Attention, ce modèle de document scientifique est destiné à l'évaluation des projets Blanc n'impliquant pas de coopération internationale dans le cadre d'un accord bilatéral.

Acronyme / Acronym	**MSDOS**		
Titre du projet	Systèmes multidimensionnels, digression sur la stabilité		
Proposal title	Multidimensional Systems: Digression On Stability		
Comité d'évaluation / Evaluation panel	Simi 3		
Type de recherche / Type of research	☒ Recherche Fondamentale / Basic Research ☐ Recherche Industrielle / Industrial Research ☐ Développement Expérimental / Experimental Development		
Coopération internationale / International cooperation	☒ Oui, en dehors d'un accord bilatéral / Yes, outside of a bilateral agreement ☐ Non / No		
Aide totale demandée / Grant requested	290000 €	**Durée du projet / Projet duration**	48 mois
Partenaire coordinateur / Coordinator partner	Identité du coordinateur (nom, prénom) : Bachelier Olivier Identification de l'établissement (laboratoire, tutelle, entreprise…) : Université de Poitiers		
Lien avec un projet du programme *Investissements d'Avenir* (IA) / Link with a project of the *Investment for the Future* programme	☐ Oui ☒ Non si oui, préciser :		

Personnes impliquées dans le projet / People involved in the project :

Organisation	Last name	First name	Current position	Field of research	Involvement in the project (PM)	Rôle & responsabilité dans le projet / Contribution to the project
Poitiers University (LIAS) **(in charge)**	Bachelier	Olivier	Professeur	nD systems, robust control	24	*General coordinator and in charge of task 2.* Expertise on linear systems and S-procedure approaches.
Poitiers University (LIAS)	Yeganefar	Nima	Mcf	nD systems, Lyapunov stability	24	*Coordinator tasks 1 and 6.* Expertise on time-delay systems, nD systems, and Lyapunov techniques.
Poitiers University (LIAS)	xxxx	xxxx	PhD	Control systems	36	Affected to tasks 1 and 2.
Poitiers University (LIAS)	xxxx	xxxx	Master		24	Affected to task 5.
LATP	Yeganefar	Nader	Mcf	Riemannian geometry	12	Expertise in analyze and geometry.
INRIA Saclay **(in charge)**	Quadrat	Alban	Inria	nD systems	17	*Coordinator tasks 3 and 5.* Expertise in algebraic methods and symbolic computation.
INRIA Saclay	Mounier	Hugues	Inria		14	Expertise in algebraic methods, nonlinear systems and PDEs.
INRIA Saclay	xxxx	xxxx	Post doc	Control systems/Maths	12	Affected to task 3.
XLIM **(in charge)**	Cluzeau	Thomas	Mcf	nD systems	16	Expertise in algebraic approach
XLIM	Moulay	Emmanuel	CNRS	Nonlinear systems	16	*Coordinator task 4.* Expertise on nonlinear systems and PDEs.
XLIM	Silva	Francisco	Mcf	PDEs	8	Expertise on nonlinear systems and PDEs.
ISSI Poland **(in charge)**	Paszke	Wojciech	Lecturer	nD systems	12	Expertise on repetitive systems.

1. Executive summary of the proposal

The MSDOS project questions the stability and stabilization of multidimensional systems also known as *n*D systems. It is aimed at expanding both the theoretical and practical aspect of the field. MSDOS is decomposed into 6 different tasks. Three tasks are indeed devoted to advance the theory of multidimensional systems in stability and stabilization: one based on the Lyapunov theory, one focused on repetitive systems and one using a fractional representation approach. The last three ones are focused on the practical aspects of the field: first the results obtained will be applied to study other infinite dimensional systems using an *n*D approach, second a set of packages will be proposed for analysis and synthesis problems, and simulation of *n*D systems, third the creation of a draft course on multidimensional systems will be available. The project should significantly help creating a stronger community of researcher in France around this exciting field which is one of the main goals of the project on par with the obtained theoretical advances.
The work will be handled by four different partners with complementary skills starting with LIAS in Poitiers, INRIA Saclay-Île-de-France in Paris, XLIM (Limoges and LATP in Marseille) and an international collaboration with ISSI (Poland).

Keywords: multidimensional systems, Lyapunov theory, stability/stabilization

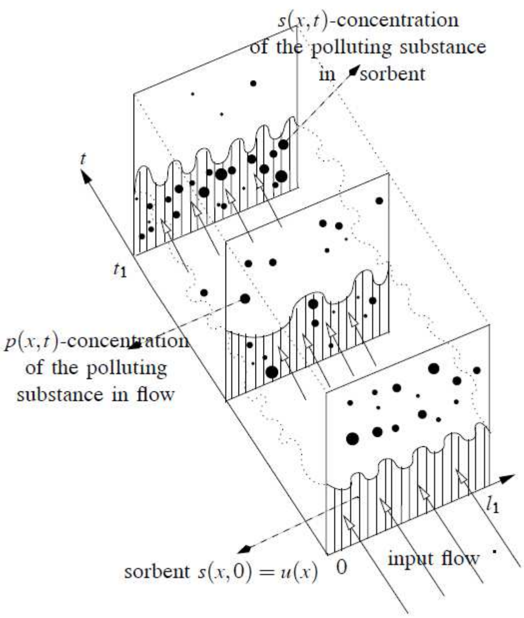
2. Context, position and objectives of the proposal

2.1. Context, social and economic issues

The dilemma for the control engineer has always been to find the proper model, close enough to the real system but simple enough to allow the study. The researcher on the other hand is mainly interested in discovering new paths that have not been investigated, the secret place to gold mining. When both the engineer and the researcher reach the same path, it is the start of a most likely outstanding project. The idea of analyzing multidimensional systems (*n*D) started in such an environment. The problem of the engineer facing more and more complex models was solved by the researcher who understood that these systems could be modeled and controlled using a multidimensional approach. No wonder that the success this new area of research encountered in the late 70s was of great impact: X-ray enhancement, seismic data processing, geo-science, computer vision, robotic, biomedical engineering, circuits systems, other unexpected fields such as financial science, neuroscience, psychology, social science were all studied through the lens of *n*D systems.

Why it is so? Most systems have a natural tendency to have multiple dimensions which are often neglected for simplicity. So instead of using 1D digital filter, scientists started to investigate the implications of digital filters with 2 or more independent variables. Surprising results were soon discovered which fascinated both the mathematicians and the engineers. The class of systems that can be modeled as multidimensional systems is therefore very large. As part of the systems of infinite dimensions, they can also be used to investigate time-delay systems or partial differential equations with a completely different framework, most of the time leading to original result (for references, see section 2.3).

So when in the 70s the study of multidimensional systems blossomed in the international communities, one could have expected a high impact on the engineering and scientific community. However, since then, and especially in France, it has not achieved the recognition that was expected considering its many applications and scientific challenges. The intrinsic mathematical and computational difficulties –as the time needed for the necessary calculations is indeed skyrocketing as soon as one starts climbing the dimensions– could explain why so few people are working on the subject in France nowadays. But we believe this is not the main reason why the subject is not very popular in the French scientific community; an incentive is needed to gather more researchers for this



exciting problematic and hopefully this project will provide it. Our main goal will be therefore to create and develop a complete theory on the stability of the multidimensional systems and to provide several computing tools to help studying *n*D systems; thus allowing the French community to easily engage onto the steep path of multidimensional systems.

2.2. POSITION OF THE PROJECT

The field of multidimensional system has been historically a strong community with its own journal (Multidimensional Systems and Signal Processing, Springer) and conference (IEEE conference called *n*DS). Several important laboratories are extremely active in the field especially in Europe, for instance the Institute of control and computation engineering (ISSI, partner of the project) in Poland which focuses on a special area of *n*D systems called repetitive systems. Strong groups can also be found in Britain (University of Southampton), in Germany (RWTH-Aachen University, Wuppertal University), in Portugal (Universities of Aveiro and Porto) and in Spain (University of Valladolid). A strong and deeply interconnected international network actively contributes to the field.

So far, in France, this research area is not part of any workgroup yet (e.g., GdR MACS) but it has been studied by some independent French scientists. In this context, the genesis of the MSDOS project is interesting. A few contacts have been made by people in LIAS with the researchers in Poland (ISSI) and this first exchange led to several publications (see next section). Soon after, Nima Yeganefar joined the LIAS and started to supervise a PhD on multidimensional systems (*n*D systems). The reinforcement of this area of research was noticed in the international community which gave the team in LIAS the opportunity to organize the first IEEE workshop on multidimensional systems in France, September 2011 in Poitiers (http://laii.univ-poitiers.fr/nDS11/). This conference –of which the general chairman was Olivier Bachelier– was the first conference of the kind in France and has certainly contributed to the genesis of the MSDOS project. Indeed, during the conference contacts were made between the current members of the project and the interactions with the Polish team were reinforced.

