

# INRIA, Evaluation of Theme Interaction and Visualization

Project-team Alice

October 2010

Project-team title : Alice: Geometry and Light

Scientific leader : Bruno Lévy

Research center : Nancy Grand-Est

## 1 Personnel

Personnel (May 2006 (creation))

	Misc.	INRIA	CNRS	University	<b>Total</b>
DR (1) / Professors					
CR (2) / Assistant Professors		4			<b>4</b>
Permanent Engineers (3)					
Temporary Engineers (4)		3			<b>3</b>
PhD Students	3	2	1		<b>6</b>
Post-Doc.					
<b>Total</b>	<b>3</b>	<b>9</b>	<b>1</b>		<b>13</b>
External Collaborators				1	<b>1</b>
Visitors (> 1 month)					

- (1) “Senior Research Scientist (Directeur de Recherche)”
- (2) “Junior Research Scientist (Chargé de Recherche)”
- (3) “Civil servant (CNRS, INRIA, ...)”
- (4) “Associated with a contract (Ingénieur Expert or Ingénieur Associé)”

Personnel (October 2010)

	Misc.	INRIA	CNRS	University	<b>Total</b>
DR / Professors		1			<b>1</b>
CR / Assistant Professor		5		1	<b>6</b>
Permanent Engineer					
Temporary Engineer		1			<b>1</b>
PhD Students	4	5			<b>9</b>
Post-Doc.		2			
<b>Total</b>	<b>4</b>	<b>13</b>			<b>17</b>
External Collaborators				1	<b>1</b>
Visitors (> 1 month)				1	<b>1</b>

## Evolution of staff

	Misc.	INRIA	CNRS	University	total
DR / Professors		+1			+1
CR / Assistant Professors		+3-2		+1	+2
Arrival		3		1	4
Leaving		1			1

**Comments :** The ALICE project has now reached the “critical mass” in terms of permanent researchers. The “boost” from the ERC Starting Grant allowed to attract talented candidates to join the project. Four new permanent researchers (Sylvain Lefebvre, Dmitry Sokolov, Rhaleb Zayer and Samuel Hornus) joined the project during the evaluation period: 1 new assistant professor (Dmitry Sokolov) and 2 new CR (Rhaleb Zayer and Samuel Hornus). Last year, Sylvain Lefebvre (CR) moved from Sophia (REVES project) to Nancy. Until Jan. 2010 he had a joint appointment with REVES, his activities during the joint appointment period are described in both REVES and ALICE reports. Xavier Cavin left the project under an “industrial sabbatical” to create the Scalable Graphics startup (-1 CR). Bruno Lévy was promoted from CR to DR (-1 CR, +1 DR). Bruno Jobard (University of Pau) joined the team this year in September with a temporary assignment (“Delegation”), for a 1 or 2 years period.

In terms of skills, the new team remains well balanced between the two main objectives of ALICE. The *geometry* research axis is strengthened with Rhaleb Zayer (differential geometry) and Samuel Hornus (computational geometry), and the *light* (or rendering) research axis can explore new avenues with Sylvain Lefebvre (texturing, by-example modeling) and Dmitry Sokolov (fractals and subdivision). The presence of Bruno Jobard will help reviving our research topics in scientific visualization, that were slowed down with the “industrial sabbatical leave” of Xavier Cavin. Most importantly, cross-fertilization between geometry and rendering is an important part of the research strategy in ALICE. The new researchers have an excellent culture and interest in both aspects, based on a deep knowledge of advanced mathematical subjects (finite elements, computational geometry, differential geometry, statistical methods, fractals). We think that this is the cornerstone that will maintain the coherency within the ALICE project in the future.

## Current composition of the project-team (October 2010):

### Head:

- Bruno Lévy, Senior Researcher (DR INRIA)

### Administration:

- Isabelle Herlich, Administrative Assistant (AI)

### Permanent researchers:

- Laurent Alonso, Research Associate (CR INRIA)
- Samuel Hornus, Research Associate (CR INRIA)
- Sylvain Lefebvre, Research Associate (CR INRIA) (joint appointment with REVES until Jan. 31 2010)
- Nicolas Ray, Research Associate (CR INRIA)
- Dmitry Sokolov, Assistant Professor (MnC Nancy I University)

- Rhaleb Zayer, Research Associate (CR INRIA)

**Visiting researcher:**

- Bruno Jobard, Associate Professor (University of Pau, “Délégation”)

**Ph.D. students:**

- Nicolas Cherpeaux (GOCAD consortium, co-advised with Guillaume Caumon, started in Sept. 2007)
- Alejandro Galindo (ANR Physigraphics, started in Sept. 2010)
- Thomas Jost (ERC GOODSHAPE, co-advised with Sylvain Contassot - ALGORILLE project, started in Sept. 2009)
- Anass Lasram (ANR Similar Cities, started in Oct. 2009)
- Kun Liu (ANR Physigraphics, started in Sept. 2010)
- Romain Merlan (GOCAD consortium, co-advised with Guillaume Caumon, started in Sept. 2009)
- Vincent Nivoliers (“Ecole Normale Supérieure” grant, started in Sept. 2008)
- Jeanne Pellerin (GOCAD consortium, co-advised with Guillaume Caumon, started in Sept. 2010)
- Thomas Viard (GOCAD consortium, co-advised with Guillaume Caumon, started in Sept. 2007)

**Post Docs:**

- Kai Wang (ERC GOODSHAPE)
- DongMing Yan (ERC GOODSHAPE)

**Training Periods:**

- David Lopez (ERC GOODSHAPE)

**Software developers:**

- Nicolas Saugnier (ERC GOODSHAPE)

**Current position of former project-team members (May 2006 - Sept. 2010):**

- Luc Buatois: Ph.D. student → Paradigm Geophysical / GOCAD, Nancy
- Laurent Castanié: Ph.D. student → Paradigm Geophysical / GOCAD, Paris
- Xavier Cavin: CR INRIA → CEO Scalable Graphics, Nancy (industrial sabbatical)
- Mathieu Chavent: Ph.D. student (co-advised with B. Maigret, computational chemistry) → CEA (French institute for advanced nuclear studies), Paris
- Weiming Dong: Ph.D. student → associate professor in Beijing/ LIAMA and CAS institute, PR China

- Gregory Lecot: Ph.D student → Eugen Systems (Videogame development studio), Paris
- Wan-Chiu Li: Ph.D. student → Paradigm Geophysical / GOCAD, Nancy
- Yang Liu: Post-Doc. → Microsoft Research China
- Christophe Mion: Software developer → Scalable Graphics, Nancy
- Thibault Neiger: Software developer → Scalable Graphics, Nancy
- Rodrigo Toledo: Ph.D. student → Petrobras (main Brazilian oil company)
- Bruno Vallet: Ph.D. student (Corps telecom X) → IGN (French Geography Institute), Paris
- Rhaleb Zayer: Post-Doc. → permanent researcher (CR) in ALICE

### Latest INRIA enlistments

- Rhaleb Zayer, CR2 (2009)
  - **Micro-C.V.:** Ph.D. with Hans-Peter Seidel (MPII Saarebrücken), Post-Doc in ALICE;
  - **Specialites:** differential geometry, finite element modeling, computational physics;
  - **Highlight:** obtained a “chaire d’excellence” grant from ANR (300 KEuros).
- Sylvain Lefebvre, CR1 (2009)
  - **Micro-C.V.:** Ph.D. with Fabrice Neyret (IMAGIS/EVATION), Post-Doc with Hugues Hoppe (Microsoft Research), Hired by INRIA REVES in Sept. 2006, moved to ALICE in late 2009 (joint appointment with REVES until end of Jan. 2010);
  - **Specialities:** texture synthesis, real-time rendering, by-example modeling;
  - **Highlight:** Eurographics young researcher award in 2010.
- Samuel Hornus, CR2 (2010).
  - **Micro-C.V.:** Ph.D. with Claude Puech (IMAGIS), Post-Doc in KAIST (Korea), Post-Doc in GEOMETRICA (INRIA Sophia) and Post-Doc in ALICE;
  - **Specialities:** Computational geometry, visibility, real-time rendering;
  - **Highlight:** Author of the  $n - D$  Delaunay triangulation algorithm in CGAL.

## 2 Work progress

### 2.1 Keywords

Computer Graphics, Geometry Processing, Texture mapping.

### 2.2 Context and overall goal of the project

ALICE is an INRIA Project-team on 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, scalable and numerically stable* (see below).

