IN PARTNERSHIP WITH:
CNRS
Université de Lorraine

Activity Report 2012

Project-Team VEGAS

Effective Geometric Algorithms for Surfaces and Visibility

IN COLLABORATION WITH: Laboratoire lorrain de recherche en informatique et ses applications (LORIA)

RESEARCH CENTER
Nancy - Grand Est

THEME
Algorithms, Certification, and Cryptography

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Project-Team VEGAS

Keywords: Algorithmic Geometry, Computational Geometry, Computer Algebra

Creation of the Project-Team: August 01, 2005 .

1. Members

Research Scientists

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Xavier Goaoc [Junior Researcher, Inria, HdR]
Marc Pouget [Junior Researcher Inria]
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Faculty Member

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Administrative Assistant

Helene Zganic [Research technician (TR) Inria]

2. Overall Objectives

2.1. Introduction

The main scientific objective of the VEGAS research team is to *contribute to the development of an effective geometric computing* dedicated to *non-trivial geometric objects*. Included among its main tasks are the study and development of new algorithms for the manipulation of geometric objects, the experimentation of algorithms, the production of high-quality software, and the application of such algorithms and implementations to research domains that deal with a large amount of geometric data, notably solid modeling and computer graphics.

Computational geometry has traditionally treated linear objects like line segments and polygons in the plane, and point sets and polytopes in three-dimensional space, occasionally (and more recently) venturing into the world of non-linear curves such as circles and ellipses. The methodological experience and the know-how accumulated over the last thirty years have been enormous.

For many applications, particularly in the fields of computer graphics and solid modeling, it is necessary to manipulate more general objects such as curves and surfaces given in either implicit or parametric form. Typically such objects are handled by approximating them by simple objects such as triangles. This approach is extremely important and it has been used in almost all of the usable software existing in industry today. It does, however, have some disadvantages. Using a tessellated form in place of its exact geometry may introduce spurious numerical errors (the famous gap between the wing and the body of the aircraft), not to mention that thousands if not hundreds of thousands of triangles could be needed to adequately represent the object. Moreover, the curved objects that we consider are not necessarily everyday three-dimensional objects, but also abstract mathematical objects that are not linear, that may live in high-dimensional space, and whose geometry we do not control. For example, the set of lines in 3D (at the core of visibility issues) that are tangent to three polyhedra span a piecewise ruled quadratic surface, and the lines tangent to a sphere correspond, in projective five-dimensional space, to the intersection of two quadratic hypersurfaces.

Effectiveness is a key word of our research project. By requiring our algorithms to be effective, we imply that the algorithms should be *robust, efficient,* and *versatile*. By robust we mean algorithms that do not crash on degenerate inputs and always output topologically consistent data. By efficient we mean algorithms that run reasonably quickly on realistic data where performance is ascertained both experimentally and theoretically. Finally, by versatile we mean algorithms that work for classes of objects that are general enough to cover realistic situations and that account for the *exact geometry* of the objects, in particular when they are curved.

2.2. Highlights of the Year

BEST PAPER AWARD :

[18] **Multinerves and Helly Numbers of Acyclic Families in Symposium on Computational Geometry - SoCG '12**. É. C. DE VERDIÈRE, G. GINOT, X. GOAOC.

3. Application Domains

3.1. Computer graphics

We are interested in the application of our work to virtual prototyping, which refers to the many steps required for the creation of a realistic virtual representation from a CAD/CAM model.

When designing an automobile, detailed physical mockups of the interior are built to study the design and evaluate human factors and ergonomic issues. These hand-made prototypes are costly, time consuming, and difficult to modify. To shorten the design cycle and improve interactivity and reliability, realistic rendering and immersive virtual reality provide an effective alternative. A virtual prototype can replace a physical mockup for the analysis of such design aspects as visibility of instruments and mirrors, reachability and accessibility, and aesthetics and appeal.

Virtual prototyping encompasses most of our work on effective geometric computing. In particular, our work on 3D visibility should have fruitful applications in this domain. As already explained, meshing objects of the scene along the main discontinuities of the visibility function can have a dramatic impact on the realism of the simulations.

3.2. Solid modeling

Solid modeling, i.e., the computer representation and manipulation of 3D shapes, has historically developed somewhat in parallel to computational geometry. Both communities are concerned with geometric algorithms and deal with many of the same issues. But while the computational geometry community has been mathematically inclined and essentially concerned with linear objects, solid modeling has traditionally had closer ties to industry and has been more concerned with curved surfaces.

