agence d'évaluation de la recherche et de l'enseignement supérieur

Dossier d'évaluation
d'une unité de recherche
Vague E : campagne d'évaluation 2013-2014

Nom de l'unité : Centre de Recherches en Mathématiques Appliquées
Acronyme : CMAP (École Polytechnique, CNRS)
Nom du directeur pour le contrat en cours : Antonin Chambolle
Nom du directeur pour le contrat à venir :

Type de demande: Renouvellement à l'identique
Choix de l'évaluation intedisciplinaire de l'unité de recherche: NON

Dossier d'évaluation

1 Présentation de l'Unité

1.1 General presentation

History, situation of the CMAP. The CMAP was created in 1974 by a small community of mathematicians of the École Polytechnique who were interested to study applied problems, related in particular to industrial and engineering issues. The first director was Jean-Claude Nédelec (still active as a member of the lab), and active in the lab were the professors Jacques-Louis Lions (applied analysis) and Jacques Neveu (probability theory). At that time, the main research themes were on the numerical analysis of PDEs, with a special emphasis on applications (to industrial problems), and numerical programming. The lab quickly developed, integrating Pierre Arnaud Raviard (numerical analysis), Michel Métivier (probability theory) and developing accordingly its research in numerical analysis on one side, and theoretical and applied probability on the other side. The CMAP is associated with the CNRS since the 1980's and is now an "Unité Mixte de Recherche" (UMR 7641) jointly funded by the École Polytechnique and the CNRS, and which also hosts now 4 INRIA Teams ("équipes projets communes" or "EPC").

During its now relatively long history, it has trained numerous young researchers (see the list of recent PhDs in appendix), some going then to work in the public or private industry, other pursuing an academic career. Three spin-off companies were directly founded by researcher while working at CMAP in the late 90's and early 2000's: IMACS in 1994, by Toufic Abboud, offers scientific computing solutions for acoustic or electromagnetic problems in the industry;

Let It Wave, by Stéphane Mallat in 2001, was sold in 2010 and eventually closed; "Finance-concept" by Rama Cont (and Marco Avellaneda, around 2002) is a consulting company specialized in risk management.

A specificity of the CMAP in the French applied mathematics landscape is this location at the École Polytechnique, in the DepMapp: the students at the École Polytechnique are a bit different from students from other higher education institutions, on one hand because of their quality, and on the other because of the future responsibilities that many of them will have later on in the industry, public administration or research. Therefore, more than many other laboratories, an essential vocation of the CMAP is to be an exemplary "showcase" of applied mathematics, towards the young students of the school. In a dual perspective of training engineers and attracting some of the students to research careers, the Department of Applied Mathematics DepMapp, and in particular its laboratory the CMAP must present a wide range of disciplines with strong growth prospects.

The CMAP, now, covers a large spectrum of the research in applied mathematics. The common link between all its members is the idea that mathematics can be developed to help answering problems raised in other fields or in the society (such as problems in physics, biology, ecology, computer science, mechanics, or in finance or the industry). Hence, they all are interested, at various degrees, in mathematical modelling, mathematical and numerical analysis, as well as scientific computing and simulation. The mathematical fields, or application, may differ a lot. The CMAP has teams which work mostly with probabilistic tools, a large group of researchers in analysis (PDEs, control, optimization), and a few teams interested in computer science and algorithms.

The lab is located on the Palaiseau campus of the École Polytechnique, on the "plateau de Saclay". The total surface occupied is 1250 m^2 (mostly offices, library, small conference room, meeting room) on two floors (2nd and 3rd level of the aisle "0" of the research laboratories). The lab was very constrained until 2012, with quite a few offices of about $15m^2$ with three researchers or engineers, a large ($50m^2$) room with up to 12 PhD students (!), however, thanks to the building of new offices for the computer science department, new spaces could be freed for the CMAP which by now has enough office spaces. Institutionally, the CMAP is the only laboratory of the academic department "DepMapp" of applied mathematics at the École Polytechniques, and it is deeply integrated with the academic team (even if, as in all departments, not all part-time professors are members of the lab, however the proportion is important).

Recent evolution. During the past 5 years, the lab has undergone remarkable evolution and expansion. This had been initiated by the previous direction, which started in particular the policy of developing joint research with INRIA through common teams, resident at CMAP. The teams COMMANDS, MAXPLUS arrived in 2006 and 2008, respectively, with emphasis on optimal control, bringing to the laboratory new applications, sometimes at the interface with computer science (Optimization of Energy, Program Verification, Operations Research, ...).

The team DEFI was incorporated slightly after 2008, allowing to maintain a strong group in inverse problems and electromagnetism in the lab after the departure of H. Ammari.

The GECO team joined later, in 2011. It was created from the small team funded by Ugo Boscain's "GeCoMethods" ERC starting grant, and is specialized in subRiemannian geometry and in control of quantum mechanical systems via geometric control techniques, bringing to the CMAP a new field of applications.

The teams of probability theory were renewed, after the hiring of Nizar Touzi and Sylvie Méléard both in 2006. The first one, winner of an ERC advanced grand in 2012, was hired to maintain the expertize of the lab in financial mathematics, and developed more generally probabilistic tools for nonlinear analysis. The second created in the lab a team MEV ("Modélisation pour l'évolution du vivant") which has been developing probabilistic tools for the study of ecology and populations. This theme was totally new in CMAP at that time, and is now a major research activity of the lab.

Of course, these evolutions were resulting in an expansion of the scientific activities of the CMAP, as the historical themes (such as shape optimization, PDEs for physics) did also continue to follow their productive and fruitful paths, in a more and more exciting scientific environment.

An important feature of the CMAP is that it benefits a lot from interaction with private industrial or financial companies, through research grants, PhD funding ("CIFRE") and Academic and research Chairs of the department DepMapp. In the past years, for instance, one professor (F. Alouges) and one assistant professor (B. Merlet) where temporarily hired thanks to the funding of the Chaire MMSN with EADS. These positions where then confirmed by the École Polytechnique. One young CNRS researcher also holds a part-time academic position which is currently funded by a Chair, and the lab also hires an administrative assistant thanks to such funding.

The Chair MMSN, "Modélisation Mathématique et Simulation Numérique", was held by Grégoire Allaire and funded by the EADS Fundation, for 4 years until march 2012. At the date of July, 2013, the CMAP/DepMapp benefits from a funding of the four following Chairs[1]:

- Modélisation Mathématique et Biodiversité (with the MNHN, funded by VEOLIA Environnement), held by Sylvie Méléard;
- Marchés en Mutation (funded by Fédération Bancaire Française [FBF]), held in CMAP by Nizar Touzi (also, Monique Jeanblanc and Nicole El Karoui) (evolution of the Chair "Dérivés du Futur" which ended in Dec. 2012);
- Finance et développement durable : approche quantitative (funded by EDF, Crédit Agricole), held by Pierre-Louis Lions at U. Paris-Dauphine and partly funding the activities of Nizar Touzi;
- Risques Financiers (funded by Société Générale), held by Nicole El Karoui and supporting also Nizar Touzi.

Scientific goals and current contract The current contract (initially signed for 2009–2012) was putting the stress on a few developments, in particular:

- The development of statistics, based on the arrival of the ENSAE and the laboratory "CREST" in 2012 near the École Polytechnique;
- The expansion of the INRIA teams and the development of new teams;
- The development of High Performance Computing.

A first move was made in 2009 when A. Tsybakov, professor at CREST-ENSAE, was hired as a part-time full professor in the DepMapp. However, it was soon understood that ENSAE would not move so soon to Palaiseau (it is now becoming more likely that it will actually move in the next years). Hence the lab had to adapt its strategy. A brillant young "Professeur Chargé de Cours"

[1]See details on table 4 in Annexe 6.

(PCC), C. Giraud, was hired in 2008 by École Polytechnique, and started to develop the group of statistics within the lab. This is an ongoing success. In 2012, he was hired as a Professor in Paris-Sud, and simultaneously as a part-time professor in the DepMapp, to develop our interaction with the statisticians at Orsay, in particular towards the issues of "big data" and applications to biology. The same year, the CMAP encouraged new researchers to join and maintain a strong group within its walls: two young researchers (one CNRS "Chargé de Recherche" (CR) and one École Polytechnique PCC), specialized in high-dimensional statistics and learning were hired. In Sept. 2013, a new professor in Statistics and Signal Processing (Erwan Le Pennec, CR INRIA) is also joining this team. The idea is now to better structure this group, by building up a new team gathering the researchers in high-dimensional statistics, numerical probability and signal processing in a larger and coherent ensemble.

On the side of the INRIA, the development and integration of the new teams was very successful. The CMAP now hosts four teams ("EPC" or *Équipes-projet communes INRIA-École Polytechnique*) which develop applications and interactions with computer science or automatic control.

Concerning the last point, we found very difficult to hire a good professor in High Performance Computing, with a strong mathematical orientation. We experienced that there are very few good candidates and they concentrate, therefore, on the few departments where the field is already well developed. Quite a few of our researchers are developing code, within the lab or with colleagues elsewhere, but it is a task for the next years to try to push them to work together and to help them with a competent technical support. And, possibly, to find a good "leader" who could organize a coherent team focussing its activities on this theme.

Structure The current structure of the CMAP consists in research teams working in roughly three main themes, one around PDEs and Numerical Analysis, one around Probability theory, statistics and its applications, and a last theme is related to applications to computer and information science and in particular automatic control of systems. A detailed presentation is found in Sec. 1.3.2. Of course, it may happen that a researcher is working between two teams or even different themes. In the last section 4, we will describe how this structure will be transformed in the next years, to adapt to the evolution of the lab and the interest of researchers to emerging subjects.

These scientific teams are supported by an administrative staff which is described below in Section 1.3.5, and in Annexe 4 (page 74) under the supervision of Nasséra Naar, "administratrice-gestionnaire" of the lab, and a technical staff which is organized in a "Cellule Informatique et Calcul Scientifique" described on page 8.

1.2 Profil d'activité

The CMAP is an academic research department and all its researchers are mostly devoted to academic tasks, either research or teaching. One can say that 75% of the researchers and engineers work in academic research or academic training, while 25% develop solutions which can be useful for other researchers or industrial companies, but these are very rough figures (many researchers develop simultaneously high level academic research with applications to industry). The % of time in training is also hard to evaluate: what can be said is that with 50 to 60 PhD students each year, the lab has about 1.25 PhD students for each full-time researcher. Since about 20 researchers have an "habilitation", on average each professor is training 3 students. Section 3 develops the involvement of the CMAP's researchers into academic training at the Master's level.

1.3 Organisation et vie de l'unité

1.3.1 The context

The École Polytechnique is divided into "academic and research departments" which usually host several research labs (UMRs). An important point is that the CMAP is the only research unit of the academic "Département d'Enseignement-Recherche" of Applied Mathematics of the École Polytechnique ("DepMapp"). It means in particular that all the full-time academic staff which is hired in applied math at the École Polytechnique is supposed to conduct their research with the CMAP, and that the scientific and academic strategies of both the lab and academic department have to be organized and decided in common. In particular, the head of the CMAP is automatically a member of the department council, and conversely the head of the department (now, Prof. Sylvie Méléard), is a member of both councils (Comité Scientifique and Conseil de Laboratoire) of the CMAP. A consultation and dialogue between both parts always occurs before any important scientific decision is taken. The staff of the academic department and the lab slightly differ, though, since not all teachers are members of the lab (the department also hires many part-time professors who have their main position outside of the École Polytechnique) and a few researchers of the CMAP do not hold teaching positions in the department.

1.3.2 Scientific organization

The research of the CMAP can be roughly divided into three main themes. We describe here the subdivision which was inherited from the previous contract, although it will be clear that the recent evolutions in the lab will lead us to stress more the activity of a few teams, while other are in the process of being restructured for the next contract.

One "historical" theme gathers researchers interested in PDEs and numerical analysis, and consists in the following groups:

- Nonlinear Partial Differential Equations for Physics (Anne de Bouard);
- Mechanics, Materials and Shape Optimization (Grégoire Allaire);
- EPC INRIA "DEFI" (Détermination de Formes et Identification, Houssem Haddar).

The next theme gathers researchers who develop probability theory with applications to finance, to evolution laws in biology, or to statistics.

- Mathematical Models for the Evolution of Biological Systems (Modélisation de l'évolution du vivant or MEV, Sylvie Méléard);
- Financial Mathematics (Nizar Touzi);
- Modeling and Random Simulation and Statistics (Carl Graham);
- Statistics and Signal (Stéphane Mallat).

The last theme is related to applications to information and computer science, and in particular automatic control of systems. It includes the teams

- EPC INRIA "COMMANDS" (Contrôle, Optimisation, Modèles, Méthodes et Applications pour les Systèmes Dynamiques non linéaires, Frédéric Bonnans), which also has researchers at ENSTA's Unité de Mathématiques Appliquées (H. Zidani);

- EPC INRIA "MaxPlus" (Max-plus algebras and mathematics of decision, Stéphane Gaubert);
- EPC INRIA "GeCo" (Geometric Control, Mario Sigalotti). This last team studies sub-Riemannian geometry, the control of the Schroedinger equation, and more generally geometric control. Its research is thus also close to the first theme;
- The group of Alexandre d'Aspremont and his students, funded by the ERC grant "SIPA" (Semidefinite Programming with Applications in Statistical Learning), which have been active in the lab for the past two years (2011-2013).

The research team on "Statistics and signal" has been active in the past five years, under the supervision of Stéphane Mallat, who left the lab one year ago. It is presented below as part of the theme "Random modeling and applications", although it could be considered as in between the last two themes (random modeling and mathematics for computer science). Its contour will be redefined for the next five years, as we will mention later on, in order to integrate and develop the numerical probability and high dimensional statistics ("big data").

More generally, the subdivision will be adapted for the next five years, as quite a few researchers left the lab while other moved in, and new scientific themes are emerging and developing. This will be described in details in the section on the strategy for the next contract (see Section 4, and the new subdivision on page 74).

1.3.3 Staff

The staff of the lab, in June, 2013, was:

- **12** academics hired by École Polytechnique (5 full professors, 6 "professeurs chargés de cours" and 1 "maitre de conférences"). Two new academics joined the DepMapp in Sept., 2013 (1 associate professor and one PCC);
- **15** CNRS researchers (8 research directors, 7 "chargés de recherche", one DR was on a temporary ERC funded contract, and was just hired on a permanent CNRS position at ENS, Paris, while another DR is currently joining the lab);
- **9** INRIA researchers (5 research directors, 4 "chargés de recherche");
- **6** engineers for scientific computing: 1 CNRS, 2 permanent positions at École Polytechnique, 2 temporary INRIA research engineers, 1 hired on a contract;
- **3** 1/3 administrative staff (including 1 1/3 for the administration of the INRIA teams, see also description below). Two positions are currently vacant.
- **2** administrative staff serve the "DepMAPP" (département de mathématiques appliquées), the academic department the CMAP is attached to. They both help the lab with a few tasks (Chair administration and organization, updates of the web site, management of the Master's students).

The CMAP had lost quite a few CNRS researchers until 2006 $\sim$ 2008, however its previous director, Kamel Hamdache, had succeeded in reverting this tendancy, attracting new researchers and new teams to the lab. In the past five years, the CMAP has been an attractive lab which many young researchers wanted to join, and its population has been slightly, but constantly growing.

1.3.4 Funding

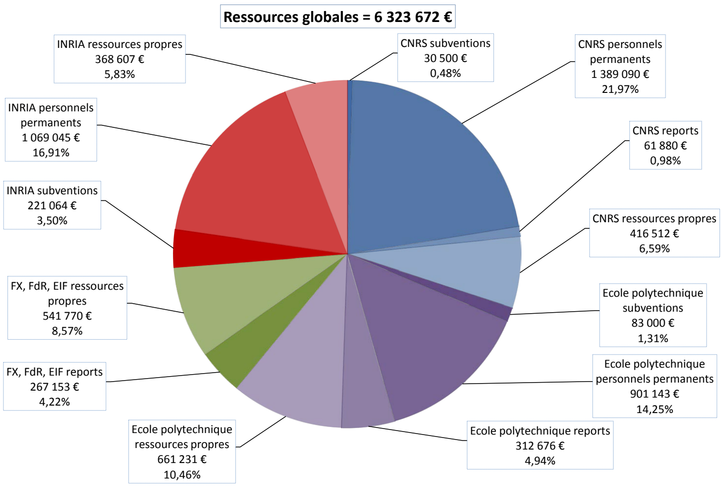

Figure 1: Origins and destination of resources in 2012

The graphics shows the origins of the expenses of the lab in 2012. This includes the staff expenses of the CNRS, INRIA and École Polytechnique in permanent positions. The global expenses that year were of a bit more than 6 millions euros, among which the permanent positions amount to 53%. Beyond this figure, the organisms grant very little to the CMAP, which relies mostly for its research on public and private contracts. In particular, most of the members are participating in ANR projects, of course not all hosted in the lab itself (the lab is currently involved in 6 projects plus 3 in the INRIA teams, administered by the INRIA). The CMAP was hosting 3 ERC Grants in June, 2013, though one was just be transferred to the École Normale Supérieure at the beginning of the academic year 2013-14 with the departure of Alexandre d'Aspremont[2].

The private contracts include Industrial Chairs funding the academic department DepMapp (involving also quite often other institutions), several specific contracts such as CIFRE funding, and the participation into 2 "FUI[3]" consortiums with industrial partners.

1.3.5 Administrative Organization, Councils

The CMAP, which is a relatively small lab (with respect to "giants" such as the mathematics institutes of Toulouse, Lyon or Grenoble), has a director, Antonin Chambolle (DR CNRS), and no official assistant director, although Anne de Bouard (DR CNRS) is playing this role. The scientific and common decisions are supported by a Scientific Committee and a Laboratory Council (Conseil de Laboratoire) which meet roughly twice a year. The members or the Scientific Committee are chosen by the heads of the CMAP and DepMapp. The current Committee was set up in 2009 to help and advise the new director in its scientific decisions. Its current members are Grégoire Allaire (PR), François Alouges (PR), Anne de Bouard (DR CNRS), Antonin Chambolle (DR CNRS), Houssem Haddard (DR INRIA), Stéphane Gaubert (DR INRIA), Vincent Giovangigli (DR CNRS), Sylvie Méléard (PR), Nizar Touzi (PR).

The "Conseil de laboratoire" currently has 17 members (15+the director and the administrator, A. Chambolle and N. Naar), among which 5 represent the administrative and technical staff, 3 represent the PhD students, and the other are researchers of the lab. About two thirds of these members are elected by their pairs, the other are chosen by the director of the lab. The president of the DepMapp becomes automatically a member. This council meets about twice a year to discuss the general policy of the lab. The last meeting was on July 5th, 2013.

The administrative and technical staff is organized as follows:

[2] Stéphane Mallat also quit the lab right after winning an ERC grant last year.
[3] *Fonds Unique Interministériel*

Head of the admin. staff:	**Nasséra Naar** (IR EP[4], administrative and budget management)
Assistants:	**Alexandra Noiret** (missions, IDs, library...) temporary position funded by the "Chaires". *One Assistant EP, to be hired*
INRIA admin. assistant:	1 assistant physically in CMAP, in charge of the teams COMMANDS, DEFI, MaxPlus, (**Jessica Gameiro** arriving Oct. 1st, 2013), and 1/3 of an assistant for the team GECO (Christelle Liévin, *not in CMAP*)
Research assistant:	**Aldjia Mazari** (IR EP, research commercialization, conventions, chair budget management)
DepMapp management:	**Nathalie Hurel** (IE EP[5]; management of the academic department, and management of some of the chairs) **Sandra Schnackenbourg** (management and organization of the Master curricula, web sites of the DepMapp and CMAP).

We also are trying to hire (supported by the ERC funding of Nizar Touzi) an assistant, in particular for the management of the European grants.

1.3.6 Computer system

In addition, the CMAP hosts a team oriented towards the maintenance of the computing facilities of the lab, and the development of scientific computing, called *"Cellule Informatique et Calcul Scientifique"*.

It is a "CTAI1" center[6] approved by the CNRS which manages the computer system of the CMAP and DepMapp. The unit is organized around two poles, "Scientific computing" and "System and network administration".

Its heads are **Robert Brizzi** (IR1 CNRS), who is in charge of organizing and developing the scientific computing platform, and **Sylvain Ferrand** (IE EP), who works as a system manager and engineer, and is responsible for the computer system of the CMAP (management of the computers and network, servers, backups). They are backed by two research engineers, **Radoin Belaouar** (IR2 E.P.) and **Michael Grasseau** (IR2 E.P.), who are supposed to support the research teams with their needs in scientific computing (numerical simulations, parallelization, etc). A few other research engineers are hired on temporary position by INRIA or by the lab to help on specific development projects: **Thomas Abballe** is hired on the "Rodin" project to develop a platform for shape and topology optimization of mechanical parts for the industry (in collaboration with the Renault group), and **Daphné Giorgi** and **Stephan Maindrault** are hired by INRIA to help the COMMANDS Team develop the "Bocop" project, an open-source toolbox for solving optimal control problems.

