Activity Report 2013

Project-Team ALICE

Geometry and Lighting

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Keywords: Computer Graphics, Geometry Processing, Visualization

Creation of the Project-Team: 2006 January 09.

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2. Overall Objectives

2.1. Introduction

ALICE is one of the six teams in the Algorithms, Computation, Geometry and Image group in Inria Nancy Grand-Est.

ALICE is a project-team in Computer Graphics. The fundamental aspects of this domain concern the interaction of *light* with the *geometry* of the objects. The lighting problem consists in designing accurate and efficient *numerical simulation* methods for the light transport equation. The geometrical problem consists in developing new solutions to *transform and optimize geometric representations*. Our original approach to both issues is to restate the problems in terms of *numerical optimization*. We try to develop solutions that are *provably correct*, *numerically stable* and *scalable*.

- By provably correct, we mean that some properties/invariants of the initial object need to be preserved by our solutions.
- By numerically stable, we mean that our solutions need to be resistant to the degeneracies often encountered in industrial data sets.
- By scalable, we mean that our solutions need to be applicable to data sets of industrial size.

To reach these goals, our approach consists in transforming the physical or geometric problem into a numerical optimization problem, studying the properties of the objective function and designing efficient minimization algorithms. To properly construct these discretizations, we use the formalism of finite element modeling, geometry and topology. We are also interested in fundamental concepts that were recently introduced into the geometry processing community, such as discrete exterior calculus, spectral geometry processing and theory of sampling.

The main applications of our results concern scientific visualization. We develop cooperations with researchers and people from the industry, who experiment applications of our general solutions to various domains, comprising CAD, industrial design, oil exploration and plasma physics. Our solutions are distributed in both open-source software (Graphite, OpenNL, CGAL) and industrial software (Gocad, DVIZ).

3. Research Program

3.1. Introduction

Computer Graphics is a quickly evolving domain of research. These last few years, both acquisition techniques (e.g., range laser scanners) and computer graphics hardware (the so-called GPU's, for Graphics Processing Units) have made considerable advances. However, despite these advances, fundamental problems still remain open. For instance, a scanned mesh composed of hundred million triangles cannot be used directly in real-time visualization or complex numerical simulation. To design efficient solutions for these difficult problems, ALICE studies two fundamental issues in Computer Graphics:

- the representation of the objects, i.e., their geometry and physical properties;
- the interaction between these objects and light.

Historically, these two issues have been studied by independent research communities. However, we think that they share a common theoretical basis. For instance, multi-resolution and wavelets were mathematical tools used by both communities [27]. We develop a new approach, which consists in studying the geometry and lighting from the *numerical analysis* point of view. In our approach, geometry processing and light simulation are systematically restated as a (possibly non-linear and/or constrained) functional optimization problem. This type of formulation leads to algorithms that are more efficient. Our long-term research goal is to find a formulation that permits a unified treatment of geometry and illumination over this geometry.

3.2. Geometry Processing for Engineering

Keywords: Mesh processing, parameterization, splines

Geometry processing recently emerged (in the middle of the 90's) as a promising strategy to solve the geometric modeling problems encountered when manipulating meshes composed of hundred millions of elements. Since a mesh may be considered to be a *sampling* of a surface - in other words a *signal* - the *digital signal processing* formalism was a natural theoretic background for this subdomain (see e.g., [28]). Researchers of this domain then studied different aspects of this formalism applied to geometric modeling.

Although many advances have been made in the geometry processing area, important problems still remain open. Even if shape acquisition and filtering is much easier than 30 years ago, a scanned mesh composed of hundred million triangles cannot be used directly in real-time visualization or complex numerical simulation. For this reason, automatic methods to convert those large meshes into higher level representations are necessary. However, these automatic methods do not exist yet. For instance, the pioneer Henri Gouraud often mentions in his talks that the *data acquisition* problem is still open. Malcolm Sabin, another pioneer of the "Computer Aided Geometric Design" and "Subdivision" approaches, mentioned during several conferences of the domain that constructing the optimum control-mesh of a subdivision surface so as to approximate a given surface is still an open problem. More generally, converting a mesh model into a higher level representation, consisting of a set of equations, is a difficult problem for which no satisfying solutions have been proposed. This is one of the long-term goals of international initiatives, such as the AIMShape European network of excellence.

Motivated by gridding application for finite elements modeling for oil and gas exploration, in the frame of the Gocad project, we started studying geometry processing in the late 90's and contributed to this area at the early stages of its development. We developed the LSCM method (Least Squares Conformal Maps) in cooperation with Alias Wavefront [5]. This method has become the de-facto standard in automatic unwrapping, and was adopted by several 3D modeling packages (including Maya and Blender). We experimented various applications of the method, including normal mapping, mesh completion and light simulation [2].

However, classical mesh parameterization requires to partition the considered object into a set of topological disks. For this reason, we designed a new method (Periodic Global Parameterization) that generates a continuous set of coordinates over the object [6]. We also showed the applicability of this method, by proposing the first algorithm that converts a scanned mesh into a Spline surface automatically [4].

We are still not fully satisfied with these results, since the method remains quite complicated. We think that a deeper understanding of the underlying theory is likely to lead to both efficient and simple methods. For this reason, in 2012 we studied several ways of discretizing partial differential equations on meshes, including Finite Element Modeling and Discrete Exterior Calculus. In 2013, we also explored Spectral Geometry Processing and Sampling Theory (more on this below).

3.3. Computer Graphics

Keywords: texture synthesis, shape synthesis, texture mapping, visibility

Content creation is one of the major challenges in Computer Graphics. Modeling shapes and surface appearances which are visually appealing and at the same time enforce precise design constraints is a task only accessible to highly skilled and trained designers.

In this context the team focuses on methods for by-example content creation. Given an input example and a set of constraints, we design algorithms that can automatically generate a new shape (geometry+texture). We formulate the problem of content synthesis as the joint optimization of several objectives: Preserving the local appearance of the example, enforcing global objectives (size, symmetries, mechanical properties), reaching user defined constraints (locally specified geometry, contacts). This results in a wide range of optimization problems, from statistical approaches (Markov Random fields), to combinatorial and linear optimization techniques.

As as complement to the design of techniques for automatic content creation, we also work on the representation of the content, so as to allow for its efficient manipulation. In this context we develop data-structures and algorithms targeted at massively parallel architectures, such as GPUs. These are critical to reach the interactive rates expected from a content creation technique. We also propose novel ways to store and access content stored along surfaces [7] or in volumes [1][24].

The team also continues research in core topics of computer graphics at the heart of realistic rendering and realistic light simulation techniques; for example, mapping textures on surfaces, or devising visibility relationships between 3D objects populating space.

4. Software and Platforms

4.1. Vorpaline

Participants: Dobrina Boltcheva, Bruno Lévy, Thierry Valentin.

