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INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team ISA

Models, algorithms and geometry for computer graphics and vision

Lorraine

THEME COG

Activity Report

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Table of contents

1. Team

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2. Overall Objectives

The ISA project conducts research in two complementary fields: *computer vision*, one of the main objectives of which is the geometric reconstruction, either explicit or implicit, of 3D models from images, and *computer graphics*, a principal aim of which being, conversely, to generate images from 3D geometrical models.

The *fundamental scientific problems* tackled by the project are essentially of geometrical (differential geometry, projective and algebraic geometry), numerical (multi-resolution analysis, integral equations solving) and algorithmic (complexity analysis, parallel algorithmics) nature.

Members of the ISA project have developed *software applications* in many domains, notably: oil and gas research, scientific visualization, virtual prototyping, augmented reality.

The ISA project is divided into three research groups, corresponding to three research areas:

1. Modeling by vision (medical imaging, augmented reality)
2. Geometric computing
3. Numerical simulation and visualization

3. Scientific Foundations

3.1. Modeling by vision

Keywords: *Registration*, *augmented reality*, *medical imaging*, *tracking*, *viewpoint computation*, *volumetric segmentation*.

Participants: Michael Aron, René Anxionnat, Marie-Odile Berger, Sébastien Gorges, Erwan Kerrien, Gilles Simon, Javier Flavio Vigueras Gomes, Brigitte Wrobel-Dautcourt.

Recent progress in both the graphics and the computer vision fields now makes it possible to develop efficient systems for a seamless integration of real scenes and computer generated objects. This concept is referred to as Augmented Reality (AR) in the following. Fundamentally, AR is about the augmentation of human visual perception: supplying information not ordinarily detectable by human senses. Potential applications of AR are important and include maintenance and repair of complex equipment, medical visualization, collaborative work, and applications in cultural heritage.

Though promising, AR is barely at the demonstration phase today and several challenges must be overcome to prove the full potential of AR. Making AR work outdoors or in unprepared environments is a good example of what remains an enormous challenge.

The underlying research topics for solving key problems encountered in AR mainly concern real-time pose estimation, tracking and 3D reconstruction. In the past, we have proposed various solutions for pose estimation as well as semi-interactive methods for solving occlusion. Currently, we focus our effort on real-time pose estimation.

We also develop applications in medical imaging which are based on these fundamental research topics.

3.1.1. Augmented reality

One of the most basic problems currently limiting Augmented Reality applications is the registration problem. The objects in the real and virtual worlds must be properly aligned with respect to each other, or the illusion that the two worlds coexist will be compromised. In addition, accurate registration is needed by many applications.

As a large number of potential AR applications are interactive, real time pose computation is required. Although the registration problem has received a lot of attention in the computer vision community, the problem of real-time registration is still far from being a solved problem, especially for unstructured environments. Ideally, an AR system should work in all environments, without the need to prepare the scene ahead of time, and the user should walk anywhere he pleases.

For several years, the ISA project has aimed at developing on-line and markerless methods for camera pose computation. Within the European Project ARIS, we are currently working on a real-time system for camera tracking designed for indoor scenes. The main difficulty with online tracking is to ensure robustness of the process. Indeed, for off-line processes, robustness is achieved by using spatial and temporal coherence of the considered sequence through move-matching techniques. To get robustness for open-loop systems, we have developed a method which combines the advantage of move-matching methods and model-based methods [10] by using a piecewise-planar model of the environment. This methodology can then be used in a wide variety of environments: indoor scenes, urban scenes, ...

Besides the research on real-time viewpoint computation, our current research effort mainly concerns the development of methods for camera stabilization. Indeed it appears that statistical fluctuations in the viewpoint computations lead to unpleasant jittering or sliding effects, especially when the camera motion is small. We are currently investigating the use of model selection in order to improve the visual impression.

Finally, it is well known that existing methods for pose computation are individually inaccurate. Vision based methods are accurate but they usually cannot keep up with quick, abrupt user movements. On the other hand, magnetic trackers are inaccurate but they are robust and place minimal constraints on user motion. Hence, there is a challenge to integrate vision and sensor based tracking in order to combine the accuracy of vision based tracking with the robustness of magnetic trackers. This topic is now addressed by our team. Within the ARIS project, we are currently working on a system that makes an inertial sensor (MT9- Xsens) cooperate with the camera based system in order to improve the robustness of the AR system to abrupt motions of the users, especially head motion. This work thus contributes to reduce the constraints on the users and the need to carefully control the environment during an AR application.

3.1.2. Medical imaging

For the last 10 years, we have been working in close collaboration with the neuroradiology laboratory (CHU-University Hospital of Nancy) and General Electric. As several imaging modalities are now available in a per-operative context (2D and 3D angiography, MRI, ...), our aim is to develop a multi-modality framework to help therapeutic decision.

In [6], we proposed an efficient solution to the registration of 2D/3D angiographic images and 3D/MRI images. Since then, we have mainly been interested in the effective use of a multimodality framework in the treatment of arteriovenous malformations (AVM). The treatment of AVM is classically a two-stage process: embolization or endovascular treatment is first performed. This step is then followed by a stereotactic irradiation of the remnant. Hence an accurate definition of the target is a parameter of great importance for the treatment. Our short term aim is to perform an accurate detection of the AVM shape within a multimodality framework. Our long term aim is to develop multimodality and augmented reality tools which make cooperate various image modalities (2D and 3D angiography,fluoroscopic images, MRI, ...) in order to help and to guide physicians in clinical routine. From a practical point of view, we are involved in two research areas. First, S. Gorges began his PhD this year with the aim to define augmented realty tools for neuronavigation that make a real-time imagery (fluoroscopy) cooperate with a pre-operative imagery (3D angiography). On the other hand, we are currently involved in a urology project. Using contrast-enhanced CT scanners of the same patient acquired at different times, our aim is to build the vascular systems of the kidney. It will be used by the physician for planning surgery.

3.2. Geometric computing for rendering complex scenes

Keywords: *3D visibility*, *Effective geometry*, *mathematics for graphics*, *model conversion*, *modeling*, *robustness*.

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In the field of 3D modeling, there are several different approaches for representing objects, each adapted to a precise application. Volumetric modeling represents objects as Boolean combinations of solids while surface modeling represents objects by their boundaries. The surfaces being manipulated may be represented by functions (quadrics, splines) or they may be discretized in the form of sets of polygons.

This diversity of possible representations and the geometric problems and topological difficulties that they induce on visualization methods have led us to establish a core group around the notion of "Geometry for graphics". The accent is on the use of the latest mathematical techniques and the development of new algorithms which will lead to an increase in realism and robustness in the visualization of complex scenes and to enhance the theoretical bases and underlying techniques.

Results obtained are principally on the conversion between different representations of objects, the combinatorics behind these representations and the methods for preserving the topology of the corresponding models, and finally, visibility queries in environments composed of simple curved objects.

3.2.1. *Theory and applications of three-dimensional visibility*

The notion of 3D visibility plays a fundamental role in computed graphics. In this field, the computation of objects visible from a given point, the computation of shadows or of penumbra are examples of visibility computations. In global illumination methods (radiosity algorithms), it is necessary to determine, in a very repetitive manner, if two points of a scene are mutually visible. The computations can be excessively expensive. In radiosity, it is not unusual that between 50 and 70% of the simulation is spent answering visibility queries.

