ACTIVITY REPORT

2007
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6. RESPONSIBILITIES
1. PERSONNEL
1 Academic staff

ABSIL Pierre-Antoine
Pierre-Antoine Absil is associate professor, Université Catholique de Louvain. Engineer in Physics and PhD in Applied Sciences (Université de Liège, 1998 and 2003). Postdoctoral positions with Florida State University (2003-2005) and the University of Cambridge (2005-2006). His research area is in computational mathematics, with particular interests in numerics on manifolds, linear and nonlinear programming algorithms, and biomedical applications.

BASTIN Georges
Georges Bastin received the electrical engineering degree and the PhD degree, both from Université Catholique de Louvain, Louvain-la-Neuve, Belgium. He is presently Professor in the Center for Systems Engineering and Applied Mechanics (CESAME) at the Université Catholique de Louvain. His main research interests are in system identification, nonlinear control theory, adaptive systems and random fields with applications to mechanical systems and robotics, biological and chemical processes, and environmental problems.
BEN-NAOUM Kouider
Kouider Ben-Naoum, Université Catholique de Louvain (Department of Mathematical Engineering) obtained a doctoral degree at the Université de Lille (France) in 1983 and a PhD in Mathematical Sciences at the Université Catholique de Louvain (Belgium) in 1994. He held research and teaching positions at the Université d’Oran (Algeria) 1983-1990; at the Université Catholique de Louvain (Belgium) 1991-1997; at the Université de Mons-Hainaut (Belgium) 1997-1999; and finally at the Université Catholique de Louvain where he currently is a pedagogical adviser in mathematics and a teacher since 2000. His scientific interests lie in the field of nonlinear analysis, number theory and engineering education.

BLONDEL Vincent
Vincent D. Blondel received a degree in Applied Mathematics from the Université Catholique de Louvain in 1988, a Master Degree in Pure Mathematics from Imperial College (London, UK) and a PhD in 1992. He was the Göran Gustafsson Fellow at the Royal Institute of Technology (Stockholm, Sweden) in 1992-1993 and was a research fellow at the French National Research Center in Control and Computer Science (INRIA, Rocquencourt-Paris) in 1993-1994. He has held research and teaching positions at Oxford University (1992), the Australian National University (1991), the University of California at Berkeley (1998), the Santa Fe Institute (2000), the Ecole Normale Supérieure in Lyon (1998), the University of Paris VII (1999 and 2000).
In 2005-2006 he was visiting professor and Fullbright Scholar at the Massachusetts Institute of Technology (Cambridge, USA). He has been a recipient of a Grant from the Trustees of the Mathematics Institute of Oxford University (1992), the Prize Agathon De Potter of the Belgian Royal Academy of Science (1993), the Prize Paul Dubois of the Montefiore Institute (1993), the triennial SIAM prize on control and systems theory in 2002, the Ruberti price of the IEEE in 2006 and the Prize Adolphe Wetrems of the Belgic Royal Academy of Science (2006).

CAMPION Guy
Mechanical engineering and PhD degree, Université Catholique de Louvain. Research Associate (Fonds National de la Recherche Scientifique). Part-time Professor at the CESAME.
His main research interests are: nonlinear control theory, adaptive control, modelling and control of mechanical systems, and specially nonholonomic systems such as mobile robots.
DELANNAY Laurent
Laurent Delannay received a degree in Mechanical Engineering from the Université Catholique de Louvain in 1996, and a PhD in Materials Sciences from the Katholieke Universiteit Leuven in 2001. He was postdoctoral fellow at the Ecole Nationale Supérieure des Mines de Paris (Sophia Antipolis, France) in 2002, and later member of Cesame at UCL. Since 2006, he is research associate (chercheur qualifié) of the National Fund for Scientific Research (FNRS) and part-time associate professor at UCL.
His main research interests are: the multiscale modelling of advanced metallic alloys deformed under finite strains (e.g. crystal plasticity and mean-field theories), the simulation of metal forming operations, and the mathematical description of crystallographic texture.

DELEERSNIJDER Eric
Research associate with the Belgian National Fund for Scientific Research (FNRS) and part-time reader (UCL). Docteur en sciences appliquées (mécanique), UCL, 1992. Visiting scientist at the Laboratoire de Météorologie Dynamique du CNRS (Ecole normale supérieure, Paris), 1993-1994; Chargé de recherche associé du CNRS at the Institut de Recherche Mathématique de Rennes, 2001; Gastdocent at the Environmental Fluid Mechanics Section, Delft University of Technology, 2003. Member of the editorial board of several scientific journals. Development of CART (Constituent-oriented Age and Residence time Theory) and SLIM (Second-generation Louvain-la-Neuve Ice-ocean Model).
DOCHAIN Denis

Denis Dochain completed his PhD thesis in 1986 and a “thèse d’agrégation de l’enseignement supérieur” in 1994, respectively, at the Université Catholique de Louvain (UCL), Belgium. He has been CNRS research associate at the LAAS (Toulouse, France) in 1989, Professor at the Ecole Polytechnique de Montréal, Canada in 1987-88 and 1990-92, and invited Professor at the Queen’s University, Kingston, Canada from 2002 to 2004. He has been with the FNRS (Fonds National de la Recherche Scientifique, National Fund for Scientific Research), Belgium since 1990. Since September 1999, he is Professor at the CESAME (Center for Systems Engineering and Applied Mechanics), UCL, and Honorary Research Director of the FNRS.

Since 2005, he is Full Professor at the UCL. He is associate editor of ”Automatica”, the "IEEE Transactions on Automatic Control” and of the ”Journal of Process Control”. He is chairing the IFAC Coordinating Committee on Process and Power Systems. He received the Best Referee Award of the Journal of Process Control in 1999 and is an Outstanding Reviewer for Automatica in 2003-2004. His main research interests are in the field of distributed parameter systems, nonlinear systems, parameter and state estimation, and adaptive extremum seeking control with application to bioprocesses, chemical processes, pulp and paper processes, polymerisation reactors, electric systems, biomedical systems and environmental systems.
DOGHRI Issam

Issam Doghri obtained a degree in Civil Engineering from Ecole Nationale d’Ingénieurs de Tunis in 1985, a M.S. in Applied Mechanics from Ecole Normale Supérieure de Cachan in 1986 and a Ph.D. in Mechanics from Université Pierre et Marie Curie in 1989. He was a post-doc. at University of California at Santa Barbara from 9/89 till 11/90 and a developer at Centric Engineering Systems Inc. in Palo Alto, California from 12/90 till 9/94. He joined Université Catholique de Louvain in 10/94 where he is a professor of mechanical engineering.

His area of expertise is in computational mechanics of materials. He is the author of a book published by Springer and about 50 scientific papers. He co-founded a start-up company (e-Xstream engineering SA).

DUPRET François

François Dupret has pursued all his career at the Université Catholique de Louvain, were he became professor in 1990. His major research interests relate to the application of Continuum Mechanics to the numerical modelling of Materials Forming Processes, including in particular the simulation of Thermoplastics Injection Molding and Bulk Single Crystal Growth.

He started the FEMAGSoft spin-off company in 2003 with a view to further developing and commercializing the FEMAG software, which is devoted to Crystal Growth simulation and is used by major silicon growers in the world.

He currently teaches Continuum Mechanics, Fluid Mechanics, Simulation of Forming Processes, and Irreversible Thermodynamics.
GEVERS Michel
Professor at UCL, since 1973. PhD Stanford University, 1972. Senior Research Fellow at the Australian National University, 1983-1986. Visiting Professor at the University of Newcastle, Australia, the Australian National University and the Technical University of Vienna. System identification, system theory, estimation and filtering, robust control. Doctor Honoris Causa of the VUB. Chaire Francqui at the ULB, 1994. Fellow and Distinguished Member of the IEEE. Distinguished Lecturer of the IEEE Control Systems Society. Coordinator of the Interuniversity Attraction Pole on Dynamical Systems and Control. Belgian team leader of the European Research Network on System Identification (ERNSI). Associate Editor: European Journal of Control, and Mathematics of Control, Signals and Systems. His present research interests are in system identification, robust control, identification for control, and data-based model-free controller tuning.

KEUNINGS Roland
LEFEVRE Philippe
Major research interest: investigation of the neural control of movement, by combining both experimental and modelling approaches. Teaching: modelling of biological systems and biomedical engineering (coordinator of the program in biomedical engineering).
He has a broad experience on the interaction between vision and movement.

LEGAT Vincent
NESTEROV Yurii
Yurii Nesterov received a master degree in Applied Mathematics in 1977 at Moscow State University, and Ph.D. degree in 1984 at Institute of Control Sciences, Moscow. Since 1977 he worked at Central Economical and Mathematical Institute, Acad. Sci. USSR. In 1993-2000 he was a visitor professor at CORE. Starting from 2000, he is a professor at INMA and remains a member of CORE.
His research interests are related to complexity issues and efficient methods for solving various optimization problems. The main results are obtained in Convex Optimization (optimal methods for smooth problems, polynomial-time interior-point methods, smoothing technique for structural optimization). Among other developments, we mention SDP-relaxations for Boolean problems, representation of sums of squares, cubic regularization of Newton method. He is an author of 4 monographs and more than 70 refereed papers in the leading optimization journals. In 2000, he won the triennial Dantzig Prize awarded by SIAM and Mathematical Programming Society for a research having a major impact on the field of mathematical programming.

PAPALEXANDRIS Miltiadis
Miltiadis Papalexandris, Chaire-Tractebel - Pôle Energie, Associate Professor in the Department of Mechanical Engineering. Dipl. in Naval Architecture and Marine Engineering, National Technical University of Athens, 1991. MSc in Aeronautics, California Institute of Technology, 1993. PhD in Aeronautics and Applied Mathematics, California Institute of Technology, 1997. From 1998 until 2002 he was a member of the Technical Staff of NASA’s Jet Propulsion Laboratory. He joined UCL in September 2002. His research activities include numerical simulation of high-speed reacting flows (explosions, detonations, etc), modelling and simulation of subsonic reacting flows, algorithm development for hyperbolic differential equations, and modelling and simulation of flows of heterogeneous two-phase mixtures.
Pr. Papalexandris has published 28 articles in peer-reviewed journals. He is a member of APS, AIAA, and the Combustion Institute.

REMACLE Jean-François
Pr. Remacle did a PhD in Engineering at the Université de Liège (1992-1997) Thereafter, he was Post-Doctoral Fellow and Research Associate at Ecole Polytechnique de Montréal between 1997 and 1999. He was hired as Research associate and Research Associate Professor at Rensselaer Polytechnic Institute where he worked closely with Pr. M. Shephard and Pr. J.E. Flaherty. Pr. Remacle joined the UCL in 2002 as an Assistant Professor. Pr. Remacle’s research interests are principally focused on the numerical analysis and the efficient implementation of high order and adaptive methods for solving Partial Differential equations. Topics of interest that are currently covered are: 1) High order Discontinuous Galerkin Methods 2) Anisotropic mesh adaptation 3) eXtended Finite Element Methods (XFEM) 4) Large scale aeroacoustic simulations on parallel computers 5) Fluid-Structure Interaction. Pr. Remacle has published over 25 papers in peer-reviewed journals. He is reviewer of APNUM, IJNMF... He is member of IACM, USACM and ECCOMAS.

SEPULCHRE Rodolphe
His research involves control problems in nonlinear dynamical systems. Specific current interests include: Dynamics and control of bounce juggling. Dynamics and control of collective motion. Oscillators as systems. Geometric design of numerical algorithms. Sensorless control of induction motors (consultant for Schneider-Toshiba S.A, France)
VAN DOOREN Paul
He received the Householder Award in 1981 and the Wilkinson Prize of Numerical Analysis and Scientific Computing in 1989. He is a Fellow of the IEEE and an Associate Editor of several journals in numerical analysis and systems and control theory. His main interests lie in the areas of numerical linear algebra and systems and control theory.

WERTZ Vincent
His main research interests are in the fields of identification, predictive control, fuzzy control and industrial applications. Lately, he has also been involved in a major pedagogical reform of the first and second year teaching program of the school of engineering.
WINCKELMANS Grégoire
Grégoire Winckelmans did his Mechanical Engineering degree at UCL (1983) followed by a Postgraduate Diploma Course at the von Karman Institute for Fluid Dynamics (1984). He then went to the USA to complete a M.S. degree in Aeronautics (1985) followed by a Ph.D. degree in Aeronautics (1989) at the California Institute of Technology (CALTECH), Graduate Aeronautical Laboratories. He worked two years on MHD/CFD in a small high tech company, and then returned to CALTECH as postdoctoral fellow. He was Assistant Professor at the University of Sherbrooke, Canada, from 1993 to 1995. He has been professor at UCL since 1996. His expertise lies in the modelling and numerical simulation of complex, high Reynolds number, flows: including turbulent flows and aircraft wake vortex flows.

WINKIN Joseph
His main research interests are in control and system theory and more specifically in distributed parameter systems, infinite dimensional systems, and analysis and control design of reactor models. He has been selected as “outstanding reviewer of the IEEE Transactions on Automatic Control” for the year 2005.
2 Academic and post-doctoral visitors

<table>
<thead>
<tr>
<th>Name</th>
<th>Start Date</th>
<th>End Date</th>
<th>Institution, Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achhab E.</td>
<td>13/08/07</td>
<td>06/09/07</td>
<td>Ecole Supérieure de Technologie, Safi, Marocoo</td>
</tr>
<tr>
<td>Anderson BDO.</td>
<td>03/09/07</td>
<td>20/09/07</td>
<td>ANU, RSISE, Australia</td>
</tr>
<tr>
<td>Badler J.</td>
<td>18/04/07</td>
<td>31/12/07</td>
<td>Smith-Kettlewell Eye Research Institute, San Francisco, USA</td>
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<tr>
<td>Fidan B.</td>
<td>11/06/07</td>
<td>30/06/07</td>
<td>National ICT, Australia</td>
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<td>Blohm G.</td>
<td>01/01/07</td>
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<td>University of York, Canada</td>
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<td>Delvenne J.-C.</td>
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<td>UCL, Belgium</td>
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<td>Bombois X.</td>
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<td>Delft University, Holland</td>
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<td>Gauton Ph.</td>
<td>01/01/07</td>
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<td>LIAFA, University of Paris, France</td>
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<td>Guillaume J.-L.</td>
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<td>LIAFA, University of Paris, France</td>
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<td>Ivanov S.</td>
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<td>Technical University, Munich, Germany</td>
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<td>Jiang Z.</td>
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<td>Université de Nantes, France</td>
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<td>Kushagra N.</td>
<td>07/02/07</td>
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<td>Indian Institute of Technology, Kanpur, Inde</td>
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<td>Lambiotte R.</td>
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<td>Lefebvre E.</td>
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<td>University of Moscow, Russia</td>
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<tr>
<td>Prochazka H.</td>
<td>01/01/07</td>
<td>31/08/07</td>
<td>Institut National Polytechnique de Grenoble, France</td>
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3 Scientific staff

<table>
<thead>
<tr>
<th>Name</th>
<th>Date</th>
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<tr>
<td>ANDRE Thibaut</td>
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<td>BENICH Nadia</td>
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<td>BERNARD Paul-Emile</td>
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<td>BIOUSH François</td>
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<td>BLAISE Sébastien</td>
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<td>BOUILLON Sylvain</td>
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<td>BRASSART Laurence</td>
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<td>BRICTEUX Gaëten</td>
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<td>CHARES Robert</td>
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<td>COLLIGNON Laurent</td>
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<td>COMBLEN Richard</td>
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<td>COPPE Sébastien</td>
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<td>COULAUD Jean-Baptiste</td>
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<td>DE BRAUWERE Anouk</td>
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<td>DE BRYE Benjamin</td>
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<td>de KERCHOVE Christobald</td>
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<td>DELSAUTE Brieux</td>
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<td>DELVENNE Jean-Charles</td>
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<td>FRAIKIN Catherine</td>
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<td>FRANCOIS Damien</td>
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<td>GUILLAUME Jean-Loup</td>
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<td>GOURGUE Olivier</td>
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<td>HAUT Bernard</td>
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<td>HEDDA Néjib</td>
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<td>HENDRICKX Julien</td>
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<td>HO NGOC Diep</td>
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<td>JUNGER M Raphael</td>
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<td>KAMMOUN Slim</td>
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<td>KRINGS Gautier</td>
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<td>LAMBIOTTE Renaud</td>
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<td>LAMBRECHTS Jonathan</td>
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LECLERCQ Guillaume 17/10/07 - 31/12/07
LEFEVRE Etienne 01/10/07 - 31/12/07
LITAER Olivier 01/01/07 - 31/12/07
MARCHANDISE Emilie 01/01/07 - 31/12/07
MELCHIOR Maxime 01/01/07 - 31/12/07
MILED Bilel 24/05/07 - 31/12/07
MOENS Luc 01/01/07 - 31/12/07
NINOVE Laure 01/01/07 - 31/12/07
ONCLINX Victor 01/01/07 - 31/12/07
ORBAN de XIVRY Jean-Jacques 01/01/07 - 31/12/07
OTHMANI Yamen 01/10/07 - 31/12/07
PASTOR Franck 01/01/07 - 31/12/07
SELMI Abdellatif 07/04/07 - 07/06/07
SIMEONOVA Iliyana 01/01/07 - 31/12/07
WHITE Laurent 01/01/07 - 31/12/07
WHITE Olivier 01/01/07 - 15/07/07
WILLEMETS Marie 03/04/07 - 31/12/07

4 Administrative and technical staff

CONVERT Olivier Computer analyst (part-time)
DE BOECK Lydia Secretary (half-time)
DETIENNE Nicolas Computer analyst (half-time)
DEWAN Michel Technician
HISETTE Isabelle Secretary (part-time)
HUENS Etienne Computer analyst
LOOCKX Edward Technician
SERGANT Michèle Secretary
TERMOLLE Michèle Secretary
## 5 Short-term visitors

<table>
<thead>
<tr>
<th>Date</th>
<th>Name</th>
<th>Institution</th>
<th>Location</th>
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<tbody>
<tr>
<td>26/01/07</td>
<td>WILLEM'S J.</td>
<td>KU Leuven, Belgium</td>
<td></td>
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<tr>
<td>02/02/07</td>
<td>BOMBOIS X.</td>
<td>Delft University of Technology, Holland</td>
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<td>05/03/07</td>
<td>SMITH A.</td>
<td>University of Montréal, Canada</td>
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2. RESEARCH ACTIVITIES
1 Research themes

In this section, we give an overview of the research activities at Cesame during the period covered by the report.