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.

Besides Computer Graphics, our goal is to 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, plasma physics. . .

### 2.3 Objectives for the evaluation period

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[Commented excerpt from the initial ALICE project proposal](#) <sup>1</sup> (May 2006)

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ALICE was created in May 2006. The following four pages summarize the objectives that we presented in our initial project proposal. We outline some important remarks and facts, inserted in *bold blue italics*.

ALICE aims at developing new solutions to represent geometric objects (surfaces, volumes, . . .) and physical properties attached to them. Since our main research interest is Computer Graphics, we pay a particular attention to photometric properties.

To study both classes of problems (digital geometry processing and numerical simulation of light), our common approach is composed of the following steps :

1. formalize the problem as a PDE (Partial Derivatives Equation) ;
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 Numerical Analysis methods, such as Conjugate Gradient, Gauss-Newton, Lagrange, Galerkin, Monte-Carlo. . .

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<sup>1</sup>[alice.loria.fr/alice\\_proposal.pdf](http://alice.loria.fr/alice_proposal.pdf)

We try to design solutions that are *provably correct*, *scalable* and *numerically stable*:

- by provably correct, we mean that we want to ensure the existence and uniqueness of the solution. In addition, in the case of a meshed model, we try to design methods that are independent of the mesh density. In the case of mesh parameterization, we want to ensure the injectivity of the constructed mapping;
- by scalable, we mean that our solutions need to be applicable to data sets of industrial size. For instance, for a scanned mesh, 10 millions triangles is now an average;
- by numerically stable, we mean that our solutions need to be resistant to the degeneracies often encountered in industrial data sets.

The next subsections describes the research directions *planned in 2006* for applying our approach to Digital Geometry Processing (Section 2.3.1) and to the numerical simulation of light (Section 2.3.2). We then present in Section 2.3.3 our longer-term research plans, common to both disciplines.

### 2.3.1 Objectives in Geometry Processing (as described in initial ALICE project proposal)

3D shapes are represented by two categories of models: meshed objects and the “curves and surfaces” family of representations. One of our objectives is to design a new solution to automatically convert a meshed model into a “curves and surfaces” representation. Note that a solution to this difficult problem would immediately have applications to many other Computer Graphics problems, including texture mapping, visualization of large models, remeshing and grid generation.

Automatic conversion from mesh to “curves and surfaces” representations is a tedious geometry processing problem due to their fundamental difference. While a mesh is a discrete representation of the geometry by enumeration and sampling, “curves and surfaces” describes the geometry in a continuous way by equations:  $x = x(u, v), y = y(u, v), z = z(u, v)$ . While one can easily discretize continuous data by using adequate sampling, the reverse process is much more difficult. This reverse problem is identified to be one of the difficult open problems in Digital Geometry Processing.

We propose to develop a new functional optimization method, that constructs a segmentation (step 1) and a parameterization (step 2) at the same time. *This resulted in the Periodic Global Parameterization method that we proposed in late 2006* [RLL+06].

Besides a possible application to Spline fitting *that we published in* [LRL06], the functional representation of surfaces constructed by our approach can have applications in texture mapping *However this requires some non-trivial developments, as we explain in* [RNLL10]. Our goal is now to try to forecast what will be the evolution of this topic, based on the following remark: until recently, Computer Graphics only required a *surfacic* representation of the objects. We believe that future applications will require a *volumic* representation of the objects. For this reason, we think that in the next few years, the emerging research topic related with those volumic representations will have the same

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[RLL+06] Nicolas Ray, Wan Chiu Li, Bruno Lévy, Alla Sheffer, and Pierre Alliez. Periodic global parameterization. *ACM Transactions on Graphics*, 2006.

[LRL06] Wan-Chiu Li, Nicolas Ray, and Bruno Levy. Automatic and interactive mesh to t-spline conversion. In *EG/ACM Symposium on Geometry Processing*, 2006.

development as surface parameterization. To construct these 3D representations, we plan to develop a simple 3D generalization of our functional representation *We developed a method for volumetric meshing this year [LL10]*.

### 2.3.2 Objectives in Numerical Simulation of Light

*(as described in initial ALICE project proposal)*

*At the time of the project proposal, we focused on the rendering equation. We now consider more general numerical problems (see research results and future work plan below).* The numerical simulation of light means solving for light intensity in the Rendering Equation. The solution of this equation is characterized by smooth variations almost everywhere, except near shadow boundaries and highlights. The two main difficulties are the problem of *representation* and the problem of *sampling*:

- **representation:** define a function space in which the solution of the Rendering Equation can be approximated using a minimum quantity of information (i.e., a minimum number of coefficients);
- **sampling:** given a fixed number of basis functions, choose the elements of a function basis so as to obtain the best approximation of the solution.

We aim at studying both the solution mechanism and the problem of sampling. In a dynamic environment, where objects and lights change, it would be interesting to define a dynamic representation of the lighting, continuously enforcing the Rendering Equation and ensuring that an optimum sampling of its solution is constructed. Our plans to study those general problems, related to both Digital Geometry Processing and Numerical Light Simulation axes, are detailed in the next section.

**Our approach to Numerical Light Simulation:** Richard Feynman (Nobel Prize in physics) mentions in his lectures that physical models are a “smoothed” version of reality. The global behavior and interaction of multiple particles is captured by physical entities of a larger scale. According to Feynman, the striking similarities between equations governing various physical phenomena (e.g. Navier-Stokes in fluid dynamics and Maxwell in electromagnetism) is an illusion that comes from the way the phenomena are modeled and represented by “smoothed” larger-scale values (i.e., *fluxes* in the case of fluids and electromagnetism). Note that those larger-scale values do not necessarily directly correspond to a physical intuition, they can reside in a more abstract “computational” space. We try to restate the problem as an abstract numerical computation problem, on which more sophisticated methods can be applied (a plane flies like a bird, but it does not flap its wings). From this point of view, our approach to the problem of Numerical Light Simulation is the same as what we do in Digital Geometry Processing. We try to consider the problem from a computational point of view, and focus on the link between the numerical simulation process and the properties of the solution of the Rendering Equation.

### 2.3.3 Objectives in Numerical Approximation

*(as described in initial ALICE project proposal)*

This section describes our longer term research directions, for problems that are common to the “Digital Geometry Processing” and the “Simulation of light” research axes. *We now study a superset of the problems listed in this section in the frame of our GOODSHAPE project, supported by the European Research Council.*

The general class of problems we are interested in may be formalized as follows: given  $f$ , a function<sup>2</sup>, given a linear space of functions  $\phi_k$ , find the vector  $x$  such that  $\tilde{f} = \sum x_k \phi_k$  is the best approximation of  $f$  (e.g. relative to the  $L^2$  norm  $\int (f - \tilde{f})^2$ ).

We propose to study a more general formulation of the problem where the functions of  $\phi_k$  depend on a vector of *unknown* parameters  $p$ . Now we want to find the vector  $x$  and the vector  $p$  such that  $\tilde{f} = \sum x_k \phi_k(p)$  is the best approximation of  $f$ . For instance, suppose that the function  $\tilde{f}$  is a bivariate piecewise linear function, defined on the triangles of a Delaunay triangulation. There is one basis function  $\phi_k$  per vertex  $k$  of the triangulation, and the vector of parameters  $p$  corresponds to the coordinates of all the vertices of the triangulation. Optimizing for both  $x$  and  $p$  means finding the best approximation *and the best sampling* at the same time. Because basis functions  $\phi_k$  have non-trivial relations with the parameters  $p$ , classic numerical optimization methods cannot be applied. In our example, the supports of the basis functions  $\phi_k$  depend on the combinatorics of the Delaunay triangulation of the vertices  $p$ . This yields discontinuities of the derivatives of the  $\phi_k$  functions relative to  $p$  that prevent classic optimization methods from being applied. *We proved that for Centroidal Voronoi Tessellations, these derivatives are continuous up to the second order [LWL<sup>+</sup>08]*

Lloyd's relaxation method<sup>[Llo82]</sup> iteratively updates the locations of a set of sites (in our context, they correspond to the  $p$  parameters) until their configuration converges to an optimum. However, Lloyd's relaxation does not converge quickly. One of our goals is to find a more efficient algorithm that computes an optimum sampling. We plan to attack this general problem with the following approaches:

