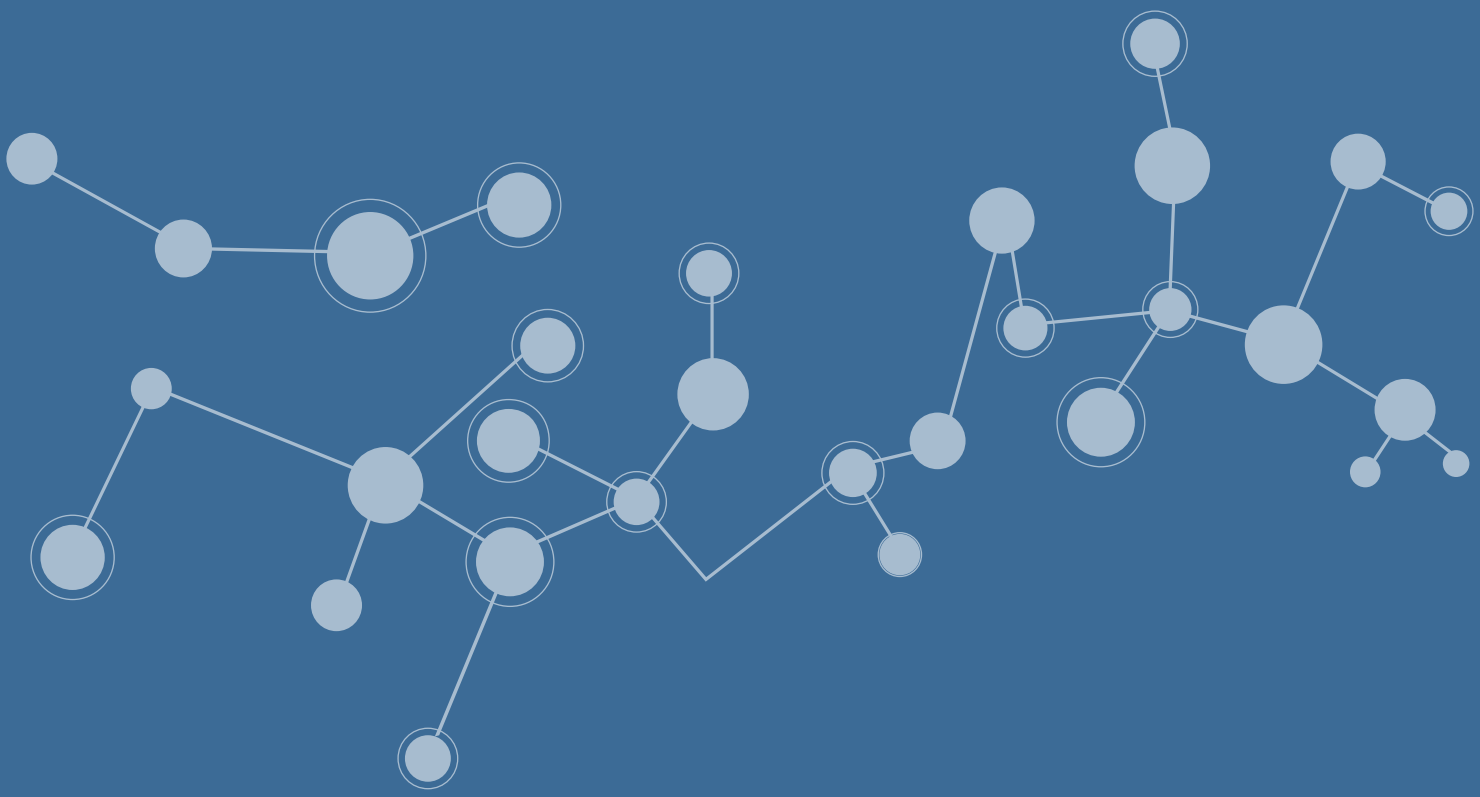
DOCUMENT D'AUTO-ÉVALUATION

DEPARTMENT 1

Algorithms, Computation, Geometry and Image



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DAE Département 1 : Algorithmique, calcul, image et géométrie

DEPARTMENT HEAD
Sylvain Lazard

Department 1 entitled *Algorithms, Computation, Image and Geometry* regroups seven teams that share scientific interests on these topics. Beside *algorithms* which is a common center of interest to all these teams (and of course to some teams of other departments as well), we share several other areas of interest. *Geometry* plays an important role in all teams. *Symbolic and algebraic computing* is of common interest to CARAMBA and GAMBLE, *image* is of interest to ADAGIO, PIXEL and TANGRAM, *combinatorics and complexity* also concerns several groups as ADAGIO, CARAMBA, and GAMBLE, *certified computing* (in a sense that sometimes requires computing with arbitrary precision numbers) is also of common interest to CARAMBA, GAMBLE, ADAGIO, and PIXEL. Finally *machine learning* concerns ABC, PIXEL and TANGRAM.

DAE Département 1 : Algorithmique, calcul, image et géométrie

1. Retour sur l'évaluation 2011-2016

Critère 1 : qualité et production scientifiques

Appréciation et recommandations : Les équipes ont toutes une excellente dynamique, notamment autour de leurs leaders scientifiques. Les résultats scientifiques, toujours notables, quelquefois exceptionnels, se concrétisent par des publications significatives au meilleur niveau. Il faut continuer à viser l'excellence, tout en accompagnant davantage les scientifiques moins productifs, pour qu'elle soit le fait de tous.

Nous avons continué à viser l'excellence. Nous décrivons nos actions d'accompagnement des chercheurs les moins productifs dans le DAE du labo (§D3R2).

Critère 2 : rayonnement et attractivité académiques

Appréciation et recommandations : Toutes les équipes bénéficient d'un excellent rayonnement : de très nombreuses collaborations en France et à l'étranger ont débouché sur des publications communes, beaucoup d'articles et de démonstrations ont remporté de nombreux prix. Pour deux de ces équipes, ce rayonnement est exceptionnel. Les équipes ADAGIO et MAGRIT pourraient profiter des collaborations internationales de leurs partenaires nationaux pour accentuer leur reconnaissance internationale. Il faudrait mettre en place un recrutement de cadres (enseignants-chercheurs ou chercheurs) pour les équipes ADAGIO et MAGRIT, vraiment déficitaires de ce point de vue.

La reconnaissance internationale de l'équipe Magrit-Tangram est excellente ; en témoigne leur équipe associée CURATIVE [1] établie depuis 2017 avec le laboratoire de Biorobotics à l'université d'Harvard à Cambridge (voir pour plus de détails la section 6 ci-dessous et la Section 5 page 200 du Portefolio D1-1).

L'équipe Adagio est fortement impliquée dans une collaboration de long terme avec les acteurs académiques et socio-économiques français en foresterie ; ces actions sont soutenues par deux projets ANR (cf. section 1 page 89 du Portefolio D1-1) ; ce projet en lien avec des acteurs socio-économiques régionaux est national par nature.

Les recrutements de chercheurs et enseignants-chercheurs ne sont pas pilotés par les départements. L'equipe Magrit-Tangram à cependant recruté un PR (en promotion) durant la période, soit 1/3 des 3 cadres (PR/DR) recrutés par le département durant la période.

Critère 3 : interactions avec l'environnement économique, social, culturel et sanitaire

Appréciation et recommandations : Il y a de très importants développements logiciels, très visibles pour toutes les équipes, et une attention soutenue à la diffusion de leurs thèmes sociétaux ou pluridisciplinaires. Mais les collaborations avec les mathématiciens devraient être renforcées. Le département pourrait s'investir davantage dans la vulgarisation scientifique pour attirer des jeunes sur ses thèmes, et rester imaginatif sur de potentielles interactions sociétales, même dans les thématiques plus fondamentales.