The computer system consists of servers running Linux, about 100 linux workstation, portable computers (Mac and PC), Windows running machines for the administration a few machines dedicated to computing ($\sim$ 70 cores). It relies heavily on open source systems, which saves significant software costs while ensuring reliable operation and facilitating the administration of the park. The annual budget is about 60 - 80k, mostly for the purchase of equipment, the share

[4] "Ingénieure de Recherche École Polytechnique".
[5] "Ingénieure d'Études École Polytechnique".
[6] Centre de traitement automatisé de l'information.

spent on software is very low. The teams keeps up to date the software and computational tools available to the researchers. Many commercial software (Matlab, Maple, compilers) are shared between the laboratories of the school to reduce costs. Researchers usually develop on their own assigned machines, and perform their calculations, either on their machine or on other machines on the network, more rarely on national resources calculation. A few researchers also develop codes with partners and run them in other departments with more powerful computing facilities.

During the past period, a number of actions have been undertaken to modernize the computer system, especially with the development of virtualization on servers to reduce costs in hardware, power consumption and increase overall system reliability. The main lab infrastructure servers (web, email) were replaced by virtualized machines. Emphasis has also been placed on data security with the implementation of encryption of laptops and the establishment of a platform for centralized backup of laptops. New machines dedicated to scientific computing were installed (with today a total of 72 cores on dedicated machines).

1.3.7 Scientific animation

The CMAP organizes a general seminar every other week, on Tuesdays, with two seminars whose audience is supposed to be all members of the laboratory. It means that the speakers are asked to spend at least half their talk explaining the context and methods.

Besides this general seminar, each group organizes its own working groups and seminars:

- Working group "Stochastic models in Finance" each Monday morning, with two talks (from one researcher of the group and one extern), with about 15 participants. Once a month, the seminar is co-organized with ENSTA (F. Russo). This year, one session per month will also be organized with Evry University (M. Jeanblanc) in the context of the industrial Chair "Marchés en mutations" (with Evry and the Fédération Bancaire Française).
- The finance team also co-organizes each week the "Séminaire Bachelier" at IHP (Institut Henri Poincaré, Paris) with the other Paris teams, and twice a month the seminar "Finance des Marchés d'Energie" with the FIME joint laboratory EDF-U. Paris Dauphine-Ensae-Polytechnique, every other Friday.
- Calculus of variations, once a month (this seminar, in 2013-2014, was merged with the UPMC, U. Diderot, Orsay, and Paris-Dauphine seminars);
- DEFI working group, on Wednesdays 14:00-16:00, organized with ENSTA (L. Bourgeois, M. Bonnet, UMA) with about 10 participants each week;
- MEV working group, every other Wednesday 16:00-18:30 (with two talks);
- in 2012, Davide Barilari (ex-GECO, now at Paris 6) was the main organizer of the seminar of sub-Riemanian geometry, about twice a month at IHP, Paris;
- until June, 2010 was also organized a joint CMAP-CMLS-CPHT seminar by A. de Bouard, P. Collet, F. Golse, S. Kuksin, once a month, on "Random problems in PDEs and high dimensional systems" (until the departure of S. Kuksin from CMLS).

1.4 Faits marquants

The CMAP is a research laboratory which has an important activity, well recognized in the mathematical community. Its researchers won in the past five years more than 6 scientific prizes and 8 chairs or prestigious funding, from the local "Chaire Marjoulet" of the École Polytechnique to the ERC advanced grant. The scientific production over five years is of more than 500 peer-reviewed journal papers, and more than 650 papers if one includes the proceedings and book chapters, for 37 researchers, while between 15 and 20 PhD theses are defended each year. This is detailed in the Section 2.2 (see in particular the "Awards" paragraphs), in Annexe 6 ("Productions scientifiques"), see "References", and Annexe 7.

During the past five years, the environment of the lab has been rapidly evolving. The "Fondation Mathématique Jacques Hadamard" has been funded in Feb., 2011 after a long evolution initiated by Yves Laszlo, at that time director of the CMLS at École Polytechnique (Centre Mathématique Laurent Schwartz). The goal was to gather together all mathematicians, pure and applied, in the mathematics departments of the institutions which were to be part, in the future, of the "Université Paris-Saclay". This involves, in particular, the LMO (Laboratoire de Mathématiques d'Orsay), the CMLA at ENS-Cachan, and the CMAP and CMLS. The IHÉS was also among the founders, and the idea is to further integrate the mathematicians of the institutions which will move to the Saclay area in the next years (and to start with, the ENSTA which is already on the campus).

The LabEx "Mathématiques Hadamard" (LMH), driven by FMJH, was selected within the framework of the call for projects "Laboratoires d'Excellence" of 2011 ("Investissements d'Avenir"). Centered around the partneship of 9 mathematics laboratories, LMH has the dual purpose of developing interaction with other mathematical disciplines and uniting partners on common issues. Three programs were launched: Mathematics and Engineering, Mathematics for Life Sciences and Mathematics and Physics. In all three cases, support as diverse as scholarships for students (masters, doctoral or post-doctoral), support for the organization of workshops, support for setting up industry-oriented projects or for creating new master curricula were granted. CMAP is a leading actor in the LabEx LMH: the "Mathematics and Engineering" program supervised by François Alouges, and the team MEV of Sylvie Méléard is a cornerstone of the "Mathematics for Life Sciences" program.

In February 2012 EDF and the FMJH (Jacques Hadamard Mathematics Foundation) have signed a sponsorship agreement for five years, creating the Gaspard Monge Program for Optimization and Operations Research (PGMO) within the FMJH. This sponsorship project aims to develop a research community composed of mathematicians from academia and industry around the theme of optimization and operations research. It is part of the future main center of EDF R&D which is currently being built on the campus of Paris Saclay. This program allows to promote scientific exchange between researchers, academic as industrial, to increase the research effort in optimization (with industrial applications in mind), to increase the visibility and to structure the teaching of the masters of optimization in Ile-de-France, offering the students a broader view on training opportunities and opportunities of this sector, especially in the industrial world . CMAP is a leading player in the PGMO, mostly through the groups of Shape Optimization, Signal Processing and the INRIA Teams. Among other things, G. Allaire is currently the coordinator of the Program.

2 Réalisations

2.1 Production scientifique - scientific production

The scientific production is presented according to the scientific organization of the lab described in Section 1.3.2.

2.1.1 Applied analysis

Equations aux dérivées partielles non-linéaires pour la physique. (*Nonlinear PDEs in Physics.*) Team under the supervision of A. de Bouard, including the permanent researchers:

- **François Alouges**, Professor at Ecole Polytechnique,
- **Radoin Belaouar**, Research engineer at Ecole Polytechnique,
- **Frederic Coquel**, CNRS Research director,
- **Anne de Bouard**, CNRS Research director,
- **Vincent Giovangigli**, CNRS Research director,
- **Jean-Claude Guillot**, Professor, now retired,
- **Kamel Hamdache**, CNRS Research director,
- **Aline Lefebvre-Lepot**, CNRS "Chargée de recherche"
- **Benoit Merlet**, "Professeur chargé de cours" at Ecole Polytechnique
- **Roman Novikov**, CNRS Research Director

The team is currently training the following PhD students :

- **Matthieu Aussal** (F. Alouges and Brian FG Katz (LIMSI-CNRS), CIFRE DMS, 2011–)
- **Laetitia Giraldi** (F. Alouges, DGA, 2010–2013)
- **Antoine Hocquet** (A. de Bouard and F. Alouges, ASN, 2013–)
- **Thanh Nhan Nguyen** (F. Alouges and B. Merlet, 2010–2013)
- **Mikhail Isaev** (R. Novikov, 2011–)

and the following students where trained during the period 2009-2013 :

- Maxime Gazeau (A. de Bouard, PhD 2012), now postdoc INRIA in Lille
- Anna Kazeykina (R. Novikov, PhD 2012), now Maitre de Conférences à l'Université d'Orsay;
- Jimena Royo-Letellier (A. Aftalion, PhD 2013)
- Matteo Santacesaria (R. Novikov, PhD 2012), now postdoc in Université de Grenoble.

Some researchers of the team are also advising or co-advising students which are not working at CMAP: F. Coquel is co-advising Tassadit Asmaa with Q. Huy Tran (IFPen[7] and UPMC) and Khalid Haddaoui with E. Godlewski (ONERA and UPMC); he is also supervising the thesis of Sophie Gerald at Onera Chatillon (ONERA/UPMC, defense in Sept. 2013). V. Giovangigli is co-advising with Y. Mauriot (ONERA) the thesis of Pierre Gaillard.

The team"Partial differential equations for physics" was created in 2008, after several members have joined the CMAP. It gathers people involved in the study of physical problems by

[7]Institut Français du Pétrole - Énergies Nouvelles

means of models based on (mainly nonlinear) PDEs, from the point of view of modeling, mathematical analysis of the models, as well as numerical simulations. Our domains of interest are fluid mechanics, and in particular interaction between fluid and structures or reactive fluids, electromagnetism, in particular ferromagnetism, propagation in dispersive media (nonlinear optics, plasmas) and inverse problems. Most of the researchers of the team contribute to several of those activities.

Fluid mechanics. Permanent researchers : F. Alouges, F. Coquel, A. de Bouard, V. Giovangigli, K. Hamdache, A. Lefebvre-Lepot, B. Merlet.

Part of the activities of the team is devoted to the study of models with applications in fluid mechanics. Three of the confirmed researchers of the team are collaborating on the interaction between fluid and structures; reactive fluids, compressible fluids and modeling of biological systems is also an important part of the activity in this domain.

Fluid-structures interactions. One of the topic is the study of the swimming capabilities of micro-objects, that has been investigated for five years by F. Alouges, together with A. Lefebvre-Lepot and B. Merlet, in collaboration with A. de Simone (from the SISSA, Trieste). On the theoretical side, this turns out to be a control problem which possesses a universal structure that they have unveiled. This also allows them to develop numerical strategies to understand the optimal swimming capabilities of micromechanisms.

A. Lefebvre-Lepot has developped the SCoPI software which is dedicated to the simulation of collections of particles in interaction (granular flows, suspensions, crowd motion). The originality of the code lies in its ability to take the lubrication force into account through a viscous contact model [211], and has led to collaborations with the FAST laboratory (Orsay). Concerning fluid-particle simulations, the viscous contact has been coupled with two fluid codes (collaborations with P. Laure, LJAD, Nice, and L. Lobry, LPMC, Nice) [569, 568] and with B. Fabrèges, LMO, Orsay). With M. Grasseau and B. Merlet, A. Lefebvre-Lepot is integrating in SCoPI a fluid solver based on Spherical Harmonics. They are also working with B. Merlet on another method to better take into account the lubrication forces using a decomposition of the problem in regular-singular parts. Modeling and convergence of the scheme has also been studied in the case of inelastic collisions [212].

Reactive fluids. During the 2008–2013 period V. Giovangigli has investigated the modeling, the mathematical analysis and the numerical simulation of multicomponent reactive flows. The concept of volume viscosity and the relaxation of internal energy in polyatomic gas mixtures has first been investigated in a kinetic multitemperature framework[32, 31, 541]. The impact of the volume viscosity coefficient in fast flows has also been established, the success of Stokes' hypothesis resulting mainly from small Mach numbers [28]. V. Giovangigli has also investigated multicomponent transport in partially ionized mixtures subjected to weak or strong magnetized fields [60, 63]. New iterative methods have been introduced for fast evaluation of transport coefficients independently of the ionization rate and the magnetic field intensity [63, 64]. He has also studied higher order entropies which are kinetic entropy estomators in fluid flows suggested by Enskog enpansion of Boltzmann entropy [56, 57, 58, 59]. This leads to entropic principles for small Knudsen of Mach numbers and to new a priori estimates that are invariants under the proper changes of scale [56, 57, 58, 59]. V. Giovangigli has also investigated reactive nonideal fluids, thermodynamic instabilities and supercritical combustion [65, 66, 68, 69]. Finally, various aspects of complex reactive fluids have been analyzed, notably the general theory of multicomponent mixtures as derived form the kinetic theory of gases [67, 549], the impact of Soret effect in sooting ethylene flames [548], Saint-Venant equations for thin viscous layers with a temperature equation [62], and the stability of solid fuel flames [82, 71].

Magnetic fluids. K. Hamdache's main research program concerns the dynamic of magnetic fluids (also called ferrofluids) which are suspensions of ferromagnetic nanoparticles in carrier liquids. These fluids have found a wide variety of applications in engineering. Recent years have seen intensive investigations on the possibility of future biomedical applications of magnetic fluids, and the interest for these fluids has developed in connection with technical applications (vibration damping, acoustics, nanoduct flows, nanomotors, nanogenerators, nanopumps and other nanoscale devices). A number of works show that ferrofluids can be treated as homogeneous monophase fluids. K. Hamdache and his collaborators studied the solvability of the models proposed by Rosensweig and by Sliomis. They considered the cases of incompressible as well as compressible fluids for various magnetization laws. They also investigated the dynamics of heat transfer in such models with different heat transfer laws. This main program is developed in collaboration with Y. Amirat. Two theses on this subject are in preparation where the Maxwell-Cattaneo heat transfer law is used (F. Aggoune and A. Louardani).

K. Hamdache also discussed, with others collaborators and students (D. Hamroun and L. Hadjadj), other mathematical questions arising in biology. Finally, he considered with B. Jaffal, the motion of non-Newtonian fluid flows (fluids of second grade) in the presence of a magnetic field.

Nonlinear hyperbolic equations. The problems tackled by F. Coquel are mostly motivated by complex compressible media and the discontinuous waves propagating within such media under various asymptotic regimes. His research activities are conducted in a broad sense: from the mathematical modeling to scientific computing, including numerical analysis, and are always carried out on the basis of a permanent interplay between mathematical tools and applicative constraints. Actually and in a significant part, these programs are conducted with researchers involved in R&D labs from some of the major french industries (see section 3). A large part of his work is devoted to the analysis and numerical approximation of small scale sensitive shock solutions, referred to as non-classical shock solutions. The reported small scale sensitiveness makes quite challenging the numerical capture of the non-classical shock solutions. He has also paid a strong interest in the coupling of hyperbolic equations, both in the conservative and non-conservative settings. By contrast to the former, the latter has received little attention but is actually important in several applications where the conservation property is lost. Within the frame of thin coupling interfaces, uniqueness may be lost when resonance takes place as first exemplified by Isaacson-Temple. This has motivated the introduction of the concept of thick interfaces for which uniqueness is proved in the scalar setting in several space dimensions. Several well-balanced numerical methods for the coupling of systems have been proposed. Besides, F. Coquel pays a strong interest in the numerical approximation of entropy weak solutions thanks to relaxation approximation procedures with a specific attention to asymptotic preserving and well balanced issues. He is also quite involved in the derivation of large time step methods.

Dispersive surface waves. A. de Bouard is investigating the influence of noise on the dynamics of dispersive waves. In the modeling of hydrodynamic surface waves she has obtained in a collaboration with W. Craig (McMaster University) and others a formal derivation of dispersive equations of Boussinesq and Korteweg de Vries type, from the water wave problem in the presence of a random rough bottom, modeled by a stationary mixing random process. The limit equation is deterministic in a framework moving with a white noise velocity [185].

She has also pushed further, in collaboration with E. Gautier (ENSAE), her investigation of the dynamics of solitons of the Korteweg-de Vries equation in the presence of an additive noise, using large deviation techniques, and she was able to obtain matching lower and upper bounds of exit times for the soliton [188].

Electromagnetism . Permanent researchers : F. Alouges, A. de Bouard, B. Merlet, R. Novikov.

Micromagnetics. Micromagnetism as introduced by W. Brown is a variational theory which describes the behavior of ferromagnetic materials. The micromagnetic is a nonlocal perturbation of the Dirichlet energy subjected to non linear constraints: the vector field representing the magnetization has constant magnitude.

F. Alouges has been working in this topic for several years. Recently, in collaboration with physicists in Grenoble, he has developed a new finite element scheme for solving Landau-Lifshitz's equations which proved to be precise in practice but also to have interesting mathematical properties. On the theoretical viewpoint, a new controllability result has been obtained in collaboration with K. Beauchard (CMLS). Besides, B. Merlet, with R. Ignat, has analysed by Γ-convergence the micromagnetic energy in some particular regimes. The limit magnetization is a 2D unit divergence free vector field minimizing a line energy. In a subsequent work, they systematically study line energies. F. Alouges and B. Merlet have proved in a collaboration with G. Di Frata that, in the limit of small convex particles, local minimizers of the micromagnetic energy are constant. This provides a rigorous justification of the Stoner-Wohlfarth model. They also establish that in sufficiently small ellipsoidal particles, local minimizers are exactly constant. This result proves a 45 year old conjecture of W. Brown.

Electromagnetic scattering and inverse problems. There is a long standing collaboration of F. Alouges with D. Levadoux who is engineer at ONERA, based on the development of a new BEM code for the electromagnetic scattering of 3D objects. Based on new paradigms, the code is becoming easier to maintain, much more versatile, and proves to be 25 faster than its industrial counterpart which is used for production at ONERA. The scientific contributions in this field are twofold: they develop new mathematical method that aim at precondition the underlying linear systems, and they also use domain decomposition techniques for integral equations. In collaboration with a company (Digital Media Solutions), they are currently using this code in the framework of acoustics and more specifically 3D audio. The idea is to develop numerical simulations of the so-called HRTF (Head Related Transfer Functions) which are the footprints of the 3D sound image felt by the listener.

The research domain of R. Novikov consists of inverse problems and their applications. This domain involves simultaneously pure and applied mathematics. The objective of inverse problems consists in determining the structure of an object from spectral data (for example, from X-ray photographs or ultrasonographycal data for this object). Inverse problems arise in medical imaging, non-destructive testing and different domains of physics. On a mathematical level inverse problems are usually reduced to studies of properties of maps between coefficients of partial differential equations and related spectral data (for example, scattering data). These studies are of obvious independent interest. Besides, transforms of direct and inverse scattering problems permit to study a series of non-linear partial differential equations in a similar way as linear partial differential equations are studied using direct and inverse Fourier transforms. The principle objective of R. Novikov's works consist in creating methods for solving multidimensional inverse problems, mathematically justified and admitting practical applications.

Nonlinear dispersive waves in optics. During the last four years, A. de Bouard has started to be interested in the modeling of light propagation in optic fibers, and in particular in the modeling of fluctuations due to inhomogeneities, that can lead to limiting effects in the long distance propagation. The models describe the dynamics of the electric field enveloppe and are essentially based on stochastic nonlinear Schrödinger equations. She has considered with A. Debussche (Rennes) the case where inhomogeneities occurs from dispersion management, and the noise term affect the dispersion, and with M. Gazeau, PhD student at the CMAP, the case where inhomogeneities result in random birefringence, giving rise to a stochastic Manakov equation. In each case,well posedness and diffusion-approximation results, which justify the use of white noise in time, have been proved.

In collaboration with R. Fukuizumi (Tohoku University), she has also studied stochastic models in Bose-Einstein condensation, based on the Gross-Pitaevskii equation. Theoretical existence results have been improved thanks to new representation formula, and the dynamics of solutions close to solitary waves have been investigated.

Quantum field theory. Permanent researcher : J.C. Guillot. During the last five years J.C. Guillot has been mainly concerned with the study of mathematical models chosen from the Quantum Field Theory. More precisely he has studied the spectral theory of models from the Standard Model for elementary particles which involve the weak interactions describing the decay of the leptons and of the intermediate bosons. His main contribution has been to prove the existence of a unique ground state and that the spectrum of the associated Hamiltonians is absolutely continuous between the energy of the ground state and the first threshold in the weak coupling regime.

Materials, Mechanics, Shape Optimization and DEFI.

The teams "Materials, Mechanics and Shape Optimization" (supervised by G. Allaire) and "DEFI" (INRIA team supervised by H. Haddar) work in applied Analysis of PDEs and Calculus of Variations, with applications to mechanics, industrial problems, inverse problems (inverse scattering, electromagnetic imaging). They gather the following researchers and engineers:

- **Grégoire Allaire**, Professor at Ecole Polytechnique,
- **Thomas Aballe**, Research engineer at Ecole Polytechnique,
- **Robert Brizzi**, CNRS Research engineer,
- **Antonin Chambolle**, CNRS Research director,
- **Houssem Haddar**, INRIA Research director,
- **Olivier Pantz**, "Professeur chargé de cours" at Ecole Polytechnique,
- **Jing Rebecca Li**, INRIA "chargée de recherche".

It is currently training the following PhD Students

- **Lorenzo Audibert** (H. Haddar, CIFRE EDF, 2012–)
- **Leila Azem** (O. Pantz et Hamdi Zorgati, LJLL, Paris 6, 2012–)
- **Gabriel Delgado** (G. Allaire, CIFRE EADS IW, 2010–)
- **Ramalah Harsha Hutrigurda** (G. Allaire, 2010–2013)
- **Zixian Jiang** (H. Haddar, 2010–)
- **Gwenaël Mercier** (A. Chambolle, ASN ENS Cachan, 2012–);
- **Thibault Mercier** (H. Haddar, CIFRE EDF, 2012–)
- **Georgios Michailidis** (G. Allaire, CIFRE Renault, 2011–)
- **Dang Nguyen** (J.-R. Li and D. Grebenkov (labo. PMC, Matière Condensée, Polytechnique), 2010–)
- **Tobias Rienmueller** (H. Haddar et Armin Lechleiter (Brême), 2012–)
- **Franck Ouaki** (G. Allaire, CIFRE IFPEN, 2010–)

G. Allaire is also co-advising Charles Dapogny at the UMPC (with P. Frey, since 2010).

Optimal design. Permanent researchers: G. Allaire, O. Pantz.

