Activity Report 2018

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:

A5. - Interaction, multimedia and robotics
A5.3. - Image processing and analysis
A5.3.2. - Sparse modeling and image representation
A5.3.3. - Pattern recognition
A5.5.1. - Geometrical modeling
A5.6. - Virtual reality, augmented reality
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Other Research Topics and Application Domains:

B2.5. - Handicap and personal assistances
B3.3. - Geosciences
B5.1. - Factory of the future
B5.6. - Robotic systems
B5.7. - 3D printing
B8.3. - Urbanism and urban planning

1. Team, Visitors, External Collaborators

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Mathieu Desbrun [Caltech, International Chair, Advanced Research position, until Nov 2018]

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Onur Tasar [Inria, funded by CNES and ACRI]
Vincent Vadez [Dorea, from Sep 2018]

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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. Applications

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 deliverable of our research will be 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 ambition 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. Consolidation being best achieved with the help of an engineer, we will search for additional funding. 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 ambition 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

The TITANE project-team has been evaluated by Inria in October 2018. We obtained three new ANR projects, the renewal of a collaborative contract with Google and a new Cifre PhD thesis with Dorea technology. Since September 2018 Pierre Alliez is head of science (délégué scientifique) of the Inria Sophia Antipolis center. He is also full paper co-chair of the Eurographics 2019 conference.

6. New Software and Platforms

6.1. CGAL Barycentric_coordinates_2

Module CGAL : Barycentric coordinates 2D
KEYWORD: Computational geometry
FUNCTIONAL DESCRIPTION: This package offers an efficient and robust implementation of two-dimensional closed-form generalized barycentric coordinates defined for simple two-dimensional polygons.

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

6.2. dtk-nurbs-probing

KEYWORDS: Algorithm - CAD - Numerical algorithm - Geometric algorithms
FUNCTIONAL DESCRIPTION: This library offers tools for computing intersection between linear primitives and the constitutive elements of CAD objects (curves and surfaces). It is thus possible to compute intersections between a linear primitive with a trimmed or untrimmed NURBS surface, as well with Bezier surfaces. It is also possible, in the xy plane, to compute the intersections between linear primitives and NURBS curves as well as Bezier curves.

- Participants: Come Le Breton, Laurent Busé and Pierre Alliez
- Contact: Come Le Breton

6.3. MeshMantics

KEYWORDS: Classification - 3D modeling
FUNCTIONAL DESCRIPTION: This software component enables the classification of surface meshes in accordance to common outdoor urban classes such as ground, facades, walls, roofs and vegetation.

- Participants: Florent Lafarge, Pierre Alliez and Yannick Verdié
- Contact: Pierre Alliez

6.4. Module CGAL : Point Set Processing

KEYWORD: Geometry Processing
FUNCTIONAL DESCRIPTION: This CGAL 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: Clément Jamin, Laurent Saboret and Pierre Alliez
- Contact: Pierre Alliez
- URL: http://doc.cgal.org/latest/Point_set_processing_3/index.html#Chapter_Point_Set_Processing

6.5. Module CGAL : Scale space surface reconstruction

KEYWORD: Geometric algorithms
SCIENTIFIC DESCRIPTION: This CGAL 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.
FUNCTIONAL DESCRIPTION: This method allows to reconstruct 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

6.6. 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/

6.7. 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 can be done either with a command line or with a graphical user interface that allows to combine several operations including several simplification methods.

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

7. New Results

7.1. Analysis

7.1.1. Planar Shape Detection at Structural Scales

Participants: Hao Fang, Mathieu Desbrun, Florent Lafarge [contact].

Shape detection, abstraction, man-made objects, point clouds, surface reconstruction.

Interpreting 3D data such as point clouds or surface meshes depends heavily on the scale of observation. Yet, existing algorithms for shape detection rely on trial-and-error parameter tunings to output configurations representative of a structural scale. We present a framework to automatically extract a set of representations that capture the shape and structure of man-made objects at different key abstraction levels. A shape-collapsing process first generates a fine-to-coarse sequence of shape representations by exploiting local planarity. This sequence is then analyzed to identify significant geometric variations between successive representations through a supervised energy minimization. Our framework is flexible enough to learn how to detect both existing structural formalisms such as the CityGML Levels Of Details, and expert-specified levels of abstraction. Experiments on different input data and classes of man-made objects, as well as comparisons with existing shape detection methods, illustrate the strengths of our approach in terms of efficiency and flexibility. Figure 1 illustrates the goal of our method. This work has been published in the proceedings of CVPR [16].

7.1.2. Multi-task Deep Learning for Satellite Image Pansharpening and Segmentation

Participants: Andrew Khalel, Onur Tasar, Yuliya Tarabalka [contact].

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

Segmentation, pansharpening, multi-task, joint learning

We proposed a novel multi-task framework to learn satellite image pansharpening and segmentation jointly. Our framework is based on encoder-decoder architecture, where both tasks share the same encoder but each one has its own decoder (see Fig. 2). We compare our framework against single-task models with different architectures. Results show that our framework outperforms all other approaches in both tasks.