1. https://team.inria.fr/curative/

Nos relations avec les mathématiciens sont soutenues sur le long terme. Nous listons nos collaborations avec des mathématiciens durant la periode d'évaluation en footnote. [2] Concernant la vulgarisation scientifique, nos actions sont également nombreuses : Cf. section 3 ci-dessous.

Critère 4 : organisation et vie du département

Appréciation et recommandations : Il faut développer l'animation scientifique du département [...] Le département ne devrait pas se limiter à élaborer une politique " réactive", mais développer davantage une politique scientifique prospective [...]

La politique scientifique prospective est a priori gérée par les équipes à l'interieur des départements, ce qui est un choix stratégique du laboratoire, décliné dans les départements. La direction du laboratoire et les responsables de départements pilotent néanmoins les réorganisations d'équipes quand cela est utile. Il faut également souligner que les équipes travaillent régulièrement à leur politique scientifique : Les équipes Inria (Caramba, Gamble, MFX, Pixel, Tangram) rédigent tous les 4-5 ans un document de prospective scientifique à l'occasion de leur évaluation Inria. Ces documents de prospective étaient aussi demandés à toutes les équipes lors des évaluations HCERES antérieures et ont été demandés par l'UL en 2021 en prévision de la présente vague d'évaluation (document qui n'est plus demandé in fine par l'HCERES). De plus, à la suite de ces travaux de prospective effectués par les equipes, la direction du laboratoire avec (tous) les responsables de départements ont organisé une journée par département de réflexion prospective avec les responsables d'équipes, à l'automne 2021.

Concernant l'animation scientifique, nous organisons au sein du département depuis 2016-2017 des séminaires mensuels et des journées annuelles ; cf. section 7 ci-dessous pour plus de détails.

2. Nous avons des collaborations avec des probabilistes, notamment avec Julien Michel (Laboratoire de Mathématiques et Applications, Poitier) [58], Nicolas Chenavier (Laboratoire de Mathématiques Pures et Appliquées, Univ. du Littoral Cote d'Opale) [108], Imre Barany (Institute of Mathematics, Budapest, Hongrie) [161] et Laurent Decreusefond (Telecom ParisTech) [214]. Ces collaborations sont structurées dans l'ANR Présage (2011-2015) et l'équipe associée Trip (2018-2020) portées par O. Devillers (LORIA) et impliquant de plus Nicolas Broutin (Laboratoire de Probabilités, Statistique et Modélisation, Sorbonne Univ.), Pierre Calka et Benjamin Dadoun (Laboratoire de Mathématiques, Rouen), Philippe Chassaing, Valentin Féray, et Régine Marchand (IECL, Nancy) et Arnaud Rousselle (Institut de Mathématiques, Dijon).

Nous collaborons avec des mathématiciens en géométrie non-Euclidienne : Gert Vegter (Bernoulli Institute for Mathematics and Computer Science, Groningen, Pays Bas) [238, 365, 366, 380, 481], Vanessa Robins (Mathématiques appliquées, Australian National University) [480], Myfanwy Evans (Institute for Mathematics, Postdam, Allemagne) (Benedikt Kolbe et Myfanwy E Evans. "Enumerating Isotopy Classes of Tilings guided by the symmetry of Triply-Periodic Minimal Surfaces". In : *SIAM Journal on Applied Algebra and Geometry* 6.1 [2022]. Accepted and to appear. doi : 10.1137/20M1358943. hal-03482422), ainsi qu'avec Jean-Marc Schlenker et Hugo Parlier (Dpt. de Mathématiques, Luxembourg) [477, 334] dans un projet ANR international (SoS).

En géométrie non-linéaire, nous avons une collaboration suivie avec Fabrice Rouillier (Inria, Institut de Mathématiques de Jussieu, Paris) [46, 250, 91, 117, 463] (Daouda Niang Diatta, Sény Diatta, Fabrice Rouillier, Marie-Françoise Roy et Michael Sagraloff. "Bounds for polynomials on algebraic numbers and application to curve topology". In : *Discrete and Computational Geometry* [février 2022]. doi : 10.1007/s00454-021-00353-w. hal-01891417) et également avec Marie-Françoise Roy (Institut de Recherche Mathématique de Rennes) (Daouda Niang Diatta, Sény Diatta, Fabrice Rouillier, Marie-Françoise Roy et Michael Sagraloff. "Bounds for polynomials on algebraic numbers and application to curve topology". In : *Discrete and Computational Geometry* [février 2022]. doi : 10.1007/s00454-021-00353-w. hal-01891417) et Frédéric Bihan (Laboratoire de Mathématiques LAMA, Université Savoie Mont Blanc) [103] géométrie algébrique.

Nous collaborons en géométrie discrète avec Andreas Holmsen (Department of Mathematical Sciences, KAIST, Corée du Sud), Martin Tancer (Department of Applied Mathematics, Charles Univ., Tchèquie) [141] et Boris Bukh (Carneggie Mellon University, Pittsburg, USA) [135].

Critère 5 : implication dans la formation par la recherche

Appréciation et recommandations : Les thèmes du D1 sont faiblement représentés dans les masters, même ceux de la géométrie et de l'image, malgré la mise en place d'une orientation très appliquée dans le Master " Apprentissage, Vision et Robotique " à partir de 2018. [...]

Même si la filière " Apprentissage, Vision et Robotique " peut ouvrir des perspectives au Continuum Géométrie- Image pour recruter des doctorants de profil plus appliqué, elle ne peut pas permettre le recrutement de doctorants sur la culture D1. On peut songer à monter un parcours dans le Master Informatique spécialisé dans les thèmes géométrie et image ; on peut aussi chercher à monter non pas une filière complète, mais quelques enseignements typiques de la culture " MathInfo " du D1, en collaboration avec des mathématiciens.

Il faudrait aussi ré-équilibrer la composition des membres du D1, et recruter au moins un PR (sur les thèmes géométrie et image par exemple) qui soit sur le site principal de l'UL, avec l'objectif de peser davantage dans les contenus au niveau L et porter une filière du master qui reflète la culture D1. Parallèlement, il serait important que les chercheurs du D1 comprennent leur intérêt à s'investir davantage dans les masters.

Dans cette situation défavorable, le D1 doit rester vigilant afin de garder l'accès aux allocations de l'université. C'est en particulier important pour des équipes comme ADAGIO.

Les membres du D1 s'investissent dans les responsabilités d'enseignement et de formation par la recherche. Citons notamment : F. Lauer est responsable du M1 Informatique à Nancy depuis 2016. I. Debled-Rennesson est co-responsable de la filière "Apprentissage, Vision et Robotique" du M2 Informatique. M. Minier est responsable de l'orientation "Sécurité Informatique, Réseaux et Architectures Virtuelles" du M2 Informatique. P. Gaudry a été entre 2016 et 2020 le vice-président de la Commission de mention Informatique de l'École doctorale IAEM. S. Lazard est responsable (national) de la Mission Jeunes Chercheurs Inria depuis 2018.

Concernant les contrats doctoraux, notons en premier lieu que le département recrute de façon substantielle des doctorants issus des formations locales.[3] Au sein du laboratoire, le D1 est bien doté de contrats doctoraux de l'université avec une ou deux allocations tous les ans (sur 6 ou 7). Enfin, l'équipe Adagio a une bonne dynamique avec les recrutements de 3 nouveaux doctorants sur les quatre dernières années.

Concernant les recrutements, comme déjà mentionné dans la section 1, le département a recruté 1 PR (en promotion) sur les thématiques d'image à Nancy, F. Sur, dans l'équipe Tangram.