1.1 Modelling, analysis and control of infinite-dimensional (bio)chemical systems

Project leaders: G. Bastin, D. Dochain, V. Wertz, J. Winkin
Researchers: I. Aksikas, V. Dos Santos, A. Dramé, C. Henri, L. Noon
Researchers: Prof. V. Halloin (Service de Génie Chimique, ULB) and M.E. Achhab, B. Abouzaid, N. Barje (LINMA, UCD, Morocco)

The dynamics of many chemical and biochemical processes are described by partial differential equations (PDEs). Among these, tubular reactors cover a large class of applications, and are sometimes called ”Diffusion-Convection-Reaction systems” since their dynamical model are typically a combination of these three terms. The main source of nonlinearities is concentrated in the kinetic terms of the model equations.

The steady-state multiplicity and stability have been analyzed for a tubular biochemical reactor nonlinear model. It is mainly reported that at least three steady states may exist and that there is an alternation of stable and unstable equilibrium profiles.

A biochemical reactor distributed parameter model with time delay in the growth response has been studied. It has long been known that the classical models of growth response such as Monod or Haldane models, are not able to account for the oscillations in chemostat occurring under suitable operational conditions as it has been observed in many experimental studies. The need of considering a time delay in the growth response, as a source of oscillations, has been therefore emphasized by many authors. Following the same idea, we have considered a distributed parameter model with time delay. The model consists of the hydrodynamic term and the reaction term which contains the growth response. The time delay is considered in the growth response since this term does not depend on the hydrodynamic of the reactor. The hydrodynamics of bioreactors does not affect the structure of the microbial growth function. For similar reactions this function has the same properties. Therefore, the delay can be considered in the growth response for the same reasons as in the chemostat models. The existence and positivity of solutions of the distributed parameter model were investigated. We proved the well-posedness of the system in the sense that the solutions exist and are positive on the whole time interval. In addition, the existence of Hopf bifurcation to periodic solutions near trivial equilibrium was established.

Another class of infinite-dimensional models that is of growing importance due to the increasing industrial applications is the class of population balance models, characterized
by integro-differential equations. In the present instance, the particles and their distribution of size, or of age for living organisms, play a central role in the process dynamics; this covers a large spectrum of applications in industry for polymer, crystallization, biotechnology or any process in which the size distribution of particles is essential for process quality. In this activity, population models are developed in order to improve the knowledge of the process dynamics with the objective to design monitoring and control tools that can improve the process efficiency. This part of the project is run in cooperation with Dow Corning and with the partial support of the pharmaceutical company Lilly.

Since full state measurement is not realizable in practice for infinite dimensional systems, the issue of reconstructing the state based on output measurements is of paramount importance. Exponentially convergent observers have been studied for a class of nonlinear distributed parameter parameter systems, with an application to isothermal and non-isothermal plug flow reactors.

Another problem which has been investigated is that of feedback stabilization of infinite dimensional linear systems with control constraints (and additionnally control rate constraints) using finite dimensional and infinite dimensional observers and observed state feedback. The work derives necessary and sufficient conditions for a set of admissible initial state to be positively invariant while satisfying the control constraints. The extension of finite dimensional predictive control strategies to a class of infinite dimensional systems has also been investigated.

The LQ-optimal control problem has been solved for a class of first-order hyperbolic PDE’s that includes convection reaction processes arising in chemical engineering. First the dynamical properties, viz exponential stability, reachability and observability of the linearized model have been analyzed. Each of these properties can be characterized by a specific related operator Lyapunov algebraic equation whose solution can be constructed from a matrix Lyapunov differential equation. Next, an optimal control has been designed on the basis of a linearized model by using the corresponding operator Riccati algebraic equation that can be solved via certain matrix Riccati differential equation. The computed LQ-control was applied to the nonlinear model and the closed-loop system performances were analyzed. Some simple conditions have been shown to guarantee the asymptotic stability and the optimality of the closed-loop nonlinear system with respect to a modified cost criterion.

References: 05.36, 06.122, 07.012, 07.019, 07.060, 07.061, 07.062, 07.063, 07.064, 07.065, 07.066, 07.136, 07.137
1.2 Real-time optimization via adaptive extremum seeking

*Project leader*: Denis Dochain  
*Researcher*: Audrey Favache  
*Collaborations*: Prof. Martin Guay (Chemical Eng. Dept, Queen’s University, Kingston, Canada), Prof. Michel Perrier (Ecole Polytechnique de Montréal, Canada)

Most adaptive control schemes documented in the literature are developed for regulation to known setpoints or tracking known reference trajectories. In some applications, however, the control objective could be to optimize an objective function that can be a function of unknown parameters, or to select the desired states to keep a performance function at its extremum value. Self-optimizing control and extremum seeking control are two methods to handle these kinds of optimization problems. The task of extremum seeking is to find the operating setpoints that maximize or minimize an objective function. In our work, we investigate adaptive extremum seeking schemes that utilize explicit structure information of the objective function that depends on system states and unknown plant parameters. The scheme is based on Lyapunov’s stability theorem. As a result, the global stability is ensured during the seeking of the extremum of the nonlinear system. It is also shown that once a certain level of persistence of excitation (PE) condition is satisfied, the convergence of the extremum seeking mechanism can be guaranteed. Different versions and different case studies have been considered:

1. for chemical, biochemical and biomedical systems
2. for continuous and discontinuous (batch, fed-batch) processes and for periodic systems.

*References*: 06.007, 06.077, 07.048, 07.148

![Graph of Adaptive extremum seeking of an non isothermal reactor](image-url)
1.3 Thermodynamics and process control : entropy as a tool for control analysis and design

*Project leader*: Denis Dochain  
*Researcher*: Audrey Favache  
*Collaboration*: Prof. Bernhard Maschke (LAGEP, Lyon, France)

Scientific work of the past decades has allowed the development of new approaches to non-linear system analysis and control. In order to link these theoretical developments to the specific aspects of process dynamics, it may be interesting to use concepts such as energy and, maybe even more, entropy. In the area of chemical systems, some basic researches were already realized in this point of view. Ydstie, Alonso and al. have established some links between passivity and thermodynamics (through the notion of entropy) for a system respecting conservation laws, but these researches remain at a very general level. Control laws for such systems were designed using the theory of passive systems, but this work remains restricted and incomplete in what concerns thermodynamics and very abstract. Among others, application of this sort of control laws to a real system could be impossible because it would require the real time measurement of non measurable variables such as chemical potential for example. Moreover, the developed theory doesn’t take into account the possible existence of multiple equilibrium states, despite this phenomenon is common in chemical systems.

During the last years, an energy-based approach for modeling and analyzing systems which respect conservation laws was developed. The main idea consists in viewing these systems as a transformation process of energy from one form into another (electrical energy into mechanical one, potential energy into kinetic one, ...). In this way, the system is viewed as the interconnection of sub-systems and the global behavior is determined by the properties of each of them and by the properties of the interconnection. In this point of view, control systems are themselves dynamical systems that exchange energy with the system and shape the total energy of the closed loop system. Each element is connected to one or several others through “ports”, i.e. a couple of variables (a flow variable and an effort variable: in electricity these can be respectively the current and the tension) whose product is a power representing the power exchanged through this port. The sorts of systems studied under this point of view are essentially electrical and mechanical systems because the network approach and the view in terms of flows and efforts is rather obvious. Tools from differential geometry like Dirac structures allow the analysis of such systems. They contain information about the interconnection and permit then to use mathematical tools to analyze the system. The coupling of two independent systems is not a problem either: it is sufficient to couple together the tools of differential geometry representing each system and to add the new interconnection and so all necessary tools for the analysis...
of the global system are provided.

Chemical processes respect conservation laws of thermodynamics, but contrary to electromechanical systems, the network approach is much less evident and intuitive (e.g.: in a reactor there is not a clear element that stores energy like a capacity or a spring, nor there is an element that clearly dissipates energy like a resistance or a damper). Furthermore, in electromechanical systems the notion of entropy does not appear: it is not an energy but gives information about the energy of the system. An increase of energy expresses that despite total energy is conserved, it changes form, what modifies the ability of the system, among others, to provide work. This supplementary notion does not exist in electromechanical systems and thus chemical systems cannot be studied by applying directly the same theory and the same tools. But chemical systems also respect some common principles with electromechanical systems, like the total energy conservation. The developed theory has therefore to be adapted by taking into account the existence of the second principle. New elements of differential geometry must be introduced because Dirac structures for example can no longer be used for chemical systems. Mrugala and al. have worked on the formal mathematical representation of thermodynamic systems and they have represented them with new tools of differential geometry: the contact structures. This work, in the direct continuity of Gibb’s researches, focuses principally on the first principle and only few studies deal with the representation of the second principle with formal mathematical tools.

One of the principal aims of this research activity is to study the link between irreversible thermodynamics (which are the ones concerned by the phenomena occurring in chemical processes), chemical engineering and the theory of dynamical systems and, among others, the one of passive and dissipative systems. The aim is to allow stability analysis of chemical reactors and the design of control tools by using tools of differential geometry and non-linear automatics, e.g. contact structures, Lyapunov functions, dissipative and passive systems. In particular, the interest will go to the ways how to express the second principle of thermodynamics with formal mathematical tools such as differential geometry, in order to complete what has already be done for the first principle. Then my work will focus on how to use this mathematical formalism to study the behavior of chemical reactors and processes with the help of non-linear systems theory. The main idea is to build a systematic approach for the analysis of chemical systems and to allow the development of the network approach to the chemical processes. This is very interesting in the framework of chemical engineering, because chemical processes are nearly all constituted of an interconnection of unit operations.

Reference: 06.121
1.4 State observers for uncertain systems

*Project leader:* Denis Dochain  
*Researcher:* Frédéric Sauvage  
*Collaborations:* Prof. Martin Guay (Chemical Eng. Dept, Queen’s University, Kingston, Canada), Dr Alain Rapaport (LASB, INRA, Montpellier, France), Dr Thierry Monge (Total, Cray Valley, France)

A key question in process control is how to monitor reactant and product concentrations in a reliable and cost effective manner. The monitoring of batch processes poses specific questions, typically related to the time limitation of the batch operation. However, it appears that, in many practical applications, only some of the concentrations of the components involved and critical for quality control are available for on-line measurement. For instance, rates are available for on-line measurement while the values of the concentrations of products, reactants and/or biomass are often available via off-line analysis. An interesting alternative that circumvents and exploits the use of a model in conjunction with a limited set of measurements is the use of state observers. An important difficulty when applying state observers to (bio)chemical processes is related to the uncertainty of (some of) the terms in the models used to described their dynamics. Uncertainty in the model parameters can generate possibly large bias in the estimation of the unmeasured stat dissolved oxygen concentration in bioreactors, temperature in non-isothermal reactors and gaseous flowes. One specific challenge of state observation and parameter estimation in batch processes is to design algorithms that are able to provide reliable estimates very quickly after the beginning of the batch.
In the present research activity, observers that converge in finite-time have been developed and tested on batch polymerisation reactor models and data. These combine two observers operated in parallel but with a time delay and designed in such a way that the state observation converge exactly to the unmeasured state variables after a time equal to the observers’ time delay. Moreover, interval observers that provide upper and lower bounds of the state estimates have been developed in order to handle the process model uncertainties. Such observers exploit in particular the notion of system cooperativity and have also been tested on batch polymerisation reactor models and data. This project is run partially with the support of Total.

References: 06.061, 06.075, 07.006, 07.017

1.5 Neural control of movement

Project leader: P. Lefèvre

These research activities combine theoretical and experimental approaches to investigate the neural control of movement and its interactions with the external world. The mathematical models that are developed are based on experimental results from both normal and pathological subjects (clinical studies) and focus on the interaction between different types of eye movements and on eye/hand coordination. The oculomotor system is characterized by the interaction between peripheral reflexes and central motor commands of visual origin. The dynamical properties of the oculomotor plant are very simple, thus it is a good testing bench for studying interfaces between sensory and motor systems in the brain. Moreover, in gaze orientation, combined eye and head motions are good examples of control of imbedded platforms. In addition, the neural control of gaze in natural conditions requires the interaction between different strategies of oculomotor control. In particular, some eye movements are controlled by visual feedback (smooth pursuit: slow movements) whereas others are controlled in open loop with respect to vision (saccades: fast movements). We investigate how different types of movements interact and what is the role played by sensory inputs and internal models in their programming and execution. We are also interested in investigating these mechanisms in patients (clinical studies). Other fields of research include eye-head coordination, eye-hand coordination and the role of prediction and anticipation in motor control.

Research topics
Our main research objective is to gain further insight into the nature and characteristics of high-level perceptual and motor representations in the human brain. In particular, we are interested in the role played by internal models and prediction in our behaviour. The following topics are covered by our group:
1. Modeling the neural control of movement. We develop mathematical models of eye-head coordination (including the vestibulo-ocular reflex), saccades and smooth pursuit eye movements and their interaction, as well as the coordination between eye and hand movements. Different types of models are developed: distributed parameters models (detailed models of particular brain structures like the superior colliculus or the cerebellum) or lumped models based on transfer functions (models describing the global input/output behavior).

2. Interaction between different types of eye movements. We investigate the role of sensory inputs to the smooth pursuit system and its interaction with the saccadic system. We also focus on the processing of retinal and extraretinal signals for memory guided movements.

3. The influence of micro-gravity on motor control and the challenge of dexterous manipulation in microgravity.

4. Human performance and the role of visual feedback in rhythmic tasks (juggling).

5. Clinical applications in motor control. We investigated the properties of saccades in Duane retraction syndrome.

References: 06.046, 07.013, 07.020, 07.029, 07.033, 07.128, 07.129
1.6 Nonnegative factorizations and iterations for large nonnegative matrices

Project leaders: Vincent Blondel, Yurii Nesterov, Paul Van Dooren
Researcher: D.N. Ho
Collaborations: N. Gillis, F. Glineur (CORE/UCL)

This research looks at algorithmic aspects of nonnegative matrix factorizations and its use in applications of graph clustering and related problems. We introduce some variants of the factorization problem that has applications in the analysis of credit risk management systems in finance, and allow to preserve some invariants in the approximate factorization. These invariants have typically a precise meaning in every particular application.

We focussed on a fast updating algorithm that was based on solving exactly the rank one approximation problem, and the use that in an iterative scheme in order to converge to a local minimum of the approximation error. This problem is known to be non-convex and NP hard when formulated in an appropriate manner. Nevertheless, the results obtained by our method are quite encouraging.

The method can also be adapted to incorporate weighting and also to yield sparse bases for the objects that are being analyzed. In the example below we show the basis functions obtained by our algorithm on a database of face pictures. The obtained bases functions are clearly sparse and concentrated around features of the faces, such as cheeks, eyes, eyebrows, lips, etc. These bases functions were obtained automatically and focus even more on these subparts when weighting is incorporated.

![Basis functions for face pictures (without and with weighting)](image)

We have developed algorithms that have essentially a linear complexity per iteration step, and are quite efficient for large problems. These algorithms approximate the solution of a variety of problems related to the classification, analysis and clustering of graphs and networks.

References: 07.037, 07.078, 07.155
1.7 Persistence and control of formations

Project leader: Vincent Blondel
Researchers: J. Hendrickx, R. Jungers, J.C. Delvenne
Collaborations: R. Carli, S. Zampieri (Univ. Padova), B. Fidan, B. Anderson (ANU)

In [05.038], we consider formations of autonomous agents moving in a 2-dimensional space. Each agent tries to maintain its distances toward a pre-specified group of other agents constant and the problem is to determine if one can guarantee that the distance between every pair of agents (even those not explicitly maintained) remains constant, resulting in the persistence of the formation shape. The constraints on the distance between agents are described by a directed graph and define persistent graphs. A graph is persistent if the shapes of almost all corresponding agent formations persist. Various properties of persistent graphs and a combinatorial criterion to decide persistence were derived. The concept of minimal persistence (persistence with the least possible number of edges for a given number of vertices) was introduced, and the results were applied to the interesting special case of cycle-free graphs. Analogously to the powerful results about Henneberg sequences in minimal rigidity theory, different types of directed graph operations have been proposed allowing one to sequentially build any minimally persistent graph, each intermediate graph being also minimally persistent. It was proven that any minimally persistent formation can be obtained from any other one by a sequence of elementary local operations such that minimal persistence is preserved throughout the reorganization process [07.120]. The notion of persistence was generalized to provide a theoretical framework for real world applications, which often are in three-dimensional space. It was shown that many of the properties of rigid and/or persistent formations established in $\mathbb{R}^2$ are also valid for higher dimensions. Some practical issues raised in multi-agent formation control in three-dimensional space were considered. A new phenomenon, not present in $\mathbb{R}^2$, was exhibited whereby subsets of agents can behave in a problematic way. When this behaviour is precluded, the graph depicting the multi-agent formation is said to be structurally persistent. The characteristics of structurally persistent graphs were analyzed and a streamlined test for structural persistence was obtained. Connections between the allocation of degrees of freedom across agents and the characteristics of persistence and/or structural persistence of a directed graph have been studied [07.122].

We also proved that for a set of communicating agents to compute the average of their initial positions (average consensus problem), the optimal topology of communication is given by a de Bruijn’s graph. Consensus is then reached in a finitely many steps. A more general family of strategies, constructed by block Kronecker products, is investigated and compared to Cayley strategies.

References: 05.038, 07.070, 07.118, 07.120, 07.122
1.8 Hybrid systems and switching dynamics

Project leader: Vincent Blondel, Yurii Nesterov
Researchers: J. Hendrickx, R. Jungers
Collaboration: V. Protasov (Moscow Univ.)