7.1.3. Incremental Learning for Semantic Segmentation of Large-Scale Remote Sensing Data

Participants: Onur Tasar, Pierre Alliez, Yuliya Tarabalka [contact].

This work has been done in collaboration with CNES and ACRI-ST.

Incremental learning, catastrophic forgetting, semantic segmentation, convolutional neural networks

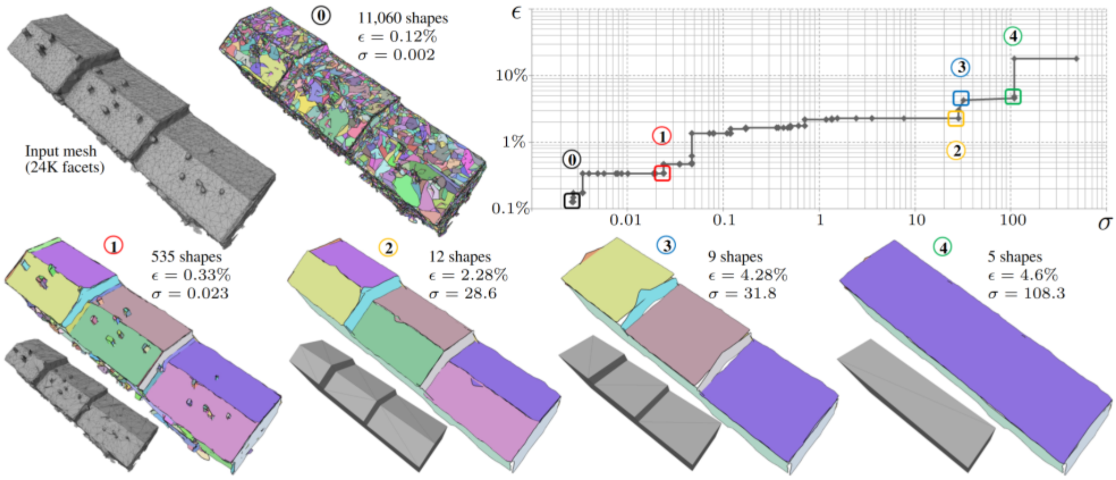


Figure 1. Planar shape detection at structural scales. Starting from 3D data (here a dense mesh generated by MultiView Stereo, top left), our algorithm produces a set of high-level representations with planar primitives (representations 1–4) describing the object at different representative structural scales (bottom). By progressively merging planar regions of an initial state (representation 0), one creates a sequence of representations whose further analysis allows for the extraction of a few structurally relevant representations (top right). Such shape representations can be used, for instance, as input for piecewise-planar reconstruction (see grey compact meshes). Note that each shape is displayed as a colored polygon computed as the α-shape of its inliers projected onto the shape.

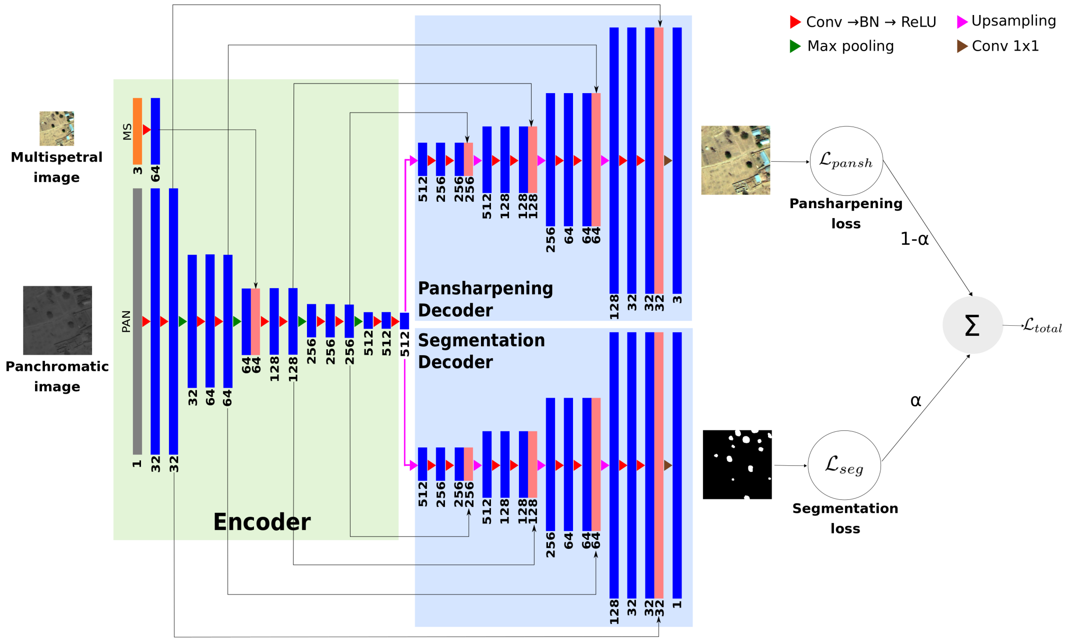


Figure 2. Overal framework for joint segmentation and pansharpening.