Critère 6 : perspectives et stratégie scientifique à cinq ans

Appréciation et recommandations : [...] Il est essentiel que [l'équipe ABC] se rapproche des activités d'apprentissage et de fouille de données menées au sein des départements D4 et D5, et y apporte ses points de vue complémentaires. Ensuite, même s'il y a des arguments scientifiques qui justifient la scission de l'équipe ALICE, cette scission doit être accompagnée par le département, afin de préserver des interactions fortes entre les deux moitiés, et éviter un émiettement supplémentaire des équipes du D1. Enfin, comme CARAMBA et VEGAS sont deux équipes très proches, qui partagent beaucoup de méthodes et de compétences, elles devraient réfléchir à des collaborations plus précises, sur un sujet mieux délimité, où elles pourraient vraiment travailler ensemble.

L'équipe ABC s'est rapprochée de l'équipe Orpailleur (D4) sur des thématiques de fouille de données et co-encadre avec eux la thèse de F. Gaschi (depuis 2020) [424]. ABC s'est également

3. 16 doctorants issues des formations locales : Khaidja Musayeva, Rémi Decelle, Florian Delconte, Pierre Rolin, Daryna Panicheva, David Lopez, Jean Hergel et Jimmy Etienne : **Master FST informatique** ; Charles Duménil, Tom Masini : **Master FST Math** ; Nathan Boulangeot : **Master FST Physique** ; Arnaud Botella et Julien Renaudeau : **ENSG** ; Maxence Reberol : **Supelec Metz** ; Louis Masucci et Tom Masini : **Polytech Nancy** ; Justine Basselin, Rémi Decelle : **Télécom Nancy.**

rapprochée de l'équipe Capsid (D5) avec qui ils ont à présent un séminaire commun et co-encadrent la thèse d'A. Moniot (depuis 2019) [345, 483, 484].

Concernant ALICE : Comme mentionné plus haut (§ 1), notre stratégie est de déléguer le plus possible aux équipes leurs politiques scientifiques. Le département n'a donc pas "accompagné la scission de l'equipe ALICE afin de préserver des interactions fortes entre les deux moitiés" mais les membres des deux équipes ont néanmoins conservé des interactions importantes [73, 127, 139, 205].

Les équipes CARAMBA et VEGAS-GAMBLE sont deux équipes dont les cultures scientifiques ont une intersection non vide mais leurs thématiques de recherche sont assez éloignées.

2. Domaine 3 : Production scientifique

2.1. Référence 1 : La production scientifique de l'équipe satisfait à des critères de qualité.

2.1.1 Synopsis

L'UL a demandé aux laboratoires de rédiger pour juin 2021 les bilans des laboratoires en vue de l'évaluation HCERES 2016-2020. Ce document est présenté dans le Portefolio D1-1, et nous y faisons référence régulièrement dans le présent document. Pour faciliter la lecture des évaluateurs, nous avons extrait des éléments de notre rapport de juin 2021 pour les reproduire ici ; nous les avons cependant laissés en anglais, ce qui explique le mélange de langues dans ce présent document.

Les sections suivantes sont organisées comme suit : §2 Composition du département ; §3 Thématiques de recherche ; §4 Principaux résultats ; §5 Production scientifique et qualité ; §6 Réputation académique ; §7 Vie du département ; §8 Relations académiques.

2.1.2 Composition

Le département est composé (en 2021) de 44 enseignants-chercheurs et chercheurs permanents (5 PR, 15 MCF, 9 DR, 15 CR) et d'une soixantaine de non permanents dont une moitié de doctorants (37 sur 78 en 2021) ; voir Portefolio D1-1 pour les détails. Le département est de plus structuré en 7 équipes, de 4 à 10 permanents chacune, dont les thématiques scientifiques sont bien ciblées et cohérentes dans des projets d'équipes. Cette structuration en équipe-projets est historique et est héritée de l'époque où la direction du laboratoire et le centre Inria était commune. Cette structuration est efficace car l'impact scientifique de ces equipes est supérieure à la somme de ses parties et elle donne un excellent cadre pour l'accompagnement des doctorants, postdoctorants et jeunes chercheurs.

Ces équipes sont les suivantes :

ABC Apprentissage et Biologie Computationnelle (statistical learning theory, bioinformatics).

ADAGIO Applying Discrete Algorithms to Geometry and Imagery.

CARAMBA Cryptology, arithmetic : algebraic methods for better algorithms (EPC Inria).

GAMBLE Geometric Algorithms and Models : Beyond the Linear and Euclidean realm (EPC Inria).

MFX Matter from Graphics, 3D printing (EPC Inria).

PIXEL Digital geometry processing (EPC Inria).

TANGRAM Visual Registration with Physically Coherent Models (EPC Inria).

2.1.3 Research topics

[Extrait du Portfolio D1-1, Section 2.]

Keywords : algorithms, computing (symbolic, algebraic and numerical), geometry (computational, discrete, probabilistic and non-linear), classification and statistical learning, image processing, 3D printing, computer vision.

Before detailing the research topics of each team, we briefly describe here the main common centers of interest of these teams, in *Algorithms and computation*, *Geometry* and *Image*.

Algorithms and computation is central to the scientific culture of the department and it covers various domains. First, research on *combinatorics and complexity analysis* (worst case or probabilistic) naturally concern several groups, in particular, ADAGIO, CARAMBA, and GAMBLE. On an algorithmic level, *optimization* problems, including convex programming, mixed-integer programming and non-convex optimization are central to the teams ABC, PIXEL, MFX, and TANGRAM, while they also are of some interest to the GAMBLE team. *Learning theory* and *classification* are also of concern to several groups ; it is central to ABC's research but other groups share some interest on this topic, in particular TANGRAM and PIXEL (constrained optimization, spectral analysis). *Arithmetic and certified computing*, in the sense that algorithms are usually designed over the reals although they are implemented with integers or floating-point numbers, plays an important role in CARAMBA, GAMBLE, ADAGIO, and PIXEL. On an algorithmic level, CARAMBA and GAMBLE are also very involved in *symbolic and algebraic computing*.

Geometry : As hinted above, geometry plays an important role in all teams. Geometry refers here to a wide spectrum of theories, each of which depending both on the mathematical objects under considerations (e.g. simplicial and cellular complexes, algebraic curves and surfaces) and on the properties that are studied (e.g. intersections, topology, singularities, combinatorial structure). The forms of geometry known as *discrete, projective, digital, algebraic*, and *computational* are each of interest to several groups.

Image : Finally, the department is interested in methods that use images as input data *(image analysis, image processing, registration, modeling from images)* and methods that produce images *(image synthesis, texture generation)*. These two classes of methods share a common background of interest to half the teams of the department, namely PIXEL, TANGRAM, MFX and ADAGIO.

The application domains of the department include geometric modeling, imaging, augmented reality, numerical simulation, videogames, bioinformatics, computer algebra systems and cryptography. This spectrum of applications is quite large and it should be mentioned that most teams have fairly disjoint such application domains. This can be explained by the fact that departments were created to bring together teams with the same scientific culture rather than with an application-based view. The rest of this section summarizes the research topics of the six teams.

ABC contributes to three different fields : **learning theory, statistics and biology.** Its contribution to the learning theory regards pattern recognition, regression and unsupervised learning. It primarily takes the form of guaranteed risks and model selection methods. The main topic addressed in statistics is the specification and analysis of semi-parametric models, including kernel machines. In biology, the focus is on the empirical inference of structures.

ADAGIO's goal is to develop efficient algorithms on **discrete and digital structures.** In order to develop efficient algorithms, the properties of the underlying structures need to be understood thoroughly. The main objective of ADAGIO is to study these properties, which can be *geometrical*, *arithmetical* or *combinatorial* depending on the situation. More specifically,

ADAGIO is interested in the fundamental aspects of *discrete and digital geometry*, which characterizes discrete objects that have a geometric (planar or spatial) interpretation. The general goal is to define a theoretical framework to translate to $\mathbb{Z}^n$ basic notions of the Euclidean geometry (such as distance, length and convexity) as faithfully as possible. The algorithms developed by ADAGIO are naturally used in imagery applications.

