems appearing in mathematical physics and engineering sciences (e.g., Burgers' equation, shallow water, Euler equations for an incompressible fluid, traffic flow, gas flow). In [44], we have shown how constructive methods of differential algebra and algebraic analysis could be combined to extend results obtained in [45] and [104] for linear PD systems and how they allowed us to compute conservation laws, internal symmetries and decompositions of the solution space of certain classes of quasilinear PD systems. The algorithms have been implemented in the JANETMORPHISMS package dedicated to this new approach (see Section 5.6).

6.3. Stabilization problems & Noncommutative geometry

Participant: Alban Quadrat [correspondent].

In [124], [123], [122], it was shown how the fractional representation approach to analysis and synthesis problems developed by Vidyasagar, Desoer, Callier, Francis, Zames..., could be recast into a modern algebraic analysis approach based on module theory (e.g., fractional ideals, algebraic lattices) and the theory of Banach algebras. This new approach successfully solved open questions in the literature. Basing ourselves on this new approach, we explain in [126] why the non-commutative geometry developed by Alain Connes is a natural framework for the study of stabilizing problems of infinite-dimensional systems. Using the 1-dimensional quantized calculus developed in non-commutative geometry and results obtained in [124], [123], [122], we show that every stabilizable system and their stabilizing controllers naturally admit geometric structures such as connections, curvatures, Chern classes... These results are the first steps toward the use of the natural geometry of the stabilizable systems and their stabilizing controllers in the study of the important H_∞ and H_2 -problems.

6.4. Stabilization of time-delay systems

Participants: Alban Quadrat [correspondent], Arnaud Quadrat [SAGEM, MASSY].

In [127], we study the stabilization problem of a linear system formed by a simple integrator and a time-delay. We show that the stabilizing controllers of such a system can be rewritten as the closed-loop system defined by the stabilizing controllers of the simple integrator and a distributed delay. This result is used to study tracking problems appearing in the study of inertially stabilized platforms for optical imaging systems.

6.5. Singular boundary problems

Participants: Georg Regensburger [correspondent], Anja Korporal [RICAM, Linz], Bruno Buchberger [RISC, Linz], Markus Rosenkranz [Univ. Kent].

In [55], we present results on algorithmic methods for singular boundary problems for linear ordinary differential equations. Moreover, the implementation of integro-differential operators and the corresponding algorithms for boundary problems in the computer algebra system Maple is discussed. The operations implemented for regular boundary problems include computing Green's operators as well as composing and factoring boundary problems. For singular boundary problems, compatibility conditions and generalized Green's operators can be computed. In [94], we give a survey and new results on our algebraic and symbolic approach to boundary problem developed over the last years. The construction of integro-differential operators and polynomials over an integro-differential algebra is described in detail along with a generic implementation of the corresponding canonical forms and algorithms.

6.6. Model of reaction networks

Participants: Georg Regensburger [correspondent], Stefan Müller [RICAM, Linz].

In a joint work, Stefan Müller and G. Regensburger propose a notion of generalized mass action systems that could serve as a more realistic model for reaction networks in intracellular environments; classical mass action systems capture chemical reaction networks in homogeneous and dilute solutions, see e.g. [111] and [114]. We show that several results of Chemical Reaction Network Theory carry over to the case of generalized mass action kinetics. Our main result essentially states that, if the sign vectors of the stoichiometric and the kinetic-order subspace coincide, there exists a unique positive complex balancing equilibrium in every stoichiometric compatibility class.

6.7. Ruin probabilities

Participants: Georg Regensburger [correspondent], Hansjörg Albrecher [Univ. Lausanne], Corina Constantinescu [Univ. Lausanne], Zbigniew Palmowski [Univ. Wroclaw], Markus Rosenkranz [Univ. Kent].

In a cooperation with Hansjörg Albrecher, Corina Constantinescu (both University of Lausanne), Zbigniew Palmowski (University of Wroclaw), and Markus Rosenkranz (University of Kent), we developed a symbolic technique to obtain asymptotic expressions for ruin probabilities and discounted penalty functions in renewal insurance risk models when the premium income depends on the present surplus of the insurance portfolio. The analysis is based on boundary problems for linear ordinary differential equations with variable coefficients and the corresponding Green's operators (integral operators), generalizing the approach from [99]. We obtain also closed-form solutions for more specific functions in the compound Poisson risk model.