A set of matrices is said to have the finiteness property if the maximal rate of growth of long products of matrices taken from the set can be obtained by a periodic product. It was conjectured that all finite sets of real matrices have the finiteness property. This conjecture is now known to be false but no explicit counterexample to the conjecture is available and in particular it is unclear if a counterexample is possible whose matrices have rational or binary entries. The paper [07.067] proves that finite sets of nonnegative rational matrices have the finiteness property if and only if pairs of binary matrices do. It is also shown that all pairs of $2 \times 20$ binary matrices have the finiteness property. Since stability is algorithmically decidable for sets of matrices that have the finiteness property, it follows that if all pairs of binary matrices have the finiteness property then stability is decidable for sets of nonnegative rational matrices.

For a given finite set $\Sigma$ of matrices with nonnegative integer entries the growth of $\max_t(\Sigma) = \max\{||A_1...A_t|| : A_i \in \Sigma\}$ was studied. The paper [07.119] shows how to determine in polynomial time whether the growth with $t$ is bounded, polynomial, or exponential. The problem of estimating the growth rate of switched systems has been generalized to homogeneous systems.

Overlap-free words are words over the binary alphabet $A = \{a, b\}$ that do not contain factors of the form $xvxxv$, where $x \in A$ and $v \in A^*$. The asymptotic growth of the number $u_n$ of overlap-free words of length $n$ as $n \to \infty$ has been investigated. Formulas were obtained for the minimal and maximal rates of growth of $u_n$, in terms of the lower, and joint spectral radius of sets of matrices of dimension $20 \times 20$. New estimates of the rates of growth were obtained that are within 0.4% and 0.03% of their exact values, as opposed to previously known bounds 11% and 3%, respectively. The value of $u_n$ was actually shown to have the same rate of growth for almost all natural numbers $n$. This average growth is distinct from the maximal and minimal rates and is expressed in terms of a spectral quantity (the Lyapunov exponent) [07.121]. The reference [07.117] contains an interview with Prof. Gil Strang on the introduction and history of the joint spectral radius.

References: 07.042, 07.067, 07.071, 07.072, 07.073, 07.079, 07.119, 07.117, 07.121, 07.150, 07.153, 07.154
1.9 Optimization

*Project leaders*: Y. Nesterov, P. Van Dooren  
*Researchers*: R. Richtarik, C. Fraikin  
*Collaborations*: P.A. Absil, Th. Cason, F. Glineur (UCL/CORE)

We developed the theory of optimization methods in several directions. For the large-scale convex problems represented by an oracle, we developed new primal-dual schemes with reliable stopping criterion both for optimization formulations and for variational inequalities. Second-order schemes with provable global complexity bounds were extended to systems of nonlinear equations. For problems with known structure, we showed how to use smoothing techniques in Semidefinite Programming. For interior-point schemes, we developed the new primal-dual infeasible-start long-step primal-dual method based on the concept of parabolic target space. Finally, we managed to find an efficient way to extend smoothing techniques to optimization problems related to large graphs. We also worked on optimization problems of functions defined on manifolds, more precisely projected correlation functions that are useful for the visualization of similarity measures of large scale graphs. These problems are typically nonconvex but we derived algorithms that converge to stationary points of the cost function and hence typically provide local minima of the cost function. We showed that these problems arise in a quite large variety of settings and we obtained new improved algorithms that are guaranteed to converge to local minima.

A polynomial-time algorithm was also provided for the single-facility location problem with mixed norms, i.e. the problem of minimizing the sum of the distances from a point to a set of fixed points in $\mathbb{R}^n$, where each distance can be measured according to a different $p$-norm. It was based on the use of an interior-method applied to a structured conic formulation obtained by decomposing the nonlinear components of the objective into a series of constraints involving three-dimensional cones, for which a self-concordant barrier was known. This work has been further generalized to a large class of structured convex problems involving powers, exponentials and logarithms.

A new optimization algorithm was also proposed for indefinite quadratic programming problems. The algorithm is of the interior-point type and uses an efficient quasi-Newton technique, specifically designed for the quadratic programming structure, that guarantees that the primal direction is a descent direction for the objective function. Global convergence as well as local quadratic convergence of the constructed sequence to Karush-Kuhn-Tucker points is proved under nondegeneracy assumptions.

Several problems of science and engineering can be phrased as finding an optimizer of a cost function defined on a nonlinear manifold. Depending on the problem under consideration, the advantages of the manifold-based approach over a “traditional” approach are a reduced computational complexity and stronger convergence results. We are currently
analyzing how these ideas can be used to analyze large graphs as well.
References: 07.058, 05.132, 05.134, 06.092

1.10 Autonomous agent systems

Project leaders: Vincent Blondel
Researchers: Jean-Charles Delvenne, Julien Hendrickx, Raphaël Jungers
Researchers: B.D.O. Anderson (Australian National University)

In a first contribution, we have studied systems of autonomous agents seeking consensus. In such systems, each agent has a value, which it updates by averaging that of other agents. Eventually, all agents may obtain a common value, in which case we say that the system reaches a consensus. One major difficulty in the study of such systems is the possible dependence of the interaction and communication topology on the values of the agents. We have considered two paradigmatic systems presenting behaviours that cannot be explained if this dependence is ignored. Taking it explicitly into account, we have then obtained results on the convergence properties of these systems, and on the stability of their equilibria.

A second contribution concerns the study of persistent graphs. Persistence is a generalization to directed graphs of the undirected notion of rigidity, and captures many properties of two dimensional agent formations. In the context of moving autonomous agent formations, persistence characterizes the efficacy of a directed structure of unilateral distances constraints seeking to preserve a formation shape. We have established more clearly the link between the persistence of a graph and the behaviour of the agents in the corresponding formation. We have also provided necessary and sufficient conditions to merge several persistent graphs into a larger persistent graph by addition of edges between the initial graphs. This latter result is motivated by the possible need to temporarily merge and split autonomous agents formations.

1.11 Joint spectral radius, hybrid systems and their applications

Project leaders: Vincent Blondel, Yurii Nesterov
Researchers: R. Jungers, J.C. Delvenne
Researchers: V. Protasov (Moscow University)

The joint spectral radius has numerous applications in diverse areas. In recent works, we have found new applications of this mathematical tool, and we have advanced in the understanding of longstanding theoretical problems:

- We have shown that the joint spectral radius is the key concept to understand the growth of the number of overlap-free words, a longstanding problem in combinatorics on words. We have also shown how several related quantities (the joint
spectral subradius and the Lyapunov exponent) are useful to fully understand the asymptotic growth of overlap-free words. These results allow accurate numerical solutions to this problem.

- On the theoretical side, we have advanced in the understanding of the finiteness property of sets of matrices, which is a problem of importance in control of hybrid systems. We have shown that the finiteness property holds for nonnegative rational matrices if and only if it holds for binary matrices, and we have shown that this property holds for 2 by 2 binary matrices (a similar result is also proved for matrices with negative entries).

1.12 Model reduction

*Project leaders*: P. Van Dooren, Y. Nesterov, P.A. Absil

*Researchers*: K. Unneland, P. Richtarik

*Collaboration*: K. Gallivan (FSU)

We worked on a novel scheme for positive real balanced truncation, which is a combination of the already existing Lyapunov balancing and Riccati balancing. This new method is less computationally demanding and can be proved to yield positive real reduced order systems when applied to an original plant that is also positive real. A variant was also proposed to perform positive real frequency weighted balanced truncation. Work was also done on approximating MIMO rational transfer function of high degree by another one of much smaller degree, using a $H_2$ norm criterion. We showed that the gradients of the error function can then efficiently be computed and that the stationary points of that error function are all described by particular tangential interpolation conditions. A descent method was then derived based on the solution of Sylvester equations.

We also derived an algorithm for estimating the $H_{\infty}$-norm of a large linear time invariant dynamical system described by a discrete time state-space model. The algorithm is designed to be efficient for state-space models where the state transition matrix is large and sparse and where the state dimension is much larger than the input and output dimensions of the system. The technique is based on the use of Chandrasekhar iterations for computing the solution of a Riccati equation in order to estimate the $H_{\infty}$-norm of the transfer function.

*References*: 07.021, 07.023, 07.034, 07.044, 07.157
1.13 Numerical methods for large graphs

Project leaders : V. Blondel, Y. Nesterov, P. Van Dooren
Researchers : J.C. Delvenne, R. Lambiotte, J.L. Guillaume, Ph. Gauron, C. Fraikin, C. de Kerchove, D. Ho, E. Lefebvre
Collaborations : S. Yaliraki (Imperial College)

We had an increasing activity in computational issues related to large graphs and networks. A first topic are local leaders in random uncorrelated networks, i.e. nodes whose degree is higher or equal than the degree of all of their neighbors. An analytical expression is found for the probability of a node of degree $k$ to be a local leader. This quantity is shown to exhibit a transition from a situation where high degree nodes are local leaders to a situation where we are not when the tail of the degree distribution behaves like the power-law $\sim k^{-\gamma}$ with $\gamma_c = 3$. Theoretical results are verified by computer simulations and the importance of finite-size effects is discussed.

A second topic is that of determining the proportion of edges that are discovered in an Erdős-Renyi graph when one constructs all shortest paths from a given source node to all other nodes. This problem is equivalent to the one of determining the proportion of edges connecting nodes that are at identical distance from the source node. The evolution of this quantity with the probability of existence of the edges exhibits intriguing oscillatory behavior. In order to perform their analysis, we introduce a new way of computing the distribution of distances between nodes. This method outperforms previous similar analyses and leads to estimates that coincide remarkably well with numerical simulations. It allows one to characterize the phase transitions appearing when the connectivity probability varies.

A third topic is that of ranking systems, such as the Google PageRank which was also analyzed from different points of view. A non-linear version was proposed and analyzed and the sensitivity of the PageRank to modifications of inlinks and outlinks was analyzed. Optimal strategies for choosing ones’ outlinks as well as those of a group of nodes, were derived. The problem of projected graph similarity was introduced. It can be seen as a low rank approximation of the concept of similarity matrix, which was introduced earlier by the same group and can also be viewed as a ranking system. The graph similarity concept was also extended to colored graphs : here one can only compare nodes of a same color but edges between all nodes need to be used anyway in the comparison. We also proposed techniques to compare edges between graphs, rather than nodes, which could be used to compare roadmaps.

References : 06.146, 07.068, 07.076, 07.079, 07.082, 07.114, 07.116, 07.158, 08.001, 08.002, 08.003, 08.004, 08.005
The complexity of overlapping hierarchies of clusters

1.14 Mobile telephony

*Project leader*: V. Blondel, P. Van Dooren  
*Researchers*: R. Lambiotte, J.L. Guillaume, Ph. Gauron, E. Huens, C. de Kerchove, G. Krings, E. Lefebvre  
*Collaborations*: Z. Smoreda, C. Prieur, B. Poulain (FTRD)

Every mobile telephone company has a few millions customers placing phone calls to numerous other customers every day. A one million node network is difficult to handle, optimize or even draw. Such tasks become much easier if one possesses a hierarchical or reduced-size representation of the network which describes well the influence of the smaller scale behavior. How can such a simpler representation be found and how can the network size be reduced while still keeping some key features of the network? Several basic properties of a moderate size network are easy to analyze or can sometimes be recognized by mere visual inspection. This is very difficult for networks of millions of vertices.

In this project we analyzed several statistical properties of the mobile to mobile communications of a major service provider in Europe. We proposed numerical schemes for detecting the communities in this large network and showed connections with several parameters such as the language of the users, the distance of the calls and the duration of the calls.

*References*: 07.114, 08.006, 08.007
1.15 Clustering of large graphs in biological systems and social sciences

Project leader: J.-C. Delvenne
Collaboration: Prof. Sophia Yaliraki, Prof. Mauricio Barahona, Joao Barrigana da Costa (Imperial College London)

In the recent years huge amount of data have been collected in various fields such as biology and social sciences. This data is often organised under the form of (weighted or unweighted) graphs. For instance, the graph with scientists as vertices and their collaboration as edges. Or the graph of atoms of a protein as vertices, and their chemical bonds as edges. Or the graph of configurations of a large molecule as vertices and the possible elementary transitions as edges.

One way to analyse large graphs is to identify clusters, i.e., densely connected groups of vertices which have relatively few connections between them. Around such a loose concept have blossomed many several definitions and many more algorithms to find such clusters.

We propose a criterion of quality for clustering, i.e., a partition of the graph into clusters. Our method is perform a random walk on the graph and look at how fast the walker forgets the cluster she started from. This is quantified by tools familiar to statistical physicists. Our criterion depends on a time parameter, which allows to favour different clusterings at different time scales. For the shortest time scale, it contains Newman and Girvan’s modularity (a popular measure of quality for clusterings) as a particular case. For the longest time scale, the Fiedler clustering (clustering in two parts according to the sign of the second eigenvector of the laplacian of the graph) is typically optimal.

This criterion has been tested on a scientific collaboration graph and a protein graph to assess the quality of different clustering algorithms, and produce a hierarchy of clusterings. This theory is extended into a new notion of distance between Markov chains, related to previous works on quasi-stationary distributions and model reduction for Markov chains.
1.16 Numerical tensor techniques for spectral analysis

Project leaders: S. Van Huffel (KUL), L. De Lathauwer (KUL), P.-A. Absil
Researchers: M. Ishteva (KUL)

The research topics of this project are multilinear algebra, numerical linear algebra and spectral analysis. The main problem considered is the generalization of numerical techniques for the computation of the best rank-R approximation of matrices to the computation of the best rank-(R1,R2,R3) and best rank-R approximations of higher-order tensors. The results will be used for derivation of high-precision methods for spectral analysis. In particular, matrix-based methods for harmonic analysis will be generalized to tensor-based techniques.

1.17 Geometric optimization methods for gene expression analysis

Project leaders: Rodolphe Sepulchre (ULg), Andrew Teschendorff (U. of Cambridge), P.-A. Absil
Researcher: M. Journée (ULg)

The transcriptome is the set of all mRNA molecules in a given cell. Unlike the genome, which is roughly similar for all the cells of an organism, the transcriptome may vary from one cell to another according to the biological functions of that cell as well as to the external stimuli. The transcriptome reflects the activity of all the genes within the cell. Microarray technology provides a quantitative measure of the concentration of mRNA molecules in a cell for the whole transcriptome in a systematic way. This technology yields a huge amount of data, typically related to several thousand genes over a few hundred experiments, which correspond, e.g., to different patients, tissues or environmental conditions. Algorithms are required to reduce the dimension of the data set and to provide some insight about the relation between the transcriptome of a cell and its phenotype.

Our research interest is to design optimization algorithms to tackle this task. We focus our interest on the theory of optimization over matrix manifolds, which is a formalism that incorporates optimization constraints directly into the search space and performs unconstrained optimization over a nonlinear matrix manifold. Each iterate belongs thus to the manifold and satisfies the constraints.

Algorithms performing independent component analysis have first been considered. This consists in maximizing an estimator of statistical independence over the orthogonal group.
We then construct methods to generate sparse principal components. Several new algorithms have thus been derived that all differ by the geometry of the underlying matrix manifold and the considered cost function.

References: 06.092, 07.058, 07.007,

1.18 Control of rhythmic systems

Project leaders:  R. Sepulchre (ULg/Cesame), P. Lefèvre
Researchers:  D.E. Chang (ULg), M. Gérard (ULg), R. Ronsse (ULg/Cesame)

In this research, we investigate some fundamental questions pertaining to the modeling and control of rhythmic systems. Synchronization between the rhythmic controller and the controlled system is viewed as the design principle, leading to robust control of limit cycles with large basins of attraction.

This synchronization principle is illustrated in the lab with the "Wiper" robot (Figure): a puck slides on a tilted air-hockey table (frictionless motion) and is periodically impacted by two edges. These edges are controlled by two independent motors and can be viewed as an idealization of the juggler’s arms.

The "Wiper" setup

Periodic motions of the puck that correspond to some juggling pattern can be stabilized with an harmonic sinusoidal actuation of the edges. This actuation requires no feedback measurement on the puck state and is therefore considered as an open-loop control, forc-
ing the frequency-locking between the edges and the puck.

In a feedback approach, we designed a control law that mirrors the puck dynamics w.r.t. the edges. This mirror control robustly stabilizes the same periodic motions of the puck, with large basins of attraction.

Current investigations concern the experimental validation of feedback control laws and the modeling of human control in a similar task: a subject is asked to control the edges in order to stabilize a periodic motion of the puck. We quantify the human tendency to control this task relying on an open-loop passive actuation, or to develop a feedback strategy based on sensory information.

1.19 Dynamical modelling of metabolic systems

*Project leader:* G. Bastin  
*Researcher:* A. Provost  
*Collaborations:* Prof Y. Chitour (Dept. of Mathematics, Université d’Orsay, France), Dr. F. Grognard (INRIA, Sophia-Antipolis, France), Prof. Y.-J. Schneider (Unit of Biochemistry, UCL) et Prof. S. Agathos (Lab. of Bioengineering, UCL)

A new methodology has been established for bioprocess dynamical modelling in the situation where extracellular species are the only available data besides the biomass itself. The elementary metabolic flux-modes are computed as the unique convex basis of the space spanned by the columns of the stoichiometric matrix of the metabolic network (see figure). The elementary flux modes are then expressed as macroscopic reactions connecting the extracellular substrates and products. A dynamical model, compatible with the metabolism, is derived from the set of these macro-reactions. The methodology is illustrated with experimental data from Chinese Hamster Ovary (CHO) cultivated in stirred flasks in a serum-free medium.  
For this research, the paper A.06.031 has received the ”Best Paper Award 2006” of the journal Bioprocess and Biosystems Engineering”
New results have also been obtained regarding the stability analysis of metabolic systems with feedback inhibition. Without inhibition, the system is cooperative and has a single globally asymptotically stable equilibrium. In the common situation where there is inhibition, the stability analysis is much more intricate. The analysis has been focused on a class of systems represented by an acyclic network of mono-molecular enzymatic reactions with so-called cumulative inhibition. It has been shown that the system has a single equilibrium. Furthermore, sufficient conditions on the kinetic parameters have been exhibited which guarantee that this equilibrium is globally attracting.

Finally, when these conditions are not satisfied, it has been shown with an example that the equilibrium may become unstable with an attracting limit cycle.