CARAMBA studies the algorithmic aspects of **cryptography and cryptanalysis** from the top-level mathematical background down to the optimized high-performance software implementations. CARAMBA strives in particular to develop and provide fast software dealing with various mathematical objects. These mathematical objects are of utmost importance for cryptology, as they are the background of the most widely developed cryptographic primitives, such as the RSA cryptosystem or the Diffie-Hellman key exchange. One central challenge is the assessment of the security of proposed cryptographic primitives through the study of two cornerstone problems : the integer factorization and discrete logarithm problems. Another key challenge is to produce cryptographic implementations that are both efficient and secure.

GAMBLE's objective is to contribute to the development of an effective geometric computing dedicated to non-trivial geometric objects and spaces. Our main axes of research focus on the design of data structures and algorithms in **computational geometry** and the study of their **combinatorial and probabilistic properties.** We focus in particular on **non-linear objects** and **non-Euclidean spaces**.

MFX focusses on the computational aspects of shape modeling and processing for **Additive Manufacturing (3D printing).** We address the challenges that arise in the shape modeling task and its processing for AM as a single unified process. The **modeling techniques** we develop take into account the geometric constraints imposed by the manufacturing processes (e.g., minimal thickness, overhang angles, trapped material) as well as the desired object functionality (e.g., rigidity, porosity). We also develop novel AM **deposition strategies and geometric algorithms** for the actual fabrication of the modeled objects.

PIXEL is a research team in digital geometry processing. We are interested in **parameterization techniques, meshing and reconstruction of objects from 3D point clouds.** We investigate mathematically correct, scalable and numerically stable solutions, by studying the properties of the objective function in order to develop efficient optimization algorithms. In cooperation with industrial partners, we also develop applications of our research in various fields, in particular in oil exploration, bio-chemistry and computer-aided design.

TANGRAM does research in **computer vision** and aims at addressing some specific aspects of modeling and visual registration which are still largely unsolved. Indeed, difficulties originate in the nature of the scene (poorly textured or specular environments), or in the motion undergone by the object. Physically coherent modeling, accurate registration and development of associated robust estimation techniques are the main focus of the team. Targeted transdisciplinary applications are mixed and augmented reality, computational photomechanics and minimally invasive medical interventions.

2.1.4 Main Results

We shortly present some main results we obtained in our three axes of research, namely *Algorithms and Computation*, *Geometry* and *Image*. [Extrait du Portfolio D1-1 Section 3 page 7.]

Algorithms and Computation

NFS-like algorithms for factoring and discrete logarithm (Caramba). The number field sieve (NFS) is the best known algorithm for factoring integers used in the RSA cryptosystem, with time and space complexities that are not fully exponential but still far from polynomial.[4] Many variants of NFS have been designed to handle other problems, in particular the discrete logarithm problem (DLP) in finite fields.

Our main results concern both the fundamental algorithms used in NFS and setting new records. The progress in fundamental algorithms enables us to set new records, and in many cases targetting new records forces us to invent new algorithms.

Among the fundamental algorithms, we have made progress on the DLP over elliptic curves [55], the search and ranking of polynomials for NFS [43, 175], sieving for DLP [6], saving vectors in the block Lanczos algorithm [459], computations with sparse matrices [243], faster individual logarithms for DLP [144], and studying asymptotic complexities [331, 224].

We have set new (and current) records for integer factorization with the factorization of RSA with 250 decimal digits [329, 437] and for discrete logarithm computations, both over prime fields and prime-power fields [57, 247, 270, 329, 194].

On the cryptanalysis side, we had two major contributions : we performed a record kilobit DLP computation over a kilobit field, which had a nice impact since it showed that one could "forge" a DLP key [267] ; and in the LogJam attack [101] we showed how one could defeat some still currently used 512-bit DLP keys.

Isolating singular points & Certified drawing of plane curves (Gamble). Almost all systems for drawing planar curves are subject to errors such as missing self-intersections or components. A key subproblem, which has received a lot of attention in the literature, is to isolate the singular and critical points of such curves. We reached a major achievement on this subproblem by presenting algorithms that are morally optimal in the sense that improving them would essentially require to improve bounds on several other fundamental problems (on resultants and roots isolation of univariate polynomials) that have hold for decades [46, 91]. We also developped an efficient software for providing certified drawings, which can be queried on a web server : *Isotop*. For possibly-analytic generic manifolds that often appear in applications, we also developed a new certified numerical approach based on Catastrophe Theory that allows us to handle 2D projections of smooth nD curves and 3D projections of smooth 4D surfaces that were beyond reach with previous state-of-the-art algorithms [116, 309, 382, 21, 223]. The originality of these works resides in the design of *certified and numerical* approaches.

Fast roots isolation (Gamble). We developed a breakthrough method for the two fundamental problems of evaluating a polynomial on multiple points and finding its complex roots, with a bit complexity quasi-linear in the degree. In particular, our approach solves a problem that has been open for 50 years. It was selected to the prestigious conference FOCS [431], and the practical efficiency of this method led to a transfer contract with Waterloo Maple Inc.

Theory of margin multi-category pattern classification (ABC). One of the main open problems of this theory is the characterization of how the confidence interval of an upper bound on the probability of error should vary as a function of the three basic parameters which are the sample size m, the number C of categories and the margin parameter γ. We made two major contributions on these dependences. First, we refuted

4. Complexities are expressed with the function $L_N(\alpha, \beta) = \exp(\beta(\log N)^\alpha(\log\log N)^{1-\alpha})$, with $\alpha = \frac{1}{3}$ for NFS.

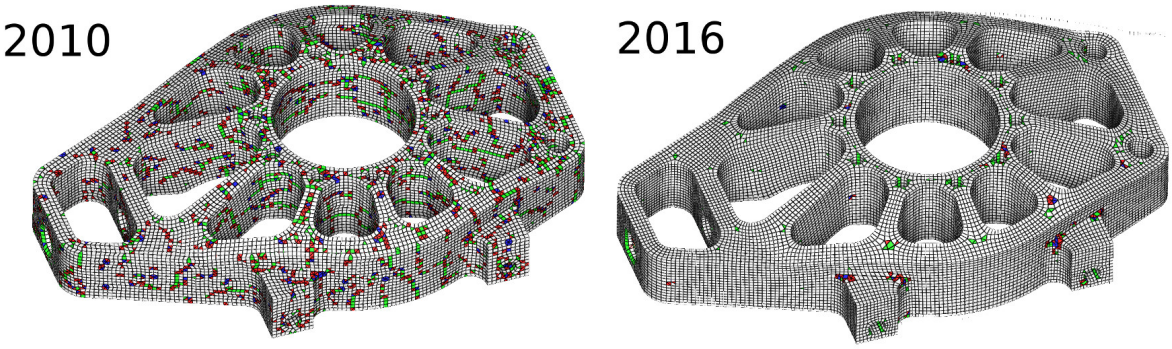

FIGURE 1.1 – Hexahedral meshes.

a classical conjecture and stated that, irrespective of the choice of the margin loss function, even when no hypotheses are made regarding a coupling among the outputs of the classifier, it is always possible to obtain a confidence interval depending sublinearly on C [85]. Our second contribution (preprint) deals with the use of combinatorial dimensions to measure the *capacity* of the class of margin functions [479]. We established that sharper bounds could be obtained by replacing the standard scale-sensitive combinatorial dimension, the fat-shattering dimension, with γ-Ψ-dimensions. This time, the gain is located in the dependence on γ.

Switching regression (ABC). Regression is a standard problem in machine learning for which numerous methods and analyses are available. However, most assume that the optimal target model is a smooth function. Switching regression is a setting closely related to piecewise-smooth regression, where the data generating process can switch between the different operating modes or models arbitrarily. Our main achievements are the development of global optimization algorithms for two particularly difficult non-convex problems raised by switching regression : switching linear regression and bounded-error estimation [119]. While most works focus on local optimization heuristics without global optimality guarantees or with guarantees valid only under restrictive conditions, our approach always yields a solution with a certificate of global optimality. We also obtained statistical guarantees for those models [189, 342].