So this project appears to be the continuity of the work that has been done in the LIAS for the past four years. It is also the first project that gathers almost all the members of the French scientific community actively working in the field with the support of a mathematician from the LATP. Most of the members know one another and have been working together for the past few years. Creating a strong French community on the subject with the support from a leading international group in the field –the Polish group– will allow us to generate a very exciting environment for an intense and successful research.

2.3. OBJECTIVES, ORIGINALITY AND NOVELTY OF THE PROJECT

Objectives:

The MSDOS project has been designed to embrace the different areas of multidimensional systems, most specifically the stability and stabilization of multidimensional systems. This project is therefore clearly designed to have the highest possible impact in the French but also the international community. The objectives are therefore both theoretical and practical.

- Theoretical objectives:

One of the ultimate goals of the project is to create a complete set of definitions and analyzing tools, coherent with the existing ones in the 1D systems framework, whatever the approach used, to study the *n*D system (state-space, input/output or algebraic approach). To achieve this objective, we would have to bypass many problems such as the ones pointed out in the previous section. Several important issues on stability/stabilization of *n*D systems remain to be investigated. Indeed, we will have to revisit the definitions of stability à la Lyapunov (delta/epsilon stability), study the link between double coprime factorization and stabilization, explore the relation between the well known *S*-procedure and the criteria obtained via Lyapunov theory, etc.

- Practical objectives:

Several important deliveries are to be expected. On the one hand, packages dedicated to analysis and synthesis problems, and simulation of *n*D systems will be developed. A symbolic package for analyzing *n*D systems (structural properties, invariants, algebraic analysis, and transformation between equivalent representations of *n*D systems: transfer matrices, state-space representation, Roesser or Fornasini-Marchesini models, modified Spencer form) will first be developed in the computer algebra system Maple. For synthesis problems (structural stabilization, computation of doubly coprime factorizations, computation of Youla-Kucera parametrizations, simultaneous and strong stabilization, robust control), as it will require both numerical and algebraic calculations, we will develop a symbolic-numeric package in the important system Sage (http://www.sagemath.org) which allows us to interconnect different computer algebras (Maple) and scientific computation packages (Scilab or Matlab). To help popularizing the field, easy add-ons will be created for Scilab or Matlab to perform recurrent tasks such as simulating the trajectories of an *n*D system whatever the initial model (Fornasini or Roesser, continuous, discontinuous or repetitive systems, etc.). These 3 different layers (numerical simulation, structural properties, and synthesis problems) will simultaneously be available through the Sage system. A secondary goal dependent on the theoretical work will be to question the stability/stabilization of distributed systems (partial differential equations), interconnected systems, and time-delay systems in light of the new tools developed during the project. These two well-known areas can be indeed modelized under certain conditions as *n*D systems. Comparing our results with existing criteria in these fields would provide an excellent marker of success. On the other hand, the educational aspect is also of high importance for the members of this project (see section 4 later on), and therefore a draft course on multidimensional systems, focusing on the results obtained during the 4 year project, will be the starting point of a complete course for students attending the proposed research master degree called “Master Science Technologie et Santé”. We will also propose the organization of a summer school on multidimensional systems in France (e.g., International Summer School of Automatic, GIPSA Lab, Grenoble). This could be the first step towards the writing of a French book on multidimensional systems.

Evaluation criteria:

In the light of what we have previously said, two immediate criteria can be proposed: the functionality/accessibility of the different packages developed during the project. But it would not be an ambitious project if we were only looking at how successful our results were. Many researchers have experienced the disappointment felt when important results are discovered but go unnoticed by the community – and not only the experts in the field. A good marker is therefore the impact of our publications within the community of multidimensional systems, and also from a broad scope of researchers especially in France. If we do not manage to attract the attention of the French community by alluring new colleagues into the field, then the project will have certainly missed one of its main objectives.

2.4. STATE OF THE ART

Multidimensional (*n*D) systems were firstly based on the theory of functions and polynomials of several variables (real or complex) and were introduced in the early sixties as part of problems arising from the image processing field when authors started investigating multidimensional digital filters. At the time, the focus was therefore mainly on linear systems and transfer functions. Instead of working with a transfer function which depended on one independent variable, they looked at polynomial functions of *2* and generally *n* variables and this approach was convenient when dealing with image processing if you consider the dimensions as a discretization of the horizontal and vertical length of a picture. So the early focus was on digital filtering with multi variable transfer functions.

The first models were introduced a bit later with the work of Roesser [ROE75] and Fornasini-Marchesini [FOR76, FOR78] and further enhanced in a much more complex general system early 2000 ([BOC05]) with both discrete and continuous state variables. With the introduction of state space models and the development of several tools for the *n*D case such as the use of LMIs (linear matrix inequalities) and Lyapunov techniques to derive stability conditions, a growing interest was raised concerning 2D systems [PAN84,LIU94, HIN97, DU99, GAL01b, BLI02, GAL02, GAL03, PAS04, LIU08, KAC09, KOJ09, AVE11] etc. Numerous applications have been studied particularly in the image and signal processing, coding/decoding, filtering [BOS01,BOS10], the study of PDEs via a discretization [MAR84] or with a continuous approach (see the work in [DYM11] where a control of a sorption process is proposed), the analysis of time-delay systems with an algebraic approach [CHY05, CHY07, LOI07, CLU09, BOU10], mathematical physics [POM99, POM04, CHY05] etc. More recently repetitive controls (for systems such as long-wall cutting or metal rolling operations) and iterative learning control theory have shown to have a natural *n*D structure [ROG07]. Finally, a rich interplay between multidimensional systems theory and a modern mathematical theory called algebraic analysis (algebraic D-modules) was developed in a series of publications [OBE90, POM99, ZER00, POM04, CHY05, CHY07, CLU08, CLU09, BOUD10, QUAa11, QUAb11,QUA13]. This led to the development of a behavioral approach to multidimensional systems as well as new algorithms with dedicated symbolic packages in Maple, Singular and GAP 4 for the constructive study of structural properties of multidimensional systems (e.g., primeness, controllability, observability, extendability, flatness, invariants, autonomous elements, purity). This new ongoing field has already brought an active cross-fertilization between multidimensional systems, modern algebra, and symbolic computation.

Our project focuses on stability and stabilization. It is interesting to point out that the stability approach was mainly in the input/output spirit – i.e. the system was considered as a black box represented by a transfer function – and tools were quickly developed (such as a generalization of the Z-transform) to study the roots of such polynomials mostly representing multidimensional digital filters [BOS77,JUR78,DUD84,JUR86,GAL01a,BOS10]. An important issue in multidimensional systems theory is therefore to extend classical results and techniques developed for stability/stabilization problems of 1D systems to *n*D systems [OBE06]. For instance, one specific problem is the stabilization. For 1D systems, it is well-known that exponential stabilization (i.e., the closed-loop transfer matrix has no poles in the complex unit disc) is equivalent to the existence of so-called doubly coprime factorizations of the transfer matrix of the plant over the ring of proper and stable real rational functions [VID85]. Generalization of exponential stabilization to *n*D systems led to the concept of structural stabilization (i.e., the closed-loop transfer matrix has no poles in the complex unit poly-disc) (see, e.g., [LIN85,LINa01,LINb01]). In [LIN98,LINa01], Zhiping Lin conjectured that every structurally stabilizable multidimensional linear system admits doubly coprime factorizations, and thus a Youla-Kucera parametrization of all the stabilizing controllers. A positive answer to this conjecture would allow one to successfully extend robust and optimization techniques developed for 1D systems to *n*D systems (see [BAL10] for a complete survey). This open conjecture was solved in [QUAa06, QUAb06] based on the combination of modern algebraic techniques and a difficult result obtained by the Fields Medalist Pierre Deligne reproduced in [KAM84]. Unfortunately, no constructive proof of this result is known for the general case yet (*n*D systems). This problem can be understood as a kind of generalization of the well-known but difficult Quillen-Suslin theorem which solves Serre's conjecture [LAM07]. See [FAB07] for a constructive version of the Quillen-Suslin theorem and for constructive solutions of the so-called Lin-Bose's conjectures for *n*D systems [LINb01] and their implementations in a symbolic package. See also [FAB07, CHY05, CLU08, CLU09, BOU10] for important applications of the Quillen-Suslin theorem to multidimensional systems theory.

Considering the numerical difficulties arising with increasing dimensions especially whilst trying to evaluate or to locate the roots, new stability techniques based on Lyapunov theory emerged in the nineties ([LIU94], [HIN97]). With the introduction and the generalization of linear matrix inequalities ([BOY94], [ROG02]), both frequency and time-domain approaches led to similar results expressed in terms of LMIs (only sufficient conditions are provided) and not surprisingly the higher the order of the system is the more conservative the results are ([GHA11]). Quite recently, the introduction of delays in the state-space model was initiated in [PAS04], and several results are now available in the literature generalizing the study of time-delay systems to the multidimensional case ([BEN10], [HMA10], [TIW10], [WAN09]).