In spite of remarkable success of the convolutional neural networks on semantic segmentation, they suffer from catastrophic forgetting: a significant performance drop for the already learned classes when new classes are added on the data, having no annotations for the old classes. We propose an incremental learning methodology, enabling to learn segmenting new classes without hindering dense labeling abilities for the previous classes, although the entire previous data are not accessible. The key points of the proposed approach are adapting the network to learn new as well as old classes on the new training data, and allowing it to remember the previously learned information for the old classes. For adaptation, we keep a frozen copy of the previously trained network, which is used as a memory for the updated network in absence of annotations for the former classes. The updated network minimizes a loss function, which balances the discrepancy between outputs for the previous classes from the memory and updated networks, and the mis-classification rate between outputs for the new classes from the updated network and the new ground-truth. For remembering, we either regularly feed samples from the stored, little fraction of the previous data or use the memory network, depending on whether the new dat (see Fig. 3)a are collected from completely different geographic areas or from the same city. Our experimental results prove that it is possible to add new classes to the network, while maintaining its performance for the previous classes, despite the whole previous training data are not available. This work was submitted to IEEE Transactions on Geoscience and Remote Sensing (TGRS) and is currently on arXiV [25].

7.1.4. Multimodal Image Alignment through a Multiscale Chain of Neural Networks with Application to Remote Sensing

Participants: Nicolas Girard, Yuliya Tarabalka [contact].

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

Multimodal, Alignment, Registration, Remote sensing

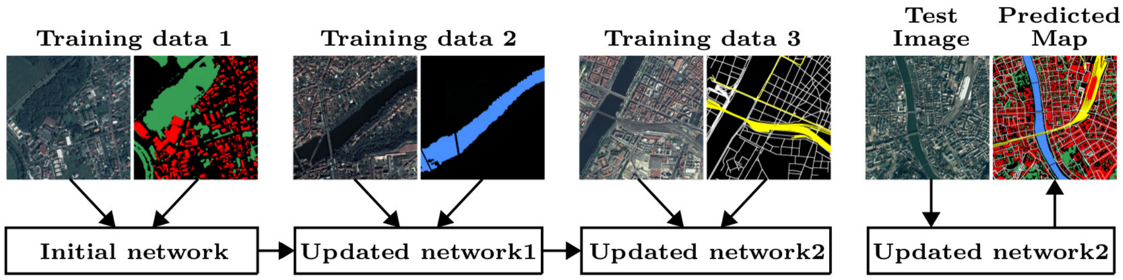


Figure 3. An example incremental learning scenario. Firstly, satellite images as well as their label maps for building and high vegetation classes are fed to the network. Then, from the second training data, the network learns water class without forgetting building and high vegetation classes. Finally, road and railway classes are taught to the network. Whenever new training data are obtained, we store only a small part of the previous ones for the network to remember. When a new test image comes, the network is able to detect all the classes.

We tackle here the problem of multimodal image non-rigid registration, which is of prime importance in remote sensing and medical imaging. The difficulties encountered by classical registration approaches include feature design and slow optimization by gradient descent. By analyzing these methods, we note the significance of the notion of scale. We design easy-to-train, fully-convolutional neural networks able to learn scale-specific features. Once chained appropriately, they perform global registration in linear time, getting rid of gradient descent schemes by predicting directly the deformation.

We show their performance in terms of quality and speed through various tasks of remote sensing multimodal image alignment. In particular, we are able to register correctly cadastral maps of buildings as well as road polylines onto RGB images, and outperform current keypoint matching methods (see Fig. 4). This work has been published in the proceedings of ECCV [20].

7.1.5. Aligning and Updating Cadaster Maps with Aerial Images by Multi-Task, Multi-Resolution Deep Learning

Participants: Nicolas Girard, Yuliya Tarabalka [contact].

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

Alignment, Registration, Multi-task, Multi-resolution

A large part of the world is already covered by maps of buildings, through projects such as OpenStreetMap. However when a new image of an already covered area is captured, it does not align perfectly with the buildings of the already existing map, due to a change of capture angle, atmospheric perturbations, human error when annotating buildings or lack of precision of the map data. Some of those deformations can be partially corrected, but not perfectly, which leads to misalignments. Additionally, new buildings can appear in the image. Leveraging multi-task learning, our deep learning model aligns the existing building polygons to the new image through a displacement output, and also detects new buildings that do not appear in the cadaster through a segmentation output (see Fig. 5). It uses multiple neural networks at successive resolutions to output a displacement field and a pixel-wise segmentation of the new buildings from coarser to finer scales. We also apply our method to buildings height estimation, by aligning cadaster data to the rooftops of stereo images.

7.2. Reconstruction

7.2.1. Kinetic Polygonal Partitioning of Images

Participants: Jean-Philippe Bauchet, Florent Lafarge [contact].