Geometry

Hexahedral meshes (Pixel). Meshes composed of hexahedra (deformed cubes) are desirable for certain numerical simulations because they can improve both performances and precision. However, they are very difficult to generate. We developed in 2010 one of the first fully automatic algorithms that generates "hex-dominant" hybrid meshes ; see Figure 1.1 (left) where non-hexahedra are colored. Based on an optimization of a direction field [257] and a global parameterization steered by the direction field [72], we made a quantum leap in 2016 where we succeeded to significantly reduce the number of non-hexahedral elements as shown in Figure 1.1 (right).

Robustness of 3D meshes (Gamble). We presented a breakthrough result on the problem of removing self-intersections in 3D polygonal meshes [176]. The problem is to compute a set of interior-disjoint triangles whose geometry is close to that of the input and such that the output vertices have coordinates of fixed precision, typically *doubles*. This problem is important in academic and industrial contexts because many applications require models

without self intersections. Despite its theoretical and practical relevance, there was almost no literature on the subject and we presented the first satisfactory theoretical solution.

Infill structures for additive manufacturing (MFX). We introduced the notion of procedural stochastic foams for Additive Manufacturing [69, 95, 125, 147, 196, 226]. These methods provide an efficient way to process and fabricate complex internal micro-structures whose density and orientation can be freely scaled in space, which produces oriented orthotropic mechanical responses within the volume of the object. This yields lightweight objects whose deformations can be controlled.

Geometry Processing for additive manufacturing (MFX). We contributed several advances on the topic of geometry processing for additive manufacturing : novel techniques for the computation of offset surfaces [353, 367], slicing strategies [77, 201], trajectory generation algorithms for curved deposition [73, 109, 139, 152], and variable width 2D offsetting [184].

Discrete geometric structures (Gamble). We proved that order types of various classical models of random point sets typically encounter only a vanishingly small fraction of all order types (of the given size) [340]. This reveals that these combinatorial structures are hard to sample in practice, and therefore that the geometric algorithms that *de facto* operate on them are difficult to test. We also presented solutions for two open problems from the 1970's : the algorithmic complexity of deciding the shellability of a simplicial complex [141] and a conjecture of Bondy and Hajnal on the growth function of hypergraphs [135].

Pose from ellipsoid-ellipse correspondences (Tangram). Given an ellipsoid, there is an infinity of planes and projection centers (i.e. poses) that produce the same projected ellipse. We have investigated novel ways to infer the pose from a small number of ellipse-ellipsoid correspondences.We proved that a closed form estimate of the translation can be uniquely inferred from the rotation matrix of the pose [312]. The trajectory of a camera for one correspondence was derived in [22]. This approach is however sentive to errors on the detected ellipses. With more than two correspondences, we proposed [178] a robust full 6D pose method which operates from at least two object detections and reduces the DoF to only one thanks to two simplifying yet realistic assumptions.

Image

Localization and 3D tracking (Tangram). The challenge of image-based localization is to compute pose estimates with a good accuracy regardless of the user's motion, the nature of the scene or the environmental conditions. One of our main achievement is the development of new strategies that take advantage of the impressive progress made by object recognition techniques, and especially of their good invariance to illumination and viewpoint changes. Contrary to existing techniques that require an accurate model of the scene for training, our methods work from generic algorithms such as semantic labeling or object detection. In the context of registration of buildings for urban augmented reality, we have proposed an original Expectation-Maximization framework which jointly refines registration and semantic segmentation and allows us to cope with inherently noisy semantic maps [266, 12]. Another achievement is the development of pose algorithms which use objects as landmarks and approximate 2D detected objects with ellipses and 3D objects with ellipsoids. These contributions [313, 351] build on our theoretical results on pose from ellipsoid-ellipse correspondences described above.

Biomechanical models for modeling and tracking curved and deformable objects & Applications to medical imaging (Tangram). We focussed on biomechanical

models for handling shape and deformation constraints, and improving the modeling and tracking of curved and deformable objects. We addressed in particular the problems of image registration applied to minimally invasive liver surgery [288, 16, 177], image segmentation of heart mitral valve chordae in Computerized Tomography (CT) images [130, 320, 321], and 3D reconstruction of the catheter from 2D X-ray images in interventional radiology [241, 4, 283, 28, 197]. All these projects were based on strong collaborations with partners in clinical research and biomechanical simulation (CHRU Nancy, IHU Strasbourg, Mimesis Inria team and the Biorobotics lab in Harvard).

Contactless measurement for experimental solid mechanics (Tangram). We are engaged in a trandisciplinary collaboration with Institut Pascal on image-based estimation of displacement and strain fields at the surface of materials subjected to mechanical deformation. The aim is to assess and improve the metrological performance of both measurement techniques routinely used in experimental mechanics, namely digital image correlation (DIC) based on random speckle patterns, and the so-called grid method based on Fourier analysis of a regular grid. For instance, measurement resolution of DIC was characterized by taking into account subpixel interpolation in [45], a comprehensive analysis of the grid method was discussed in [60] (2016 Fylde prize for the best paper in the Strain journal), and both methods were confronted in a principled analysis [84] and enhanced through image restoration techniques [142]. A variant of grids, namely checkerboard patterns [143], turned out to give the best compromise between metrological indicators [181], see patent [491]. A synthetic speckle image generator [129] permitted us to build datasets included in the international DIC challenge.[5] This is of uttermost importance to assess the metrological performance of the available DIC variants. A patent was also filed [491].

Geometric tools for noisy digital contour analysis (Adagio). We developed tools for computing geometric characteristics on the discrete noisy curves. In particular, we proposed a new discrete structure called the *Adaptive Tangential Cover* (ACT) [254, 97], which is composed of a sequence of maximum blurred segments of variable thicknesses adapted to the irregular noise present along the curve. This permits to compute decompositions of curves into circular arcs and segments as well as polygonal simplifications [359, 360, 272, 126, 319]. The experimental results demonstrate the efficiency and robustness of the approach and we applied it to hand gesture recognition [279].

CT scans of wood trunks (Adagio). Through a collaboration started in 2010 with INRAE, we worked on the analysis of wood quality based on Lidar data from CT scanners and photos taken in the forest or in a sawmill. One particular issue is the detection of wood knots in trunks in order to optimize their cuts [358]. We also worked on tracking logs from the forest to the sawmill, using biometric information from images of log sections. Here, the images come from low-cost sensors such as smartphone cameras and we developped several methods [377, 378] for automatically detecting different characteristics on log-end images such as pith, growth rings, heartwood and sapwood. Another nice achievment is the detection of defects on tree trunks from high resolution TLS (Terrestrial Laser Scanner) point cloud [352, 261, 457, 195] based on our work on the detection of the center line of 3D objects [251, 357].

2.1.5 Scientific production and quality

La production scientifique sur les six années 2016-2021 pour le département est de 4 livres, 35 thèses, 6 HDR, 189 publications journaux, 143 publications dans des conférences majeures et

5. https://sem.org/dicchallenge

52 dans d'autres conférences.

En termes de qualité des supports de publications, nous avons publié 21 articles dans ACM Transactions on Graphics (TOG) correspondant à 15 articles SIGGRAPH et 6 SIGGRAPH Asia. En dehors de la communauté d'infographie, la diversité des supports de publication renommés est plus diverse et nous en donnons une cartographie ci-dessous.