6.8. Systems of linear ordinary integro-differential equations

Participants: Alban Quadrat, Georg Regensburger [correspondent].

A. Quadrat and G. Regensburger (in the frame of his grant) are working on a new approach for studying algebraic and algorithmic properties of systems of linear ordinary integro-differential equations with boundary conditions. In a recent series of papers, in particular, [100], [101], V. V. Bavula obtained numerous algebraic results for modules over the ring of integro-differential operators with polynomial coefficients using generalized Weyl algebras. We are interested in how far some of his approach can be made algorithmic and generalized to boundary problems. First results in this direction were presented at the Journées Nationales de Calcul Formel (JNCF 2011).

6.9. Stabilization of MIMO fractional systems with delays

Participants: Catherine Bonnet, Le Ha Vy Nguyen, Alban Quadrat.

In order to yield the set of all stabilizing controllers of a large class of MIMO fractional time-delay systems, we may look for coprime factorizations of the transfer function and their corresponding Bézout factors. As primary results, in considering H_∞ stability, left coprime factorizations and left Bézout factors have been determined analytically from the transfer function. Then a particular stabilizing controller has been derived. We also proved the existence of right coprime factorizations.

6.10. Stability analysis of (fractional) delay systems of neutral type

Participants: Catherine Bonnet, André Fioravanti [UNICAMP], Le Ha Vy Nguyen.

The H_∞ -stability analysis of (fractional) delay systems of neutral type has been studied in [14]. It was shown that the chains of poles are asymptotic to vertical axes which position depend on the roots of a certain polynomial (easily determined from the given transfer function). In [14] the case of roots of multiplicity one was completely treated whereas the case of roots of multiplicity greater than one was considered only in the particular case of neutral systems whose transfer function is a product of transfer functions of neutral systems with one delay. This year, we have studied more deeply the case of roots of multiplicity greater than one for both, standard and fractional delay systems.

6.11. Matrix Norm Approach for Control of Linear Time-Delay Systems

Participants: Catherine Bonnet, André Fioravanti [UNICAMP], José Claudio Geromel [UNICAMP], Silviu Niculescu.

In [46], we have treated the time-delay linear systems control design in the framework of complete and partial information. We were able to find linear controllers that increase the first stability window imposing at the same time that the delay-free system is stable using some properties about the norms of the state-space matrices. Our method treated the design problem by numeric routines based on Linear Matrix Inequalities (LMI) arisen from classical linear time invariant system theory coupled together with a unidimensional search. Both the state and output feedback design, were solved.

6.12. Interval Observers

Participants: Frédéric Mazenc, Silviu Niculescu, Olivier Bernard [UNICAMP].

The technique, based on the notion of interval observer, is a recent state estimation technique, which offers the advantage of providing information on the current state of a system at any instant of time. The first interval observers were relying on the assumption that the system was cooperative or, roughly speaking, "almost" cooperative.

In the contribution [25], we have proved that, for any time-invariant exponentially stable linear system with additive disturbances, time-varying exponentially stable interval observers can be constructed. The technique of construction relies on the Jordan canonical form that any real matrix admits and on time-varying changes of coordinates for elementary Jordan blocks which lead to cooperative linear systems. We applied our to the case of linear systems with input and output that are detectable.

The paper [31] focused on the analysis and the design of families of interval observers for linear systems with a point-wise delay. First, we proved that classical interval observers for systems without delays are *not robust* with respect to the presence of delays, no matter how small delays are. Next, we have shown that, in general, for linear systems with delay, the classical interval observers endowed with a point-wise delay are *unstable*. A new type of design of interval observers enabling to circumvent these obstacles is proposed. It provides with framers that incorporate *distributed delay* terms. The proposed interval observers are assessed through a non-linear biotechnological model.

6.13. Partial Differential Equations

Participants: Frédéric Mazenc, Christophe Prieur [GIPSA Lab, CNRS].

