INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team ISA

Models, algorithms and geometry for computer graphics and vision

Lorraine

THEME 3B

Activity Report

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1. Team

ISA is a research project common to INRIA, CNRS, INPL, Université Henri Poincaré Nancy 1, Université Nancy 2.

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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

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

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

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 Esprit 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. We intend to consider this problem in the very near future.

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 arterioveinous malformations (AVM). The treatment of AVM is classically a two-stage process: embolisation 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 aim is to perform an accurate detection of the AVM shape within a multimodality framework.

We are also 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

Participants: Laurent Dupont, Hazel Everett, Marc Glisse [since 9/1/03], Xavier Goaoc, Cédric Lamathe [since 11/1/03], Geoffroy Lauvaux, Sylvain Lazard, Bruno Lévy, Jean-Claude Paul, Sylvain Petitjean, Nicolas Ray, Rodrigo Toledo.

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

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 [40][38]. 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 [3]. 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 [16]. This probabilistic result doesn't 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 very much 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.

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 mechanical pieces can be well modeled by quadric patches (degree 2 surfaces, including planes, spheres, cylinders and cones) and torii [41]. 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 poses 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 coherent the geometric information 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 implemented a robust and optimal algorithm for the computation of an exact parametric form of the intersection of two quadrics. Our method is based on the projective formalism, techniques of linear algebra and number theory, and new theorems characterizing the rationality of the intersection [25]. 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 [39]).

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 project.

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 latest results make it possible to transform a large triangulated surface into a HPC (Hierarchical Parametric Cluster), a new parametric hierarchical representation. Using this representation, it is possible to compute global light simulations on scenes comprising gigantic models (several million triangles).

3.3. Numerical simulation and visualization

Participants: Laurent Alonso, Frédéric Blaise, Xavier Cavin, Gilles Dépret, Bruno Lévy, Ben Wan Chiu Li, Jean-Claude Paul, Luciano Pereira Dos Reis, Nicolas Ray, Rodrigo Toledo, Jérémie Turbet, Jean-Christophe Ulysse, Xiaopeng Zhang.

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

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 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 on the SGI Altix supercomputer and the new SGI Ultimate Garphics engine operated at the "Charles Hermite High Performance Computing and Visualization" Program. 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

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

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 Etat-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 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

Key words: *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

Key words: *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

Key words: *Health*.

We have been working for ten years in close collaboration with the neuroradiology laboratory (CHU Nancy) and General Electric (GEMSE). Our methods and software are tested in clinical context at the neurological hospital (Nancy).

4.5. Forest growth simulation

Participants: Frédéric Blaise, Xiaopeng Zhang.

Key words: *Environment*, *plant modeling*, *forest*, *visualization*, *immersive environments*.

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 to 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

Key words: *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 real-time augmented reality system which makes use of a multi-planar model of the scene. Even when the precision of the viewpoints is improved by considering several planes, fluctuations in the parameters are often observed and may lead to unpleasant visual impressions such as jittering or sliding when augmented scenes are considered.

Following Matsunaga and Kanatani, we are investigating this year the use of motion model selections to reduce fluctuations of the camera parameters and to improve the visual impression of the augmented scene. There are different branches using model selection, but there is no such successful criterion in general. For this reason, we try to compare different model selection and we especially consider the criteria which involve the covariance matrix on the estimated parameters and the Fisher information matrix. Indeed, criteria such as the one of Akaike are often only asymptotic approximations of a criterion which includes the covariance or the information matrix. Experiments which were conducted on synthetic and real images proved that the criteria which involved the covariance matrix or the Fisher information matrix gave the best results. They allow us to produce smoother trajectories and better visual impression. In addition, model selection reduces noticeably the drift problems that are common when long sequences are considered [31][32].