Clearly, there is considerable potential for interaction between the two fields. Standing somewhere in the middle, our project has a lot to offer. Among the geometric questions related to solid modeling that are of interest to us, let us mention: the description of geometric shapes, the representation of solids, the conversion between different representations, data structures for graphical rendering of models and robustness of geometric computations.

3.3. Fast prototyping

We work in collaboration with CIRTES on rapid prototyping. CIRTES, a company based in Saint-Dié-des-Vosges, has designed a technique called Stratoconception® where a prototype of a 3D computer model is constructed by first decomposing the model into layers and then manufacturing separately each layer, typically out of wood of standard thickness (e.g. 1 cm), with a three-axis CNC (Computer Numerical Controls) milling machine. The layers are then assembled together to form the object. The Stratoconception® technique is cheap and allows fast prototyping of large models.

When the model is complex, for example an art sculpture, some parts of the models may be inaccessible to the milling machine. These inaccessible regions are sanded out by hand in a post-processing phase. This phase is very consuming in time and resources. We work on minimizing the amount of work to be done in this last phase by improving the algorithmic techniques for decomposing the model into layers, that is, finding a direction of slicing and a position of the first layer.

4. Software

4.1. QI: Quadrics Intersection

QI stands for "Quadrics Intersection". QI is the first exact, robust, efficient and usable implementation of an algorithm for parameterizing the intersection of two arbitrary quadrics, given in implicit form, with integer coefficients. This implementation is based on the parameterization method described in [10], [29], [30], [31] and represents the first complete and robust solution to what is perhaps the most basic problem of solid modeling by implicit curved surfaces.

QI is written in C++ and builds upon the LiDIA computational number theory library [24] bundled with the GMP multi-precision integer arithmetic [23]. QI can routinely compute parameterizations of quadrics having coefficients with up to 50 digits in less than 100 milliseconds on an average PC; see [10] for detailed benchmarks.

Our implementation consists of roughly 18,000 lines of source code. QI has being registered at the Agence pour la Protection des Programmes (APP). It is distributed under the free for non-commercial use Inria license and will be distributed under the QPL license in the next release. The implementation can also be queried via a web interface [25].

Since its official first release in June 2004, QI has been downloaded six times a month on average and it has been included in the geometric library EXACUS developed at the Max-Planck-Institut für Informatik (Saarbrücken, Germany). QI is also used in a broad range of applications; for instance, it is used in photochemistry for studying the interactions between potential energy surfaces, in computer vision for computing the image of conics seen by a catadioptric camera with a paraboloidal mirror, and in mathematics for computing flows of hypersurfaces of revolution based on constant-volume average curvature.

4.2. Isotop: Topology and Geometry of Planar Algebraic Curves

ISOTOP is a Maple software for computing the topology of an algebraic plane curve, that is, for computing an arrangement of polylines isotopic to the input curve. This problem is a necessary key step for computing arrangements of algebraic curves and has also applications for curve plotting. This software has been developed since 2007 in collaboration with F. Rouillier from Inria Paris - Rocquencourt. It is based on the method described in [28] which incorporates several improvements over previous methods. In particular, our approach does not require generic position.

Isotop is registered at the APP (June 15th 2011) with reference IDDN.FR.001.240007.000.S.P.2011.000.10000. This version is competitive with other implementations (such as ALCIX and INSULATE developed at MPII Saarbrücken, Germany and TOP developed at Santander Univ., Spain). It performs similarly for small-degree curves and performs significantly better for higher degrees, in particular when the curves are not in generic position.

We are currently working on an improved version integrating our new bivariate polynomial solver [27].

4.3. CGAL: Computational Geometry Algorithms Library

Born as a European project, CGAL (http://www.cgal.org) has become the standard library for computational geometry. It offers easy access to efficient and reliable geometric algorithms in the form of a C++ library. CGAL is used in various areas needing geometric computation, such as: computer graphics, scientific visualization, computer aided design and modeling, geographic information systems, molecular biology, medical imaging, robotics and motion planning, mesh generation, numerical methods...