Members of the team are deeply invested in this project. In LIAS, important results have been published over the last few years [GHAa11, GHAb11, GHAd11] including collaborations with ISSI [GHAc11]. A recent publication [YEG13] – a joint effort of LIAS/XLIM and the mathematician in LATP – revisits the definitions of stability in light of the Lyapunov framework and proposes the first converse Lyapunov theorem. This article that we consider essential in the field would not have been possible without the mathematical skills found in LATP. Joint efforts between LIAS and ISSI have also yielded numerous publications extending important criteria such as the KYP lemma (Kalman-Yakubovich-Popov) to the multidimensional case [BAC06, BAC08, BAC] or the stability problem using the S-procedure approach

[GHA13]. Alban Quadrat (INRIA Saclay) has been a prominent figure of the international *n*D community in the past 15 years (associate editor of the Journal Multidimensional Systems and Signal Processing, Program committee of nDS11, organizer of invited sessions at international conferences (e.g., MTNS 2006, MTNS 2010, SSSC 2013) dedicated to *n*D systems, PHC Polonium with ISSI (2003-2004)). In collaboration with Thomas Cluzeau (XLIM), another member of the project, and Daniel Robertz (RWTH-Aachen University, Germany), they are developing rich interplays between multidimensional systems, algebraic analysis (D-modules), symbolic computation, and mathematical physics (PHC Procope 2006-2007, PHC Procope 2010-2011).

3. SCIENTIFIC AND TECHNICAL PROGRAM, PROJECT ORGANISATION

3.1. SCIENTIFIC PROGRAMME AND PROJECT STRUCTURE

The MSDOS project questions the stability and stabilization of multidimensional systems. The project is composed of 5 different laboratories, divided into 4 different partners with complementary skills: people using algebraic approach (INRIA Saclay-Île-de-France/XLIM), people familiar with nonlinear techniques based on Lyapunov theory (XLIM/LIAS), people with expertise in time delay systems and PDEs (LIAS/XLIM), people with strong knowledge in the special class of repetitive systems (ISSI) and mathematicians (LATP, XLIM) that can apprehend the underlying mathematical difficulties of these different frameworks with genuine eyes. The integration of the mathematicians to the project is actually very important as most of the tools used during the project are difficult mathematical tools. The task of the members in control will be to clarify the problematic so that the mathematicians can focus only on the intrinsic difficulties.

The project is therefore naturally divided into 6 different tasks:

- The first 3 ones (Tasks 1-2-3) will be devoted to the theory and focused on achieving the designated theoretical goals (section 2.4). More specifically, the task 1 concerns the stability of *n*D systems using nonlinear techniques mainly based on Lyapunov theory. Task 2 is mainly devoted to the study of repetitive systems and task 3 uses algebraic and geometric tools in order to analyze the problem of stabilization. Obviously these 3 tasks are interconnected. For instance a definition of stability given in task 1 will impact the work of task 2 or 3 and reciprocally. A very high importance will be given to publications in important journals/conferences in the field (*n*DS/Multidimensional System and Theories) but also in national/international journals. 1 PhD position (LIAS) and 1 postdoctorate position (12 months, INRIA Saclay) will reinforce this first set of tasks.
- The last 3 ones (Tasks 4-5-6) are designed to the practical side of the project and their designated goals. We will first try to apply the obtained theoretical results in order to study other infinite-dimensional systems such as time delay systems (TDS) and partial differential equations (PDEs) using an *n*D approach (task 4). Task 5 will focus on the coding and implementation of packages which will help studying *n*D systems. Finally during task 6 we will try to aggregate all the results obtained during tasks 1-2-3-4-5 hence providing the basis for a future course on the stability of multidimensional systems.

The diagram given below summarizes the relations between the different tasks.

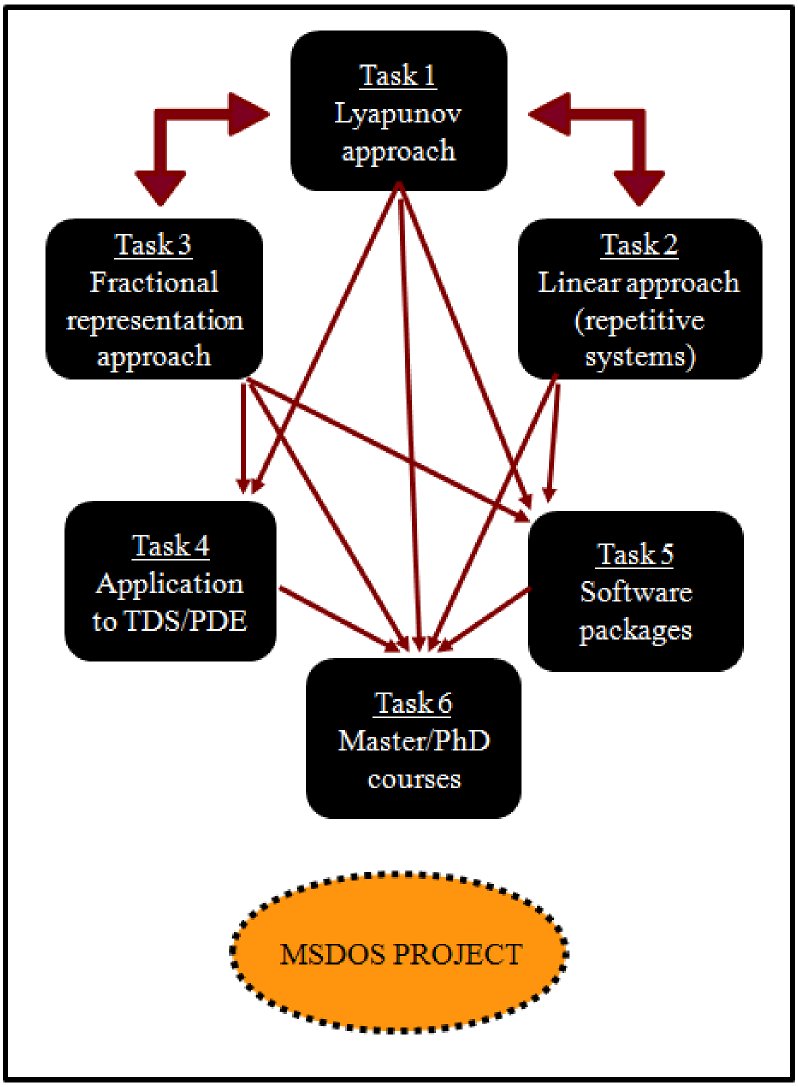


Fig. 2: Relations between the tasks developed in the MSDOS project

3.2. DESCRIPTION BY TASK

3.2.1 TASK 1. LYAPUNOV THEORY (NONLINEAR TOOLS)

Goals.
Constructing a comprehensive and coherent set of definitions/theorems to analyze the stability and stabilization of *n*D systems.

Program.
Coming from a nonlinear background especially with a Lyapunov approach, both Emmanuel Moulay and Nima Yeganefar were interested in generalizing the usual Lyapunov theorems to multidimensional systems. They soon realized that the generalization of the Lyapunov work has already been proposed in the literature of the multidimensional systems (and recently in [VAL00], [OBE06] and [NAP11]) but it was not coherent with the existing ones in the 1D case – for instance, in most papers the asymptotic stability only consist in checking the attractivity (lim x(t)=0) without first studying the (Lyapunov) stability sometimes referred to the ε-δ stability. This is mainly because the field has almost exclusively worked with linear systems. The questions we want to answer is therefore how to generalize all the work in the 1D case that has been unveiled to the most general *n*D case, i.e. how do we define stability in the Lyapunov sense, asymptotic stability, exponential stability, practical stability, uniform stability, etc.? What theorems à la Lyapunov can we provide in order to check/guarantee these conditions? Ultimately we would like to build a complete stability theory similar to what we can find in the 1D case [KHA02]. A preliminary work towards this goal [YEG13] has

been accepted for publication in IEEE-TAC. In this article we provide strong incentives based on concrete examples as to why we need to revisit the stability definitions and theorems in *n*D systems.
Because all these concepts have been thoroughly studied in the 1D case and sometimes extended to the *n*D case without the necessary precautions, this work is an important one. Moreover, questions about the links between usual state-space models and general 2D transfer functions will be held. Particularly, Goodman exposed surprising results in [GOO97] showing that the numerator in some special cases can influence the BIBO stability (Bounded Input Bounded Output) of the system which has no counterpart in the 1D case. How does it impact the state-space system? Can we find, as Goodman proposed, sufficient and necessary stability conditions in light of our new definitions?