This year, our activity in neurology mainly concerns the detection of cerebral arteriovenous malformations (AVM). The radiotherapic treatment of AVM requires an accurate estimation of the AVM shape. This estimation is classically obtained from the delineation of the AVM in several 2D angiographic views. A clinical study of the inter-observer variability in the AVM detection was first performed in [20]. It proves that the estimated volume varies a lot between observers. To improve the AVM delineation and to reduce variability, we propose to use other imaging modalities such as 3D angiography and MRI in a multi-modality framework. A first step towards this goal is to propose a framework for AVM delineation which 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 modeled, the recovered shapes have proved to be in accordance with the current and handmade Gold Standard. Convincing results are shown in [12].

Our activity in urology led us towards the study of a non-rigid registration method to put into correspondence two contrast-enhanced CT scanners of the same patient acquired at two different times. Two methods were tested. On the first hand, a thin plate spline-based interpolation was not judged correct by the physicians whom we collaborate with, neither for the quality of the result, nor for the usability of the method. On the second hand, a completely automatic multiresolution method was implemented that aims at optimizing the local correlation score. The precision of the results was rated very satisfactory by the physicians and they considered the computation time to be reasonable in a clinical setup.

The next step in the collaboration aims at integrating the segmentation results (studied one year ago) and the registration results (studied this year) in order to build a system for the segmentation of contrast-enhanced CT scans of the abdomen that takes into account the dynamics of the progression of the contrast medium within the patient.

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 types of object, we published a fundamental result that there is a linear number of visibility events in a 3D scene [16].

Our results on 3D visibility with polyhedral objects have been the following. We characterized the transversals to arbitrary segments in 3D [23][35]. We presented some results about the size of the silhouette of a polyhedron in terms of its size [19]. We also proved 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. This result, which follows a preliminary publication [3], will be submitted for conference publication in December.

Concerning curved objects, we presented a new approach for computing the visibility complex of algebraic curved objects (submitted to a conference in September). We improved the previous known bounds on the number of combinatorially distinct transversals to balls [24][36]. Finally, we solved the long-standing open problem that four balls admit infinitely many tangents only if their centers are collinear; we actually characterized the degenerate configurations in which four balls admit infinitely many tangents (these results will be submitted for conference publication in December).

On the theme of robust computation on curved objects, we published a conference version of our algorithm for computing efficiently and exactly a near-optimal parametric form of the intersection of two quadrics surfaces [25]. These results are major. Indeed, 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. Beside the guaranty of near-optimality of our solution, the observed actual size of our output parameterizations is small. Moreover it is, on some representative examples, at least 17 000 times smaller than the size of the parameterizations output by the previous known algorithm. We implemented our algorithm in C++. We made a quadric intersection server available at our Quadrics web page and we will make a first release of our code before the end of the year.

Our results in numerical geometry concern the parameterization of large triangulated models using a cascadic multigrid algorithm [28]. Using this algorithm, it is possible to automatically generate texture coordinates for large models. We have applied this method to the automatic generation of texture atlases for the visualization of radiosity simulations [29]. We have also developed new geometric methods operating in parameter space. Our DDE method (Dual Domain Extrapolation) [18] is a Discrete Fairing operator. Using DDE, the borders of the surface can be let free to move, and holes can be easily filled. Using a parameterization, it is also possible to design efficient remeshing algorithms. Our anisotropic remeshing algorithms [14] creates a mesh naturally adapted to the shape of the surface. The method is based on an estimation of the curvature tensor and on the integration of its stream lines in parameter space.

6.3. Numerical simulation and visualization

6.3.1. Light transport equation

Since the computing times of our high-order wavelet radiosity algorithm remain significant, we try to improve the oracle function and explore how to use non-tree wavelets. Other insights are also experimented in order to improve the scalability of our parallel algorithm.

The rendering of a very large set of pre-computed radiosity values also needed to be solve. In order to generate only one texture for each object, the parametric spaces of each of its parts must be gathered. This problem is NP-complete, but we have developed heuristics providing good results for the polygons resulting from our segmentation algorithm.