Vorpaline is an automatic surfacic and volumetric mesh generation software, distributed with a commercial license. Vorpaline is based on the main scientific results stemming from projets GoodShape and VORPALINE, funded by the European Research Council, about optimal quantization, centroidal Voronoi diagrams and fast/parallel computation of Voronoi diagrams in high-dimension space. The current version (1.0) provides functionalities such as isotropic/adaptive/anisotropic surface re-meshing, tolerant surface re-meshing, mesh repair and mesh decimation. Next versions will provide functionalities such as constrained surface meshing (2.0), quad-dominant surface meshing (3.0) and hex-dominant volume meshing (4.0).

4.2. IceSL

Participants: Jérémie Dumas, Jean Hergel, Sylvain Lefebvre.

In the new software IceSL, we propose to exploit recent advances in GPU and Computer Graphics to accelerate the slicing process of objects modelled via a CSG [1] language. Our target are open source low cost *fused deposition modeling* printers such as RepRaps.

Our approach first inputs a CSG description of a scene which can be composed of both meshes and analytic primitives. During display and slicing the CSG model is converted on the fly into an intermediate representation enabling fast processing on the GPU. Slices can be quickly extracted, and the tool path is prepared through image erosion. The interactive preview of the final geometry uses the exact same code path as the slicer, providing an immediate, accurate visual feedback.

IceSL is the recipient software for our ERC research project "ShapeForge", led by Sylvain Lefebvre.

4.3. Graphite

Participants: Dobrina Boltcheva, Samuel Hornus, Bruno Lévy, David Lopez, Romain Merland, Jeanne Pellerin, Nicolas Ray.

Graphite is a research platform for computer graphics, 3D modeling and numerical geometry. It comprises all the main research results of our "geometry processing" group. Data structures for cellular complexes, parameterization, multi-resolution analysis and numerical optimization are the main features of the software. Graphite is publicly available since October 2003. It is hosted by Inria GForge since September 2008. Graphite is one of the common software platforms used in the frame of the European Network of Excellence AIMShape .

Graphite and its research-plugins are actively developed and extended. The latest version was released on January 2nd, 2014 and has been downloaded 135 times as of January 29.

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[1] Constructive Solid Geometry

Figure 1. Left. A two-colored vase is modeled in IceSL. Right. An early printed result.

4.4. GraphiteLifeExplorer

Participant: Samuel Hornus.

GLE is a 3D modeler, developed as a plugin of Graphite, dedicated to molecular biology. It is developed in cooperation with the Fourmentin Guilbert foundation and has recently been renamed "GraphiteLifeExplorer". Biologists need simple spatial modeling tools to help in understanding the role of the relative position of objects in the functioning of the cell. In this context, we develop a tool for easy DNA modeling. The tool generates DNA along any user-given curve, open or closed, allows fine-tuning of atoms position and, most importantly, exports to PDB (the Protein Daba Bank file format).

The development of GLE is currently on hold, but it is still downloaded (freely) about twice a day (1600 downloads to date). A paper describing it was published in the broad journal PLOS One [12].

4.5. OpenNL - Open Numerical Library

Participants: Bruno Lévy, Nicolas Ray, Rhaleb Zayer.

OpenNL is a standalone library for numerical optimization, especially well-suited to mesh processing. The API is inspired by the graphics API OpenGL, this makes the learning curve easy for computer graphics practitioners. The included demo program implements our LSCM [5] mesh unwrapping method. It was integrated in Blender by Brecht Van Lommel and others to create automatic texture mapping methods. OpenNL is extended with two specialized modules :

- CGAL parameterization package: this software library, developed in cooperation with Pierre Alliez and Laurent Saboret, is a CGAL package for mesh parameterization.
- Concurrent Number Cruncher: this software library extends OpenNL with parallel computing on the GPU, implemented using the CUDA API.

4.6. LibSL

Participants: Anass Lasram, Sylvain Lefebvre.

LibSL is a Simple library for graphics. Sylvain Lefebvre continued development of the LibSL graphics library (under CeCill-C licence, filed at the APP). LibSL is a toolbox for rapid prototyping of computer graphics algorithms, under both OpenGL, DirectX 9/10, Windows and Linux. The library is actively used in both the REVES / Inria Sophia-Antipolis Méditerrannée and the ALICE / Inria Nancy Grand-Est teams.

5. New Results

5.1. Geometry Processing

5.1.1. *Fitting Polynomial Volumes to Surface Meshes with Voronoi Squared Distance Minimization*

Participants: Gilles-Philippe Paillé, Bruno Lévy.

We propose a method for mapping polynomial volumes. Given a closed surface and an initial template volume grid, our method deforms the template grid by fitting its boundary to the input surface while minimizing a volume distortion criterion. The result is a point-to-point map distorting linear cells into curved ones. Our method is based on several extensions of Voronoi Squared Distance Minimization (VSDM) combined with a higher-order finite element formulation of the deformation energy. This allows us to globally optimize the mapping without prior parameterization. The anisotropic VSDM formulation allows for sharp and semi-sharp features to be implicitly preserved without tagging. We use a hierarchical finite element function basis that selectively adapts to the geometric details. This makes both the method more efficient and the representation more compact. We apply our method to geometric modeling applications in computer-aided design and computer graphics, including mixed-element meshing, mesh optimization, subdivision volume fitting, and shell meshing.

This work was presented at the "ACM Symposium on Geometry Processing" and published in the "Computer Graphics Forum" journal [16].
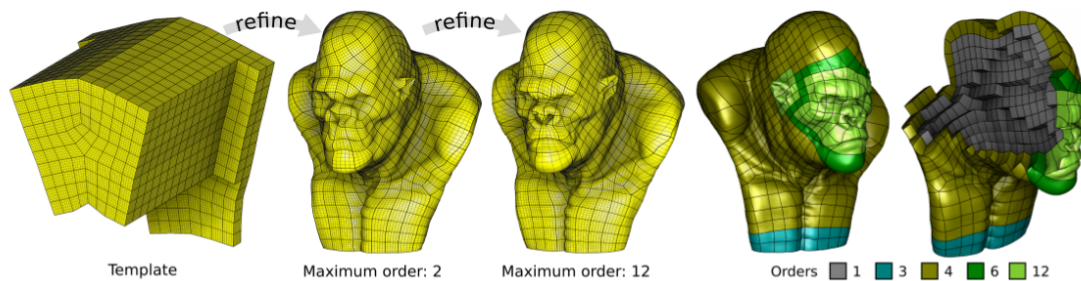
Figure 2. Fitting Polynomial Volumes to Surface Meshes with Voronoi Squared Distance Minimization

5.1.2. *Particle-Based Anisotropic Surface Meshing*

Participant: Bruno Lévy.