In computational geometry, many problems lead to standard, though difficult, algebraic questions such as computing the real roots of a system of equations, computing the sign of a polynomial at the roots of a system, or determining the dimension of a set of solutions. we want to make state-of-the-art algebraic software more accessible to the computational geometry community, in particular, through the computational geometric library CGAL. On this line, we contributed a model of the *Univariate Algebraic Kernel* concept for algebraic computations [26] (see Sections 8.2.2 and 8.4). This CGAL package improves, for instance, the efficiency of the computation of arrangements of polynomial functions in CGAL [32]. We are currently developing a model of the *Bivariate Algebraic Kernel* based on our new bivariate polynomial solver [27]. This work is done in collaboration with F. Rouillier at Inria Paris - Rocquencourt and L. Peñaranda at the university of Athens.

4.4. Fast_polynomial: fast polynomial evaluation software

The library *fast_polynomial* [1] provides fast evaluation and composition of polynomials over several types of data. It is interfaced for the computer algebra system *sage*. This software is meant to be a first step toward a certified numerical software to compute the topology of algebraic curves and surfaces. It can also be useful as is and is submitted for integration in the computer algebra system *Sage*.

This software is focused on *fast online computation*, *multivariate evaluation*, *modularity*, and *efficiency*.

Fast online computation. The library is optimized for the evaluation of a polynomial on several point arguments given one after the other. The main motivation is numerical path tracking of algebraic curves, where a given polynomial criterion must be evaluated several thousands of times on different values arising along the path.

Multivariate evaluation. The library provides specialized fast evaluation of multivariate polynomials with several schemes, specialized for different types such as *mpz* big ints, *boost* intervals with hardware precision, *mpfi* intervals with any given precision, etc.

Modularity. The evaluation scheme can be easily changed and adapted to the user needs. Moreover, the code is designed to easily extend the library with specialization over new *C++* objects.

Efficiency. The library uses several tools and methods to provide high efficiency. First, the code uses templates, such that after the compilation of a polynomial for a specific type, the evaluation performance is equivalent to low-level evaluation. Locality is also taken into account: the memory footprint is minimized, such that an evaluation using the classical Hörner scheme will use $O(1)$ temporary objects and divide and conquer schemes will use $O(log(n))$ temporary objects, where n is the degree of the polynomial. Finally, divide and conquer schemes can be evaluated in parallel, using a number of threads provided by the user.

5. New Results

5.1. Classical computational geometry

5.1.1. Complexity analysis of random geometric structures made simpler

Average-case analysis of data-structures or algorithms is commonly used in computational geometry when the more classical worst-case analysis is deemed overly pessimistic. Since these analyses are often intricate, the models of random geometric data that can be handled are often simplistic and far from "realistic inputs".

[1] http://trac.sagemath.org/sage_trac/ticket/13358

In a joint work with Olivier Devillers and Marc Glisse (Inria GEOMETRICA) [20], we presented a new simple scheme for the analysis of geometric structures. While this scheme only produces results up to a polylog factor, it is much simpler to apply than the classical techniques and therefore succeeds in analyzing new input distributions related to smoothed complexity analysis. We illustrated our method on two classical structures: convex hulls and Delaunay triangulations. Specifically, we gave short and elementary proofs of the classical results that n points uniformly distributed in a ball in R^d have a convex hull and a Delaunay triangulation of respective expected complexities $\widetilde{\Theta}(n^{((d+1)/(d-1))})$ and $\widetilde{\Theta}(n)$. We then prove that if we start with n points well-spread on a sphere, e.g. an (ϵ, κ)-sample of that sphere, and perturb that sample by moving each point randomly and uniformly within distance at most δ of its initial position, then the expected complexity of the convex hull of the resulting point set is $\widetilde{\Theta}(\sqrt{(n)}^{(1-1/d)}\delta^{-(d-1)/(4d)})$.

5.1.2. *On the monotonicity of the expected number of facets of a random polytope*

Let K be a compact convex body in R^d, let K_n be the convex hull of n points chosen uniformly and independently in K, and let $f_i(K_n)$ denote the number of i-dimensional faces of K_n.