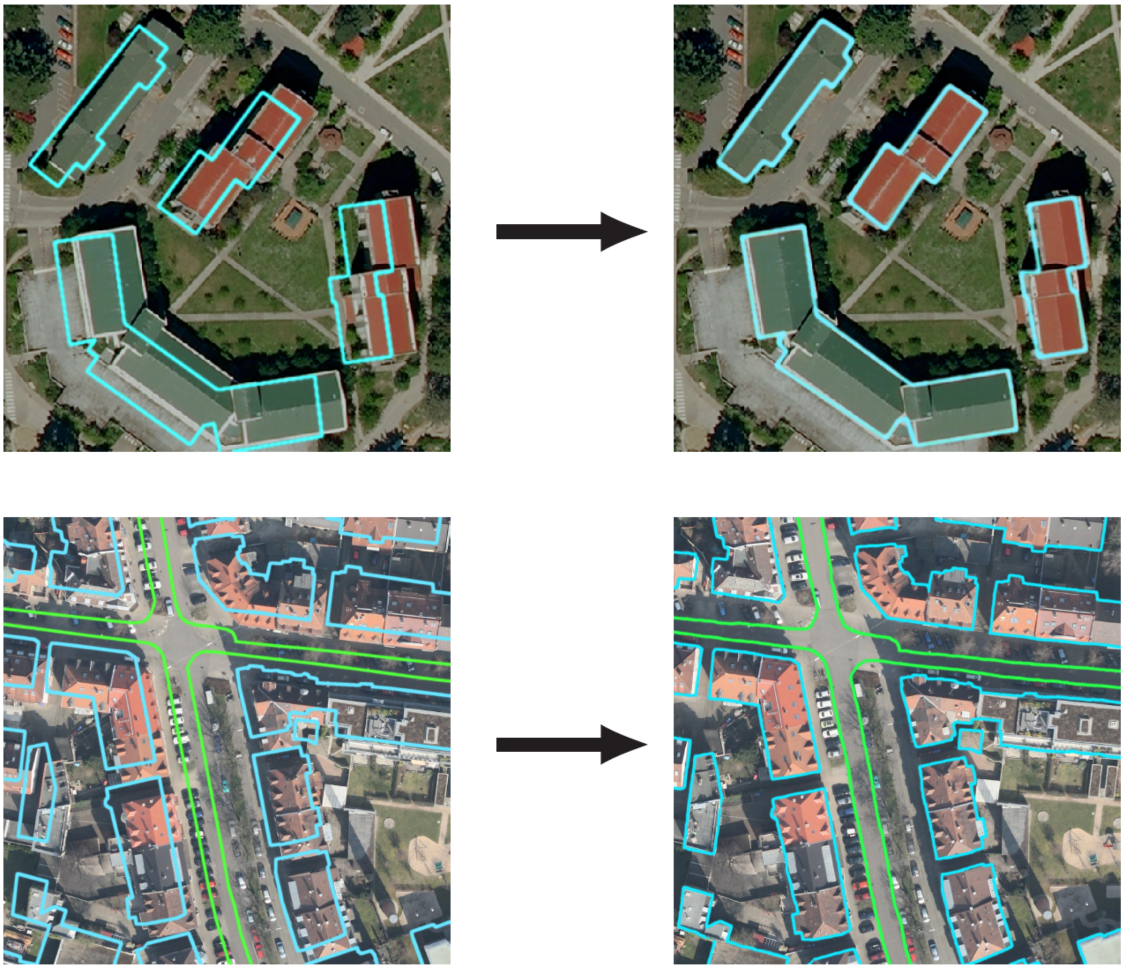


Figure 4. Multi-modal alignment.

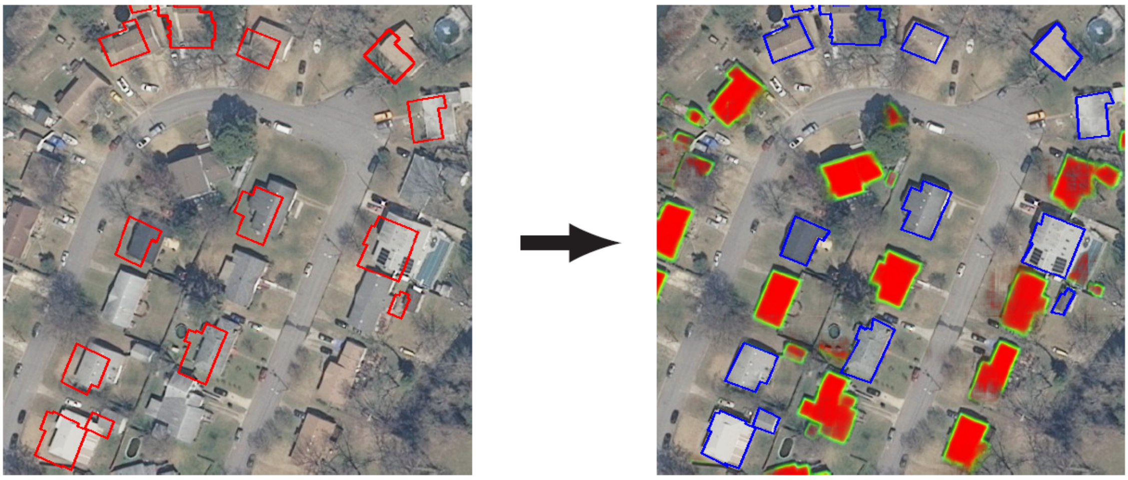


Figure 5. Multi-task learning with 2 tasks: multi-modal alignment and semantic segmentation.