In [33] and [65], for families of partial differential equations (PDEs) with particular stabilizing boundary conditions, we have constructed strict Lyapunov functions. The PDEs under consideration were parabolic and, in addition to the diffusion term, might contain a nonlinear source term plus a convection term. The boundary conditions were the classical Dirichlet conditions, or the Neumann boundary conditions or a periodic one. The constructions relied on the knowledge of weak Lyapunov functions for the nonlinear source term. The strict Lyapunov functions were used to prove asymptotic stability in the framework of an appropriate topology. Moreover, when an uncertainty is considered, our construction of a strict Lyapunov function made it possible to establish some robustness properties of Input-to-State Stability (ISS) type.

In [64], we have considered a family of time-varying hyperbolic systems of balance laws. The partial differential equations of this family can be stabilized by selecting suitable boundary conditions. For the stabilized systems, the classical technique of construction of Lyapunov functions provides with a function which is a weak Lyapunov function in some cases, but is not in others. We transform this function through a strictification approach which gives a time-varying strict Lyapunov function which allows us to establish asymptotic stability in the general case and a robustness property with respect to additive disturbances of Input-to-State Stability (ISS) type.

6.14. Positive solutions

Participants: Frédéric Mazenc, Siviu Niculescu.

In the work [32], we propose a new approach for the stabilization of nonlinear time-varying forward-complete systems with delay in the input. This approach is a *new reduction model* approach, which relies on operators of a new type. It presents three advantages. First, the corresponding control laws do not include distributed terms. Second, it yields closed-loop systems with positive solutions that can be easily derived. Finally, the stabilized systems possess some robustness properties (for instance of ISS type) that can be estimated.

6.15. Backstepping with delay

Participants: Frédéric Mazenc, Siviu Niculescu, Mounir Bekaik.

In the contributions [30] and [63], we revisited the problem of constructing globally asymptotically stabilizing control laws for nonlinear systems in feedback form with a known pointwise delay in the input. The result we obtained covers a family of systems wider than those studied in the literature and endows with control laws with a single delay, in contrast to those given in previous works which include two distinct pointwise delays or distributed delays. The strategy of design is based on the construction of an appropriate Lyapunov-Krasovskii functional. An illustrative example ends the paper.

6.16. Certifying good performance for adaptive systems

Participants: Frédéric Mazenc, Michael Malisoff [Louisiana State University].

The usual adaptive control problem is to design a controller that forces all trajectories of the system to track a prescribed trajectory, while keeping the estimator of the unknown constant parameter vector bounded. We studied the important and more difficult adaptive tracking and estimation problem of simultaneously (1) forcing the trajectories of the system to track a given trajectory and (2) identifying the parameter vector. This problem was known to be solvable when the regressor satisfies a persistency of excitation condition, but the known results did not provide a strict Lyapunov function for the augmented error dynamics and so could not certify good performance such as ISS with respect to uncertainty added to the controller.

Our main result from [118] covers adaptively controlled first-order nonlinear systems that satisfy the persistency of excitation condition and are affine in the unknown parameter vector. Our contribution consists in particular in constructing global strict Lyapunov functions for the augmented error dynamics. In [28], we extended [118] to adaptive tracking for nonlinear systems in feedback form with multiple inputs and unknown high-frequency gains multiplying the controllers. The control gains must be identified as part of the control objective. High-frequency gains are important for electric motors, flight dynamics, and robot manipulators. We used a persistency of excitation condition that again ensured tracking and parameter identification and led to the explicit construction of a global strict Lyapunov function for the closed loop augmented error dynamics. The strict Lyapunov function was key to proving integral ISS with respect to time varying uncertainties added to the unknown parameters.

6.17. Improved Model Predictive Control design

Participants: Sorin Olaru, Morten Hovd [NTNU, Trondheim, Norway].

New results [38] have been obtained toward the computation of feasible sets for linear model predictive control techniques, based on set relations and not on the conventional orthogonal projection. Further, the problem of computing suitable inner approximations of the feasible sets was considered. Such approximations are characterized by simpler polytopic representations, and preserve essential properties as convexity, positive invariance, inclusion of the set of expected initial states.

6.18. Particle Swarm Optimization for reduced order Hinfini controllers with constraints handling

Participants: Guillaume Sandou, Gilles Duc [Supelec (E3S) Control Department], Mohamed Yagoubi [Ecole des Mines de Nante].