List of top journals in which we have published (non-exhaustive)

TOG – ACM Transactions on Graphics (21) [50, 69, 257, 72, 77, 81, 95, 109, 125, 127, 131, 139, 145, 147, 152, 156, 184, 196, 201, 218, 232] [6]
JoCG – Journal of Computational Geometry (8) [42, 52, 53, 58, 82, 106, 107, 167]
DCG – Discrete and Computational Geometry (4) [48, 124, 165, 176]
Mathematics of Computation (4) [66, 136, 144, 190]
Designs, Codes and Cryptography (4) [55, 96, 111, 183]
Computer-Aided Design (7) [73, 80, 297, 212, 215, 216, 226]
Journal of Mathematical Imaging and Vision (3) [75, 122, 129]
Experimental Mechanics (3) [45, 59, 84]
Journal of the ACM (2) [138, 141]
Automatica (3) [68, 119, 203]
Journal of Number Theory (2) [187, 193]
Computer Graphics Forum (4) [93, 155, 204, 205]
IEEE Transactions on Information Theory (1) [191]
TNNLS – IEEE Transactions on Neural Networks and Learning Systems (1) [189]
Bulletin of the AMS (1) [137]
Medical Image Analysis (1) [90]
International Journal of Control (1) [134]
IEEE Transactions on Automatic Control (1) [199]

List of top conferences in which we have published (non-exhaustive)

SIGGRAPH (15) [50, 69, 72, 77, 95, 109, 125, 131, 139, 147, 152, 156, 184, 218, 232]
SoCG – Symp. on Computational Geometry (8) [238, 242, 271, 287, 314, 334, 340, 425]
DGCI – Int. Conf. on Discrete Geometry for Computer Imagery (7) [254, 272, 278, 98, 284, 310, 322]
SIGGRAPH ASIA (6) [257, 81, 127, 145, 196, 201]
ISSAC –Int. Symp. on Symbolic and Algebraic Computation (5) [243, 245, 253, 259, 265]
ISMAR – Int. Symp. on Mixed and Augmented Reality (4) [249, 255, 266, 313]
Crypto (3) [329, 331, 333]
ESA – European Symp. on Algorithms (3) – [286, 304, 347]
ICPR – Int. Conf. on Pattern Recognition (3) [251, 261, 294]
Asiacrypt (5) [303, 306, 403, 404, 414]
FOCS – Symp. on Foundations of Computer Science (1) [431]
ECCV – European Conf. on Computer Vision (1) [300]
Eurocrypt (1) [267]
AISTATS – Int. Conf. on Artificial Intelligence and Statistics (1) [342]
IJCAI – Int. Joint Conf. on Artificial Intelligence (1) [269]
NeurIPS (formerly NIPS) – Conf. on Neural Information Processing Systems (1) [277]

Software. Nous avons également produit 35 logiciels durant la période. Nous citons très brièvement les plus importants ci-desssous et référons à la section "Software" page 13 du Portfolio D1-1 pour plus détails : **CADO-NFS** est un important software pour la factorisation d'entiers et le calcul de logarithmes discrets. **GNU MPFR** et **MPC** sont des bibliothèques d'arithmétique avec arrondi exact, lesquelles sont requises pour la compilation de GCC. **Belenios**, un

6. In Computer Graphics, all the proceedings of the top conferences are published as a special issue of a journal : ACM Transactions on Graphics for SIGGRAPH and SIGGRAPH ASIA ; Computer Graphics Forum for EUROGRAPHICS and ACM Symposium on Geometry Processing.

système de vote electronique sécurisé, utilisé en 2020 sur plus de 140 élections et 100 000 votants. **IceSL**, un modeleur 3D pour l'impression additive. **Geogram** et **Graphite** sont deux softwares de maillage et de modélisation 3D, téléchargés environ 50 000 fois chaque depuis 2016. **CGAL** est la bibliothèque de référence mondiale pour les algorithmes géométriques, dans laquelle nous avons contribué 4 packages de triangulation et maillage. **Isotop** est un des très rares algorithmes de tracé certifié de courbes algébriques dans le plan et le seul accessible en ligne. **DGtal** est une bibliothèque open source pour la géométrie des pixels. **TheGridMethod**, une boîte à outil pour la mesure de déplacement et déformation en mécanique expérimentale. >**V**< est un software rapide et efficace pour détecter les points de fuite dans les images non calibrées de scènes urbaines ou intérieures.

2.1.6 Academic reputation and appeal

Prix et distinctions. Nous avons obtenu 18 prix et distinctions : 4 prix de thèse, 2 ERC (starting grant et PoC), 1 IUF, 2 "bug bounties" (sur le vote électronique) , 1 record de calcul, 2 prix L'Oréal-UNESCO et Fullbright, et 8 prix de meilleurs articles. Voir la section "Prizes and Distinctions" page 15 du Portfolio D1-1 pour plus détails.

Invitations et visites. Nous avons été invités à donner des présentations dans au moins 56 évènements internationaux dont 5 " keynote presentations". Voir la section "Invited talks" page 16 du Portfolio D1-1 pour les détails.

E. Thomé a obtenu une bourse Fullbright pour passer une année sabbatique à l'Université de Californie à SanDiego en 2021-2022. A. Guillevic passe une année sabbatique (2021-2022) à l'Université Aarhus Universitet au Danemark. P.-F. Villard a passé un an et demi en année sabbatique (2014-2016) à l'Université Harvard à Cambridge (USA), puis à nouveau 3 fois 1 mois de 2017 à 2019. Il a également passé 3 fois 1 mois de 2017 à 2019 à l'Université d'Uppsala (Suède). De nombreux autres séjours internationaux d'une semaine à un mois ont eu lieu au cours de la période ; Voir la section 2.3.6 Portfolio D1-1 pour les détails.

Les collègues suivants nous ont également rendu visite au cours de la période : Robert Howe (Biorobotics Lab, Cambridge, USA, une semaine), Peter Hammer (Harvard Medical School, Boston, MA, USA, 2 semaines), Douglas Perin (Harvard School of Engineering and Applied Sciences, 2 semaines) semaines), Gert Vegter (Université de Groningue, Pays-Bas, environ 3 fois 1 mois plus 2 semaines), Matthijs Ebbens (Université de Groningue, 1 semaine), Jean-Lou De Carufel et Prosenjit Bose (Carleton Univ., Canada, 1 semaine chacun), Martin Tancer, Vojta Kalusza et Pavel Paták (Université Charles, Canada, 1 semaine chacun). Pavel Paták (Université Charles, Prague, 1 semaine chacun), Andreas Holmsen et Otfried Cheong (KAIST, Corée du Sud, 1 semaine chacun), Zuzanna Patáková (IST Austria, Vienne, 1 semaine) nous ont également rendu visite durant la période d'évaluation.

Projets et contrats. Durant la période 2016-2021, le département a eu, outre les 2 projets ERC (1 starting grant 2012–2017 et 1 Proof of Concept en 2018) et l'IUF junior (2014–2019), 18 projets ANR (dont 8 en tant que coordinateur), ainsi que de nombreuses autres contrats académiques (1 FUI, 2 PEPS, 1 CPER, 1 Région, 1 PIC, 2 projets interdisciplinaires de l'UL, 1 PHC, 1 programme exploratoire Inria, 1 DGA, 1 GDR).

Nous avons également eu 15 contrats avec des entreprises : Docapost, Idemia, NomadicLabs, Canton de Genève, Swiss Post, GE Healthcare, Geometry Factory, AddUp, MapleSoft, Schlumberger, RhinoTerrain, Polygonal Design, CEA, Total, Saint Gobain. Voir la section "Relations with companies and economic players" page 18 du Portfolio D1-1 pour les détails.

Editorial and organizational activities.

Program and Paper Committees. Department members participated to the PCs of many major conferences in our fields and in particular, SIGGRAPH, SIGGRAPH ASIA, SGP, SMI, Pacific Graphics and Euro Graphics in computer graphics, Eurocrypt and Asiacrypt in Cryptology, ISSAC in computer algebra, SoCG in computational geometry, DGCI and IWCIA in discrete geometry, and ICML in machine learning.