Objects that are far apart may have very complicated and unintuitive visual interactions, and because of this, visibility queries are intrinsically global. This partially explains that, until now, researchers have primarily used ad hoc structures, of limited use, to answer specific queries on-the-fly. Unfortunately, experience has shown that these structures do not scale up. The lack of a well-defined mathematical base and the non-exploitation of the intrinsic properties of 3D visibility results in structures that are not usable on models consisting of many hundreds of thousands of primitives, both from the viewpoint of complexity and robustness (geometric degeneracies, aligned surfaces, ...).

We have chosen a different approach which consists of computing ahead of time (that is, off-line) a 3D global visibility structure for which queries can be answered very efficiently on-the-fly (on line). The 3D visibility complex is such a structure, recently introduced to computational geometry and graphics [41][39]. We approach 3D global visibility problems from two directions: we study, on the one hand, the theoretical foundations and, on the other hand, we work on the practical aspects related to the development of efficient and robust visibility algorithms.

From the theoretical point of view, we study, for example, the problem of computing lines tangent to four among k polytopes. We have shown much better bounds on the number of these tangents than were previously known [27]. These results give a measure of the complexity of the vertices (cells of dimension 0) of the visibility complex of faceted objects, in particular, for triangulated scenes.

From a practical point of view, we have, for example, studied the problem of the complexity for these 3D global visibility structures, considered by many to be prohibitive. The size of these structures in the worst case is $O(n^4)$, where n is the number of objects in the scene. But we have, in fact, shown that when the objects are uniformly distributed, the complexity is linear in the size of the input [4]. This probabilistic result does not prejudice the complexity observed in real scenes where the objects are not uniformly distributed. However, initial empirical studies show that, even for real scenes, the observed complexity is largely inferior to the theoretical worst-case complexity, as our probabilistic result appears to indicate.

We are currently working on translating these positive signs into efficient algorithms. We are studying new algorithms for the construction of the visibility complex, putting the accent on the complexity and the robustness [12].

3.2.2. Reliable geometric computations on surfaces

Simple algebraic surfaces cover a variety of forms sufficient for representing the majority of objects encountered in the fields of design, architecture and industrial manufacturing. It has been estimated that 95% of all mechanical pieces can be well modeled by quadric patches (degree 2 surfaces, including planes, spheres, cylinders and cones) and torii [42]. It is important, then, to be able to process these surfaces in a robust and efficient manner, notably in view of their use in realistic rendering.

In comparison with polygonal representations, modeling and visualization of scenes of quadrics pose new problems. We study, in particular, problems related to the visualization and realistic rendering of such models. We work alongside the members of the theme "Simulation and high-performance visualization" on the development of the method called virtual meshing which allows us to go beyond real geometry of objects by creating a geometric abstraction better adapted to light calculations [1].

Early on in the rendering process, but along with the development of a tool for illuminating curved surfaces, it is important to have a reliable process for converting from volumetric to surface models. Many conventional modelers are based on the assembly – union, intersection, difference – of simple volumes (a paradigm called Constructive Solid Geometry or CSG), typically quadric volumes. On the other hand, illumination by the radiosity method can only be done on surface representations of objects (called BRep for Boundary Representation). It is necessary, therefore, to be able to pass, in a robust manner, from one representation to the other, an operation known as CSG-BRep conversion, in order to profit from the power of the virtual mesh. The idea is to make the geometric information coherent with the topological information which translates the relations of proximity and inclusion of different elements.

A fundamental step of this conversion is the computation of the intersection of two primitive volumes. We have recently developed and implemented a robust and near-optimal algorithm for the computation of an exact parametric form of the intersection of two quadrics [5][34]. Our method is based on the projective formalism, techniques of linear algebra and number theory, and new theorems characterizing the rationality of the intersection. This is the first general approach to the intersection of two quadrics that is usable in practice (as opposed to the approach used until now, that of J. Levin [40]).

Lately we have worked on the use of this general algorithm in an application context. We continue to work on the development of a loop for exact CSG-BRep conversion for models for which the basic primitives are quadric volumes. This work calls for the resolution of algebraic systems for which we collaborate with the members of the Spaces and Salsa projects.

3.2.3. Numerical geometry

This research topic aims at developing new formalisms to represent and manipulate geometric objects (surfaces, volumes, ...). More precisely, we study objects discretized as cellular complexes, such as triangulated and polygonal surfaces, 3D structured and unstructured grids.

Triangulated surfaces are widely used representations for 3D geometric objects. Using them, it is easy to adaptively approximate any surfacic geometry, and they can be efficiently displayed by computer graphics hardware. For these two reasons, many existing geometric objects are available in this form.

However, designing geometric operators acting on triangulated surfaces is a challenging task, since the piecewise-linear nature of triangulated surfaces does not permit applying the standard differential geometry methods. To overcome this problem, our approach is composed of the following steps:

1. formalize the operator as a PDE (Partial Derivatives Equation). At this step, notions from physics can help the intuition. For instance, the expression of the flexion energy of a thin plate can be used to design smoothing operators;
2. discretize the operator in a form compatible with the representation of the object, using numerical schemes such as finite differences, finite elements, Galerkin, ...
3. study the discretized operator, and prove its properties, such as existence and uniqueness of the solution, independence to the discretization, ...

4. design a minimization algorithm, based on NA (Numerical Algorithm) methods, such as Conjugate Gradient, Gauss-Newton, Lagrange, ...To keep computation times reasonable, it is possible to use several acceleration techniques, such as preconditioners and multi-scale/multi-grid approaches.

The formalism we use combines aspects from differential geometry with numerical analysis, linear algebra, discrete topology, graph theory and complex analysis.

The originality of our approach is the translation of the modeling problem into an algebraic structure that reflects the geometric structure of the problem. For instance, in the case of the parameterization of triangulated surfaces, it is possible to express objective functions measuring the quality of the parameterization using Hermitian forms. The complex numbers of these forms correspond to both points and similarity transforms in $\mathbb{R}^2$, and provide a geometric interpretation of the eigenvalues of the matrix. Moreover, this matrix presents a structure that can be iteratively constructed with elementary operators acting on the mesh. This makes it possible to derive algebraic properties of the matrix using structural induction on the mesh.

The operators defined using our approach can be applied to many computer graphics related problems. For instance, our parameterization approaches can be used to texture-map 3D objects, to convert triangulated surfaces into polynomial representations, to remesh triangulated surfaces, to design discrete fairing operators, ...

Our main direction is now to design algorithms that process raw data (e.g. a triangulated surface obtained from a 3D scanner) and extract automatically a higher-level representation (e.g. parametric surfaces). This higher-level representation is best suited for numerical simulations, and more particularly the simulation of global illumination.

3.3. Numerical simulation and visualization

Keywords: *Global illumination*, *algorithms for high-performance visualization*, *hierarchical algorithms and parallelism*, *integral equations*.

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Computer generated realistic images allow to create imaginary worlds, design prototypes, or evaluate virtual products or spaces. Creating algorithms to produce such images involves modeling the physical properties of light emitted from light sources and reflecting from surfaces or scattering in a media, and the propagation of light as it travels through the space. From a mathematical point of view, it involves solving an integral equation, the light transport equation, and uses basic methods of scientific computing.

Our team has worked for years on applying finite element approaches to this problem and on visualization algorithms to compute images from the computed data. We have developed algorithms which can be used in various application domains of science, such as geology, molecular dynamics, or physics. These algorithms are based on both computational graphics methods and high-performance hardware management.