1. **Direct optimization:** The most ambitious way of dealing with this problem consists in directly reconsidering Centroidal Voronoi Tessellations from the point of view of numerical optimization. This would replace Lloyd's relaxation with a more efficient algorithm. If we do not succeed with this approach, we plan to explore two other solutions, outlined below. *We successfully explored this first option. Based on our result in [LWL<sup>+</sup>08], we replaced Lloyd relaxation with Newton's optimization method, resulting in a 100× acceleration factor. We also developed several generalizations [LLW09, LL10] ;*
2. **Prolongated discrete optimization:** if the previous approach is not feasible, another possibility is to consider a continuous function that interpolates our unknown discrete function, express an objective function defined in a way that its minimizer satisfies the discrete optimality condition, and extract the discrete solution from the continuous minimizer. *We applied this idea to vector field design with topology control [RVLL08, RVAL08];*
3. **Mixed numerical/symbolic approaches:** to solve these difficult optimization problems, another possibility is to develop tools that manipulate both numeric and symbolic representations of the function at the same time. *We used mixed Numerical/symbolic computation as a means of "prototyping" our mathematical methods in [LL10], as explained in our SIGGRAPH 2010 slides.*

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**End of commented excerpt from the initial ALICE project proposal (May 2006)**

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<sup>2</sup> $f$  can be either explicitly given, or defined to be the solution of a Partial Differential Equation

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[Llo82] S. Lloyd. Least square quantization in PCM. *IEEE Trans. Inform. Theory*, 28:129–137, 1982.



## 2.4 Progress Report on Objective 1 for the 2007-2010 evaluation period: Mathematical Foundations of Geometry Processing

### 2.4.1 Executive summary

3D geometric objects play a central role in many industrial processes (modeling, scientific visualisation, numerical simulation). However, constructing the underlying representations from the data is difficult and often done manually.

Geometry Processing has recently-emerged as a highly competitive scientific domain that studies this type of problems. ALICE researchers contributed to this domain, by developing several parameterization algorithms that construct a “geometric coordinate system” of the object. In a certain sense, one can also say that this constructs an *abstraction* of the geometry. Once the geometry is abstracted, re-instanting it into alternate representations is made easier. ALICE proposes to fully study the fundamental aspects of this point of view, and climb one additional level of abstraction. Thus, we consider the more general problem of constructing a *dynamic function basis* attached to the object. This abstracted form makes the meaningful parameters (or the “control knobs”) appear. We explore applications to real-time rendering and to numerical simulations.

### 2.4.2 Scientific achievements

**Our approach:** In the ALICE project proposal (see previous section), we proposed to optimize a function basis with respect to approximation properties (see paragraph 2.3.3 in the previous section). During the evaluation period, we proposed a possible mathematical framework that refines this general idea by introducing what we call a *dynamic function basis* : We consider the problem of the numerical approximation of the solutions of PDEs, expressed by the following equation:  $Lf = g$  where  $L$  is a linear operator,  $f$  is the unknown function, and the function  $g$  is the right hand side. The classic Finite Element formulation (Galerkin) projects this equation onto a linear function basis ( $\phi_k$ ). In our setting, the approximation of the solution is also represented in a function basis ( $\phi_k$ ), but all those functions ( $\phi_k$ ) depend on an additional *unknown* vector of parameters  $p$ . For instance, we suppose that the function  $f$  is a bivariate piecewise linear function, defined on the faces of a Delaunay triangulation. This setting corresponds to exactly one basis function  $\phi_k$  per vertex  $k$  of the triangulation, and the vector of parameters  $p$  then corresponds to all the coordinates  $(x_k, y_k)$  at all the vertices of the triangulation. The function  $f$  is then given by  $f(x) = \sum \alpha_i \phi_i(p, x)$ . We will first explore the problem of minimizing the residual  $F(\alpha, p) = \|Lf - g\|^2$  (Lest Squares Finite Elements) :

$$F(\alpha, p) = \|Lf - g\|^2 = \alpha^t M \alpha - 2\alpha^t c + \langle g, g \rangle$$

$$\text{where } m_{i,j} = \langle L\phi_i, L\phi_j \rangle \quad ; \quad c_i = \langle L\phi_i, g \rangle$$

The main difficulty comes from the non-linear dependencies introduced by the additional vector of parameters  $p$ . The other difficulty is that in the general case, the expression of the energy functional  $F$  depends on the value of the parameters  $p$  ( $F$  is piecewise defined). To compute the fixed points of  $F$ , we have designed a general framework, based on Newton’s algorithm:

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 $\alpha \leftarrow \alpha_0 \quad ; \quad p \leftarrow p_0$ 
while  $\|\nabla F(\alpha, p)\| > \epsilon$ 

    solve  $\begin{pmatrix} \nabla_{\alpha, \alpha}^2 F & \nabla_{\alpha, p}^2 F \\ \nabla_{p, \alpha}^2 F & \nabla_{p, p}^2 F \end{pmatrix} \begin{pmatrix} \delta_\alpha \\ \delta_p \end{pmatrix} = \begin{pmatrix} -\nabla_\alpha F \\ -\nabla_p F \end{pmatrix}$ 

     $\alpha \leftarrow \alpha + \delta_\alpha \quad ; \quad p \leftarrow p + \delta_p$ 
end//while

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We can now imagine a research program to instantiate our general framework in increasingly complex settings :

- 2D,  $L = Id$ : a function approximation problem. We proposed an application to image vectorization [LL06].
- 3D,  $L = Id$ : surface and volume meshing *results are presented in this report*;
- 3D: light simulation; optimizing for the parameters  $p$  corresponds to a *numerical approach* to computing the visibility complex for next evaluation (see Sect. 5);
- 3D + t: dynamic simulations (e.g., fluids) for next evaluation (see Sect. 5).

Such a dynamic function basis can be associated with a mesh (e.g. in Finite Element Modeling). The optimal orientation of these elements to approximate a given geometry is determined by the principal directions of curvatures [d'A00] (or in the more general case of function approximation, the eigenstructure of the Hessian). We studied methods based on *differential geometry* to define and optimize such a guidance tensor field (see **Topology and Geometry-aware Vector Field Processing** below), to derive a *global parameterization* from them, or to construct an orthonormal function basis from the eigenstructure of a differential operator (**Spectral Geometry Processing**). As an alternative to differential geometry, we also studied the **theory of sampling**. Note that the formulation of these mathematical problems result in large systems of equations, that correspond to the discretized versions of the equations. We also proposed efficient **numerical optimization methods**, that combine efficient algorithms and hardware to solve these equations.

**Topology and Geometry-aware Vector Field Processing** To steer a remeshing or a parameterization algorithm, it is possible to define a guidance vector field, along which the elements or the iso-parameter curves of the parameterization will be aligned. It is important to understand the *geometry* and the *topology* of such vector fields, and the way both characteristics interact. Moreover, the mathematical objects that are manipulated are more general than vector fields and can exhibit a N-fold symmetry. To study these objects, we introduced in [RVLL08] the notion of *N-Symmetry Direction Field* together with a discrete representation. We also derived a discrete version of the Poincaré-Hopf theorem, that relates the topology of the vector field with the topology of the manifold on which it is defined. We explain that the topological degrees of freedom of a vector field are not only the indices of the singularities, but also the winding numbers of the vector field along a homotopy basis. Based on this theorem, we proposed an algorithm

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- [LL06] Gregory Lecot and Bruno Lévy. Ardeco: Automatic region detection and conversion. In *Eurographics Symposium on Rendering*, 2006.
- [d'A00] E.F. d'Azevedo. Are bilinear quadrilaterals better than linear triangles? *SIAM Journal of Scientific Computing*, 22:198–217, 2000.