Editorial responsibilities. Department members are editors of many of the main journals in our fields. In particular, JoCG, CGTA, IJCGA in computational geometry, IPOL in image processing, ToSC and the *Journal of Algebra* in Cryptology and computational algebra, and *Graphical Models* and TOG in computer graphics. We also have two members in the CGAL Editorial Board.

Steering committees. We are or were member of the steering committees of several conferences : Computational Geometry (chair), ESA in algorithmic, Elliptic Curve Cryptography and ANTS in cryptography and number theory, and DGCI in discrete geometry.

Workshop organizations. Our department regularly organizes various conferences and workshops with, in particular, 17 international events and 7 French ones during the evaluation period.

Services as expert or evaluator.

Thesis and habilitation committees, Hiring committees. We participated to at least 126 PhD and Habilitation committees including 52 as external examiners (rapporteurs), from 2016 to 2020 and excluding those as advisor. We also served in 59 hiring committees for faculty positions or INRIA CRCN positions from 2016 to 2020.

Non-local scientific responsibilities. We chair(ed) the followings commitees and panels : Association française pour la reconnaissance et l'interprétation des formes (AFRIF), its thesis prize committe, and the INRIA Mission Jeunes Chercheurs (url).

We also serve(d) in the followings : HCERES visiting commitees of LTSI (Rennes) and CRIStAL (Lille), CNU 27, Inria evaluation committee, Conseil Scientifique and Conseil D'Administration de la Société Informatique de France (SIF), INRIA BIL, Commission Pédagogique Nationale du MENRT multimedia et Internet, Young Researcher Fellow EGFR, Conseil Scientifique du GdR IM, Comité de direction du GdR IG-RV, CA de l'AFIG, International Association for Pattern Recognition (IAPR, TC18), Comité de pilotage GT-C2 (groupe de travail Codage et Cryptographie).

Local scientific responsibilities. We chair(ed) or co-chair(ed) the followings commitees, panels and diplomas : computer science Master 1st year ; one tracks and one sub-track of the same Master in 2nd year (*Apprentissage, Vision et Robotique* and *Sécurité Informatique, Réseaux et Architectures Virtuelles orientation*) ; Polytech Ingeneer diploma speciality (*Systèmes d'Information et Réseaux*) ; Commission de mention Informatique of the École doctorale IAEM of the University of Lorraine (until 2020) (url) ; Inria "Comipers" hiring committee for PhD and postdoc positions ; two Bachelor diplomas and the fablab "Charlylab" at I.U.T. Nancy-Charlemagne (since 2018) ; German-French virtual center for cybersecurity between LORIA and CISPA (Saarbrucken, Germany) ; LUE impact project DigiTrust (2018-2022).

2.1.7 Life of the department

Seminars We have several types of seminars. First, we have regular meetings where team members explain an article she/he recently read or on-going work. The informal atmosphere of those is critical and since the department has about a hundred members (including non-permanents), these seminars are organized by the 7 teams of the department in order to keep

them small and scientifically focussed. Precisely, MFX, Gamble and Tangram organize such meetings about weekly, bi-weekly and monthly respectively, and Caramba organize them weekly with more formal monthly events. Since the beginning of the pandemic, all these events have moved online with an increased frequency and including other means of interactions (Gathertown, twitter, online chat service, etc.)

Second, we organize department seminars where we invite outside speakers. These seminars are held about monthly (url) and have been on halt since the beginning of the pandemic.

We also organize every year a day of the department in which our PhD students present their work (url) (cancelled in 2020). This is both a way to interact scientifically within the departement and it also helps the thesis committes (Comités de suivi individuel de thèse) to follow the work and help detect possible difficulties that PhD students may have.

Finally, we also co-organize a joint inter-department seminar on the topic of security (SSL). It is held roughly on a monthly-basis and organized by the teams Caramba (dept. 1), Carbone and Pesto (dept. 2), and Resist and Coast (dept. 3). This complement team seminars, with less technical talks targeting a larger audience. While the core participants are from teams working in computer security, there are often participants from other teams or even from outside the lab. This seminar is also on halt since the beginning of the pandemic.

Governance. We run our department with a council that consists of the head of the department and the heads of the teams. This council handles matters at the level of the department such as the recruitment evaluations for PhD candidates and interns on UL contracts, the department bugdet, and the needs for new faculty positions (*profils de postes*). It is also involved in the evaluation process when creating new teams within the department.

It should also be noted that the atmosphere in our department is very pleasant at all levels. We also tend to share the same scientific culture and standards, which naturally facilitates our governance and life.

Recruitments and gender parity. We started the period with 32 permanent members and we recruited 16 new members and lost 5. Hence, 37% of our current permanent members (16 out of 43) were not here at the beginning of the period. This is an important evolution but it has been accomplished smoothly.

In terms of gender parity, we started the period with 7 women in 32 permanent members, that is 22%, and we now have 13 women in 43 members, that is 30%. We are very happy to have substantially improved it. However, our gender parity is sadly still at 22% among PhD students.

2.1.8 Long-term academic relations

Collaborations. We have a large set of collaborators with about 460 co-authors outside the lab over the evaluation period. We have many long-term collaborations with French collegues (see the team's reports – Portfolio D1-1 – for details). Among our main international collaborations we cite those with

- N. Heninger from University of California, San Diego on Cryptography [267, 101, 329, 437, 478].
- Gert Vegter (Groningen) [238, 365, 366, 380, 481] and with Jean-Marc Schlenker and Hugo Parlier (Luxembourg) [477, 334] on non-Euclidean computational geometry, through the Inria Associate Team OrbiCG [7] and the international ANR–FNR SoS project. [8]

7. https://members.loria.fr/Monique.Teillaud/collab/Astonishing/
8. https://members.loria.fr/Monique.Teillaud/collab/SoS/

- Daniele Panozzo (New York) [139, 201], Marc Alexa (TU Berlin) [77, 139], Charlie CL Wang and Tim Kuipers (TU Delft) [109, 139, 184] and Li-Yi Wei and Wenping Wang (Hong Kong) [50, 81, 102, 482] on 3D printing.
- Peter Hammer at the Harvard Biorobotics Lab. through the Inria CURATIVE Associate Team [9] whose aim is to produce patient-based simulation of a closing mitral valve on pathological cases [320, 321].

Finally, we mention two interesting strong inter-disciplinary collaborations we built with :

- The University Hospital of Nancy, GE Healthcare, and MIMESIS Inria team in the context of interventional radiology. Several PhDs were co-supervised with these partners [4, 16, 28]. The PhD thesis of Y. Assis is currently co-supervided by Tangram and CHRU.
- INRAE on image processing applications for the detection of tree defects and wood knots from images of wood trunks [352, 358, 65, 261, 457, 378, 195]. The PhD of Remi Decelle is currently co-supervided in this context.

2.2. Référence 2 : La production scientifique est proportionnée au potentiel de recherche de l'équipe et répartie entre ses personnels

2.2.1 Homogénéité de la production scientifique entre les permanents.

Voir DAE labo.

2.2.2 Accompagnement des jeunes chercheurs.

Voir DAE labo.

2.2.3 Accompagnement des chercheurs qui reprennent l'activité recherche.

Voir DAE labo.

2.2.4 Production scientifique des doctorants.

3.5 publications en moyenne par doctorant en fin de thèse.

3. Domaine 4 : Inscription des activités de recherche dans la société

3.1. Référence 1 : L'équipe se distingue par la qualité de ses interactions non-académiques

We had 7 Cifre grants over the period : S. Rasoamiaramanana (Caramba, 2017–2020) with Orange Gardens at Châtillon-Montrouge (url) [27] ; S. Masson (Caramba, 2018–2020) with Thales Communication & Security, Gennevilliers (url) [26] ; F. Gaschi (ABC, 2020–current) with Posos (url) ; N. Aubry (Adagio, 2013–2018) with Numalliance (url) [3] ; J. Renaudeau (Pixel, 2016–2019) with Schlumberger (url) [20] ; J. Basselin (Pixel, 2019–current) with RhinoTerrain (url) ; C. Delmas (Tangram, 2013–2017) with GE Healthcare (url) [4].

