Activity Report 2015

Project-Team TITANE

Geometric Modeling of 3D Environments

RESEARCH CENTER
Sophia Antipolis - Méditerranée

THEME
Interaction and visualization

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Project-Team TITANE

Creation of the Team: 2013 January 01, updated into Project-Team: 2014 January 01

Keywords:

Computer Science and Digital Science:
5.3. - Image processing and analysis
5.4.4. - 3D and spatio-temporal reconstruction
5.5.1. - Geometrical modeling
7.5. - Geometry

Other Research Topics and Application Domains:
3.3. - Geosciences
5. - Industry of the future
8. - Smart Cities and Territories
9.4.1. - Computer science

1. Members

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2. Overall Objectives

2.1. General Presentation

Our overall objective is the computerized geometric modeling of complex scenes from physical measurements. On the geometric modeling and processing pipeline, this objective corresponds to steps required for conversion from physical to effective digital representations: *analysis*, *reconstruction* and *approximation*. Another longer term objective is the *synthesis* of complex scenes. This objective is related to analysis as we assume that the main sources of data are measurements, and synthesis is assumed to be carried out from samples.

The related scientific challenges include i) being resilient to defect-laden data due to the uncertainty in the measurement processes and imperfect algorithms along the pipeline, ii) being resilient to heterogeneous data, both in type and in scale, iii) dealing with massive data, and iv) recovering or preserving the structure of complex scenes. We define the quality of a computerized representation by its i) geometric accuracy, or faithfulness to the physical scene, ii) complexity, iii) structure accuracy and control, and iv) amenability to effective processing and high level scene understanding.

3. Research Program

3.1. Context

Geometric modeling and processing revolve around three main end goals: a computerized shape representation that can be visualized (creating a realistic or artistic depiction), simulated (anticipating the real) or realized (manufacturing a conceptual or engineering design). Aside from the mere editing of geometry, central research themes in geometric modeling involve conversions between physical (real), discrete (digital), and mathematical (abstract) representations. Going from physical to digital is referred to as shape acquisition and reconstruction; going from mathematical to discrete is referred to as shape approximation and mesh generation; going from discrete to physical is referred to as shape rationalization.

Geometric modeling has become an indispensable component for computational and reverse engineering. Simulations are now routinely performed on complex shapes issued not only from computer-aided design but also from an increasing amount of available measurements. The scale of acquired data is quickly growing: we no longer deal exclusively with individual shapes, but with entire *scenes*, possibly at the scale of entire cities, with many objects defined as structured shapes. We are witnessing a rapid evolution of the acquisition paradigms with an increasing variety of sensors and the development of community data, as well as disseminated data.

In recent years, the evolution of acquisition technologies and methods has translated in an increasing overlap of algorithms and data in the computer vision, image processing, and computer graphics communities. Beyond the rapid increase of resolution through technological advances of sensors and methods for mosaicing images, the line between laser scan data and photos is getting thinner. Combining, e.g., laser scanners with panoramic cameras leads to massive 3D point sets with color attributes. In addition, it is now possible to generate dense point sets not just from laser scanners but also from photogrammetry techniques when using a well-designed acquisition protocol. Depth cameras are getting increasingly common, and beyond retrieving depth information we can enrich the main acquisition systems with additional hardware to measure geometric information about the sensor and improve data registration: e.g., accelerometers or GPS for geographic location, and compasses or gyrometers for orientation. Finally, complex scenes can be observed at different scales ranging from satellite to pedestrian through aerial levels.

These evolutions allow practitioners to measure urban scenes at resolutions that were until now possible only at the scale of individual shapes. The related scientific challenge is however more than just dealing with massive data sets coming from increase of resolution, as complex scenes are composed of multiple objects with structural relationships. The latter relate i) to the way the individual shapes are grouped to form objects, object classes or hierarchies, ii) to geometry when dealing with similarity, regularity, parallelism or symmetry, and iii) to domain-specific semantic considerations. Beyond reconstruction and approximation, consolidation and synthesis of complex scenes require rich structural relationships.

The problems arising from these evolutions suggest that the strengths of geometry and images may be combined in the form of new methodological solutions such as photo-consistent reconstruction. In addition, the process of measuring the geometry of sensors (through gyrometers and accelerometers) often requires both geometry process and image analysis for improved accuracy and robustness. Modeling urban scenes from measurements illustrates this growing synergy, and it has become a central concern for a variety of applications ranging from urban planning to simulation through rendering and special effects.

3.2. Analysis

Complex scenes are usually composed of a large number of objects which may significantly differ in terms of complexity, diversity, and density. These objects must be identified and their structural relationships must be recovered in order to model the scenes with improved robustness, low complexity, variable levels of details and ultimately, semantization (automated process of increasing degree of semantic content).

Object classification is an ill-posed task in which the objects composing a scene are detected and recognized with respect to predefined classes, the objective going beyond scene segmentation. The high variability in each class may explain the success of the stochastic approach which is able to model widely variable classes. As it requires a priori knowledge this process is often domain-specific such as for urban scenes where we wish to distinguish between instances as ground, vegetation and buildings. Additional challenges arise when each class must be refined, such as roof super-structures for urban reconstruction.

Structure extraction consists in recovering structural relationships between objects or parts of object. The structure may be related to adjacencies between objects, hierarchical decomposition, singularities or canonical geometric relationships. It is crucial for effective geometric modeling through levels of details or hierarchical multiresolution modeling. Ideally we wish to learn the structural rules that govern the physical scene manufacturing. Understanding the main canonical geometric relationships between object parts involves detecting regular structures and equivalences under certain transformations such as parallelism, orthogonality and symmetry. Identifying structural and geometric repetitions or symmetries is relevant for dealing with missing data during data consolidation.

Data consolidation is a problem of growing interest for practitioners, with the increase of heterogeneous and defect-laden data. To be exploitable, such defect-laden data must be consolidated by improving the data sampling quality and by reinforcing the geometrical and structural relations sub-tending the observed scenes. Enforcing canonical geometric relationships such as local coplanarity or orthogonality is relevant for registration of heterogeneous or redundant data, as well as for improving the robustness of the reconstruction process.

3.3. Approximation

Our objective is to explore the approximation of complex shapes and scenes with surface and volume meshes, as well as on surface and domain tiling. A general way to state the shape approximation problem is to say that we search for the shape discretization (possibly with several levels of detail) that realizes the best complexity / distortion trade-off. Such a problem statement requires defining a discretization model, an error metric to measure distortion as well as a way to measure complexity. The latter is most commonly expressed in number of polygon primitives, but other measures closer to information theory lead to measurements such as number of bits or minimum description length.

For surface meshes we intend to conceive methods which provide control and guarantees both over the global approximation error and over the validity of the embedding. In addition, we seek for resilience to heterogeneous data, and robustness to noise and outliers. This would allow repairing and simplifying triangle soups with cracks, self-intersections and gaps. Another exploratory objective is to deal generically with different error metrics such as the symmetric Hausdorff distance, or a Sobolev norm which mixes errors in geometry and normals.

For surface and domain tiling the term meshing is substituted for tiling to stress the fact that tiles may be not just simple elements, but can model complex smooth shapes such as bilinear quadrangles. Quadrangle surface tiling is central for the so-called *resurfacing* problem in reverse engineering: the goal is to tile an input raw surface geometry such that the union of the tiles approximates the input well and such that each tile matches certain properties related to its shape or its size. In addition, we may require parameterization domains with a simple structure. Our goal is to devise surface tiling algorithms that are both reliable and resilient to defect-laden inputs, effective from the shape approximation point of view, and with flexible control upon the structure of the tiling.

3.4. Reconstruction

Assuming a geometric dataset made out of points or slices, the process of shape reconstruction amounts to recovering a surface or a solid that matches these samples. This problem is inherently ill-posed as infinitely-many shapes may fit the data. One must thus regularize the problem and add priors such as simplicity or smoothness of the inferred shape.

The concept of geometric simplicity has led to a number of interpolating techniques commonly based upon the Delaunay triangulation. The concept of smoothness has led to a number of approximating techniques that commonly compute an implicit function such that one of its isosurfaces approximates the inferred surface. Reconstruction algorithms can also use an explicit set of prior shapes for inference by assuming that the observed data can be described by these predefined prior shapes. One key lesson learned in the shape problem is that there is probably not a single solution which can solve all cases, each of them coming with its own distinctive features. In addition, some data sets such as point sets acquired on urban scenes are very domain-specific and require a dedicated line of research.