References: 05.067, 06.031, 06.002, 06.003, 06.080
1.20 Boundary control of systems of conservation laws: theory and applications

*Project leaders:* G. Bastin, L. Moens  
*Researcher:* B. Haut  
*Collaborations:* Prof. J-M. Coron (Dept. of Mathematics, Université Paris IV), Prof. B. d’Andréa-Novel, Ecole des Mines de Paris), Prof. J. Winkin (Dept. of mathematics, Facultés universitaires de Namur).

In the Sambre river, hydraulic gates driven by programmable automata are used to control the level and the flow rate. On the left, a gate in operation. On the right, the gate is removed from the water for a maintenance operation.

Conservation laws are hyperbolic partial differential equations that are commonly used to express the fundamental dynamics of conservative systems. Many physical networks having an engineering interest are described by systems of 2x2 hyperbolic conservation laws. Among others, we may mention for instance Saint-Venant equations for hydraulic networks, isothermal Euler equations for gas pipeline networks, or Aw-Rascle equations for road traffic networks. In 2007, our main contribution has been to show how entropy-based Lyapunov functions can be used for the stability analysis of equilibria in physical networks of conservation laws. The analysis gives a sufficient stability condition which is weaker than the condition which was previously known in the literature. Various extensions and generalisations have been addressed, including the introduction of integral actions to deal with the cancellation of static errors. The approach has been applied to ramp-metering control of road traffic networks and to water flow control in networks of open channels. In particular, this methodology is used for the control of the hydraulic...
gates of the Meuse and Sambre rivers within the framework of a contract with the Administration des voies navigables, Ministère de l’Equipement et des transports de la Région Wallonne.

References: A05.033, A06.047, A07.002, A07.008, A07.009, A07.043, A07.127, A07.132, A07.133

1.21 Machine learning

Project leader: V. Wertz
Researchers: D. Francois, V. Onclinx

The Machine Learning Group brings together people from different departments working on themes related to machine learning such as Artificial Neural Networks, Fuzzy Logic, Statistical Modelling, Quantitative Methods, etc. The group more specifically focuses on:

1. Data dimensionality reduction (feature selection and nonlinear projection)
2. Predicting temporal data (time series and sequences)
3. Model selection and validation (statistical sampling and resampling)
4. Food control and biomedical applications

In the CESAME, the following themes are under study:

1. Nonparametric and interpretative methods for spectral variable selection
   Reducing the (initially large) number of spectral variables in a Near Infrared (NIR) spectra calibration (modelling) problem often allows building simpler, and more accurate, models. It furthermore brings information about the relevant frequency ranges, for which an interpretation can be sought.

   Two main obstacles are encountered when selecting features from high-dimensional data. Firstly, given the large number of initial features, even greedy approaches can become costly. Secondly, the results of the procedure are often unstable: the selected feature subset sometimes highly depends on the values of the parameters of the feature selection method. Indeed, high-dimensional data often have highly-correlated variables, a property called collinearity, especially when the data are generated by sampling a continuous signal. Such redundancy makes the interpretation of the selected variables uneasy, as many different and distinct variable subsets can be equally relevant for the prediction.
Our research focuses on methods dedicated to spectral variable selection, addressing the needs in computational power, interpretability of the selected variables, and stability of the results. Approaches based on resampling for nonparametric hypothesis testing and variable grouping by clustering, and signal decomposition (Independent component analysis and Spline basis projections) have been investigated.

References: 06.111, 07.141

2. **Nonlinear projections on manifolds**

One of the major problems in data mining, machine learning and data analysis is to represent the complex structure of data that live in a high-dimensional space. The aim of the data projection is to make easier the visualization of data and of their structure.

Several methods have been developed to preserve the pairwise distances between data. These data projection methods have to deal with a compromise between "trustworthiness" and "continuity". The trustworthiness objective means that data close in the projection space may be trusted to be close in their original space. Conversely, the continuity objective means that originally close data remain close after projection. In general, nonlinear projection methods cannot perfectly reach these two objectives simultaneously without strong and often unrealistic hypotheses on the data. Most current developments in the field of nonlinear projection adopt a specific point of view with regard to this compromise.

However, most current developments aiming at visualizing data project the latter in the Euclidean two-dimensional space. By trying to project on more complex manifolds embedded in a three-dimensional space, we hope that both the trustworthiness and continuity of the projection can be substantially improved. For example, projecting on a sphere, a torus or a cylinder can be more adapted to some more complex structures of data. Then, visualizing the sphere, torus or cylinder can be achieved by deterministic coordinate transformation methods.

This work presents a way to preserve the pairwise distances between data on a manifold embedded in a three-dimensional space. In order to achieve this goal, we use the theory of optimisation on a manifold. The pairwise distance criterion is indeed expressed in terms of distances on the manifold, therefore of the locations of data on this manifold after projection. Directly optimising the criterion is unfeasible in general. The gradient descent principle is then adapted to project data living in a three-dimensional space, with an additional constraint that they have to belong to a two-dimensional manifold.

3. **Economical aspects of machine learning**

The field of machine learning is more and more recognized to have a strong potential in business applications, especially in data mining operations for instance
for business decision making, customized software developing, or automated process monitoring. Large companies like Microsoft, Google, Yahoo, are massively investing in machine learning, dedicating entire research departments to it.

However, small and medium businesses can also benefit from machine learning to gain a competitive advantage. In the context of creating a spin-off company providing services in data mining based on the expertise and experience of the team in machine learning, the market opportunity is investigated.

4. **High dimensional data analysis**

The tools we use to analyse data have been designed having in mind schemes that the human mind can grasp and visualize. Those tools, for which we have a strong intuition about their behaviour in low dimensional spaces, are also used when data are higher-dimensional. But then, what happens if something that we consider intuitively relevant in low dimension has counter intuitive properties in higher-dimensional spaces? Obviously, our intuition about the tools gets lost, but does it have an effect on the performances of those tools as well? Whether the goal of the analysis is to classify or cluster data, or else predict some response value (prediction) according to some predictors, many nonlinear tools we use are based on a dis/similarity measurement between data elements. When data is made of numerical attributes, measuring dissimilarity is most often done by computing the square root of the sum of squared attribute differences.

Actually, data are embedded in the Euclidean vector space, where each data element is represented by a point in that space. The dimension of that space is the number of attributes related to an observation. The metric induced by the Euclidean norm on that space (the Euclidean distance) is used to measure dissimilarity. The core of the idea is that the respective vector representations of similar data element are close in the space. But in a high dimensional space, all distances seem to concentrate! That is all pairwise distances between each element of any high-dimensional data set seem confined in a small interval.

The concentration of the norm raises one question: does it affect data analysis tools that rely on the computation of Euclidean distance to estimate dissimilarity between data elements? Our research examines this question from a theoretical viewpoint but also on practical applications of several data analysis methods on high dimensional problems involving data made of hundreds of attributes. Alternatively, instead of working directly in high-dimensional spaces, one can use feature selection methods in order to reduce the number of attributes of each data vector, prior to applying data analysis methods such as classification, prediction or others.

*Reference*: 07.142

5. **Empirical taxonomy of start-up firms growth trajectories**
Over the past decades, new and small firm growth has received considerable attention from researchers and policy-makers around the world. New firms are a key element in regional economic development and represent as such an interesting research subject.

Despite their importance to regional development, knowledge about new firm growth is still scattered and little knowledge is available regarding how firms grow and perform over time. Recent entrepreneurship research argues that there is a strong need for a conceptual scheme and for longitudinal growth studies. The underlying assumption is that growth is a heterogeneous phenomenon that naturally happens over time; it should therefore be analysed in a dynamic process perspective and across multiple organizational contexts. Indeed, while most new and small firm growth studies have focused on the explanation of the performance using cross-sectional data and/or have assumed that growth is an uninterrupted process; longitudinal approaches have shown that regular growth is the exception rather than the rule. However longitudinal approaches generate methodological challenges which require new research methods because firm growth is a complex phenomenon. It is not uni-dimensional. It is hard to predict and assess. Further, it can manifest itself in various ways, and consequently it can have differential effects on several different levels.

In this context, the purpose of this research is to present an original method that can accommodate, in a systematic way, the analysis of new firm growth trajectory based on a multidimensional construct of organic growth. More specifically, our objective is to establish whether the early growth of a firm is a process basically idiosyncratic i.e. related to the individual characteristics of each firm or typical growth trajectories exist and are adopted by a majority of firms. We analysed the growth trajectories of 741 Belgian firms created between 1992 and 2002 and which have grown above micro-firm size. We developed and tested an original methodology allowing an empirical taxonomy of early growth trajectories across multiple sectors, integrating the multidimensional aspect of growth.

Reference: 07.031

6. Automatic downtime classification for process monitoring

Downtimes which occur at a plant often must be labelled by qualified agents and stored for reporting and plant performance analysis. This labelling requires precious time from human workers, hence reducing their productivity.

This projects aims at building a system for automatic labelling of downtimes from the set of alarms which occurred in the plant before the downtime is observed. A simple classifier has been built, which gives interesting preliminary results. Methods for downtime and alarms visualisation as time sequences have also been developed.
### 1.22 Experiment design issues in system identification

*Project leader*: M. Gevers  
*Researchers*: A. Bazanella (Universidade Federal do Rio Grande del Sul, Brasil), D. Bonvin, A. Karimi et L. Miskovic (Ecole Polytechnique Fédérale de Lausanne)

A lot of our recent work on identification of linear systems has focused on experiment design questions. One of the problems we have addressed was triggered by a question sent to us by an expert in the identification of multivariable systems who performs a lot of identification work for chemical and petrochemical companies: is it necessary to excite all external input signals to identify a system that has more than one input? We have shown that, contrary to a widely held view, it is not necessary to excite all such inputs. We have given precise excitation conditions for the identifiability of systems with several inputs, under both open-loop and closed-loop operating conditions.

One of the key concepts in identification is the concept of “sufficient richness” of the excitation signal. Motivated by recent results on optimal experiment design and by the more and more prevalent use of multisine excitation signals, we have examined the minimal degree of richness that is required of an input signal in order to guarantee identifiability of the chosen model structure. Preliminary results have been presented at a workshop. They show, in particular, that for closed-loop identification there is a precise and quantifiable trade-off between the controller complexity and the required degree of richness of the external signal.

*References*: 06.074, 07.005, 07.018

### 1.23 Data-based control design

*Project leader*: M. Gevers  
*Researchers*: B.D.O. Anderson (Australian National University), A. Bazanella (Universidade Federal do Rio Grande del Sul, Brasil), D. Bonvin, A. Karimi et L. Miskovic (Ecole Polytechnique Fédérale de Lausanne)

For more than ten years now, CESAME has produced methods for data-based control design, i.e. control design methods that do not require a model of the dynamical system to be controlled. In 2007, this work was pursued in two directions. One of these has been the extension to multivariable systems of a method initially developed at EPFL (Lausanne), called correlation-based tuning (CbT). The CbT method was inspired by the Iterative Feedback Tuning (IFT) method developed at CESAME in 1994: the minimization of a control performance criterion is replaced by an instrumental-variable approach which
eliminates the effect of the disturbances. Our second contribution has been to increase the
domain of attraction of the minimum of control design criteria based on quadratic norms.
This has been achieved by a thorough analysis of the effect of different design parameters
on the shape of these criteria and a clever selection of some of these parameters. We have
introduced the idea of cost function shaping and shown that, by introducing a succession
of intermediate control design criterion, one can significantly enlarge the domain of at-
traction of the global minimum, thereby avoiding the problem of convergence to a local
minimum.

References : 07.112, 07.028

1.24 Non-Newtonian fluid mechanics and rheology of polymeric
liquids

Project leaders : R. Keunings, C. Bailly (FSA/MAPR/POLY)
Researchers : S. Dhole, F. Stadler

Like other rheologically-complex fluids, polymeric liquids are known to exhibit a va-
rity of non-Newtonian flow properties. In particular, they are viscoelastic or memory
materials, which implies that the macroscopic stress endured by a fluid element depends
upon the history of the deformation experienced by that element. Viscoelastic flow be-
aviour is responsible for numerous flow phenomena of scientific and industrial relevance
that cannot be predicted by the classical Navier-Stokes equations, which are only valid for
structurally much simpler (Newtonian) fluids like air and water. The scientific community
active in rheology and non-Newtonian fluid mechanics aims at predicting, understanding,
and possibly controlling these phenomena using a combination of suitable physical the-
ories, mathematical models, and numerical simulation methods. Obviously, the input of
experimental studies is essential, not only for the observation of flow phenomena, but also
for the detailed rheometrical and molecular characterization of polymeric systems.

The rheological behaviour of non-Newtonian liquids is dictated by the flow-induced evol-
ution of their internal microstructure. In flowing homogeneous polymers, the relevant
microstructure is the conformation of the macromolecules, namely their orientation and
degree of stretch relative to the equilibrium state. Each macroscopic fluid element con-
tains a large number of polymers with a statistical distribution of conformations. During
flow, the polymer conformations evolve along the fluid trajectories. Also, the macroscopic
stress carried by each fluid element is itself governed by the distribution of conformations
within that element. Rheologists thus face a challenging non-linear coupling between
rheological behaviour, flow-induced evolution of the microstructure, and operating con-
ditions (such as flow geometry and boundary conditions). In this context, our team is
involved in a long-term project entitled Dynamics of Entangled Macromolecular Fluids
(2003-2009). The goal of this Concerted Research Action project (ARC in French) is to
address the following basic question: What is the signature of molecular architecture in
the rheometrical and complex flow response of entangled polymeric liquids? To this end, we explore the relation between macromolecular structure and rheological behaviour in entangled systems by means of an integrated approach that combines experimental characterization, theoretical modelling, and numerical simulation. In particular, we study the linear and non-linear dynamics of model entangled fluids having a well-characterized molecular structure.

Recent highlights are as follows:
(i) The successful completion of our modelling work on linear viscoelastic properties of polydisperse mixtures of star and linear polymers. The new tube model developed by E. van Ruymbeke leads to very accurate predictions when compared to experimental data for benchmark model systems and has a wide applicability potential for more complex mixtures.
(ii) A new tube model for predicting large deformations of linear polymers. The CRAFT model developed by A. Leygue accurately predicts shear as well as elongational flow of linear polymer melts and solutions from knowledge of a limited set of material parameters. The novelty is that the model is built as a non-linear extension of a linear model, thus clearly preserving the physical meaning of the parameters extracted from linear viscoelasticity. Although rather sophisticated, CRAFT can in principle be used for complex flow simulations.
(iii) A comparison of the "Lissajous" and "harmonic" analyses of large amplitude oscillatory shear flows. Our analysis demonstrates that the so-called "secondary loops" observed on stress vs. shear rate diagrams can be related to specific values for ratios of the stress

\[ \gamma_0 = 10 \]
\[ \nu = 0.2 \text{ Hz} \]
curve higher harmonics. Since secondary loops are thought to represent the signature of important molecular characteristics (long chain branching), the harmonic analysis therefore provides direct access to this information.

(iv) A critical analysis of the basic assumptions of tube models. C.Y. Liu’s results indicate that even the most recent and sophisticated versions of tube models do not fully describe the dynamics of real polymer chains. This unexpected result provides interesting leads for potential improvements.

References : 05.020, 05.112, 06.009, 06.040, 06.041, 06.042, 06.043, 06.044, 06.089, 06.090, 06.091

1.25 Development of modelling, identification and control methodologies for dynamical systems.

Project leaders : M. Gevers, V. Wertz
Researchers: A. Lecchini, R. Hildebrand, G. Solari

The research in identification aims at evaluating the quality of identified models (i.e. quantification of model errors), at integrating the control objective in the identification strategy and at developing new methodologies for non linear systems (fuzzy models, neural networks,...). The control research aims at developing control algorithms for new classes of systems (e.g. non linear systems, distributed parameter systems, fuzzy logic systems, ...) and for poorly modelled systems.

1.26 Multivariable control of power plants

Project leader : V. Wertz
Collaborations : E. Silva and G.C. Goodwin (CDSC, University of Newcastle, Australia), B. Codrons (Laborelec)

This research aims at improving the control of coal fired power plants by using multivariable controllers based on a twoinput-two output high level linear model. A specific feature of such plants is the existence of a very large delay between one of the inputs and all outputs of the system. First, tracking performance limitations have been investigated and the performance trade-off between two conflicting objectives, namely tracking one process variable while constraining the other one has been made explicit. This result provides a benchmark against which practical controller designs for power plants an be assessed.

Reference: 07.038
1.27 **Optimal control of differentially flat systems with singularities; application to mobile robots**

*Project leader:* G. Campion  
*Researcher:* J.-B. Coulaud

The concept of gap-singularity is introduced to characterize a class of dynamical systems for which there is a discontinuous relation between the distance between trajectories in the state-space and the one defined on the outputs. For a system with gap singularities some trajectories are topologically isolated. This implies that if such a trajectory is optimal for some performance index an algorithm which does not take the gap-singularities into account will not be able to converge to it. A typical example of such systems is a mobile robots equipped only with steerable wheels. Our contribution is twofold:

- We have introduced and analysed the concept of gap singularities to describe particular phenomena related to the choice of the outputs for some nonlinear systems, namely differentially flat system. We have investigated the relationship between gap-singularity and singularity of flatness and we have show how to take into account these singularities for optimal trajectory planning.

- We have proposed an improvement for recent software packages like Nonlinear Trajectory Generation (NTG) by taking into account some structural properties of the original problem, namely the smoothness of the functions characterizing the path constraints.

*References:* A07.51, A07.105

1.28 **Development and use of the second-generation Louvain-la-Neuve ice-ocean model (SLIM)**

*Project leader:* Eric Deleersnijder  
*Coordinators:* Thierry Fichefet, Vincent Legat and Jean-François Remacle  
*Researchers:* Paul-Emile Bernard, Sébastien Blaise, Richard Comblen, Olivier Gourgue, Emmanuel Hanert, Jonathan Lambrechts, Sébastien Legrand, Olivier Lietaer, Jonathan Toubeau, Laurent White

*Web site:* www.climate.be/SLIM
In 1969, the *Journal of Computational Physics* published a seminal article by K. Bryan presenting the first ocean general circulation model. Since then, many numerical studies of the World Ocean and subregions of it - including shelf seas, coastal regions, estuaries, etc. - used models that were all directly, or indirectly, inspired by Bryan’s: similar geophysical fluid mechanics equations were solved numerically using a conservative finite-difference method on a structured grid. Some aspects of these models are now deemed to be out of date. In particular, the use of a structured grid leads to a marked lack of flexibility in the space resolution and does not allow to take advantage of the potential of modern numerical methods, such as finite elements, which are at their best on unstructured meshes.