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. In order to compute the interaction of proteins, we have proposed a fast and robust approach using a non-structured 3D mesh. 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. Our simplification algorithm is based on a strong error control process and a view-dependent branch mesh reorganization. All data are computed from the GreenLab Model. Finally, data of physical simulations have been also explored. Turbulent thermal diffusivities in fusion can be analyzed today by scientists from Vlasov codes, thanks to Graphite, which now allows the visualization of time-varying unstructured data.

High Performance computing and visualization algorithms have been developed in cooperation with the SGI company in the last years. More recently, we introduced a new software architecture allowing to combine several CPU's and several GPU's (graphic cards). We showed that this combination, which exploits the geometrical engines of the graphic cards, allowed for a very significant speed-up of the geometric calculations which appear in certain scientific applications, without hindering the acceleration of traditional parallelism. With the SGI company, we study the scaling of such configurations in order to optimize the interactions of the CPU's and GPU's and to find the best compromise number of CPU's/number of GPU's.

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 70 employees in 5 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. It has now 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 operating system).

7.2.3. General Electric Medical Systems

The partnership with General Electric on the “Modeling by vision” research area started in 1995. In the past few years, it bore on the supervision of CIFRE Ph.D. fellows on the topic of using a multi-modal framework in interventional neuro-radiology. A new Ph.D. will start in January 2004.

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 Feedart (INRIA new investigation grant)

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. In addition, a system for tracking markers or characteristic points on the face is under development. These features will be used to reduce the under-determination of the acoustic-to-articulatory inversion.

8.2.4. ARC Plasma (INRIA new investigation grant)

Participants: Laurent Alonso, Gilles Dépret, Bruno Lévy, Jean-Claude Paul.

The ARC Plasma aims at fostering scientific cooperation on the topic of the complementarity between simulation and virtual reality in the area of thermonuclear fusion. The scientific objective is to considerably improve the reliability of the numerical simulations thanks to the implementation of suitable techniques of visualization.

8.2.5. ARC TéléGéo (INRIA new investigation grant)

Participants: Bruno Lévy, Sylvain Petitjean, Nicolas Ray.

The ARC TéléGéo aims at creating a synergy on the topic of network transmission of geometrical objects. Participants work on developing new techniques for manipulating and representing geometrical data for applications on heterogeneous networks. The concerned fields include computational geometry, coding, data compression and computer graphics.

8.2.6. 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.

8.2.7. 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. A first meeting will take place on January 8, 2004 the purpose of which is to explore potential areas of collaboration. A second meeting will take place in May 2004.

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

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

The goal of the AS is to identify key problems in the emerging field of augmented reality. A two-day meeting was organized on September 15th and 16th in Paris. This meeting allowed us to point out that many research systems have been demonstrated but there are still major obstacles limiting the wider use of augmented reality. Two workshops will be organized by some of the AS members in 2004.

8.2.9. 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.

8.2.10. 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.

8.2.11. 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.

8.2.12. 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.

8.2.13. 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 [25]. More generally, robust geometric computation on curved objects involves dealing with algebraic polynomials and systems, a specialty of the Spaces group.

8.2.14. 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 [15], with O. Devillers on 3D visibility problems [16] and with P. Alliez and F. Cazals on the parameterization of triangulated surfaces and remeshing problems.

8.2.15. 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.

8.2.16. 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.

8.2.17. Conferences, meetings and tutorial organization

The ORASIS 2003 conference was organized in May (Gérardmer, France) by the ISA team. This french conference on computer vision is organized every alternate year [11].

8.2.18. Associations

- B. Lévy is a member of the PhD thesis award committee of SPECIF.
- 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: 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. Besides the work on the use of models for improving camera stabilization (see section 6.1), much work has been done to integrate the components of the mobile unit. The renderer developed by the University of Manchester is now connected to the real-time tracking system. Currently, the system has been successfully tested both on offline and online tracking sequences.