In a joint work with Olivier Devillers and Marc Glisse (Inria GEOMETRICA) and Matthias Reitzner (Univ. Osnabruck) [21], we showed that for planar convex sets, $E(f_0(K_n))$ is increasing in n. In dimension $d \geq 3$ we prove that if $lim_{n\to\infty}\frac{E(f_{d-1}(K_n))}{An^c} = 1$ for some constants A and $c > 0$ then the function $E(f_{d-1}(K_n))$ is increasing for n large enough. In particular, the number of facets of the convex hull of n random points distributed uniformly and independently in a smooth compact convex body is asymptotically increasing. Our proof relies on a random sampling argument.

5.1.3. *Embedding geometric structures*

We continued working this year on the problem of embedding geometric objects on a grid of $\mathbb{R}^3$. Essentially all industrial applications take, as input, models defined with a fixed-precision floating-point arithmetic, typically doubles. As a consequence, geometric objects constructed using exact arithmetic must be embedded on a fixed-precision grid before they can be used as input in other software. More precisely, the problem is, given a geometric object, to find a similar object representable with fixed-precision floating-point arithmetic, where similar means topologically equivalent, close according to some distance function, etc. We are working on the problem of rounding polyhedral subdivisions on a grid of $\mathbb{R}^3$, where the only known method, due to Fortune in 1999, considers a grid whose refinement depends on the combinatorial complexity of the input, which does not solve the problem at hand. This project is joint work with Olivier Devillers (Inria Geometrica) and William Lenhart (Williams College, USA) who was in sabbatical in our team in 2012.

5.2. Non-linear computational geometry

5.2.1. *Geometry of robotic mechanisms*

Parallel manipulators are a family of mechanisms, the geometry of which is difficult to compute in general. The use of algebraic methods allowed us to describe precisely the geometry of the configurations of different specific parallel manipulators, in collaboration with researchers from the IRCCyN laboratory in Nantes.

More precisely, moving a parallel robot toward specific parametric values can break it. A challenge is to describe this set of singularities. This was adressed for a planar mechanism with three degrees of freedom in [16] and a spatial mechanism with six degrees of freedom in [12].

Then, a more challenging question arises naturally. Given a familly of mechanisms parametrized by some construction variables, is it possible to find a mechanism that has no singularities? A method based on Gröbner bases was proposed in [17] for a specific family of planar parallel robot with two degrees of freedom.

5.2.2. Solving bivariate systems and topology of algebraic curves

In the context of our algorithm Isotop for computing the topology of algebraic curves [28], we study the bit complexity of solving a system of two bivariate polynomials of total degree d with integer coefficients of bitsize τ. We focus on the problem of computing a Rational Univariate Representation (RUR) of the solutions, that is, roughly speaking, a univariate polynomial and two rational functions which map the roots of the polynomial to the two coordinates of the solutions of the system.

We work on an algorithm for computing RURs with worst-case bit complexity in $O(d^8 + d^7\tau + d^5\tau^2)$ (where polylogarithmic factors are omitted). In addition, we show that certified approximations of the real solutions can be computed from this representation with $O(d^8 + d^7\tau)$ bit operations. It should be stressed that our algorithm is deterministic and that it makes no genericity assumption.

When $\tau \in O(d^2)$, this complexity decreases by a factor d^2 the best known upper bound for computing Rational Univariate Representations of such systems and it matches the recent best known complexity (Emeliyanenko and Sagraloff, 2012) for "only" computing certified approximations of the solutions. This shows, in particular, that computing RURs of bivariate systems is in a similar class of (known) complexity as computing certified approximations of *one* of the variables of its real solutions.

This work is on-going and is done in collaboration with Fabrice Rouillier (Inria Ouragan).

5.3. Combinatorics and combinatorial geometry

5.3.1. Multinerves and Helly numbers of acyclic families

The nerve of a family of sets is a simplicial complex that records the intersection pattern of its subfamilies. Nerves are widely used in computational geometry and topology, because the nerve theorem guarantees that the nerve of a family of geometric objects has the same topology as the union of the objects, if they form a good cover.

In a joint work with Éric Colin de Verdière (CNRS-ENS) and Grégory Ginot (Univ. Paris 6) we relaxed the good cover assumption to the case where each subfamily intersects in a disjoint union of possibly several homology cells, and we proved a generalization of the nerve theorem in this framework, using spectral sequences from algebraic topology. We then deduced a new topological Helly-type theorem that unifies previous results of Amenta, Kalai and Meshulam, and Matoušek. This Helly-type theorem is used to (re)prove, in a unified way, bounds on transversal Helly numbers in geometric transversal theory.