3.3.1. Light transport equation

In order to solve the light transport equation, we apply a finite element method. High-order wavelet radiosity values are computed on scenes made of parametric surfaces with arbitrary trimming curves. By contrast with past approaches that require a tessellation of the input surfaces (be it made up of triangles or patches with simple trimming curves) or some form of geometric approximation, our method takes fully advantage of the rich and compact mathematical representation of objects. At its core lies the virtual mesh, an abstraction of the input geometry that allows complex shapes to be illuminated as if they were simple primitives. The virtual mesh is a collection of normalized square domains to which the input surfaces are mapped while preserving their energy properties. Radiosity values are then computed on these supports before being lifted back to the original surfaces.

Various objects and environments, designed for interactive applications or virtual reality, have been simulated. They show that, by exactly integrating curved surfaces in the resolution process, the virtual mesh allows complex and large models to be rendered more quickly, more accurately and much more naturally than with previously known methods. Current work includes generalizing the virtual mesh approach to complex geometric surfaces and extensions allowing computation of complex lighting reflectance and scattering.

3.3.2. Scientific visualization

The objective is to design and implement scalable high-fidelity visualization solutions for scientific applications such as geology, molecular dynamics, botanics or physics. Our aim is that the solutions we provide to the scientists allow them to explore in the temporal, spatial, and visualization domains of their 3D (or more) data at high resolution. This new high resolution explorability, likely not presently available to most scientist groups, help lead to many new insights or more accurate engineering decisions.

In most cases, we conduct performance evaluation on the SGI Origin3800 supercomputer and the new SGI Ultimate Vision graphics engine operated at the “Charles Hermite High Performance Computing and Visualization” center. Algorithms are performance oriented in order to provide large scale parallel simulations and interactive viewing, fast geometric computations, or visualization of time-varying unstructured data. High-performance architecture and hardware programming, groupware and networking solutions, and virtual reality technologies are also experimented in the group.

4. Application Domains

4.1. Scientific visualization

Keywords: *Geology*, *forestry*, *molecular dynamics*, *numerical mock-ups*, *plasma*.

All the following applications are developed within the “Charles Hermite High Performance Computing and Visualization Program” on the SGI Altix supercomputer. This program includes more than twenty Research Institutions and Industrial Companies and is supported by the “Contrat de Plan État-Région Lorraine”.

4.1.1. Geology

This application domain is lead by the gOcad consortium, created by Prof. Mallet. The consortium involves 48 universities and most of the major Oil and Gas companies. ISA contributes to gOcad with numerical geometry and visualization algorithms for oil and gas engineering. The currently explored domains are complex and dynamic structural models construction, extremely large sismic volumes exploration, and drilling evaluation and planning.

4.1.2. Plasma

The computation of turbulent thermal diffusivities in fusion plasmas is of prime importance since the energy confinement time is determined by these transport coefficients. An original approach is developed to study trapped ion instability. A Vlasov code is used to determine the behavior of the instability near the threshold and compare with analytical solutions of the Vlasov equation. Some interesting features which appear in the nonlinear regime are explored thanks to a specialized module of the Graphite library (in cooperation with LPMI-CNRS and CEA).

4.1.3. Molecular dynamics

Protein docking is a fundamental biological process that links two proteins. This link is typically defined by an interaction between two large zones of the protein boundaries. Visualizing such an interface is useful to understand the process thanks to 3D protein structures, to estimate the quality of docking simulation results, and to classify interactions in order to predict docking affinity between classes of interacting zones (in cooperation with LCTN-CNRS).

4.1.4. Numerical mock-ups

Computed images and immersive visualization systems are used to design and evaluate virtual products in the aircraft and car industry. In this application, the CAD models used are extremely large and the images have to be computed from an accurate physically-based simulation process. Other developments are experimented with the car industry on an application of distant visualization and immersive virtual reality (in cooperation with VSP-Technology).

4.1.5. Forestry

The architecture of plants depends on the nature and on the relative arrangement of all parts; it is, at any given time, the expression of an equilibrium between endogeneous growth process and exogeneous constraints applied by the environment. The goal of the application is to simulate and visualize the growing of trees in a forestry engineering context (in cooperation with CIRAD, INRA, and ENGREF).

4.2. Computer-aided design

Keywords: *Process engineering*.

The computer-aided design application uses certain results of research of the topics “Geometric computing” (section 3.2) and “Simulation and high-performance visualization” (section 3.3). The Candela software and its immersive Candela-VR extension, commercialized by our start-up company VSP-Technology, are based on this technology.

4.3. Augmented reality

Keywords: *Multimedia*.

Our results on augmented reality are conducted within a European project (ARIS). Its aim is to overcome limitations of current AR solutions by providing a seamless integration of virtual objects in real environments.

4.4. Medical imaging

Keywords: *Health*.

We have been working for ten years in close collaboration with the neuroradiology laboratory (CHU, University Hospital, Nancy) and GE Health Care (formerly GE Medical Systems). Our methods and software are tested in clinical context at the neurological hospital (Nancy). The CIFRE PhD thesis of S. Gorges started in february 2005 in collaboration with GE Health Care. Its aim is to design tools for neuronavigation that take advantage of a real-time imagery (fluoroscopy) and a pre-operative imagery (3D angiography).

4.5. Forest growth simulation

Keywords: *Environment*, *forest*, *immersive environments*, *plant modeling*, *visualization*.

Participants: Frédéric Blaise, Xiaopeng Zhang.

Integrating information coming from different sources, getting a better understanding of the relationships between 3D objects, having a better way to represent and to interact with large models are topics of high interest in many applications. The development of a visualization tool must also be based on the central data model, in order to display in real time the modifications caused by the different modeling tools; furthermore, it should benefit from the different immersive environments (like Caves, Reality Centers or workbenches) which give the user a much more accurate insight of the model than a regular computer screen. These general considerations can be applied to different fields of research and, in particular, to forestry applications.

In the field of forestry management, the creation of visual tools of high quality represents a very important scientific and technical issue today. Forestry management is disputed by various social movements, and the administrative organisms are ready for their stronger implication in the decisions. For that, the current dialogue tools are defective: because of the very slow growth of the forests, it is necessary to rest on realistic visual tools for the discussion of management scenarios taking effect on several decades. Within the framework of a collaboration between various institutes (INRIA, CIRAD, INRA, ENGREF), we try to develop tools allowing to help in the management of plantings by using geographic information systems (GIS), the models of forest production of INRA-ENGREF, the plant architecture models of CIRAD and the knowledge in high-performance computing and visualization of the ISA project (applications for Increased Reality in real time) in INRIA. This project is called SILVES: Computer simulations and visualization software applied to sylviculture.

Thus, within the framework of the ISA project, the scientific project SILVES results in an integrated software platform to represent, simulate and visualize forestry spaces in their current state and during their evolution in order to better control the management decisions. The geometrical modeling of forest covers could also be used by others interested by the structure of forests: simulation of forest fires, simulation of the wind within the covers and resistance to breakage, evaluation of the wood quality according to the forestry constraints, etc.

The scientific objectives of project SILVES can be divided into three principal research topics:

1. 3D visualization of GIS data. Use of the software IMAGIS (visualization of GIS) and software AMAP (simulation of the growth of the plants) developed in CIRAD.
2. Coupling plant architecture models and forest production models. The main idea is to develop an interactive relationship between structure-function models and forest production models in order to pull together advantages of each system: on the one hand, the tree architecture is well described but the stand structure is not managed; on the other hand, forest production is estimated at broad scales but the tree description is very simplified. Coupling both approaches would then offer realistic simulations on a large area, with a good description at the stand and the tree level (including tree architecture, wood quality, etc.).
3. High-performance computing and visualization. Simulation in real time of forest covers and visualization in immersed room. Development of a unified interface allowing to modify the characteristics of the simulation (forestry choices for example) with AMAP and IMAGIS supported as back-end.