Shape optimization is a classical topic in applied analysis. Topology optimization is rather recent, going back to the 80's and the works of Murat-Tartar, Lurie-Cherkaev, Kohn-Strang, and the decisive contribution of Bendsoe-Kikuchi who popularized among engineers the so-called homogenization method for topology optimization of mechanical structures. There are several methods of topology optimization. The earliest one, and still the most used, is the homogenization method, including its simplified variant SIMP. It is at the basis of most commercial softwares (including the market leader, Optistruct from Altair). Other approaches are soft kill heuristics, genetic algorithms, topological derivative and level set methods. The latter one (which was initiated by our team in collaboration with F. Jouve, LJLL) turned out to be a very interesting alternative to homogenization-based methods. Indeed, the homogenization method uses as design variables a material density: while it is very convenient to transform a discrete 0/1 optimization problem into a continuous one, it involves a penalization step to remove intermediate densities corresponding to undesirable composite materials. Unfortunately this last penalization step is sometime very inefficient for difficult problems. On the contrary, the level set method relies on a crisp definition of the structure shape and therefore does not require any penalization process. In this setting topology changes are allowed either by the intrinsic capabilities of the level set algorithm of Osher and Sethian, or by explicit nucleation of holes thanks to the topological derivative. One of our main current effort is to bring this mature scientific field into business: namely, we develop a commercial software with industrial partners.

Our work on shape and topology optimization can be roughly separated in two categories. First, some works explore new methods, both from an analytical and numerical point of view. Second, other works are more devoted to applications in engineering with the ultimate goal of having a definite impact in industry.

To the first category belong our works on shape optimization based on small amplitude homogenization (with A. Kelly) [11], on damage and fracture modeling (with F. Jouve and N. Van Goethem) [9], and on long time behavior of optimal design for the heat equation (with A. Munch and F. Periago) [12].

The second category features much more applied work, mostly in the framework of the RODIN project which is a consortium of various companies and universities which has been sponsored by the FUI AAP 13 for 3 years, starting on July 2012. The industrial partners are: Renault, EADS, ESI, Eurodecision, Alneos, DPS. The academic partners are: CMAP at Ecole Polytechnique, Laboratoire J.-L. Lions at Paris 6 and 7 Universities, centre de recherches Bordeaux Sud-Ouest at INRIA. The goal of the RODIN project is to perform research and develop a computer code on geometry and topology optimization of solid structures, based on the level set method. RODIN is the acronym of "Robust structural Optimization for Design in INdustry".

With C. Dapogny (Renault and LJLL) and P. Frey (LJLL) [24], [23] we propose a method for structural optimization that relies on two alternative descriptions of shapes : on the one hand, they are exactly meshed so that mechanical evaluations by finite elements are accurate ; on the other hand, we resort to a level-set characterization to describe their deformation along the shape gradient. The key ingredient is a meshing algorithm for building a mesh, suitable for numerical computations, out of a piecewise linear level-set function on an unstructured mesh. Therefore, our approach is at the same time a geometric optimization method (since shapes are exactly meshed) and a topology optimization method (since the topology of successive shapes can change thanks to the power of the level-set method).

With F. Jouve (LJLL) and G. Michailidis (Renault and CMAP), we propose a method to handle geometric constraints in shape and topology optimization. In the framework of the level-set method we rely on a notion of local thickness which is computed using the signed-distance function to the boundary of the shape. We implement this method in two and three space dimensions for a model of linear elasticity. We consider various formulations of the constrained optimization problem and compute a shape derivative to advect the shape. We discuss different ways to handle the constraints. The resulting optimized shape is strongly dependent on the initial guess and on the way the constraints are being treated.

With G. Delgado (EADS) we work on the optimization of composite materials draping. These composite structures are constructed by lamination of a sequence of unidirectional reinforced layers or plies. Each ply is typically a thin sheet of carbon fibers impregnated with polymer matrix material. The optimization variables are the geometries of these layers and they are parameterized by a level set function. In a first instance, we treat the problem of mass minimization (with a constraint on the maximal compliance) for a cantilever type composite structure, laminated with four layers of a given orthotropic material at different angles. The elasticity analysis is performed with the software Freefem++, coupled with a C++ routine to solve, by a finite difference scheme, the evolution of the level sets.

With K. Trabelsi (LMCS), we developed new optimization strategies. The introduction of those approaches is driven by the wish to propose an alternative to the standard penalization step used in the homogenization method. The main goal consists in being able to weight the optimality of the shape against its geometrical complexity. To this end, two methods have been tested. The first one could be seen as a blend between now classical methods of shape optimization (geometrical, topological, homogenization). It defines a sequences of problems depending on a matter contained in a unknown working box. Geometrical and homogenization methods are respectively applied to the optimization of the working box and the allocation of matter into it. The problem reduces itself to the homogenization problem, when the matter ratio is equal to zero and to a geometrical optimization problem when it is equal to one. Hence we construct a continuum of problems, depending on the matter ratio, that enable us to gradually pass from the homogenization problem to the geometrical method. Another and completely different approach, that we called dehomogenization, consists in trying to construct explicitly a sequence of shapes of growing geometrical complexity, converging toward the optimal composite. This approach leads to very good results in the case of compliance optimization in the two dimensional case and remains to be extended to the three dimensional case and to other cost functions.

With D. Schmitt (EDF) [547], we used shape optimization techniques to design new concepts of fast breeding nuclear reactor in order to minimize a thermal counter-reaction known as the sodium void effect. In this kind of reactors, by increasing the temperature, the core may become liable to a strong increase of reactivity, a key-parameter governing the chain-reaction at quasi-static states. New unexpected designs have thus been obtained. To obtain more realistic solutions, other criteria have to be optimized too, what as been done by weighting the initial cost function with other cost functions. We know seek to integrate feasibility constraints into the process and to study the dependance of the solution with respect to the chosen weights.

Homogenization. Permanent researchers: G. Allaire, R. Brizzi, H. Haddar.

G. Allaire studied wave propagation in periodic media under some specific asymptotic regimes. The model is either the scalar wave equation or Maxwell system. Two different phenomena were studied. On the one hand, localization can be obtained under some special geometric assumptions in a macroscopically varying periodic medium [4]. It is a deterministic and asymptotic variant of the well-known Anderson localization for random media. On the other hand, diffraction was carefully studied for the long-time behavior of monochromatic Bloch wave packets [3], [19]. More precisely, for an ϵ periodic wave equation and for times of order $1/\epsilon$, we construct accurate approximate solutions of three scale WKB type. The leading profile is both transported at the group velocity and dispersed by a Schrödinger equation given by the quadratic approximation of the Bloch dispersion relation at the plane wave. This type of result explains the "slow light" phenomenon as well as unusual losses in optical fibers made of photonic crystals.

G. Allaire and R. Brizzi studied various models of convection, diffusion and reaction in porous media [5], [6], [7], [8], [13], [14]. The main goal is to obtain macroscopic models with explicit formula for the effective coefficients. One possible motivation is the underground storage of nuclear waste. It is known that microscopic phenomena at the pore scale may have a dramatic effect at the macroscopic scale, especially for the long times involved by nuclear waste storage. Therefore, a priori small effects like electrokinetics (the coupling of electrostatic with convection-diffusion) are actually very important. This work is done in collaboration with physical chemists who are providing realistic electrokinetic models to which we apply homogenization theory. The so-called ideal case, corresponding to the Poisson-Boltzmann model, must be replaced by the MSA (mean spherical approximation) model which takes into account steric and particle correlation effects. We obtained new results on the existence of solutions, on their asymptotic behavior with respect to physical parameters (like the ratio between the Debye length and the pore size), on their homogenization and on the variations of the dispersion tensor compared to the ideal case.

G. Allaire is also interested in multiscale finite element methods [10], [540] and in various applications of homogenization to nuclear reactor physics [2], [17], [20].

H. Haddar studied thin layer models for scattering problems associated with periodically oscillating media confined into thin layer. He specifically considered the case where the periodicity size is comparable to the thickness of the thin layer but is very small compared to the incident wavelength. This setting has been suggested by CEA Leti and was motivated by a non destructive testing experiment using electromagnetic waves (the specific industrial application is confidential). The goal here is to replace the thin layer by equivalent transmission conditions that are high order accurate in terms of the layer width and also uniformly stable with respect to this small parameter. The derivation of these equivalent models is based on combination of homogenization techniques for periodic media and matched asymptotic techniques to handle boundary layer effect at the transition between the periodic layer and the outer domain. One interesting outcome from this study was to observe that natural non trivial models are in general not uniformly stable with respect to the layer width if they are expressed at the limiting interface. A family of stabilized model has been suggested by splitting this interface [107]. Both scalar and electromagnetic problems have been addressed [108]. This work was in the continuity of previous works where the case of homogeneous coatings or interfaces has been considered [104], [86].

Calculus of variations. Permanent researchers: A. Chambolle, O. Pantz.

The activities of A. Chambolle in the team of shape optimization are relative to curve and surface evolutions, fracture growth, homogenization and qualitative results in the calculus of variation (convexity, regularity). With M. Novaga, V. Caselles, G. Bellettini and a few others, he has studied in particular variational approaches to the mean curvature flow related to various interfacial energies, in particular anisotropic and crystalline energies [27, 29, 53, 38]. A forthcoming paper addresses the existence of regular crystalline flows in 2D with quite general forcing term, a recent paper also shows existence of regular solutions for the mean curvature flow with obstacle [25] (both with M. Novaga). These topics are studied by the PhD student G. Mercier. It is interesting that a variational approach can be implemented with very general (including nonlocal) perimeters, this is the subject of current studies with M. Morini and M. Ponsiglione and of the paper [48]. Related to these issues are some works on homogenization or on singular limits of approximate perimeters (which can be of some use in imaging or shape optimization problems), such as [50, 543] with the PhD student G. Thouroude (2009-2012) or [51, 47]. Eventually, regularity results for minimizers of the total variation were derived in [35, 36], after a paper of 2007 on the discontinuities which was awarded in July 2008 a "SIAM Outstanding paper" award (with V. Caselles and M. Novaga). G. Mercier is currently trying to improve these results. Results on the optimization of these singular problems for imaging are mentioned in the paragraph "Signal, Statistics, Data" of the theme 2.1.2, however one should mention here two recent studies on the numerical computation of homogenized energies, in particular in the context of free surfaces [33, 34], both with a former postdoc S. Cacace and other collaborators (L. Fedeli was also for some time in CMAP during his PhD).

Other works related to free surfaces in various context (including infinite dimension spaces) were done by, or in collaboration with the PhD student M. Goldman (2008–2012), see [40, 43, 72, 73, 74].

The activity of A.C. relative to fracture mechanics and fracture growth was more important in the previous years (with in particular [52]). However, quite recently, he has contributed to a few results in the variational theory of quasi-static fracture growth (proposed in the 90s by Francfort and Marigo), with original results concerning branching, kinking, and the singularities at the tip of 2D fractures with as little assumptions as possible on the cracks [39, 42, 44]. A.C. is currently working in collaboration with J.-F. Babadjian and A. Lemenant to extend some of these results to more general situations.

Inverse problems (INRIA Team DEFI, "Détermination de formes et Identification") . Permanent researchers: H. Haddar, A. Lechleiter (now at Uni. Bremen, Germany), Jing-Rebecca Li. Current postdocs: Kamel Riahi and Dinh Liem Nguyen.

We study the design, analysis and implementation of efficient numerical methods to solve inverse problems in connection with waves, elasticity and diffusion. Sought practical applications include radar and sonar applications, bio-medical imaging techniques, non-destructive testing, structural design, composite materials and diffusion magnetic resonance imaging. Roughly speaking, the model problem consists in determining information on the geometry (topology) and/or the physical properties of unknown targets from given measurements, for instance measurements of diffracted waves or induced magnetic fields. In general these problems are non linear and also severely ill-posed which requires special attention from regularization point of view and non-trivial adaptations of classical optimization methods. During the last four years we were particularly interested in the development of the following themes.

Qualitative methods for inverse scattering problems. We can divide our contribution to this theme into two main packages. The first one is related to sampling methods and the second one is related to interior transmission eigenvalues. The first one is dedicated to the inverse geometrical problem where one is interested in re-constructing the shape of an unknown scatterer from measurements of scattered fields. The second one is dedicated to the analysis of special resonant frequencies that can be extracted from multifrequency measurements of scattered fields due to dielectric inhomogeneities and the use of such frequencies in non destructive testing applications.

Sampling methods. Although these methods are now well established and monographs have been written on the subject there are still many open questions related to this topic and a large progression is needed to address challenging applications. Our main contributions here can be divided into two. A first one is the development of so called factorization-method for non-standard inverse scattering settings. This method, introduced by A. Kirsch in 1998, is the most established qualitative method for inverse scattering problems where one is interested in reconstructing the shape of inclusions from the knowledge of the farfield operator at a fixed frequency in the resonant regime. Let us recall that this method provides an exact characterization of the obstacle shape using the range of an operator explicitly constructed from the farfield data. Hence, in contrast with other sampling methods, it also gives uniqueness results for the inverse problem independent from physical parameters (related to the considered inverse scattering setting). The analysis is therefore much harder and usually requires more restrictive assumptions on the settings than the linear sampling method for instance. We can summarize our main contributions here in the following items.

- Link between the Factorization method and other sampling methods [84, 85, 120];
- The direct and inverse problems for periodic and/or unbounded structures [121, 123, 125] and a preprint;
- Inverse scattering from cracks and screens [88, 91];
- The factorization method for general class of boundary conditions and weakly nonlinear materials [122] and a preprint.

Our second main contribution is the development of qualitative shape inversion methods for time dependent data. So far we were only able to extend the analysis of the Linear Sampling Method to the cases where the collected data correspond with causal measurements of scattered near fields [103, 115].

Transmission eigenvalues. The so-called transmission eigenvalues are related to the interior transmission problem which arises in inverse scattering theory for inhomogeneous media. It is a boundary value problem for a coupled set of equations defined on the support of the scattering object. The frequency values for which non trivial solutions to the interior transmission problem exist are called transmission eigenvalues. These frequencies extend the notion of cavity eigenfrequencies in the case of perfectly conducting scatterers to the case of dielectrics. However, the transmission eigenvalue problem is a nonlinear and non-selfadjoint eigenvalue problem that is not covered by the standard theory of eigenvalue problems for elliptic equations. We are currently developing approaches where these frequencies can be used in identifying (qualitative informations on) the medium properties. Our research on this topic is mainly done in the framework of the associate team ISIP with the University of Delaware. A review article on the state of art concerning the transmission eigenvalue problem has been written in collaboration with F. Cakoni [552]. We are also in the process of editing a special issue of the journal Inverse Problems dedicated to the use of these transmission eigenvalues in inverse problems. Our main contributions can be regrouped in the following items:

- Existence, discreteness and Faber-Krahn type inequalities for transmission eigenvalues [101, 100, 98, 90]
- Analysis of transmission eigenvalues for dielectrics with cavities or inclusions [97, 99, 106]
- Numerical evaluation of transmission eigenvalues and estimates on refractive index [96, 95, 109]

Direct and inverse models for Diffusion MRI. We are interested in developing techniques to solve the problem of quantifying brain tissue microstructure using diffusion Magnetic Resonance Imaging (dMRI), an imaging modality that is being rapidly applied to all physiological and pathological conditions where cellular-level changes affect the random displacement of water in tissue. The question of precisely how tissue microstructure affects the measured dMRI signal has been attacked up to now mostly by medical MR physicists. A lot of work has been done in solving the inverse problem regarding axons in the brain white matter, because axons are impermeable and are 'mostly' aligned in bundles. Due to the geometrical simplicity of the bundles of axons in the brain white matter (and in the spinal cord), both analytical solution and numerical simulation can be done relatively simply. Two important research groups are the University College London Microstructure Imaging Group, and the Vanderbilt University Institute of Imaging Science. The simulation done by these groups are usually Monte-Carlo simulations on cells with impermeable membranes (like the axons mentioned above) or finite difference methods on a partial differential equation model.

Our first main result is the efficient numerical simulation of the microscopic PDE model of dMRI in complex tissue geometries. The effect on the MRI signal of water diffusion in biological tissues in the presence of applied magnetic field gradient pulses can be modeled by a multiple compartment Bloch-Torrey partial differential equation. We numerically solved this equation and simulated the resulting diffusion MRI (dMRI) signal for complex tissue geometries and arbitrary-shaped diffusion-encoding gradient time profiles. Our approach involves solving the Bloch-Torrey equation by coupling a finite elements discretization in space with an efficient time discretization using an explicit Runge-Kutta-Chebyshev method (see [555] and a recent preprint with D. Calhoun, Boise State Univ., C. Poupon and D. Le Bihan, NEUROSPIN). Our second main result is in formulating reduced models for long time diffusion in complex tissue geometries. Using homogenization techniques, two models for the long time dMRI signal were developed, one is an analytical model and the other is a ODE model. The latter works on wider range of gradient amplitudes than the former, but the former is easier to invert. Both are much simpler to analyze and invert than the original microscopic PDE model. These results are unique in that they are completely mathematically justified. They are more accurate in approximating the full microscopic PDE model in the long time than the other reduced model (called the Karger model) used up to now by MR physicists. The Karger model was actually a phenomenological model developed by physicists for a different application (diffusion in crystals) see [556] and submitted preprints.

Iterative and Hybrid inversion methods The use of iterative methods for non linear inverse problems is a classical approach with a long history and large and rich literature. Our first goal here is to transpose most recent shape and topological optimization methods (See section on Optimal design) to inverse shape problems with appropriate regularization schemes. The first studied case is the identification of deposits from eddy current measurements [553]. The second one is related to the extension of steepest descent method for obstacles with generalized impedance boundary conditions ([93], PhD Thesis of N. Chaulet). Our second objective is to couple these methods to the over-mentioned qualitative methods in order to improve theirs computational performances and convergence properties. This has been developed in the framework of the PhD thesis of D. Nicolas jointly supervised by G. Allaire and H. Haddar. Another class of iterative methods for inverse problems is the so-called decomposition methods. In these methods, one tries to decouple the ill-posedness and the non-linearity of the inverse problem. The conformal mapping method (Akduman-Haddar-Kress, 04) falls in this class and we were interested in its extension to impedance tomography [111] as well as inverse scattering at low frequencies [112].

2.1.2 Random modeling and applications

Mathematical Models for the Evolution of Biological Systems (“MEV”, Modélisation pour l’Évolution du Vivant). This team, under the supervision of Sylvie Méléard, develops mostly probabilistic theory and tools for the study of evolutionary systems in biology. Its members are:

- **Sylvie Méléard**, Professor at Ecole Polytechnique,
- **Vincent Bansaye**, “Professeur chargé de cours” at Ecole Polytechnique,
- **Hélène Morlon**, CNRS “chargée de recherche”,
- **Amandine Véber**, CNRS “chargée de recherche”.

The team was created shortly before 2008 and rapidly expanded, due to a strong interest in the community in these applications. The following were hired after 2008: V. Bansaye (2009), H. Morlon (2011), A. Véber (2010).

Until September 2012, C. Giraud (now Professor at Université Paris-Sud, Orsay) was also with CMAP, working in this team. He is now an active external collaborator of the group. Another collaborator was Chi Viet Tran (now Maitre de Conférences Lille 1) between Sept. 2010 and Sept. 2012, and J.-R. Chazotte, a CNRS “chargé de recherche” with the CPHT, Ecole Polytechnique, is also a regular collaborator of the team MEV. The team will evolve in the next contract to incorporate other researchers in applied probability theory interested in similar systems and tools, possibly with other applications (see Section 4).

The MEV team, funded by a “Chaire” with Veolia and several ANR contracts, hired in the past years the following **Postdoctoral fellows**:

FABIEN CONDAMINE (2012–2013), directed by H. Morlon
ANKIT GUPTA (2011–2012), directed by S. Méléard
CHUNMAO HUANG (2011), directed by V. Bansaye
SEPIDEH MIRRAHIMI (2011–2012), directed by S. Gaubert and S. Méléard
Daniel Moen (2012–), directed by H. Morlon
MATHIEU RICHARD (2012–2013), directed by S. Méléard

Hannah Salim (2013), Fellowship Chateaubriand

The following **PhD students** are being or were trained with the team MEV:
Geoffroy Berthelot (2010–2013), directed by J.-J. Toussaint (IRMES), D. Couvet (MnHn) and V. Bansaye.
Camille Coron (2010–2013), directed by S. Méléard
Manon Costa (2012 –), directed by S. Méléard
Clément Fabre (2009 –), directed by S. Méléard
Hélène Leman (2012–), directed by S. Méléard and Amandine Véber
Jonathan Rolland (2011–), directed by F. Jiguet (MNHN) and H. Morlon
Charline Smadi (2011 –), directed by J.-F. Delmas (CERMICS) and S. Méléard

Past PhD students:
FLORENT BARRET (PhD 2012), directed by A. Bovier (Bonn) and S. Méléard - Post-doc at Leipzig.
DENIS VILLEMONAIS (PhD 2011), directed by S. Méléard. Assistant Professor at Ecole des Mines de Nancy.