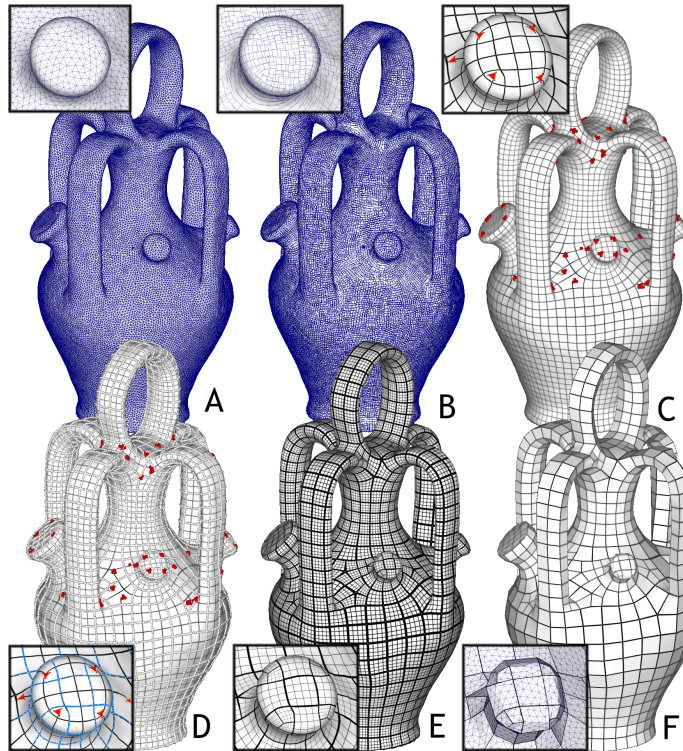


Figure 1: From a triangulated mesh (A) our algorithm generates a guidance vector field (B), used to steer a global parameterization (C). Singularities are processed (D,E). A control mesh is finally extracted, with a one-to-one correspondence with the initial surface (F). .

that can provably generate a vector field of prescribed topology. However, it is not always desired to completely specify the topology of a vector field: some applications just need to generate a vector field that is “smooth enough”, with a topology that is “simple enough”. For this reason, we proposed in [RVAL09] an algorithm that lets the topology emerge, with a user-defined parameter to weight the relative importance of smoothness and simple topology. The implementation is available in our Graphite software.

**Global Parameterization** We have worked on the problem of automatically converting a triangulated mesh surface into a Spline surface (see Figure 1). This problem setting corresponds to the case (3D,  $L = Id$ ) in the list above. Our Periodic Global Parameterization algorithm<sup>[RLL<sup>+</sup>06]</sup> computes a geometric coordinate system aligned with a vector field (e.g., obtained by our methods described in the previous paragraph). Such a coordinate system can be used to automatically convert a triangulated surfaces into Spline surfaces<sup>[LRL06]</sup>. The implementation is available in our Graphite software.

**Spectral Geometry Processing** Another possibility to find an efficient function basis is to compute the eigenfunctions of a symmetric operator. For instance, one may consider the eigenfunction of the Laplace operator (or Laplace-Beltrami, its generalization to curved surfaces). We used this approach with a continuous-setting formulation to define an efficient function basis. The eigenfunctions are defined by  $\Delta\phi = \lambda\phi$  where  $\Delta$  denotes

[RLL<sup>+</sup>06] Nicolas Ray, Wan Chiu Li, Bruno Lévy, Alla Sheffer, and Pierre Alliez. Periodic global parameterization. *ACM Transactions on Graphics*, 2006.

[LRL06] Wan-Chiu Li, Nicolas Ray, and Bruno Levy. Automatic and interactive mesh to t-spline conversion. In *EG/ACM Symposium on Geometry Processing*, 2006.

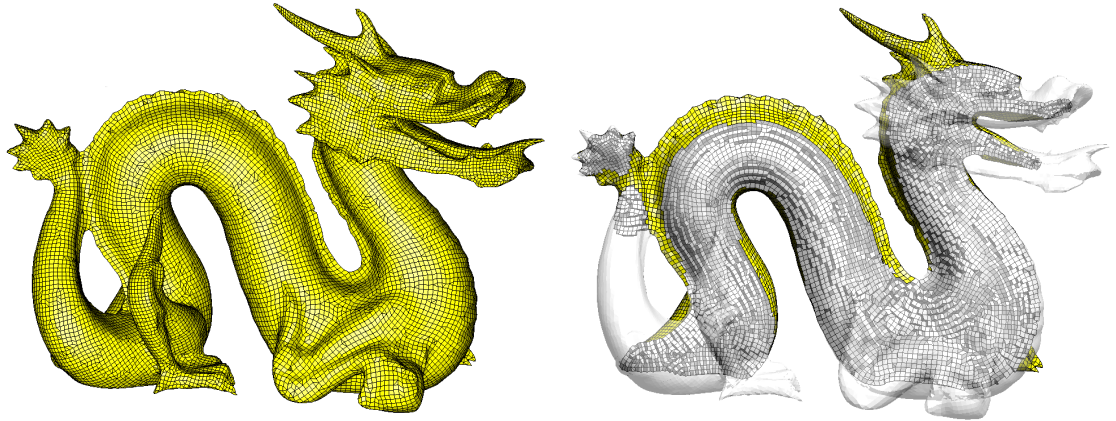


Figure 2: *Variational Hex-Dominant Meshing with  $L_p$ -Centroidal Voronoi Tessellation* .

the Laplace operator,  $\phi$  an eigenfunction and  $\lambda$  the associated eigenvalue. Since  $\Delta$  is symmetric, its eigenfunctions are orthogonal, i.e. two eigenfunctions  $\phi_1, \phi_2$  associated with eigenvalues  $\lambda_1 \neq \lambda_2$  respectively satisfy  $\langle \phi_1, \phi_2 \rangle = 0$ , where:

$$\langle \phi_1, \phi_2 \rangle = \int_{\Omega} \phi_1 \phi_2 ds$$

We first presented the general idea during our invited talk at Shape Modeling International [Lev06], together with a method to compute these eigenfunctions (that we call *manifold harmonics*), initially for small objects. Our method is based on a FEM (Finite Element Modeling) approach, applied to the  $P_1$  function basis defined of the mesh. To simplify the computations, we use the classical result  $\langle f, \Delta g \rangle = - \langle \nabla f, \nabla g \rangle$  (for a closed integration domain). We proposed also a version based on discrete exterior calculus and a new algorithm to efficiently solve the numerical problem, based on spectral transforms and multiresolution [VL07, VL08]. The new algorithm scales up well and can handle models of several hundred thousand vertices. We gave courses on this topic at SIGGRAPH Asia 2009 [LZ09] and SIGGRAPH 2010 [LZ10], and distributed software to reproduce our results (“GoodVibrations” plugin for our Graphite software).

**Theory of Sampling** In its more general form, the dynamic function basis formalism requires to study the optimality of the sampling. In information theory, this can be measured by the notion of quantization noise power, traditionally minimized by Lloyd relaxation. We revisited Lloyd relaxation with our dynamic function basis point of view. The first step was to prove that the quantization noise power is a function of class  $C^2$  [LWL<sup>+</sup>09], and to design an efficient Newton-based algorithm with faster speed of convergence (up to 100× faster as compared to the standard Lloyd relaxation). To apply this algorithm to surface meshing, we developed a fast and exact method to compute a Restricted Voronoi Diagram [YLL<sup>+</sup>09], i.e. the intersection between a 3D Voronoi diagram and a surface. We also developed the volumetric version of this algorithm [YWLL10]. Equipped with these fundamental building blocks, we were freed from the constraints imposed by Lloyd relaxation and could study more general objective functions. Thus, we generalized the quantization noise power to higher momenta, and defined  $L_p$  Centroidal Voronoi Tessellation (see Figure 2), a sampling algorithm that produces cubical Voronoi

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[Lev06] Bruno Levy. Laplace-beltrami eigenfunctions: Towards an algorithm that understands geometry. In *IEEE International Conference on Shape Modeling and Applications, invited talk*, 2006.

cells [LL10]. The implementation will be available in the next release of our Graphite software (GoodMesh plugin).

**Numerical optimization** All the research topic described above depend on efficient numerical methods. We proposed the *Concurrent Number Cruncher*, a parallel preconditioned sparse conjugate gradient solver on the GPU [BCL07, BCL08]. The implementation for the latest generation of GPUs (Fermi) is available in our OpenNL public library.

### 2.4.3 Collaborations

- Wenping Wang, University of Hong-Kong: cooperation on Centroidal Voronoi Tessellations, student exchanges, joint publications : [LWL<sup>+</sup>09, LL10, LLW09];
- we published with Mario Botsch, Leif Kobbelt, Mark Pauly and Pierre Alliez the book *Polygon Mesh Processing* [BKP<sup>+</sup>10]. This book is based on the material that we wrote for our courses [BPK<sup>+</sup>07, BPK<sup>+</sup>08];
- we gave with Kai Hormann (TU Clausthal) and Alla Sheffer (U. of British Columbia) a course on mesh parameterization at SIGGRAPH 2007 [HLS07];
- we gave with Richard Hao Zhang (Simon Fraser University) a course on Spectral Mesh Processing at SIGGRAPH Asia 2009 [LZ09] and SIGGRAPH 2010 [LZ10];
- Dmitry Sokolov is a member of the ANR project Moditere, on the modelisation of fractal objects. He co-advises the Ph.D. thesis of Sergei Podkorytov with Christophe Gentil (University of Bourgogne).