It is impossible to transform step by step a structured grid model to an unstructured mesh model. Therefore, a revolution in ocean and marine model design is needed, paving the way for the second generation of models. At UCL, scientists from the institute of geophysics and the faculty of applied sciences have teamed up to develop a second-generation model (SLIM), using the finite element method to solve the governing equations. A number of its building blocks are now operational, including those concerned with mesh generation, the propagation of Poincaré waves, and the Mellor-Yamada turbulence closure scheme. Various depth-integrated and reduced-gravity versions of SLIM (i.e. 2D models), including one featuring an adaptive mesh system, are being applied to the Gulf of Mexico, the Great Barrier Reef and Lake Tanganyika. A three dimensional version of SLIM was used to study the vertical transport induced by tidal forcing in the vicinity of a shallow-water island. A prototype of a baroclinic three-dimensional model is already available and is applied to a shallow sea region. Finally, we are currently developing a finite element model of large-scale sea ice dynamics with viscous-plastic rheology. A simulation of the Arctic ice pack is being carried out on a realistic mesh by using NCEP/NCAR reanalysis of the atmospheric fields to drive our model.
1.29 Development and use of the constituent-oriented age and residence time theory (CART)

Project leaders: Eric Deleersnijder (UCL) and Eric Delhez (Ulg)
Researchers: Olivier Gourgue, Laurent White
Web site: www.climate.be/CART

Nowadays marine models routinely produce large amounts of results. Making sense of all these real numbers is not a trivial task. This is why specific interpretation methods are needed, such as estimating timescales. In this respect, a comprehensive theory (CART) is developed that allows for the estimation of timescales such as the age and the residence time from the solution of partial differential problems. At any time and position, the age - a measure of the elapsed time - of every constituent, or group of constituents, of seawater can be estimated in such a way that advection, diffusion and production/destruction are properly taken into account. Applications thereof have been dealt with, including the space-time development of the age of passive and radioactive tracers released by a point source, the relation between various ages in the World Ocean - to evaluate ventilation rates -, and a study of the rate at which matter is transferred from one trophic level to another in a rather complex ecological model. The residence time is usually defined as the time taken by a water/tracer parcel to leave the domain of interest. In the framework of CART, a rigorous generic method is suggested for evaluating, at any time and position, the residence time as the solution of an inverse/adjoint partial differential problem. An alternative version of the residence time, the exposure time, was also considered. Surprisingly, an idealised study revealed the existence of a boundary layer in the neighbourhood of open "entering" boundaries, which must be taken into account in practical applications.
On the other hand, a closed-form, steady-state solution was found for the residence time of settling particles (phytoplankton, silts, marine snow, etc.) in the upper mixed layer that exhibits a couple of unexpected properties. Finally, ages and residence times have been simulated on the Northwestern European Continental Shelf.

1.30 Advanced modelling of gas flow and transport phenomena inside a piece of wood that undergoes pyrolysis

Project leaders: Miltiadis Papalexandris, Hervé Jeanmart
Researcher: Kuborn Xavier

This project concerns the modelling and simulation of gas flow and transport phenomena that occur inside a piece of wood that undergoes pyrolysis. In our study, the piece of wood is considered as a porous medium. In the first phase of this project we will apply extended thermodynamic theories for the derivation of new constitutive equations that can accurately predict the interaction between the gaseous phase and the porous medium. In the second phase we will apply a new numerical method, recently developed by our team, for the execution of detailed numerical simulations.

1.31 Development of an interactive, real-time simulator of ventilation systems of tunnels in case of fire

Project leaders: Jacques Eddy, Miltiadis Papalexandris
Researcher: Rachel Dutrieue

This project concerns the development of a simulator of ventilation systems that is capable of taking into account the case of a fire in a tunnel. This simulator will contain two parts. The first part is the modelling of the evolution of a fire in a more-or-less confined space and the transport of smoke in a flow of fresh air. The second part is an interactive algorithm for use in real time. If equipped with a visualization system, this simulator can be a valuable tool to tunnel operations personnel for a rapid and efficient response in case of fire.

1.32 Combustion and reacting flows

Project leader: Miltiadis Papalexandris
Researchers: Vincent Deledicque, Bamdad Lessani, Siva Muppala
This project concerns the development of LES models for turbulent premixing flames. It also concerns the numerical study of tridimensional gaseous detonations and the development of mathematical models and numerical methods for the supersonic combustion of heterogeneous mixtures of fluids with granular materials.

1.33 Numerical methods for turbulent flows

*Project leader:* Grégoire Winckelmans  
*Researchers:* Laurent Georges, Laurent Bricteux, Goeric Daeninck, Matthieu Duponcheel

Development of efficient parallel codes for the simulation of wall-bounded turbulent flows and application to aerodynamics and aeroacoustics.

A first project aims at the development and validation of efficient parallel codes for the simulation, using DNS, LES or hybrid RANS-LES approaches, of wall-bounded turbulent flows. The first effort aims at developing and validating a “research” code: it uses the staggered approach for incompressible flows and fourth order finite differences. The second effort, done in strong collaboration with the CENAERO, aims at developing and validating a code for general applications (research and industry): it uses a finite volume approach for compressible flows and with unstructured meshes. Both codes are designed so as to run efficiently on parallel architectures with many processors. Validations include channel flows and bluff-body flow aerodynamics (e.g., LES of flow past a sphere at \(\text{Re}=1000\)).

A second project concerns two doctoral theses: one in finalization phase (G. Daeninck, also one year fellow at Stanford U., on this subject, funded by the BAEF), one starting in Oct. 2005 (M. Duponcheel). It aims at the development and validation of novel hybrid approaches for the simulation of wall-bounded turbulent flows. Because of the excessive resources (CPU, memory) required for wall-resolved Large-Eddy Simulation (LES) approaches, it is most necessary to combine them with the less-resource demanding Reynolds-Averaged Navier-Stokes (RANS) approaches. The developments are always done in the framework of high performance parallel computing, also on cluster type architectures. The aim will also be, in collaboration with the CENAERO and its partners, to compute the noise source terms, to be used by acoustic propagation codes.

1.34 Simulation of high Reynolds number wake flows and shear flows

*Project leader:* Grégoire Winckelmans 
*Researchers:* Roger Cocle, Goeric Daeninck, François Thirifay
A first project aims at the efficient combination of the vortex-in-cell and the fast multipole method. We use the multipole method to obtain the boundary condition to provide to the grid-based Poisson solver used in the hybrid (Eulerian-Lagrangian) vortex-in-cell-method. This allows to simulate unbounded flows in unsteady aerodynamics, while still using a minimal grid (which only contains the vorticity region). The case of half unbounded flows (i.e., with a flat ground) is also studied. Applications are time-developing flows: aircraft wake vortices (also in ground effects), vortex rings, etc.. The case of space-developing flows is also studied: wake flows, jets.

A second project aims at the development of efficient numerical methods, based on vortex particle methods combined with panel methods, for the simulation of unsteady flows and with massive separation. The application is vehicle aerodynamics (trucks, cars, also in ground effect), dynamic stall of lifting surfaces (wings), etc. Hybrid numerical approaches (Eulerian for the zones close to the body surface, Lagrangian for the rest) are also developed. Hybrid turbulence modelling approaches (of DES type, and of hybrid RANS-LES type) are also studied. The obtention of the noise sources, produced by the unsteady wake flow, is also studied.

A third project focuses on the simulation of high Reynolds number non-reactive and reactive shear flows using Lagrangian particle methods. The project considers the simulation of shear flows (shear layer, jet), without or with chemical reactions. The application to the case of combustion in a co-flowing jet (diffusion flame) is particularly studied.

1.35 Design of a windowless spallation target for a prototype accelerator driven system

Project leaders: Grégoire Winckelmans, Hervé Jeanmart
Researcher: Jean-Marie Seynhaeve

Research Convention (150 kEuro, Phases I to V) with the SCK-CEN for the project MYRRHA: design of a windowless spallation target for a prototype accelerator driven system (an ADS nuclear reactor). It aims at providing protons and neutrons for various R and D topics: waste transmutation, proton therapy, new neutron-based isotopes, etc. The project also involves studies for liquid metals (Pb-Bi) flowing at high rates, together with free surfaces and a hydraulic jump. The liquid metal target also permits to remove the heat by forced convection. Our work is for flow modelling in the inlet geometry of the spallation target (also using FLUENT), flow and potential heat transfer analyses (also by similarity analyses), and for experimental modelling: a water loop realization, trials, flow visualization and measurements (LDV velocity, pressures) within the spallation target geometry, a second water loop realization with near vacuum at the free surface, new trials, visualizations and measurements, testing of various designs.
1.36 LASEF: Lidar with fiber-based source

Project leader: Grégoire Winckelmans
Researcher: Laurent Bricteux

Contract (310 kEuro) from Région Wallonne, DGTRE, Division de la Recherche et de la Coopération Scientifique, as partner in the project LASEF, Lidar with fiber-based source. The project is led by UCL-TELE, group of P. Sobiesky and B. Macq; other partner is FPMs-TCTS, group of B. Gosselin; the Multitel research center is a subcontractor. Our work (48 man-months) is LES of wake vortices (also including interactions with the atmosphere turbulence, the wind, and the ground), operational modelling of wake vortices using the P-VFS tool (Probabilistic use of the Vortex Forecast System), and participation in the development and validation of a LIDAR signal simulator.

1.37 Aircraft wake phenomena and applications

Project leader: Grégoire Winckelmans
Researchers: Goéric Daeninck, Olivier Desenfans, Thimothée Lonfils, Thomas Duquesne, Vincent Treve, Raphaël Capart, Laurent Bricteux, Louis Dufresne, Roger Cocle, Matthieu Duponcheel

A first contract (FAR-Wake, 230 kEuro) concerns fundamental research on aircraft wake phenomena. As partner in a Specific Targeted Research Project (STREP) of the European Commission 6th Framework Programme, our work is LES of instabilities and decay in multiple vortex systems, of end effects, of wake vortex interactions with jets and wakes, of wake vortices in ground effects (IGE) also with cross and/or head wind; towing tank experiments of wake vortices IGE; operational modeling of wake vortex behavior IGE, also by improving the tool Probabilistic use of the Vortex Forecast System (P-VFS).

A second contract (FLYSAFE, 208 kEuro) concerns Airborne Integrated Systems for Safety Improvement, Flight Hazard Protection and All Weather Operations. As partner in an Integrated Project (IP) of the European Commission 6th Framework Programme, our work (24 man-months) is for operational modelling of wake vortex behavior prediction in cruise (for onboard systems applications, also in RVSM space (Reduced Vertical Separation)), using our real-time models/tools VFS and P-VFS, and for support to wake vortex detection enhanced by prediction.

A third contract (WakeNet2-Europe, 44 kEuro) concerns a Thematic Network on Aircraft Wake Turbulence. As partner in a project of the European Community 5th Framework Programme, our work is for exchange of information, participation to workshops, etc. We are also co-leader, with DLR-FT, of the Work Group 4 on ”wake vortex characterization
and encounter parameters”.

A fourth contract (AWIATOR, 232 kEuro) concerns Aircraft WIng with Advanced Technology Operation. As partner in a Technology Platform (TP) project of the European Community 5th Framework Programme, we study wake vortex control devices (34 man-months): for modelling, using vortex methods, of wake vortex rollup from near wakes and/or span loadings of different A340 configurations; for large-scale LES studies (using the vortex-in-cell method and the spectral method) of instabilities and decay in the far wake, for LES studies of the retained configurations and using, as input, the measured near vorticity fields; for LES studies of instabilities development when using active devices.

1.38 Modelling of the disagglomeration of carbon black agglomerates in rubber matrix

*Project leader:* Vincent Legat  
*Researcher:* Bernard Alsteens  
*Framework:* Brite Euram- Project GROWTH-ROTOR

The physics of the dispersion of porous and fibrous agglomerates in a flow field has not been widely addressed in the past, despite its importance. This is mainly due to the technical difficulties associated with the observation of the kinetics of disagglomeration and the wide range of size that must be probed. Fillers are introduced in the rubber part designed to operate under extreme condition (tyre, aerospace, offshore applications, etc) to increase their mechanical resistance.

The objective of this work is to improve the efficiency of the batch mixers used for the mixing of carbon black in rubber matrix. All present rubber mixes still contain a large number of carbon black agglomerates, not fully broken down into the sub-micron particles that reinforce the rubber. The approach selected to reach this objective is to use up-to-date simulation techniques. We develop a model that predicts the evolution of the size of the agglomerates during the mixing. This evolution depends on the flow generated by the motion of the rotor in the mixer chambers. This flow is calculated with Polyflow code that used Finite Element Method and Mesh Superposition technique. The geometries of the rotors of the mixer is then modified from the result obtained with our model.

The improvement of the mixing process is characterized by the reduction of the agglomerate sizes in mixes.

*Reference:* 03.74
1.39 Finite elements simulation of vibro-acoustic problems

Project leader: Vincent Legat
Researchers: David Onderbeke, Christophe Friebel
Framework: Projet Région Wallonne

- Incompatible meshes One topic of this research is the coupling of non-matching FEM grids. Our goal is to develop a robust and efficient algorithm able to ensure regularity conditions along the common interface of the acoustic or structural sub-domains. The boundaries may be incompatible from both topological and geometrical point of view. One way to overcome this difficulty is to build a median interface, on which we can define a Lagrange multipliers field, or compute penalty terms. For this, we minimize a trade-off between distances and smoothing contributions. An advantage of this method is the ability to manage the discretization of the coupling fields.

- Discontinuous Galerkin Methods We also consider time-dependent acoustics in enclosed spaces. We model and simulate sound propagation inside non-dissipative fluids using the finite element method. The acoustic pressure propagation equation (linearized one) is discretized in 2D space within a generic Discontinuous Galerkin framework. Time integration is performed with a 4-stage Runge-Kutta scheme. The walls’ behavior and the applicability of non-reflecting time-dependent boundary conditions are studied.

1.40 Nonlinear micromechanics of composite materials

Project leader: Issam Doghri
Researchers: Christophe Friebel, Olivier Pierard, Amine Ouaar, Omar Abbad
Spin-off: e-Xstream engineering (http://www.e-xstream.com)

The general research interest of our team is computational mechanics of materials, that is the development of mathematical models, numerical algorithms and software with the final aim of predicting the behavior of engineering materials using computer simulations. Our major research focus is on the development of micro-macro or multi-scale methods which are able to predict the influence of the micro-structure on the macroscopic properties of composites. We are mainly concerned with inelastic material behavior, that is rate-dependent phenomena (e.g., visco-elasticity) or irreversible phenomena (e.g., plasticity, visco-plasticity, damage) and/or finite deformations. In 2005, we worked on the following subjects:

- Micro-macro mechanics and acoustics of viscoelastic polymer-matrix composites with multiple phases of coated inclusions (prediction of vibrational or acoustic damping, of stiffness and other mechanical properties), ref. [04.108];
• Homogenization of viscoplastic metal- and polymer-matrix composites (investigation of the so-called affine formulation, prediction of rate-dependent behavior);

• Micro-mechanics of deformation and damage in brittle materials (numerical studies of concrete- and mortar-matrix composites), refs. [04.110] and [05.80]

• Homogenization of two-phase elasto-plastic composites (investigation of the incremental formulation), refs. [03.18] and [05.45];

• Homogenization of inelastic composites with misaligned fibers, ref. [04.64]

• Mechanics of Carbon nanotube microstructures, ref. [05.48]

• Homogenization of finite-strain hyperelastic composites (application to reinforced rubber-matrix materials).

Bending test of a beam reinforced with randomly oriented short fibers. Finite element analysis at the macroscopic level and homogenization schemes at the microscopic one.
1.41 Micro-macro modelling of plasticity in heterogeneous polycrystalline metals

*Project leader*: Laurent Delannay (Collaborateur scientifique du FNRS)
*Researcher*: Maxime Melchior

The numerical models developed in this project provide improved predictions of the mechanical properties of single- and multi-phase metallic alloys. A micro-macro modelling approach is adopted and the predictions are systematically tested against experimental observations. Constitutive laws, including crystal plasticity theory, are implemented in finite element codes, either for the simulation of "real-scale" forming processes, or for a "microscopic" prediction of the heterogeneous strain field throughout polycrystalline aggregates. Let us mention some results published in 2005: Original techniques have been proposed for the representation of a polycrystalline aggregate with a finite element mesh. In the first case, grains are shaped as truncated octahedrons [04.94, 06.16], whereas the second technique, producing irregular grain shapes and sizes, is designed for multiphase alloys (collaboration with Prof. J-F. Remacle (GCE, UCL)). We have developed a texture discretisation algorithm adapted to polycrystals with non-uniform grain size. Thanks to such mathematical treatment of texture data, fewer grains are required in crystal plasticity simulations [05.55, 06.15]. Reduced grain samplings have also been used in order to decrease the computational cost of macroscopic deep drawing simulations [04.95]. Another field of research is the development of advanced Taylor-type models. Here, simplifying assumptions are formulated about the interaction of adjacent grains. Such "multi-site" models yield surprisingly accurate predictions of rolling textures in cubic [04.66] and hexagonal metals [05.81]. Specific attention has also been paid to transformation induced plasticity (TRIP) in multiphase steels [05.56, 05.100]. The challenge is to predict the rate at which the "soft" austenite phase transforms into the "hard" martensite. The phase trans-
formation criterion is formulated at the crystal level and the scale transition is achieved using a mean-field approach.

References: 04.66, 04.94, 04.95, 04.137, 05.55, 05.56, 05.81, 05.100, 05.101, 06.15, 06.16, 06.17

Pole figure representation of the texture predicted after cold rolling.