Research activities The aim of our group is to develop sophisticated random models allowing to understand better how the genetic structure of a population impacts its dynamics and its evolution, and how ecological interactions can produce gene selection. We also attempted to understand better the effect of environmental variations on biodiversity. This lead to major developments in the following fields:

- **Coalescent processes and models of genealogies.** These were studied under many different scenarios, including age-structured populations [288], coevolving populations (e.g. the evolution of a parasite population vertically transmitted from parents to offspring [244], the influence of the history of the individuals in their future behaviors [287]. This will enable us to use some of their properties in the analysis of several models of interest in ecology, in which a fluctuating population size is much more relevant (if not essential). From a statistical point of view, an importance sampler of binary trees consistent with a given pattern of mutation is in the process of being devised.
- **Branching processes.** Multitype branching processes (where the state of an individual represents e.g. its current habitat, its phenotype,...) and processes in random environment (with a particular interest in extinction/survival probabilities, growth rates, interplay between the demographic and environmental stochasticity...) have been largely developed mathematically in order to understand particular ecological processes [246, 249]. The latter processes combine demographic and environmental stochasticity which can both explain rare events.
- **Spatially structured populations and measure-valued processes.** Here again, the range of scenarios considered was rather large. Multitype branching processes and branching

processes in random environments were the basis of most of the investigations about the long-term behavior of populations structured into discrete demes [251]. On the other hand, a better understanding of the neutral evolution of a population living in a continuum was brought by several works on a new measure-valued process that extends the well-known Fleming-Viot superprocesses to the case where reproduction events are spatially restricted [259, 277]. The influence of a weak selective advantage is now being studied in the same context [257]. Still in the realm of continuous geographical spaces, competition for resources between the individuals of the population was studied thanks to a model based on historical processes (objects that are already present in the superprocess literature, but are much more complex here due to the interactions between individuals, [287]).

- **Quasistationarity and metastability.** In particular, Yaglom limits were obtained for a range of diffusions including the most famous examples in population dynamics and genetics [289]. In addition, the quasistationary behaviors of several models with neutral (or nearly neutral) mutations conditioned on non-extinction for a long time were described and translated into interesting properties of the biological systems modelled in this way [268].
- **Models of speciation.** The framework of adaptive dynamics -very rare mutations on a timescale where fixation (if it occurs) is instantaneous- was used in [267, 270] and [577] to give a criterion for the possibility of evolutionary branchings. This constitutes the first step towards the understanding of sympatric speciation, a key question in evolutionary biology. Other topics of interest included the vortex of extinction, whereby a population is all the more driven to extinction as its size is small [272].
- **Macroecology, macroevolution and microbial diversity.** A common theme to these research directions is the use of molecular phylogenies (trees describing the evolutionary relationship among species) and of branching processes modelling these phylogenies, potentially in a spatial context. This allows to study speciation and extinction rates, the ecological factors influencing these rates, the processes underlying community assembly, and the resulting biodiversity dynamics [271, 284, 294].

Past or current PhD projects:

- The PhD work of **F. Barret** aims at studying some differential or parabolic, semi-linear partial differential equations perturbed by an additive white noise in the small noise asymptotics. The main aim is the computation of the expected time of metastable transitions which occur between different stable equilibria of the deterministic dynamical system. The main result is a formula, similar to the finite dimensional case (so-called Eyring-Kramers Formula), for the transition times.

- The PhD work of **J. Rolland** aims at defining the major variables of interest acting on mammals and birds evolution and at understanding better the still unexplained latitudinal diversity gradient (the fact that biodiversity is higher in tropical regions).

- The PhD work of **C. Fabre** aims at modeling (with stochastic and dynamical systems tools) the interplay between mutation, selection and migration and at understanding how this interplay may affect the evolution towards specialized or generalists traits.

- The PhD work of **C. Coron** aims at modeling the genetic evolution of diploid populations by a multi-type logistic birth-and-death process whose birth rates are designed to model Mendelian reproduction. The first part of the PhD is devoted to the study of the mutational meltdown, a phenomenon in which the size of a small population decreases more and more rapidly due to more and more frequent fixations of deleterious mutations. The second part of the thesis concerns the convergence, under a large population approximation, toward a slow-fast stochastic dynamics and the quasi-stationary behavior of the population.

- The PhD work of **M. Costa** aims at developing a probabilistic model to include trophic interactions in the framework of adaptive dynamics. Considering prey-predator networks, one wants to understand the impact of this interaction on the species' evolution, the mechanism of diversification and the development of complex networks. Moreover, the model will include new time scales related to the difference of generation time that appears between different species in these networks.

- The PhD work of **H. Leman** aims at understanding the influence of a spatial structure on Darwinian evolution and exploring how a heterogeneous environment favors diversity, by the use of stochastic and deterministic analysis. The evolution of the population is represented by an individual-based model where movements of individuals are modeled by a diffusion process. Supposing a large number of individuals, the mean behaviour of the population is described by a non-local partial differential equation.

Probability and Financial Mathematics This team is supervised by Nizar Touzi (Professor). Its current composition is the following

- **Emmanuel Bacry** (Chargé de Recherche CNRS)
- **Jocelyne Bion-Nadal** (Chargée de Recherche CNRS)
- **Stefano De Marco** (Assistant Professor since 09/12)
- **Emmanuel Gobet** (Professor since 09/10)
- **Caroline Hillairet** (Assistant Professor)
- **Nizar Touzi**, (Professor)

In the past recent years:

- Nicole El Karoui (Professor until 08/09), retired from Polytechnique.
- Peter Tankov (Assistant Professor until 08/11). Peter defended his *Habilitation à Diriger les Recherches* in December 2011. Our department does not allow for promotions from the Assistant Professor level. Peter is presently Professor at University Diderot Paris 7.
- Mathieu Rosenbaum (Assistant Professor until 08/11). Mathieu defended his *Habilitation à Diriger les Recherches* in December 2011. Our department does not allow for promotions from the Assistant Professor level. Mathieu is presently Professor at University Pierre et Marie Curie Paris 6.

During the last five years, our team hosted the following Postdoctoral fellows

- Pierre Etoré (01/08 to 08/08)
- Gonçalo Dos Reis (01/09 to 03/11)
- Cristophe Frei (10/10 to 06/11)
- Noufel Frikha (ATER, 09/11 to 08/12)
- Rudra Jena (01/09 to 05/11)
- Mohamed M'rad (10/09 to 08/10)
- Piergiacomo Sabino (01/09 to 06/09)
- **Plamen Turkejiev** (01/13 – Present).

Our team also hosts the following Associate members:

- Laurent Denis (University of Le Mans)
- Pierre Henry-Labordère (Société Générale)
- Anis Matoussi (University of Le Mans)
- Jean-François Muzy (University of Corsica)
- Denis Talay (INRIA Sophia Antipolis)
- Jérôme Lelong (University of Grenoble)
- Céline Labart (University of Chamberry)

Our group hosts many visitors all over the year. We have also hosted Jianfeng Zhang (USC) during his sabbatical semester 2010, Cody Hyndman (Concordia University, Montreal) during his sabbatical 09/2012–07/2013. We shall also host Alexander Cox (University of Bath) during his sabbatical semester 09/2013–12/2013.

The PhD students in Financial Mathematics, currently trained in the CMAP are

- **Zhen-Jie Ren** (Supervisor: Nizar Touzi, started 2010): Path-dependent Partial Differential Equations.
- **Guillaume Royer** (Supervisor: Nizar Touzi, started 2010): Martingale Optimal Transport.
- **Gaoyue Guo** (Supervisor: Nizar Touzi, starting September 2013): Continuous-time martingale optimal transport and PCOC.
- **Romain Bompis** (Supervisor: Emmanuel Gobet, started September 2010, Monge allocation Ecole Polytechnique): Stochastic expansion for diffusions and applications.
- **Qihao She** (Supervisors: Emmanuel Gobet and Nicolas Privault (NTU, Singapore), starting Septembre 2013).
- **Relu Adrian Luga** (Supervisor: Emmanuel Bacry, started 2010): Statistical Analysis of Order Books.

The past PhD student during the last fives years were:

1. Khalil Al Dayri, Market Microstructure and Modeling of the Trading Flow. Supervisor: E. Bacry and M. Hoffman, defended in 2012. Khalil is presently quant at *Antares Technologies*.
2. Harry Bensusan, Dynamic Modellling and Applications to Life Insurance Derivatives. Supervisor: Nicole El Karoui, defended in 2010. Harry is presently quant at Société Générale.
3. Isabelle Camilier, Contributions to Long-Term Interest Rates and Stochastic Analysis of Determinantal Point Processes. Supervisor: Nicole El Karoui, defended 2010. Isabelle is presently Post-Doc at Stanford University.
4. Tarik Ben Zineb, Efficient Valuation of GMWB Contrats. Supervisor: Emmanuel Gobet, defended December 2012. Tarik is presently quant at Thomson-Reuters.
5. Laurent Duvernet, Statistical Analysis of Multi-Fractal Random Walk Processes. Supervisor: Emmanuel Bacry and Marc Hoffman, defended in 2010. Laurent is presently Assistant Professor at University Paris 10 Nanterre.
6. Gilles-Edouard Espinosa, Some Applications of Stochastic Control in Finance. Supervisor: Nizar Touzi, defended 05/10. Gilles-Edouard is presently quant at BNPParibas.
7. Emilie Fabre, Some Contributions to Control and Backward Equations in finance. Supervisor: Nizar Touzi, defended 02/12. Emilie is presently quant at Société Générale.

8. Arash Fahim, Pobabilistic Numerical Methods for Nonlinear PDEs, Application to Carbon Markets. Supervisor: Nizar Touzi, defended 03/10. Arash is presently Assistant Professor at the University of Florida.
9. Nabil Kazi-Tani, Dynamic Risk Measures and Second Order Backward SDEs. Supervisors: Nicole El Karoui and Jocelyne Bion-Nadal, defended 12/12. Nabil is presently Assistant Professor at University of Lyon.
10. Younes Kchia. Semimartingales and Recent Problems in Quantitative Finance. Supervisors: Philip Protter and Nizar Touzi. Younès is presently at ANZ Singapoor.
11. Nicolas Landon, Risk Management in Energy Markets. Supervisor: Emmanuel Gobet, defended February 2013. Nicolas is presently quant at Dexia.
12. Mohammed M'rad, Progressive Utilities and Stochastic Flows. Supervisor: Nicole El Karoui, defended in 2009. Mohamed is presently Assistant Professor at University Paris Nord 13.
13. Trung-Lap Nguyen, Financial Risk in Insurance and Long term risk. Supervisor: Nicole El Karoui, defended 09/12.
14. David Nicolay, Volatility Dynamics. Supervisor: Nicole El Karoui, defended in 2011. David is presently quant at UBS London.
15. Dylan Possamaï, On Second Order Backward SDEs and Related Problems in Finance. Supervisor: Nizar Touzi, defended 12/11. Dylan is presently Assistant Professor at University Paris Dauphine.
16. Xiaolu Tan, Stochastic Control for Optimal Transportation and Probabilistic Numerical Methods for PDEs. Supervisors: Nizar Touzi and Frédéric Bonnans, defended 12/11. Xiaolu is presently Assistant Professor at University Paris Dauphine.
17. Chao Zhou, Model Uncertainty and Second Order Backward SDEs. Supervisor: Anis Matoussi, defended 12/12. Chao is presently Assistant Professor at NUS (Singapour).

Research activities Our research is motivated by applications to financial mathematics which opens news perspectives and raises new problems in stochastic analysis, numerical approximation techniques, and statistical methods. Therefore, our topics of interest range from applied problems in financial engineering, required sophisticated mathematical techniques, to theoretical problems in stochastic analysis and stochastic control theory, with an emphasis on the related numerical and the statistical aspects.

- **Path-dependent partial differential equations** (Bion Nadal, Touzi): motivated by applications in stochastic control and financial mathematics, the theory of backward stochastic differential equations (BSDE) has experienced a huge development since the early nineties. In the Markov framework, a BSDE is associated to a semilinear parabolic second order partial differential equation (PDE), and the solution of a BSDE is in fact a specific Sobolev solution of the corresponding PDE. For this reason, BSDEs can be viewed as a Sobolev solution of a semilinear path-dependent PDE. A first stream of contributions of our team to this area is the extension to the context where the underlying noise is a martingale in a general probability space [309]. These developments are motivated by continuous-time dynamic risk measurement . Another important contribution to the theory of BSDEs was achieved in [370] by the extension to the second order which can then be viewed as a Sobolev solution of a fully nonlinear parabolic second order path-dependent PDE. In particular, similar to Hamilton-Jacobi-Bellman equations, second order BSDEs provide a unique characterization of the value function of a stochastic control problem in a possibly non-Markov framework. Recently, a new point of view was developed in [330] and two preprints (Ekren, Touzi, Zhang, "Viscosity solutions of fully nonlinear parabolic path dependent PDEs part I and II, arXiv 1210.0006-7) which develop a notion of viscosity solutions for path-dependent parabolic second order PDEs. The main difficulty is to by-pass the local compactness requirement of the underlying state space in the standard theory of viscosity solution. This is achieved by replacing the pointwise tangency condition by a tangency condition in the sense of an optimal stopping problem under nonlinear expectation.

- **Martingale optimal transport** (Touzi): the robust management of risks requires to weaken as much as possible the assumptions on the model. In this context, an interesting ramification of the theory of optimal transport was introduced in [336]. Assume that the financial market obeys to the no-arbitrage condition, and that there exists a linear continuous pricing rule. Assume further that the prices of European calls of all strikes, and with some given maturities, are available for trading. Then, the problem of robust hedging of derivatives can be identified to the Kantorovitch dual of an optimal transport problem on the space of paths with a martingale restriction on the set of coupling measures. The transport cost is determined by nature of the derivative contract under consideration. Moreover, this new optimal transport problem is closely connected with the Skorohod embedding problem [336] (also a recent preprint authored by Pierre Henry-Labordère, Jan Obloj, Peter Spoida, and Nizar Touzi) and the newly developed theory of PCOC (Processus croissants pour l'ordre convex). Another recent contribution is the analogue of the Brenier theorem in the martingale context. This was achieved in the one-dimensional case (Henry-Labordère and Touzi, preprint), and the general context is an ongoing project.

  This active new topic was funded by the ANR (Project ISOTACE), and by the ERC (Advanced grant ROFIRM).

- **Approximation and simulation of non-linear systems** (Gobet, Touzi, Turkejiev): motivated by applications in stochastic control and optimal stopping problems, an important activity of our team is on the design of new probabilistic algorithms for the approximation of the solution of a FBSDE and, more generally, second-order BSDE. Another more involved motivation is the problem of optimal transportation under controlled dynamics whose dual formulation reduces to optimization of BSDEs [373], paving the way for new numerical methods for optimal transport problems.

  Gobet introduced an optimal time-discretization of BSDEs whose specification is made according to the fractional smoothness (on Wiener space) of the terminal condition [342][337]. The numerical approximation of 2BSDEs is addressed in[335] where a bound on the rate of convergence is obtained by adapting techniques from viscosity solutions theory. New fully-implementable schemes for BSDEs are designed, by using marked branching processes (preprint Henry-Labordère, Tan, Touzi in revision for "Stoch. Proc. and their Application"), or empirical least-squares regressions based on modern statistical learning tools (preprint E. Gobet, P. Turkedjiev, 2013). These methods are developed and analyzed under rather great generality, to provide efficient and robust algorithms and to handle multi-dimensional situations. Designing parallel algorithms is also an important concern for us, which we intend to develop further in the future.

  This research topic benefits from the financial support of the *Initiative de Recherches "Méthodes numériques pour le contrôle stochastique"* supported by FiME laboratory.

- **Control of stochastic systems and applications to finance:** (Bion Nadal, Hillairet, Tankov, Touzi): Optimal decision making in finance is usually formulated by stochastic control problems with specific features requiring new mathematical developments. An important contribution of our group is the control theory of stochastic target problems [319] which can be viewed as an extension of standard stochastic control problems, and which are intimately connected to geometric equations describing front propagation in differential geometry. A second important contribution to the general theory is the newly developed weak dynamic programming principle [317] which by-passes the heavy measurability issues in the classical dynamic programming principle. Motivated by the importance of path-dependency in finance, in particular in the measurement of risk [313, 314, 312, 310, 311], an extension of the dynamic programming approach was developed in the context of path-dependent stochastic control problems (Ekren, Touzi, Zhang, preprints). Moreover, many applications to relevant problems in finance are developed. For instance, the problem of hedging and optimal investment under liquidity cost [323, 325, 352, 353], optimal investment in jump-diffusion models, possibly under risk measure type of constraint, [324, 327], optimal investment under capital gains taxes [372], optimal decision making under partial information [346, 347].
- **Asymptotic methods and applications** (De Marco, Gobet, Tankov, Touzi): similar to the standard engineering applications, asymptotic approximations are widely used in the financial industry. This is in particular very developed in the context of the calibration of models. A relevant point of view was developed in order to address systematically, and efficiently, the asymptotic approximation of valuation functionals [306, 305]. In addition, S. De Marco produced, before his integration with CMAP in Sept. 2012, a paper which provides theoretical results on the gaussian bounds on the density of diffusions in the context of non-Lipschitz coefficients, and two articles (with C. Martini and V. Bally) where he derives asymptotics of the implied volatility surface so as to improve calibration techniques. He has been further investigating these questions in [328] and a recent preprint with P. Friz.

  Another important question is the design of a (random) time grid, representing the dates of discrete-time trading, which is optimal in the sense that it asymptotically minimizes the continuous-time hedging error. An elegant general solution of this problem was derived in [341]. Finally, the asymptotic expansion of the problem of optimal investment under small transaction costs was solved in [367]. A rigorous derivation of the first order expansion was open since the early nineties. In the context of a power utility function, this was solved in the previous literature by relying on the explicit structure of the problem. The general case solved in [367, 356] adapts the modern viscosity solutions approach to homogenization to the present problem where the fast variable is determined endogenously by the optimization of the limiting system.
- **Financial engineering** (De Marco, Gobet, Hillairet, Tankov, Touzi): many new problems have emerged from the recent financial crisis which require new developments based on stochastic analysis, optimization tools, numerical methods, and simulation techniques. El Karoui and Hillairet have explored the new problems arising in longevity risk and the related derivatives [304]. Tankov [324] analyzed gap risk contract whose payoffs is contingent to a downward jump in the underlying asset price process. Motivated by concrete financial contract introduce by the French government, Hillairet [579] analyzes the relevance of Public-Private partnership. Tankov [375] provided an improvement of the known model-free bounds

on the pricing of multi-asset derivatives. Touzi studied the effect of illiquidity in options hedging and provided a characterization in [323] in terms of a degenerate fully nonlinear PDE. The corresponding small illiquidity expansion is analyzed in [355]. Tankov studied the problem of optimal portfolio allocation under illiquidity risk in [325, 352, 353]. Gobet [306, 305] introduced new expansion techniques suitable for model calibration. Gobet [341] solved the problem of optimal choice of (random) discrete trading times in the sense of the minimization of the continuous-time asymptotics of the hedging error. Similar discretization problems were analyzed in [320, 376, 308, 364]. Finally, Touzi [321] analyzed CO2 emission derivatives which gives rise to Singular FBSDEs .

- **Statistics of continuous-time processes and order books analysis** (Bacry, Rosenbaum): With the increase of electronic trading and with the different crisis and krachs that took place in the last decade, accurate modeling of financial time-series has become a major challenge. This challenge must clearly be addressed at very various time-scales : from the ultra-high frequency (of the order of the ms, i.e., the time-scale of the order-book), to the microstructure time-scale (of the order of the second) down to the daily or the monthly scales where the price is clearly diffusive. This is the key to understanding the underlying dynamics of price formation and the key to many applications (risk control, regulation, market design, market making, high frequency hedging, optimal execution, . . .). The recent contributions of our team in this area are in two directions:

  – Using the theory of invariance scaling phenomena, [393, 390, 394, 408] developed some particularly parcimonious models that account for most stylized facts of price time-series on a wide time-scale (from 1 hour to several years). The so-called Multifractal Random Walk (MRW) model only uses 3 parameters and has been proved to be particularly elegant and useful for risk forecast. These models are now become very standard multifractal models that are studied by many international academic teams.
  – Microstructure models based on (multivariate) high frequency point processes models are introduced in [388, 389]. These models reproduce very accurately microstructure effects (signature plot, Epps effect, . . .). Moreover their diffusive properties can be controlled easily since there are closed formula that express the covariance diffusive matrix in terms of the microscopic parameters[388, 389]. In that sense they should be particularly useful for studying the systemic risk induced by high-frequency trading and understanding how it can be controlled through regulation. Theses models make extensive use of Hawkes processes and can be seen as building blocks that can be easily put together for addressing a particular issue. Moreover, recently (preprint with J.-F. Muzy), E. Bacry has developed a new non-parametric estimation algorithm for Hawkes processes that can make parameter estimation of any of these models very efficient. These works have been presented in several international conferences (including both conferences ”Market Microstructure : confronting many viewpoints” in 2010 and 2012).

Signal, statistics, data. This section will describe the work of the members of the former team “statistics, learning and signal” (supervised by S. Mallat, now with École Normale Supérieure), some members of the team “modeling and random simulation and statistics” (all in other teams, but addressing sometimes issues which are beyond the scopes of their team), and recently hired members of the lab who work in the topics of high (or huge)-dimensional statistics.