4.6. Stratoconception

Keywords: *Fast prototyping*.

We work in collaboration with the CIRTES company on rapid prototyping. CIRTES has designed a technique called Stratoconception where a 3D computer model to be built is decomposed into layers and each layer is manufactured, 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.

5. Software

5.1. gOcad

gOcad is a 3D modeler dedicated to geosciences. gOcad is now commercialized by Earth Decision Sciences (formerly T-Surf), a company which was initially a start-up company of the project. gOcad is used by all major oil compagnies (Total-Fina-Elf, ChevronTexaco, Petrobras, ...), and has became a de facto standard in geo-modeling.

5.2. Candela

Candela is a library dedicated to light simulation. Candela is the property of INRIA-Transfer. Candela-VR is an extension of Candela which makes possible to display the result of a simulation in environments with several CPU's and GPU's. An exclusive user licence was yielded to the start-up company VSP-Technology.

5.3. Graphite

Graphite is a research platform for computer graphics, 3D modeling and numerical geometry. It comprises all the main research results of the last three years from our "Numerical Geometry" group. Data structures for cellular complexes, parameterization, multi-resolution analysis and numerical optimization are the main features of the software. Graphite is publically available since October 2003, and is now used by researchers from Geometrica (INRIA Sophia Antipolis), Artis (INRIA Grenoble), LSIIT (Strasbourg), Technion (Israel), Stanford University (United States), Harvard University (United States), University of British Columbia (Canada). Graphite is one of the common software platforms that will be used in the frame of the European Network of Excellence AIM at Shape.

5.4. QI

QI (for quadrics intersection) is a software that computes an exact parametric form of the intersection of two real quadrics in three-dimensional space given by implicit equations with rational coefficients. The functions parameterizing the intersection contain no square root whenever it is possible and the coefficients of these functions are algebraic numbers with at most one extra square root. Furthermore, for each geometric type of intersection, the number of square roots in the coefficients is always minimal in the worst case.

6. New Results

6.1. Modeling by vision

For several years, we have aimed at developing a vision-based real-time augmented reality system which makes use of a multi-planar model of the scene. However, as pure vision-based tracking methods cannot usually keep up with fast or abrupt user movements, a hybrid approach which combines the accuracy of vision-based methods and the robustness of inertial tracking systems has been studied during this year.

A robust and accurate tracking has been obtained from the coupling of camera and inertial sensor data (MT9, Xsens) [24]. The underlying idea is to use the inertial sensor to guide the matching process when the visual tracking fails. Errors on sensor acquisitions are propagated and are used to refine the shape and size of the regions where key points are searched for. As a result, we obtain a matching stage that is robust to abrupt motions. A second important contribution of this work is to address the camera/sensor synchronization. Indeed, our experiments proved that the synchronization delay between camera and sensor acquisition is not constant over time. This problem is seldom addressed in the AR literature. We then propose an original solution to this problem and identify the actual sensor data by comparing the predicted numbers of inliers using the sensor to the number of inliers observed when the visual tracking fails. This hybrid system was demonstrated at the final review of ARIS project by end august. Demonstrations proved significant improvements of the robustness of the system especially to abrupt head motions of the users.

As most AR applications consider camera with constant focal length, we addressed during this year the problem of defining a camera model that is well suited to this common practical case. This is important in practice because it allows us to reduce the numbers of estimated parameters and to improve the robustness of the process. Our experiments proved that considering varying principal point while keeping the focal length constant allows us to obtain a reprojection error similar to the one obtained with full calibration while imposing existing constraints on the camera (no zooming). A robust calibration process has been proposed in the context of multi-planar environments. Robustness is here obtained by estimating independently the principal point position (using the center line constraint) and the viewpoint [35].

On the theme of medical imaging, we followed two main directions of research. First we continued our activities on malformation delineation in neuroradiology within a multimodality framework. A software which integrates our research results is now available in clinical use. Our framework for delineation of arteriovenous malformations makes use of 2D and 3D angiographic images: the initial estimate obtained with 2D angiographic images is then refined within the 3D volume using deformable models. Using statistical shape models, the recovered shapes have been proved to be in accordance with the current and hand-made Gold Standard. Convincing results are shown in [26][25]. Second, we began to investigate the use of augmented reality in interventional neuroradiology. The idea is to design tools for neuronavigation that take advantage of a real-time imagery (fluoroscopy) and a pre-operative imagery (3D angiography) to improve the guidance of the catheter. In order to be able to merge information extracted both from fluoroscopic and 3D angiographic images, we investigated during this year the problem of modeling the acquisition geometry of the C-arm that is used for angiography acquisition.

6.2. Geometric computing for rendering complex scenes

On the theme of 3D visibility, we followed two main directions of research, one in which the objects of the scenes are polyhedra, the other in which we considered curved objects. Related to both directions of research, X. Goaoc defended his Ph.D. thesis in May [12].

Our results on 3D visibility with polyhedral objects have been the following. We presented an important result on the number of lines tangent to four among k possibly intersecting arbitrary convex polytopes, significantly improving the previous known results on the subject [27]. We also established upper and lower bounds on the number of lines (or, in degenerate cases, of connected components of lines) that are tangent to four triangles in 3D [28]. Finally we presented some new methods for optimizing the direction of stratification in a process of rapid prototyping using techniques for minimizing the shadow volume cast by two light sources at infinity (in opposite directions) on a sliced polyhedron depending on its orientation [33].

Concerning curved objects, we solved two long-standing open conjectures. First we proved that a family of n disjoint unit spheres in $\mathbb{R}^d$ admits at most 2 distinct geometric permutations if $n > 8$, and at most 3 otherwise [19]. Second we proved that four balls of arbitrary radii in 3D admit infinitely many common tangents only if their centers are collinear; we actually characterized the degenerate configurations in which four balls admit infinitely many tangents [16].

On the theme of robust computation on curved objects, we have presented in a conference last year [5] a new algorithm for computing efficiently and exactly a near-optimal parametric form of the intersection of two quadric surfaces. These theoretical results are major in the sense that the output solution is a rational parameterization whenever one exists and the coefficients are algebraic numbers with at most one extra square root. Furthermore, for each geometric type of intersection, the number of square roots in the coefficients is always minimal in the worst case. Since then we have improved our algorithm to minimize the size (i.e., the number of digits) of the integer coefficients that appear in the parameterizations. We have implemented this algorithm in C++ and analyzed its practical behavior on generic data, on degenerate data, as well as on "real-life" data. We showed that our implementation is extremely efficient in practice and that the observed actual size of our output parameterizations is small. We published a conference version of these results [34] and L. Dupont defended is Ph.D. thesis in October [11]. We maintain a quadric intersection server available at our Quadrics web page and we released our code in June. We note that our code has been embodied into the library EXACUS developed at the Max-Planck-Institut für Informatik (Saarbrücken, Germany).

In Digital Geometry Processing, surface parameterization has been a very active area of research for several years (for instance, an entire paper session was devoted to this issue in Siggraph 2004). Parameterization with convex boundary conditions is now well known and has now solid theoric foundations. In contrast, robust and provably correct (i.e. one-to-one) free-boundary parameterization was still an open problem. To deal with this problem, we have designed ABF++, a new method, accepted by the journal ACM Transactions on Graphics. Given a triangulated mesh with millions of triangles, our ABF++ method constructs a provably correct parameterization in minutes. The ABF++ method is based on the numerical constrained optimization of a non-linear functional, using Newton-Lagrange method. We have observed and exploited the special structure of the matrix of the second order derivatives. This special structure makes it possible to design a solution mechanism that reduces the required computations by several order of magnitudes as compared to a naive implementation of Newton's method.