Efficient dedicated methods have been developed for Hinfinity controller synthesis. However, such methods require translating the design objectives using weighting filters, whose tuning is not easy; in addition they lead to high order controllers which have to be reduced. A particle swarm optimization method is used to solve both problems successively: after having optimized the filters according to the design specifications using a full order controller but no reformulation of the constraints, a reduced-order one is computed using the obtained filters. Experimental tests for a pendulum in the cart exhibit much more than satisfactory results [95], [52]. In addition, the design of Hinfinity static output feedback has been done and tested using the Compleib library and exhibiting similar results to those obtained with the HIFOO solver [86].

6.19. Ant colony for symbolic regression

Participants: Guillaume Sandou, Bianca Minodora Heiman.

The identification of systems is a key feature to get representative models and so to design efficient control laws. Numerous methods exist to identify the parameters of nonlinear systems when the global structure of the model is given. The problem appears to be much more difficult when this structure is unknown (symbolic regression). We introduce ant colony optimization (ACO) in solving the problem of non linear systems identification in the case of an unknown structure of the mode [53]. Numerical results prove the viability of the approach.

6.20. Robust optimization for energy management

Participants: Guillaume Sandou, Henri Borsenberger, Philippe Dessante [Supelec (E3S) Energy Department].

Many studies have considered the solution of Unit Commitment problems for the management of energy networks. In this field, earlier work addressed the problem in deterministic cases and in cases dealing with demand uncertainties. In this paper [15], the authors develop a method to deal with uncertainties related to the cost function. Indeed, such uncertainties often occur in energy networks (waste incinerator with a priori unknown waste amounts, cogeneration plant with uncertainty of the sold electricity price...). The corresponding optimization problems are large scale stochastic non-linear mixed integer problems. The developed solution method is a recourse based programming one. The main idea is to consider that amounts of energy to produce can be slightly adapted in real time, whereas the on/off statuses of units have to be decided very early in the management procedure. Results show that the proposed approach remains compatible with existing Unit Commitment programming methods and presents an obvious interest with reasonable computing loads.

6.21. Modeling and control of Acute Myeloid Leukemia

Participants: José Luis Avila Alonso, Annabelle Ballesta [BANG project-team], Frédéric Bonnans [COMMANDS project-team], Catherine Bonnet, Jean Clairambault [BANG project-team], Xavier Dupuis [COMMANDS project-team], Pierre Hirsch [INSERM Paris (Team18 of UMR 872) Cordeliers Research Centre and St. Antoine Hospital, Paris], Jean-Pierre Marie [INSERM Paris (Team18 of UMR 872) Cordeliers Research Centre and St. Antoine Hospital, Paris], Faten Merhi [INSERM Paris (Team18 of UMR 872) Cordeliers Research Centre and St. Antoine Hospital, Paris], Silviu Niculescu, Hitay Özbay [Bilkent University, Ankara, Turkey], Ruoping Tang [INSERM Paris (Team18 of UMR 872) Cordeliers Research Centre and St. Antoine Hospital, Paris].

In order to better take into account physiological phenomena as well as better understand the effect of the new anti-FLT3 therapy for AML, we have modified the model M. Adimy and F. Crauste in two ways [88]:

- we have introduced a modeling of quick self-renewal of cells in each stage of maturation.
- we have modeled each phase of the proliferating compartment (that is G_1 , S , G_2 and M) separately. For the time being, only the M -phase is supposed to have a fixed time duration as it is well-known that the short time necessary to perform mitosis is hardly submitted to any variation.

In parallel to this modeling task, Faten Merhi and Annabelle Ballesta have performed experiments in order to identify parameters of the model. These experiments (which will continue in 2012) tend to show that we will converge to a patient-dependant model.

6.22. Chronic myelogenous leukemia

Participants: Frédéric Mazenc, Silviu Niculescu, Peter Kim [Univ. of Sydney].