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 2nd Workshop on Geometry Problems in Computer Graphics (Bellairs Research Institute of McGill University, Barbados, 8-14 Feb.). S. Whitesides visited our group for two weeks and S. Lazard visited McGill for ten days. Also, L. Zhang visited our group for two months and then came back in September with the goal of starting in 2004 a Ph.D. in graphics in our group. 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 2nd Workshop on Geometry Problems in Computer Graphics (Bellairs Research Institute of McGill University, Barbados, 8-14 Feb.).
- S. Lazard co-organised the Lorraine-Saarland Workshop on Geometry and CAD (MPII, Saarbrücken, 14 April).
- 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 and ICCV'03.
- S. Petitjean was a member of the program committee of ICCV'03.
- G. Simon was a member of the program committee of ISMAR'03.
- A tutorial on Photorealistic Augmented Reality was given by all the members of the ARIS project at ISMAR'03.

8.5. Visiting scientists

International visitors of at least a week:

- D. Bremner (Univ. of New Brunswick, Canada) invited prof., 6 weeks.
- S. Whitesides (McGill Univ., Canada) visiting prof., 2 weeks.
- I. Streinu (Smith College, Massachusetts, USA), invited prof., 4 weeks.
- C. Borcea (Rider Univ., USA), visiting prof., 4 weeks.
- M. Hemmer (Mainz Univ., Germany), visiting student, 1 week.
- L. Zhang (McGill Univ., Canada) visiting student, 2 months.
- A. Sheffer (Technion Univ., Israel), visiting prof., 1 week.

International visitors of less than a week:

- C. Damez (MPII Saarbrücken, Germany), C. Miraglia Herrera de Figueiredo (UFRJ, Brazil), L. de Figueiredo (UFRJ, Brazil), S. Pion (MPII Saarbrücken, Germany), E. Schoemer (Mainz Univ., Germany), F. Sottile (Univ. of Masssachusetts, USA), H. Baogang (CASIA Beijing, P.R. China).

International visits:

- J.-C. Paul, Tsinghua University, China, 2 weeks.
- X. Goaoc, Eindhoven Univ., Holland, 1 week.
- H. Everett, Munich Tech. Univ., Germany, 2 days.
- S. Lazard, Munich Tech. Univ., Germany, 2 days; McGill Univ. Canada, 10 days; Texas A&M Univ. USA, 1 day.
- F. Blaise and X. Zhang, LIAMA, Beijing, P.R. China, 10 days.
- X. Cavin and N. Ray, Univ. of Utah, USA, 3 days. Beckman Institute, Urbana Champaign, USA, 3 days.

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:

CCCG’03 (Halifax, Canada), ECG Workshop on Applications Involving Geometric Algorithms with Curved Objects (Saarbrücken, Germany), ESA’03 (Budapest, Hungary), Lorraine-Saarland Workshop on Geometry and CAD (Saarbrücken, Germany), 2nd International Workshop on Geometry Problems in Computer Graphics (Bellairs Research Institute of McGill University, Barbados), Journées nationales de calcul formel (Luminy), Journées de géométrie algorithmique (Giens), École Adéquation Algorithmes Arithmétique (Dijon), 2nd Eindhoven-Carleton Workshop on I/O efficient data structures in geometry (Hilvesum, Holland), SoCG’03 (San Diego, USA), journées ORASIS (Gérardmer, France), Vision, Video and Graphics (Bath, UK), International Symposium on Mixed and Augmented Reality (ISMAR’04, Tokyo), International Congress and Exhibition on Computer Assisted Radiology and Surgery (CARS’03, Londres, Royaume-Uni), PMA’03 (Beijing, P.R. China), ISIITA’03 (Beijing, P.R. China), SGP’03, VisSym’03 (Grenoble, France), SIGGRAPH’03 (San Diego, USA), Eurographics’03 (Granada, Spain), Pacific Graphics’03 (Canmore, Canada), Visualization’03 (Seattle, USA).

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