This work was presented at SoCG 2012 [18], where it received one of the two "best paper" awards.

5.3.2. Set systems and families of permutations with small traces

In a joint work with Otfried Cheong (KAIST, South Korea) and Cyril Nicaud (Univ. Marne-La-Vallée), we studied two problems of the following flavor: how large can a family of combinatorial objects defined on a finite set be if its number of distinct "projections" on any small subset is bounded? We first consider set systems, where the "projections" is the standard notion of trace, and for which we generalized Sauer's Lemma on the size of set systems with bounded VC-dimension. We then studied families of permutations, where the "projections" corresponds to the notion of containment used in the study of permutations with excluded patterns, and for which we delineated the main growth rates ensured by projection conditions. One of our motivations for considering these questions is the "geometric permutation problem" in geometric transversal theory, a question that has been open for two decades.

This work was published in the European Journal of Combinatorics [13].

5.3.3. Simplifying inclusion-exclusion formulas

Let $F = \{F_1, F_2, ..., F_n\}$ be a family of n sets on a ground set X, such as a family of balls in R^d. For every finite measure μ on X, such that the sets of F are measurable, the classical inclusion-exclusion formula asserts that $\mu(F_1 \cup F_2 \cup \bullet\bullet\bullet \cup F_n) = \sum_{I:\varnothing\neq I\subseteq[n]} (-1)^{|I|+1}\mu(\cap_{i\in I} F_i)$; that is, the measure of the union is expressed using measures of various intersections. The number of terms in this formula is exponential in n, and a significant amount of research, originating in applied areas, has been devoted to constructing simpler formulas for particular families F.

In a joint work with Jiří Matoušek, Pavel Paták, Zuzana Safernová and Martin Tancer (Charles Univ., Prague) [22] we provided the apparently first upper bound valid for an arbitrary F: we showed that every system F of n sets with m nonempty fields in the Venn diagram admits an inclusion-exclusion formula with $m^{O((log n)^2)}$ terms and with ± 1 coefficients, and that such a formula can be computed in $m^{O((log n)^2)}$ expected time. We also constructed systems of n sets on n points for which every valid inclusion-exclusion formula has the sum of absolute values of the coefficients at least $\Omega(n^{3/2})$.

6. Partnerships and Cooperations

6.1. National Initiatives

6.1.1. ANR

The ANR blanc PRESAGE brings together computational geometers (from the VEGAS and GEOMETRICA projects of Inria) and probabilistic geometers (from Universities of Rouen, Orléans and Poitiers) to tackle new probabilistic geometry problems arising from the design and analysis of geometric algorithms and data structures. We focus on properties of discrete structures induced by or underlying random continuous geometric objects.

This is a four year project, with a total budget of 400kE, that started on Dec. 31st, 2011. It is coordinated by Xavier Goaoc (VEGAS).

6.2. International Research Visitors

6.2.1. Visits of International Scientists

William J. Lenhart, Williams College (USA), one year sabbatical until July 2012.

Boris Aronov, from NYU-Poly, visited the VEGAS project for 2 weeks in October.

Martin Tancer, Pavel Paták and Zuzana Safernová, from Charles Univ. in Prague, visited the VEGAS project for 1 week in August.

Hyo-Sil Kim (postdoc at POSTECH, South Korea) and Jae-Soon Ha (PhD student at KAIST, South Korea) visited the VEGAS project for 2 weeks in February.

7. Dissemination

7.1. Scientific Animation

Program and Paper Committee:

- Sylvain Lazard: Program committee of the ACM Symposium on Computational Geometry 2012 (SoCG'12) and of the European Workshop on Computational Geometry (EuroCG'12).
- Sylvain Petitjean: Program committee of the IEEE International Conference on Computer Vision and Pattern Recognition (CVPR'12).

Editorial responsibilities:

- Xavier Goaoc: Editor of the *Journal of Computational Geometry*.
- Sylvain Petitjean: Editor of *Graphical Models* (Elsevier).