The paper [26] focuses on the stability analysis of a delay-differential system encountered in modeling immune dynamics during imatinib treatment for chronic myelogenous leukemia (CML). A simple algorithm is proposed for the analysis of delay effects on the stability. Such an algorithm takes advantage of the particular structure of the dynamical interconnections of the model. The analysis shows that the model yields three fixed points, two of which are always unstable and one of which is sometimes stable. The stable fixed point corresponds to an equilibrium solution in which the leukemia population is kept below the cytogenetic remission level. This result implies that, during imatinib treatment, the resulting anti-leukemia immune response can serve to control the leukemia population. However, the rate of approach to the stable fixed point is very slow, indicating that the immune response is largely ineffective at driving the leukemia population towards the stable fixed point. To extend the stability analysis with respect to the delay parameter, we conduct a global nonlinear analysis to demonstrate the existence of unbounded solutions. We provide sufficient conditions based on initial cell concentrations that guarantee unbounded solutions and comment on how these conditions can serve to predict whether imatinib treatment will result in a sustained remission based on a patient's initial leukemia load and initial anti-leukemia T cell concentration.

6.23. Control of a model of human heart

Participants: Frédéric Mazenc, Michael Malisoff [Louisiana State University], Marcio de Queiroz [Louisiana State University].

We worked on the control of human heart rate during exercise [27], which is a problem that has implications for the development of protocols for athletics, assessing physical fitness, weight management, and the prevention of heart failure. We provided new stabilization techniques, based on the notion of tracking, for a recently-proposed nonlinear model for human heart rate response that describes the central and peripheral local responses during and after treadmill exercise. The control we proposed respect the sign constraint imposed by the model and we proposed observers to cope with the case (important from a practical point of view) where some of the variables are not measured.

6.24. Marine Robotic Surveys

Participants: Frédéric Mazenc, Michael Malisoff [Louisiana State University], Fumin Zhang [Georgia Tech.].

The works [24], [61] was inspired by the recent Deepwater Horizon oil spill disaster. The goal was to develop and implement robotic surveying methods to evaluate the immediate and longer term environmental impacts of the oil spills. It was joint with Michael Malisoff from the LSU and a Georgia Tech robotics team led by Fumin Zhang. Robotic surveying methods provide a low cost and convenient way to collect data in marsh areas that are difficult to access by human based methods. We designed strict Lyapunov functions that made it possible to use ISS to quantify the robustness of collision avoiding curve tracking controllers under controller uncertainty. The controllers are designed to keep the robot a fixed distance from, but moving parallel to, a two dimensional curve. Four challenges in applying ISS to curve tracking are (a) the need to restrict the magnitudes of the uncertainty to keep the state in the state space and build a strict Lyapunov function, (b) the likelihood of time delays in the controllers in real time applications, (c) possible parameter uncertainty such as unknown control gains, and (d) generalizations to three dimensional curve tracking. We overcame challenge (a) by finding maximum bounds on the perturbations that maintain forward invariance of a nested family of hexagons that fill the state space and transforming a nonstrict Lyapunov function into a strict Lyapunov function on the full state space. To address challenge (b), we used a Lyapunov-Krasovskii approach from [119] to convert the strict Lyapunov function into a Lyapunov-Krasovskii functional. This led to an upper bound on the admissible controller delay that can be introduced into the controller while still maintaining ISS.

7. Contracts and Grants with Industry

7.1. Contracts with Industry

Alban Quadrat and Arnaud Quadrat (SAGEM Défense Sécurité, Etablissement de MASSY) have initiated discussions between SAGEM, the DISCO project and the L2S about a future collaboration in the direction of the analysis of the effect of the time-delay in inertially stabilized platforms for optical imaging systems. We hope that these discussions will conclude in a contract in 2012 on this subject.

8. Partnerships and Cooperations

8.1. Regional Initiatives

- + DIGITEO Project (DIM LSC) ALMA
Project title: Mathematical Analysis of Acute Myeloid Leukemia
Decembrer 2010 - December 2013
Coordinator: Catherine Bonnet
Other partners: Inria Paris-Rocquencourt, France, L2S, France, INSERM, Cordeliers Research Center, France.

Abstract: this project studies a model of leukaemia based on previous works by M. Adimy and F. Crauste (Lyon), with theoretical model design adjustments and analysis in J. L. Avila Alonso's Ph D thesis and experimental parameter identification initiated by F. Merhi, postdoc of Bang (Dec. 2010-Nov. 2011), working at St. Antoine Hospital (Paris) on biological experiments on leukaemic cells.