Polygons, image segmentation, object contouring, kinetic framework

Recent works showed that floating polygons can be an interesting alternative to traditional superpixels, especially for analyzing scenes with strong geometric signatures, as man-made environments. Existing algorithms produce homogeneously-sized polygons that fail to capture thin geometric structures and over-partition large uniform areas. We propose a kinetic approach that brings more flexibility on polygon shape and size. The key idea consists in progressively extending pre-detected line-segments until they meet each other. Our experiments demonstrate that output partitions both contain less polygons and better capture geometric structures than those delivered by existing methods. We also show the applicative potential of the method when used as preprocessing in object contouring. Figure 6 illustrates the goal of our method. This work has been published in the proceedings of CVPR [15].

7.2.2. Polygonization of Binary Classification Maps Using Mesh Approximation with Right Angle Regularity

Participants: Onur Tasar, Pierre Alliez, Yuliya Tarabalka [contact].

Work in collaboration with Emmanuel Maggiori.

Polygonization, vectorization, remote sensing, classification maps, mesh approximation, right angles

One of the most popular and challenging tasks in remote sensing applications is the generation of digitized representations of Earth's objects from satellite raster image data. A common approach to tackle this challenge is a two-step method that first involves performing a pixel-wise classification of the raster data, then vectorizing the obtained classification map. We propose a novel approach, which recasts the polygonization problem as a mesh-based approximation of the input classification map, where binary labels are assigned to the mesh triangles to represent the building class. A dense initial mesh is decimated and optimized using local edge and vertex-based operators in order to minimize an objective function that models a balance between fidelity to the classification map in ℓ_1 norm sense, right angle regularity for polygonized buildings, and final mesh complexity (see Fig. 7). Experiments show that adding the right angle objective yields better representations quantitatively and qualitatively than previous work and commonly used polygon generalization methods in remote sensing literature for similar number of vertices. This work was published at IGARSS [19].

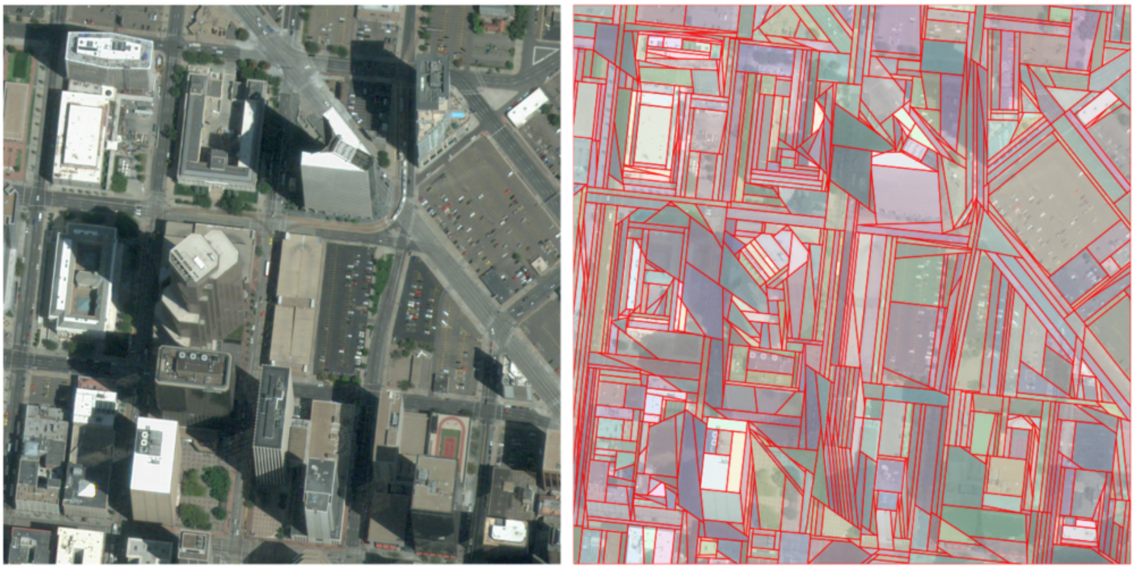
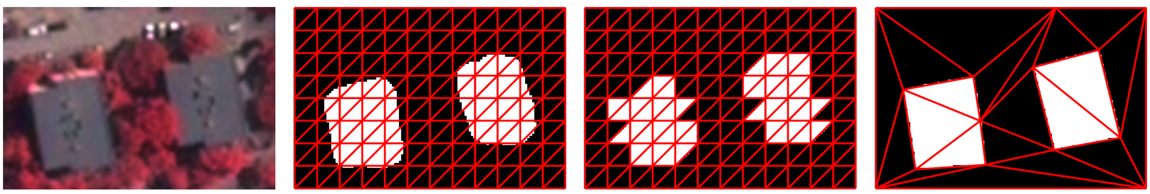