This paper introduces a particle-based approach for anisotropic surface meshing. Given an input polygonal mesh endowed with a Riemannian metric and a specified number of vertices, the method generates a metric-adapted mesh. The main idea consists of mapping the anisotropic space into a higher dimensional isotropic one, called "embedding space". The vertices of the mesh are generated by uniformly sampling the surface in this higher dimensional embedding space, and the sampling is further regularized by optimizing an energy function with a quasi-Newton algorithm. All the computations can be re-expressed in terms of the dot product in the embedding space, and the Jacobian matrices of the mappings that connect different spaces. This transform makes it unnecessary to explicitly represent the coordinates in the embedding space, and also provides all necessary expressions of energy and forces for efficient computations. Through energy

optimization, it naturally leads to the desired anisotropic particle distributions in the original space. The triangles are then generated by computing the Restricted Anisotropic Voronoi Diagram and its dual Delaunay triangulation. We compare our results qualitatively and quantitatively with the state-of-the-art in anisotropic surface meshing on several examples, using the standard measurement criteria. This work was published in the "ACM Transactions on Graphics" journal (SIGGRAPH conference proceedings) [19].

5.1.3. *Approximating Functions on a Mesh with Restricted Voronoi Diagrams*
Participant: Bruno Lévy.

We propose a method that computes a piecewise constant approximation of a function defined on a mesh. The approximation is associated with the cells of a restricted Voronoi diagram. Our method optimizes an objective function measuring the quality of the approximation. This objective function depends on the placement of the samples that define the restricted Voronoi diagram and their associated function values. We study the continuity of the objective function, derive the closed-form expression of its derivatives and use them to design a numerical solution mechanism. The method can be applied to a function that has discontinuities, and the result aligns the boundaries of the Voronoi cells with the discontinuities. Some examples are shown, suggesting potential applications in image vectorization and compact representation of lighting. This work was presented at the "ACM Symposium on Geometry Processing" and published in the "Computer Graphics Forum" journal [15].
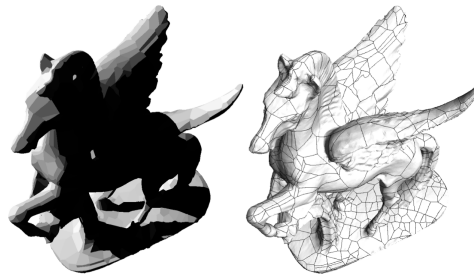
*Figure 3. Approximating Functions on a Mesh with Restricted Voronoi Diagrams*

5.1.4. *Spectral Clustering of Plant Units From 3D Point Clouds*
Participant: Dobrina Boltcheva.

High-resolution terrestrial Light Detection And Ranging (tLiDAR), a 3-D remote sensing technique, has recently been applied for measuring the 3-D characteristics of vegetation from grass to forest plant species. The resulting data are known as a point cloud which shows the 3-D position of all the hits by the laser beam giving a raw sketch of the spatial distribution of plant elements in 3-D, but without explicit information on their geometry and connectivity.

We have developed a new approach based on a delineation algorithm (Fig. 4) that clusters a point cloud into elementary plant units such as internodes, petioles and leaves. The algorithm creates a graph (points + edges) to recover plausible neighbouring relationships between the points and embeds this graph in a spectral space in order to segment the point-cloud into meaningful elementary plant units.

We have presented this work at the 7th International Conference on Functional—Structural Plant Models (FSPM) which took place in Finland this summer [21].

5.1.5. *Fixing Normal Constraints for Generation of Polycubes*
Participants: Nicolas Ray, Dmitry Sokolov.

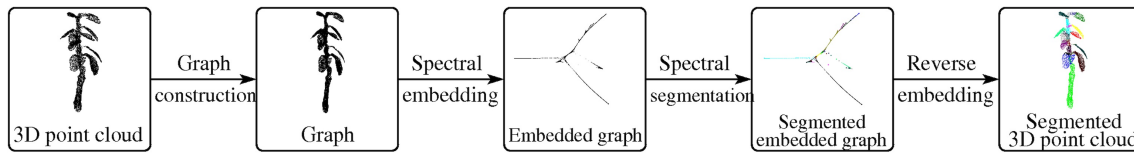*Figure 4. From a point cloud scan of a plant to a segmentation of its leaves.*

A polycube is a piecewise linearly defined surface where all faces are squares that are perpendicular to an axis of a global basis. Deforming triangulated surfaces to polycubes provides maps (form the original surface to the polycube) that can be used for a number of applications including hex-meshing. To define such a deformation, it is necessary to determine, for each point of the original surface, what will be its orientation (global axis) in the polycube.

This problem is actually tackled by heuristics that basically affect the closest global axis to the surface normal. Coupled with a mesh deformation as pre-processing and some fixing rules as a post-processing, it is able to provide nice results for a number of surfaces. However, nothing ensures that the surface can be deformed to a polycube having these desired face orientations.

We have worked on a method able to determine if there exists a deformation of the surface that respects a given orientation constraint on each point. We have also designed an automatic solution that can fix constraints that would prevent the existence of a deformation into a polycube (Figure 5).

This study has highlighted that the constraints on desired orientation are global and requires constrained optimization methods to be solved. Our current solution is able to manage many cases where previous works would fail, but we can still produce some complex cases where interactions between dimension may lead to deadlocks.

5.1.6. *Some Basic Geometric Considerations in Variational Multiview Stereo*
Participant: Rhaleb Zayer.

We developed a technique for processing correspondences originating from dense variational matching in the context of multiview stereo. Such data tends to be very large and can easily encompass tens or hundreds of millions of points, these figures keep growing as high resolution images are becoming mainstream. Inspired by Lambert's cosine law, we regard the matching as sequences of planar maps across neighboring views, and show how to take advantage of geometric properties of such maps to favor image areas where the cosine angle between the surface normal and the line of sight is maximal. As the approach operates in the planar domain on smaller subsets of neighboring views, it is computationally efficient and has a low memory footprint. A preprint is in preparation.

5.1.7. *Multi-frontal Propagation Based Matching*
Participants: Rhaleb Zayer, Patricio Galindo.