In recent years the *smooth, closed case* (i.e., shapes without sharp features nor boundaries) has received considerable attention. However, the state-of-the-art methods have several shortcomings: in addition to being in general not robust to outliers and not sufficiently robust to noise, they often require additional attributes as input, such as lines of sight or oriented normals. We wish to devise shape reconstruction methods which are both geometrically and topologically accurate without requiring additional attributes, while exhibiting resilience to defect-laden inputs. Resilience formally translates into stability with respect to noise and outliers. Correctness of the reconstruction translates into convergence in geometry and (stable parts of) topology of the reconstruction with respect to the inferred shape known through measurements.

Moving from the smooth, closed case to the *piecewise smooth case* (possibly with boundaries) is considerably harder as the ill-posedness of the problem applies to each sub-feature of the inferred shape. Further, very few approaches tackle the combined issue of robustness (to sampling defects, noise and outliers) and feature reconstruction.

4. Application Domains

4.1. Application Domains

In addition to tackling enduring scientific challenges, our research on geometric modeling and processing is motivated by applications to computational engineering, reverse engineering, digital mapping and urban planning. The main deliverables of our research are algorithms with theoretical foundations. Ultimately we wish to contribute making geometry modeling and processing routine for practitioners who deal with real-world data. Our contributions may also be used as a sound basis for future software and technology developments.

Our first objective for technology transfer is to consolidate the components of our research experiments in the form of new software components for the CGAL (Computational Geometry Algorithms Library) library. Through CGAL we wish to contribute to the “standard geometric toolbox”, so as to provide a generic answer to application needs instead of fragmenting our contributions. We already cooperate with the Inria spin-off company Geometry Factory, which commercializes CGAL, maintains it and provide technical support. Our second objective is to increase the research momentum of companies through advising Cifre Ph.D. theses and postdoctoral fellows on topics that match our research program.

5. Highlights of the Year

5.1. Highlights of the Year

Yuliya Tarabalka has joined our team since January 2015, making our initial objective to implement a synergy between geometry and image/vision more concrete.

On robust reconstruction of complex shapes and scenes we obtained a wide range of new results. One noticeable result is an approach for reconstruction of indoor scenes, which received the U. V. Helava Award Best Paper 2014. In our quest for semantized reconstruction we contributed an approach for reconstruction of levels of details of urban scenes, in accordance to the CityGML format. This work has been published in ACM Transactions on Graphics, and presented at ACM SIGGRAPH 2015. We also contributed a robust 3D reconstruction approach for underwater scenes, the latter exhibiting many new challenges in terms of data defect such as uncertainty and unprecedented level of outliers. Finally, we contributed a STAR (state of the art) report at the EUROGRAPHICS conference on 3D reconstruction from point clouds, which is being converted into a survey for the Computer Graphics Forum journal.

Our two-year efforts on the problem of isotopic shape approximation have turned into a new publication at the premier venue in Computer Graphics: the ACM SIGGRAPH conference 2015, and a patent. We derived a novel algorithm that generates a surface triangle mesh, given an input tolerance volume guaranteed to be within the tolerance, intersection free and topologically correct. Despite being a long standing problem, there was still no robust and practical solution to this enduring scientific challenge. This problem is both relevant to, and timely for, the increasing variety of industrial applications that involve raw geometric data.

The scientific impact of our contributions is illustrated by publications in premier journal and conference venues in our field, both in geometry processing and computer vision: ACM Transactions on Graphics and SIGGRAPH, Computer Graphics Forum, EUROGRAPHICS, IEEE Conference on Computer Vision and Pattern Recognition (CVPR), IJCV, IJRS/ISPRS. Note also that our work on underwater reconstruction has been published in the premier journal on robotic research.

Awards

Xavier Rolland-Nevière obtained the best student paper award for “track IFS” of ICASSP (IEEE International Conference on Acoustics, Speech and Signal Processing) .

Sven Oesau, Florent Lafarge and Pierre Alliez received the U.V. Helava Award Best Paper for year 2014: “Indoor Scene Reconstruction using Feature Sensitive Primitive Extraction and Graph-cut”. ISPRS Journal of Photogrammetry and Remote Sensing, 2014.

BEST PAPER AWARD:

[16]
R.-N. XAVIER, G. DOËRR, P. ALLIEZ. *Anti-Cropping Blind Resynchronization for 3D Watermarking*, in "IEEE International Conference on Acoustic, Speech Signal Processing (ICASSP)", Brisbane, Australia, April 2015, https://hal.inria.fr/hal-01111196

6. New Software and Platforms

6.1. CGAL Barycentric coordinates 2D

SCIENTIFIC DESCRIPTION

The package 2D Generalized Barycentric Coordinates offers an efficient and robust implementation of two-dimensional closed-form generalized barycentric coordinates defined for simple two-dimensional polygons. If coordinates with respect to multivariate scattered points instead of a polygon are required, please refer to natural neighbour coordinates from the package 2D and Surface Function Interpolation. The package includes an implementation of Wachspress, mean value, and discrete harmonic coordinates and provides some extra functions to compute barycentric coordinates with respect to segments (segment coordinates) and triangles (triangle coordinates).

- Participants: Pierre Alliez and Dmitry Anisimov
- Contact: Pierre Alliez

6.2. Module CGAL: Point Set Processing

SCIENTIFIC DESCRIPTION

This component implements methods to analyze and process unorganized point sets. The input is an unorganized point set, possibly with normal attributes (unoriented or oriented). The point set can be analyzed to measure its average spacing, and processed through functions devoted to the simplification, outlier removal, smoothing, normal estimation, normal orientation and feature edges estimation.

- Participants: Pierre Alliez, Laurent Saboret and Clément Jamin
- Contact: Pierre Alliez
- URL: http://doc.cgal.org/latest/Point_set_processing_3/index.html

6.3. Module CGAL: Scale-space surface reconstruction

KEYWORD: Geometric algorithms
SCIENTIFIC DESCRIPTION

This package implements a surface reconstruction method which takes as input an unordered point set and computes a triangulated surface mesh interpolating the point set. We assume that the input points were sampled from the surface of an object. The method can also process point sets sampled from the interior of the object, although we cannot provide guarantees on the output. This method can handle a decent amount of noise and outliers. The point set may greatly undersample the object in occluded regions, although no surface will be reconstructed to fill these regions.

See http://doc.cgal.org/latest/Scale_space_reconstruction_3/index.html
FUNCTIONAL DESCRIPTION

This method reconstructs a surface that interpolates a set of 3D points. This method provides an efficient alternative to the Poisson surface reconstruction method. The main difference in output is that this method reconstructs a surface that interpolates the point set, as opposed to approximating the point set. How the surface connects the points depends on a scale variable, which can be estimated semi-automatically.

- Participants: Pierre Alliez and Thijs Van Lankveld
- Contact: Pierre Alliez
- URL: http://doc.cgal.org/latest/Scale_space_reconstruction_3/index.html

6.4. Skeleton-Blockers

Skeleton-Blockers data-structure

KEYWORDS: C++ - Mesh - Triangulation - Topology - 3D
FUNCTIONAL DESCRIPTION

Skeleton-Blockers is a compact, efficient and generic data-structure that can represent any simplicial complex. The implementation is in C++11.

- Participant: David Salinas
- Contact: David Salinas
- URL: https://project.inria.fr/gudhi/software/

6.5. Structure-preserving Decimation

KEYWORDS: Mesh - 3D - Multi-View reconstruction
FUNCTIONAL DESCRIPTION

Structure-preserving decimation is a software that can simplify 3D meshes while preserving some of their structure. Simplification is performed through either a command line or a graphical user interface that can combine several operations including several simplification methods.

- Participants: David Salinas, Pierre Alliez and Florent Lafarge
- Contact: David Salinas

7. New Results

7.1. Analysis

7.1.1. Planar Shape Detection and Regularization in Tandem

Participants: Sven Oesau, Florent Lafarge, Pierre Alliez.