Figure 6. Kinetic partitioning into polygons. Our algorithm decomposes an image (left) into a partition of convex polygons (right). While superpixel-based methods impose homogeneously-sized regions, our polygons are more meaningful, capturing both large components and thin lineic structures that compose, for instance, urban scenes.



(a) (b) (c) (d)

Figure 7. Input image and example labeled meshes. (a) Input image, (b) Initial fine lattice, (c) Initial and (d) Optimized labeled triangle meshes. The triangles labeled as building are indicated by white.

7.2.3. End-to-End Learning of Polygons for Remote Sensing Image Classification

Participants: Nicolas Girard, Yuliya Tarabalka [contact].

High-resolution aerial images, polygon, vectorial, regression, deep learning, convolutional neural networks

While geographic information systems typically use polygonal representations to map Earth's objects, most state-of-the-art methods produce maps by performing pixelwise classification of remote sensing images, then vectorizing the outputs. This work studies if one can learn to directly output a vectorial semantic labeling of the image. We here cast a mapping problem as a polygon prediction task, and propose a deep learning approach which predicts vertices of the polygons outlining objects of interest. Experimental results on the Solar photovoltaic array location dataset show that the proposed network succeeds in learning to regress polygon coordinates, yielding directly vectorial map outputs (see Fig. 8). This work has been published in the proceedings of IGARSS [14].

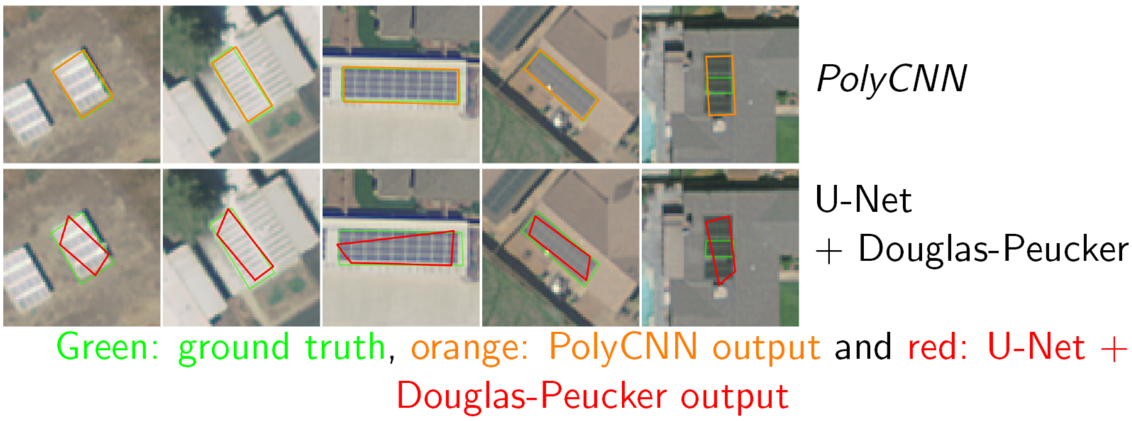


Figure 8. Results of polygon reconstruction with a deep neural network.

7.3. Approximation

7.3.1. Curved Optimal Delaunay Triangulation

Participants: Mathieu Desbrun, Pierre Alliez [contact].

Work in collaboration with Leman Feng (Ecole des Ponts ParisTech), Hervé Delingette (EPIONE) and Laurent Busé (AROMATH).

Higher-order meshing, Optimal Delaunay Triangulations, higher order finite elements, Bézier elements.

Meshes with curvilinear elements hold the appealing promise of enhanced geometric flexibility and higher-order numerical accuracy compared to their commonly-used straight-edge counterparts. However, the generation of curved meshes remains a computationally expensive endeavor with current meshing approaches: high-order parametric elements are notoriously difficult to conform to a given boundary geometry, and enforcing a smooth and non-degenerate Jacobian everywhere brings additional numerical difficulties to the meshing of complex domains. In this paper, we propose an extension of Optimal Delaunay Triangulations (ODT) to curved and graded isotropic meshes. By exploiting a continuum mechanics interpretation of ODT instead of the usual approximation theoretical foundations, we formulate a very robust geometry and topology optimization of Bézier meshes based on a new simple functional promoting isotropic and uniform Jacobians throughout the domain. We demonstrate that our resulting curved meshes can adapt to complex domains with high precision even for a small count of elements thanks to the added flexibility afforded by more control points and higher order basis functions (see Figure 9). This work has been published in the proceedings of ACM SIGGRAPH conference [12].