We consider the propagation-based matching problem, which deals with expanding a limited set of correspondences towards a quasi-dense map across two views. Two issues which have not received much interest in earlier work are raised here. The traversal of weakly textured regions is shown to negatively impact the quality of subsequent correspondences. Analysis of the propagation results using the commonly adopted global best-fit strategy reveals that only a small subset of the input seeds contributes effectively to the propagation, which is probably not optimal since the quality of the matches may deteriorate as the propagation region becomes significantly large as shown in figure 7-bottom. This research extends existing propagation techniques in two ways: (i) The selection of reliable expansion regions is automatized and adapted to the propagation by categorizing the image into three regions, no-propagation regions, safe-propagation regions and buffer-regions where
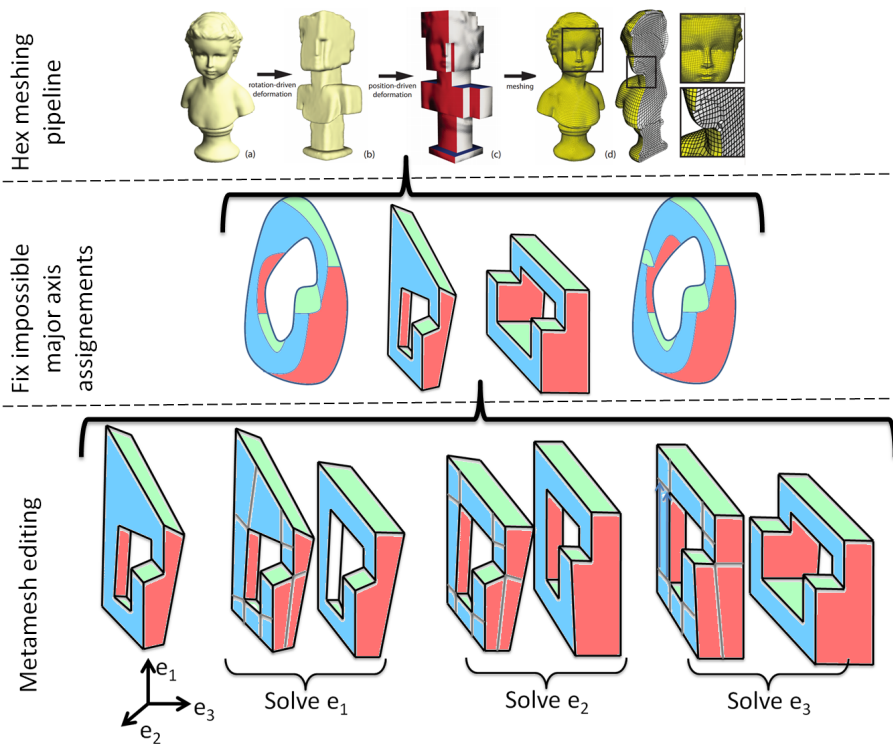
Figure 5. **Upper row:** *the surface is deformed to make its normals closer to major axis, but to reach an equality, we need to have a coherent "wished orientation" of the faces.* **Middle row:** *we define a valid deformation into a polycube by editing the "wished orientation".* **Lower row:** *the resolution is performed a dimension at a time.*
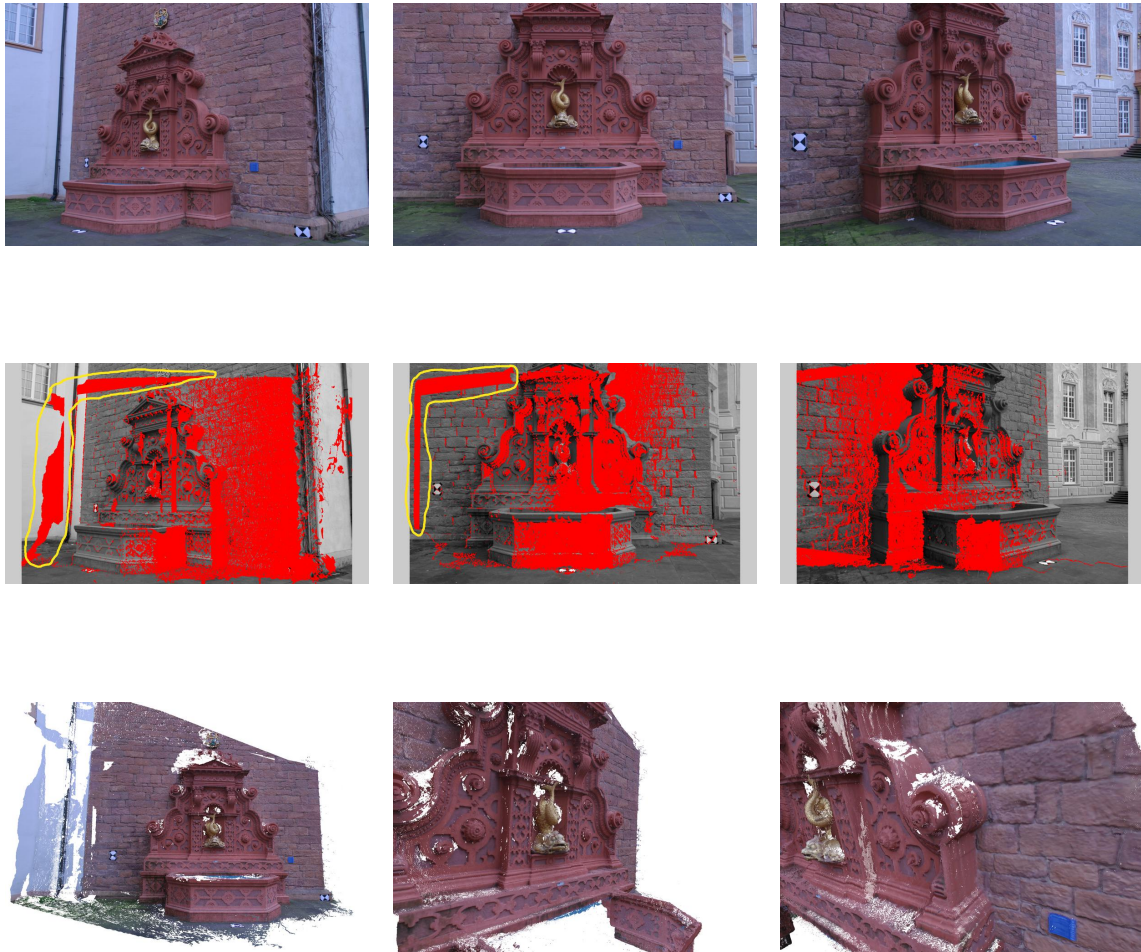
Figure 6. Processing best viewed regions in the Fountain data set (top). Each view represents the central image of a triplet (other two images not shown). The red-colored regions (middle) represent areas best viewed in the triplet. Yellow-marked regions represent regions which are only visible in the triplet and therefore are included even if they do not comply with the best view requirement. The resulting reconstruction (bottom) shows an almost outlier free point cloud.