Finite element modelling of crystal plasticity at the micron scale.
1.42 Micro injection moulding, modelling and numerical simulation

*Project leader*: François Dupret  
*Researchers*: Cécile Jeggy, Olivier Magotte  
*Framework*: Brite-Euram

**Physical model**

Compared to classical injection moulding, the space and time scales are reduced when micro-parts are produced. Hence, some effects which are usually neglected must require particular attention: effect of macro-molecular chain orientation (including effect on the viscosity law), visco-elasticity, polymer crystallization (enhanced by flow-induced chain orientation), thermodynamic effects, slippage on the walls, ...

Experimental results clearly indicate that flow instabilities can occur during filling. It is highly unlikely that a generalized-Newtonian model can ever predict such instabilities in creeping flow (which is a valid assumption in micro-injection moulding). Besides, from moulding experiments and viscometric data, scaling analysis suggests that visco-elastic effects (as induced by macro-molecular chain orientation) should play a major role in micro-injection moulding. It is therefore intended to consider visco-elastic models in order to predict the flow and heat transfer. The effect of polymer crystallization (which is also induced by chain orientation) is more complex and will be considered at a latter stage.

**Numerical simulation (for the filling of 3D micro-cavities)**

The development of a simulation software for the micro-injection molding process is confronted to two problems: (i) how to calculate the flow, and (ii) how to handle the evolving domain? These two difficulties are solved by means of a 3D algorithm using:

- A finite element flow solver in order to predict the new pressure, velocity, extra-stress, ... fields. The incompressible, isothermal flow of a Giesekus fluid is considered, which requires a numerical scheme adapted to this non-linear visco-elastic model. The method developed here is based on the \( \theta \)-splitting method. Continuous tri-quadratic elements are used for the velocity field together with continuous tri-linear elements for the pressure field.

- A geometrical solver in order to calculate the new domain at each time step. The front tracking is based on a pseudo-concentration variable transported by the flow, that is then used to predict the filling rate of the mesh cells. The automatic mesh generator is based on Delaunay mesh generation principles. The tetrahedrization algorithm is based on the node insertion technique. In order to avoid algorithmic problem due to round-off errors, all geometrical computations (e.g. 3D orientation tests) are exactly computed by use of an exact representation of the rational numbers.
1.43 Modelling of bulk crystal growth processes

*Project leaders:* François Dupret, Nathalie Van den Bogaert  
*Researchers:* Brieux Delsaute, Wu Liang, Roman Rolinsky, François Bioul, Nicolas Van Goethem, Vincent Regnier  
*Spin-off:* FEMAGSOFT SA

Single crystals are used in several high tech applications. However, the Czochralski (CZ), Liquid Encapsulated Czochralski (LEC), Floating Zone (FZ), Vertical Bridgman (VB),... crystal growth processes represent complex technologies due to very high quality and purity requirements, elevated processing temperatures, and above all the absence of easy correlation between product quality and operating conditions. The general objective of our team is an accurate modelling of these processes and the corresponding research interests currently focus on:

- The development of geometrical tools in order to obtain an integrated software for the prediction of the entire crystal growth processes. For this purpose, new geometrical tools and new meshing techniques are developed: these include geometry representation by rational Bézier curves, automatic 2D and 1D mesh generators, mesh conditioning, unstructured mesh deformation, secondary meshes for calculation of free surfaces, exact control of mesh density at different levels, and automatic re-meshing at several stages of the growth process due to the important evolution of the system geometry (e.g. for initial dip-in of crystal seed into the melt, tail-end, necking or crystal detaching from melt after tail-end stage).

- The modelling of the melt and gas flows. Both 2D and 3D models are investigated, including the effect of magnetic fields (axial, cusp or rotating fields). A special technique is developed to calculate the effect of transverse magnetic fields in a simplified way. Melt flow details are analyzed by 3D models, while relevant “axisymmetric averaged” models are developed in order to take into account the effect of flow structured oscillations and turbulence on the global heat transfer in the furnace. Melt flow is also coupled to species concentration (in particular concentration of dopant and impurities such as oxygen in silicon growth). Gas flow in the enclosures is taken into account through specific models.

- The prediction of crystal quality. From the pre-calculated evolution of crystal temperature, composition and shape, crystal quality is evaluated in terms of defect density (including formation, diffusion and recombination of interstitials and vacancies and their further agglomeration in micro-defects), of dislocation density (using visco-plastic models or new models based on tensorial representation of dislocation density), and of residual stresses.
• The modelling of particular features of the Floating Zone growth process. We develop models for the induction heating system, including the effect of the tangential force exerted on melt surface, and for accurate calculation of the fusion interface.

• The development of off-line crystal growth optimisation methods. The objective of these methods is to determine the evolution of the different process parameters (heater power, pull rate, crucible and crystal rotation rates, magnetic fields, power distribution, etc.) in order to optimize selected process variables characterizing crystal shape and quality, the FEMAG simulation software playing the role of the real process.

This research activity has led to the development of a commercial simulation software, FEMAG-CZ, used by crystal growers for the design of new furnaces and for the definition of optimal operating conditions, and presently marketed by a spin-off company, FEMAG-Soft SA. This software predicts the global temperature in the overall Czochralski furnace, the solid-liquid interface shape, the crystal radius, and the melt flow, by coupling all heat transfer modes: radiation in the enclosures, convection in the melt and the ambient gas, conduction in the solids and the melt, release of latent heat at the solid-liquid interface, and power supply from the heating system. Other processes are under investigation with a view to commercializing the FEMAG-FZ, FEMAG-LEC, FEMAG-OX, FEMAG-VB, etc..., simulation tools (as devoted to predict Floating zone, Liquid Encapsulated Czochalski, Oxide, Halide, Vertical Bridgman, Vertical Gradient Freeze growth processes).
1.44 Numerical simulation of liquid moulding processes

Project leader: François Dupret
Researcher: Fabrice Loix

Liquid Moulding Technologies (LMT) are more and more used to produce high quality composite parts. In such processes, a resin is injected into a mould where a rigid network of fibres is placed beforehand. The resin is cured by heat activation (Resin Transfer Moulding process) or chemical reaction (Structural Reaction Injection Moulding process). Fibre orientation is perfectly controlled and the mechanical properties of the solid part are very high.

The objective of the present research was to predict the 3D phenomena occurring during the filling stage of SRIM and RTM moulding processes. Therefore, the flow, heat exchanges, and chemical reactions were represented by means of appropriate physical models. Non-isotropic effects were taken into account as a function of the fibre network structure, and second-order tensors are used to model permeability and heat and species diffusion. Hydrodynamic dispersion is modelled by means of a fourth-order tensor, this effect resulting in an additional mechanical mixing within the fluid phase. Finally, inertia is considered by means of the Forchheimer or Brinkman flow models. The Finite Element Method (FEM) was selected to discretize the equations. Appropriate stabilization techniques adapted to numerically hyperbolic problems are used in order to remove advection-generated wiggles. A general decoupling strategy has been developed to determine the pressure, temperature and species concentration fields at every time step of the simulation. Each subsystem is solved by using a linearisation technique combined with a rapid iterative linear solver adapted to 3D problems.

In order to better understand the complex mass, momentum, heat, and species transport mechanisms occuring in non-isotropic porous media, a new micro-macro model has been
developed. This model is based on representing the porous medium at the micro-scale by a network of simple connectors and junctions, which are further assembled to simulate the medium complexity at the macro-scale. Very satisfactory experimental comparisons have been performed. Examples illustrating the influence of the different physical effects governing SRIM and RTM have been analysed.
2 Research programmes and contracts

2.1 European Programmes


*Project title:* Hybrid Control: Taming Heterogeneity and Complexity of Networked Embedded Systems

*Promoter:* V. Blondel

*Partners:* FIST France Innovation Scientifique et Transfert (F Ronan Stephan), CNRS (Centre National de la Recherche Scientifique)(Françoise Lamnabhi-Lagarrigue), UCL Université Catholique de Louvain-BE (Vincent Blondel), ETHZ Swiss Federal Institute of Technology Zurich-CH (Manfred Morari), RUB (Ruhr-Universität Bochum-D, Jan Lunze), UNIDO Universität Dortmund-D (Sebastian Engell), DLR Deutsches Zentrum für Luft- und Raumfahrt-D (Martin Otter), UMD Otto-von-Guericke-Universität Magdeburg-D (Jörg Raisch), US Universidad de Sevilla-E (Eduardo Camacho), SUP-ELEC Ecole Supérieure d’Electricité-F (Hervé Gueguen), INRIA-F (Giancarlo Ferrari Trecate), UPAT University of Patras-GR (John Lygeros), UAQ Universita degli Studi dell’Aquila-I (Maria Domenica di Benedetto), UNIPI Università di Pisa-I (Antonio Bicchi), UNISI Universita degli Studi di Siena-I (Alberto Bemporad), PARADES-I (Alberto Sangiovanni-Vincentelli), TUE Technische Universiteit Eindhoven-NL (Maurice Heemels, Henk Nijmeijer), UT Universiteit Twente-NL (Arjan van der Schaft), TUD Technische Universität Delft-NL (Bart de Schutter), KTH Royal Institute of Technology-SE (Karl Henrik Johansson), ULIN Linköpings Universitet-SE (Lennart Ljung), LTH Lund Institute of Technology-SE (Anders Rantzer), UCAM University of Cambridge-UK (Jan Maciejowski)


*Promoter:* V. Blondel

AUTOMATHA European Science Foundation (Physical and Engineering Sciences). Un projet multidisciplinaire entre les mathématiques, l’informatique théorique et les applications. Ce programme veut catalyser l’interaction entre la théorie des automaties et ses nouvelles applications. Il mettra sur pied des canaux de communication entre les scientifiques Europeens et les groupes intéressés dans les applications de la théorie des automaties.

*Promoter:* V. Blondel
CENAERO (Centre for Research in Aeronautics)

Funds: The center benefits of the support of the Region Wallonne and of the structural funds FEDER and FSE of the European Community.

Representative: G. Winckelmans for UCL and member of the Board of Directors (with A. Dangoisse of Administration de la Recherche) and member of the Scientific Committee

Partners: Belgian industrials active in aeronautics (members of EWA, Entreprises wallonnes de l’aéronautique, universities (UCL, ULB, Ulg) and VKI.

2.2 Belgian Federal Programmes

Interuniversity Attraction Pole VI/4 (2007-2011)

CESAME is the pilot team of IAP VI/4.

Project title: Dynamical systems and control: computation, identification and modelling

Promoter-Coordinator: M. Gevers, Université catholique de Louvain (UCL - INMA)

Partners:
- Katholieke Universiteit Leuven - KUL1, Prof. J. Vandewalle; Universiteit Gent (UGent) - SYSTeMS, Prof. D. Aeyels;
- Vrije Universiteit Brussel (VUB - ELEC), Professor R. Pintelon;
- Katholieke Universiteit Leuven - KUL2, Prof. D. Roose;
- Université de Liège (ULg - SYST), Professor R. Sepulchre;
- Université Libre de Bruxelles (ULB), Professor M. Kinnaert;
- Faculté Polytechnique de Mons (FPMs), Professor A. Vande Wouwer

SSTC (PRODEX: The programme for the development of scientific experiments) (2005-2009)

Project title: Dexterous manipulation in microgravity

Promoter: P. Lefèvre


Project title: Tracing and integrated modelling of natural and anthropogenic effects on hydrosystems: the scheldt river basin and adjacent coastal north sea

UCL P.I.: E. Deleersnijder

Funded by the Belgian Science Policy
**Fonds pour la recherche Fondamentale Collective de Belgique (FRFC) (2005-2009)**

*Project title*: Numerical simulation: application in solid state physics, physical oceanography and fluid dynamics  
*Promoter*: E. Deleersnijder, X. Gonze, G. Winckelmans,

**Fonds de Recherche en Sciences Médicales, FNRS (FRSM) (2008-2012)**

*Project title*: Neuropsychopharmacology of anticipatory smooth pursuit eye movements  
*Promoter*: P. Lefèvre, M. Missal, A. Ivanoiu

**FRSM (Fonds de Recherche en Sciences Médicales, FNRS) (2004-2008)**

*Project title*: Neuronal basis of attention  
*Promoters*: P. Lefèvre, M. Missal, E. Olivier (NEFY/UCL)

### 2.3 Regional Programmes

**Region Wallonne (Programme Winnomat)**

*Project title*: Développement d’aciers laminés TRIP/TWIP à ultra-hautes performances pour applications automobiles.  
*Promoters*: L. Delannay, I. Doghri  
*Partners*: Unités IMAP et MEMA (UCL), Prof. P. Bouillard et Dr. T. Massard (ULB), Dr. M. Lamberigts (CRM)

### 2.4 Programme of the Communauté Française de Belgique


*Project title*: Dynamics of Entangled Macromolecular Fluids  
*Promoters*: R. Keunings, Ch. Bailly (POLY)


*Project title*: Neural bases of internal representations: from perception to action.  
*Promoters*: P. Lefèvre, M. Crommelinck, E. Olivier, B. Rossion, M. Missal

Project title: Algorithmic challenges in large networks
Promoters: V. Blondel, Y. Nesterov, P. Van Dooren


Project title: A second-generation model of the ocean system
Promoters: E. Deleersnijder, Th. Fichefet, V. Legat, J.F. Remacle, (POLY)

Projet de coopération scientifique inter-universitaire, Agence universitaire de la Francophonie (AUF) (2006-2007)

Project title: Analysis, simulation and control of complex systems
Promoter: V. Wertz
Partners: Prof. M. Elarbi Achhab, LINMA, Faculté des Sciences, Université Chouaib Doukkali, El Jadida, Maroc and Prof. Henda El Fekih, LAMSIN, Ecole Nationale d’Ingénieurs de Tunis (ENIT), Tunisie

Coopération Universitaire au Développement (CUD) (2004-2007)

Project title: Projet PIC 2004 “Création d’un pôle de compétence en mécanique appliquée à la construction”
Promoter: I. Doghri
Partners: UCL, ULB, ULg, FPMs, ENIT (Tunis)

First Spin-off (2003-2007)

Project title: Simulation numérique de la croissance des cristaux (CRYSGROW)
Promoter: F. Dupret
Partner: FEMAG Soft S.A.

2.5 Industrial contracts

France Telecom, Orange Labs (2006-2007)

Project title: Analysis of mobile phone network.
Promoters: V. Blondel, P. Van Dooren
SCK-CEN (Belgium)

Project title: Myrrha project: design, numerical modeling, and experimental modeling for a windowless design of the spallation target for new ADS-type reactors. Phase IV. 

LILLY (Belgium) (2005-2008)

Project title: Mise à l’échelle de procédés de cristallisation.
Promoter: D. Dochain

TOTAL (Belgium) (2005-2007)

Project title: Surveillance de procédés de production de polymères
Promoter: D. Dochain

2.6 Other international contracts

National Science Foundation (USA) (2003 - 2007)

Project title: NSF Collaborative Research grant (ACI-0324944) on Model Reduction of Dynamical Systems for Real Time Control
Promoters: A. Antoulas, D. Sorensen (Rice Univ.), Sameh (Purdue Univ.), K. Gallivan (FSU), P. Van Dooren.
3. PUBLICATIONS
Theses


07.128 Orbán de Xivry Jean-Jacques, Tracking the invisible requires prediction and internal models Saccades during anticipation of a pursuit target, December 14, 2007.


07.130 Sauvage Frédéric, Design and application of state observers for exothermic fed-batch reactors with uncertain kinetics and heat transfer, December 12, 2007.

Chapters of book


Special issue

Published papers


06.097 LEGRAND S., E. DELEERSNIJDER, E. DELHEZ, V. LEGAT, “Unstructured, anisotropic mesh generation for the Northwestern European continental shelf, the continental slope and the neighbouring ocean”, *Continental Shelf Research*, vol.27, 2007, pp.1344-1356.