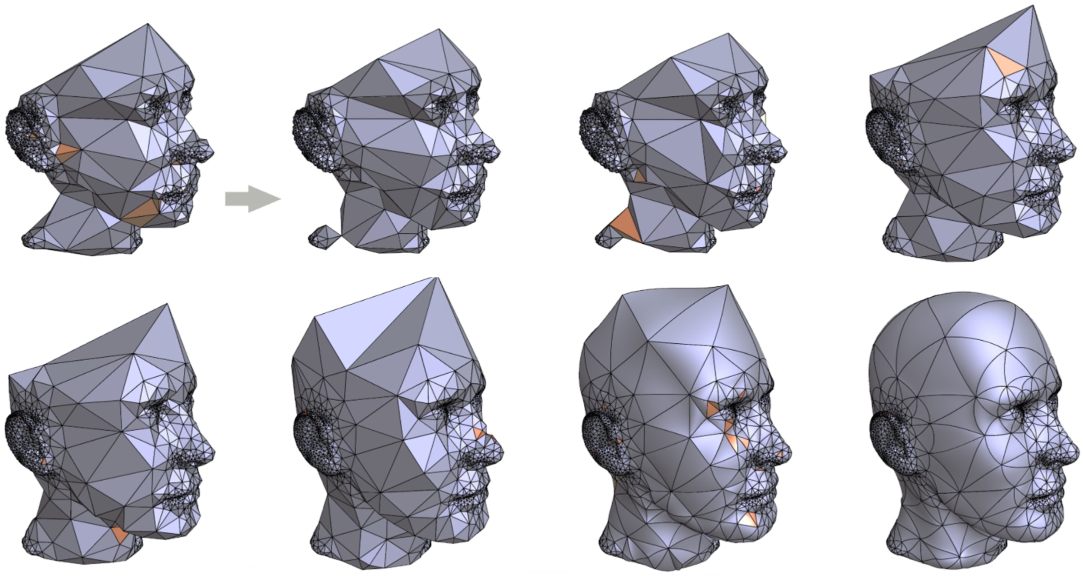


Figure 9. Generation of a curved optimal Delaunay triangulation.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Grants with Industry

8.1.1. Google Chrome University Research Programme

Participants: Pierre Alliez, Cédric Portaneri.

We developed a novel approach and software prototype for the compression of 3D models. Our main focus is on progressive compression of surface triangle meshes with color textures, with emphasis on fine grain, genericity and flexible metric. The proposed methodology is to turn the input models into a stream of refinements, in which both mesh and texture refinement details are multiplexed in accordance to rate-distortion principles. Fine grain is achieved through considering all components, local as well as non-local, from both the mesh and its textures: mesh complexity, vertex accuracy, texture definition and accuracy. We leveraged the recent advances on perceptual metrics to improve the visual appearance, and performed joint consolidation and encoding of the models to further optimize the rate-distortion tradeoffs and visual perception.

8.1.2. Dorea technology

Participants: Vincent Vadez, Pierre Alliez [contact].

In collaboration with SME Dorea Technology, our objective is to advance the knowledge on the thermal simulation of satellites, via geometric model reduction. The survival of a satellite is related to the temperature of its components, the variation of which must be controlled within safety intervals. In this context, the thermal simulation of the satellite for its design is crucial to anticipate the reality of its operation. The project started in August 2018, for a total duration of 3 years.

8.1.3. Luxcarta

Participants: Jean-Philippe Bauchet, Florent Lafarge [contact].

The goal of this collaboration is to design automated approaches for producing city models from the last generation of satellites. The models should conform to the level 2 (LOD2) of the popular CityGML format. The project started in October 2016, for a total duration of 3 years.

8.1.4. CNES and Acri-ST

Participants: Onur Tasar, Pierre Alliez, Yuliya Tarabalka [contact].

The aim is to devise efficient representations for satellite images. The project started in October 2017, for a total duration of 3 years.

8.1.5. CSTB

Participants: Hao Fang, Florent Lafarge [contact].

The goal of this recent collaboration is to develop methods for analyzing and exploring scale-spaces into urban 3D data. The project started in March 2016, for a total duration of 3 years.

9. Partnerships and Cooperations

9.1. National Initiatives

9.1.1. ANR

9.1.1.1. PISCO: Perceptual Levels of Detail for Interactive and Immersive Remote Visualization of Complex 3D Scenes

Participants: Pierre Alliez [contact], Flora Quilichini, Florent Lafarge.

The way of consuming and visualizing this 3D content is evolving from standard screens to Virtual and Mixed Reality (VR/MR). Our objective is to devise novel algorithms and tools allowing interactive visualization, in these constrained contexts (Virtual and Mixed reality, with local/remote 3D content), with a high quality of user experience. Partners: Inria, LIRIS INSA Lyon Institut National des Sciences Appiquées (coordinator), Laboratoire d'Informatique en Images et Systèmes d'Information LS2N Nantes University. Total budget 550 KE, 121 KE for TITANE. The project started in January 2018, for a total duration of 4 years.