### 2.4.4 External support

- ERC GOODSHAPE: 2008 - 2013, 1.1M Euros
- ANR Physigraphics: 2010 - 2013, 300K Euros

## 2.5 Progress Report on Objective 2 for the 2007-2010 evaluation period: Rendering and Visualization

### 2.5.1 Executive summary

We study methods to efficiently display 3D objects and attributes attached to them, such as colors or more elaborate photometric properties (for realistic rendering) or physical properties such as heat, pressure, velocities . . . (for scientific visualization). The idea is to define a representation of geometry and properties best suited to interactive visualization with the graphic hardware.

We have applied our geometric algorithms presented in the previous section to the traditional problem of **texture mapping**. This year, with Sylvain Lefebvre, Samuel Hornus and Dmitry Sokolov who joined the project, we extended our research topics to include texture synthesis (and more generally content creation, see Section 5). We have developed geometric representations for **scientific visualization** in molecular modeling.



Figure 3: (a) From a source image our synthesizer generates new textures fitting surfaces of any size. (b) The user has precise control over the results. (c) Our algorithm synthesizes textures by reordering strips of the source image. Each result is a path in a graph describing the space of synthesizable images. Only the path need to be stored in memory. Decoding is performed during display, in the pixel shader.

### 2.5.2 Scientific achievements

**Texture mapping:** Discontinuities (or seams) near chart boundaries is a major issue in texture mapping. Based on recent advances in mesh parameterization (including our Periodic Global Parameterization method [RLL<sup>+</sup>06]), we propose a solution to make these seams invisible [RNLL10], while still generating a standard texture atlas. Global parameterization methods ensure that the grid defined by the  $u, v$  coordinates perfectly matches near chart boundaries. However, this property of the  $u, v$  coordinates needs to be complemented by a set of constraints on the colors stored in the texels. We propose an algorithm that solves for all the necessary constraints between texel values, including through different magnification modes (nearest, bilinear, biquadratic and bicubic), and across facets using different texture resolutions.

**Texture synthesis:** We introduced in [LHL10] a new texture synthesis algorithm targeted at architectural textures (see Figure 3). While most existing algorithms support only stochastic textures, ours is able to synthesize new images from highly-structured examples such as images of architectural elements (facades, windows, doors, etc.). In addition, our approach is designed so that results are compactly encoded and quickly accessed from the graphics processor during the rendering process. Thus, when used as textures our synthesis results use little memory compared to the equivalent images they represent. We have also used texture synthesis to perform rendering based on a single image, as we explain in [BVL10]. We do this by combining an image-analogies type approach and a reprojection scheme. Based only on a single segmented image, we are able to move around at near-interactive rates. *Note: The work above was developed during the REVES-ALICE joint-appointment period of Sylvain Lefebvre and therefore also appears in the REVES report.* We also developed in cooperation with GeorgiaTech an alternative representation for spatially varying materials [RLW<sup>+</sup>09] together with interactive methods to create/edit it.

**Scientific Visualization with Alternative Representations:** We developed a ray-casting algorithm for algebraic implicit surfaces [dTLP07]. We applied this algorithm to visualize large CAD models with tubes and pipes [dTLP08], [dTL08] and molecular surfaces [CLM08] (see Figure 4). This article was in the top 25 downloaded papers of Journal of Molecular Graphics, and Matthieu Chavent was awarded the national Ph.D prize from GMM Group (Graphics and Molecular Modeling). We also developed a ray-caster for height fields and used it to introduce geometry textures [dTWL07, dTWL08], a

[RLL<sup>+</sup>06] Nicolas Ray, Wan Chiu Li, Bruno Lévy, Alla Sheffer, and Pierre Alliez. Periodic global parameterization. *ACM Transactions on Graphics*, 2006.



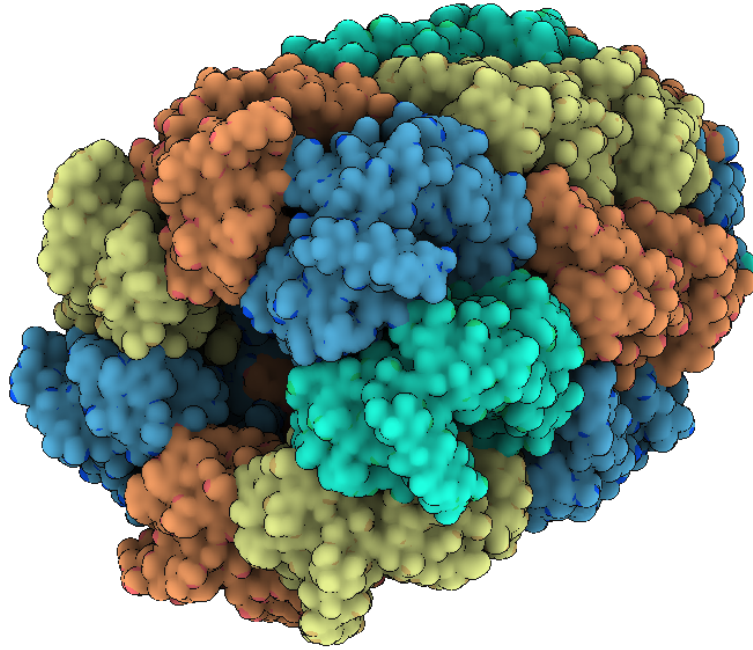


Figure 4: *Interactive visualization of a molecule, using GPU-accelerated ray-tracing and screen-space ambient occlusion.* .

method to add fine details to an otherwise coarse geometry.

### 2.5.3 Collaborations

- Gustavo Patow and Ismael Garcia, Girona University, Spain (6 month stay, common research on dynamic perfect hashing for texture mapping).
- Greg Turk (GeorgiaTech), Nabla associate team. Common publication: [RLW<sup>+</sup>09]
- Christian Eisenacher, Marc Stamminger (U. Erlangen). Common publication: [BELS10]
- Matthäus Chajdas (Erlangen, TU Munich). Common publication: [CLS10]
- the collaboration with the REVES team continues, with common research projects between Sylvain Lefebvre, George Drettakis and Ares Lagae
- We co-advised with Bernard Maigret the Ph.D. thesis of Matthieu Chavent on molecular modeling and visualization. Common publication: [CLM08]

### 2.5.4 External support

- ANR Similar Cities : Jan 2009 - Jan 2013, 209 K Euros

## 2.6 Self assessment

### Strengths

- Within 4 years of existence, ALICE hired excellent permanent researchers and reached a critical mass. Their skills cover the wide spectrum required by the project;
- our strategy based on a general mathematical formulation allowed us to significantly improve fundamental algorithms (Lloyd), solve important open problems (mesh to spline conversion, hexaedral-dominant meshing, by-example texture synthesis) and publish the results in major venues (ACM SIGGRAPH, ACM TOG, Eurographics). Some of our papers already have a visible impact on the community and initiated a new research direction (e.g., quadrangulation, spectral methods) ;
- we gave courses to disseminate the mathematical background that we have acquired (3 courses on 3 different topics at SIGGRAPH, 6 courses in total) ;
- the coherency of the research project helped the researchers in ALICE to apply for funding. Some of the projects (GOODSHAPE, Physigraphics) provide us with sufficient resources to avoid spreading the effort in applying to multiple grants;
- the software developed by the team (Graphite, OpenNL, LibSL) is both a memory of the “know-how” of the team and a good communication vector. Most of the algorithms described in the articles that we published since the beginning are still functional and can be used. In a certain sense, each new research result is “multiplied” instead of being “added” to the previous work, since it can be combined with all our previous algorithms. Moreover, our publically available implementations helps promoting our research results in the community, that can reproduce our results, measure and compare the performance of several algorithms etc...