To sum up the purposes of this task:

- to generalize the Lyapunov stability concepts from the 1D to the *n*D case;
- to provide theorems in order to analyze the different notions of stability (sufficient and necessary conditions);
- to study the problem of stabilization within the previous framework;
- to question the existing results on *n*D transfer functions in light of the work previously done;

Methods.
The techniques used during this task are based on the Lyapunov theory in control systems. Difficult mathematical tools are necessary especially when dealing with converse theorems (roughly speaking proving that a Lyapunov functions exists if the system is stable) mostly based on algebra and analysis.

Deliveries.
The final memoire of the PhD thesis.
The final report of the task.

Risks.
Questioning definitions and proposing new ones is a difficult task in a field with strong attachments to its community. Strong incentives need to be carefully given and designed in order to convince the entire community.

People involved:
Ni. Yeganefar (LIAS, in charge), Na. Yeganefar (LATP), E. Moulay (XLIM), F. Silva (XLIM)
PhD candidate (LIAS).

3.2.2 Task 2. Repetitive Systems (Linear tools)

Goals.
Investigating the stability/stabilization of repetitive and iterative learning systems.

Program.
The last decade, W. Paszke has been successfully investigating on Repetitive Processes (RP) and Iterative Learning Control (ILC) which are known to be two main practical instances of nD-models. Through his collaboration with Prof. K. Galkowski (Univ. of Zielona Gora, PL, and of Torun, PL) and Prof. E. Rogers (Univ. of Southhampton, UK), W. Paszke has proposed interesting LMI approaches to the (possibly robust) stability analysis and stabilization of RP or ILC schemes (which are very close to each other). ILC is known to provide very interesting design strategies in various domains, the most famous being robotics. Besides, quite recently, with O. Bachelier, he proposed the first « generic nD-version » of the celebrated Kalman-Yakubobvich-Popov (KYP) lemma which offers a large possibility to approach many problems encountered in the study of hybrid Roesser models. Even more recently, a new piece of their work was accepted for publication. It deals with the exploitation of the finite frequency version of the KYP to the special context of uncertain linear RP [PAS13]. In this paper, they showed the relevance of constraining the frequency range in the analysis and design of RP, which offers new perspectives for future investigations. Moreover, N. Yeganefar and O. Bachelier have proposed in 2011 an *S*-procedure approach to the study of Roesser models, which is even more general than the KYP lemma. They extended this result to the case where the Roesser models are also subject to parametric uncertainties under the form of implicit linear Fractional representations (LFR) [GHA13]. They highlighted the way how various dimensions and uncertain

parameters could be handled about in the same fashion through S-procedure, as already approached in [BEC96]. With such tools, based upon the resolution of LMI systems, one can propose a more systematic approach to the derivation of LMI conditions for numerous problems related to analysis and control of Roesser models.
Therefore, the purposes of this task are:

- to encompass many (if not all) LMI conditions related to *n*D models, and encountered in the literature, into one single framework based upon *S*-procedure. This could open new tracks to the reduction of the conservatism of existing sufficient conditions. This more general approach could also be a key for the dissemination of the proposed work and its educational impact.
- to understand how to specialize the *S*-procedure to the particular case of RP and ILC, still to reduce the pessimism of existing conditions.

Methods.
Clearly, the methods would be based upon the LMI framework, the so-called *S-procedure* and its very famous instance, i.e. the *KYP lemma*, especially adapted to the *n*D Roesser models. Besides, the *projection lemma* should also be a very useful mathematical tool to derive forthcoming results.

Deliveries.
The final report of the task.

Risks.
There is no actual risk to be considered for the first purpose for which the ideas are very clear and the work has already started. For the specialization to the case of ILC and RP, if more legibility among various results can be reasonably expected, it is not possible at this stage to predict with certainty that new less conservative LMI conditions will eventually be derived.

People involved:
O. Bachelier (LIAS, in charge), W. Paszke (ISSI), Ni. Yeganefar (LIAS), PhD. candidate (LIAS)

3.2.3 Task 3. Fractional representation approach

Goals.
Constructive study of structural stabilizability and its relations with the existence of doubly coprime factorizations. Use of these results to study robust/optimal/simultaneous/strong stabilization problems for *n*D systems.

Program.
This task first aims at developing a constructive version of a result due to the Fields Medalist Pierre Deligne (reproduced in [KAM84]) which, when combined with algebraic results developed in [QUAa06,QUAb06], proves that every structural stabilizable plant (i.e., plant admitting a controller such that the closed-loop transfer matrix has no poles in the complex unit poly-disc) admits doubly coprime factorizations. This result was conjectured by Z. Lin [LIN98,LINa01,LINb01] who solved this problem for particular classes of *n*D systems. The proof given in [KAM84] does not give hints about how to explicitly compute the corresponding doubly coprime factorizations. To achieve this goal, we first need to be able to constructively compute in the ring *A* of rational functions without poles in the complex unit poly-disc. To do that, we have to investigate how to combine *Gröbner basis techniques* [BEC98,BUC85] with techniques coming from *Cylindrical Algebraic Decomposition (CAD)* [ANR84,COL75]. Then, the module structure of the ring *A* has to be effectively investigated into since Deligne's result asserts that finitely generated projective modules over *A* are free. In particular, we will investigate how bases of free *A*-modules can be explicitly computed: a basis gives a doubly coprime factorization (the projectivity property being equivalent to structural stabilizability) [QUAa06,QUAb06]. These results will then allow us to constructively extend classical methods developed for 1D systems [VID85] to *n*D systems (e.g., computation of the Youla-Kucera parametrization of all stabilizing controllers; use of this parametrization to transform nonlinear optimal problems (e.g., H_2 H_∞) into affine and thus convex optimal problems; constructive study of the strong [YIN98,YIN99], simultaneous and robust stabilization problems). For a recent survey of these methods for *n*D systems (based on the knowledge of doubly coprime factorizations), see [BAL10].

Methods.

The study of constructive computation in the ring *A* of rational functions without poles in the complex unit poly-disc will be made by combining different techniques developed within the symbolic computation community such as *Gröbner basis techniques* and *Cylindrical Algebraic Decomposition (CAD) methods* [BEC98,BUC85,ANR84,COL75]. Techniques developed in [BEN99,JUR78,JUR86,LIN LIN98,LINa01,LINb01] and in the references therein will be constructively studied using Gröbner basis and CAD. Then, the module structure of the ring *A* will be constructively studied based on general homological methods developed in [QUAa03,QUAb03,QUAa06,QUAb06,QUA10]. Moreover, we will closely study Deligne's proof to understand if a constructive version of this result can be extracted. Using Serre-Swan's correspondence (*K*-theory) showing that projective (resp., free) modules correspond to vector (resp., trivial vector) bundles and using the recent introduction of ideas of noncommutative geometry [QUA12], differential geometric techniques (e.g., connections, curvatures, Chern characters, characteristic classes) can also be used to study Deligne's theorem. Hence, the expertise in differential geometry of Na. Yeganefar from the LATP will also be useful toward the resolution of the main problem of this task, and will certainly give rise to new unexpected developments. Based on the above results, we will study the strong stabilization problem following [YIN98,YIN99] and its standard connection with the simultaneous stabilization problem [VID85]. Finally, robust stabilization problems will be studied following [BAL10] and the references therein.

Deliveries.

The final report of the task.

Risks.

The study of a constructive version of Deligne's result is a delicate issue which belongs to a general problem in modern algebra which aims at recognizing when projective modules are free (*K*-theory). The first problem investigated in this task can be understood as a kind of generalization of the famous Quillen-Suslin theorem [LAM07], which solves a question raised by Jean-Pierre Serre (another Fields Medalist). This fact explains why the corresponding problem of control theory (computation of doubly coprime factorization of stabilizing *n*D systems) has been largely open since the 80s. We will use our expertise in this domain (e.g., constructive version of the Quillen-Suslin theorem [FAB07], constructive version of Stafford theorem [QUA07], implementations of these theorems in computer algebra systems, constructive solutions of Lin-Bose's conjectures extending Serre's conjecture [FAB07]) to investigate this problem. Moreover, this problem has been studied in the literature of *n*D systems and was completely/partially solved for particular classes of *n*D systems [LIN98,LINa01,LINb01]. If no full solution can be obtained, then we will restrict our attention to important subclasses of *n*D systems satisfying certain conditions (e.g., 0-dimensional case, Roesser or Fornasini-Marchesini models, repetitive systems). Any success in this direction will have an impact on the multidimensional systems community. Finally, help from M. Benidir (Paris Sud, L2S) [BEN 99], a specialist on stabilities of *n*D systems, will be useful as well as the help from both A. Mahboubi (Inria Saclay) and M. Safey El Din (Paris 6, Inria Rocquencourt), specialists in CAD techniques and real algebraic geometry.