Hence we will describe part of the activities of

- Stéphane Mallat, former Professor at Ecole Polytechnique,
- **Stéphanie Allassonnière**, “professeure chargée de cours” at Ecole Polytechnique,
- **Emmanuel Bacry**, CNRS “chargé de recherche”,
- **Antonin Chambolle**, CNRS Research director,
- **Stéphane Gaïffas**, “professeur chargé de cours” at Ecole Polytechnique,
- **Carl Graham**, CNRS “chargé de recherche”,
- **Guillaume Lecué**, CNRS “chargé de recherche”

The current PhD students are

- **Joakim Andèn** (S. Mallat, EDX);
- **Laurent Sifre** (S. Mallat, EDX);
- Islem Rekik (S. Allassonnière and J. Wardlaw, Edinburgh *PhD Edinburgh Univ, 2010–*);
- **Hao Xu** (S. Allassonnière and B. Thirion, Neurospin, 2011–);
- **Luis Felipe Olmos Marchant** (C. Graham and B. Kauffmann – CIFRE Orange labs 2013);
- **Etienne Corman** (A. Chambolle and M. Ovsjanikov (LIX), DGA and Industrial Project “TANDEM2” 2013–);
- **Pauline Tan** (A. Chambolle and P. Monasse (CERTIS ENPC), ASN ENS Cachan, 2013–).

Classification (S. Mallat and students). In 2008, S. Mallat came back as a Professor at École Polytechnique after 3 years of leave during which he was the CEO of a semi-conductor start-up “Let It Wave” for high-definition television, which was created based on mathematical results previously obtained at the CMAP. During the last 5 years, he supervised the work of the following PhD students: Guoshen Yu, 2009, Joan Bruna, 2013, and currently Joakim Andèn and Laurent Sifre.

After finishing on-going work with G. Yu, on super-resolution inverse problems (leading to a patent, see Sec. 2.3, the student G. Yu also registered another patent on a shape recognition system based on “ASIFT” affine-invariant features), S. Mallat began a new research program on signal classification, for sounds and images.

For classification problems, it is necessary to build invariant representations, relatively to group actions such as translations, rotations, frequency transpositions, but which are also stable to actions of diffeomorphisms which deform signals. Classical Fourier or canonical invariants do not satisfy this stability property. From 2010 to 2013, S. Mallat and his group has developped a new theory of invariants, based on non-linear “scattering operators”, which provide stable invariants to the action of diffeomorphisms. A scattering operator is a product of non-linear and non-commutative operators obtained with wavelet transforms, and modulus operators.

J. Bruna and S. Mallat have developped classification algorithms for texture images and manuscript digits, with scattering operators, providing state of the art results on standard data bases. L. Sifre has generalized the scattering transform to the non-commutative roto-translation group, and developped applications to rotation invariant image texture classification. Audio classification is another domain where stable invariants play a fundamental role. During his thesis, J. Andèn developped a scattering tranform for audio processing, with applications to music genre and phonem classification.

Statistics of shapes (S. Allassonnière, C. Giraud.) S. Allassonnière arrived in September 2008. Her research topics are related to statistical analysis of images with applications in particular in the medical domain. Her main collaborators are E. Kuhn (INRA, Jouy-en-Josas), A. Trouvé (CMLA, ENS Cachan), B. Thirion (INRIA Parietal, Saclay), J. Wardlaw (U. of Edinburgh), S. Durrleman (INRIA Aramis, Roquencourt) and S. Joshi (U. of Utah). She is currently PI of the "MMoVNI" Digiteo project (multi-modal atlas estimation) and participates to the ANR projects "HM-TC" (hippocampus study through imaging and cognitive technics for Alzheimer's disease understanding) and IRM-Group (Invariant extraction from populations of images for classification tasks). She is currently co-supervising two PhD students : H. Xu (co-supervised by B. Thirion) and I. Rekik (co-supervised by J. Wardlaw).

Her interest is motivated by a major question: how can we estimate a complete atlas of the brain from a given population of images with theoretical guaranties about the output estimates? This question reveals three aspects: (1) modeling the wide range of observations we are provided with, (2) estimating this atlas numerically from these models and (3) proving the statistical relevance of the estimates. These are the three directions she is contributing.

First is the modeling issue. To deal with real medical data implies to consider the anatomical constraints and to be able to produce a complete atlas of the brain which shows all information captured by all the modalities. With S. Durrleman and S. Joshi, SA generalized a model proposed in [Allassonnière, Amit, Trouvé, JRSS, 2007] so that it takes into account diffeomorphic deformations [396] to reflect anatomical constrains. With H. Xu, she introduced probabilistic maps of anatomical and functional tissues into the model [599] which is currenlty the PhD subject of H. Xu. The goal is to show active areas related to different cognitive tasks which are constrained to appear on the cortex or the cortical structures of the brain. This enables to increase the accuracy of atlas based segmentations of new patients and the understanding or the different areas of brain activity.

Medical images also come now along time to analyze the temporal evolution of a disease. To perform this analysis, SA modeled the spatio-temporal scenario of two pathologies. First, brain glioma -join work with the INRIA Asclepios project [410] - was modeled using a front propagation in the reaction-diffusion model. This enabled to estimate the initial time and source of the tumor as well as its propagation coefficient which relates to the aggressiveness of the tumor. This was also used to predict the possible evolution of the tumor front for low grade glioma patients. Concerning stroke evolution, [409, 411], SA proposed to use a piecewise geodesic regression. This last work is the PhD subject of I. Rekik in collaboration with J. Wardlaw, Professor of Applied Neuroimaging in the Division of Clinical Neurosciences, Western General Hospital, Edinburgh. The goal is to extract from the spatio-temporal scenario different correlations between two modalities in order to confirm or contradict stroke postulates.

These modeling shows the importance of the registrations between images. Therefore, in collaboration with L. Younes (CIS, JHU) and then C. Giraud (CMAP, U. Orsay), SA proposed to generalize two existing statistical models which capture and highlight complementary aspects of the deformations. On the one hand, Probabilistic Independent Component Analysis (ICA) shows that a small number of patterns were discriminative for the Alzheimer's disease (AD) diagnosis [412]. On the other hand, the non local Gaussian Graphical Model (GGM) showed long distance dependencies between different areas of the hippocampus for healthy controls [596] which tend to disappear for AD patients.

The other aspect of the question is the numerical estimation process. Deterministic algorithms were showing failures, therefore, in collaboration with E. Kuhn, SA proposed to use a stochastic algorithm to perform the numerical estimation of the atlas for the atlas estimation models [387, 385], applied to medical data [386, 598, 597] and radar aircraft images [406, 618] in collaboration with a ONERA team and Telecom ParisTech.

E. Kuhn and SA proved asymptotic properties of the estimators and algorithms which ensures the relevance of the estimated atlases and provides confidence intervals. These algorithms are generic so that that they can be applied to a large range of models for parameter estimation issues.

Multifractal signal analysis E. Bacry is a specialist in scale invariance. He has introduced in 2002 a very popular multifractal model (Multifractal Random Walk) that is now studied or used in applications by many international academic teams. He is still working actively on some extensions [408]. It is a particularly parcimonious (only 3 parameters) and has remarkable scale-invariance properties ("exact" scale-invariance, increment stationnarity, . . .). He has used it successfully for modeling fully developed turbulent flows (see [407]) as well as financial time-series on a very wide range of scales (see for instance [393, 390, 394]) for which he proved it lead to a very accurate multi scale volatility predictor. Within this framework, he has recently developed a particularly powerful theory (the so-called "Mixed asymptotics" framework) that uncovers many problems that arises generically in the estimation of the parameters of multifractal models [391, 612] which, for instance, lead, for the first time, to a clear mathematical understanding for the "negative fractal dimensions" introduced by Mandelbrot back in the 70's.

Parallely, he has been working on analysis and modelization of high frequency financial time-series. For this application he has extensively been working on modeled based on random point processes and more particularly on Hawkes processes. E. Bacry has obtained many important results on Hawkes processes such as explicit diffusive limits [389] or brand new and efficient non parametric estimation procedures, see [395] and a new preprint ("A point process model for price formation") with J.-F. Muzy. Hawkes processes have been extensively used for many years for earthquake signals modelization. There are getting more and more popular for many other applications. E. Bacry is currently working on applications of Hawkes processes on earthquake, finance and viral diffusion on the net (e.g., on twitter). For this purpose, he is studying the properties of sparse Hawkes based models in very high dimension.

High-dimensional statistics and learning (C. Giraud, until 2012, G. Lecué and S. Gaïffas, since Sept. 2012). C. Giraud was promoted as a Professor at Université Paris-Sud (Orsay) in Sept. 2012. Simultaneously, the lab hired G. Lecué and S. Gaiffas. G. Lecué was formerly a researcher at CEREMADE, Univ. Paris-Dauphine. S. Gaïffas was working in Paris 6, at the Laboratoire de Statistique Théorique et Appliquée.

Since 2008, the main research activities of C. Giraud concern high-dimensional statistics with a special interest in life-sciences applications. From a methodological side, C. Giraud has developed some efficient and provably optimal procedures for adaptative estimation in Gaussian Graphical Model, high-dimension regression and multivariate regression. These procedures are implemented in R packages. Furthermore, he has developed a procedure for selecting estimators which is an efficient alternative to Cross-Validation with strong statistical properties. From an applicative side, C. Giraud has developed some statistical methods for analyzing proteomics data, ecological monitoring data and participative sciences data. This last topic gathers almost all the difficulties that can be faced by a statistician : massive data sets, high-dimensionality, spatio-temporal structures, severely incomplete data, ill-posed inverse problems, strong heterogeneity, etc. With a small sub-group of the Cistats group, C. Giraud currently develops a statistical methodology which converts into reality the long-standing hope to exploit the large participative sciences data bases freely available on internet for biodiversity monitoring. This methodological innovation offers some important scientific perspectives for biodiversity monitoring and it will enable to tight the link between the associations involved in participative sciences and the scientific labs.

G. Lecué is also working on theoretical statistics for high-dimensional data — he is currently a member of the related ANR programs PROGNOSTIC, 2009 - 2013 (Statistics, Univ. Paris-6) and PARCIMONIE, 2009 - 2013 (Statistics, Paris 7). Learning on high-dimensional data presupposes a underlying structure of small dimension. For example, signals with sparse support in some "good" basis, very large but low-rank matrices, functions defined on high dimensional spaces but which depend only on a small number of variables, large graphs but organized in small communities, etc.. One goal of the statistician is then to identify this (these) structure(s) from the (sometimes noisy) data. It is then necessary to find procedures that benefit from these structures where they exist. The example of penalization methods enforcing sparsity criteria is typical in the field of learning. Concerning the analysis of large matrices with low rank, G. Lecué proposed (with S. Gaïffas, K. Bertin) a penalization procedure where the penalization is a mixture of several terms which impose particular structures, and of conventional estimators. The performance of these procedures depend only on the intrinsic dimension of the problem and not on the size of the ambient space. On the issue of aggregation of estimators, G. Lecué has built two optimal procedures with S. Mendelson and P. Rigollet. This framework is difficult because conventional statistical procedures are suboptimal here. Other results were obtained by G. Lecué on the cross-validation method, the aggregate with exponential weights for the problem of convex aggregation and the single-index model.

The topics of research of S. Gaïffas are also statistical machine learning in high dimension and big data. He is currently mainly working on the following issues:

- Unsupervised learning in high dimension and clustering. He proposes an alternative to l^1 penalization of a Gaussian Mixture, by using a Bayesian approach, that ensures that the barycenters of the mixture share the same sparsity support. A fast procedure based on a greedy proposal is introduced.
- Change point detection, point processes. He is supervising a phd thesis at Univ. Paris 6 on the detection of change points in the intensity of point processes, where applications are mainly in the fields of high-frequency genomic profiling.
- Inference of time-varying networks, mutual-excitement networks. In this work, the problem of link prediction in a time-evolving graph is considered, using a time-series modeling for the graph features.
- Mutual-excitement networks. A modelization of interacting agents is proposed using mutually-exciting Hawkes processes. A convex objective is introduced for this problem, that allows to uncover the hidden network structure existing among the agents.

Apart from the paper [403], the scientific production of G. Lecué and S. Gaïffas at CMAP is of course very reduced and consists in the submitted preprints of 2013:

- S. Gaïffas and B. Michel: *Sparse Bayesian unsupervised learning*,

- S. Gaïffas and G. Lecué: *Weighted algorithms for compressed sensing and matrix completion*,
- G. Lecué and S. Mendelson: *Learning subgaussian classes: Upper and minimax bounds*,
- G. Lecué and P. Rigollet: *Optimal learning with Q-aggregation.*

Communication Networks C. Graham's current main focus is communication network modeling, in transitory and stationary regimes. In this, he investigates asymptotic regimes and limit theorems, aiming to allow for tractable performance evaluation. He has adapted to this field some of the techniques he had perfected on stochastic analysis and Monte Carlo methods for statistical mechanics models related, *e.g.*, to the Vlasov and Boltzmann equations.

Recent studies with P. Robert (Inria) bear on AIMD (additive increase, multiplicative decrease) algorithms of the kind found in the congestion avoidance part of TCP (transmission control protocol). In [401, 402, 615, 614], mean-field multi-class models were derived and analysed, in which classes account in particular for the graph structure of the routes through the network. The collaboration continues on other classes of models, in which more varied realistic features are being incorporated.

Mean-field multi-class models have seldom been studied rigorously, and the papers [399, 400] extend classic results for exchangeable systems (*e.g.*, the de Finetti theorem or Hewitt-Savage 0-1 law) under the natural symmetry assumption of exchangeability only *within* classes.

A well-established model for information exchange and belief formation in a network of exchangeable peers is investigated in [398] with J.-Y. Le Boudec (EPFL) and his master student J. Gómez-Serrano.

C. Graham co-directs with B. Kauffmann (Orange Labs) the PhD thesis of L. F. Olmos Marchant. The thesis takes place both in an industrial setting at Orange Labs and at the École Polytechnique, and benefits of a "CIFRE" scholarship. Its goal is to establish stochastic models for the requests in the Internet for videos and such resources, and to use them to analyse the huge data sets owned by Orange on this traffic. The ultimate goal is to provide better dimensioning rules and updating algorithms for internet caches for Orange, and this goes well beyond the scope of a thesis.

C. Graham has written a book [613] on Markov chains, which introduces their uses in Monte Carlo methods and some related aspects of their qualitative long-time behavior. With D. Talay (Inria), he has written the books [616] and its augmented translation [617] on more advanced probabilistic numerical methods, and is currently writing a book on more advanced aspects of the topic.

Analysis and Optimization for imaging The work of A. Chambolle on signal processing has less to do with statistics, although it is related to the minimization of nonsmooth problems which arise commonly in sparse signal analysis. He has directed the thesis of M. Goldman (2011, mostly in Nonlinear Analysis), K. Jalalzai (2012) and now co-supervizes two students in imaging: E. Corman (shape matching, optimization, 2013–) and P. Tan (stereo vision, 2013–).

A. Chambolle has worked in the past recent years with the group of Daniel Cremers (first in Bonn, now at T.U. Munich) on convex approaches for optimization in imaging. The idea is to try to find convex envelopes of energies which arise in typical imaging reconstruction problem (3D reconstruction, optical flow...), which is more or less always possible at the expense of an exponential increase of the number of variables. Hence the real difficulty is to find a compromize which remains computationally tractable but is faithful enough to the original problem and gives a relevant solution. The work [41], a bit theoretical but already cited about 100 times in Scholar Google, influenced many researchers working on image segmentation problems. A collaboration with students of D. Cremers, TU Munich (T. Pock, now at TU Graz, E. Strekalovskyi, TU Munich) let to further studies in the same direction (see [81], the book chapter [603], and the proceedings [604, 606, 607], a paper is also to appear in SIIMS).

The issue of optimizing the total variation or the singular energies appearing in the previously mentioned work led him (with D. Cremers, T. Pock) to study the efficient convex optimization algorithms available for such nonsmooth problems, and also to propose and analyze new variants (in particular, accelerated) of such algorithms. Recent advances with T. Pock [49, 605] have received much attention in the imaging and learning communities. The student M. Goldman has also performed a study, in the continuous setting, of system of PDEs arising in this context [74].

A. Chambolle has also been interested in graph based methods for solving variants of the same problems. See in particular [38, 601] with J. Darbon, Current research (in the framework of the EANOI ANR Blanc International project, with T. Pock) aims at understanding how to take profit of both worlds (combinatorial optimization techniques lead to exact solutions of some problems, while convex analysis techniques are easily parallelized). Other works on the numerical analysis of approximations of the Total Variations or variants are found in [45, 51, 608].

Important contributions have been made on the theoretical analysis of the TV reconstruction model (properties of solutions, regularity...) This is a long standing collaboration with G. Bellettini, V. Caselles, M. Novaga, and a few other, and many papers have been written [36, 30] and the chapters [600, 602]. The thesis of K. Jalalzai was in part developing some of these results. This expertise is well acknowledged and A. Chambolle was invited a few times to teach lectures on these aspects (Park City, Utah, July 2010, RICAM, Linz, Aug. 2009, and next October in Verona, Italy).

2.1.3 Automatic control and mathematics for technology and information science

Clearly, some of the topics of the previous subject (signal and learning) could also appear under the theme "mathematics for computer science". We present here, rather, the works of three INRIA teams which are all related to decision, automatic control and command, though all three using very different tools. We also present the activities of the ERC-funded group of Alexandre d'Aspremont, related to operations research and mathematical programming, who arrived in 2011 at CMAP and is leaving in September, 2013 to move to École Normale Supérieure.

COMMANDS (INRIA Team, Joseph Frédéric Bonnans). This team has two permanent members at CMAP, **J. Frédéric Bonnans** (INRIA Research director) and **Pierre Martinon** (INRIA "Chargé de Recherche"). It also hires two INRIA research engineers, **Daphné Giorgi** and **Stephan Maindrault** (on temporary contracts). The team is also partially located with the "Unité de Mathématiques Appliquées" (UMA) of the school ENSTA (Hasnaa Zidani).

In the past recent years was also present a post-doc Adriano Festa (funded by the European project ITN-SADCO), and it is currently training the PhD students **Xavier Dupuis** (ENS Lyon fellowship, 9/2010), **Laurent Pfeiffer** (Monge Polytechnique fellowship, 9/2010), **Nicolas Grebille** (CIFRE EDF, 11/2012). The team is funded in great part by the INRIA, but also by private and public contracts (CNES, ADT "Action de Développement Technologique" funding 2 engineers, Argentina's research agency, ITN-SADCO European project[8], STIC AmSud "Energy

[8]Managed by the ENSTA partner of the team Commands, Hasnaa Zidani.

Optimization").

One first focus of the team is trajectory optimization, from the theoretical analysis to the design of efficient algorithms and their use in industrial applications. Recent scientific achievements on this topic include the second order analysis of optimal control problems, control of infinite dimensional systems, and software tools.

On second order optimality conditions, we designed a shooting algorithm in the general framework of state constraints of any order, [492], [497, 496, 498], [500]. We also proposed an error estimation for interior point methods [508],[509, 512], in the context of singular (nonsmooth) perturbation. Using a decomposition principle separating the large and small variations of the control, we established some second oder optimality conditions for strong minima [504], [511],[647]. We also studied shooting methods in presence of singular arcs, [510], [515].

Our work in infinite dimensional systems was motivated by medical applications, and led us to investigate second order optimality conditions for state constrained problems, one of the key points here is to properly define the order of the constraint [501], [517]. We also extended the second order analysis in this setting for elliptic and parabolic PDEs, [516], [499], [502].

The team conducted several studies with the French Space Agency (CNES) on optimizing the ascent phase of several space launchers, [493, 494]. In the field of bio-processes, we started a study on the production of gas by a bioreactor coupling the growth of micro-algae capable of photosynthesis and anaerobic bacteria. We used in particular the softwares *Bocop* and *Shoot* developed by the team, and began to study the coupling of these approaches with Hamilton-Jacobi-Bellmann methods, [505].

The second focus of the team regroups stochastic control and energy optimization. Recent works cover the topics of second order HJB equations, optimality conditions for stochastic control problems, stochastic programming and optimization of energy networks.

We developed a duality estimate in order to give an upper bound to the price of general variance options, taking advantage of the Dubins-Schwartz's time change theorem, that allows to reduce the problem to the one of computing American options, [519].

Using variational methods, we studied general first- and second-order optimality conditions for stochastic control problems [513], and also showed that the classical suboptimality estimate for the solutions of problems with logarithmic penalty also hold for stochastic control problems with non-negativity control constraints, [512].

In the framework of Z. Cen's thesis dealing with the management of a Natural Liquefied Gas portfolio, we have shown how to combine the Stochastic Dynamic Dual Programing (SDDP) technique with optimal quantization of the price process in order to solve the continuous relaxation, and the related problem of sensitivity estimates. We also found heuristics based on the analysis of integrity cuts, that improve the bounds known for the integer problem, [514], [646].

Finally, the team has several works related to the optimization of energy systems with deterministic models, involving cooperative games [491], global methods for the design of steady-state gas network combining convex relaxations and branch-and-bound, [495], [506], the analytic resolution of the optimum trunkline problem [507], robustness problems for buildings [503], and applying sensitivity analysis techniques (Danskin's theorem) to the outages of nuclear power plants.