With the aim of designing methods to automatically convert meshed models into parametric surfaces (B-Splines), we have also developped a new globally smooth mostly isometric parameterization method. By allowing the presence of more singular points than required by general topology, our methods produces a regular sampling of a surfacic mesh of arbitrary genus. Many applications are possible, including mesh-to-spline conversion, anisotropic remeshing, skeleton extraction, texture mapping and texture synthesis.

6.3. Numerical simulation and visualization

6.3.1. Light transport equation

Our virtual mesh method is an abstraction of the input geometry that allows complex shapes to be illuminated as if they were simple primitives. The virtual mesh is a collection of normalized square domains to which the input surfaces are mapped while preserving their energy properties. The virtual mesh has been applied to radiosity computations on parametric surfaces: radiosity values are computed on the supports before being lifted back to the original surfaces.

We have extended the virtual mesh in several ways. First, we have introduced the parametric master element, that allows to apply the virtual mesh to meshed models composed of millions of facets. Our method decomposes the model into a set of charts homeomorphic to discs, and puts each chart in correspondence with a 2D parameter space. This representation can be directly used by our Virtual Mesh generic method.

Another direction of research that we explore is extending the applicability of finite-element based lighting simulation to a wider class of phenomena, mostly specular reflections and refractions. We have experimented two different approaches:

- expressing the lighting transfer in terms of *irradiance* instead of *radiance* transfers makes it possible to convolve the solution by a Bidirectional Reflectance Distribution Function at visualization time. This gives a good approximation of lighting transfers for glossy objects, that can be displayed in real time by computer graphics hardware;
- the other approach that we did experiment was developping a hybrid solver, combining a finite element based solver for the diffuse part with a monte-carlo solver (photon mapping) for the specular part. In addition, our hybrid solver can accurately compute reflective and refractive caustics. By reprojecting the monte-carlo sampled term in the finite element basis, it is possible to take into account specular-to-diffuse transfers, and to benefit from hardware accelerated real-time rendering.

Future work will consider more complex phenomena (e.g. subsurface scattering) and new computation methods (multiscale simulation, sampling-based approaches, second-order approximations of the local lighting model ...).

6.3.2. Scientific visualization

We have proposed a hierarchy of algorithms and data structures for visualizing grids with various topologies. Our generic slicing-based rendering algorithm has a smaller complexity than previous approaches. The use of combinatorial information indeed confers an optimal complexity on the algorithm, which is linear with the size of the slices. The rendering method is able to process arbitrary meshes and does not require the preliminary tetrahedralization of the grid. Using the combinatorial information of the grid makes it possible to update quickly the data structure when the scalar field is modified. This generic method is applied to different types of grids. We have recently optimized the representation of those grids when they are composed of a limited type of cells (e.g. tetrahedra, prisms, pyramids, hexaedra...). Our framework was sucessfully applied to geological data by Laurent Castanié (CIFRE Ph.D.) in the frame of Gocad, an industrial application, and a paper was accepted by the journal Computers and Geosciences.

In order to compute the interaction of proteins, we have proposed a fast and robust approach using a non-structured 3D mesh [22]. The first step of our algorithm is a 3D Delaunay tetrahedralization computation using atoms as vertices. This volume representation enables both a fast detection of atoms that are close to each other and a decomposition of the volume into tetrahedra that are easier to manipulate. This tetrahedralization is then used to detect the volume between proteins (as a set of tetrahedra) and to extract an iso-surface (the interface) in this volume.

Visualization of forest models is a challenging task when the main botanical attributes of plants have to be preserved. The objective is to decrease the computing time necessary to the display of a complex scene like a forest cover by simplifying the geometry of some trees while preserving the graphic quality of the unit. Two complementary approaches were studied:

- *Progressive quad foliage simplification.* Development of a method of progressive mesh decimation for the leaves and the branches according to the distance with the observer. This simplification algorithm is based on a strong error control process and a view-dependent branch mesh reorganization.
- *Modeling of the geometry of a tree by simple primitives: points and lines.* Development of a technique of sampling allowing the description of a three-dimensional object by graphic primitives simpler than the traditional polygons: the points.

7. Contracts and Grants with Industry

7.1. Start-up company creation

7.1.1. Earth Decision Sciences

The company Earth Decision Sciences (formerly T-Surf) develops and commercializes the modeler gOcad. gOcad is a 3D modeler dedicated to geosciences. This company was initially created as a start-up company of the National School of Geology and members of ISA project. It has now 100 employees in 7 countries (France, United States, Brazil, Dubai, Canada, ...).

7.1.2. VSP-Technology

VSP-Technology (CEO: François Cuny) was created in December 2001. Its objective is to provide services for a realistic and interactive visualization of complex 3D models. The Candelux and X-Mesh products are based on industrialized research results from the research on global light simulation and on numerical geometry done in ISA. VSP now hires 20 employees in Paris and Nancy.

7.2. Partnerships

7.2.1. Gocad Consortium

The gOcad software is developed in the context of a consortium that encloses some forty universities and thirty oil and gas companies around the world. This software is dedicated to modeling and visualizing the underground.

7.2.2. SGI

Our partnership with SGI started in 1996. This partnership has included the development of graphical software (OpenGL Performer, OpenGL Multipipe SDK) and intensive testing of the Origin 2000 supercomputer. In the very near future, we will be testing the new Ultimate Vision graphics accelerators (based on standard ATI graphics chipsets) and the new Altix supercomputer (based on Intel processors and the Linux kernel).

7.2.3. GE Health care

The partnership with GE Health Care (formerly GE Medical Systems) on the “Modeling by vision” research area started in 1995. In the past few years, it bore on the supervision of CIFRE PhD fellows on the topic of using a multi-modal framework in interventional neuroradiology. A new PhD started in January 2004 on the design of augmented reality tools for neuronavigation.

8. Other Grants and Activities

8.1. Regional initiatives

8.1.1. The "Charles Hermite High Performance Computing and Visualization Program"

Participant: Jean-Claude Paul.

This program, lead by Jean-Claude Paul, is supported by the "Contrat de Plan État-Région Lorraine". It includes more than twenty Academic Institutions and Industrial Companies. Computing and networking resources which are allocated to the the Program are the SGI Altix supercomputer, the new Ultimate Vision Graphics accelerators, the "Reality Center" immersive space configuration, and the VTHD++ network.

8.2. National initiatives

8.2.1. ACI Geo-Grid (ministry grant)

Participants: Bruno Lévy, Jean-Claude Paul, Luciano Perreira dos Reis.

Our ACI Geo-Grid aims at developping new tools for collaborative modeling for oil exploration. Based on ISA's expertise in geometric modeling and advanced visualization, we develop these tools in cooperation with Petrobras and the gOcad consortium.

8.2.2. ACI Data Masses (ministry grant)

Participant: Bruno Lévy.

The Data Masses ACI studies new ways of handling large geometrical databases. ISA's contribution concerns the parameterization of large triangulated surfaces and the segmentation of geometric objects based on an approximation of the curvature tensor.

8.2.3. ARC Docking (INRIA new investigation grant)

Participants: Xavier Cavin, Nicolas Ray.

The ARC Docking aims at fostering scientific cooperation on the topic of the complementarity between simulation and virtual reality in the area of molecular docking. The scientific objective is to enhance the molecular docking process thanks to the development of new techniques, implemented in an immersive visualization system coupled to a force-feedback manipulation device.