### Weaknesses

- The geometric aspect of our “dynamic function basis” research program required a careful analysis and the mathematical developments listed in the previous section. For this reason, we do not present results yet for the numerical simulation of light. Now that we understand the geometric aspect, we plan to apply our dynamic approximation scheme to solving PDEs (including light transport and fluids, see Section 5). Some preliminary results and discussions with experienced researchers of the field (F. Durand) encourage us to continue developing our original approach to lighting;
- administratively, advising Ph.D. students requires to defend a HdR (“Habilitation Thesis”). In ALICE, only B. Lévy has the HdR, which is not reasonable for a team with 7 permanent researchers. However, N. Ray and S. Lefebvre are in the process of writing and defending it (this is a key objective for the next evaluation period);
- attracting good Ph.D. students is difficult, since there is not such a thing as a “computer graphics” master in Nancy. ALICE is somewhat isolated in this theme in Nancy. The strong connections with the community allowed us to attract good post-doc students and applicants for permanent researcher positions, but this does not apply to the undergraduate level;
- the rapid growth of the team is a strength but could be also a weakness. There is a risk of losing the initial focus of ALICE. However, we think that the interests and mathematical skills of the new researchers point towards the right direction;
- three of our submissions to ACM SIGGRAPH were redirected to ACM Transactions on Graphics (and finally accepted). The main reason was a lack of clarity in the writing. We now have a better strategy and we schedule longer-term projects ( $> 1$  year) for writing some of the articles. This strategy was successful this year;



## 3 Knowledge dissemination

### 3.1 Publications

	2007	2008	2009	2010
PhD Thesis	1	2	1	1
H.D.R (*)		1		
Journal		7	5	8
Conference proceedings (**)	4	2	1	3
Book chapter				
Book (written)				1
Book (edited)	1	2	2	2
Patent				2
Technical report	1	1	2	
Deliverable				
Courses (***)	2	2	1	1

(\*) HDR Habilitation à diriger des Recherches

(\*\*) Conference with a program committee

(\*\*\*) Given at SIGGRAPH, SIGGRAPH Asia, Eurographics and ECCV

#### Publications in main journals during evaluation period :

1. ACM Transactions on Graphics: 3 (+ 2 ACM SIGGRAPH + 1 under revision)
2. IEEE Transactions on Visualization and Computer Graphics: 2
3. Computer Graphics Forum: 2 (+ 1 Eurographics + 2 SGP + 2 EGSR)

#### Publications in main conferences during evaluation period :

1. ACM SIGGRAPH: 2 (+ 3 courses + 1 course at SIGGRAPH Asia)
2. Eurographics: 1 (+ 1 course)
3. ACM/EG Symposium on Geometry Processing: 2
4. Eurographics Symposium on Rendering: 2

### 3.2 Software

**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. Last year (2009), Graphite obtained the “most innovative” special prize at the “trophées du libre” international open-source software competition, and the 3rd prize in the “scientific software” category.

**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 mesh unwrapping method. It was integrated in Blender by Brecht Van Lommel and others to create automatic texture mapping methods. Our mesh unwrapping algorithms have now become the de-facto standard for mesh unwrapping in several industrial mesh modeling packages (including Maya, Silo, Catia). OpenNL is extended with two specialized modules :

- CGAL parameterization package : this software library, developed in cooperation with Pierre Alliez and Laurent Saboret (INRIA Geometrica), is a CGAL package for mesh parameterization. It includes a special, generic version of OpenNL, compatible with CGAL requirements of genericity;
- Concurrent Number Cruncher : this software library extends OpenNL with parallel computing on the GPU, implemented using the CUDA API, and supporting the new Fermi architecture. OpenNL/CNC is referenced on NVidia website (tools for Tesla / Jacobi Preconditioned Conjugate Gradient solver)

**Intersurf** is a plugin of the VMD (Visual Molecular Dynamics) software. VMD is developed by the Theoretical and Computational Biophysics Group at the Beckmann Institute at University of Illinois. The Intersurf plugin is released with the official version of VMD since the 1.8.3 release (more than 30K users). It provides surfaces representing the interaction between two groups of atoms, and colors can be added to represent interaction forces between these groups of atoms.

**LibSL:** Computer Graphics research requires a variety of specialized tools: image and mesh manipulation, interaction with several graphics API on several platforms, graphics processor (GPU) programming. To ease programming in this context, Sylvain Lefebvre has developed a C++ graphics-programming toolbox. It simplifies several programming tasks and ease sharing and compilation of code under various environments. The library is available as a private project on the INRIA Forge. It is currently used by several students and researchers within the REVES and ALICE teams.

### 3.3 Valorization and technology transfert

#### Transfert to the industry

- Xavier Cavin created the *Scalable Graphics* start-up in January 2007. They market software solutions (DViz and Direct Transport Compositor) for high performance visualization with PC clusters;
- we kept strong relations with the GOCAD consortium and the Earth Decision Sciences company. Several former ALICE members joined this company (3 during the evaluation period, 6 in total). They transferred their research result to GOCAD (high performance numerical solvers and geometry processing tools for earth sciences modeling);
- the cooperation with the XXXXXX<sup>3</sup> company resulted in new high-quality volume rendering tools in Graphite;

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<sup>3</sup>confidentiality clauses do not allow to disclose the name.

- By-example Synthesis of Architectural Textures [LHL10]: A patent was filed to protect the technology, with the goal of transferring it to our industrial partners in the ANR Similar Cites;
- Lp Centroidal Voronoi Tessellation [LL10]: A patent was filed to protect the technology. We are investigating possibilities for industrial transfers, including our partners of the GOCAD consortium;

### **Transfert to other scientific domains**

- We develop relations with the Applied Mathematics Community, and plan to extend them in the future. B. Lévy participated to 2 minisymposia on spectral mesh processing at ICIAM 2007 (International Congress of Industrial and Applied Mathematics). B. Lévy organized a keynote talk at ACM/EG SGP by Naoki Saito (researcher in applied mathematics) and co-organized a “PDE and meshing” day in Nancy with the mathematics department (Xavier Antoine). B. Lévy was invited at several thematic days in France organized by applied mathematics labs. We contributed material for books on topology (Bill Basener, Rochester Institute of Technology) and illustrations for the American Mathematical Society (Dana Mackenzie).;
- we experiment applications of our visualization algorithms in bio-chemistry. The results of the Ph.D. thesis of Matthieu Chavent had a good impact in this community (most downloaded article, Ph.D. thesis prize of the French GMM association of molecular modeling and graphics). We cooperate with the “Fourmentin Guilbert” foundation to develop a 3D molecular modeler (Micromegas plugin of Graphite) that will help validate hypothesis on molecular mechanics in living cells.

### **3.4 Teaching**

Dmitry Sokolov teaches “Modeles de perception et raisonnement” M1 “Infographie”, M1 “Geometrie et representation dans l’espace”, L2+L3 “Logique et modeles de calcul”, M1 “Synthese d’images 3D”, M1 “Unité Bureautique et Communication électronique”, L1 (230h) ;

Bruno Lévy teaches “Visualisation”, M2 (30h), “Numerical Optimization”, ENSG (3h)

Sylvain Lefebvre teaches “Computer Graphics”, ENSG, 10h

Sylvain Lefebvre and Bruno Lévy teach “Computer Graphics” with George Drettakis (REVES), Ecole Centrale Paris, 15h

ALICE team members participate on a regular basis to science fair events and talks for the general public. Vincent Nivoliers received the prize of the best scientific animation at the science fair in 2010.

We gave courses and tutorials at SIGGRAPH [BPK<sup>+</sup>07, HLS07, LZ10], SIGGRAPH ASIA [LZ09], Eurographics [BPK<sup>+</sup>08] and ECCV.

### **3.5 Visibility**

#### **Awards and highly competitive grants**

Sylvain Lefebvre (joint appointment REVES-ALICE) was awarded the Eurographics Young Researcher Award in 2010

Bruno Lévy received a research grant from the European Research Council (1.1 M Euros, 0.3 percent acceptance rate, all disciplines of science)

Rhaleb Zayer received a “Chaire d’excellence” grant from the ANR (300K Euros)

Guillaume Caumon (external collaborator, head of GOCAD consortium) received the researcher prize of the International Association of Mathematical Geology

Our project “Geometric Intelligence” received a grant from Microsoft Research (100K Euros) (“tools for advancing science” CfP, Europe-wide)

Bruno Lévy received the 1st researcher prize from the Regional Council of Lorraine

Our software Graphite received the special prize “most innovative project” and the third prize in the “scientific software” category at the international open source software competition “les trophées du libre”

Mathieu Chavent received the Ph.D thesis prize awarded by the GMM association

Our SIGGRAPH course [BPK<sup>+</sup>07] received the best course notes award

Our paper “Concurrent Number Cruncher” [BCL07] received the best paper award at HPCC2010

### **Editorial activities**

Bruno Lévy was program co-chair of ACM SPM 2007, ACM SPM 2008 and ACM/EG SGP 2010

Bruno Lévy is associate editor of Graphical Models (Elsevier)

Sylvain Lefebvre was a PC member of ACM SIGGRAPH 2010 (and 2011)

Bruno Lévy was a PC member of ACM SIGGRAPH 2008

ALICE team members were PC members of ACM SIGGRAPH, Eurographics, IEEE VIS, EGSR, ACM/EG SGP, SIAM/ACM SPM, IEEE SMI, I3D, Pacific Graphics, NASAGEM, NORDIA.