seeds can propagate but cannot generate new seeds. (ii) A multi-frontal propagation approach is proposed with emphasis on the balance between the greedy nature of the original algorithm and the contribution of the seeds. A preprint is in preparation.
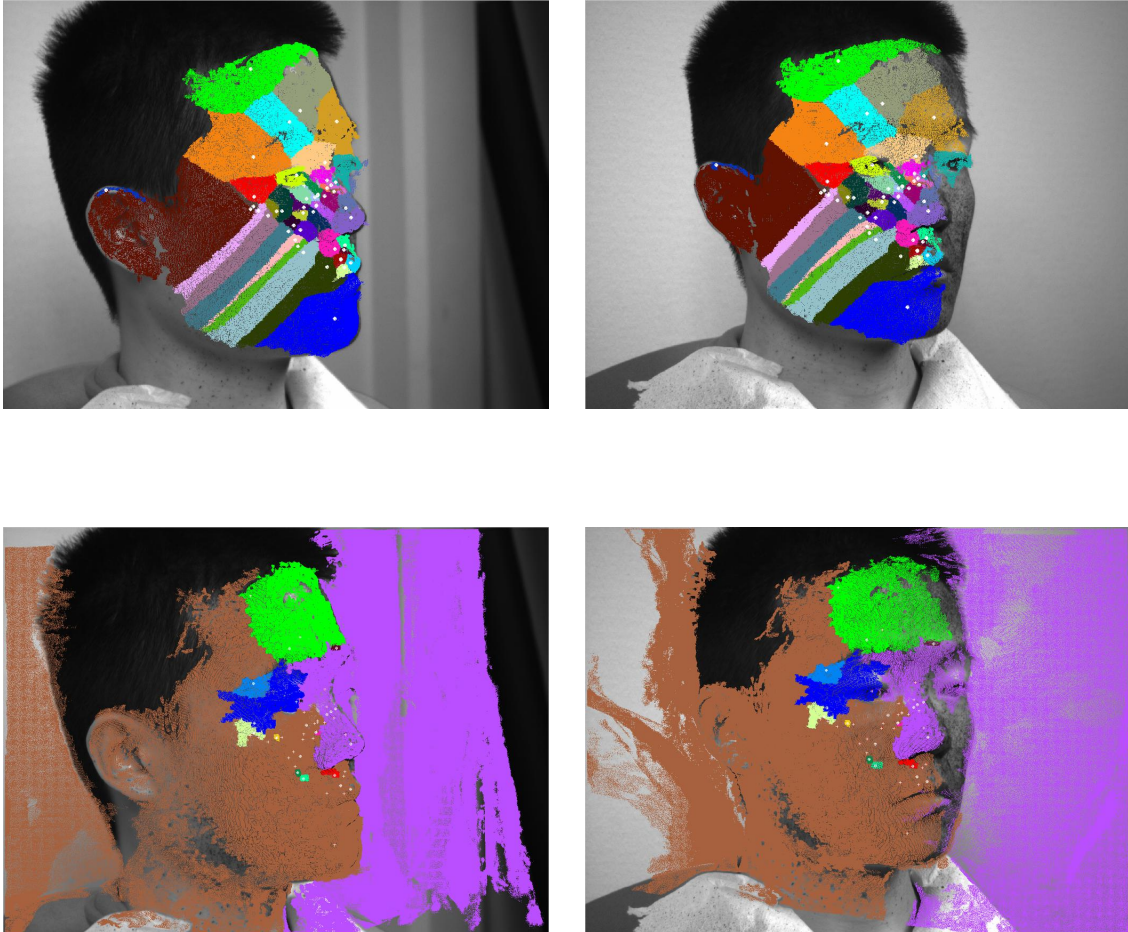
Figure 7. Typical result of our approach (top), compared to a best-first strategy (bottom). In both experiments, the same initial seeds were used (≈ 40 seeds). The descendants of each initial seed are uniquely colored. Our approach clearly allows all seeds to contribute, whereas the greedy approach marginalize a majority of them.

5.1.8. Large Deformations of Slender Objects
Participant: Rhaleb Zayer.

We studied the problem of large spatial deformation in the context of interactive editing of slender curve-like objects. The deformation is analyzed in the local frame of the individual curve segments (beams) and the rigid motion of the local frame is updated using a total Lagrangian approach. Analysis of the virtual work in the light of this decoupling allows formulating the Hessian of the deformation in a simple but principled manner. The resulting representation is sparser than existing derivations and can handle the simultaneous action of torques, and forces, efficiently, so as to reproduce a natural behavior in such path dependent situations. The proposed approach is conceptually simple, easy to implement, and suitable for object editing. The numerical

solution is carried out using an efficient iterative scheme which allows stable convergence. A preprint is in preparation.

Figure 8. Typical editing examples of slender objects under various constraint, the faded snapshots shows initial or intermediate configurations.

5.2. Computer Graphics

5.2.1. By-example Synthesis of Curvilinear Structured Patterns
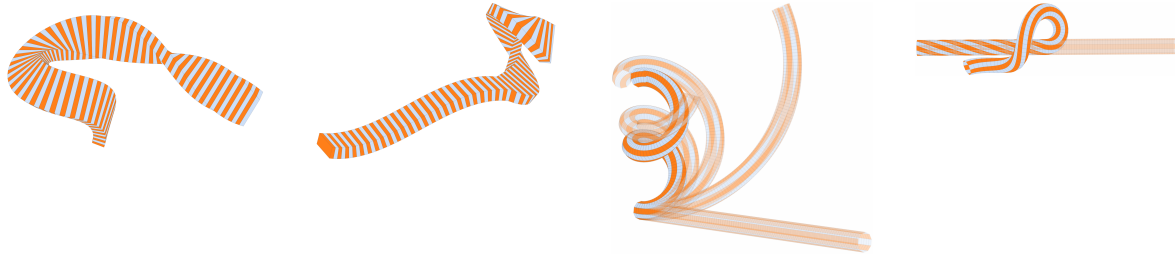
Participants: Anass Lasram, Sylvain Lefebvre.

Many algorithms in Computer Graphics require to synthesize a pattern along a curve. This is for instance the case with line stylization, to decorate objects with elaborate patterns (chains, laces, scratches), or to synthesize curvilinear features such as mountain ridges, rivers or roads. We describe a simple yet effective method for this problem. Our method addresses the main challenge of maintaining the continuity of the pattern while following the curve. It allows some freedom to the synthesized pattern: It may locally diverge from the curve so as to allow for a more natural global result. This also lets the pattern escape areas of overlaps or fold-overs. This makes our method particularly well suited to structured, detailed patterns following complex curves. Our synthesizer copies tilted pieces of the exemplar along the curve, following its orientation. The result is optimized through a shortest path search, with dynamic programming. We speed up the process by an efficient parallel implementation. Finally, since discontinuities may always remain we propose an optional post-processing step optimally deforming neighboring pieces to smooth the transitions.

This work was presented at the Eurographics conference and published in the "Computer Graphics Forum" journal [20].

5.2.2. Game Level Layout

Participant: Sylvain Lefebvre.

This work is a collaboration with the University of British Columbia. We consider a long standing problem in the video game industry: How to automatically generate game levels. Most procedural game levels tend to exhibit a random organization, reducing their interest. Instead, our approach lets a professional game designer describe the global organization of the level through a planar graph, capturing the connectivity and sequencing of different level 'rooms'. Our approach then automatically generates multiple level geometries that correspond to this high-level description.

The work will be presented at *Eurographics 2014* [13].