People involved.

T. Cluzeau (XLIM), H. Mounier (Paris Sud), A. Quadrat (INRIA Saclay-Île-de-France, in charge), Na. Yeganefar (LATP), Postdoctorate student (INRIA Saclay-Île-de-France)

3.2.4 Task 4. Application to spatially distributed systems and to time-delay systems

Goals.

Finite-dimensional/lumped approximation of a spatially distributed system (e.g., a partial differential equation) generally produces a high dimensional system with a large number of inputs and outputs, which yields tedious control designs. The recent technological progress makes feasible the idea of microscopic devices with actuating, sensing, computing, and telecommunications devices such as *microelectromechanical systems* (MEMS). The possibility to produce large arrays of such devices and to instrument systems governed by partial differential equations with them gives unprecedented capabilities for control (e.g., flow control for drag reduction [HO96], smart mechanical structures [BAN96]). Moreover, networks of autonomous units with sensing and actuation capabilities (e.g., platoons [MEL71,CHU74], automated highway systems [RAZ96,SWA99], airplane formation flight [WOL96], satellite constellations [SHA01]) has brought a renewal of interest in the study of distributed control design for spatially interconnected systems [BAM02,DAN03,DUL04,LAN05], systems interconnected over a graph [LAN04] or over a discrete symmetry group [REC04]. The goal of this task is to apply the different results developed in Tasks 1-3 to plant defined by large numbers of interconnected systems or by spatially distributed systems (infinite, periodic, finite extent, boundary conditions) [LAN05]. More classically, we will also apply the results which will be developed in the other tasks to differential time-delay systems. Finally, the above approaches show that a natural framework for the study of spatially distributed linear systems (e.g., partial differential equations) should be based on sheaf theory [BRE97] and algebraic analysis [KAS86]. This new approach which will be investigated and applications to the above classes of systems will be given.

Program.
Since the class of *n*D systems contains the class of systems over rings [SON76], constant time-delay systems and underdetermined systems of PDEs can be directly studied within the framework of *n*D systems. For instance, see [DYM11] for a model and the control of a sorption process using 2D systems, and [BQ10,CHY05,CLU08,CLU09,FLI98,MOU05,POM99,POM04,QUA10,QUA13] for the applications of techniques based on polynomial matrices and module theory to constant time-delays linear systems and underdetermined linear systems of PDEs (e.g., elasticity, electromagnetism, general relativity).

We will apply the different results developed in the other tasks to the class of spatially distributed systems [BAM02,DAN03,DUL04,LAN05], systems interconnected over a graph [LAN04] or over a discrete symmetry group [REC04]. Our results will bring a new light on the study of these important classes of systems. Explicit examples of spatially distributed systems of finite extent, i.e., defined over a bounded domain, with boundary conditions will be studied; in particular, the two-sided platoon [LAN05] and the problem of stabilization of fluid flow in a channel [BAM02]. Since the approach developed in [BAM02,DAN03,DUL04,LAN05] avoids finite-approximations of distributed systems (which lead to high dimensional systems with a large number of inputs and outputs), our results will yield tractable and computable results which are easily implementable in our dedicated symbolic or numerical packages.

In [BAM02,DAN03,DUL04, LAN04,LAN05, REC04], spatially distributed systems and of interconnected systems are considered as families of ordinary differential systems, i.e., 1D systems, parameterized by continuous variables (e.g., the Laplace variables corresponding to the space variables) or by discrete ones (e.g., the position of the units in the interconnection topology, the discretization variables). This approach goes in a similar direction as the one initiated in [MOU05] which considers certain classes of partial differential equations with boundary actuators and sensors as a sheaf of ordinary differential systems over the domain of the system. Based on sheaf theory [BRE97] and algebraic analysis [KAS86], a general approach to distributed systems, suitable for analysis and synthesis problems, will be investigated and applied on classical linear partial differential equations. Finally, this approach will be compared with [WOI09,WOI10].

Methods.
Techniques based on polynomial matrices and module theory will be directly applied to constant time-delay systems and underdetermined systems of PDEs as explained in [CHY05, FLI98,MOU05,POM99, QUA10].

Algebraic methods developed in Task 3 will be used for the study of time-delay systems. Indeed, the main motivation for the study of the ring of rational functions without poles in the complex unit poly-disc in [KAM84] was the study of differential time-delay systems of neutral type in the frequency domain.

Moreover, linear/nonlinear techniques (Lyapunov functions, linear matrix inequalities, S-procedure, optimal control) will be used to study spatially distributed systems and interconnected systems and they will be compared with the ones developed in [BAM02,DAN03,DUL04, LAN04,LAN05, REC04].

Deliveries.
The final report of the task.

Risks.
There is no actual risk for the first two points of the program. The only risk of this task could be the last point since our knowledge may not enable us to find a sheaf theoretical approach to control problems for

distributed. If so, our investigations will help us find the main problems and discuss them with specialists of sheaf theory and algebraic analysis (e.g., P. Schapira, Paris 6, C. Sabbah, Polytechnique).

People involved.
H. Mounier (Paris Sud), A. Quadrat (INRIA Saclay-Île-de-France, in charge), Cluzeau (XLIM), F. Silva (XLIM)

3.2.5 TASK 5. *N*D PACKAGES

Goals.
Development of symbolic, symbolic-numeric and numeric packages dedicated to the study of multidimensional systems and particularly to the simulation (computation of trajectories for different models such as Fornasini or Roesser, continuous, discontinuous or repetitive systems), to analysis problems (structural properties, invariants, equivalent representations, transformations from one representation to another one), and to synthesis problems of *n*D systems (computation of stabilizing controllers and of the Youla-Kucera parameterization of all the stabilizing controllers, study of robust/optimal/strong/simultaneous stabilization problems). Since these 3 packages will be developed in a computer algebra system (Maple) and in a scientific computation system (Matlab or Scilab), an interface in the system Sage (http://www.sagemath.org/) will be developed so that the 3 packages can be simultaneously used within the same friendly system. These packages with their interfaces will be the first general package dedicated to multidimensional systems and this set aims at being the main one used by the multidimensional systems theorists.

Program.
This is divided into 2 sub-goals.

The first one is to develop a Maple package dedicated to the symbolic study of *n*D systems, and particularly to the equivalent representations of *n*D systems (e.g., transfer matrices, Fornasini or Roesser models, continuous, discontinuous or repetitive systems, modified Spencer form). An important issue for Task 3.3.4, which aims at combining different approaches to stabilities and stabilization problems, is to pass from one representation of an *n*D system to another one by means of explicit transformations. An emphasis will also be put on realization problems of *n*D systems defined by transfer matrices.

The second sub-goal is to develop a package in Matlab or Scilab for the simulation of different models of *n*D systems (e.g., Fornasini or Roesser, continuous, discontinuous or repetitive systems). This task will be done by Master students (LIAS) in collaborations with Ni. Yeganefar.

Finally, using the existing interfaces between the Sage system and Maple, Matlab and Scilab systems, the 3 packages will be interconnected through Sage in order to be simultaneously used within the same friendly system.

Methods.
First sub-goal: Within the algebraic analysis framework, the problem of the equivalence of different representations of an *n*D system can be reformulated as the problem of determining different presentations of a finitely presented module, intrinsically defining the *n*D system, over a certain ring of functional operators. Within homological algebra, the problem of passing from one representation to another leads to the computation of certain homotopy maps. To achieve this goal, we will use constructive results developed in [CLU08, CLU09,CLU11] and constructive version of some of their extensions developed in [WAR78]. These results will be implemented in Maple based upon the *OreModules* [CHY07] and *OreMorphisms* [CLU09] packages.

Deliveries.
Three different packages (the first one in Maple, the second one in Sage using Maple and Matlab or Scilab, and the third one in Matlab or Scilab) and their interfaces in the Sage system.

Risks.
First sub-goal: Based on our experience of developing the Maple packages *OreModules* [CHY07] and *OreMorphisms* [CLU09], this task should be rather straightforward.

Second sub-goal: Our experience (*QuillenSuslin* [FAB07] and *Stafford* [QUA07] packages) will be precious while developing this new package. If no constructive proof of Deligne's theorem can be obtained, then we will focus on important sub-classes of *n*D systems for which doubly coprime factorization can be explicitly obtained or use the general parametrization of all the stabilizing controllers developed in [QUAb06].

Last sub-goal: No risk.