Workshop organizations:

- Sylvain Lazard co-organized with S. Whitesides (Victoria University) the 11th Inria - McGill - Victoria Workshop on Computational Geometry [2] (Bellairs Research Institute of McGill University) in Feb. (1 week workshop on invitation).
- Xavier Goaoc was co-organiser of the *Journées de Géométrie Algorithmique* 2012 (http://jga2012.fr). This event gathered the french community of computational geometry (50-60 participants) for one week.
- Xavier Goaoc was co-organiser of *Algorithms & Permutations* 2012 (http://igm.univ-mlv.fr/AlgoB/algoperm2012/). This event gathered $\sim$ 70 participants from theoretical computer science for two days.
- Xavier Goaoc organized a *workshop on interactions between stochastic and computational geometries* (http://webloria.loria.fr/~goaoc/ANR-Presage/meetings.html) where 21 participants, on invitation, worked for a week on research problems at the interface between stochastic and computational geometries.

Other responsibilities:

- Sylvain Lazard: Head of the Inria Nancy-Grand Est *PhD and Post-doc hiring committee* (since 2009). Member of the *Bureau du Département Informatique de Formation Doctorale* of the *École Doctorale IAE+M* (since 2009). Member of the hiring committee for St Dié assistant professor position. Chargé de formation par la recherche for Inria Nancy-Grand Est.
- Laurent Dupont: *Responsible* of admissions of IUT Charlemagne, University Nancy 2 (September 2011- September 2012). *Member* of Commission Pédagogique Nationale Infocom/SRC (since 2011). *Member* of Commission Information Scientifique (Inria/Loria).
- Xavier Goaoc: Chair of the Inria *COST-GTRI committee* (since 2011).
- Guillaume Moroz: Member of the organizing committee of the *Olympiades académiques de mathématiques*. *Vice delegate* of the *Commission des Utilisateurs des Moyens Informatiques pour la Recherche*. Invited to give a course at Young researcher School EJCIM 2012 and doctoral school of science and technology of Versailles.
- Sylvain Petitjean: Until August: *Scientific delegate* of Inria Nancy Grand-Est and chairman of its *Project committee* (since 2009). Member of the *Executive committee* of Inria Nancy Grand-Est, member of its *Commission des développements technologiques*. Member of Inria's *Evaluation committee*. Since September: Acting director of the Inria Nancy Grand-Est. Member of Inria's *Executive committee*.
- Marc Pouget: Member of the CGAL Editorial Board (since 2008).

7.2. Teaching - Supervision - Juries

7.2.1. Teaching

Master: Marc Pouget and Xavier Goaoc, *Introduction à la géométrie algorithmique*, 10.5 HETD, M1, École Nationale Supérieure de Géologie, France

Master: Xavier Goaoc, *Recherche opérationnelle*, 25 HETD, M1, École des Mines de Nancy.

Master: Xavier Goaoc, *Pépites en géométrie algorithmique*, 4.5 HETD, M1, École des Mines de Nancy.

Licence: Laurent Dupont, *Systèmes de Gestion de Bases de Données Avancé*, 40h, Université de Lorraine (IUT Charlemagne).

Licence:Laurent Dupont, *Concepts et Outils Internet*, 40h, Université de Lorraine (IUT Charlemagne).

[2] Workshop on Computational Geometry

Licence: Laurent Dupont, *Programmation Objet et Évènementielle*, 40h, Université de Lorraine (IUT Charlemagne).

Licence: Laurent Dupont, *Rich Internet Applications*, 40h, Université de Lorraine (IUT Charlemagne).

Licence: Laurent Dupont and Yacine Bouzidi, *Programmation de Sites Web Dynamiques*, 68h, Université de Lorraine (IUT Charlemagne).

Licence: Laurent Dupont and Yacine Bouzidi, *Algorithmique*, 76h, Université de Lorraine (IUT Charlemagne).

Licence: Sylvain Lazard, *Algorithms and Complexity*, 25h, L3, Université de Lorraine.

7.2.2. Supervision

PhD in progress : Yacine Bouzidi, Résolution de systèmes algébriques bivariés et topologie de courbes planes, started in October 2010, Sylvain Lazard et Marc Pouget

PhD in progress : Fabien Mathieu, Simulation numériques 3D pour le prototypage rapide par Stratoconception, thèse CIFRE with CIRTES, started in February 2012 and stopped in September 2012 for administrative reasons, Sylvain Lazard.

7.2.3. Juries

- Xavier Goaoc was on the reading and defense committees of the thesis of Daniela Maftuleac, Aix-Marseille Univ, Juin 2012.

8. Bibliography

Major publications by the team in recent years

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