07.039 BITTANTI S., M. GEVERS, “Prelude to eight essays on the history of control science in the XX-th Century”, European Journal of Control, "On the dawn and


**Published conference papers**


Journal papers accepted or submitted


Conference papers accepted or submitted


ENGINEERING THESES

1. ADAM QUENTIN
   “Modélisation de marées sur l’océan mondial par la méthode des éléments finis”
   Promoter : Vincent Legat
   Lecteurs : V. Blondel, R. Comblen, E. Deleersnijder

2. BROWET ARNAUD
   “Capital humain et distribution internationale de revenus : Une analyse prospective”
   Promoters : F. Docquier, Ch.Hafner
   Lecteur : V. Blondel

3. BORCKMANS PIERRE & CAMBIER BENOÎT
   “Génétique et théorie de l’information : l’identification de gènes par les codes correcteurs d’erreur”
   Promoters : L. Vandendorpe, M. Verleysen
   Lecteur : Ph. Lefèvre
4. CHANG CHIA-TCHE
“Polynômes et Sommes de Carrés”
Promoter : F. Glineur
Lecteurs : P. Van Dooren, Y. Nesterov

5. CHIEM JEAN-CHRISTOPHE
“Étude de la coordination entre l’œil et la main dans la manipulation fine d’objet”
Promoter : Ph. Lefèvre
Lecteurs : J.L. Thonnard, F. Crevecoeur

6. COPPE SÉBASTIEN
“Analyse du rôle joué par l’anticipation dans le contrôle des mouvements oculaires”
Promoter : Ph. Lefèvre
Lecteurs : M. Missal, J.J. Orban de Xivry

7. COPPIETERS RÉGIS
“Optimisation sur des espaces non euclidiens : Estimation de pose”
Promoters : P.A. Absil, P. Van Dooren
Lecteur : D. François

8. COURTOIS GEOFFREY
“Vérification numérique d’inégalités polynomiales”
Promoter : F. Glineur
Lecteurs : V. Blondel, P.A. Absil

9. DEBAISIEUX AUDRIC
“Optimisation de tournées de véhicules pour la gestion de déchets stockés dans des conteneurs”
Promoter : L. Wolsey
Lecteurs : J. Raucq, Y. Pochet

10. DEBRULLE ARNAUD
“Optimisation d’une aube de turbomachine : algorithme de Nelder-Mead et pénalisation de contraintes”
Promoter : F. Glineur
Lecteurs : G. Bastin, Keiichi Ito (CENAERO)

11. DERMINE SUZANNE
“Essai de classification des cordelettes Khipus utilisées par les Incas comme moyen de communication : un exemple d’ethno-cryptographie”
Promoter : J.J. Quisquater
Lecteurs : V. Blondel, A. Magnus

12. DE VOS NICOLAS
“Affectation optimale des prestations des conducteurs de train aux dépôts à l’exemple de certaines lignes du réseau ferroviaire belge”
13. BONHEURE DOMINIQUE
“Equation de Schrödinger non-linéaire dans la limite semi-classique”
Promoter : D. Bonheure
Lecteurs : P. Habets, M. Willem

14. DRUENNE ÉRIC
“Évaluation d’actifs par réplication et gestion de portefeuille, application à portefeuille d’actifs du secteur de l’électricité”
Promoter : Y. Smeers
Lecteurs : M. Denuit, Verbeeck (Electrabel)

15. GILLIS NICOLAS
“Approximation et sous-approximation de matrices par factorisation positives : algorithmes, complexité et applications”
Promoter : F. Glineur
Lecteurs : P. Van Dooren, Ho Ngoc Diep

16. GOUDENHOOFDT EDOUARD
“Analyse de méthodes de recherche directe et du filtre de Kalman d’ensemble pour l’optimisation des paramètres d’un modèle climatique”
Promoters : H. Gosse, V. Legat
Lecteurs : M. Crucifix (ASTR), F. Glineur

17. LECLERCQ GUILLAUME
“L’utilisation des radars météorologiques dans les modèles pluie-débit”
Promoter : G. Bastin
Lecteurs : L. Moens, L. Vandendorpe

18. LEFEBVRE ÉTIENNE
“Communities in complex networks models and algorithms”
Promoter : V. Blondel
Lecteurs : P. Van Dooren, J.L. Guillaume

19. LEFEVRE LUDOVIC
“Tarification d’options à barrière au moyen des processus de Lévy”
Promoters : P. Devolder, Y. Smeers
Lecteur : M. Denuit

20. MAHIAT THIBAULT
“Validation d’un modèle océanique en éléments finis dans le cas test DOME”
Promoter : V. Legat
Lecteurs : R. Comblen, A. Magnus
21. ORBAN DE XIVRY FRANÇOIS XAVIER
“Simulation de la dynamique de glace en antarctique”
*Promoters*: V. Legat, Th. Fichefet
*Lecteurs*: V. Blondel, O. Lietaer

22. RAUSENS BRIAN
“Développement d’une méthode lagrangienne de particules pour l’étude de connectivité des récifs. Application à la Grande Barrière de Corail”
*Promoter*: V. Legat
*Lecteurs*: E. Deleersnijder, J. Lambrechts, G. Bastin

23. ROBERT ARNAUD
“Défauts dans un cristal de silicium”
*Promoter*: F. Dupret
*Lecteurs*: P.A. Absil, N. Van Goethem

24. THUNUS SABRINA
“Un problème de lot-sizing avec incertitude sur la demande”
*Promoter*: L. Wolsey
*Lecteurs*: Y. Pochet, F. Glineur

25. VERSTRAETE NICOLAS
“Estimation en ligne des paramètres d’un véhicule automobile”
*Promoters*: G. Campion, G. Bastin
*Lecteur*: B. Dehez
4. TEACHING
1 Undergraduate and Graduate Teaching

1.1 Applied Mathematics and Computational Sciences

Mathematics 1 - FSAB1101
(K. Ben-Naoum, M. Verleysen, V. Wertz)

Mathematics 2 - FSAB1102
(K. Ben-Naoum, Camille Debiève, François Glineur, Enrico Vitale)

Mathematics 3 - FSAB1103
(K. Ben-Naoum, V. Blondel, J.F. Remacle, Grégoire Winckelmans)

Mathématiques discrètes I : Théorie et algorithmique des graphes - INMA1691
(V. Blondel)

Modèles et méthodes d’optimisation I - INMA1702
(V. Blondel)

Analyse numérique - INMA1170
(P. Van Dooren - P.-A. Absil)

Méthodes avancées en automatique - INMA2360
(P.-A. Absil, V. Wertz)

Systèmes dynamiques non linéaires - INMA2361
(P.-A. Absil R. Sepulchre)

Théorie des matrices - INMA2380
(P. Van Dooren)

Algorithmique numérique - INMA2710
(P. Van Dooren)

Complexity of algorithms - INAM2111
(V. Blondel)

Applied Mathematics : Signals and systems - FSAB1106
(G. Bastin, V. Wertz)

Mechanics and heat transfer I - MECA1321
(G. Winckelmans, V. Legat)

Fluid mechanics and heat transfer II - MECA2322
(G. Winckelmans, M. Giot)

Numerical methods in fluid mechanics - MECA2660
(G. Winckelmans)

External flow aerodynamics - MECA2323
(G. Winckelmans, F. Dupret)

Turbulence - MECA2853
(G. Winckelmans, G. Schayes)

Séminaire d’analyse numérique - MATH2830
(P. Van Dooren)

Projet en mathématiques appliquées - INMA1375
(P.-A. Absil)
1.2 Systems and Control

Automatic Control: theory and implementation - MECA2671
(M. Gevers, V. Wertz)
Automatic Control: Fundamentals
(G. Bastin, D. Dochain)
Process simulation - MAPR2145
(D. Dochain, F. Thyrion)
System identification - ELEC2875
(M. Gevers)
Advanced methods in automatic control - INMA2360
(P.-A. Absil, G. Bastin, M. Gevers, V. Wertz)
Process Control - MAPR2300
(D. Dochain, G. Bastin)
Modelling and design of chemical reactors - MAPR2330
(D. Dochain)
Seminars in systems theory - INMA2120
(G. Bastin, G. Campion, D. Dochain, M. Gevers, Ph. Lefèvre, P. Van Dooren, V. Wertz)

1.3 Biomedical engineering

Introduction to biomedical engineering - FSAB1225
(Ph. Lefèvre)
Project in biomedical engineering - FSAB1230
(Ph. Lefèvre et al.)
Modelling of biological systems - GBIO2060
(Ph. Lefèvre, G. Bastin)
Introduction to life sciences (part II) - FSA2221
(Ph. Lefèvre, G. Bastin, V. Legat, Y.J. Schneider, S. Agathos)

2 Post-Graduate Training

2.1 Graduate School in Systems, Optimization, Control and Networks (SOCN)

The Graduate School in Systems and Control was started in the Spring of 1992 at the initiative of the subnetwork Modelling and Control of IUAP 17, jointly with the groups PMA (KUL) and the Dienst Elektriciteit (VUB) of the IAP 50. Within the framework of the new IAP’s the Graduate School in Systems and Control is organized jointly by the seven teams of IAP V/22 and by three teams of IP V/06 on “Advanced mechatronics Systems”.

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The aim is to provide advanced courses in systems and control theory and to give an overview of recent research developments in this field. The school has been primarily intended for doctoral students, although a number of engineers from industry and academics have also taken the courses. They have been widely publicized in all centers that are active in systems and control in Belgium. The courses can now be taken as partial fulfillment of the PhD programme in several universities in Belgium.

More information on http://www.inma.ucl.ac.be/graduate/

A. Spring 2007 session

1. Design Methods for Control Systems

   Lecturers: M. Steinbuch (Eindhoven University of Technology, The Netherlands) and G. Meinsma (University of Twente, The Netherlands)

   Objective:
   The course presents “classical”, “modern” and “post modern” notions about linear control system design. First the basic principles, potentials, advantages, pitfalls and limitations of feedback control are presented. An effort is made to explain the fundamental design aspects of stability, performance and robustness.

   Next, various well-known classical single-loop control system design methods, including Quantitative Feedback Theory, are reviewed and their strengths and weaknesses are analyzed. The course includes a survey of design aspects that are characteristic for multivariable systems, such as interaction, decoupling and input-output pairing. Further LQ, LQG and some of their extensions are reviewed. Their potential for single- and multi-loop design is examined. After a thorough presentation of structured and unstructured uncertainty, model design methods based on H-infinity-optimization (in particular, the mixed sensitivity problem and McFarlane-Glover’s loopshaping problem) and $\mu$-synthesis are presented.

   Contents:

   - Introduction to feedback theory. Basic feedback theory, closed-loop stability, stability robustness, loop shaping, limits of performance.
   - Classical control system design. Design goals and classical performance criteria, integral control, frequency response analysis, compensator design, classical methods for compensator design. Quantitative Feedback Theory.
   - Multivariable Control, Multivariable poles and zeros, interaction, interaction measures, decoupling, input-output pairing, servo compensators.
• LQ, LQG and Control System Design, LQ basic theory, some extensions of LQ theory, design by LQ theory, LQG basic theory, asymptotic analysis, design by LQG theory, optimization, examples and applications

• Uncertainty models and robustness, Parametric robustness analysis, the basic perturbation model, the small-gain theorem, stability robustness of the basic perturbation model, stability robustness of feedback systems, numerator-denominator perturbations, structured singular value robustness analysis, combined performance and stability robustness.

• $H_\infty$ optimization and $\mu$-synthesis. The mixed sensitivity problem, loop shaping, the standard $H_\infty$ control problem, state space solution, optimal and sub-optimal solutions, integral control and HF roll-off, $\mu$-synthesis, application of $\mu$-synthesis.

Prerequisites : Basic undergraduate courses in systems and control. Some familiarity with MATLAB is helpful for doing the homework exercises.


2. An Introduction to Monte Carlo, Markov Chain Monte Carlo (MCMC), and Sequential Monte Carlo Methods (SMC)

Lecturer : A. Srivastava (Florida State University, U.S.A.)

Overview :

This course is geared towards introducing basic techniques from computational statistics, for use in engineering problems. In particular, we focus on random sampling, Monte Carlo estimation, and stochastic optimization techniques, in problems where complex probability distributions result from nonlinear systems and non-Gaussian noise. As an example, we demonstrate the use of these random sampling techniques in nonlinear filtering. Similarly, we also apply these tools to develop stochastic optimization techniques.

Specific Aims :

(i) To introduce basic ideas behind random sampling and Monte Carlo estimation.

(ii) To demonstrate computational approaches for solving complex estimation and optimization problems that are difficult to solve analytically.

(iii) To demonstrate Kalman filtering and nonlinear filtering from a Bayesian perspective, and to introduce SMC methods for nonlinear filtering.
Contents:

- Monte Carlo Methods: Motivation, classical Monte Carlo techniques, simulation of random variables, error reduction techniques
- Sequential Monte Carlo Methods (also called particle filtering or ensemble Kalman Filtering), Kalman filter for Gauss-Markov systems (from a Bayesian perspective), importance sampling, sequential Monte Carlo algorithm, applications to hidden Markov models
- Stochastic Optimization: Gradient process, stochastic gradient process (Langevin’s diffusion process), Metropolis-adjusted stochastic gradient process, simulated annealing.

Prerequisites: Linear algebra, advanced calculus, introduction to probability theory.

Supporting material: A printed version of all class notes will be handed out in the first lecture. As an additional reference, the textbook “Monte Carlo Statistical Methods” by C. P. Robert and G. Casella (2004) can also be used although it will not be necessary.

Evaluation procedure: Homework problems to be implemented in Matlab and evaluated on the basis of cumulative homework performances.

Dates: May 2, 4, 9, 11, 14, 16, 2007

B. Fall 2007 session

3. Optimization Algorithms on Matrix Manifolds
Lecturers: P.-A. Absil (Université catholique de Louvain, Belgium) and R. Sepulchre (Université de Liège, Belgium)

Overview:
The course offers an introduction to the theory and applications of numerical optimization on manifolds. This area of computational mathematics deals with the analysis and design of algorithms for optimizing a real-valued function whose domain, instead of being the classical Euclidean space $\mathbb{R}^n$, is in general a non-Euclidean space endowed with a differentiable structure. This includes real-valued functions on smooth surfaces of $\mathbb{R}^n$, and more generally on sets that can be “smoothly” parameterized. Optimization techniques on manifolds find applications in several areas, including the eigenvalue problem, blind source separation (via independent component analysis), pose estimation in computer vision, and model reduction of dynamical systems.

**Aim of the course:**

- Motivate why manifold theory provides natural foundations for the development of matrix algorithms for several major computational problems and why the resulting numerical algorithms can be highly competitive.
- Provide the students with the necessary background in differential geometry instrumental to algorithmic developments.
- Develop classical optimization algorithms on matrix manifolds: steepest-descent, Newton, conjugate gradients, trust-region methods.
- Guide the student through the concrete calculations that turn an abstract geometric algorithm into a numerical implementation.
- Illustrate the many problems from linear algebra, advanced signal processing, and statistical analysis that can be recast as optimization problems on matrix manifolds.

**Contents:**

(a) Motivating examples: Eigenvalue problem, independent component analysis, computer vision, dynamical systems. Manifolds, submanifolds, quotient manifolds.

(b) First-order geometry: Tangent vectors, Riemannian metric, gradient vector fields, gradient flows.

(c) First-order algorithms: Retractions, steepest-descent methods, line-search strategies. Optimization on the orthogonal group and independent component analysis.

(d) Second-order geometry and Newton’s method: Newton’s method in $\mathbb{R}^n$, affine connections, Riemannian connection, parallel translation, geodesics, Newton’s method on manifolds.

(e) Models and trust-region methods. Optimization of the Rayleigh quotient on the sphere and on the Grassmann manifold.
Vector transport, approximate Newton methods, conjugate gradients. Applications.

*Prerequisites:* Basic knowledge of matrix algebra and real analysis. No specific background in differential geometry or numerical optimization is assumed.


*Evaluation procedure:* The students design and implement an algorithm for independent component analysis and apply it to image processing or gene expression analysis problems. The task will be split into homeworks.

**Dates:** October 01, 04, 08, 11, 15, 18, 2007.

This course took place at CESAME, Louvain-la-Neuve.

4. **Numerical methods for Nonlinear Optimal Control**  
*Lecturer:* M. Diehl (K.U.Leuven, Belgium)

**Objective:**

The course develops numerical solution strategies for optimization problems with underlying differential equation models. After a brief overview of sequential and simultaneous approaches to optimal control, we focus on the latter class, which solve both the model equations and the optimality conditions in a ‘one-shot’ approach. Here, exploitation of sparsity in the linear solvers is of crucial importance. Special topics include the treatment of distributed inequalities by interior point methods, periodic problems. Finally, we discuss real world applications from chemical and mechanical engineering.

**Contents:**

(a) Optimal Control: Introduction and Overview  
(b) Dynamic Programming and Indirect Approaches (Pontryagin)  
(c) Direct Transcription Methods (ODE Sensititivity, Single Shooting)  
(d) Direct Collocation, Treatment of Sparsity  
(e) Direct Multiple Shooting  
(f) Applications and Extensions: Multi-Stage Processes, Periodicity

*Prerequisites:* Participants are assumed to have a knowledge of linear algebra and calculus. Basic knowledge in optimisation and numerical simulation of dynamic
systems is advantageous.

Related references:

Dates: November 26, 29 and December 03, 06, 07, 2007.

This course took place at the Katholieke Universiteit Leuven.

5. Convex Optimization: Models and Methods
Lecturer: F. Glineur (Université catholique de Louvain)

Overview:

The purpose of this course is to give an overview of the field of convex optimization, focussing both on the modelling and algorithmic aspects.

The course starts with an introduction to the notion of structured convex optimization and the reasons why this class of problems is worth studying, both from the theoretical (favourable algorithmic complexity) and practical points of view (resolution of large-scale problems). Various techniques allowing the formulation of optimization problems in a convex way are presented, emphasizing the roles of duality and conic formulations. Convex problems can be solved by a class of methods called interior-point algorithms, whose key concepts are explained along with the corresponding algorithmic complexity results. Finally, some noteworthy applications of convex optimization are described.

Lecture 1. Introduction: Convex sets, convex functions and convex optimization; black-box vs. structured optimization and complexity.
Lecture 2. Models: Convex modelling of optimization problems; linear, quadratic and semi definite modelling
Lecture 3. Models: Duality for convex optimization; conic formulation; convex separable optimization
Lecture 4. Methods: Interior-point methods for linear optimization; complexity
Lecture 5. Methods: Interior-point methods for convex optimization; self-concordant barrier functions
Lecture 6. Applications: Polynomial optimization, MAX-CUT, machine learning, etc.

References:
- S. Wright, Primal-Dual Interior-Point Methods, SIAM, 1996.

Dates: Fridays 10/11, 17/11, 24/11, 1/12, 8/12, 15/12

This course took place at CORE, 34 voie du Roman Pays, B-1348, Louvain-la-Neuve.

6. Integer and mixed integer programming

Lecturer: L. A. Wolsey (Université catholique de Louvain)

Overview:

In this course we examine the main results underlying the theory of integer and mixed integer programming. Examples are chosen with the practical goal of understanding what happens in the existing commercial systems such as Cplex and Xpress-MP, and of learning how to improve problem formulations and/or use or design alternative algorithms if and when these MIP systems fail.

Lecture 2. Valid Inequalities for General IPs and MIPs
Lecture 3. Valid Inequalities and Convex Hulls for “Easy” Structured MIP Sets
Lecture 4. Valid Inequalities, Lifting and Separation for ”Hard” Structured MIP Sets
Lecture 5. Branch-and-Cut and Applications
References:

Dates: Wednesday afternoons (14h-17h) from 14/2/07 until 21/3/07

This course took place at CORE, 34 voie du Roman Pays, B-1348, Louvain-la-Neuve.

7. Identification of Linear Systems in the presence of Nonlinear Distortions / A frequency Domain Approach

Lecturer: J. Schoukens (Vrije Universiteit, Brussel)

This course was given in the framework of the Chaire Francqui at ULB.

Overview:

Linear models are at the basis of many engineering activities. The aim of this course is to identify these models from experimental data. In real life, nonlinear distortions violate the ideal linear framework. Two solutions are discussed to extend the classic linear modelling approach. First the linear framework is extended to include these distortions using best linear approximations and nonlinear noise sources. Alternatively, the nonlinear distortions are explicitly modelled.