The team commands has regular collaborations with the following researchers and groups:

- F. Alvarez (U. Chile, Santiago) on interior-point algorithms in optimal control [509]

- T. Bayen (U. Montpellier II) on the control of elliptic equations [516], and the study of bioreactors for the production of methane.
- A. Dmitruk (Moscow State U.) and P. Lotito (Tandil, Argentina) on problems with singular arcs [510]
- N. Osmolovskii (Moscow State U.) on quadratic growth conditions [504], [647], [511],
- C. de la Vega (U. Buenos Aires) on hereditary systems [501], [517].

INRIA Team MAXPLUS: team under the supervision of Stéphane Gaubert.

The Maxplus project develops theory, algorithms, and applications of "maxplus" or "tropical" methods (the two terms are nowadays essentially synonyms) to optimal control, game theory, and combinatorics. Its works ranges from analysis to discrete mathematics, the tools of tropical and metric geometry, and positivity properties, being a bridge between these two worlds. In particular, the team's work has a strong interface with computer science (Program Verification, Operations Research), and it collaborates closely with computer science teams at CEA/MeASI and LIX. Its current members are:

- **Stéphane Gaubert**, INRIA DR1, team leader, also Professeur chargé de cours d'exercice imcomplet at École Polytechnique (part time teaching position).
- **Marianne Akian**, INRIA DR2, "responsable permanent" (co-head)
- **Cormac Walsh**, INRIA CR1
- **Xavier Allamigeon**, Ingénieur du corps des Mines under secondment.

Currently, the following PhD students are working in this team:

- **Pascal Benchimol** (S. Gaubert, Monge/DGA Fellowship, 2011–), co-supervision X. Allamigeon, Michael Joswig (TU Berlin);
- **Victor Magron** (B. Werner, LIX, INRIA Fellowship, 2010–), co-supervision S. Gaubert and X. Allamigeon, member of MAXPLUS since 2013;
- **Andrea Marchesini** (M. Akian, Standard Fellowship, 2012–), co-supervision S. Gaubert. Françoise Tisseur (Maths, U. Manchester) participates to the supervision.
- **Zheng Qu** (S. Gaubert, AMX Fellowship, 2010–). Shanjian Tang (Fudan, Shanghai) participates to the supervision.

The team has trained the following PhD students.

- Guillaume Sagnol (2010) S. Gaubert, M. Bouhtou (Orange Labs), funded by a contract with Orange Labs, now post-doc with ZIB, Berlin, in the team of Martin Groetshell;
- Assalé Adje (2011) S. Gaubert and É. Goubault (CEA), funded by Region Ile-de-France. After a post-doc at LSV, ENS Cachan, hired by Actility[9], a R& D company specialized in smart grids optimization;
- Meisam Sharify (2011), S. Gaubert, INRIA CORDIS fellowship. Laura Grigori from LRI, Orsay (now LJLL, Paris 6) participated to the supervision. Currently a post-doc in the Math. Dep. of U. Manchester, with Françoise Tisseur and Mark Kambites;
- Sylvie Detournay (2012), M. Akian, INRIA CORDIS fellowship. Hired as Junior Consultant IT by Soprabanking Software, Bruxelles[10];

[9] `http://www.actility.com/`
[10] `http://www.soprabanking.com/`

- Paul Poncet (2012), M. Akian. PhD as a Research Engineer employed by GDF-Suez, still with GDF-Suez.
- Olivier Fercoq (2012), S. Gaubert (and M. Akian, M. Bouhtou, Orange Labs). Funded by Orange Labs, now post-doc Edinburgh, Math. Dep., (Peter Richtarik).

The team has also cosupervised a PhD student (whose primary supervisor was in another team): Thomas Lepoutre (PhD 2009), PhD in the BANG team (LJLL Paris 6 and INRIA), supervised by Benoît Perthame (BANG) cosupervised by Jean Clairambault (BANG) and S. Gaubert (MAXPLUS). Th. Lepoutre has been hired as CR by INRIA.

The team has trained the following post-docs: Guillaume Vigeral (2009-2010) worked with S. Gaubert, being supported by the PASO Digiteo project. (Now Maitre Conf. "Chaire CNRS" at Ceremade, University Paris-Dauphine); Sergei Sergeev (2011-2012), with X. Allamigeon and S. Gaubert, supported by the ANR ASOPT project. (Now with a three years post-doc/lecturer position in the Math. Dep. of U. Birmingham); Sepideh Mirrahimi (2011-2012), joint post-doc with the MEV team. Now Chargée de Recherche CNRS at Institut Mathématique de Toulouse.

The MAXPLUS team also had a long-term invited researcher, Ricardo Katz, investigador ajunto (permanent researcher, similar to CR1) at CONICET, Argentina (Instituto Beppo Levi, Universidad Nacional de Rosario) stayed in the team during one year thanks to a fellowship from CONICET.

Nonlinear Perron-Frobenius and metric geometry methods in optimal control: from ergodic problems to the attenuation of the curse of dimensionality Methods of nonlinear Perron Frobenius theory have been developed to solve dynamic decision problems (optimal control or zero-sum games), specially the ones which arise in *long term* problems, for instance when the value function involves an *ergodic cost* (mean payoff per time unit). The solution of one or two player games involves Bellman or Shapley operators (or their infinitesimal analogues, Hamilton-Jacobi PDE), which are order preserving and nonexpansive in classical metrics (sup-norm, Thompson's metric or Hilbert's projective metric on cones), and therefore can be approached by operator or metric methods.

Results obtained by Akian, Gaubert and Walsh concern the *boundary theory* of optimal control problems, with the representation of stationnary strategies in terms of an horoboundary. The latter was defined by Gromov in the metric geometry context. It is shown in [433] that every potential function (additive eigenvector of an ergodic control problem) can be reprented as a supremum of certain fundamental solutions, which can be put in one to one correspondence with the Busemann points (limits of "almost geodesics"). This is related to current developments in weak KAM theory, and in particular to works of Fathi (the boundary being an abstract version of the Aubry set). Some extensions of these results to stochastic control problems appeared in [426] and in a work with Lemmens (Kent) in the discrete case [431]. Gaubert and Vigeral used horofunctions to study the existence of the mean payoff of general zero-sum games [462]. Walsh applied further the tropical methods to metric geometry, computing the horoboundary of Hilbert's geometry [487], investigating the isometries of the Hilbert geometry, with Lemmens in [465] and then in [644]; computing the boundary of the Thurston's Lipschitz metric [643] and using this knowledge to determine the isometry group of the space. Other metric spaces which were studied include finitely-generated nilpotent groups [490] and two-generator Artin groups [488].

The team also applied tropical methods to develop *algorithms* for control and game problems, devoted to very *large instances* (arising from the discretization of PDE, population dynamics, web problems, and program verification). A line of works concerns the *attenuation of the curse of dimensionality*, by representing the value function by a supremum of certain basis functions, like quadratic forms, which can be quickly propagated by various techniques. Akian, Gaubert and Lakhoua developed a tropical analogue of the finite element method, with a somehow similar theory of error estimates [622], but adapted to Hamilton-Jacobi equations. Further works have concerned the development of a different, "curse of dimensionality free" method [639], originally introduced by McEneaney. In her PhD work, Zheng Qu made further improvements [636], obtained the first error estimates that match the ones observed in practice [640], and developed new methods, allowing one to solve some structured instances in dimension $10-15$, probably unreachable by grid based methods. In her PhD, Sylvie Detournay has developed multigrid policy iteration method for zero-sum games, thus pushing in a different direction the limit of "solvable" problems [427]. Her algorithms are implemented in the C library `pigames`.

Tropical convexity, program verification, and games Tropical polyhedra refer to the tropical analogues of convex polyhedra. They were introduced by several groups, with motivations ranging from discrete event systems to combinatorics. I his PhD, X. Allamigeon (then at EADS and CEA) showed that they can be used to represent concisely the disjunctive invariants which appear in the verification of memory allocation primitives, leading to a series of works with E. Goubault and S. Gaubert, both on the verification aspects [625, 626] and on the algorithmic properties of these polyhedra. These include a tropical analogue of Motzkin's double description method, allowing to compute the vertices of a tropical polyhedron from a description by half-spaces [626, 435]. An ingredient of the algorithm is a characterization of the vertices in terms of directed hypergraphs, which can be verified in almost linear time [434]. Allamigeon implemented this in the ocaml libary TPLib. The McMullen upper bound theorem characterises the maximal number of vertices of a polyhedron, as a function of the number of inequalities defining it, and of the dimension. In a work of the team with Katz (Rosario) [436], it was shown that the same bound is still true in the tropical world, but that it is tight only in a special asymptotic regime. The facial structure (valid inequalities, analogues of Farkas lemma, etc) of tropical polyhedra was investigated in [456, 455, 437, 438]. The tropical analogues of advanced results of discrete convexity (colorful Carathéodory theorem, Tverberg theorem) were established in a work with Meunier (ENPC) [459], being motivated by a conjecture of Sierksma on the number of Tverberg partitions.

Akian, Gaubert and Guterman (Lomonossov) showed in [429] that tropical linear programming is polynomial-time equivalent to the problem of solving a deterministic mean payoff game. These results inspired a series of contributions, on the decision of linear implications [437], cyclic projections [432], fractional-linear programming [457], tropical spectral theory [461]. This equivalence relates tropical convexity with two unsolved problem, bringing a new perspective on them: (1) the complexity of mean payoff games, (2) the existence of a strongly polynomial time algorithm in classical linear programming. This has motivated the PhD thesis of P. Benchimol (started in 2011), who is developing the tropical analogues of linear programming algorithms.

In his PhD work, P. Poncet developed infinite dimensional tropical convexity, covering the tropical analogue of Choquet theory (tropical Krein-Milman and inverse Krein Milman results), making connections with the theory of continuous lattices and posets, and with inverse semigroups [473], and developing further the theory of idempotent measures (Radon-Nikodym theorem, regularity of maxitive measures), see [472] and [474].

In his PhD work (joint with CEA), A. Adjé showed that non-polyhedral invariants of programs can be efficiently determined by combining Shor relaxation techniques with policy iteration[425]. This was pursued in collaboration with H. Seidl (Munchen) [463]. These methods, together with the invariants based on tropical polyhedra, were developed within the ANR ASOPT, and more recently within the ANR CAFEIN. In his PhD work, Victor Magron (directed by B. Werner from LIX) is applying tropical approximation methods to a different field of computer science, namely, *formal proof*, developing a prover in COQ able to certify inequalities involving both semiaalgebraic and transcendant functions [627, 628], such as the ones arising in the proof of Kepler's conjecture by T. Hales.

A different class of applications of tropical geometry methods concern the accurate computation of eigenvalues, which has been the object of the PhD of Sharify [638] and now of the one of Marchesini.

From network measurement to web ranking through eigenvalue optimization The team has worked on several optimization problems raised by Orange Labs, in two successive research contracts. The first one dealt with the optimization of the measurement of IP backbone networks. It funded the PhD of G. Sagnol, who developed a new class of algorithms in experiment design, based on the identification of submodularity properties [641, 478] of spectral functions, further investigated in a collaboration with Shmuel Friedland (Chicago) [453], together with an unexpected reduction to second order cone programming [476, 477]. Sagnol's algorithms allowed one to handle very large instances (in the IP backbone of Orange, the dimension of the matrices is $n = 14000$, the number of origin-destination pairs). Fercoq studied the second problem in his PhD, also funded by Orange, motivated this time by web ranking. It involved large scale optimization of functions depending not only on the eigenvalue but also on the eigenvectors. Fercoq developed algorithms to optimize ranking measures, showing in particular that optimizing the pagerank is not much more difficult than computing it [452]. The algorithms of Fercoq also allowed him to handle a different application, to therapeutic optimization problems (collaboration with Clairambault and Lepoutre), in which one needs to minimize a Floquet eigenvalue (growth rate of tumor cells) [447, 441, 440]. The applications of tropical methods to population dynamics were further explored in the post-doc of S. Mirrahimi (joint with the MEV team of CMAP).

EPC INRIA GECO. (supervised by Mario Sigalotti and Ugo Boscain.) The main research topic of the project-team is geometric control, with a special focus on control design. The application areas that we target are control of quantum mechanical systems, neurogeometry and switched systems. The current members of the teams are **Ugo Boscain**, CNRS Research Director and **Mario Sigalotti**, INRIA Chargé de Recherches.

The teams has hosted and trained a few PhD and post-doc students, funded by the INRIA, the ERC "GeCoMethods" project of Ugo Boscain, and a few other funding (in particular, the Ecole Polytechnique's funding for foreign students).

- **Davide Barilari** [Post-doc ERC]
- **Francesca Chittaro** [Post-doc Digiteo]
- **Ghassen Didri** [Post-doc INRIA]
- **Roberta Ghezzi** [Post-doc Ecole Polytechnique]
- **Mauricio Godoy Molina** [Post-doc Ecole Polytechnique]
- **Camille Laurent** [Post-doc ERC]

- **Alexey Remizov** [Post-doc Digiteo]
- **Dario Prandi** [PhD ERC]
- **Moussa Gaye** [PhD Fondation Hadamard]

Geometric control theory provides a viewpoint and several tools, issued in particular from differential geometry, to tackle typical questions arising in the control framework: controllability, observability, stabilization, optimal control... The geometric control approach is particularly well suited for systems involving nonlinear and nonholonomic phenomena. The expression control design refers to all phases of the construction of a control law, in a mainly open-loop perspective: modeling, controllability analysis, output tracking, motion planning, simultaneous control algorithms, tracking algorithms, performance comparisons for control and tracking algorithms, simulation and implementation.

In the last years we obtained a series of results by applying techniques coming from geometric control to problems of heat diffusion in sub-Riemannian manifolds and to problems of quantum control. Sub-Riemannian geometry is an extension of Riemannian geometry. The birth of the subject goes back to Carathéodory's 1909 seminal paper on the foundations of Carnot thermodynamics, followed by E. Cartan's 1928 address at the International Congress of Mathematicians in Bologna. Sub-Riemannian manifolds model media with a constrained dynamics: motion at any point is only allowed along a limited set of directions (called horizontal ones), which are prescribed by the physical problem at hand. When the set of horizontal directions coincides with the whole tangent space, we obtain Riemannian manifolds. In the last twenty years, sub-Riemannian geometry has emerged as an independent research domain, with motivations and ramifications in several parts of pure and applied mathematics. From the theoretical point of view, sub-Riemannian geometry is the geometry underlying the theory of hypoelliptic and many problems of geometric measure theory. In applications it appears in the study of many mechanical problems (robotics, cars with trailers, etc.) and recently in modern fields of research such as mathematical models of human behaviour, quantum control or motion of self-propulsed micro-organism. Nowadays sub-Riemannian geometry is usually considered as a fast-developing branch of Optimal Control Theory. For what concerns heat diffusion, we were able to relate the small-time heat asymptotics to the properties of the sub-Riemannian distance. In particular, from the heat asymptotics we were able to recover the presence of the cut locus, namely the set of points where the distance loses his smoothness. In certain cases we were also able to detect the presence of a nontrivial generalized curvature. The study of heat diffusion in sub-Riemannian manifolds has some crucial applications in image reconstruction following a model due to Petitot, Citti and Sarti.

Another important class of results that we obtained concerns the problem of how to measure the volume in sub-Riemannian geometry. Different notions of volume gives rise to different diffusion processes, that we compared.

Regarding quantum control, we studied the problem of inducing a transition among the energy levels of a quantum system described by a discrete-spectrum Schroedinger equation (e.g. a rotating molecule) by means of some external fields. We gave some sufficient conditions for the approximate controllability of the Schroedinger equation and we have shown that these conditions are generically satisfied. We also studied the controllability properties of some natural models for rotating molecules. Quantum control is one of the stepping stones in quantum technology as in nuclear magnetic resonance and in chemical physics.

Semidefinite Programming, Algorithms and Applications. The team SIPA is the small group of **Alexandre d'Aspremont** (CNRS Research Director), formerly with Princeton University, and who was awarded an ERC Grant in 2010 to work with CMAP. He has worked with the following students and postdocs:

- **Fajwel Fogel**, Ph.D student ERC (2012-...).
- **Martin Jaggi**, postdoc ERC (2012). Still at CMAP, but financed by a two year Swiss National Science Foundation fellowship.
- Rodolphe Jenatton, postdoc ERC (2012). Now at Criteo.

Interior point algorithms and a dramatic growth in computing power have revolutionized optimization in the last two decades: highly nonlinear problems which were previously thought intractable are now routinely solved at reasonable scales. Semidefinite programs (i.e. linear programs on the cone of positive semidefinite matrices) are a perfect example of this trend: reasonably large, highly nonlinear but convex eigenvalue optimization problems are now solved efficiently by reliable numerical packages. This in turn means that a wide array of new applications for semidefinite programming have been discovered, mimicking the early development of linear programming.

Some of these new applications come with radically different algorithmic requirements: while interior point methods solve relatively small problems with a high precision, most recent applications (for example in statistical learning) form very large-scale problems, for which current algorithm cannot perform even a single iteration, with comparatively low precision targets. The work of the SIPA group seeks to break this limit by deriving reliable first-order algorithms for solving large-scale semidefinite programs with a significantly lower cost per iteration, using for example subsampling techniques to considerably reduce the cost of forming gradients. Beyond these algorithmic challenges, the group also focus heavily on applications of convex programming to statistical learning and signal processing theory where optimization and duality results quantify the statistical performance of coding or variable selection algorithms for example. Finally, another central goal is to produce efficient, customized algorithms for some key problems arising in machine learning and statistics.

Recent contributions in this vein, developed with both SIPA students or postdocs and outside collaborators, include the first formulation of an affine invariant first-order algorithm with optimal complexity and a stochastic smoothing technique for regularizing large-scale semidefinite programs, or efficient relaxations for permutation problems arising in gene sequence assembly and for phase reconstruction in diffraction imaging.

2.2 Rayonnement et attractivité académiques

2.2.1 General activities

The CMAP was the organizer of the 2009 SMAI national congress fo the French Applied and Industrial Math. Society. It took place in La Colle Sur Loup close to Nice. There were 247 participants. The 10 plenary conferences where held by A. Buffa (Pavia), M.-P. Cani (Computer science, INPG and INRIA, Grenoble), R. Carmona (Princeton, USA), N. Fournier (LAMA, Paris 12), J.-B. Lasserre (LAAS-CNRS, Toulouse), B. Perthame (LJLL, Paris 6), S. Piperno (Cermics, ENPC), S. Serfaty (CIMS, New York and LJLL, Paris 6), A. Tsybakov (CREST and Paris 6), M. Unser (EPFL, Suisse). There were also 15 minisymposia on topics such as operation research, image processing, compressed sensing, statistics and medicine, optimal transportation or financial mathematics. A morning session was dedicated to the mathematics in the industry and economy (with a talk of Stéphane Mallat on the creation of startup companies), and there were several poster sessions and 80 additional oral communications.

The organization was supported by CEA, CNRS, INRIA, Ecole Polytechnique, but also the spin-off IMACS and the Academic Chairs of the department: Chaire MMSN (EADS/CMAP), Chaire Risques Financiers, Chaire Finance et Développement Durable : Aspects quantitatifs, Chaire Dérivés du Futur.

2.2.2 Applied analysis

Awards. Two members of the Nonlinear PDEs team have won prestigious prices during the last five years : V. Giovangigli has been awarded the price *"Jacques Louis Lions"* 2011, while F. Alouges has obtained the *"prix de la Recherche, mention Renault-Mobilité durable"* in 2010.

Low Reynolds number swimmers. In a collaboration between F. Alouges (CMAP, Palaiseau) and A. DeSimone (SISSA, Trieste) which started in 2008, a universal control structure has been discovered. Starting with the 3 sphere swimmer of Najafi and Golestanian, the authors have afterwards generalized their approach in order to treat more complicated system in a more generic way. This has been done involving several collaborators from both institutions. This research was rewarded by the prize La Recherche in 2010, and both researchers have been invited to give more than 10 conferences each on this topic, in front of very various audiences. Both in France and Italy, the subject has emerged and is now widening in the mathematical community. New collaborations with physicists (among which a team in Spintec, CEA Grenoble, with which the authors aim at building magnetic microswimmers) have recently started making this research theme even more pluridisciplinar and active.

G. Allaire received the *Dargelos prize* in 2013, from the alumni association of École Polytechnique and in 2011 the *"Grand Prix of the EADS corporate foundation (sciences and engineering)"* awarded by the Académie des Sciences de Paris.

Invitations, participation in networks, conference organization, ... All the members of the teams involved in this theme are participating in various ANR projects and GDR.

In the PDE team, F. Alouges is the Principal Investigator of the ANR project "Micromanip" (2008–2013), and is responsible for the project "Mathematics and engineering" of the Labex "LMH" launched in 2012. K. Hamdache is one of the coordinators of the French-Maghrebin network "LEM2I (LIA CNRS). F. Coquel is a member of the newly created Indo-French Center for Applied Mathematics (IFCAM), located at Bangalore, India, at which he will give a series of lectures in August 2013. Between 2008 and 2013, nineteen foreign researchers have been invited by members of the team, for periods varying from one week to three months.