In collaboration with EADS ASTRIUM

We contributed a method for planar shape detection and regularization from raw point sets. The geometric modeling and processing of man-made environments from measurement data often relies upon robust detection of planar primitive shapes. In addition, the detection and reinforcement of regularities between planar parts is a means to increase resilience to missing or defect-laden data as well as to reduce the complexity of models and algorithms down the modeling pipeline. The main novelty behind our method is to perform detection and regularization in tandem. We first sample a sparse set of seeds uniformly on the input point set, then perform in parallel shape detection through region growing, interleaved with regularization through detection and reinforcement of regular relationships (coplanar, parallel and orthogonal). In addition to addressing the end goal of regularization, such reinforcement also improves data fitting and provides guidance for clustering small parts into larger planar parts (Figure 1). We evaluate our approach against a wide range of inputs and under four criteria: geometric fidelity, coverage, regularity and running times. Our approach compares well with available implementations such as the efficient RANSAC-based approach proposed by Schnabel and co-authors in 2007 [8]. This work has been published in the Computer Graphics Forum journal.

7.1.2. Image partitioning into convex polygons

Participants: Liuyun Duan, Florent Lafarge.

In collaboration with Geoimage

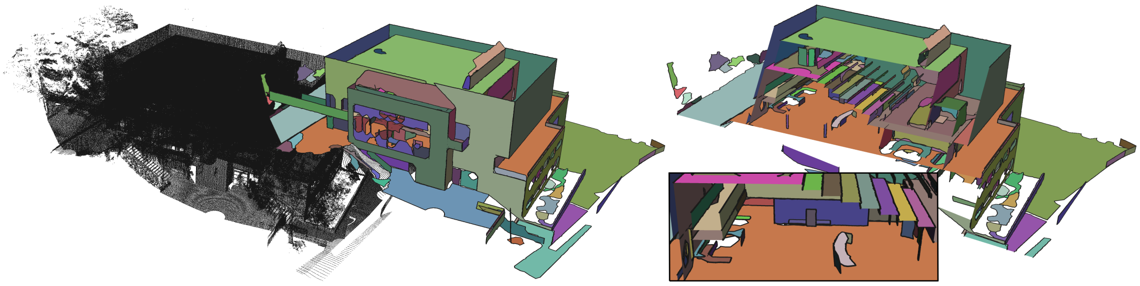


Figure 1. Shape detection and regularization. The input point set (5.2M points) has been acquired via a LIDAR scanner, from the inside and outside of a physical building. 200 shapes have been detected, aligned with 12 different directions in 179 different planes. The cross section depicts the auditorium in the upper floor and the entrance hall in the lower floor. The closeup highlights the steps of the auditorium which are made up of perfectly parallel and orthogonal planes.

The over-segmentation of images into atomic regions has become a standard and powerful tool in Vision. Traditional superpixel methods, that operate at the pixel level, cannot directly capture the geometric information disseminated into the images. We propose an alternative to these methods by operating at the level of geometric shapes. Our algorithm partitions images into convex polygons. It presents several interesting properties in terms of geometric guarantees, region compactness and scalability. The overall strategy consists in building a Voronoi diagram that conforms to preliminarily detected line-segments, before homogenizing the partition by spatial point process distributed over the image gradient. Our method is particularly adapted to images with strong geometric signatures, typically man-made objects and environments (Figure 2). We show the potential of our approach with experiments on large-scale images and comparisons with state-of-the-art superpixel methods [17]. This work has been published in the Computer Graphics Forum journal. Published in the proceedings of CVPR (IEEE conference on Computer Vision and Pattern Recognition).

7.1.3. Object Classification via Planar Abstraction

Participants: Sven Oesau, Florent Lafarge, Pierre Alliez.

In collaboration with EADS ASTRIUM.

We contributed a supervised machine learning approach for classification of objects from sampled point data. The main idea consists in first abstracting the input object into planar parts at several scales, then discriminate between the different classes of objects solely through features derived from these planar shapes. Abstracting into planar shapes provides a means to both reduce the computational complexity and improve robustness to defects inherent to the acquisition process. Measuring statistical properties and relationships between planar shapes offers invariance to scale and orientation. A random forest is then used for solving the multiclass classification problem. We demonstrate the potential of our approach on a set of indoor objects from the Princeton shape benchmark and on objects acquired from indoor scenes and compare the performance of our method with other point-based shape descriptors [22] (see Figure 3).

7.1.4. Optimizing partition trees for multi-object segmentation with shape prior

Participants: Emmanuel Maggiori, Yuliya Tarabalka.

This work has been done in collaboration with Dr. Guillaume Charpiat (TAO team, Inria Saclay).

Partition trees, multi-class segmentation, shape priors, graph cut.

Figure 2. Image partitioning into convex polygons.

(a)	Bottle	Chair	Couch	Lamp	Mug	Shelf	Table	Vase
Bottle	2	0	0	0	1	0	0	2
Chair	0	4	1	0	0	0	0	0
Couch	0	0	5	0	0	0	0	0
Lamp	0	1	0	3	1	0	0	0
Mug	0	0	0	0	4	0	0	1
Shelf	0	0	0	0	0	5	0	0
Table	0	0	0	0	0	0	5	0
Vase	0	0	0	0	0	0	0	5

(b)	Bottle	Chair	Couch	Lamp	Mug	Shelf	Table	Vase
Bottle	2	0	0	0	1	0	0	
Chair	1	4	0	0	0	0	0	0
Couch	0	1	3	0	0	0	1	0
Lamp	0	0	0	4	1	0	0	0
Mug	0	0	0	0	4	0	0	1
Shelf	0	0	0	0	0	5	0	0
Table	0	0	0	0	0	0	5	0
Vase	1	0	0	0	0	0	0	4

(c)	Bottle	Chair	Couch	Lamp	Mug	Shelf	Table	Vase
Bottle	4	0	0	0	0	0	0	1
Chair	0	2	1	1	0	1	0	0
Couch	0	1	4	0	0	0	1	0
Lamp	0	0	1	3	0	0	0	0
Mug	2	0	0	0	1	0	0	2
Shelf	0	0	0	0	0	5	0	0
Table	0	0	0	0	0	0	5	0
Vase	0	0	0	1	0	0	0	4

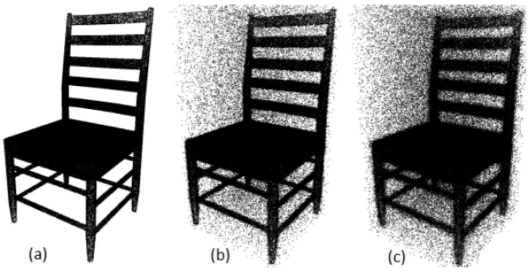
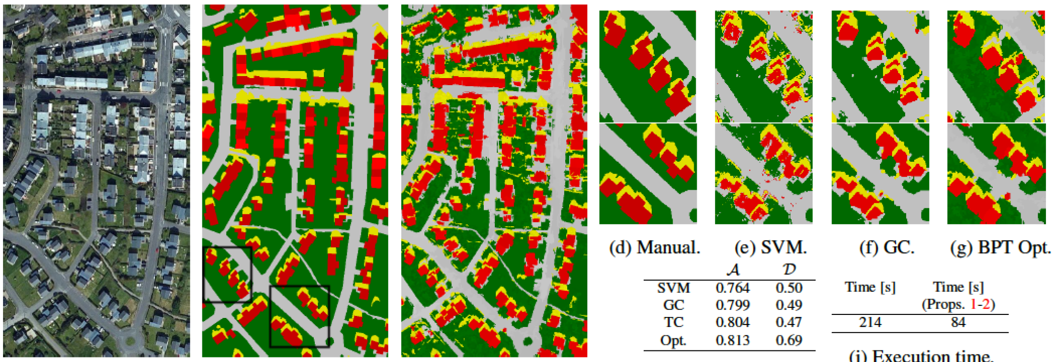


Figure 3. Classification. Left: We used four tabletop object classes from the Princeton Shape Benchmark: Bottle, Lamp, Mug and Vase. We also select four furniture object classes common to indoor scenes: Chair, Couch, Shelf and Table. Right: We evaluate our approach through computing a confusion matrix, for an increasing amount of noise and outliers. (a): Without noise and outliers. The precision of the class prediction is $82,5\%$*. The classifier is not reliable for classifying the bottles, which get mislabeled as vases. (b): Added* 10% *outliers and* 0.5% *noise. Compared to the noise-free version the precision slightly dropped to* 77.5%*. (c): Added* 20% *outliers and* 1% *noise. The method maintains a precision of* 70% *for this level of noise.*

A partition tree is a hierarchical representation of an image. Once constructed, it can be repeatedly processed to extract information. Multi-object multi-class image segmentation with shape priors is one of the tasks that can be efficiently done upon an available tree. The traditional construction approach is a greedy clustering based on color similarities. However, not considering higher level cues during the construction phase leads to trees that might not accurately represent the underlying objects in the scene, inducing mistakes in the later segmentation. We proposed a method to optimize a tree based both on color distributions and shape priors [15]. It consists in pruning and regrafting tree branches in order to minimize the energy of the best segmentation that can be extracted from the tree. Theoretical guarantees help reduce the search space and make the optimization efficient. Our experiments (see Figure 4) show that we succeed in incorporating shape information to restructure a tree, which in turn enables to extract from it good quality multi-object segmentations with shape priors. Published in the proceedings of BMVC (British Machine Vision Conference).