Specific Aims:

- To give an introduction to system identification theory: this offers a systematic approach to the extraction of models from experimental data. Besides the plant model, identification theory also provides a description of the uncertainty bounds.
- To discuss the nonparametric and parametric identification of linear dynamic systems: the discussions are made in the frequency domain, but many results carry over to the time domain formulation. The equivalences and differences between time-and frequency domain identification are highlighted.
- To analyse the impact of nonlinear distortions on the linear framework: Are there nonlinear distortions present? At what level? What is their nature? The Volterra/Wiener theory is used as a framework.
- To include nonlinear distortions in the linear system identification theory.
- To model nonlinear distortions using different classes of nonlinear models.
During the course many illustrations with experimental results coming from different application fields are shown.

Outline:

- **February 7, 2007 at 16:30**
  Inaugural Lecture (1 Hour)

- **February 8, 2007 from 10:00 to 12:45**
  Frequency Response Function Measurements (2.5 hours) Setup; random and periodic excitations; bias and variance analysis; leakage; averaging techniques; experiment design; extension to multiple-input-multiple-output systems;

- **February 15, 2007 from 10:00 to 12:45**
  Impact of Nonlinear Distortions on the Linear Framework (2.5 hours) Nonlinear framework; coherent and stochastic nonlinear contributions; best linear approximation; detection, qualification and quantification of nonlinear distortions; optimized experiments.

- **February 22, 2007 from 10:00 to 12:45**
  System Identification (2.5 hours) Introduction; consistency, efficiency, Cramer-Rao bound; (weighted) least squares and maximum likelihood estimation; errors-in-variables framework; model selection; model errors.

- **March 1, 2007 from 10:00 to 12:45**
  Identification of Linear Systems (2.5 hours) Basic choices (including time- and frequency domain identification); errors-in-variables and output error formulation; (non)parametric noise models; model selection; impact of nonlinear distortions.

- **March 8, 2007 from 10:00 to 12:45**
  Identification of Nonlinear Systems (2.5 hours) Basic problem; models: non-parametric, block structured, and state space representation; initialization methods.

This course took place at Solbosch Campus of ULB, 50 Av. F.D. Roosevelt, B-1050 Brussels

8. **Polytopes and Graphs**

   **Lecturers**: J.P. Doignon and S. Fiorini (ULB, Brussels)

   **Content**:

   (a) Introduction to polytopes: fundamental notions, cyclic polytopes and other basic examples, permutahedron and associahedron, faces, polarity, rational and 0/1-polytopes.
(b) Steinitz’s Theorem (a graph is the graph of a 3-polytope iff it is planar and 3-connected) : Truemper’s revision of Steinitz’s original proof.

(c) Gale transforms: various definitions, classification of polytopes with few vertices, nonrational polytopes, (oriented) matroids.

(d) The Upper Bound Theorem: shellability, the Euler-Poincaré formula, h-vectors and the Dehn-Sommerville equations, maximizing the number of facets.

(e) Topics following suggestions from the audience.

References :

Dates : 13/03, 20/03, 27/03, 17/04, 27/04

This course took place at ULB, Brussels.
2.2 The Graduate School in Computational Mechanics (GRASMECH)

Organized under the auspices of the National Committee on Theoretical and Applied Mechanics.
The participants came from the following institutions: Katholieke Universiteit Leuven, Université Catholique de Louvain, Université de Liège, Université Gent, Université Libre de Bruxelles, Von Karman Institute, Vrije Universiteit Brussel.
The purpose of the Graduate School is to organise courses in the field of Computational Mechanics, on a third cycle level, to all Belgian graduate students, in compliance with the rules of the parent institution of the student. The field of science in ”Computational Mechanics” is very wide.

Five subgroups are identified:

1. solid mechanics and acoustics
2. materials processing
3. fluid mechanics
4. rheologically complex materials
5. numerical aspects and programming

The school is primarily intended for doctoral students and researchers. Engineers from industry and professors from other educational institutions are also welcome.

Micromechanics of heterogeneous materials: modelling and computation (UCL, Louvain-la-Neuve)


Date: February 14, 15, 16, 2007

Topics:
1. Mean-field homogenization (I. Doghri, 9 hours)
2. Micro-macro modelling of metals based on crystal plasticity theory (L. Delannay, 2 hours)
3. Software for industrial applications (L. Adam, 1 hour)

4. Aspects of microstructure evolution (M. Geers, 2 hours)

5. Computational homogenization for highly non-linear heterogeneous solids (V. Kouznetsova, 2 hours)

6. Asymptotic homogenization (R. Peerlings, 2 hours)

Contents:

1. Mean-field homogenization (I. Doghri, 9 hours)
   - Examples of heterogeneous materials (composites, porous materials, ...)
   - Overview of scale transition methods
   - General averaging theorems
   - Mean-field homogenization: general results
   - Eshelby results
   - Single inclusion problem
   - Hills results
   - Mean-field homogenization models: self-consistent, Mori-Tanaka, double inclusion, ...
   - Linear thermo-elastic composites
   - Multi-phase composites
   - Orientation tensors
   - Inelastic material behavior: review
   - Homogenization in linear viscoelasticity
   - Homogenization in elasto-plasticity
   - Homogenization in elasto-viscoplasticity
   - Finite strains or rotations: review (stresss measures, strain measures, hypere-elasticity...)
   - Finite strains or rotations: general averaging results
   - Homogenization in finite strain hyperelasticity
   - Related topics: second-order formulations, debonding, clustering, size effects, other microstructures, etc.

2. Micro-macro modelling of metals based on crystal plasticity theory (L. Delannay, 2 hours)
   - Introduction: effect of texture on the anisotropy of metals 114
• an elastic-viscoplastic constitutive law adapted to single crystals
• micro-macro modelling of the polycrystalline aggregate
• prediction of the development of texture, anisotropy, and internal stresses

3. Software for industrial applications (L. Adam, 1 hour)
• Numerical simulation of representative volume elements Multi-scale numerical
  • simulation of composite products

4. Aspects of microstructure evolution (M. Geers, 2 hours)
• Examples of microstructure evolution
  • Thermodynamical and kinetical aspects
  • Mathematical approaches
  • phase field models

5. Computational homogenization for highly non-linear heterogeneous solids (V. Kouznetsova, 2 hours)
  • first-order computational homogenization towards a local continuum
  • theoretical concepts and implementation aspects
  • second-order computational homogenization, towards a second-gradient continuum
  • computational homogenization of structured thin sheets towards a shell continuum

6. Asymptotic homogenization (R. Peerlings, 2 hours)
• Introduction
• Theory
• Numerical aspects
• Examples
• Extensions: higher orders, nonlinearity, damage
5. SEMINARS AND WORKSHOPS
1 Seminars CESAME

- Tuna Emre (ULg), “A lecture on homogeneity”, 20/03/2007.
• Martin GUAY (Queen’s University, Canada), “Adaptive optimization techniques for control and estimation”, 23/10/2007.


2 Seminars of the ARC on “Large Graphs and Networks”

• Cristobald DE KERCHOVE (UCL), “Reputation systems: Can we trust everyone?”, 02/02/2007.


• Dr. Fabricio ROSSI(INRIA, France), “Graph mining problems”, 01/03/2007.

• Prof. Yurii NESTEROV (UCL), “Stable sets in graphs by optimization” 2/03/2007.


• Catherine FRAIKIN (UCL), “Graph matching with type constraints”, 22/03/2007.

• Damien FRANÇOIS (UCL), “Learning, spinning, and mining for fun and profit”, 21/05/2007.

• François NICOLAS (Helsinki Institute for Information Technology, Finland), “Hardness of Optimal Spaced Seed Design”, 31/05/2007.

• Philippe GAURON (Université Paris 7), Systèmes Pair-à-pair: structurer ou utiliser l’ordre naturel?”, 31/08/2007.


• Prof. Masashi SHIMBO (Nara Institute of Science and Technology, Japan), “Kernels on graph nodes and their application to link analysis”, 05/11/2007.


3 Workshops

3.1 Study days and workshops

3.1.1 Kickoff meeting of the DYSCO network VI/4

The kickoff meeting took place at the Château Ferme de Profondval, near Louvain-la-Neuve, 16 April 2007

Programme

09:15 Presentation of the DYSCO network and programme (M. Gevers)
09:30 Brief presentation of the teams ULB, FPMs, KUL1 and ULg
10:30 Poster session 1: posters of the teams ULB, FPMs, KUL1 and ULg
11:30 Plenary Lecture 1: “Recent Advances in Convex Optimization” by Stephen Boyd (Stanford University)

12:30 Lunch

14:00 Brief presentation of the teams UCL, UGent, VUB, KUL2
15:00 Poster session 2: posters of the teams UCL, UGent, VUB, KUL2
16:00 Plenary lecture 2: “Optimization on manifolds”, by Pierre-Antoine Absil (UCL)
17:00 Meeting of the promotors and coordinators
3.1.2 IAP VI/4, DYSCO Workshop

Organized by VUB, at the Royal Military Academy, 1000 Brussels, 22 November 2007

Programme

09:30-10:00 Registration
10:00-10:15 Welcome
10:15-11:15 Plenary session 1:
   Prof. Ekaterina Kostina (Faculty of Mathematics and Computer Science, University of Marburg, Germany) “Efficient Methods for Parameter Estimation and Optimum Experimental Design for Dynamic Processes”
11:15-11:45 Coffee break
11:45-13:00 Poster session 1
14:00-15:00 Plenary session 2:
   Prof. Denis Dochain (Directeur de Recherches FNRS honoraire, CESAME, UCL) “Microbial Ecology and Bioprocess Control: Opportunities and Challenges”
15:00-15:30 Coffee break
15:30-16:30 Poster session 2
3.1.3 Journée FTRD-UCL

Université Catholique de Louvain, 23 October 2007

Programme

9h30 Vincent Blondel et Paul Van Dooren (UCL)
   Introduction
9h45 Etienne Huens et Jean-Loup Guillaume (UCL)
   Nettoyage de données téléphoniques
10h30 Barbara Poulain (FTRD)
   Apprentissage supervisé
10h50 Zbigniew Smoreda (FTRD)
   Etudes sociologiques
11h30 Alina Stoica (FTRD)
   Réseaux égo-centrés
11h45 Cristobald de Kerchove (UCL)
   Analyse statistique des données
14h00 Matej Karpisek (IKAN Consulting)
   Le traitement et stockage des données chez IKAN
14h30 Paul Van Dooren et Gauthier Krings (UCL)
   Logiciels et visualisation de grands graphes
15h00 Bertil Hatt (FTRD)
   Visualisation
15h30 Renaud Lambiotte (UCL)
   Détection de communautés et évolution temporelle
3.1.4 Workshop on graph mining and dynamics
Université catholique de Louvain, 20 December 2007

Programme

14h00 Lars Elden (Linköping)
   “Graph mining and automatic translation”
14h30 Sandro Zampieri (Padova)
   “Randomized consensus algorithms over large scale networks”
15h00 Karl-Henrik Johansson (Stockholm)
   “A distributed estimator for sensor networks”
16h00 Ulrich Krause (Bremen)
   “On convex interaction of particles”
16h30 Rodolphe Sepulchre (Liège)
   “Consensus on manifolds”

3.1.5 XII Coalition Theory Network Workshop
Network and Coalition Formation among Heterogeneous Agents: Theory, Applications and Experiments
Center for Operations Research and Econometrics (CORE), Université catholique de Louvain, 18-20 January 2007

Session 1 (joint with the Department of Mathematical Engineering)
Chairman: Vincent Blondel, UCL, Belgium

Programme

9h00 Jean-Loup Guillaume Department of Mathematical Engineering, UCL, Belgium
    Complex Networks Metrology: The Internet Case
    Discussant: Raphaël Jungers and Julien Hendrickx, UCL, Belgium
9h45 Gonul Dogan Department of Methodology and Statistics, Tilburg University
    The Stability of Exchange Networks
    Discussant: Jean François Caulier, Facultés Universitaires Saint-Louis, Belgium
11h00 Marco Saerens Information Systems Research Unit, UCL, Belgium
    Some Recently Defined Kernels on a Graph
    Discussant: TBA
11h45 Dunia López-Pintado Columbia University, USA
    Social Influence, Binary Decisions and Collective Dynamics
    Discussant: Vincent Buskens, Utrecht University, The Netherlands
3.1.6  A day about the DELSARTE bound

Université catholique de Louvain, Sénat Académique, 1348 Louvain-la-Neuve, 29 October 2007

A scientific fest in honor of Philippe Delsarte, emeritus

A question: let us imagine a lot of balls with the same radius. What is the best configuration of such balls when you want to pack it at best? The discussion began with Newton, Gregory, Kepler, and many other ones. The question seems naive but is strongly related to information theory (Shannon), combinatorics, quantum communication, error-correcting codes, energy, puzzles,...

An invitation to an exclusive day with many living experts in the world.

With Talks by

- Michel GOEMANS (MIT, USA)  
  "Delsarte, Association schemes and semidefinite programming"

- Christine BACHOC (Bordeaux, France)  
  "Generalizations of P. Delsarte linear programming bound in the framework of group representation"

- Alex SAMORODNITSKY (Hebrew University of Jerusalem)  
  "What makes the linear programming bounds for codes so good?"

- Robert CALDERBANK (Princeton, USA)

- Alexander SCHRIJVER (CWI)  
  "Delsarte Triple and Semidefinite"

- Henri COHN (Microsoft Research, USA)  
  About packing

- Abhinav KUMAR (Harvard, USA)  
  "Linear programming bounds for potential energy and universally optimal configurations"

Sponsoring and organized by the following UCL partners:

- INGI department (UCL Computer Science department)
- Graduate school in Systems, Optimization, Control and Networks (SOCN)
- Graduate school on MUltimedia, SIlicon, Communications, Security Electrical and Electronics Engineering (MUSICS)

- PAI DYSCO (INMA)

- PAI BECRYPT (TELE)

- UCL Crypto Group

3.1.7 CDPS 2007, IFAC Workshop on Control of Distributed Parameter Systems

University of Namur (FUNDP, Namur, Belgium, 23-27 July 2007)
Organized by D. Dochain and J. Winkin
See http://www.fundp.ac.be/sciences/cdps07/
6. RESPONSIBILITIES
Responsibilities

BASTIN Georges

- Associate Editor Journal of Forecasting (Wiley)
- Associate Editor Electronic Journal of Control, Optimization and Calculus of variations (European series in Applied and Industrial Mathematics)
- Associate Editor European Journal of Automation (Hermes)
- Associate Editor Bioprocess and Biosystems Engineering (Springer verlag)

BLONDEL Vincent

- Associate editor of Systems and Control Letters (Elsevier Science)
- Associate editor of the Bulletin of the Belgian Mathematical Society
- Associate editor of Mathematics of Control, Signals, and Systems (Springer Verlag)
- Chairman of the Department of Mathematical Engineering
- Member of the Committee ”Mathématiques” of the Belgian Fonds National de la Recherche Scientifique (FNRS)
- Member of the Steering Committee of the International Symposium on Mathematical Theory of Neworks and Systems
- Visiting Professor and Fullbright Scholar for the year 2005-2006 at the Massachusetts Institute of Technology, USA

DELEERSNIJDER Eric

- Member of the Editorial Board of ”Ocean Modelling (since 1999), Estuarine, Coastal and Shelf Science (since 2001), Environmental Fluid Mechanics (since 2001), International Journal of Oceans and Oceanography (since 2005)
DOCHAIN Denis

- Member of the Editorial Board “Journal A”
- Associate editor of the “Journal of Process Control”
- Member of the ”International Advisory Board” of the “Canadian Journal of Chemical Engineering”
- Chairman of the IFAC Coordinating Committee on Industrial Systems

DUPRET François

- Member of the Board of Directors of ESAFORM association
- Member of the Editorial Board of “International Journal of Forming Processes”

GEVERS Michel

- Associate Editor of Mathematics of Control, Signals and Systems
- Associate Editor at Large of the European Journal of Control
- Member of the IFAC Technical Committee on Robust Control
- Member of the IFAC Technical Committee on Modelling, Identification and Signal Processing
- Member of the Research Council at UCL
- Member of the Scientific Ethics Committee of UCL
- Member of the Swedish Research Council Committee on Signals and Systems
- Distinguished lecturer from the IEEE Control Systems Society
- Promotor of the Belgian team of ERNSI (European Research Network on System identification)

KEUNINGS Roland

- Prorector for research (Prorecteur à la recherche, since 2004).
- Full Professor (Professeur ordinaire, since 1996).
- Invited Professor (Gasthoogleraar), School of Engineering, Katholieke Universiteit Leuven (since 2001).
• Co-Editor in Chief of the Journal of Non-Newtonian Fluid Mechanics, the premier scientific journal in the field (since 2001).

• Member of the Editorial Board of Rheologica Acta (since 2005).


• Member and Past-President (1996-2000) of the National Committee of Theoretical and Applied Mechanics, Royal Academy of Belgium. Research

LEGAT Vincent

• Invited Professor (Gasthoogleraar), School of Engineering, Katholieke Universiteit Leuven, Belgium

• Chairman of the Applied Mechanics Division of the Mechanical Department

VAN DOOREN Paul

• Associate Editor, SIAM Journal on Matrix Analysis and Applications, SIAM Publ.

• Associate Editor, Numerische Mathematik, Springer-Verlag, Berlin.

• Associate Editor, Linear Algebra and its Applications, Elsevier, North Holland.

• Associate Editor, Journal Comp. & Appl. Mathematics, Elsevier, North Holland.

• Associate Editor, Numerical Algorithms, Baltzer.

• Associate Editor, Applied Mathematics Letters, Pergamon, Oxford.

• Associate Editor, Electronic Transactions on Numerical Analysis

• Associate Editor, Mathematics of Control, Signals and Systems, Springer.

• Member of the ILAS Advisory Committee

WERTZ Vincent

• Member of CSS Technical Committee on Intelligent Control

• Member of IFAC Technical Committee on Modelling, Identification and Signal Processing

• Chairman of the Board of Louvain Developpement (NGO for development cooperation)
WINKIN Joseph

- Member of the Technical Committee on Distributed Parameter Systems of the IEEE Control Systems Society.