8.2.4. AS CNRS "Algorithmic and Discrete Geometry" (CNRS working group)

Participants: Hazel Everett, Xavier Goaoc, Sylvain Lazard, Marc Glisse.

The goal of the AS is to bring closer together two scientific communities, algorithmic geometry and discrete geometry. Two meetings whose purpose is to explore potential areas of collaboration have been organized in January and September.

8.2.5. AS CNRS "Real-time augmented reality" (CNRS working group)

Participants: Marie-Odile Berger, Erwan Kerrien, Gilles Simon.

This AS ended in january 2004. A satellite worshop of RFIA 2004 was organized by the members of the AS (see the online program).

8.2.6. AS CNRS "Analysis, modelling and simulation of the microworld" (CNRS working group)

Participant: Laurent Alonso.

The participation of ISA to this group is an expertise for virtual reality experiments in micro-robotics. The leader of the working group is Stéphane Régnier, Laboratoire de robotique de Paris 6, CNRS 2507.

8.2.7. ACI JemSTIC "Effective geometry for realistic visualization of complex scenes" (ministry grant) and ATIP STIC CNRS (CNRS grant)

Participants: Laurent Dupont, Hazel Everett, Xavier Goaoc, Sylvain Lazard, Bruno Lévy, Sylvain Petitjean.

The main motivation of the ACI and the ATIP is to rework the theoretical bases of fundamental techniques of computer graphics and rendering to speed up computations and move towards a better visual and physical realism. The principal objectives are the effectivity of the methods and the robustness of the calculations. Three problems of particular interest are: theoretical issues in 3D visibility, robust geometric computations on low-degree surfaces and algorithmics of large triangle meshes.

8.2.8. ODL Speech-To-Graphite (INRIA software development grant)

Participants: Fabien Boutantin, Bruno Lévy.

This project in cooperation with the Parole project (INRIA Lorraine) and the Datha association develops new tools based on our Graphite software to help deaf persons learn how to read on lips. The software animates a realistic 3D model of a face, driven by Parole's speech recognition techniques. When fully functional, the technology will be provided to deaf peoples by the Datha association.

8.2.9. The RNRT/VTHD++ Project

Participants: Xavier Cavin, Jérémie Turbet.

The VTHD++ Project, Task 5, Subtask 5, is dedicated to distant visualization experiments for CAD and realistic visual simulations.

8.2.10. Cooperation with the Spaces group

Participants: Laurent Dupont, Xavier Goaoc, Sylvain Lazard, Sylvain Petitjean.

We work in collaboration with several members of the Spaces group (LORIA-LIP6) on various problems from 3D visibility to robust computation on curved surfaces. The algorithm for computing near-optimal parameterizations of the intersection of quadric surfaces has been developed with D. Lazard. More generally, robust geometric computation on curved objects involves dealing with algebraic polynomials and systems, a specialty of the Spaces group.

8.2.11. Cooperation with the Parole group

Participants: Marie-Odile Berger, Erwan Kerrien, Brigitte Wrobel-Dautcourt.

The long term ambition of the cooperative research action Feedart is to offer articulatory feedback to deaf people acquiring language or people learning a foreign language. This project necessitates recovering articulatory parameters from the speech signal supplemented by images of the speaker's face. It also necessitates generating a talking face that produces vocal tract and face deformations consistent with those that could produce a real speaker.

Within this project, we are working on face reconstruction using a stereovision system in order to build 3D visems. During this year, a system for tracking markers or characteristic points on the face has been developped. These features are currently used by the speech group to reduce the under-determination of the acoustic-to-articulatory inversion.

8.2.12. Cooperation with the Geometrica group

Participants: Hazel Everett, Xavier Goaoc, Sylvain Lazard, Bruno Lévy, Sylvain Petitjean.

We work in collaboration with the Geometrica group (INRIA Sophia-Antipolis) on various problems. We work mainly with J.-D. Boissonnat, with O. Devillers on 3D visibility problems and with P. Alliez and F. Cazals on the parameterization of triangulated surfaces and remeshing problems.

8.2.13. Cooperation with the Galaad group

Participants: Laurent Dupont, Sylvain Lazard, Sylvain Petitjean.

We work in collaboration with the Galaad group (INRIA Sophia-Antipolis) on the problem of computing arrangments of 3D curved surfaces and in particular on arrangments of quadrics. Although no co-signed article is currently under preparation, we maintain close contact and cooperation.

8.2.14. Cooperation with the Calvi group

Participants: Bruno Lévy, Jean-Claude Paul.

We work in collaboration with the Calvi project (INRIA Lorraine) in order to improve our FEM algorithm with Domain Decomposition Methods and in order to improve visualization methods used by Calvi in their scientific computing applications.

8.2.15. Associations

- S. Petitjean is the chairman of the PhD thesis award committee of AFIT.
- L. Alonso is secretary of the national AGOS association of INRIA.

8.3. European initiatives

8.3.1. ARIS European project

Participants: Michael Aron, Marie-Odile Berger, Gilles Simon, Flavio Vigueras.

The ARIS project intends to overcome limitations of current AR solutions by providing (i) precise camera tracking, (ii) tools to reconstruct illumination and material data from images, and (iii) seamless integration of virtual and real scenes. We are especially concerned with the building of a real-time system for camera tracking which makes use of a multi-planar model of the scene. During this year, a hybrid system that makes an inertial sensor cooperate with the vision-based system has been designed in order to improve the robustness of the system to abrupt motions of the user. The renderer developed by the University of Manchester is connected to our real-time tracking system. The efficiency of the complete system was demonstrated at the final review of the project in august.

8.3.2. AIM at Shape European project

Participants: Bruno Levy, Ben Wan Chiu Li, Nicolas Ray.

The AIM at Shape European project intends to design geometrical modeling techniques improving the management of semantic information. The 3D modeling and computer graphics research domains require more and more expertise in various areas (differential geometry, numerical algorithms, combinatorial data structure, computer graphics hardware, ...). Achieving significant advances requires to master all these fundamental domains, which requires at least 10 men years for each aspect. In other words, reinventing the wheel can be a dramatic waste of time. This Network of Excellence (NoE) aims at sharing the expertise of European research groups in this area, and developping common integrated research platforms (CGAL: computational geometry library, Graphite: numerical geometry workbench, Synapse: numerical algorithms). We expect significant new fundamental results as the outcome of this strategy.

8.4. International initiatives

8.4.1. McGill-ISA associated team

Participants: Hazel Everett, Marc Glisse, Xavier Goaoc, Sylvain Lazard, Sylvain Petitjean.

The McGill-ISA associated team (INRIA program) is a joint project involving the geometry group of ISA and the computational geometry laboratory of McGill University (Montréal). The research theme is 3D visibility and, more generally, computational geometry.

In this context, we organized the 3rd Workshop on Geometry Problems in Computer Graphics (Oléron CNRS Center, May 24-29). S. Whitesides visited our group for one week and H. Everett, S. Lazard, and L. Zhang visited McGill for a week. Also, L. Zhang started a Ph.D. in January co-supervised by S. Whitesides and S. Lazard. For more details, see the McGill-ISA associated team web page.