(a) Color image. (b) Manual segment. (c) BPT optimization. (d) Manual. (e) SVM. (f) GC. (g) BPT Opt.

	$\mathcal{A}$	$\mathcal{D}$
SVM	0.764	0.50
GC	0.799	0.49
TC	0.804	0.47
Opt.	0.813	0.69

(h) Performance.

Time [s]	Time [s] (Props. 1-2)
214	84

(i) Execution time.

Figure 4. Classification results for the satellite image over Brest. $\mathcal{A}$ denotes overall classification accuracy, and $\mathcal{D}$ denotes average buildings overlap. The performance of the proposed binary partition tree (BPT) optimization method is compared with the following methods: 1) support vector machines (SVM) classification; 2) graph cut (GC) with α-expansion; 3) cut on the BPT, regularized by the number of regions without using shape priors (TC).

7.2. Reconstruction

7.2.1. LOD Generation for Urban Scenes

Participants: Florent Lafarge, Pierre Alliez.

We contributed a novel approach that reconstructs 3D urban scenes in the form of levels of detail (LODs). Starting from raw data sets such as surface meshes generated by multi-view stereo systems, our algorithm proceeds in three main steps: classification, abstraction and reconstruction (Figure 5). From geometric attributes and a set of semantic rules combined with a Markov random field, we classify the scene into four meaningful classes. The abstraction step detects and regularizes planar structures on buildings, fits icons on trees, roofs and facades, and performs filtering and simplification for LOD generation. The abstracted data are then provided as input to the reconstruction step which generates watertight buildings through a min-cut formulation on a set of 3D arrangements. Our experiments on complex buildings and large scale urban scenes show that our approach generates meaningful LODs while being robust and scalable. By combining semantic segmentation and abstraction it also outperforms general mesh approximation approaches at preserving urban structures [10]. Published in the ACM Transactions on Graphics journal.

7.2.2. A Surface Reconstruction Method for In-Detail Underwater 3D Optical Mapping

Participant: Pierre Alliez.

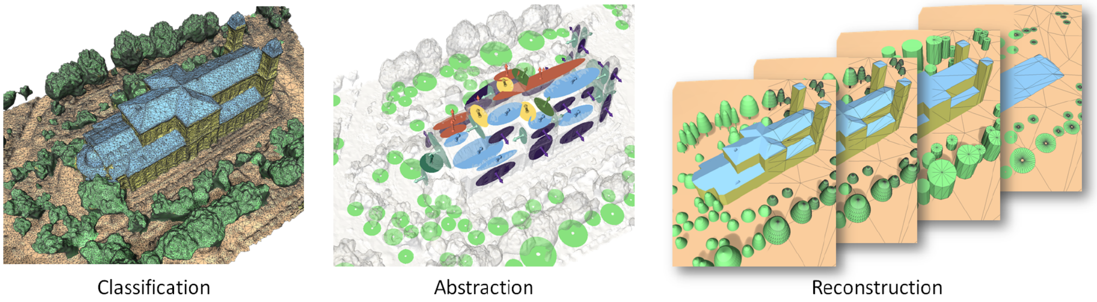


Figure 5. LOD Generation for Urban Scenes. Main steps of our algorithm.

In collaboration with Ricard Campos and Rafael Garcia from the Computer Vision and Robotics Group from University of Girona, and Mariette Yvinec from the GEOMETRICA Inria project-team.

Underwater range scanning techniques are starting to gain interest in underwater exploration, providing new tools to represent the seafloor. These scans (often) acquired by underwater robots usually result in an unstructured point cloud, but given the common downward-looking or forward-looking configuration of these sensors with respect to the scene, the problem of recovering a piecewise linear approximation representing the scene is normally solved by approximating these 3D points using a heightmap (2.5D). Nevertheless, this representation is not able to correctly represent complex structures, especially those presenting arbitrary concavities normally exhibited in underwater objects. We present a method devoted to full 3D surface reconstruction that does not assume any specific sensor configuration. The method presented is robust to common defects in raw scanned data such as outliers and noise often present in extreme environments such as underwater, both for sonar and optical surveys (Figure 6). Moreover, the proposed method does not need a manual preprocessing step. It is also generic as it does not need any information other than the points themselves to work. This property leads to its wide application to any kind of range scanning technologies and we demonstrate its versatility by using it on synthetic data, controlled laser-scans, and multibeam sonar surveys. Finally, and given the unbeatable level of detail that optical methods can provide, we analyze the application of this method on optical datasets related to biology, geology and archeology [4]. Published in the International Journal of Robotics Research.

7.2.3. Line Drawing Interpretation in a Multi-View Context

Participants: Jean-Dominique Favreau, Florent Lafarge.

In collaboration with Adrien Bousseau from the Inria project-team GraphDeco.

Many design tasks involve the creation of new objects in the context of an existing scene. Existing work in computer vision only provides partial support for such tasks. On the one hand, multi-view stereo algorithms allow the reconstruction of real-world scenes, while on the other hand algorithms for line-drawing interpretation do not take context into account. Our work combines the strength of these two domains to interpret line drawings of imaginary objects drawn over photographs of an existing scene. The main challenge we face is to identify the existing 3D structure that correlates with the line drawing while also allowing the creation of new structure that is not present in the real world. We propose a labeling algorithm to tackle this problem, where some of the labels capture dominant orientations of the real scene while a free label allows the discovery of new orientations in the imaginary scene (Figure 7). We illustrate our algorithm by interpreting line drawings for urban planing, home remodeling, furniture design and cultural heritage [18]. Published in the proceedings of CVPR (IEEE conference on Computer Vision and Pattern Recognition).

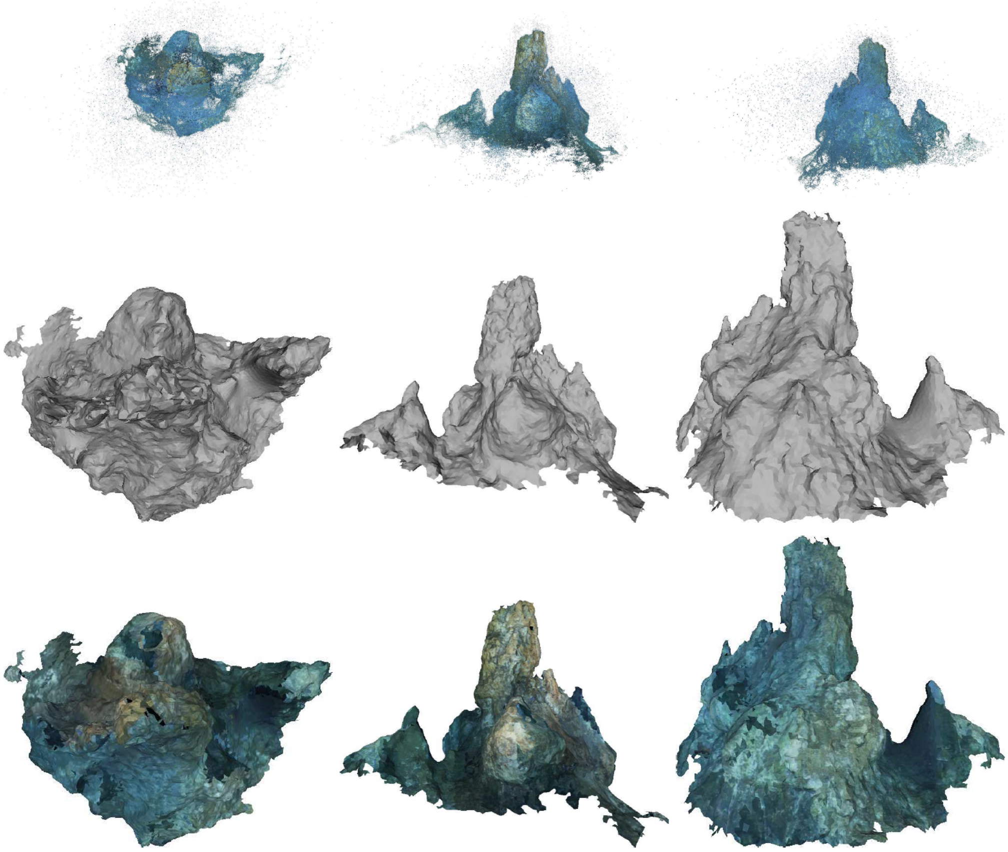


Figure 6. Underwater reconstruction.