- + DIGITEO Project (DIM Cancéropôle) ALMA2
Project title: Mathematical Analysis of Acute Myeloid Leukemia - 2
October 2011 - March 2013
Coordinator: Jean Clairambault (Inria Paris-Rocquencourt)
Other partners: Inria Saclay-Île-de-France, France, L2S, France, INSERM, Cordeliers Research Center, France.
Abstract: This project has taken over the experimental identification part in St. Antoine Hospital, together with further model design with the postdoc of A. Ballesta (BANG). With this postdoc project will also be developed the theoretical and experimental - in leukaemic cell cultures - study of combined therapies by classical cytotoxics (anthracyclins, aracytin) and recently available targeted therapies (anti-Flt-3).
- + DIGITEO Project (DIM LSC) MOISYR
Project title: Monotonie, observateurs par intervalles, et systèmes à retard
Decembre 2011 - Decembre 2014
Coordinator: Frédéric Mazenc
Other partners: organisme, labo (pays) L2S, France, Mines-ParisTech, France.
Abstract: MOISYR is concerned with the creation of the problem of extending the theory of monotone systems to the main families of continuous time systems with delay along with the application of this theory to the design of observers and interval observers. In particular, nonlinear systems with pointwise and distributed delays and stabilizable systems with delay in the input shall be considered. In a second setp, we shall extend our result to discrete time systems and to a specific class of continuous/discrete systems called Networked Control Systems.

8.2. National Initiatives

- + A. Quadrat has a long term collaboration with T. Cluzeau and M. Barkatou (University of Limoges, XLIM).

8.3. European Initiatives

8.3.1. Major European Organizations with which Disco has followed Collaborations

A. Quadrat has developed a strong collaboration with the members of the Lehrstuhl B für Mathematik and particularly with Daniel Robertz and Mohamed Barakat. He is a member of a PHC Procope developed in collaboration with the University of Limoges (XLIM) and the Lehrstuhl B für Mathematik, RWTH Aachen University (2011-2012) which aims at developing computer algebra aspects to mathematical systems theory and control theory.

C. Bonnet has developed a long term collaboration with J.R. Partington, Department of Pure Mathematics of the University of Leeds on the robust control of distributed parameter systems.

C. Bonnet and S.I. Niculescu have started a collaboration with H. Özbay, Bilkent University some years ago on various subjects including stability analysis of linear and nonlinear delay systems.

8.4. International Initiatives

8.4.1. INRIA International Partners

- C. Bonnet has started a collaboration with Unicamp, Sao Paulo Brazil and a collaboration with University of Kyoto, Japan.
- F. Mazenc has a strong collaboration with M. Malisoff, Louisiana State University, USA.

8.4.2. Visits of International Scientists

1. Corina Constantinescu, University of Lausanne, Switzerland, 5–9 July 2011.
2. André Fioravanti, Unicamp, Sao Paulo, Brazil, 22 November - 5 December 2011.
3. Anja Korporal, Radon Institute for Computational and Applied Mathematics (RICAM), Linz, Austria, 28 March–9 April 2011 and 29 November–9 December 2011.
4. Hitay Özbay, Bilkent University, Turkey, 14-18 November 2011.
5. Stefan Müller, Radon Institute for Computational and Applied Mathematics (RICAM), Linz, Austria, 2–9 June 2011.
6. Daniel Robertz, RWTH Aachen University, 3–8 October, (PHC Procope).

8.4.2.1. Internship

- Le Ha Vy Nguyen, internship 3rd year ESISAR Valence and M2R Grenoble, February-June 2011.
- Alice Clément, Fénelon Sainte Marie High School , Paris, 20-24 June 2011.