### **Other committees**

Bruno Lévy is a member of the executive committee of the Nancy Grand Est INRIA research center

Bruno Lévy was a member of the AERES visiting committee for the evaluation of the LIRIS lab (Lyon) in 2010

Bruno Lévy was a member of the selection committee for associate professor chairs: Strasbourg U. in 2008, Strasbourg/CNRS in 2008, Nancy U. in 2008 and Ensimag Grenoble in 2010

Bruno Lévy was a member of 24 Ph.D. theses committee and 2 habilitation theses committees during the evaluation period

Bruno Lévy is the scientific coordinator for the evaluation of the “Interaction and Visualization” INRIA theme

## Invited talks

Sylvain Lefebvre and Bruno Lévy gave invited talks in Paris SIGGRAPH Chapter;

Sylvain Lefebvre gave an invited talk in Italian SIGGRAPH Chapter;

Bruno Lévy gave invited talks in SMI Minisymposium 08, Stony Brook Modeling Week 08, ECCV 08 (invited tutorial), Chinese Conference on Geometric Design 09 and 8 invited talks during mathematics / Computer Sciences thematic days.

## 4 External Funding

(k euros)	2007	2008	2009	2010
INRIA Research Initiatives				
National initiatives				
ANR Physigraphics			72K	100K
ANR Similar Cities				66K
European projects				
FP6 AimAtShape	5K			
FP7 ERC Goodshape		90K	140K	220K
Associated teams				
Associate team NABLA		10K		
Industrial contracts				
GOCAD Consortium	37K	18K	80K	80K
Microsoft Research	50K	50K		
XXXXXXXX†			40K	
Scholarships				
Chavent (BDI)	40K			
Dong (INRIA/Region)	12K			
Toledo (INRIA/Region)	35K			
Vallet (X Telecom)	50K			
Nivoliens (ENS)		12K	40K	40K
Other funding				
CPER AOC (regional)		5K	5K	
CPER MIS (regional)		5K		
Fondation Fourmentin Guilbert			3K	17K
Total	229K	190K	380K	523K

† Confidentiality clauses in the contract with this company does not allow us to disclose its name.

### National initiatives

**ANR Physigraphics** This “Chaire d’excellence” project, awarded to Rhaleb Zayer, is a long term (3 years) project, with a total funding of 300K Euros. The scientific objective of this project is to develop new deformation models, where the underlying mathematics (basis functions) is adaptively learned from acquisition, and thus have inherently a clear

physical meaning. In this way, the simulation goes on par with the real deformation behavior. To address this goal the PhysiGrafix project which consists of (1) systematic tracking and reconstruction of a coarse representation of captured multi-view video deformation sequence; (2) problem reduction by encoding the physics in relevant deformation modes and elimination of irrelevant parameters (e.g. rigid body modes); (3) Adaption to refined reconstruction as well as to the addition of new footage of the same model or similar models. This research is motivated by real world applications, and in a broad scope touches upon disciplines such as virtual medicine, manufacturing and feature film industry.

**ANR Similar-Cities** This project, with Sylvain Lefebvre as the Principal Investigator, is a common project between the INRIA, CSTB (Scientific and Technical Center for Buildings) and Allegorithmic (a compagny specialized in procedural texturing), on the theme of approximating urban texture procedurally. The textures and images mapped onto the geometrical models are generated on-the-fly rather than beeing stored. The goal is to provide procedural representations that are both compact in memory and efficiently generated, even for massive urban environments (virtual citites). The final goal is to enhance the immersion and realism of interactive walkthroughs in such scenes. *Note: this project was launched by Sylvain Lefebvre when he was with REVES and continues in ALICE.*

**ANR Moditere** This project is shared between three computer sciences labs (LIRIS in Lyon, LE2I in Dijon, INRIA Nancy) and the European Pole of Plasturgy in Oyonnax. The project aims at defining new ways to create complex geometries. For instance, resonator-type mufflers are tedious to model by means of classic modeling tools. For this reason, the Moditere project proposes to explore fractal geometry as a means of generating porous volumes. Moditere considers both the topological properties (to control relations between the occupied volume and the quantity of used material) and the differential properties (to control reliefs, surface roughness and geometrical textures). Once a solid theoretical kernel is created, we plan to start close cooperations with acoustic laboratories, plastics and other industries to shorten the development-production cycle.

## European projects

**FP6 AimAtShape:** ALICE was a member of the the AIMShape Network of Excellence. The goal was 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, etc.). 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) aimed at sharing the expertise of European research groups in this area. To better share the knowledge and know-how, we proposed to develop within the network the notion of DSW (Digital Shape Workbench), i.e., a set of common integrated research platforms ( CGAL : computational geometry library, Graphite : numerical geometry workbench, Synaps: numerical algorithms).

**FP7 ERC GoodShape:** Project GoodShape (Numerical Geometric Abstraction: from bits to equations), funded by the European Research Council, involves several fundamental aspects of 3D modelling and computer graphics. It is a long-term project (5 years, started in August 2008), with a total funding of 1.1 MEuros. The process selection was highly

competitive (300 projects funded out of 9000 submissions in Europe, all disciplines of science).

GOODSHAPE is taking a new approach to the classic, essential problem of sampling, or the digital representation of objects in a computer, modeled by the notion of Dynamic Function Basis (see Section 2 for more details). This new approach proposes to simultaneously consider the problem of approximating the solution of a PDE 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.

### **Associated teams and other international projects**

**NABLA associate team:** Greg Turk’s team and ALICE belong to two different scientific communities: texture synthesis for Greg Turk and geometry processing for ALICE. We noticed that at a fundamental level, both scientific communities are interested in the same type of problems i.e. optimizing locally-defined criteria. Our main result is a joint work that introduced an interactive texturing tool based on stochastic approach to define the texture, and a geometry processing approach to define the mapping of this texture onto a surface [RLW<sup>+</sup>09]. As a follow-up, the common research project will continue with Eugene Zhang, a former student of Greg Turk, now associate professor in Oregon State U., who will visit ALICE next year (2011) for a 6 months stay.

**Cooperation with Hong-Kong University:** In the frame of the GOODSHAPE project, we cooperate with Hong-Kong university on Centroidal Voronoi Tessellations and their applications. Researchers and students from Nancy and Hong-Kong visit each other on a regular basis. We co-authored several publications in the frame of this cooperation (including 1 ACM TOG, 1 ACM SIGGRAPH, and 1 paper accepted to ACM TOG pending revisions).

**Cooperation with Girona University:** Sylvain Lefebvre started a collaboration with Gustavo Patow (researcher) and Ismael Garcia (PhD student) of Girona University, Spain, on the topic of dynamic treetree; a method to progressively texture objects as they appear or are modified on screen. Ismael Garcia is currently visiting the Alice team in INRIA Nancy which S. Lefebvre has joined.

### **Industrial contracts**

**GOCAD consortium:** The Gocad software is developed in the context of a consortium that encloses more than forty universities and thirty oil and gas companies around the world. This software is dedicated to modeling and visualizing the underground. ALICE studies the mathematical aspects of geo-modeling, and develops efficient numerical algorithms to solve the underlying optimization problems. The cooperation is formalized by several co-advised Ph.D. thesis (Laurent Castanié, Luc Buatois, Thomas Viard, Nicolas Cherpeau, Romain Merland, Jeanne Pellerin), funded by the consortium. The cooperation also consists in courses on numerical optimization given by ALICE researchers in the school of geology. Guillaume Caumon (head of Gocad consortium) is an external collaborator of the ALICE project-team.