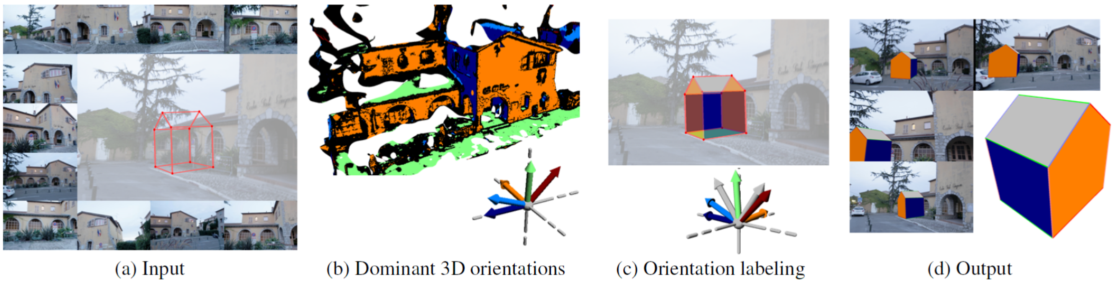

(a) Input (b) Dominant 3D orientations (c) Orientation labeling (d) Output

Figure 7. Line Drawing Interpretation. (a) Our algorithm takes as input multiple images of a scene along with a line-drawing traced over one of these images. (b) We first detect the dominant orientations of the existing scene from its multi-view stereo reconstruction. (c) Our labeling algorithm estimates the orientation of each facet of the drawing, favoring orientations already present in the scene. We visualize each dominant orientation with a random color, gray denotes new orientations. (d) We finally solve for the 3D model corresponding to the estimated orientations.

7.2.4. Marked point process model for curvilinear structures extraction

Participant: Yuliya Tarabalka [contact].

In collaboration with Seong-Gyun Jeong and Dr. Josiane Zerubia (AYIN team, Inria-SAM).

In this work, we proposed a new marked point process (MPP) model and the associated optimization technique to extract curvilinear structures [12]. Given an image, we compute the intensity variance and rotated gradient magnitude along the line segment. We constrain high level shape priors of the line segments to obtain smoothly connected line configuration. The optimization technique consists of two steps to reduce the significance of the parameter selection in our MPP model. We employ a Monte Carlo sampler with delayed rejection to collect line hypotheses over different parameter spaces. Then, we maximize the consensus among line detection results to reconstruct the most plausible curvilinear structures without parameter estimation process. Experimental results (see Figure 8) show that the algorithm effectively localizes curvilinear structures on a wide range of datasets.

7.2.5. Inference of curvilinear structure based on learning a ranking function and graph theory

Participant: Yuliya Tarabalka [contact].

In collaboration with Seong-Gyun Jeong and Dr. Josiane Zerubia from the AYIN team and Dr. Nicolas Nisse from the COATI project-team.

Curvilinear structure extraction, inference of structured data, ranking learning, graphical model, shape simplification.

To detect curvilinear structures in natural images, we proposed a novel ranking learning system and an abstract curvilinear shape inference algorithm based on graph theory. We analyze the curvilinear structures as a set of small line segments. In this work, the rankings of the line segments are exploited to systematize the topological feature of the curvilinear structures. A Structured Support Vector Machine is employed to learn the ranking function that predicts the correspondence of the given line segments and the latent curvilinear structures. We first extract curvilinear features using morphological profiles and steerable filter responses. Also, we propose an orientation-aware feature descriptor and a feature grouping operator to improve the structural integrity during the learning process. To infer the curvilinear structure, we build a graph based on the output rankings of the line segments. We progressively reconstruct the curvilinear structure by looking for paths between remote

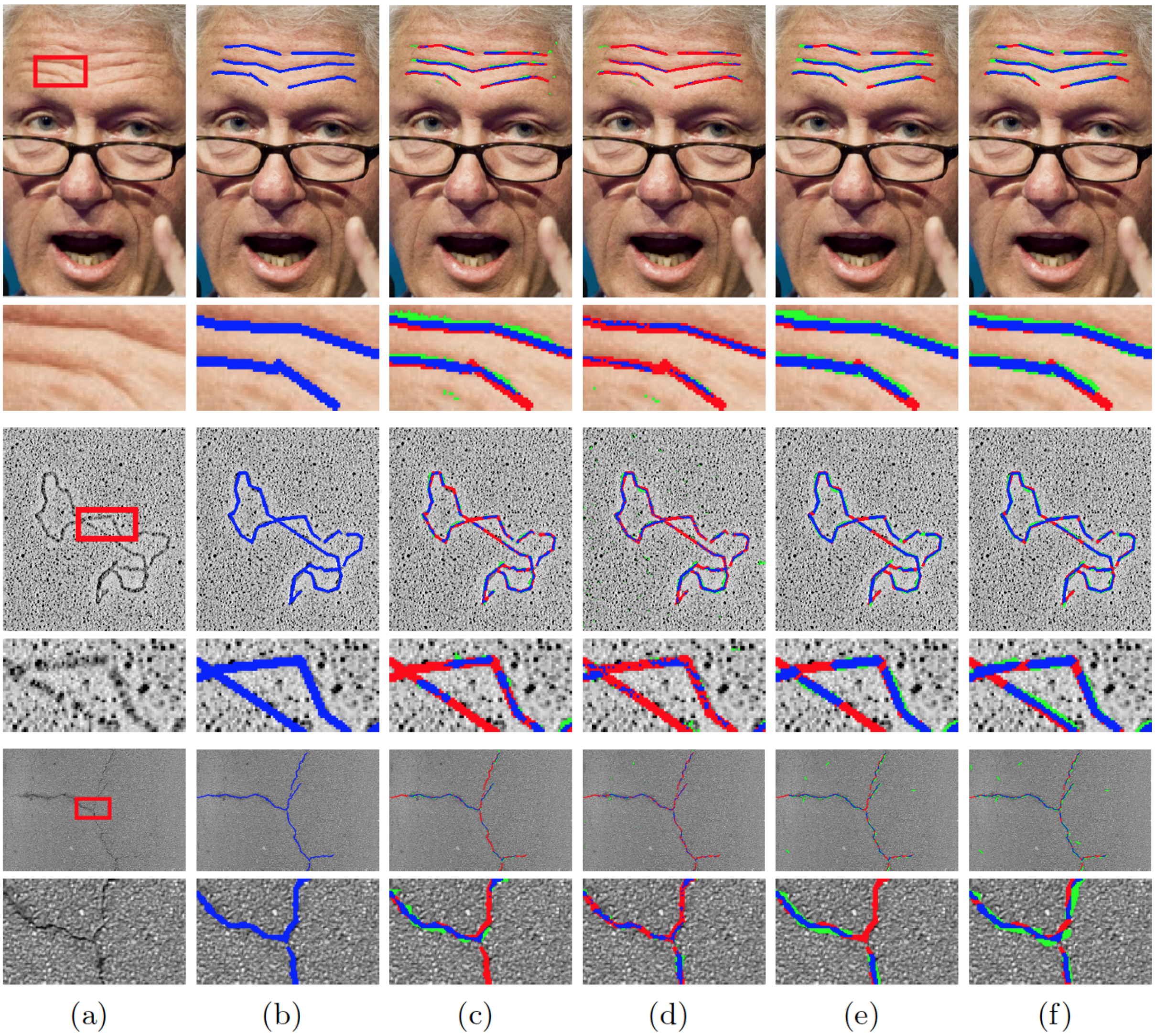
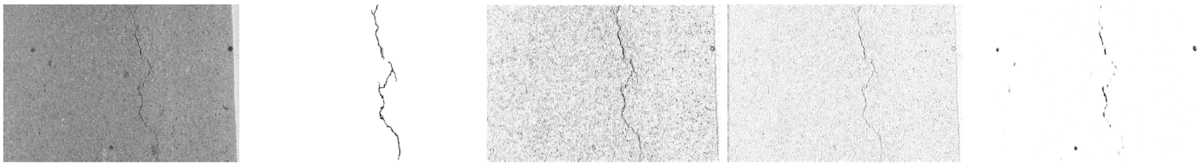