5.2.3. Dynamic Element Textures

Participant: Sylvain Lefebvre.
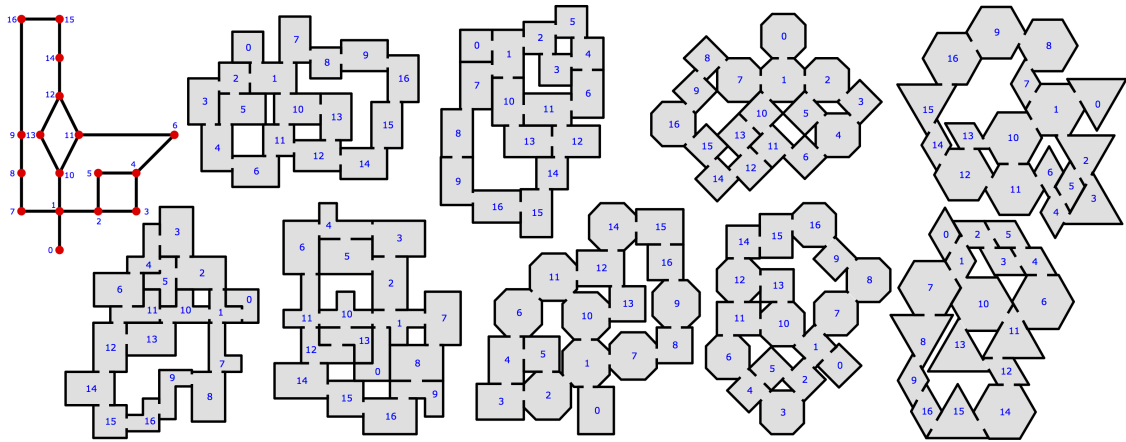
Figure 9. Game Level Layout

This work is a collaboration with Microsoft Research Asia. We consider the problem of synthesizing animated details from an example. We first define the notion of a 'textured' animation and extract details from the example animation. Intuitively, these are small scale repetitive motions found for instance for leaves in the wind or in swarms. We then propagate these motions to a coarse scale animation. Our techniques work on 1D, 2D and 3D objects.

We published this work in *ACM Transactions on Graphics (SIGGRAPH proceedings)* [14].
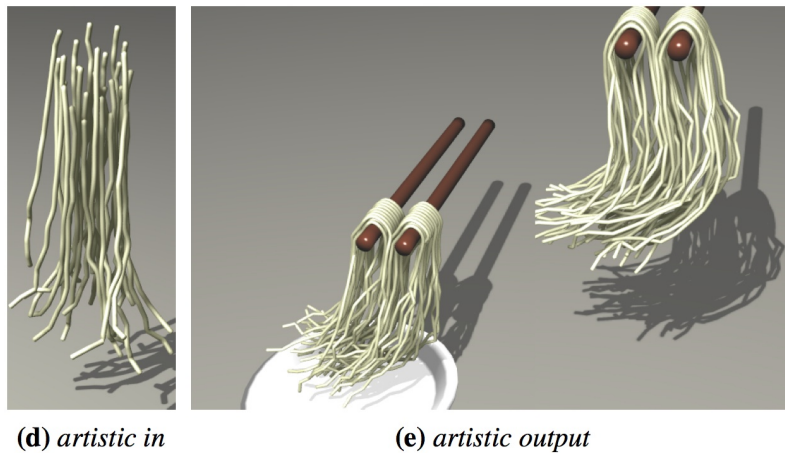
(d) *artistic in*   **(e)** *artistic output*

Figure 10. Dynamic Element Textures

5.2.4. Make It Stand: Balancing Shapes for 3D Fabrication
Participant: Sylvain Lefebvre.

This work is a collaboration with ETH Zurich. We consider the problem of balancing 3D models so that they stand in static equilibrium on their base of support after printing. We formulate the problem as the joint optimization of a voxel selection inside the model and a continuous detail preserving deformation of the outer surface.

The work has been published in *ACM Transactions on Graphics (SIGGRAPH proceedings)* [18].

5.2.5. *Clean Colors*

Participants: Jean Hergel, Sylvain Lefebvre.

In this work we consider the problem of tool path planning for low-cost FDM (Fused Deposition Modeling) printers when using multiple filaments. Our method is based on three components which together reduce most of the defects found in such prints. Our algorithm first optimizes the orientation (azimuth angle) of the print so as to minimize defects. It then builds a rampart in close proximity of the model. This captures most of the strings of plastic oozing from idle extruders. Finally, we optimize for navigation paths minimizing the apparition of defects.

The work will be presented at *Eurographics 2014* [22].

5.2.6. *Fast Fragment Sorting on the GPU*

Participants: Sylvain Lefebvre, Samuel Hornus.

In this work, we build upon our result on "hashing on the GPU" from 2011 [1] to develop new techniques for sorting per-pixel lists of fragments as the latter are rasterized. We can then obtain, for each pixel, the list of surface elements visible through that pixel, sorted according to their distance to the viewpoint. The lists are obtained in a single rasterization pass instead of two for some earlier work; this is a clear win for bandwidth usage and processing time. Two important applications are the possibility to correctly visualize transparent objects and to directly display constructive-solid-geometry models without having to compute their boundary first (the boolean operations are performed on the fly, per pixel).

Our initial work has been published as a research report [25]. It has then been extended into a book chapter [24].

The techniques developed in this work are extensively used in our 3D printing sotfware IceSL (see section 4.2).

5.2.7. *Techniques for Shooting Highly Coherent Rays*

Participant: Samuel Hornus.

This work explores novels ways to exploit the coherence of some set of rays used in the ray-tracing and other realistic image synthesis techniques. We propose new ways to traverse the usual data-structure for 3D indexes and leverage optimized and exact geometric predicates. Our first results give a faster ray shooting technique for pinhole camera rays and exhibit a remarkable increase in efficiency as the number of rays rises. A manuscript was submitted but not accepted to Eurographics.

5.3. Algorithms and analysis

Participant: Laurent Alonso.

5.3.1. *The Majority Problem*

Given a set of n elements each of which is either red or blue, Boyer and Moore's algorithm uses pairwise equal/not equal color comparisons to determine the majority color. We analyze the average behavior of their algorithm, proving that if all 2^n possible inputs are equally likely, the average number of color comparisons used is $n - \sqrt{2n/\pi} + O(1)$ and has variance $\frac{\pi-2}{\pi}n - \frac{\sqrt{2n}}{\sqrt{\pi}} + O(1)$. This joint work with Edward M. Reingold was published in the IPL journal [8].

5.3.2. The $X + Y$ Sorting Problem

Some combinatorial approaches were taken to try to find bounds on the $X + Y$ problem: Given two lists: $X = (x_1, ..., x_n), Y = (y_1, ..., y_m)$, determine the ordering of the values $x_i + y_j$ for $i \in [1, n], j \in [1, m]$.

5.4. Fractal Geometry

Participant: Dmitry Sokolov.

Fractal geometry is a relatively new branch of mathematics that studies complex objects of non-integer dimensions. It finds applications in many branches of science as objects of such complex structure often exhibit interesting properties.

In 1988 Barnsley presented the Iterative Function System (IFS) model that allows modelling complex fractal shapes with only a limited set of contractive transformations. Later many other models were based on the IFS model such as Language-Restricted IFS, Projective IFS, Controlled IFS and Boundary Controlled IFS. The latter allows modeling complex shapes with control points and specific topology. These models cover classical geometric models such as B-splines and subdivision surfaces as well as fractal shapes.

This year we focused on the analysis of the differential behaviour of the shapes described with Controlled IFS and Boundary Controlled IFS. We derive the necessary and sufficient conditions for differentiability for everywhere dense sets of points. Our study is based on the study of the eigenvalues and eigenvectors of the transformations composing the IFS.

We apply the obtained conditions to modeling curves in surfaces. We describe different examples of differential behaviour presented in shapes modeled with Controlled IFS and Boundary Controlled IFS. We also use the Boundary Controlled IFS to solve the problem of connecting different subdivision schemes. We construct a junction between Doo-Sabin and Catmull-Clark subdivision surfaces and analyse the differential behaviour of the intermediate surface.