8.4.2. Conferences, meetings and tutorial organization

- H. Everett and S. Lazard co-organized the 3rd Workshop on Geometry Problems in Computer Graphics (Oleron CNRS Center, 24-29 May).
- M.-O. Berger, E. Kerrien and N. Navab (TU München) co-organized the AMI satellite workshop of MICCAI on Augmented environments for Medical Imaging (St Malo,France, 30 September).
- B. Lévy and J.-C. Paul belonged to the Steering Committee of the 23th International gOcad Meeting, which was organized in Nancy and chaired by Jean-laurent Mallet.
- M.-O. Berger was a member of the program committee of RFIA'04, MICCAI 04, ISMAR 04.
- E. Kerrien was a member of the program committee of MICCAI 04.
- G. Simon was a member of the program committee of ISMAR 04.
- B. Lévy was a member of the program committee of EG'04, SMI'04, SGP'04.

8.5. Visiting scientists

International visitors of at least a week:

- J. Erickson (Univ. of Illinois at Urbana-Champaign, USA), invited professor, 3 months.
- S. Wismath (Univ. of Lethbridge, Canada), visiting professor, 1 week.
- S. Whitesides (McGill Univ., Canada), visiting professor, 1 week.
- K. Whittlesey (Univ. of Illinois at Urbana-Champaign, USA), visiting professor, 3 months.
- A. Sheffer (Univ. of British Columbia, Canada), visiting professor, 1 week.

International visits:

- L. Dupont, Max-Planck-Institut für Informatik (Saarbrücken, Germany), 5 months.
- X. Goaoc, Eindhoven Univ., Holland, 2 weeks.
- H. Everett, S. Lazard, and L. Zhang, McGill Univ., Canada, 1 week.
- X.Cavin and N.Ray, Univ. of Illinois at Urbana-Champaign, 3 weeks.

9. Dissemination

9.1. Teaching

- Several members of the group, in particular the professors, assistant professors and Ph.D. students, actively teach at Henri Poincaré Nancy 1 and Nancy 2 universities.
- Other members of the group also teach in the computer science DEA (Master) of Nancy. Namely H. Everett and S. Lazard teach the module "Computational geometry and graphics", M.-O. Berger and B. Lévy teach the module "Numerical algorithms for computer vision and computer graphics", and M.-O. Berger participates in the module "Pattern recognition".

9.2. Participation to conferences and workshops

Members of the group participated in the following events:

12th Annual European Symposium on Algorithms (ESA'04, Bergen, Norway), 3rd Korean workshop on computational geometry and geometric networks (Dagstuhl, Germany), final workshop of the ECG (Effective Computational Geometry for Curves and Surfaces) European project (Paris), AS Géométrie algorithmique et discrète (Lyon & Marne-la-Vallée), 3rd International Workshop on Geometry Problems in Computer Graphics (Oléron), Journées de géométrie algorithmique (Giens), 20th Symposium on Computational Geometry (SoCG'04, New-York, USA), International Symposium on Mixed and Augmented Reality (ISMAR'04, Tokyo), International Conference on Medical Image Computing and Computer Assisted Intervention (MICCAI 04, ST Malo, France), Conférence francophone sur la reconnaissance des formes et l'intelligence artificielle (RFIA 04, Toulouse), Visualization'04 (Austin, USA).

B. Lévy was invited to do a seminar on geometrical modeling during the scientific workshop of Dassault Systems (Paris), the Geometric Workshop of Schlumberger (Cambridge). B. Lévy did a presentation with O. Faugeras and F. Capello during the visit of R. Rashid (CEO Microsoft Research Intl) to G. Kahn at the INRIA in Paris.

10. Bibliography

Major publications by the team in recent years

[1] L. Alonso, F. Cuny, S. Petitjean, J.-C. Paul, S. Lazard, E. Wies. *The Virtual Mesh : A Geometric Abstraction for Efficiently Computing Radiosity*, in "ACM Transactions on Graphics", vol. 20, n° 3, 2001, p. 169-201.

[2] M.-O. Berger, B. Wrobel-Dautcourt, S. Petitjean, G. Simon. *Mixing Synthetic and Video Images of an Outdoor Urban Environment*, in "Machine Vision and Applications", vol. 11, n° 3, 1999, p. 145-159.

[3] H. Bronnimann, H. Everett, S. Lazard, F. Sottile, S. Whitesides. *Transversals to Line Segments in R3*, in "15th Canadian Conference on Computational Geometry - CCCG'2003, Halifax, Canada", Aug 2003, http://www.loria.fr/publications/2003/A03-R-082/A03-R-082.ps.

[4] O. Devillers, V. Dujmovic, H. Everett, X. Goaoc, S. Lazard, H.-S. Na, S. Petitjean. *The expected number of 3D visibility events is linear*, in "SIAM Journal on Computing", vol. 32, n° 6, Jun 2003, p. 1586-1620.

[5] L. Dupont, D. Lazard, S. Lazard, S. Petitjean. *Near-Optimal Parameterization of the Intersection of Quadrics*, in "19th ACM Symposium on Computational Geometry - SoCG 2003, San Diego, USA", ACM, Jun 2003, p. 246-255.

[6] E. Kerrien, M.-O. Berger, E. Maurincomme, L. Launay, R. Vaillant, L. Picard. *Fully automatic 3D/2D subtracted angiography registration*, in "Proceedings of Medical Image Computing and Computer-Assisted Intervention - MICCAI'99, Cambridge, England", C. Taylor, A. Colchester (editors)., Lecture Notes in Computer Science, vol. 1679, Springer, September 1999, p. 664-671.

[7] B. Levy, S. Petitjean, N. Ray, J. Maillot. *Least Squares Conformal Maps for Automatic Texture Atlas Generation*, in "Special Interest Group on Computer Graphics - SIGGRAPH'02, San-Antonio, Texas, USA", ACM (editor)., July 2002.

[8] B. LÉVY, G. CAUMON, S. CONREAUX, X. CAVIN. *Circular Incident Edge Lists : A Data Structure for Rendering Complex Unstructured Grids*, in "IEEE Visualization 2001, San-Diego, USA", IEEE, October 2001.

[9] J.-C. PAUL, X. CAVIN, L. ALONSO. *Partitioning and Scheduling Large Radiosity Computations in Parallel*, in "Journal on Parallel and Distributed Computer Practices - Special Issue on Parallel and Distributed Computer Graphics", vol. 3, n° 3, September 2000.

[10] G. SIMON, M.-O. BERGER. *Pose estimation for planar structure*, in "IEEE Computer Graphics and Applications", vol. 22, n° 6, November 2002, p. 46-53.

Doctoral dissertations and Habilitation theses

[11] L. DUPONT. *Paramétrage quasi-optimal de l'intersection de deux quadriques : théorie, algorithme et implantation*, Thèse d'université, Université Nancy II, Oct 2004, http://www.loria.fr/publications/2004/A04-T-251/A04-T-251.ps.

[12] X. GOAOC. *Structures de visibilité globales : tailles, calculs et dégénérescences*, Thèse d'université, Université Nancy 2, May 2004, http://www.loria.fr/publications/2004/A04-T-070/A04-T-070.ps.

Articles in referred journals and book chapters

[13] L. ALONSO, P. CHASSAING, F. GILLET, S. JANSON, E. M. REINGOLD, R. SCHOTT. *Quicksort with Unreliable Comparisons : A Probabilistic Analysis*, in "Combinatorics, Probability and Computing", vol. 13, n° 4-5, Jul 2004, p. 419-449.

[14] L. ALONSO, P. CHASSAING, E. M. REINGOLD, R. SCHOTT. *The worst-case chip problem*, in "Information Processing Letters", vol. 89, n° 6, Mar 2004, p. 303-308.

[15] T. ASANO, M. DE BERG, O. CHEONG, H. EVERETT, H. HAVERKORT, N. KATOH, A. WOLFF. *Optimal Spanners for Axis-Aligned Rectangles*, in "Computational Geometry : Theory and Applications", Jan 2004.