Figure 8. We visualize the localization of the curvilinear structures on input images (a). We compare with the results of a manually labeled image by a human expert (b), morphological filtering [Talbot 2007] (c), supervised feature learning [Becker 2013] (d), baseline MPP (e), and the proposed algorithm (f). Threshold values of (c) and (d) are chosen to achieve the closest recall scores to the proposed method. We use blue pixels to indicate areas which are completely corresponding to (b). Green and red pixels denote over-detected and under-detected areas, respectively, as compared with ground-truth. The name of the test images is from top to bottom: WRINKLE, DNA, *and* CRACK.

vertices in the graph. Experimental results (see Figure 9 for an example of the experimental results' comparison on the CRACK dataset) show that the proposed algorithm faithfully detects the curvilinear structures within various datasets.



(a) Input (b) Ground truth (c) Frangi et al. (1998) (d) Law and Chung (2008) (e) Becker et al. (2013)

(f) Output rankings (g) Sironi et al. (2014) (h) Jeong et al. (2015) (i) Dissimilarity scores (j) Structure inference

Figure 9. Inference of curvilinear structure on the CRACK *dataset. Our approach is depicted by (j).*

7.3. Approximation

7.3.1. *Isotopic approximation within a tolerance volume*

Participants: Manish Mandad, Pierre Alliez.

In collaboration with David Cohen-Steiner from the GEOMETRICA project-team.

We introduce an algorithm that generates a surface triangle mesh given an input tolerance volume. The mesh is guaranteed to be within the tolerance, intersection free and topologically correct. A pliant meshing algorithm is used to capture the topology and discover the anisotropy in the input tolerance volume in order to generate a concise output. We first refine a 3D Delaunay triangulation over the tolerance volume while maintaining a piecewise-linear function on this triangulation, until an isosurface of this function matches the topology sought after. We then embed the isosurface into the 3D triangulation via mutual tessellation, and simplify it while preserving the topology. Our approach extends to surfaces with boundaries and to non-manifold surfaces. We demonstrate the versatility of our approach on a variety of data sets and tolerance volumes [7]. Figure 10 illustrates the robustness of our approach on defect-laden inputs.

7.3.2. *Structure-Aware Mesh Decimation*

Participants: David Salinas, Florent Lafarge, Pierre Alliez.

We contributed to a novel approach for the decimation of triangle surface meshes. Our algorithm takes as input a triangle surface mesh and a set of planar proxies detected in a pre-processing analysis step, and structured via an adjacency graph. It then performs greedy mesh decimation through a series of edge collapse operators, designed to approximate the local mesh geometry as well as the geometry and structure of proxies (Figure 11). Such structure-preserving approach is well suited to planar abstraction, i.e., extreme decimation approximating well the planar parts while filtering out the others. Our experiments on a variety of inputs illustrate the potential of our approach in terms of improved accuracy and preservation of structure [9].

7.3.3. *CGALmesh: a Generic Framework for Delaunay Mesh Generation*

Participants: Clément Jamin, Pierre Alliez.

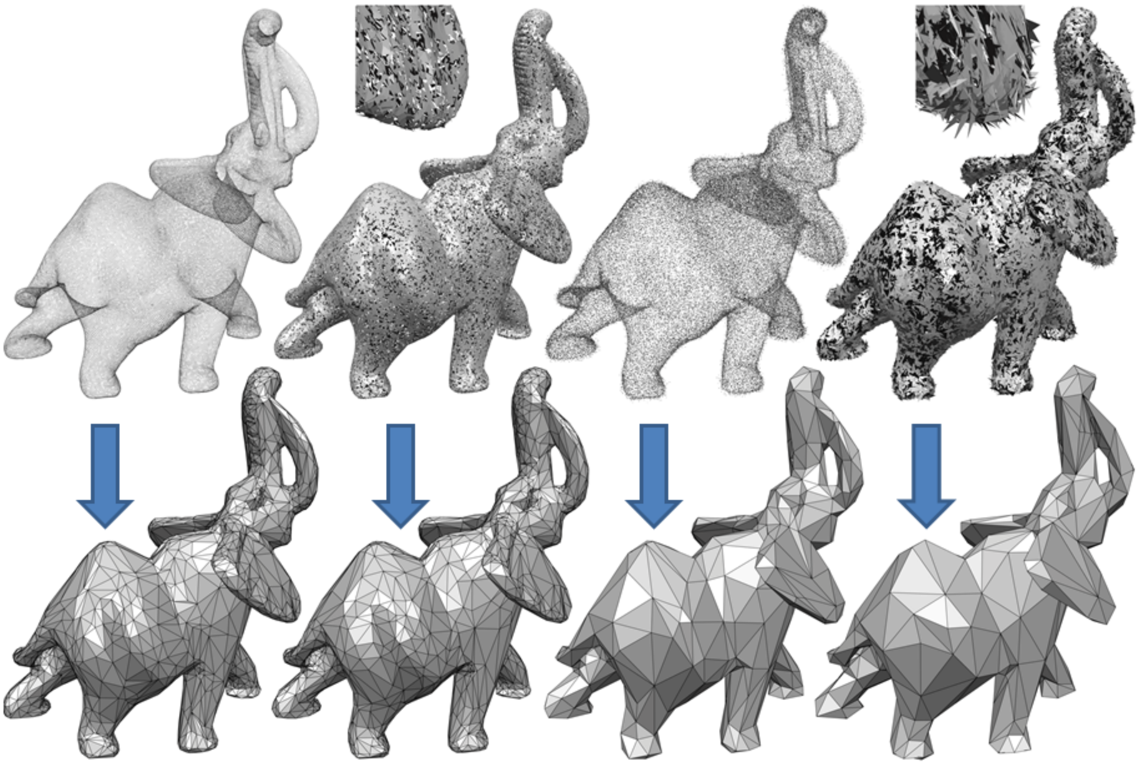


Figure 10. Isotopic approximation within a tolerance volume.

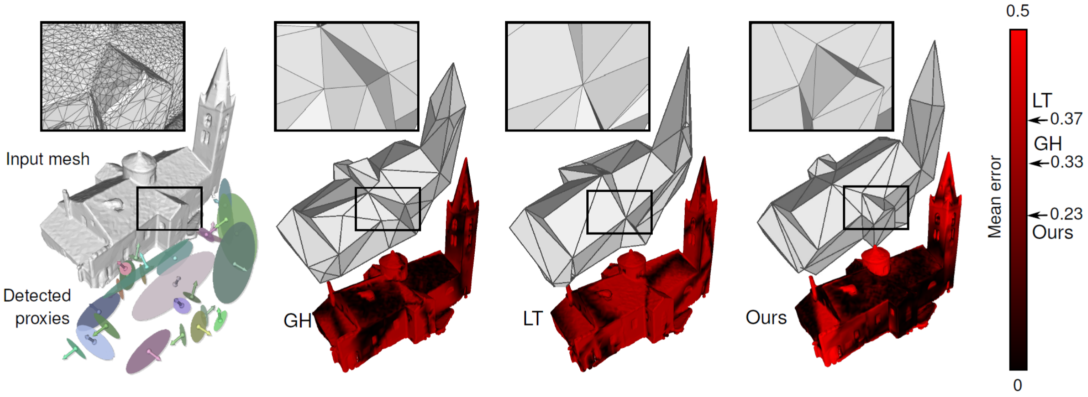


Figure 11. Structure-aware mesh decimation. Our algorithm simplifies dense triangle surface meshes via a structured set of planar proxies (left) that guides the decimation process while preserving the structure. At coarse complexity (here 50 vertices), common mesh decimation approaches (middle, quadric error metrics from Garland-Heckbert, and volume-preserving from Lindstrom-Turk) fail to reach low approximation error (see colored meshes) while preserving structure (see closeups).