An article about this work is in the publication process in LNCS.

5.5. Scientific Computing for Linear and Nonlinear Wave Problems

Participant: Xavier Antoine.

We consider the Backward Euler SPectral (BESP) scheme that was proposed for computing the stationary states of Bose-Einstein Condensates (BECs) through the Gross-Pitaevskii equation. We show that the fixed point approach introduced earlier fails to converge for fast rotating BECs. A simple alternative approach based on Krylov subspace solvers with a Laplace or Thomas-Fermi preconditioner is given. Numerical simulations (obtained with the associated freely available Matlab toolbox GPELab) for complex configurations show that the method is accurate, fast and robust for 2D/3D problems and multi-components BECs.

This work was published in the journal "Journal of Computational Physics" [9].

5.6. Accelerating Structural Biology Software

Participant: Xavier Cavin.

This work is a collaboration with Dave Ritchie (team ORPAILLEUR, Nancy). The aim of this project is to leverage parallelism, multi-core computing and GPU in order to speed-up costly computations in cryo-electron microscopy. Several tools have been developped. Two of those "gEM tools" have been the subject of two articles were published in 2013 in "Journal of Structural Biology" [10] and "BMC Structural Biology" [11].

6. Partnerships and Cooperations

6.1. Regional Initiatives

"Contrat région projet émergent" CORIDA (X. Antoine)/ALICE (B. Lévy): budget of 25 K€ shared between both teams.

6.2. National Initiatives

6.2.1. ANR BECASIM (2013 – 2016)

890 K€. X. Antoine heads the second partner, which includes Bruno Lévy. Budget for Nancy: 170 K€ of which 100 K€ are for IECL (team CORIDA). This project is managed by Inria.

6.2.2. ANR Bond (2013 – 2017)

X. Antoine is a member of ANR BOND ("projet blanc").

6.2.3. ANR TECSER

X. Antoine is a member of ANR TECSER that stemmed from the ASTRID program (DGA). The consortium gathers Inria (S. Lantéri, Nice-Sophia, ÉPI CORIDA (X. Antoine) and HIEPACS), EADS, and Nuclétudes.

Total budget: 300 K€ of which 54 K€ are for CORIDA.

6.2.4. ANR Similar-Cities (jeune chercheur)

Sylvain Lefebvre has a continued collaboration with our industrial partners Allegorithmic and the CSTB (Centre Scientifique et Technique du Bâtiment) through the ANR project Similar-Cities. A technological transfer agreement was signed in early 2013 and the project ended on February.

6.2.5. ANR Physigraphix (jeune chercheur)

Rhaleb Zayer has continued the investigations on the ANR project Physigraphix, which aim is to bridge the gap between acquisition and modeling in the context of deformable objects.

6.2.6. ANR Morpho

Dobrina Boltcheva and Bruno Lévy are involved in the ANR project Morpho. Morpho is aimed at designing new technologies for the measure and for the analysis of dynamic surface evolutions using visual data.

6.3. European Initiatives

6.3.1. FP7 Projects

6.3.1.1. GoodShape

Title: Numerical Geometric Abstractions: from bits to equations

Type: IDEAS

Instrument: ERC Starting Grant

Duration: August 2008 – July 2013

Coordinator: Inria

Inria contact: Bruno Lévy

Abstract: GoodShape involves several fundamental aspects of 3D modeling and computer graphics. GoodShape is taking a new approach to the classic, essential problem of sampling, or the digital representation of objects in a computer. This new approach proposes to simultaneously consider the problem of approximating the solution of a partial differential equation and the optimal sampling problem. The proposed approach, based on the theory of numerical optimization, is likely to lead to new algorithms, more efficient than existing methods. Possible applications are envisioned in inverse engineering and oil exploration.

6.3.1.2. ShapeForge

Title: ShapeForge: By-Example Synthesis for Fabrication

Type: IDEAS

Instrument: ERC Starting Grant

Duration: December 2012 – November 2017

Coordinator: Inria

Inria contact: Sylvain Lefebvre

Abstract: Despite the advances in fabrication technologies such as 3D printing, we still lack the software allowing for anyone to easily manipulate and create useful objects. Not many people possess the required skills and time to create elegant designs that conform to precise technical specifications. 'By–example' shape synthesis methods are promising to address this problem: New shapes are automatically synthesized by assembling parts cutout of examples. The underlying assumption is that if parts are stitched along similar areas, the result will be similar in terms of its low–level representation: Any small spatial neighbourhood in the output matches a neighbourhood in the input. However, these approaches offer little control over the global organization of the synthesized shapes, which is randomized. The ShapeForge challenge is to automatically produce new objects visually similar to a set of examples, while ensuring that the generated objects can enforce a specific purpose, such as supporting weight distributed in space, affording for seating space or allowing for light to go through. This properties are crucial for someone designing furniture, lamps, containers, stairs and many of the common objects surrounding us. The originality of our approach is to cast a new view on the problem of 'by–example' shape synthesis, formulating it as the joint optimization of 'by–example' objectives, semantic descriptions of the content, as well as structural and fabrication objectives. Throughout the project, we will consider the full creation pipeline, from modeling to the actual fabrication of objects on a 3D printer. We will test our results on printed parts, verifying that they can be fabricated and exhibit the requested structural properties in terms of stability and resistance.

6.3.1.3. VORPALINE

Title: Vorpaline PoC

Type: IDEAS

Instrument: ERC Proof of Concept

Objectif: development of the Vorpaline software (see above)

Duration: July 2013 – June 2014

Coordinator: Inria

Inria contact: Bruno Lévy.

Abstract: The VORPALINE "Proof-of-Concept" project, funded by the European Research Council, aims at transforming the scientific results stemming from the GoodShape project into a technological component directly transferable to the industry. The funding allowed us to hire an experimented software architect, Thierry Valentin, who created the industrial software architecture and development tools (continuous integration platform, non-regression tests, software quality tools ...). The result of the project is the Vorpaline software (see section 4.1).

6.4. International Initiatives

6.4.1. Participation in Other International Programs

Xavier Antoine started two collaborations:

- E. Lorin et A.D. Bandrauk (University of Carleton, Canada) and CRM, Montréal, on numerical analysis for quantum chemistry.
- W. Bao (National University of Singapore), on numerical methods for simulating Bose-Einstein condensates.

6.5. International Research Visitors

6.5.1. Visits of International Scientists

- Klaus Hildebrandt (*Max-Planck-Institut für Informatik*) visited us and gave a talk on October 22. He was invited by Rhaleb Zayer.
- Frédéric Claux visited us during two days, from IRIT in Toulouse.

6.5.2. Visits to International Teams

Sylvain Lefebvre visited

- Niloy Mitra, University College London.
- Jérôme Darbon, CNRS & UCLA.

Xavier Antoine gave an invited talk at "EMF 2013, The Ninth International Symposium on Electric and Magnetic Fields", Bruges, Belgium, April 2013.