People involved.
Thomas Cluzeau (XLIM, in charge), A. Quadrat (INRIA Saclay-Île-de-France), Postdoctorate student (INRIA Saclay-Île-de-France), Ni. Yeganefar (LIAS), Masters students (LIAS)

3.2.6 TASK 6. MASTER/PHD COURSES (DRAFT) ON *N*D SYSTEMS

Goals.
Harmonizing the results in the tasks 1/2/3 (possibly 4/5) and constructing a draft for a future written course on multidimensional systems. Preparing a workshop on nD systems.

Program.
During the precedent tasks, multiple definitions of stability and criteria should have been proposed/investigated. Synthesizing these approaches in order to have a complete and comprehensive work on stability for multidimensional systems is the program. This will be the basis of a master/PhD degree courses.

Methods.
No specific method will be used here as this task is the fusion of the precedent tasks.

Deliveries.
A draft proposal for a course synthesizing the work of the project for master/PhD students.

Risks.
No risk.

People involved.
A. Quadrat (INRIA Saclay-Île-de-France), Ni. Yeganefar (LIAS, in charge), O. Bachelier (LIAS)

3.3. TASKS SCHEDULE

The 48-month duration project will allow funding 36-month PhD grants (task 1, some margin is required for advertisement and selection) and 1 one year Post-doc position (task 3 and 5).
Here is a detailed report of the schedule and the expected deliveries (Table 1 and 2).

YEARS	Year 1				Year 2				Year 3				Year 4			
TASKS	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4
Task 1: Lyapunov theory (nonlinear tools)					M1.1			M1.2				M1.3		🗐		
Task 2: Repetitive systems (linear tools)					M2.1			M2.2			M2.3	🗐				
Task 3: Fractional representation approach				M3.1			M3.2	🗐								
Task 4: Application to time-delay systems and PDEs										M4.1				M4.2		🗐
Task 5: *n*D packages			M5.1				M5.1				M5.2 & M5.3				M5.2	🗐
Task 6: Master/PhD courses on *n*D systems														M6.1		🗐
General Project Meetings	⚐		⚐		⚐		⚐		⚐		⚐		⚐		⚐	⚐

🗐 Task Final Report

Table 1: Tasks schedule overview with related milestones

Task	Mile-stone	Deliverable (synthetic view, see detailed description in § 3.3)	Responsible	Date
1	M1.1	Detailed description of the bibliographical background on stability of *n*D systems	LIAS	Month 15
	M1.2	Report on theoretical advances on Lyapunov theories	XLIM/LIAS	Month 24
	M1.3	Report on theoretical advances of the stabilization problem and their possible applications	LIAS	Month 36
	FR1	Final Report on Task 1 and associated communications to conferences and publications	XLIM/LIAS	Month 42
2	M2.1	Detail description of the bibliographical background of repetitive systems	LIAS	Month 15
	M2.3	Intermediate report on theoretical advances	LIAS	Month 24
	M2.4	Emphasis of the interest the KYP approach on iterative learning control	ISSI	Month 33
	FR2	Final Report on Task 2 and associated communications to conferences and publications	ISSI/LIAS	Month 36
3	M3.1	Report on an algorithmic version of Deligne's proof and its applications to *n*D systems (stabilization, controllers)	INRIA	Month 12
	M3.2	Report on the strong/simultaneous/robust stabilization problems	XLIM	Month 21
	FR3	Final Report on Task 3 and associated communications to conferences and publications	INRIA/XLIM	Month 24
4	M4.1	Report on the applications to time-delay systems	XLIM/INRIA	Month 30
	M4.3	Report on the applications to distributed systems	XLIM/INRIA	Month 42
	FR4	Final Report on Task 4 and associated communications to conferences and publications	INRIA/XLIM	Month 48
5	M5.1	Master Students Report: Matlab/Scilab toolbox: Simulation of Roesser and Fornasini Models for discrete systems	LIAS	Months 9 and 21
	M5.2	Master Student Report: Matlab/Scilab toolbox: repetitive and continuous systems, analysis and synthesis	LIAS	Months 33 and 45
	M5.3	Maple toolbox: algebraic manipulations of *n*D systems and their equivalent forms	INRIA/XLIM	Months 33
	M5.4	Maple/Matlab/Sage toolbox for the synthesis of *n*D systems in the frequency domain	INRIA/XLIM	Months 45
	FR5	Final Report on Task 5 and associated communications to conferences and publications	INRIA/LIAS	Month 48
6	M6.1	Short version of the course in order to prospect	LIAS	Month 42
	FR6	Final Report on Task 6 and propositions of part of the course to different institutions	INRIA/LIAS	Month 48

Table 2: Key milestones and associated deliverables

4. DISSEMINATION AND EXPLOITATION OF RESULTS, INTELLECTUAL PROPERTY

The project is mainly dedicated to academic research. Most of its results will therefore be primary published in scientific conferences and journals with a significant attention to their quality and overall impact. One of the main contributions of the project is also the delivery of a complete toolbox for multidimensional systems which will be available on the project's website (http://www.lias-lab.fr/perso/nimayeganefar/ Please not that this address is likely to be changed). But academic research doesn't mean disconnected from the real world. Therefore we have also looked for recognition in applying to the competitiveness cluster in high technologies - *elopsys* - located in the Limousin region and we have received an agreement of labeling.

A strong emphasis will be placed on the educational part of the project especially in LIAS. With the notoriety that has been gained during the last conference on *n*D systems in LIAS, the members of the project would like to develop and expand this research area in France. This is achieved as highlighted above by publishing and/or attending important journals/conferences but also by teaching to students mainly in Master degree. Focusing on research, it is indeed easy to forget or dismiss the required educational effort in order to make these (difficult) topics accessible to students but this is – we believe – one of the most important tasks of a researcher. Far from a burden, this is actually a win-win situation where the researcher, who needs to make his work accessible to the student, learns to stand back from his work helping him to better understand his current research. At the end of the project, draft lectures/tutorials will therefore be a starting project for a future course on multidimensional systems for students attending a Master degree. The possibility to plan a workshop on the subject will also be discussed at the end of the project.

Finally, in order to continue the synergy created during the project, a debate will be held during the last meeting to discuss the opportunity of creating a new workgroup in France, part of the GDR-MACS, on multidimensional systems. This would be an important achievement of the project in terms of dissemination but it is, given the current state of the field in France, impossible to say how realistic it will be at the end of the project.

5. CONSORTIUM DESCRIPTION

5.1. PARTNERS DESCRIPTION, RELEVANCE AND COMPLEMENTARITY

This is the first time that in France most of the active researchers on multidimensional systems (XLIM, INRIA Saclay-Île-de-France, LIAS) have been gathered in order to make a significant contribution to the field. The intrinsic mathematical difficulties, skyrocketing as soon as we pass the first dimension, have lead us to seek the help of strong mathematicians (LATP, XLIM) creating a consortium largely multidisciplinary. A significant contribution could not have been achieved without the help of one of the most important laboratory in Europe on multidimensional systems (ISSI) with expertise on a specific area of *n*D systems which has received considerable attention in the past decade (i.e. repetitive systems and iterative learning control).

This is however not just a congregation of researchers from different fields as it has been already pointed out during the description of the different tasks (section 3.3). Almost each partner has a unique skill that is required in order to achieve the general goal (see section 5.3). Moreover most of the members have been working together for years and have therefore developed strong human relationships creating a healthy research environment. Emmanuel Moulay (XLIM) and Nima Yeganefar (LIAS) have been studying together since during their PhDs in Ecole Centrale de Lille. Nima Yeganefar (LIAS) and Nader Yeganefar (LATP) are brothers. They have already published and recently submitted an article for IEEE-TAC on *n*D systems. Olivier Bachelier (LIAS) and Wojciech Paszke (ISSI) count several publications on the leading journal of multidimensional systems (Multidimensional systems and Signal Processing). Thomas Cluzeau (XLIM) and Alban Quadrat (INRIA Saclay-Île-de-France) have also been collaborating together for several years now with an impressive number of publications on *n*D systems.

Below, a description of the different partner is given. A short specification on the expertise of each member is been introduced in section 5.3.

1. LIAS (Ni. Yeganefar, O. Bachelier, Na. Yeganefar (LATP), PhD student)

The “Laboratoire d’Informatique et d’Automatique pour les Systèmes” (LIAS) arises from the grouping of the “Laboratoire d’Automatique et d’Informatique Industrielle” (LAII, EA 1219) and from the “Laboratoire d’Informatique Scientifique et Industrielle" (LISI, EA 1232). This new laboratory will be officially created next year (1st of January 2012). It is composed of 35 teachers/researchers working on automatic control, electrical engineering and information technology. Selected applications are the transport, the energy and their environmental impacts. The LIAS is organized into 4 main groups and 2 transversal topics. Among these 4, the researchers involved in this project are mainly members of the group entitled “Commande Robuste des systèmes multivariables”. Olivier Bachelier was the general chairman of the last (IEEE) conference on multidimensional systems which was held in Poitiers September 2011. The conference was a huge success with more than 50 international researchers attending. The idea of the MSDOS project stemmed from the discussions during this event. Nader Yeganefar from LATP in Marseilles has been attached to XLIM for administrative reasons.