The MMOF team organized, together with the DEFI team, the PICOF 2012 conference in Palaiseau, April 2012, an important international conference in inverse problems and shape optimization.

G. Allaire participated to GNR MOMAS, ANR MICA (Mouvements d'Interfaces, Calcul et Applications) and ANR FF2a3 (3d version of FreeFem++). He was a co-organizer (since 1991) of the annual CEA/GAMNI workshop on computational fluid mechanics, of several MOMAS workshops (including Luminy, November 2009 and November 2011), of the "mathématiques et mécanique" symposium during the CFM 2011 conference in Besançon. He was also in the scientific committees of several conferences (8th World Congress on Structural and Multidisciplinary Optimization in Lisboa 2009, CSMA in Giens, IUTAM workshop in Copenhagen, GDR workshops, etc.).

J.-R. Li is the coordinator of an ANR project "Simulation of diffusion MRI signals in biological tissue" (Monte-Carlo simulation), 2010-13, with partners INRIA and Neurospin.

A. Chambolle co-organized a winter school in January 2008 on Fracture and Damage at IHP (for the ANR MICA project), and an international conference "ERC Workshop on Geometric Partial Differential Equations" in Sept. 2012 at the Centro De Giorgi, with E. Valdinoci (Milano) and M. Novaga (Pisa). He is a participant to the ANR projects "Geometrya", "HJNet", and was the coordinator of the "MICA" project until 2008 (a huge project involving teams in Brest, Marne-la-Vallée, Tours). He is now a PI (with T. Pock, TU Graz) of a franco-austrian ANR project in optimization methods for imaging "EANOI" (Blanc/International).

Editorial tasks. Besides their various expert activities, and participation in various scientific committees, the member of the Analysis teams have numerous editorial activities :

- G. Allaire is a member of the following editorial boards: *ESAIM/COCV* since 2000, *Structural and Multidisciplinary Optimization* since 2002, *Discrete and Continuous Dynamical Systems Series B* since 2003, *Computational and Applied Mathematics* since 2006, *Mathematical Models and Methods in Applied Sciences (M3AS)* since 2006, *Annali dell'Universita di Ferrara* since 2008. He also hed previous responsabilities in: *Annales de la de la Faculté des Sciences de Toulouse* (2003-2008), *SIAM Multiscale Modeling and Simulation* (2002-2010), He is a co-editor in chief of the "Mathématiques et Applications" series published by SMAI and Springer;
- F. Alouges is associate editor of *Applicable Analysis*;
- A. de Bouard is associate editor of the *Nagoya Mathematical Journal* and of the new journal *Stochastic Partial Differential Equations, Analysis and Computation*;
- A. Chambolle is a current member of the editorial boards of the journals *Journal of Mathematical Imaging and Vision* (Springer), *SIAM J. Imaging Science* (SIAM), *ESAIM: Mathematical Modelling and Numerical Analysis* (M2AN, Cambridge), *Interfaces and Free Boundaries* (EMS Publishing), *Applied Mathematics and Optimization* (Springer), *Inverse Problems and Imaging* (IPI), and the "IPOL" project (Image Processing On Line, developed at ENS-Cachan, CMLA).
- J.-R. Li is an associate editor of *SIAM J. Scientific Computing*, since 2010;
- R. Novikov is associate editor of five international journals: *EJMCA*, *Inverse Problems*, *Inverse problems in Science and Engineering*, *Journal of Mathematics*, *Journal of Inverse Problems*;

Other. G. Allaire is the President of SMAI (Société de Mathématiques Appliquées et Industrielles) since 2012, member of its board since 2005. He has been a Member of the IHP board (Institut Henri Poincaré) since 2010. He also chairs the Gaspard Monge Program for Optimization and Operation Research (PGMO) in the framework of the Fondation Mathématique Jacques Hadamard (FMJH). He also is the past president of the applied mathematics department of École Polytechnique (from 2006 to 2010) and past vice-president (from 2010 to 2012).

G. Allaire was the chairman of the research and teaching chair "Mathematical modelling and numerical simulation" at the Applied Mathematics Department of École Polytechnique between 2008 and 2012. This chair was founded by the EADS corporate foundation, INRIA and École Polytechnique and its funding permitted the hiring of two professors (one junior and one senior), two one-year post-doc positions, one PhD and several Master students.

He is a Member of the scientific council of GDR Calcul since 2008 and the President of the scientific council of GNR MOMAS (MOdélisations MAthématiques et Simulations numériques, studying the repository of nuclear waste.)

He has participated in the evaluation committees for the following departments: Laboratoire de Mathématiques de l'École Centrale de Paris (2008), département Synetics of EDF R&D (2009), INRIA Grenoble Rhône-Alpes (2010), Laboratoire de Mathématiques de Besançon (2011).

A. Chambolle is currently the head of the CMAP. He has been a member of the AERES committee for the evaluation of the Math. departments of Brest (UBO) and Vannes (UBS) in 2010.

2.2.3 Random modeling and applications

Awards. V. Bansaye has been nominated as the first holder of the *"Chaire Jean Marjoulet"* of the École Polytechnique, awarding him a special funding for inviting post-docs and collaborators.

H. Morlon was granted by the ANR a *Chaire d'Excellence* "Ecological and Evolutionary Determinants of Diversification" (ECOEVOBIO) in 2011.

N. Touzi has received the *Louis Bachelier Award* (French Academy of Sciences "grand prize") in 2012, and won an ERC Advanced Grant the same year. He also won *The University of Toronto Dean's Distinguished Visitor Chair*, Fields Institute, April-June 2010. He was awarded in 2012 an ERC advanced grant.

S. Mallat has won the *Schlumberger Chair*, IHES, 2011. He has been nominated a *EUSIPCO Fellow* en traitement du signal, 2010 and was in 2009 the titular of the *Aisenstadt Chair*, CRM, Canada. He won an ERC Advanced Grant just before moving to École Normale Supérieure in Paris in 2012, and right after the *Médaille de l'Innovation*, CNRS, 2013.

S. Allassonnière won the *Prix Excellencia 2010 for women in science* (which was awarded by the EPITA).

Invitations, participation in networks, conference organization, ... S. Méléard has set up and served as a director of an academic "Chaire" funded by the Veolia group in 2009–2015, the Chaire MMB de Modélisation mathématique et biodiversité (Mathematical Modeling of Biodiversity), between École Polytechnique, Muséum national d'Histoire naturelle and Veolia-Environnement. She has given at least seven plenary lectures in international conferences in the past 5 years, and in particular at the 8th European Conference on Mathematical and Theoretical Biology (**ECMTB**, Kraków, June 28 - July 2, 2011).

She has been the coordinator of the ANR MANEGE (Modélisation aléatoire en écologie, génétique et évolution - Random modeling in Ecology, Genetics, Evolution), a member of the ECOS project French-Chilean 2005-2008, then 2009-2012, a member of the GIS SARIMA (Soutien à la recherche en Mathématique et Informatique en Afrique). She also has been a local coordinator (for the southern Paris area) of the ANR program "MAEV", 2007–2009 (E. Pardoux).

Mathematical Modeling of the Theory of Evolution. When Darwin and its Theory of Evolution are mentioned, one does not think to Mathematics. Nevertheless if one is interested in modeling natural selection and in randomness of the reproduction or in the role of mutations, then mathematics is the right tool. S. Méléard developed in the past 6 years an original team on Mathematical Modeling for Biological Evolution Processes, in relation with some biologists of the MNHN and Régis Ferrière at ENS Paris (prof. of Eco-Evolution). From individual-based models describing the dynamics of each living individual and playing with different ecological or time scales, one can derive eco-evolution models and predict some long time maintenance, generation or destruction of biodiversity. These activities have a large international audience (invitation of S. Méléard as plenary speaker to ECMTB'11) but also in popularization conferences (BNF, Maths en Jeans).

N. Touzi has given an invited talk at the **ICM 2010** in India (Aug. 22, 2010). He also gave a plenary talk at the First Asian Quantitative Finance Conference (AQFC) (National University of Singapore (NUS), 9-11 January 2013).

A. Véber has co-organized the *Second Paris-Bath Meeting on Branching Processes*, IHP, Paris. She is a member of the *Committee on New Researchers* of the IMS (Institute of Mathematical Statistics). She has been an invited lecturer at the Workshop for women in probability, Duke, 2012, Probabilistic structures in evolution, Berlin, 2012, and SMPGD 2012, Lyon (where also H. Morlon was organizing an invited session).

H. Morlon participates to internationally renown working groups (e.g. NESCENT, CESAB) and the following scientific networks: CEBA, PI J. Chave and A. Franc (2013–), Marie-Curie IOF (Morlon scientist in charge of grant to P.-H. Fabre, co-PI J. Losos, 2013–2015), ANR JCJC (PI H. Sauquet, 2013–2016), France-Berkeley Fund (PI Morlon, co-PI C. Marshall, 2012–), Chaire Française in São Paulo state (Brasil) - PI Morlon (co-PI T. Quental, 2012–).

S. Mallat has lead the ANR Project “IRMgroup” (Invariant extraction from populations of images for classification tasks), with local participants C. Giraud, S. Allassonnière. The latter is also a participant to the ANR projects “HM-TC” (hippocampus study through imaging and cognitive technics for Alzheimer's disease understanding). She also is the PI of the local “MMoVNI” Digiteo project (multi-modal atlas estimation).

C. Giraud has been involved in the ANR Projects “HeterosYeast”, “IRMgroup”, “Parcimonie” (leader E. Le Pennec, soon with CMAP), “CBME”. He also participated to INRA funded projects “SONATA” and “SSB”, and to the CNRS Mastodon Project “Cistats” lead by the MNHN.

A. Chambolle has given a plenary talk at the conference “Scale-Space and Variational Methods in Computer Vision 2009” in Norway, June 2009 and is invited for a plenary talk at the next SIAM Conference on Imaging Science (Hong Kong, 2014). He has co-organized an international meeting “VIA2011” (variational image analysis), Heidelberg, July 2011 with M. Hintermüller, Berlin, T. Pock, Graz, C. Schnörr, Heidelberg, G. Steidl, Kaiserslautern), and co-organized the IPAM Workshop *Convex Relaxation Methods for Geometric Problems in Scientific Computing*, UCLA, Los Angeles, Feb. 11 - 15, 2013. He will be co-organizing in November, 2013 with the support of the PGMO an international conference in optimization for imaging at École Polytechnique.

Editorial tasks.

- S. Méléard is associate editor for *Mathematics in Action* (2008–), *Stochastic Processes and their Applications* (2012–), *Bernoulli* (2013–). She also is an editor for the SMAI-Springer series "Mathématiques et Applications" (2012–);

- H. Morlon serves as an associate editor for *Ecology Letters* and *Systematic Biology*;
- C. Graham is associate editor for *Annals of Applied Probability* and for *Markov Processes and Related Fields.*
- N. Touzi is a co-editor of *Finance and Stochastics* (Springer);
- E. Bacry was the co-editor of a special issue of IEEE Signal Processing Magazine on "Signal Processing for Financial Applications" (2011);
- A. Chambolle's editorial tasks were described in the section on the previous theme, including three journals in imaging and the IPOL project. He has also served in the scientific or program committees of several international imaging conferences (SSVM 2013, EMMCVPR 2011, 2013...) and as a reviewer for selective conferences such as CVPR 2013, SIGGRAPH 2011.

Other. S. Méléard is the chair of the Applied Mathematics Department (DepMapp) of the École Polytechnique (since 2010). She is also a member of the Organization Committee de la Fondation de Mathématiques Jacques Hadamard - Labex Hadamard (2010–), and has been a 2010 – 2011: Member of the Scientific Committee of INSMI, Mathematics Institute of CNRS.

2.2.4 Automatic control and mathematics for technology and information science

Awards. The GECO team won a *"Top cited article 2007–2011"* award, Annales de l'Insitut Henri Poincare, Analyse Non Lineaire/Nonlinear Anaysis, for the article "Controllability of the discrete-spectrum Schrödinger equation driven by an external field" by U. Boscain, T. Chambrion, P. Mason and M. Sigalotti.

U. Boscain (GECO team) currently holds an ERC Starting Grant "GeCoMethods", awarded in 2009.

A. d'Aspremont was also awarded an ERC Starting Grant "SIPA" in 2010, which started in 2011. The grant funded (until Sept. 2013, when he was hired on a permanent position by the CNRS, Section 07, to work at the École Normale Supérieure) his Director of Research CNRS position. He was previously an Associate Professor at Princeton University.

X. Allamigeon (MAXPLUS team) received the Gilles Kahn prize for his thesis (see details below). O. Fercoq (MAXPLUS team) received the PGMO (Programme Gaspard Monge of Optimization) 2013 prize for his thesis. This prize is given under the aegis of the MODE (Optimization) group of SMAI and of ROADEF (French Operations Research Society).

Tropical geometry and games applied to program verification. A basic issue in the verification of critical (embarked) softwares is to determine automatically program invariants. In a long term collaboration, the Maxplus team and the MeASI team of CEA/LIST led by É. Goubault (also with LIX), have developed new methods to compute accurate invariants. These are based on the discovery of an isomorphism between the fixed points problems arising in static analysis and the ones arising in zero-sum games, combined with the introduction of geometric methods leading to new approximation domains. In particular, in his PhD with EADS Innovation works, X. Allamigeon applied tropical convexity to the verification of memory allocation primitives. He received the Gilles Kahn prize (given by Société Informatique de France to one French PhD in computer science). The application of tropical geometry to problems at the interface of applied mathematics and computer science interests a growing audience (plenary talks of S. Gaubert at SIAM CT'09, FORMATS'09, SMAI'13).

Invitations, participation in networks, conference organization, ... The team COMMANDS is part of the SADCO European "ITN" network "Sensitivity Analysis for Deterministic Controller Design Instrument", 2011-2014 (Others partners: Louvain, Bayreuth, Porto, Roma - La Sapienza, Padova, P.& M. Curie, ICL, Astrium-Eads, Astos solutions, Volkswagen). However, the SADCO funds are managed by the ENSTA part of the team COMMANDS. It also holds a Digiteo (Ile-de-France) project on the Mathematical Analysis of Acute Myeloid Leukemia. F. Bonnans and L. Pfeiffer obtained in Sept. 2012 a PGMO grant in order to investigate stochastic control problems with probability constraints.

F. Bonnans coorganized the CIMPA course on dynamic optimization, Tandil (Argentina), 30/8/10-10/9/10, and the Conference of the FIME laboratory, HEC, Jouy-en-Josas, June 28-29, 2010. He was a plenary speaker at the IFAC Int. Workshop on Adaptation and Learning in Control and Signal Processing, Caen, July 3-5 2013.

S. Gaubert gave Plenary Talks at SIAM CT'09, Denver, 2009 and FORMATS 2009, Budapest; MSR'09, Nantes, and SMAI 2013, Seignosse. He co-organized, with M. De Lara, the CEA-EDF-INRIA summer school in Stochastic Optimization[11], 25 Juin - 6 Juillet, 2012, Cadarache.

The team Maxplus has been part of the ANR ASOPT (Analyse Statique et Optimization), involving teams working in program verification (INRIA Rhône Alpes, CEA MeASI, EADS Innovation Works, VERIMAG). It has also been part of the Digiteo PASO (Formal Proof, Static Analysis, and Optimization) project involving teams working in Automatic Control (Supelec/LSS) formal proof in COQ (Typical/LIX) and program verification (CEA MeASI).

The GECO group is involved of course in the ERC GeCoMethods starting grand of Ugo Boscain, but also in two ANR programs: ANR GCM ("Geometric Control Methods, Sub-Riemannian Geometry and Applications", programme Blanc), ANR ArHyCo (program ARPEGE). It also holds a local Digiteo grant CONGEO.

The ERC grant SIPA was awarded in 2010 and started in 2011. It financed two postdoctoral students and one doctoral student so far. Several publications in leading international journals such as SIAM journal on optimization, Mathematics of Operations Research, Mathematical Programming, etc. Several invited presentations to international conferences and workshops. The ERC grant SIPA partially funded the organization of an international workshop in January 2013 at les Houches, focused on "Optimization and Statistical Learning". A new edition is already planned for January 2015. The PI participated in the 2012 Japanese-French Frontiers of Science Symposium in Nice and gave a lecture on "optimization and machine learning" a lecture at Collège de France. The PI is also part of the scientific board of the Programme Gaspard Monge pour l'Optimisation (PGMO). M. Jaggi received a fellowship from the Simons foundation will spend three months at the Simons Institute for Theory of Computing at UC Berkeley, for the "Theoretical Foundations of Big Data Analysis" program. R. Jenatton was recruited by Criteo.

Editorial tasks.

- F. Bonnans is Corresponding Editor at *ESAIM:COCV*, since June 2004, and Associate Editor of *Series on Mathematics and its Applications* of the Annals of The Academy of Romanian Scientists (AOSR), since Jan. 2012, *Optimization Methods and Software*, since 2007, *Applied Mathematics and Optimization*, since 2003;
- S. Gaubert is a member since 2010 of the Editorial committee of *RAIRO - Operations research* and was until 2009 in *Discrete Event Dynamic Systems*. He also is a member of

[11] `http://www-hpc.cea.fr/SummerSchools2012-SO.htm`

the editorial committee of the collection "Mathématiques et Applications", SMAI-Springer. He also served in the programme committee of the conferences WODES'2010 (10th int. workshop on Discrete Event Systems, Berlin), NSV-3 (Third International Workshop on Numerical Software Verification, Edinburgh, 2010), POSTA'09 (Positive Systems: Theory and Applications), Valencia, Spain, and MSR 2011, 2013 (Modélisation de systèmes réactifs);

- U. Boscain is a Managing Editor of *Journal of Dynamical and Control Systems* and an Associate Editor of the journals: *SIAM Journal of Control and Optimization*, *ESAIM Control, Optimisation and Calculus of Variations*, *Mathematical Control and Related Fields*, *Analysis and Geometry in Metric Spaces*;
- M. Sigalotti is an Associate Editor of the *Journal on Dynamical and Control Systems.*

Other. F. Bonnans chairs the SMAI-MODE group (optimization and economic decision group of the French Applied Math. Society, and has been in the SMAI council (2008-2011). He has been member of the council of the Mathematical Programming Society (2006-2009, Tucker Prize Committee (2009), Optimal control technical committee of IFAC since 2003, Broyden prize committee since 2008. He also is member of the bureau of PGMO (Programme Gaspard Monge pour l'Optimisation, a branch of the FMJH Foundation, Saclay).

S. Gaubert is Deputy-head of the project committee of the INRIA Saclay – Ile-de-France center, and member of the evaluation committee of INRIA. He was a member of CSD5 "Mathematics and interactions" of the ANR until 2009, and is now a member of CNU (26th section, Applied Mathematics and applications of Mathematics, from 2012). He participated to the AERES evaluation of the M2N Lab (Mathematiques, CNAM). He also is a member of the steering committee of the PGMO.

U. Boscain is a member of the Scientific Council of INSMI (CNRS). He is the coordinator of the group studying the interactions between Mathematics and Automatics.

M. Sigalotti is a member of the IFAC Technical Committee "Distributed Parameter Systems" and local coordinator for the two ANR programs in which the team GeCo is involved.

2.3 Interactions avec l'environnement social, économique et culturel

2.3.1 Applied analysis

Industrial Partnership F. Coquel has developed strong relationships with CEA, EDF or the IFPen through various contracts. F. Alouges currently supervises a CIFRE PhD student from the company "Digital Media Solutions", who works on HRTF (Head Related Transfer Functions) which are the footprints of the 3D sound image felt by the listener. He also has regular collaborations with the ONERA (Department of electromagnetism and Radar). Concerning fluid dynamics, and in particular micro-swimmers, a recent collaboration of F. Alouges with researchers at CEA Spintec (Grenoble) aims at building such swimmers by lithography and they imagine to deform them with the help of magnetic particles. This is an ongoing project in which concrete realizations are considered.

F. Alouges is regularly consulted by Safran, CEA and ENI; F. Coquel has one day/month consulting activities for the ONERA (Chatillon), at the "Direction de la Simulation Numérique en Aérodynamique"; V. Giovangigli has one day/week consulting activities at the ONERA (Palaiseau), on the numerical simulation of complex chemical flames.

The MMOF team has or had contracts with the following companies or institutes: CEA, Dassault Aviation, EADS, IFPEN, Renault.

G. Allaire and O. Pantz participate to the RODIN project which is a consortium of various companies and universities which has been sponsored by the FUI AAP 13 for 3 years, starting on July 2012. The industrial partners are: Renault, EADS, ESI, Eurodecision, Alneos, DPS. The academic partners are: CMAP at École Polytechnique, Laboratoire J.-L. Lions at Paris 6 and 7 Universities, centre de recherches Bordeaux Sud-Ouest at INRIA. The goal of the RODIN project is to perform research and develop a computer code on geometry and topology optimization of solid structures, based on the level set method. RODIN is the acronym of "Robust structural Optimization for Design in INdustry".

G. Allaire and F. Jouve have registred their software OPTOPO (shape and topology optimization by the level set method) on October 14, 2011, file number 011678, at the office of Maitre Guillaume DEWALD, Notaire at Orsay.