9. Dissemination

9.1. Animation of the scientific community

- + C. Bonnet is a member of the IFAC Technical Committee on Robust Control, of the Program Committee of the Septième Conférence Internationale Francophone d'Automatique, CIFA 2012, Grenoble and of the CNU61 (National Council of Universities). She is also in the boards of the association *Femmes et Mathématiques* and of the consortium Cap' Maths. She is co-organizer of the "Séminaire du Plateau de Saclay".
- + Frédéric Mazenc was associate editor for the conferences : 2012 Chinese Control and Decision Conference, Taiyuan, China, 2012 American Control Conference, Montréal, Canada, Septième Conférence Internationale Francophone d'Automatique, CIFA 2012, Grenoble, 50th IEEE Conference on Decision and Control and European Control Conference, Orlando, FL, USA, He is co-organizer of the 'Séminaire du Plateau de Saclay'.
- + A. Quadrat is an Associate Editor of the international journal "Multidimensional Systems and Signal Processing" (Springer). With Thierry Coquand, he organized a mini-workshop on constructive homological algebra, its applications and its implementations at the CIRM, Luminy, 24–28/01. He was a member of the Program Committee of the "7th International Workshop on Multidimensional Systems" (nDS'11, Poitiers, 05–07/09). He was an invited speaker at the "2nd workshop on Differential Equations by Algebraic Methods" (DEAM2, Linz, 09–11/02), at the conference "Functional Equations at Limoges" (FELIM, Limoges, 14–16/03), and at the conference "Modern Constructive Algebra – Dedicated to Henri Lombardi" (Besançon, 15–16/10). He was also invited to give a lecture at the conference "Mathematics: Algorithms and Proofs" (MAP, Lorentz center, Leiden, 28–11/02–12), and to give a talk at RWTH-Aachen University (Graduiertenkolleg on "Experimental and Constructive Algebra"), and a talk at the seminar of the INRIA team project Non-A, INRIA Lille-Nord Europe. He also participated to the "7th International Workshop on Multidimensional Systems" (nDS'11, Poitiers, 05–07/09) where he presented two papers, gave a talk at the GDR SAR and a talk at the GDR EDP. He attended the conferences "MaGiX@LiX 2011" (Ecole Polytechnique, 19–24/09), "Equations différentielles et théorie de Galois" (IHES, 17–21/10), "Bicentenaire de la naissance d'Evariste Galois" (IHP, 24–28/11) and "Journées Nationales de Calcul Formel" (JNCF, Luminy, 14–18/11). Within the PHC Procope, he visited the Lehrstuhl B für Mathematik, RWTH Aachen University twice, to cowork with this group (12–18/06, 04–11/12). Finally, he was a referee for the PhD these entitled by "Linear Systems and Fliess Models" by Muhammad Khurram Zafar, Abdus Salam School of Mathematics Sciences, GC University Lahore, Pakistan, and "Reduced Order Multiobjective Control" by Christian Fischer, Mines-ParisTech, CMA, Sophia Antipolis, and he was a member of the jury for the PhD thesis "Analyse des erreurs d'estimateurs des dérivées de signaux bruités et applications", by Dayan Liu of the team project Non-A, INRIA Lille-Nord Europe.

- + G. Regensburger coedited with Markus Rosenkranz and William Sit a double special issue on “Algebraic and Algorithmic Aspects of Differential and Integral Operators” (AADIOS) in Mathematics in Computer Science, which was published in February 2011, see [131] and <http://www.springerlink.com/content/1661-8270/4/2-3/>. He coorganized the AADIOS Session at “Applications of Computer Algebra” (ACA’11, Houston, 27–30/06) and served as publicity chair and web master for “Mathematical Aspects of Computer and Information Sciences” (MACIS 2011, Beijing, 19–21/10). He was an invited speaker at “Functional Equations in LIMoges” (FELIM, Limoges, 14–16/03) and at the Symbolic Analysis workshop at the conference “Foundations of Computational Mathematics” (Symbolic Analysis@FoCM 2011, Budapest, 12–14/07). He was invited to give a talk at the Algorithms project, Joint Centre INRIA - Microsoft Research (Orsay, 31/03), and at the Laboratoire d’Informatique Fondamentale de Lille (LIFL), University of Lille I (Lille, 08/11). G. Regensburger gave contributed talks at the workshop “Constructive homological algebra methods, implementations and applications” (CIRM, Marseille, 24–28/01), at the “Second Workshop on Differential Equations by Algebraic Method” (DEAM2, Linz, 09–11/02), and at the Journées Nationales de Calcul Formel (JNCF, CIRM, Marseille 14–18/11). He participated in the conferences “MaGiX@LiX 2011” (Ecole Polytechnique, 19–24/09), “Equations différentielles et théorie de Galois” (IHES, 17–21/10), and “Célébration du bicentenaire de la naissance d’Évariste Galois” (IHP, 24–28/10).