2. INRIA Saclay-Île-de-France (A. Quadrat, Hugues Mounier (University Paris Sud, LS2), Postdoctorate student)

INRIA Saclay-Île-de-France is a national research institute dedicated to computer science and automatic control. Alban Quadrat belongs to the DISCO project which aims at developing new methods for robust control of time-delay systems, infinite-dimensional systems, and multidimensional systems. This project is a joint project with the CNRS (L2S) and Supélec. Alban Quadrat has been an active member of the international *n*D community for 15 years (associate editor of the Journal Multidimensional Systems and Signal Processing, Program committee of *n*DS11 and *n*DS13, organizer of invited sessions at international conferences (e.g., MTNS 2006, MTNS 2010, SSSC 2013) dedicated to *n*D systems, semi-plenary speaker at MTNS 2008, PHC Polonium with ISSI (2003-2004)). With his collaborators, he has developed a rich interplay between multidimensional systems, modern algebra (module theory, homological algebra), symbolic computation, and mathematical physics. Hugues Mounier, member of L2S, is one of the main iniator of the module-theoretical approach to constant time-delay systems and is a specialist of nonlinear systems and distributed parameter systems.

3. XLIM (T. Cluzeau (XLIM), E. Moulay (XLIM), F. Silva (XLIM))

XLIM is a research institute in both Limoges and Poitiers built from the grouping of several laboratories which were working mainly in the field of engineer sciences. It is a mixed research unit depending on the University of Limoges and on the French National Research Center (CNRS). The laboratory is composed of more than 350 teachers/researchers and PhD students, working in a large area of topics such as the design of electromagnetic device, photonics, cryptography and computer security, image processing, or number theory. XLIM is organized in 6 research departments; researchers involved in the project are from the department of Mathematics and Computer Sciences (Thomas Cluzeau, Francisco Silva) and Signal Image Communications (Emmanuel Moulay).

4. ISSI (W. Paszke)

Modern Control Systems and Optimization Laboratory provide a laboratory environment for both education and research in the area of computer-based control systems, optimisation, and application of artificial intelligence methods. The educational profile of the laboratory is fully correlated with the lectures on automatic control, modern control systems, and the modelling and simulation of control systems, which are delivered to both undergraduate and graduate students of Computer Science and Electrical Engineering. Multidimensional systems and repetitive processes are one of the main research areas of the laboratory.

5.2. QUALIFICATION OF THE PROJECT COORDINATOR

Olivier Bachelier received his PhD degree from the INSA in 1998. He kept on working for one year for the LAAS-CNRS and the INSA. In 1999, he joined the « Institut Universitaire de Technologie » (IUT) of the University of Poitiers and the « Laboratoire d'Automatique et d'Informatique Industrielle » (LAII) in Poitiers, where he has been working up to now. He received the "Habilitation à Diriger les Recherches (HDR)" in March 2009 and recently (2012) got promoted to the Professeur rank with a position obtained at the University of Poitiers in LIAS.

His main work interests are the robust analysis and control of uncertain linear models, particularly matrix root-clustering, robust pole placement, eigenstructure assignment. He is also interested in Descriptor linear models and linear nD-models, especially hybrid Roesser models for which he provided (together with W. Pazske and D. Mehdi) the first generic nD-version of the Kalman-Yakubovich-Popov lemma.
Since January 2012, he is an associated editor of the international journal *Multidimensional Systems and Signal Processing* (Springer). He was the general chair of the last international conference on this domain, *nDS'11*, which was held in LIAS, Poitiers, in September 2011.

He is the one who gathered the participants of the project for he has strong links with almost all the members: people from his laboratory of course but also people in XLIM and INRIA with whom he has exchanged on several occasions. He also met several times Wojciech Paszke during his short time stays at the LIAS with whom he has several publications, and finally he exchanged with Alban Quadrat during the last nDS'11 conference. As a long time researcher and heavily invested in the field, with a strong background in theoretical aspects of control systems, he brings new ideas and questions which makes him the natural leader of the group.
A publication list is available at http://laii.univ-poitiers.fr/bachelier/publications.php

5.3. QUALIFICATION AND CONTRIBUTION OF EACH PARTNER

A summary of the contribution and field or research of each member is given below.

Partner LIAS

Partner LIAS	Name	First name	Position	Field of research	PM	Contribution to the project
LIAS (in charge)	Bachelier	Olivier	Pr.	Mult. Systems	24	Coordinator task 2 Expertise on linear systems and S-procedure approaches
LIAS	Yeganefar	Nima	Mcf	Mult. Systems	24	Coordinator task 1/6 Expertise on time delay systems and Lyapunov techniques
LIAS	xxxx	xxxx	PhD	Control systems	36	Task 1/2
LIAS	xxxx	xxxx	Master		24	Task 5
LATP	Yeganefar	Nader	Mcf.	Riemannian geometry	12	Expertise in analyze and geometry

Partner INRIA Saclay-Île-de-France

Partner	Name	First name	Position	Field of research	PM	Contribution to the project
INRIA Saclay (in charge)	Quadrat	Alban	Inria	Mult. Systems	17	Coordinator task 3/5 Expertise in algebraic methods and symbolic computation
Supelec	Mounier	Hugues	Prof.	Control systems/time delay	15	Expertise in algebraic methods, nonlinear systems and PDEs

				systems		
INRIA Saclay	xxxxx	xxxxx	Post doc	Control systems/ Mathematics	12	Task 3

Partner XLIM

Partner	Name	First name	Position	Field of research	PM	Contribution to the project
XLIM (in charge)	Cluzeau	Thomas	Mcf.	Mult. Systems	20	Expertise in algebraic methods
XLIM	Moulay	Emmanuel	CNRS	Nonlinear Systems	16	Coordinator task 4 Expertise on nonlinear systems and PDEs
XLIM	Silva	Francisco	Mcf.	Control systems	8	Expertise on nonlinear systems and PDEs

Partner ISSI (Poland)

	Name	First name	Position	Field of research	PM	Contribution to the project
In charge	Paszke	Wojciech	Lecturer	Mult. Systems	12	Expertise on repetitive systems

Participation to other projects:

	name	PM	Project name, financing institution, grant allocated	Project title	coordinator name	Start and end dates
N°	Na. Yeganefar	28.8	ANR-10-BLAN 0105, 200k€	ACG	Andrei Moroianu	2011/2014
N°	E. Moulay	16	ANR-12-BLAN, 400k€	TORID	Sylvain Brémond	2013/2016
N°	H. Mounier	16	Digiteo 2011-043D, 100k€	EcceHomo	H. Mounier	2011/2015

6. Scientific justification of requested resources

6.1. Partner 1: LIAS

- *Equipment*

None

- *Staff*

1 PhD student, 36 months, tasks 1 and 2, 100% funded by the project (profile in control systems with strong mathematical skills)
4 Master students (one per year), 6 months each, mainly task 5, 100% funded by the project
Cost: 111k€

- *Subcontracting*

None

- *Travel*

LIAS+LATP
2 days stay (4 times during the project) in INRIA Saclay-Île-de-France: 3 members
1 week stay (3 times during the project) in LATP: 1 member
1 week stay (1 times during the project) in ISSI: 2 members
1 month stay in ISSI: 1 member (PhD student)
1 week stay (3 times during the project) in LIAS: 1 member (LATP)
2 international conferences on multidimensional systems: 3 members
2 international conferences: 2 members
2 national conferences: 3 members
Cost: 44k€

- *Costs justified by internal procedures of invoicing*

None

- *Other expenses*

2 laptops
Various books related to the project
Cost: 4k€

TOTAL COST FOR LIAS: 159k€ (including 110k for PhD/masters hiring)
Please note that the master students are in training (for a total of 24 months) and are not considered full researchers.