In collaboration with Mariette Yvinec and Jean-Daniel Boissonnat from the GEOMETRICA project-team.

CGALmesh is the mesh generation software package of the Computational Geometry Algorithm Library (CGAL). It generates isotropic simplicial meshes – surface triangular meshes or volume tetrahedral meshes – from input surfaces, 3D domains as well as 3D multi-domains, with or without sharp features (see Figure 12). The underlying meshing algorithm relies on restricted Delaunay triangulations to approximate domains and surfaces, and on Delaunay refinement to ensure both approximation accuracy and mesh quality. CGALmesh provides guarantees on approximation quality as well as on the size and shape of the mesh elements. It provides four optional mesh optimization algorithms to further improve the mesh quality. A distinctive property of CGALmesh is its high flexibility with respect to the input domain representation. Such a flexibility is achieved through a careful software design, gathering into a single abstract concept, denoted by the oracle, all required interface features between the meshing engine and the input domain. We already provide oracles for domains defined by polyhedral and implicit surfaces [6].

7.4. Watermarking

7.4.1. Anti-Cropping Blind Resynchronization for 3D Watermarking

Participants: Xavier Rolland-Nevière, Pierre Alliez, Gwenaël Doërr.

Radial-based 3D watermarking alters the distances between the center of mass of the 3D mesh and its vertices. These watermarking systems are inherently sensitive to cropping. To address this limitation, this paper introduces a complementary blind resynchronization module to transmit critical synchronization information to the watermark decoder. Spherical patterns formed by several secret landmark vertices are embedded alongside the payload and blindly retrieved by the decoder, thereby conveying the synchronization information needed. Experimental results showcase significant improvement against cropping, while preserving performances against valumetric attacks thanks to a control parameter that automatically switches between alternate resynchronization modes [16].

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. Astrium

Participants: Sven Oesau, Florent Lafarge, Pierre Alliez.

The main goal of this collaboration is to devise new algorithms for reconstructing 3D indoor models that are more accurate, meaningful and complete than existing methods. The conventional way for modeling indoor scenes is based on plane arrangements. This type of representation is particularly limited and must be improved by devising more complex geometric entities adapted to a detailed and semantized description of scenes.

- Starting date: April 2012

- Duration: 3 years

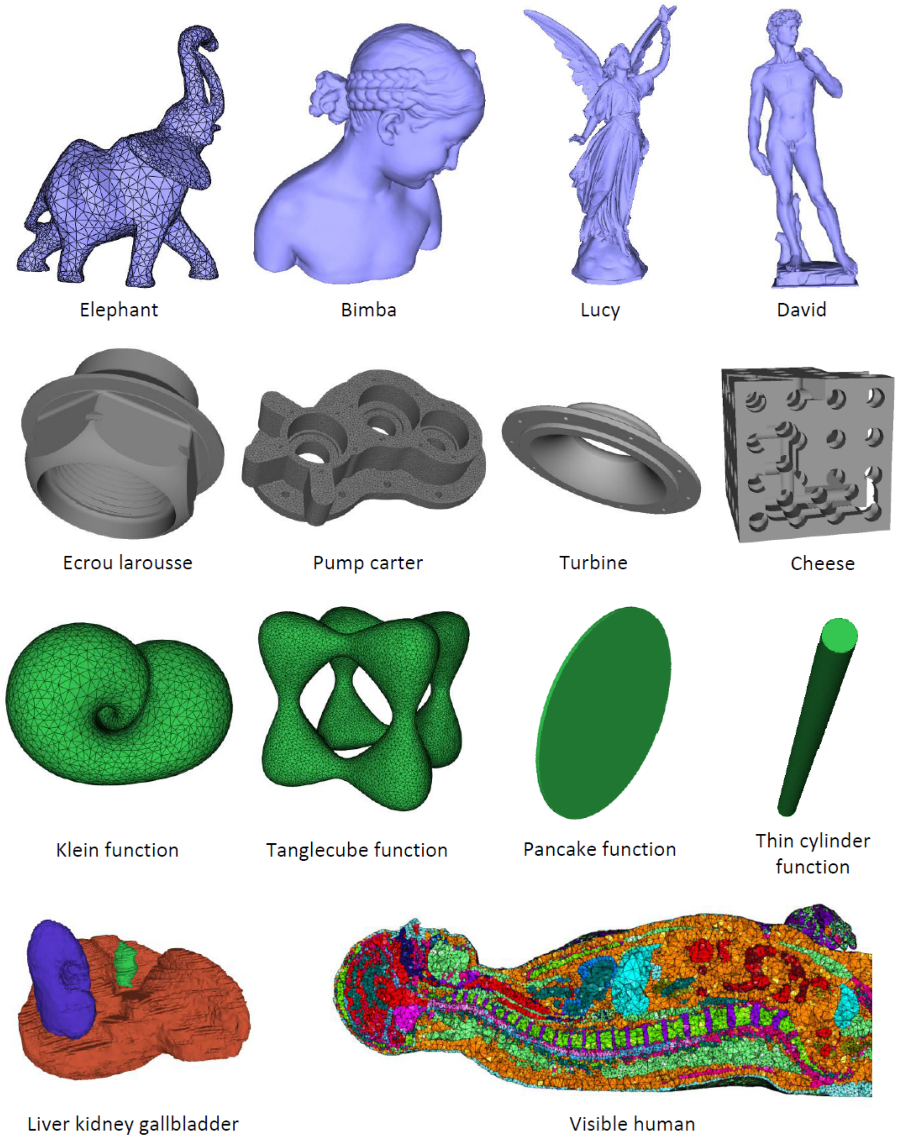
8.1.2. Geoimage

Participants: Liuyun Duan, Florent Lafarge.

The aim of this collaboration is to devise a new type of 2.5D representation from satellite multi-view stereo images which is more accurate, compact and meaningful than the conventional DEMs. A key direction consists in incorporating semantic information directly during the image matching process. This semantic information is related to the type of components of the scene, such as vegetation, roofs, building edges, roads and land.

- Starting date: November 2013

- Duration: 3 years



Elephant Bimba Lucy David

Ecrou larousse Pump carter Turbine Cheese

Klein function Tanglecube function Pancake function Thin cylinder function

Liver kidney gallbladder Visible human

Figure 12. Input domains: domains bounded by smooth surfaces (top row, in blue), CAD models with sharp features (second row, in grey), implicit functions (third row, in green), 3D images (bottom row, multicolored).

8.1.3. CSTB

Participants: Sven Oesau, Florent Lafarge.

The goal of this collaboration is to consolidate and integrate research codes implemented in Titane for urban semantization and reconstruction, into the CSTB reconstruction framework.

- Starting date: September 2015

- Duration: 6 months

8.2. Bilateral Grants with Industry

8.2.1. CNES Toulouse

Participants: Emmanuel Maggiori, Yuliya Tarabalka [PI].

Hierarchical approaches for object-oriented classification of multi-source images. Contract 150490/00.

- Starting date: November 2015

- Duration: 2 years

9. Partnerships and Cooperations

9.1. National Initiatives

9.1.1. Grand Emprunt

Culture 3D Clouds (started in October 2012, duration 3 years) is a national project aimed at devising a cloud computing platform for 3D scanning, documentation, preservation and dissemination of cultural heritage.

Information and communication technologies in the world offer new possibilities for cultural exchange, creation, education and shared knowledge to greatly expand the access to culture and heritage. Culture 3D Cloud is part of a process that aims to create a technical breakthrough approach in the field of digitization of heritage artifacts to allow the emergence of new viable business models. Today the field of 3D scanning artifacts heritage evolves slowly and only provides resources for researchers and specialists and the technology and equipment used for 3D scanning are sophisticated and require highly specialized skills. The cost is significant and limits the practicality. Culture 3D Clouds project aims at empowering the photographers and the distribution to the agencies and image banks that will develop a value chain to commercialize 3D reproductions demand for their customers and expand the market valuation of business assets (commercial publishers, public).