9.2. Teaching

Teaching

Sorin Olaru and Guillaume Sandou are associate Professors at SUPELEC.

S.I. Niculescu: differential and integral calculus, 60h, L3, Mines Paris Tech, Paris, France; signals and systems, 16h, M2R, ESIEE, Marne-la-vallée, France; Stability and control of time-delay systems, 15h, KU Leuven, Belgium.

G. Sandou : identification for control , 21h, M2, ENSTA, Paris, France.; signal analysis, 15h, M1, Ecole Militaire, Paris, France; mu-analysis, nonlinear systems, 22h, M2, Ecole des Mines de Nantes, France; Linear Quadratic and H_∞ Control, 7h, M2, Université d’Evry, France; Embedded systems and Control, 20h, L3, M1, Ecole Centrale Paris, France.

PhD & HdR :

HdR : Sorin Olaru, La commande des systèmes dynamiques sous contrainte. Interaction optimisation-géométrie-commande, University of Paris-Sud, 24 may 2011.

PhD : André Fioravanti, H_∞ -analysis and control of time-delay systems by methods in frequency domain, University of Paris-Sud, 28 June 2011. Supervisor : C. Bonnet.

Fernando Francisco Mendez Barrios, Low-order controllers for time-delay systems. An analytical approach, University of Paris-Sud, July 2011. Supervisor : S.I. Niculescu.

Warody Lombardi, Constrained control for time-delay systems, September 2011. Supervisor : S. Olaru, Co-Supervisor : S.I. Niculescu.

PhD in progress :

José Luis Avila Alonso, Mathematical Analysis of Acute Myeloid Leukemia, December 31st 2011. Supervisors : C. Bonnet, J. Clairambault and S.I. Niculescu.

Mounir Bekaik, Observation and control of time-varying delay systems, octobre 2010,. Supervisors:Frédéric Mazenc, Silviu I. Niculescu.

Abdelkarim Chakhar, Algebraic Analysis Approach to Nonlinear PD systems, September 1st 2010. Supervisors : M. Barkatou, T. Cluzeau and A. Quadrat.

Ngoc Thach Dinh, Monotony, Internal Observers and Delay systemsMonotonie, décembre 2011. Supervisors: Frédéric Mazenc, Silvère Bonnabel, Silviu I. Niculescu.

Le Ha Vy Nguyen, H_∞ Stability and control of fractional delay systems, September 15th 2011. Supervisor: C. Bonnet.

Nikola Stankovic, Fault tolerant control for delay-time systems, Supervisor: S. Oлару, Co-Supervisor: S.I. Niculescu.

10. Bibliography

Major publications by the team in recent years

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- [6] S.-I. NICULESCU. *Delay Effects on Stability: a Robust Control Approach*, Lecture Notes in Control and Information Sciences, Springer, 2001, vol. 269.
- [7] S. OLARU, D. DUMUR. *Avoiding constraints redundancy in predictive control optimization routines*, in "IEEE Trans. Automat. Control", 2005, vol. 50, n^o 9, p. 1459–1465.
- [8] A. QUADRAT. *The fractional representation approach to synthesis problems: an algebraic analysis viewpoint. Part I: (Weakly) doubly coprime factorizations, Part II: Internal stabilization*, in "SIAM J. Control & Optimization", 2003, vol. 42, n^o 1, p. 266–299, 300–320.
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- [10] G. SANDOU. *Particle swarm optimization: an efficient tool for the design of automatic control law*, in "European Control Conference", Budapest, Hungary, August 23rd-26th 2009.

Publications of the year

Doctoral Dissertations and Habilitation Theses

- [11] A. FIORAVANTI. *H_∞ -analysis and control of time-delay systems by methods in frequency domain*, University of Paris-Sud, June 2011.
- [12] S. OLARU. *La commande des systèmes dynamiques sous contrainte. Interaction optimisation-géométrie-commande*, University of Paris-Sud, May 2011, Habilitation à diriger des recherches.

Articles in International Peer-Reviewed Journal

- [13] W. AGGOUNE, I.-C. MORĂRESCU, S.-I. NICULESCU. *On vehicle following control systems with delays*, in "Mathematical Reports", 2011, vol. 13 (63), n^o 3, p. 1-14.
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