7. Dissemination

7.1. Scientific Animation

7.1.1. Program Committee

Sylvain Lefebvre: Eurographics 2014 (Full papers, and co-chair for State of the Art Reports) and SIGGRAPH Asia.

Bruno Lévy: ACM SIGGRAPH 2014, Eurographics 2013 & 2014 (co-chair), ACM/Eurographics Symp. on. Geom. Proc. 2013, Discr. Geom. for Comp. Imagery 2013, Comput. Graphics. Intl. 2013, Pacific Graphics 2013 (chair), CAD Graphics 2013 (co-chair).

Nicolas Ray: Pacific Graphics 2013 and Eurographics 2014 (Full papers).

Rhaleb Zayer: Pacific Graphics 2013 and Eurographics 2014 (Full papers).

Xavier Antoine: Waves 2013 (International Conference on Mathematical and Numerical Aspects of Waves).

7.1.2. Reviewing

Laurent Alonso: *ACM Transaction on Algorithms*, *Information Processing Letter*, *Theoretical Computer Science*.

Dobrina Boltcheva: *IEEE Transaction on Visualization & Computer Graphics*.

Samuel Hornus: *ACM Transactions on Graphics*, *Eurographics 2014*, Revue Française d'Informatique Graphique.

7.1.3. Organization

Dobrina Boltcheva co-organized the "Journées Informatique & Géométrie", that took place on November 14 and 15 in LORIA, Nancy.

7.1.4. Other

Since 2013, Xavier Antoine is "scientific delegate" at ANR, in charge of mathematics & interactions.

Since 2013, Xavier Antoine is in charge of the "Accueil de Chercheuses et Chercheurs de Haut Niveau" at ANR (Attractivité de la France et Espace Européen de la Recherche).

Since 2013, Xavier Antoine is associate editor for ISRN Applied Mathematics.

Bruno Lévy is associate editor of TVCG (IEEE) and Graphical Models (Elsevier).

B. Lévy was president of the hiring committee for Inria junior researchers ("concours Chargé de Recherche").

B. Lévy is vice head of the Charles Hermite federation (that regroups the laboratories in CS, mathematics and control theory in the Lorraine region).

7.2. Teaching - Supervision - Juries

7.2.1. Teaching

Sylvain Lefebvre was involved in the following courses:

- Cours École Centrale (9h)
- Cours École de Géologie: introduction to parallelism (3h TP) and introduction to computer graphics (3h cours, 6h TP)
- OpenCL, master M2, avec Dmitry Sokolov.
- Course on Video Game programming at "École des Mines de Nancy". Taught with Guillaume Bonfante.

Samuel Hornus was involved in the following courses:

- "Functional programming with OCaml" at ÉPITECH Nancy (private school training programmers, http://nancy.epitech.eu/). Lecture: 9h. Lab work: 18h. 3 student projects.

Dmitry Sokolov was involved in the following courses:

- Algorithmique avancée, 28h, M2 Math de l'UL, France
- Géométrie et représentation dans l'espace, 35h, L2 Informatique de l'UL, France
- Logiques et Modèles de calcul, 30h, M1 Informatique de l'UL, France
- Infographie 76h, M1 Informatique de l'UL, France
- Modèles de perception et raisonnement, 56h, M1 Informatique de l'UL, France
- Parallélisme de données, 15h, M1 Informatique de l'UL, France

Dobrina Boltcheva had 200 hours teaching duty:

- Licence ISN, IUT Saint-Dié-des-Vosges
- 2A DUT INFO, IUT Saint-Dié-des-Vosges
- 1A DUT INFO, IUT Saint-Dié-des-Vosges

Xavier Antoine gave the following invited courses:

6 hours course on numerical methods for Schrödinger equations, Workshop "Non-linear optical and atomic systems: deterministic and stochastic aspects" – January 2013, Lille, France.

3 hours course at 7th Montréal Scientific Computing Days, CRM, Montréal, QC, Canada, May 2013.

Bruno Lévy taught:

- "Numerical Geometry" (15 h) in the National School of Geology and in Nancy School of Mines.
- "initiation to computer programming" in collaboration with the Microtel association (1h per week, 10 kids aged between 7 and 12 years old).

7.2.2. Supervision

7.2.2.1. Master 2

- Jean Hergel, advised by Sylvain Lefebvre.
- Aytac Kanaci, co-advised by Sylvain Lefebvre and Amaury Habrard (St Étienne, Université Jean Monnet).

7.2.2.2. PhD thesis defended

- Sergey Podkorytov (Université de Bourgogne, co-advised by Dmitry Sokolov), "Tangent subspace of self-similar shapes". Defended on December 20 2013.
- Romain Duboscq, co-advised by Xavier Antoine, with Renaud Marty (équipe probabilité IECL).
- Romain Merland,"Generation of finite volume grids accounting for structural, petrophysical and dynamic information", advised by Guillaume Caumon and Bruno Lévy. Defended on April 18, 2013.

7.2.2.3. PhD thesis in preparation

- Kun Liu (now post-doc in London), "Modèle discret guidé par l'acquisition pour les objets déformables", Started August 2010, Rhaleb Zayer and Bruno Lévy. Kun should defend his PhD in 2014.
- Alejandro Patricio Galindo, "Traitement de l'image et video tracking pour l'extraction d'informations pertinentes", Rhaleb Zayer and Bruno Lévy.
- Arnaud Botella, "Génération de maillages non-structurés hex-dominants conformes aux domaines géologiques", Started January 2013, Guillaume Caumon and Bruno Lévy.
- Jeanne Pellerin, "Hybrid meshing for geosciences", Guillaume Caumon and Bruno Lévy.
- David Lopez, "Dynamic meshing of free surfaces in fluid simulation", Bruno Lévy.
- Jean Hergel, "Approches pour la prise en compte conjointe de la fonctionnalité des objets modélisés et des contraintes du procédé de fabrication additive", Started February 2013, Bruno Lévy.
- Jérémie Dumas, "By-example shape synthesis for 3D printing", Started September 2013, Sylvain Lefebvre and Bruno Lévy.

7.2.3. Juries

Sylvain Lefebvre was *examinateur* during the PhD defense of Matthias Holländer, who was supervised by Tamy Boubekeur (Telecom ParisTech). Title: Real-time Geometry Synthesis.

Bruno Lévy participated to the following Ph.D. and habilitation juries:

- Hunbin Li (Ph.D., Centrale Lyon)
- Kenneth Vanhoey (Ph.D, ICube, Strasbourg)
- Lionel Untereiner (Ph.D., ICube, Strasbourg)
- Alexandre Derouet-Jourdan (Ph.D., Inria Grenoble)
- Yuan Zhan (Ph.D., Hong-Kong University)
- David Salinas (Ph.D., Gipsa Lab, Grenoble)
- Guillaume Lavoué (Habilitation thesis, LIRIS, Lyon)

7.3. Popularization

Sylvain Lefebvre is a member of the *commission de médiation scientifique* and of the *comité espace transfert*.

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