[16] C. BORCEA, X. GOAOC, S. LAZARD, S. PETITJEAN. *Common Tangents to Spheres in* $R3$, in "Discrete and Computational Geometry", Sep 2004.

[17] G. CAUMON, B. LEVY, L. CASTANIE, J.-C. PAUL. *Advanced visualization for various unstructured grids using ah hoc topological structures.*, in "Computers and Geosciences", Sep 2004.

[18] S.-W. CHENG, O. CHEONG, H. EVERETT, R. VAN OOSTRUM. *Hierarchical decompositions and circular ray shooting in simple polygons*, in "Discrete and Computational Geometry", vol. 32, n° 3, Sep 2004, p. 401-415.

[19] O. CHEONG, X. GOAOC, H.-S. NA. *Geometric permutations of disjoint unit spheres*, in "Computational Geometry : Theory and Applications", May 2004.

[20] H. EVERETT, C. DE FIGUEIREDO, S. KLEIN. *The perfection and recognition of bull-reducible Berge graphs*, in "RAIRO-Theoretical Informatics and Applications", Jan 2004.

[21] C. LAMATHE. *The Number of Labelled k-Arch Graphs*, in "Journal of Integer Sequences", Article numéro 04.3.1, vol. 7, Aug 2004.

[22] N. RAY, X. CAVIN, J.-C. PAUL, B. MAIGRET. *Intersurf : dynamic interface between proteins*, in "Journal of Molecular Graphics and Modelling", Dec 2004.

[23] A. SHEFFER, B. LEVY, M. MOGILNITSKY, A. BOGOMYAKOV. *ABF++ : Fast and Robust Angle Based Flattening*, in "ACM Transactions on Graphics", Apr 2004.

Publications in Conferences and Workshops

[24] M. ARON, G. SIMON, M.-O. BERGER. *Handling uncertain sensor data in vision-based camera tracking*, in "International Symposium on Mixed and Augmented Reality - ISMAR'04, Arlington, USA", IEEE and ACM, Nov 2004.

[25] M.-O. BERGER, R. ANXIONNAT, E. KERRIEN. *A Methodology for Validating a New Imaging Modality with Respect to a Gold Standard Imagery : Example of the Use of 3DRA and MRI for AVM Delineation*, in "Medical Image Computing and Computer-Assisted Intervention - MICCAI 2004, Saint Malo, France", C. BARILLOT, D. R. HAYNOR, P. HELLIER (editors)., Lecture Notes in Computer Science, vol. 3216, Springer-Verlag, Sep 2004, p. 516-524.

[26] M.-O. BERGER, R. ANXIONNAT, E. KERRIEN. *The Use of 3D Xray angiographic Images for Volume Determination of Cerebral Arteriovenous Malformations*, in "SPIE Medical Imaging 2004, San Diego", Feb 2004, p. 634-643, http://www.loria.fr/publications/2004/A04-R-089/A04-R-089.ps.

[27] H. BRONNIMANN, O. DEVILLERS, V. DUJMOVIC, H. EVERETT, M. GLISSE, X. GOAOC, S. LAZARD, H.-S. NA, S. WHITESIDES. *The Number of Lines Tangent to Arbitrary Convex Polyhedra in 3D*, in "ACM Symposium on Computational Geometry - SoCG'2004, Brooklyn, NY", Jun 2004, http://www.loria.fr/publications/2004/A04-R-022/A04-R-022.ps.

[28] H. BRÖNNIMANN, O. DEVILLERS, S. LAZARD, F. SOTTILE. *On the number of line tangents to four triangles in three-dimensional space*, in "16th Canadian Conference on Computational Geometry - CCCG'04, Montreal, Canada", Aug 2004, http://www.loria.fr/publications/2004/A04-R-125/A04-R-125.ps.

[29] J. CHEN, M.-O. BERGER, Y. LAPRIE. *An Effective Lip Tracking Algorithm for Acoustic-to-Articulatory Inversion*, in "5th International Workshop on Image Analysis for Multimedia - WIAMIS'2004, Lisbon, Portugal", Apr 2004, http://www.loria.fr/publications/2004/A04-R-336/A04-R-336.ps.

[30] J. CHEN, Y. LAPRIE, M.-O. BERGER. *A Robust Lip Tracking System for the Acoustic to Articulatory Inversion*, in "6th IASTED International Conference on Signal and Image Processing - SIP'2004, Honolulu, Hawaii, USA", Aug 2004, http://www.loria.fr/publications/2004/A04-R-334/A04-R-334.ps.

[31] L. DUPONT, S. LAZARD, D. LAZARD, S. PETITJEAN. *Near-Optimal Parameterization of the Intersection of Quadrics : Theory and Implementation*, in "International Conference on Polynomial System Solving - ICPSS 2004, Paris, France", Nov 2004, http://www.loria.fr/publications/2004/A04-R-480/A04-R-480.ps.

[32] N. HOLZSCHUCH, L. ALONSO. *Combining Higher-Order Wavelets and Discontinuity Meshing : a Compact*

Representation for Radiosity, in "Eurographics Symposium on Rendering 2004 - EGSR 2004, Norrköping, Sweden", Jun 2004, 13.

[33] G. LAUVAUX, S. LAZARD, C. BARLIER. *Orientation des pièces artistiques pour le procédé de Stratoconception*, in "10th European Forum on Rapid Prototyping, Paris, France", Sep 2004.

[34] S. LAZARD, L. M. PEÑARANDA, S. PETITJEAN. *Intersecting Quadrics : An Efficient and Exact Implementation*, in "ACM Symposium on Computational Geometry - SoCG'2004, Brooklyn, NY", Jun 2004, http://www.loria.fr/publications/2004/A04-R-021/A04-R-021.ps.

[35] J.-F. VIGUERAS, M.-O. BERGER, G. SIMON. *On the Influence of Fixing the Principal Point in Frame-by-Frame Multiplanar Calibration*, in "International Conference on Pattern Recognition - ICPR'2004, Cambridge, Royaume Uni", Aug 2004, http://www.loria.fr/publications/2004/A04-R-088/A04-R-088.ps.

Internal Reports

[36] C. BORCEA, X. GOAOC, S. LAZARD, S. PETITJEAN. *Common Tangents to Spheres in $R3$*, Rapport de recherche, INRIA, Sep 2004, http://www.inria.fr/rrrt/rr-5325.html.

[37] S. TABBONE, L. ALONSO, D. ZIOU. *Behavior of the Laplacian of Gaussian Extrema*, Technical report, Sep 2004.

Miscellaneous

[38] F. BLAISE. *Introduction à l'Infographie - Application à la visualisation des plantes*, Jun 2004, http://www.loria.fr/publications/2004/A04-R-071/A04-R-071.ps.

Bibliography in notes

[39] F. DURAND. *Visibilité tridimensionnelle : étude analytique et applications*, Ph. D. Thesis, Université Joseph Fourier - Grenoble I, 1999.

[40] J. LEVIN. *A parametric algorithm for drawing pictures of solid objects composed of quadric surfaces*, in "Communications of the ACM", vol. 19, n° 10, 1976, p. 555-563.

[41] M. POCCHIOLA, G. VEGTER. *The Visibility Complex*, in "International Journal of Computational Geometry and Applications", vol. 6, n° 3, 1996, p. 1-30.

[42] A. REQUICHA, H. VOELCKER. *Solid modeling: a historical summary and contemporary assessment*, in "IEEE Computer Graphics and Applications", vol. 2, n° 1, 1982, p. 9-24.