A. Chambolle is the local scientific coordinator of the "TANDEM2" project, which is a consortium of various labs, coordinated by Bull-Amesys, on the detection and identification of buried landmines using SAR type methods. The project will involve in Polytechnique H. Haddar (CMAP), who will hire a PhD student, and researchers from the LIX (Computer science lab). A. Chambolle now collaborates with M. Ovsjanikov (LIX) in supervising a thesis on 3D shape recognition and classification.

Dissemination G. Allaire and F. Jouve published a series of three articles (in French) "Design et formes optimales (I, II, et III)" on the web site Images des Mathématiques[12] in december 2009.

G. Allaire has written an historical paper about Poincaré "A la recherche de l'inégalité perdue" in MATAPLI, the bulletin of SMAI, 98, June 2012.

2.3.2 Random modeling and applications

Industrial Partnership The collaboration of the MEV group with Veolia, through the Academic *Chair MMB - Mathematical modeling of Biodiversity*, has already be mentioned. The Chair "Mathematical Modeling of Biodiversity" is a research sponsorship between École Polytechnique - Muséum national d'Histoire naturelle - Veolia-Environment. It is supporting (by PhD and Post-Doc funds) the research at the interface between Ecology, Evolution and Mathematical modeling.

The group of Finance has numerous contacts with industries and banks. It is a partner of several Chairs which fund a great part of its activity: the Chair "Dérivés du Futur" with Fédération Bancaire Française [FBF] was renewed in Jan. 2013 under the name "Marchés en Mutation", it is co-held by N. Touzi, M. Jeanblanc (Evry) N. El Karoui (Emeritus, UPMC); the Chair "Finance et développement durable : approche quantitative" with EDF and Crédit Agricole, held by P.-L. Lions (U. Paris-Dauphine and Collège de France, and professor at DepMapp); the Chair "Risques Financiers" with Société Générale, held by N. El Karoui. The AXA company also funded two PhDs (one advised by E. Gobet, and one by N. El Karoui and J. Bion-Nadal). E. Gobet and N. Touzi are members of the group "FIME" ("Laboratoire de Finance des Marchés de l'Énergie"), a joint research initiative of EDF R&D, U. Paris-Dauphine, CREST ENSEA and École Polytechnique.

[12] `http://images.math.cnrs.fr/-Articles-mathematiques-.html`

In statistics C. Giraud has been involved in the two projects *Hepatinov*, leader : J.-C. Duclos-Vallée, at Hospital Paul Brousse for Developing innovating therapeutical strategies for hepatic diseases, and *SUNRISE.* (Grand Emprunt project), leader : P. Vincourt (INRA), on the Identification of genetic and molecular factors involved in the hydric stress resistance of sunflowers.

A. Chambolle is involved in the TANDEM2 project with Bull-Amesys and local companies, which is in between analysis, electromagnetism (radar), imaging and classification. This is described in the previous section 2.3.1.

Patents

- S. Mallat and G. Yu, "Bandlet video denoising and deblocking", February 2008, PCT: WO2009/098546.
- Guoshen Yu and Jean-Michel Morel (ENS Cachan): "Procédé et dispositif de reconnaissance de formes" (ASIFT) FR 0853244, 19/5/2008, École Polytechnique and ENS Cachan. Extended on May 19, 2009 zone Europe (EP09761912) + USA, Japan, China, South Korea (a licencing agreement is currently under negociation).
- S. Mallat, "Multiscale modulus filter bank and applications to pattern detection, clustering, classification and registration", 2010, EP10305565.

Dissemination The leader of the MEV group, S. Méléard, has given in the past year many public conferences for more or less general audiences:

- Muséum national d'Histoire naturelle, Inauguration de la chaire MMB, *Modélisation mathématique de la biodiversité*, 2009;
- Exposition "Biodiversités", CNRS et Ville de Paris, Trocadéro, *Modélisation mathématique de la biodiversité*, 2010;
- Inauguration de la Fondation de Mathématiques Jacques Hadamard, École Polytechnique, *Modélisation mathématique de la biodiversité*, 2011;
- Conference cycle "Savoir et Société", Nancy, *Modélisation mathématique de la biodiversité*, 2011;
- Conférence LIESSE. *ALEATOIRE - Les enjeux du cours de Probabilités en première année de l'École Polytechnique, Paris (France)*, 2012;
- BNF, cycle SMF, un texte, un mathématicien. "Darwin, le hasard et l'évolution", 2013;
- Maths en Jean: "Mathématiques du hasard et de l'évolution", 2013;
- Mini-cours pour les enseignants de classes préparatoires: Processus de branchement - Applications en Ecologie, 2013;

In the same group, also A. Véber has given two lectures for a less specialized public, a presentation to high-school students, Lycée Voltaire, Paris in 2012 and a presentation to L1-L2-preparatory class students, *Mathematic Park*, IHP, 2013. Also V. Bansaye is very active in popularization, giving scientific talks at IHP (*Mathematic park*) or organizing scientific working groups for teachers (*Graines de sciences*). His activities go way further his research themes and are described below in § 2.3.4.

2.3.3 Automatic control and mathematics for technology and information science

Industrial Partnership The COMMANDS team has numerous contacts with industrial partners, and in particular in the past recent years with EDF and Renault.

- The PhD Thesis of N. Grébille on "Numerical methods for solving stochastic equilibrium problems with applications to energy markets" is funded by EDF (CIFRE) [645].
- A contract INRIA/Renault (2010-2012) funded the thesis of G. Granato on "Energy management for an electric vehicle with range extender". The outcome of the PhD work was to assess the general interest in applying such techniques to the power management of hybrid vehicles.
- The PhD thesis of Z. Cen (F. Bonnans, 2008-2011) was supported by Total-Gas. Subject: "Management of a LNG (liquefied natural gas) portfolio asset". The outcome is a methodology and software for the management of long term contracts. Total Gas is currently implementing some of the tools resulting from the PhD in its operational software, that will be used by the Front Office in London. Part of the software will also be adapted in order to be used for the pipeline trading activities; there should be about 20 users dealing with important financial stakes, [514, 646].
- The COMMANDS team conducted a series of several R&T (Research and Technology) contracts with the CNES[13] from 2009 to 2012, and ongoing. The central theme of these works was optimizing the atmospheric ascent phase for space launchers.
- The Maxplus team collaborates with Orange Labs (M. Bouhtou), and got two research contracts (Contrat de recherche externalisé) funding the PhD theses of G. Sagnol and O. Fercoq, on the optimization of internet measurements and on the optimization of webranking, respectively. O. Fercoq developed algorithms allowing one to optimize the ranking of large scale web sites [452, 451]. Sagnol developed a new class of experiment design algorithms, allowing one to optimize the measurement of network trafic. Some of his contributions [642, 477, 478] resulted in a practical progress allowing one to handle problems which would be unacessible by standard methods (semidefinite programming problem with a full matrix of size 14000×14000 for the Orange IP backbone network). As part of his post-doc at ZIB (Berlin), Sagnol has applied the techniques developed in his thesis for the TOLLOPTCONTROL project (controlling the payment of taxes by trucks on German highway).

The team Maxplus has been also collaborating for several years with J. Clairambault (INRIA, BANG team), who is working (with physicians at INSERM) on cancer chronotherapeutics (how to optimize drug injection taking into account the influence of the circadian rythm on cell proliferation). This has led to the contributions [448, 447, 441, 440]. Another collaboration with physicians was aimed at optimize the resources in the emergency department at the Hôtel Dieu Hospital (department of Prof. Pourriat, project led by Dr. Vigneau), together with the RAP team of INRIA Paris-Rocquencourt (Ph. Robert). The student P. Benchimol did is 3rd year internship on this project, he was awarded the *"Prix du centre de recherche"* of École Polytechnique for this work.

The GECO Team participated to the INRIA program iMatch8 on Optimization and Control on Oct. 23rd, 2013. This program brings together companies and academics to discuss research and development issues.

[13] French Space Agency

Patents The COMMANDS team developed a patent with Renault cars in the framework of the PhD thesis of G. Granato on "Estimation of a car energy consumption", 12/2011.

Dissemination *A Software: Bocop, the optimal control solver*[14]. Participants: P. Martinon, V. Grélard, D. Giorgi, S. Maindrault, F. Bonnans (INRIA/COMMANDS). The Bocop project aims to develop an open-source toolbox for solving optimal control problems, with collaborations with industrial and academic partners. Several research collaborations were initiated in fields such as bio-reactors for energy production, swimming micro-robots, and quantum control for medical imaging.
TPLIB: The Tropical Polyhedra Library[15] is a ocaml library allowing one to manipulate tropical polyhedra. It computes the vertices of tropical polyhedra given by half-spaces, and vice versa. It also provides an abstract domain based on tropical polyhedra, inferring min-/max-invariants over programs.

2.3.4 Other Popularization activities

A few members of the CMAP, and in particular, V. Bansaye and J.-F. Colonna (Research Engineer F. Telecom, now retired) are very interested in popularizing mathematics and its applications towards young students or the society. The laboratory is therefore involved at various levels in the scientific popularization and more specifically in the diffusion of mathematics to college or high school students. Some of this activity has been described above (in particular in the activities of the team MEV). École Polytechnique has welcomed the congress Maths en jeans in 2013 during one afternoon and CMAP was both involved in the organization, the scientific program and the funding. The students of the lab are encouraged towards these activities and many of them participate. Also the preparation of the conference of S. Méléard ("un texte, un mathématicien") in the Bibliothèque Nationale de France was prepared thanks to several interventions of our PhD students.

V. Bansaye regularly goes in high school to talk about the jobs in research. In particular, he annually meets the students of Lycée Vilgénis in Massy and partcipate to the events organized by the "Cordées de la réussite" in Mines Paris Tech. He organizes a 11-days summer camp in Savoie each summer, gathering 34 of motivated students of "Première S" (16-17 years old). The students are mainly selected among non favorized families thanks to the Association "Paestel"[16] Research sessions around difficult problems are organized, for small groups of students supervised by a teacher or researcher, so as daily talks. It aims at introducing them to higher mathematics, make them confident and give them the desire to continue to study mathematics.

J.-F. Colonna has been interested for a long time in the vizualization of Mathematical and Physical objects. He regularly presents the lab and its activities to young students and their family. He gives talks in schools, cultural houses, and even at the Fleury-Mérogis jailhouse, thanks to the AniMath and Math en Jeans associations. His web site[17] has about 400 visitors each day and presents 5000 images and animations with a lot of comments and references (also accessible through the CNRS and MédiHAL web sites). He also participates to art exhibitions (present 3 times at the Paris Salon d'Automne, 2 exhibitions at polytechnique are also planned

[14] `http://bocop.org`
[15] `https://gforge.inria.fr/projects/tplib`
[16] `http://paestel.fr/matlesvacances`
[17] `http://www.lactamme.polytechnique.fr`

this year).

He gives seminars on fractals every year at École des Mines ParisTech (in the "Cordées de la Réussite"), and also animates École Polytechnique's "Nuit des Chercheurs" since it was created.

3 Implication de l'unité dans la formation par la recherche

The CMAP is

- the only research lab of the applied math department of École Polytechnique (DepMapp), and thus strongly involved in the curriculum of the students,
- a lab where 10 to 20 PhD theses are defended each year,
- involved in six M2 curricula of the Paris area, in applied optimization, probability, analysis.

At the École Polytechnique, our aim is to attract more students to research. So, from the 1st to the 3rd year, a lot of the training we propose is through research activities ("formation par la recherche"): there are research projects associated with almost all courses, collective scientific projects ("PSC", where a small team of students tries to solve a complex scientific or industrial problem) during the 2nd year, two short research programs during the 3rd year (called "Enseignements d'Approfondissement (EA)"). In the 3rd year there is also a 4-months research internship, either in an academic institution or, more often, in the R&D of a company. This internship is essential for the students and plays a main role to open them to research. The quality of the work which is sometimes produced is amazing, and every year "best internship" awards are given to quite a few of our students. In the past years, the interest of Ecole Polytechnique's students for the Applied Math program has been increasing, as more and more realize that this training will give them true opportunities to get exciting and challenging positions. In 2011, 2012, 2013 respectively, 95, 67 and 106 students registered with our program (of about 500). If less students seem to show an interest in financial mathematics and careers in finance, the number of students attracted by optimization (operations research) or statistics/signal processing ("big data") has been constantly growing in the past recent years.

A large part of our action consists in pushing the students to follow a master program during their 4th year at École Polytechnique. A challenge is to convince them that "formation by research" does not mean "academic jobs" but is also a very good training for job in companies. The chairs we develop with private groups help us in this task, in particular by giving some financial support for research internships abroad, and also by allowing us to organize occasionally attractive research activities (such as a stay in French Guyana to study the mathematical modeling of biodiversity in a tropical forest).

The members of the lab are teaching in the following M2 programs which can be followed by the students of the École Polytechnique:

- Mathematics for Life Sciences (MATH-SV[18]);
- Probability and Statistics (PS[19]);
- Optimization, Games, Modelization in Economics (OJME[20]), a curriculum of the Paris-6 "Mathématiques de la Modélisation" Master[21];

[18] http://www.cmap.polytechnique.fr/~giraud/MathSV/accueil.html
[19] http://webens-ng.math.u-psud.fr/M2/PS/
[20] http://www.ljll.math.umpc.fr/ojme/
[21] http://www.master.ufrmath.upmc.fr/fr/math_model.html

Table 1: Involvment of researchers of CMAP in M2 programs

Master	Researchers involved	Hours
MATH-SV	4	42h
PS	4	48h
OJME	2	42h
AN-EDP	8	101h
Probabilités & Finance	4	60h
MVA	1	18

- Numerical Analysis and PDEs (AN-EDP[22]), also a curriculum of "Mathématiques de la Modélisation";
- Probability and Finance[23];
- Mathematics, Vision, Learning (MVA[24]);

Historically, our programs were mostly organized together with the applied maths departments of Jussieu (Paris 6 and 7) universities. Since September 2012, we have developed two master programs with University Paris-Sud for the master "Probability and Statistics" (PS) and with University Paris Sud and ENS Cachan for the master "Mathematics for Life Sciences" (Math-SV). These two masters have been developed within the foundation FMJH and the latter is supported by the LABEX "Hadamard". The aim of the master PS is to lead brilliant students at the highest research level in Probability and Statistics. Four courses are given by Professors of the CMAP. The aim of the master MSV is to offer a complete and structured training in Mathematics at the interface with Life Sciences (biology, medicine, ecology). Its originality lies in its high level in mathematics, the wide range of mathematical tools treated, and the diversity of the proposed specialisations in modeling the living. Four courses are given by Professors of the CMAP.

Some lectures of these programs can be shared with other programs which are not mentioned, such as the program "Equations aux dérivées partielles et calcul scientifique" of Paris-Sud[25], or the Master of Mechanics of Polytechnique[26].

Doctorate About 10% to 15% only of the students at École Polytechnique pursue in doctoral studies after their 4th year. And, of course (and hopefully), many of them do this in other universities, in France and abroad. However, the CMAP is attractive enough to have each year a few of these students (right now six of our students are from the school). The other come from all over France and the world, with of course quite a few from Paris 11 (Orsay) or Paris 6 (UPMC) Universities, or the École Normales Supérieures (Paris, Cachan, Lyon). The CMAP now trains about 50-55 registered students (including the students arrived in Sept., 2013), a figure which has been relatively stable in the past five years, for about 20 researchers with a "HdR" (*habilitation à diriger des recherches*)[27]. This students are registered with EDX (ED 447, École Doctorale de

[22] http://www.ljll.math.umpc.fr/anedp/
[23] http://www.master-finance.proba.jussieu.fr
[24] http://www.math.ens-cachan.fr/version-francaise/formations/master-mva/
[25] http://webens-ng.math.u-psud.fr/M2/ANEDP/
[26] http://www.enseignement.polytechnique.fr/mecanique/PA-MECA/M4S-M2-FR.html
[27] (and a few researchers without HdR advising PhD students)

l'École Polytechnique). The list of the students from the past years is in Table 6 in Annexe 7. We have precised, when known, the present situation of theses students. If most end up with academic position, an important proportion is now in the private sector (in industrial or finance companies).

4 Stratégie et perspectives scientifiques pour le futur contrat

Evolution of the lab, scientific orientations The characteristic of the CMAP is that all its researchers are interested or involved in the *modeling* of processes and systems encountered in other fields, society, or the industry, in the *mathematical and numerical analysis* of these models, and in the numerical *simulation*. The primary goal of the scientific policy of the lab is to develop and maintain research teams which can be at the best international level in all these tasks. Hence the main strategy is to hire among the best researchers in all the fields of applied mathematics which are covered by the activities of one of the current teams.

The CMAP has reached a sort of nice scientific equilibrium during the past five years. The dynamic action of the previous directors (until 2008) had succeeded in stopping a slow decline of the lab (which had lost a lot of its CNRS researchers and had not been able to compensate all departures). The integration of now four INRIA teams helped develop many themes which were previously not covered, with sometimes an interesting interaction with other researchers in more "classical" topics. These teams also maintain many contacts with the industry. After the hiring of N. Touzi and S. Méléard as Professors by the DepMapp, the activities in Random modeling and simulation quickly expanded, with the hiring of a few assistant professors and researchers in applied probability, and the team "Modélisation pour l'évolution du vivant" is now an important group. With the integration this year of Lucas Gérin and Thierry Bodineau, who work with similar tools but towards different applications (statistical physics, computer science) this team will evolve and will adopt a new name, to stress the broadening of its field of applications (in particular to particle systems) which up to now was mostly restricted to biology or ecology.

The Signal and Image Processing group, after the departure of S. Mallat, had been reduced to only a few researchers (one full time, and two part time, plus a few PhD students). The recent hiring of young scientists interested in theoretical statistics and learning, and of E. Le Pennec as an associate professor in Sept. 2013, will allow to reinforce again this field as a part of a broader team in "Statistics, Image, Numerical Probability and Algorithms". The latter team will address the issues of large-dimensional statistics in general ("big data" analysis, image and signal processing, Monte-Carlo methods and numerical probability) and will be co-coached by E. Le Pennec and E. Gobet.

A possible direction for the future, but which needs a stronger support and more resources, would be to encourage the teams to develop software and scientific computing code. As shown in Annex 6 (on page 145, "Registered softwares") this is already an important part of our activity. There are now 3 full time research engineers (on temporary contracts, one hired by the École Polytechnique on a CMAP contract and two by the INRIA) who are developing code for the industry or the scientific comunity (BOCOP, see p. 54 and the RODIN project, see p. 51). However, we think that the CMAP should offer a stronger support to the researchers who want to develop scientific computing code (academic or comercial), and encourage them when possible to integrate their models and simulation in common platform. We will try to imagine efficient solutions to boost these activities. The best solution could be to hire a professor or senior researcher specialized in "High Performance Computing" and develop a corresponding team which could interact with all other teams (statistics and numerical probability, nonlinear analysis teams, ...)

Interactions with the scientific environment In the recent past years, decisions to bring a few other higher education institutions (ENSTA, Telecom, ...) have been considered and this motion should continue for a few years, with the development of the "Université Paris-Saclay". The ENSTA has already moved quite close to our location, and we should now consider tightening our links with its mathematicians.

A first step for the CMAP should be to encourage collaborations with ENSTA's UMA ("Unité de Mathématiques Appliquées"). Up to now, a few teams have already been collaborating: the INRIA COMMANDS team is "bi-localized", and has one researcher, H. Zidani, working at UMA; the Geco group is collaborating on a regular basis with F. Jean, who is an active participant of the ERC GeCoMethods grant; F. Russo participates in a joint seminar with the finance group at CMAP; L. Bourgeois and M. Bonnet are regularly exchanging with members of the CMAP and in particular the DEFI INRIA team. This collaboration should naturally increase, and the CMAP will naturally encourage it and try to tie closer bounds.

A next step (it seems that the building is already programmed) will be the construction of the new building of the ENSAE, with which a few of our researchers (in finance or statistics) already have strong ties (A. Tsybakov, professor at ENSAE, is also a part-time professor at the DepMapp and has an office at CMAP): it is expected that most mathematicians of the ENSAE will be interested in interacting with the CMAP and this can lead to the constitution of new common teams, or the development of existing teams.

At a broader level, with the expansion of the FMJH and its evolution as the "Mathematics Department" of the Université Paris-Saclay, links with the other departments of the area (LMO in Orsay, CMLA in Cachan, but also LSS in Supélec, the above-mentioned UMA or the mathematicians of École Centrale) should also be developed and reinforced. The fusion of all departments around Saclay in common institutions (common graduate school in mathematics, "school of basic sciences") will also naturally increase the collaborations.

However, we must also mention that the CMAP is already, at the Ecole Polytechnique, in a rich and stimulating research environment and this situation is probably underexploited. Natural links exist with the CMLS (Mathematics) and CPHT (Theoretical Physics), the LadHyX (Fluid Mechanics), the LIX (Computer Science), the LMS (Mechanics). A few PhD theses are co-advised by researchers from the CMAP and some other laboratory, mostly the LIX (in particular within the INRIA teams). This should also be encouraged and developed. The project of a few engineering schools of the upcoming Université Paris-Saclay to develop a Graduate School specialized in multidisciplinary training ("E.D. Interfaces") is supported by the CMAP. Its researchers, though primarily affiliated with the Graduate School of Mathematics ("E.D. Hadamard"), will be encouraged to act as co-advisors in applied multidisciplinary theses in the framework of this "Interfaces" graduate school.