**Microsoft Research:** Our proposal “Geometric Intelligence”, proposed to the CfP “Tools for Advancing Science” was awarded a grant by Microsoft Research in a highly

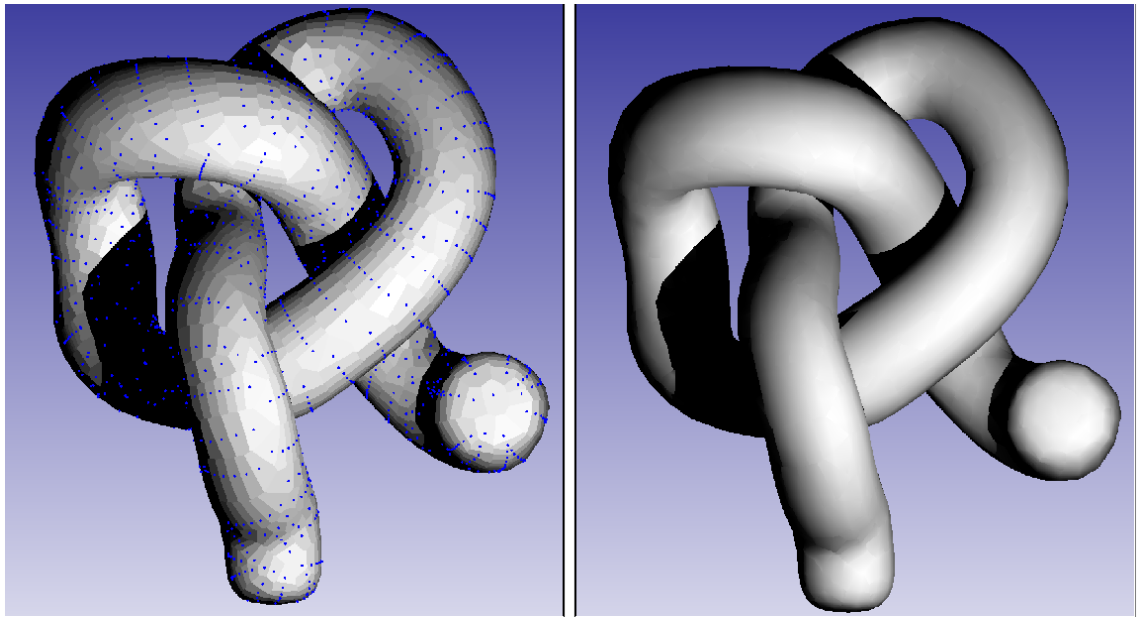


Figure 5: *Our preliminary results for the simulation of light with a dynamic function basis. Left: self-adapted function basis with constant elements. Note how shadow boundaries are captured. Right: the same with quadratic elements. .*

competitive process. The 2 years project, funded with 100KEuros, allowed to develop several fundamental algorithms (Periodic Global Parameterization) that finally led to the Dynamic Function Basis formalism now developed in the GOODSHAPE project.

## 5 Objectives for the next four years

### 5.1 Applied Mathematics and Numerical Simulation

Our work in numerical approximation is more and more connected with the applied mathematics community. One of our goals is to develop new partnerships with this community, and start studying numerical simulation problems with a “geometry processing” perspective (in particular, our “dynamic function basis” formalism). We think that our hex dominant meshing algorithm has potential applications in fluid simulation. We currently experiment them in cooperation with the Gocad consortium (for the simulation of oil flow).

We will continue the research plan outlined in Section 2.4.2. The remaining topics concern the numerical simulation of light, that was one of our initial goals. Developing the mathematical background and algorithms to tackle the geometric problem took the whole evaluation period, but we are now ready to experiment the framework with several numerical simulation of physics, namely light, fluid and acoustics. Figure 5 shows some preliminary results for the simulation of light with an optimized function basis. The elements are dynamically adapted to the variability of the solution (shadow boundaries and eigen directions of the Hessian). We also experiment our approach applied to fluid simulation (Figure 6). The development of efficient surface tracking algorithms will be also a key stone for studying how to acquire shapes and their behavior (ANR Physigraphics project). Acoustic phenomena will be studied in the frame of our ANR Moditere project.

The fundamental tools that we develop will also enable us to explore new research topics in modeling and rendering (see below).



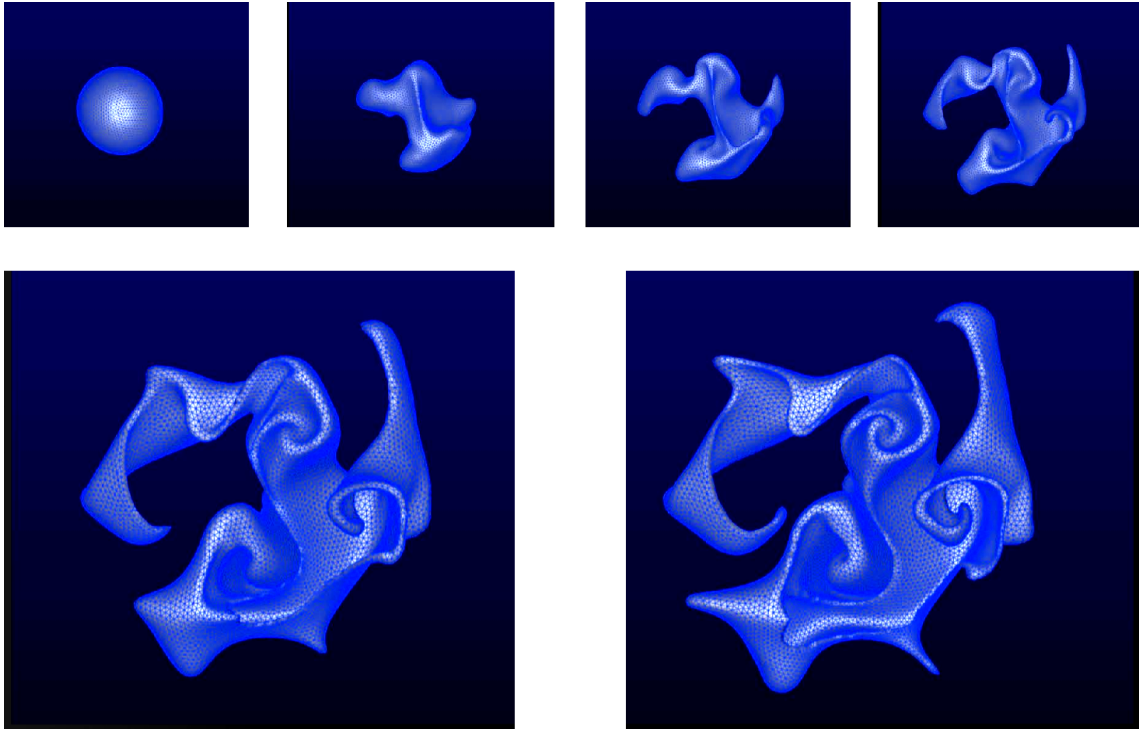


Figure 6: *Our preliminary results for the simulation of fluid with a dynamic function basis: surface tracking algorithm for a classical test case (“curlnoise”).*

## 5.2 Modeling and Rendering

Virtual environments are widely used in applications ranging from training simulators, navigation systems, movie special effects and video games. While they may depict existing or imaginary worlds, they pose the same challenges: How to create, display and interact with the massive amounts of details required to depict an immersive environment.

These problems – content creation, display and interaction – have historically been addressed separately. We plan to investigate new approaches for content generation seeking to address these problems together. Our goal is to design methods able to automatically generate large amounts of content from small examples, while still storing the results under a compact form in memory. Such approaches greatly reduce authoring time, and simultaneously reduce memory bandwidth and increase data locality enabling faster display. There is a large impact potential for the industry, as content creation cost has grown to be the largest expense in most video game and movie special effects productions.

Generating content from example requires a deep understanding of the data that is being manipulated. Graphical content is essentially made of images and geometric primitives. The images – or textures – are mapped onto the surfaces of objects in order to generate details when computing the light/surface interactions. Thus, they often store not only colors but also various surface properties such as transparency, the local orientation of surface micro-geometry, or localized light-transport information. Research on content generation directly benefits from advances in the understanding of the nature of graphical content: How to analyze and represent geometry, textures, and the interaction of light and materials. The theoretical background required for the analysis of the example content is largely shared with the fields of signal and geometry processing. The generative process often leads to complex optimization problems, which are also common in the field of geometry processing. These objective is thus a natural complement to the focus of the ALICE team on the representation of geometry and its interactions with light.

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