Start-up. We have launched in 2020 the start-up Tessael with Wan-Chiu Li, former PhD of the department, as the CEO. It provides meshing solutions based on a technology that we have been

9. https://team.inria.fr/curative/

developing since 2010. It yields extremely accurate 3D simulations of subsurface environments, opening up new opportunities in three sectors : geothermal energy, geological storage and the oil and gas industry.

Clinical partners : Nancy Hospital, IHU Strasbourg, GE Healthcare. Activities in medical imaging are conducted in tight collaborations both with clinical (CHRU Nancy and IHU Strasbourg) and industrial partners (GE Healthcare). Their aim is to promote the use of AR and simulation in the clinical routines and in particular the planning of interventional procedures.

Cryptanalysis. Our work on integer factorization and discrete logarithm is of interest for governmental agencies and standardization bodies for tuning accurately their key size recommendations. We worked on training and consulting activities with the French Ministry of Defense in 2016–2018. Due to confidentiality clauses, we cannot say much.

E-voting. In connection with our work on the Belenios software, we have participated in five contracts (Docapost, Idemia, NomadicLabs, Canton of Geneva, Swiss Post) where we evaluated the e-voting solutions of the companies and proposed them directions for improvements.

3D printing. We have a continued collaboration with the French metal additive manufacturing company *AddUp*. Details are confidential. We also have regular discussions with potential industrial partners regarding our technologies. Some are ongoing and all are covered by strict non-disclosure agreements.

MapleSoft. A renewable two-years licence and cooperation agreement was signed in 2018 between Waterloo Maple Inc., Canada and Inria, which involves the teams Gamble and Ouragan (Paris).

Meshing : Schlumberger, RhinoTerrain, Polygonal Design, CEA, Total. Following our results on parameterizations, we participated in five contracts where we developed efficient algorithms to compute and optimize meshes to improve numerical simulations.

3.2. Référence 2 : L'équipe développe des produits à destination du monde socio-économique

Patents. We had three patent during the period : *Method for measuring fields of movements and of deformations with check pattern marking and spectral method processing* (Tangram) [491] relates to computational photomechanics. *Dispositif de traitement de prise de vue* (Tangram) [490] relates to image-based localization from object detections. We also have one patent pending (Caramba).

Geometry Factory. CGAL packages developed in Gamble are commercialized by Geometry Factory. There is a permanent contract between Geometry Factory and Inria. During the period, three packages have been released : [485, 486, 488].

MapleSoft. Within our contract with Maple, we started the transfer of our software HEFROOTS for the isolation of the complex roots of a univariate polynomial [431].

Vorpaline is our 3D mesh generation proprietary software distributed by our start-up Tessael.

3.3. Référence 3 : L'équipe partage ses connaissances avec le grand public et intervient dans des débats de société

Medias : Radio broadcasts, TV, Newspapers. We wrote two articles in Binaire (hosted by Le Monde) about cryptography [472, 473] (Binaire 2018, Binaire 2019). Several newspapers articles were also written about our work : Le Monde 2016, Ars Technica 2016, Le Monde 2019,

Ars Technica 2019. Sylvain Lefebvre participated to the radio program "La méthode scientifique" on France Culture in 2017 (podcast). Bruno Lévy appeared in a documentary on France 3 which talked about our project with the astrophysicists of the IAP and the Paris Observatory, and the mathematicians of MOKAPLAN (youtube).

General public activities. We gave a talk on cryptography at La Cité des Sciences, a museum dedicated to science in Paris in 2019. We participate every year to the Fête de la Science and we participated to 3 Ateliers Google during the period.

Actions aimed at young people. We organized MATh.en.JEANS ateliers in 2016, 2017 and 2018 with high-school classes. Several lectures were also given towards middle and high school students and teachers. We gave interviews (video, radio) to promote scientific studies in 2018 and led online panel discussions to help students in high-school to have a clear picture on research in computer science in 2020. We participate to the committee for the Olympiades de mathematiques. We also participated in 2018 to the Ada Lovelace Day, an international celebration of the achievements of women in science, technology, engineering and maths. Workshops were led to introduce computer science unplugged activities at APMEP (Maths teacher association) Lorraine and NSI (computer science teachers) yearly meetings.

Popularization. The research paper [329] on RSA-240, RSA-250 factorization and discrete logarithm computation was vulgarized in [437], targetting engineers (without specific knowledge in cryptography). We also wrote a general audience paper on augmented reality [470] and two on Jan van Eyck's perspective system elucidated through computer vision [475, 476].

3D printing. We promoted 3D printing to several Maker Faire : the Maker Faire Rome 2017 (url), a major event with 100K+ visitors every year. We presented our software IceSL to students, general public and 3D printing enthusiasts and received a *Maker of Merit award* for our project. We also participated in 2019 to the Maker Faire Lille, an Inria Tech Talk at Station-F in Paris (url), the OctoberMAKE of the French FabLabs network (url) and to the Biennale du design Grand Est (url). Sylvain Lefebvre also created quick tutorial videos on Youtube (channel icesl-fr), to help introduce new users to IceSL.

Involvement in E-Educations. Dmitry Sokolov's series of e-courses on computer graphics (url1, url2, url3, url2) is widely known : 5M visitors and code used by Xamarin Workbooks (Microsoft) (url), Ogre3D (url), and Bullet (url). Erwan Kerrien participated in the creation of a MOOC for teachers of the new ICN option (Informatique et Création Numérique), which is part of the Class'Code project (url) as well as its evolution to adapt to the new Digital Science and Technology (SNT) class that is included in the 1st year core curriculum in upper secondary education. He also participated to the creation of a MOOC related to digital usages and sciences (url) in MOOCFOLIO, a PIA3-funded MOOC project (url) whose objective is to help students choose their undergraduate studies after high school.

Références bibliographiques du département 1

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[1] Arnaud Botella. "Unstructured volumetric meshing of geological models for physical phenomenon Simulations". Thèse de doct. Université de Lorraine, avril 2016. tel-01435058.

[2] Hugo Labrande. "Explicit computation of the Abel-Jacobi map and its inverse". Thèse de doct. Université de Lorraine, novembre 2016. tel-01403849.

[3] Nicolas Aubry. "Segmentation and geometric measurements : application to metal tubular objects". Thèse de doct. Université de Lorraine, juillet 2017. tel-01649874.

[4] Charlotte Delmas. "3D reconstruction of curvilinear micro-devices for interventionnal neuroradiology". Thèse de doct. Université de Lorraine, novembre 2017. tel-01653707.

[5] Jérémie Dumas. "Controllable shape synthesis for digital fabrication". Thèse de doct. Université de Lorraine, février 2017. tel-01547313.

[6] Laurent Grémy. "Sieve algorithms for the discrete logarithm in medium characteristic finite fields". Thèse de doct. Université de Lorraine, septembre 2017. tel-01647623.

[7] Mounia Hendel. "Bio-inspired methods applied to real-time analysis of biomedical signals". Thèse de doct. Université Mohamed Boudiaf des Sciences et de la Technologie - Mohamed Boudiaf d'Oran, février 2017. tel-03042290.

[8] Jean Hergel. "Synthesis of fabricable shape from partial specifications". Thèse de doct. Université de Lorraine, février 2017. tel-01546383.

[9] Pierre Rolin. “Viewpoint synthesis for camera pose initialisation”. Thèse de doct. Université de Lorraine, mars 2017. tel-01536649.

[10] Simon Abelard. “Counting points on hyperelliptic curves in large characteristic : algorithms and complexity”. Thèse de doct. Université de Lorraine, septembre 2018. tel-01876314.

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