6.2. PARTNER 2: XLIM

- *Equipment*

None

- *Staff*

None

- *Subcontracting*

None

- *Travel*

2 days stay (4 times during the project) in INRIA Saclay-Île-de-France: 2 members
1 week stay (4 times during the project) in INRIA Saclay-Île-de-France: 1 member
2 days stay (4 times during the project) in INRIA Saclay-Île-de-France: 1 member
1 week stay (1 time during the project) in LATP Marseille: 1 member
2 days stay (4 times during the project) in LIAS Poitiers: 2 members
2 international conferences on multidimensional systems: 2 members
2 international conferences: 2 members
2 national conferences: 2 members
Cost: 35k€

- *Costs justified by internal procedures of invoicing*

None

- *Other expenses*

2 laptops
Various books related to the project
5k€

TOTAL COST FOR XLIM: 40k€

6.3. Partner 3: INRIA Saclay-Île-de-France

- *Equipment*

None

- *Staff*

1 post doc position, 12 months, task 3, 100% funded by the project
Cost: 49k€

- *Subcontracting*

None

- *Travel*

2 days stay (2 times during the project) in LATP: 2 members
2 days stay (4 times during the project) in LIAS: 2 members
1 week stay (4 times during the project) in XLIM: 1 member
1 week stay (2 times during the project) in XLIM: 1 member (post doc)
2 international conferences on multidimensional systems: 2 members
2 international conferences: 2 members
2 national conferences: 2 members
Cost: 26k€

- *Costs justified by internal procedures of invoicing*

None

- *Other expenses*

1 laptop
Cost : 2k€

TOTAL COST FOR INRIA SACLAY: 77k€ (including 49k€ for post doc hiring)

6.4. Partner 4: ISSI

No funding is requested as Partner 4 is not in France.

7. References

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8. LIST OF RESUME

Bachelier, Olivier. 40 ans, Maître de conférences à l'Université de Poitiers

Bibliography

Olivier Bachelier was born in Châteauroux, France, in 1971. He received the Engineer's Degree and the "Diplome d'Etudes Approfondies" (Masters' Degree) with specialization in control from the INSA (Institut National des Sciences Appliquees) of Toulouse, France, in 1994. From December 1995 to 1998, he was a Ph.D. student at the LAAS (Laboratoire d'Analyse et d'Architecture des Systemes) of the CNRS (Centre National de la Recherche Scientifique) in Toulouse, France. He received the PhD degree from the INSA in 1998. He kept on working for one year for the LAAS-CNRS and the INSA. In 1999, he joined the « Institut Universitaire de Technologie » (IUT) of the University of Poitiers and the « Laboratoire d'Automatique et d'Informatique Industrielle » (LAII) in Poitiers, where he has been working up to now. The LAII is to join the LIAS (« Laboratoire d'Informatique, d'Automatique et des Systèmes »). He received the "Habilitation à Diriger les Recherches (HDR)" in March 2009.
His main work interests are the robust analysis and control of uncertain linear models, particularly matrix root-clustering, robust pole placement, eigenstructure assignment. He is also interested in Descriptor linear models and linear nD-models, especially hybrid Roesser models for which he provided (together with W. Pazske and D. Mehdi) the first generic nD-version of the Kalman-Yakubovich-Popov lemma.
Since January 2012, he is an associated editor of the international journal *Multidimensional Systems and Signal Processing* (Springer). He was the general chair of the last international conference on this domain, *nDS'11*, which was held in LIAS, Poitiers, in September 2011.

List of publications

1. Robust Root-Clustering analysis through extended KYP lemma
O. Bachelier, D. Mehdi
SIAM Journal on Control and Optimization, vol. 45(1), p. 368-391, 2006

2. On Pole Placement via Eigenstructure Assignment Approach
O. Bachelier, J. Bosche, D. Mehdi
IEEE Transactions on Automatic Control, vol. 51(9), p. 1554-1558, 2006

3. On the KYP lemma and the multidimensional models
O. Bachelier, W. Paszke, D. Mehdi
LAII-ESIP Research Report No. 20070410OB
Multidimensional Systems and Signal Processing, A paraître

4. Robust S-regularity of matrix pencils applied to the analysis of descriptor models
B. Sari, O. Bachelier, D. Mehdi
Linear Algebra and its Applications, vol. 435(5), p. 923-942, 2011

5. Robust control with finite frequency specification for uncertain discrete linear repetitive processes
W. Paszke, O. Bachlier
Multidimensional Systems and Signal Processing, A paraître, 2013

Cluzeau, Thomas, 35 ans, Maître de conférences à l'Université de Limoges
(*http://www.ensil.unilim.fr/~cluzeau/*)

Bibliography

Thomas Cluzeau received a MS in 2000, and a PhD in 2003 both in Mathematics, and Applications from the University of Limoges (France). He is a member of the Calcul Formel project of the DMI of XLIM (UMR CNRS 7252) from the university of Limoges. His research interests are in computer algebra, and applications.

List of publications

1 - Cluzeau, T., Quadrat, A., "Serre's reduction of linear systems of partial differential equations with holonomic adjoints", *Journal of Symbolic Computation* (JSC), 47 (2012), 1192-1213.

2 – Barkatou, M. A., Cluzeau, T., El Bacha, C., "Simple forms of higher-order linear differential systems and their applications in computing regular solutions", *Journal of Symbolic Computation* (JSC), 46 (2011), 633-658.

3 - Cluzeau, T., Quadrat, A., "Factoring and decomposing a class of linear functional systems", *Linear Algebra and its Applications* (LAA), 428 (2008), 324-381.

4 - Cluzeau, T., Quadrat, A., "*OreMorphisms*: A homological algebraic package for factoring, reducing and decomposing linear functional systems",Topics in *Time-Delay Systems: Analysis, Algorithms and Control*, J.-J. Loiseau, W. Michiels, S.-I. Niculescu, R. Sipahi, Lecture Notes in Control and Information Sciences (LNCIS), Springer, 179-195, Août 2009.

5 – Chakhar, A., Cluzeau, T., Quadrat, A., "An algebraic analysis approach to certain classes of nonlinear systems of partial differential equations", *Proceedings of the 7th international Workshop on Multidimensional (nD) Systems* (nDS'11), Poitiers (France), 05-07/09/2011.

Quadrat, Alban, 39 ans. Chargé de Recherche INRIA Saclay, DISCO project

Bibliography

Alban Quadrat was born in 1973 at Le Chesnay in France. He studied pure and applied mathematics at the University of Versailles, then he obtained a Masters degree in Control Theory and Signal Processing at the University of Orsay (Paris XI), and he received a PhD in Mathematics from the Ecole Nationale des Ponts et Chaussées (CERMICS, Paris) under the supervision of Jean-François Pommaret (1999). He joined INRIA Sophia Antipolis (France) in 2001 as a Researcher after having completed a postdoctoral position at the Department of Pure Mathematics at the University of Leeds (United Kingdom) under the supervision of J. R. Partington (Marie-Curie fellowship). He received his Habilitation in Mathematics and its Applications from the University of Nice in 2010. Since 2011, he has been working at INRIA Saclay – Île-de-France in the new project DISCO (L2S, Supélec, France).
His main interests are in mathematical systems theory (multidimensional systems, behavioural approach, infinite-dimensional systems, stabilization problems), algebra (algebraic analysis, module theory, homological algebra, symbolic computation), algebraic/differential/non-commutative geometry, and mathematical physics.
He is an associated editor of the international journal *Multidimensional Systems and Signal Processing* (Springer). He organized invited sessions on multidimensional systems and its connections with symbolic computation in international conferences (e.g., MTNS 06, MTNS 10), was a semi-plenary speaker at MTNS 08 (Virginia, USA), and a member of the program committee of the last international conference on this domain, *nDS'11* (Poitiers, 2011).

List of publications

1. Quadrat, A. (213). "Grade filtration of linear functional systems", to appear in Acta Applicandae Mathematicae, 60 pages, doi: 10.1007/s10440-012-9791-2.

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List of publications

1. E. Moulay and W. Perruquetti, “Stabilization of nonaffine systems: a constructive method for polynomial systems”, IEEE Transactions on Automatic Control, Vol. 50, No. 4, pp. 520–526, 2005.

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Bibliography

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1. Boussaada, I., Mounier H., Niculescu S.-I., Cela, A., Analysis of Drilling vibrations: A Time-Delay System Approach, *20th Mediterranean Conference on Control and Automation*, 2-6 of July 2012, Barcelona, Spain.

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Bibliography

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List of publications

1. Wojciech Paszke, Eric Rogers, Krzysztof Gałkowski: Finite Frequency Range Control Law Synthesis for Differential Linear Repetitive Processes - 50th IEEE Conference on Decision and Control and European Control Conference, December 12-15, 2011 at the Hilton Orlando Bonnet Creek, Orlando, Florida

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Bibliography

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B) Autres expériences professionnelles:

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- Membre de la commission de spécialistes d'Aix-Marseille 1 (2007-2008 et 2010), membre extérieur du comité de sélection d'Aix-Marseille 3 (2008), de Montpellier 2 (2009), et de Bordeaux 1 (2011).
- Invitation de 6 mois au Hausdorff Center for Mathematics à Bonn par W. Ballmann (printemps-été 2009).

C) Cinq principales publications depuis 2006:

- *On the fundamental group of some open manifolds*, Diff. Geom. Appl. **25**, 251-257 (2007).
- *Embeddability of some strongly pseudoconvex CR manifolds,* (avec George Marinescu), Trans. Amer. Math. Soc. **359,** 4757-4771 (2007).
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