Partners: IGN, CMN, RMN, Inria, EISTI, CNRS-MAP, UCP-ETIS, CEA, HPC Project, ValEISTI, BeIngenious.

Web site: http://c3dc.fr/.

9.2. European Initiatives

9.2.1. FP7 & H2020 Projects

9.2.1.1. IRON - Robust Geometry Processing

Type: IDEAS

Instrument: ERC Starting Grant

Duration: January 2011 - December 2015

Coordinator: Pierre Alliez

Inria contact: Pierre Alliez

Abstract: The purpose of this project is to bring forth the full scientific and technological potential of Digital Geometry Processing by consolidating its most foundational aspects. Our methodology draws from and bridges the two main communities (computer graphics and computational geometry) involved in discrete geometry to derive algorithmic and theoretical contributions that provide both robustness to noisy, unprocessed inputs, and strong guarantees on the outputs. The intended impact is to make the digital geometry pipeline as generic and ironclad as its Digital Signal Processing counterpart.

9.3. International Research Visitors

9.3.1. Visits of International Scientists

9.3.1.1. Internships

Venkata Kusupati (IIT Bombay): design of anisotropic metrics on surfaces.

Hao Fang (Ecole Centrale Paris): scale-space analysis of mesh simplification for urban scenes.

Guillaume Matheron (ENS Paris): an efficient approach to compute the optimal transportation cost for surface reconstruction.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific events organisation

10.1.1.1. General chair, scientific chair

Pierre Alliez was co-chair of the French JGA 2015 (Journées de Géométrie Algorithmique), organized in Cargèse, October 2015.

Florent Lafarge was co-chair of the ISPRS working group on point cloud processing.

10.1.1.2. Member of the organizing committees

Pierre Alliez is a member of the Steering Board of the EUROGRAPHICS Workshop on Graphics and Cultural Heritage. He is also a member of the steering committee of the French chapter of EUROGRAPHICS since 2013.

Yuliya Tarabalka chaired 5 sessions at IEEE IGARSS 2015.

10.1.2. Scientific events selection

10.1.2.1. Member of the conference program committees

Pierre Alliez: EUROGRAPHICS Symposium on Geometry Processing (Graz, Austria) and Digital Heritage 2015.

Florent Lafarge: Laser Scanning 2015 and Digital Heritage 2015.

10.1.2.2. Reviewer

Pierre Alliez was a reviewer for ACM SIGGRAPH, ACM SIGGRAPH Asia, EUROGRAPHICS.

Florent Lafarge was a reviewer for CVPR, ICCV, SIGGRAPH, SIGGRAPH Asia, EUROGRAPHICS, IJCV and JPRS.

Yuliya Tarabalka was a reviewer for the conferences IEEE ICIP 2015, IEEE IGARSS 2015, ICCV 2015, BMVC 2015.

10.1.3. Journal

10.1.3.1. Member of the editorial boards

- Pierre Alliez: associate editor of ACM Transactions on Graphics since 2009, Elsevier Graphical Models since 2010, Computer Aided Geometric Design since 2013, and the CGAL library since 2008.
- Florent Lafarge: associate editor of The Visual Computer since 2015.
- Yuliya Tarabalka was a co-editor of the special issue “Hyperspectral Imaging and Image Processing” of the Springer journal Sensing and Imaging.

10.1.4. Invited talks

Florent Lafarge was a keynote speaker at JURSE 2015, Lausanne, Switzerland on March 31 (talk:"Urban reconstruction from airborne data: how to combine semantics and geometry?"), and at Laser Scanning 2015, La grande Motte, France (talk:"Extracting and exploiting planar primitives from Laser scans").

10.1.5. Scientific expertise

Pierre Alliez was a member of the Horizon 2020 Advisory Group for Societal Challenge 6 ‘Europe in a changing world – Inclusive, Innovative and Reflective Societies. He was also an evaluator and reviewer for the H2020 and EuroSTARS programmes from the European commission. He is since October 2015 a member of the panel GEV 01 (mathematics and computer science) of ANVUR (Italian research evaluation agency). We are evaluating the period 2011-2014 through bibliometry and peer-review.

10.1.6. Research administration

Pierre Alliez: member of the BCP (bureau du CP) since 2015, comité MASTIC (popularization), and comité espace immersif.

Florent Lafarge: elected member of the CC “Comité de Centre” since 2013, and a member of the CSD “Commission de Suivi Doctoral” since 2011.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Masters: Pierre Alliez and Florent Lafarge, Ingénierie 3D, 24h, M2, University Nice Sophia Antipolis, France.

Masters: Pierre Alliez and Florent Lafarge, 3D Meshes and Applications, 32h, M2, Ecole des Ponts ParisTech, France.

Masters: Pierre Alliez, Mathématiques pour la géométrie, 24h, M2, EFREI, France.

Masters: Pierre Alliez, Modélisation géométrique, 16h, M2, Télécom SudParis, France.

Masters: Florent Lafarge, Traitement d’images numériques, 9h, M2, University Nice Sophia Antipolis, France.

Masters: Florent Lafarge, Imagerie numérique, 10h, M2, University Nice Sophia Antipolis, France.

L2: Yuliya Tarabalka, Advanced algorithms, 27.75h eq. TD (3h of lectures + 3h of TD + 27h of TP + 1h30 of exam), L2 Networks and Telecoms, IUT Nice Côte d’Azur, Sophia Antipolis, France.

Masters: Yuliya Tarabalka, Digital imaging, 7h eq. TD (2h of lectures + 4h of TD), M2 SVS ISAB, University Nice Sophia Antipolis, France.

10.2.2. Supervision

PhD: Simon Giraudot, Robust surface reconstruction, defended on May 22, Pierre Alliez.

PhD: Sven Oesau, Reconstruction of indoor scenes, defended on June 24, Florent Lafarge and Pierre Alliez.

PhD: Seong-Gyun Jeong, Curvilinear Structure Modeling and its Applications in Computer Vision, University Nice Sophia Antipolis, defended on November 2015, Yuliya Tarabalka and Josiane Zerubia.

PhD in progress: Manish Mandad, Shape approximation with guarantees, since October 2012, Pierre Alliez and David Cohen-Steiner from GEOMETRICA.

PhD in progress: Liuyun Duan, Semantized Elevation Maps, since October 2013, Florent Lafarge.

PhD in progress: Jean-Dominique Favreau, Sketch-based modeling in multi-view context, since October 2014, Florent Lafarge.

PhD in progress: Emmanuel Maggiori, Representation and Analysis of Multisensor Remote Sensing Images with Partition Trees, University Nice Sophia Antipolis, started in January 2015, Yuliya Tarabalka and Pierre Alliez.

10.2.3. Juries

Pierre Alliez:

- Paper and software award committees, EUROGRAPHICS Symposium on Geometry Processing.
- Inria CR2 recruitment committee, Inria Sophia Antipolis.
- PhD Thesis reviewer: Jérémy Levallois (LIRIS).
- PhD Thesis committee: Rodolphe Vaillant (Université Paul Sabatier / University of Victoria).
- PhD Thesis reviewer: Gilles-Philippe Paillé (Université de Montréal).
- PhD Thesis mid-term committee: Ana Vintescu (Télécom ParisTech).

Florent Lafarge:

- Thesis reviewer: Abdoulaye Abou Diakité (Université Lyon1).

Yuliya Tarabalka:

- Expert evaluator for an ANR project submission in May 2015.
- Monitoring committee for the thesis of Amine Bohi, Southern University of Toulon-Var in October 2015.

10.3. Popularization

Pierre Alliez: two seminars in highschools, participation to the “fête de la science” in Antibes, workshop on 3D reconstruction with Nicolas Douillet and cafe-in (Robust Shape Reconstruction) at Inria Sophia Antipolis.

11. Bibliography

Publications of the year

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[2] S. OESAU. *Geometric modeling of indoor scenes from acquired point data*, Université Nice Sophia Antipolis, June 2015, https://tel.archives-ouvertes.fr/tel-01176721

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[16] *Best Paper*
R.-N. XAVIER, G. DOËRR, P. ALLIEZ. *Anti-Cropping Blind Resynchronization for 3D Watermarking*, in "IEEE International Conference on Acoustic, Speech Signal Processing (ICASSP)", Brisbane, Australia, April 2015, https://hal.inria.fr/hal-01111196.

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