9.1.1.2. LOCA-3D: Localization Orientation and 3D CArtography

Participants: Fernando Ireta Munoz, Florent Lafarge, Pierre Alliez [contact].

This project is part of the ANR Challenge MALIN LOCA-3D (Localization, orientation and 3D cartography). The challenge is to develop and experiment accurate location solutions for emergency intervention officers and security forces. These solutions must be efficient inside buildings and in conditions where satellite positioning systems do not work satisfactorily. Our solution is based on an advanced inertial system, where part of the inertial sensor drift is compensated by a vision system. Partners: SME INNODURA TB (coordinator), IBISC laboratory (Evry university) and Inria. Total budget: 700 KE, 157 KE for TITANE. The project started in January 2018, for a total duration of 4 years.

9.1.1.3. EPITOME: efficient representation to structure large-scale satellite images

Participants: Nicolas Girard, Yuliya Tarabalka [PI].

The goal of this young researcher project is to devise an efficient multi-scale vectorial representation, which would structure the content of large-scale satellite images. More specifically, we seek for a novel effective representation for large-scale satellite images, that would be generic, i.e., applicable for images worldwide and for a wide range of applications, and structure-preserving, i.e. best representing the meaningful objects in the image scene. To address this challenge, we plan to bridge the gap between advanced machine learning and geometric modeling tools to devise a multi-resolution vector-based representation, together with the methods for its effective generation and manipulation. Total budget: 225 KE for TITANE. The project started in October 2017, for a total duration of 4 years.

9.1.1.4. *Faults_R_GEMS: Properties of FAULTS, a key to Realistic Generic Earthquake Modeling and hazard Simulation*

Participants: Lionel Matteo, Yuliya Tarabalka.

The goal of the project is to study the properties of seismic faults, using advanced math tools including learning approaches. The project is in collaboration with Geoazur lab (coordinator), Arizona State University, CALTECH, Ecole Centrale Paris, ENS Paris, ETH Zurich, Geosciences Montpellier, IFSTTAR, IPGP Paris, IRSN Fontenay-aux-Roses, LJAD Nice, UNAVCO Colorado and Pisa University. The project started in October 2017, for a total duration of 4 years.

9.1.1.5. *BIOM: Building Indoor and Outdoor Modeling*

Participants: Muxingzi Li, Pierre Alliez, Florent Lafarge.

The BIOM project aims at automatic, simultaneous indoor and outdoor modelling of buildings from images and dense point clouds. We want to achieve a complete, geometrically accurate, semantically annotated but nonetheless lean 3D CAD representation of buildings and objects they contain in the form of a Building Information Models (BIM) that will help manage buildings in all their life cycle (renovation, simulation, deconstruction). The project is in collaboration with IGN (coordinator), Ecole des Ponts Paristech, CSTB and INSA-ICube. Total budget: 723 KE, 150 KE for TITANE. The project started in February 2018, for a total duration of 4 years.

9.2. European Initiatives

9.2.1. FP7 & H2020 Projects

9.2.1.1. *TITANIUM - Software Components for Robust Geometry Processing*

ERC Proof of concept grant TITANIUM “Software Components for Robust Geometry Processing” (2017-2018), total 150 KE. Principal investigator: Pierre Alliez. Partner: Inria Spin-off Geometry Factory. Participants: Florent Lafarge, Dmitry Anisimov, Simon Giraudot and Andreas Fabri. We developed a software demonstrator for geometry processing and 3D urban modeling, in order to facilitate the pre-commercialization of novel software components for the CGAL Library. The outcome of TITANIUM is a versatile method for semantic classification of 3D point clouds and for semantic-aware reconstruction of urban scenes (in preparation).

9.3. International Initiatives

9.3.1. Inria International Partners

9.3.1.1. *Declared Inria International Partners*

We collaborated with Mathieu Desbrun from Caltech, David Bommes from Bern University (Switzerland), Gianmarco Cherchi and Riccardo Scateni from University of Cagliary (Sardinia).

9.4. International Research Visitors

9.4.1. Visits of International Scientists

- Mathieu Desbrun, Professor at Caltech, visited us from September to mid November.
- Michael Hemmer, research engineer at Google, visited us in December.
- Jorg Peters, Professor at University of Florida, visited us in October.

9.4.1.1. *Internships*

- Tong Zhao (Ecole des ponts ParisTech): geometric descriptors and robust principal component analysis. In collaboration with Mathieu Desbrun from Caltech.

- Vasudha Varadarajan (Birla Institute of Technology and Science, India): shape reconstruction using binary programming.
- Andrew Khalel (Cairo University, Egypt): Multi-task deep learning for simultaneous satellite image segmentation and pan-sharpening. In collaboration with Guillaume Charpiat.
- Andrii Zhygallo (TUM, Germany): Using deep learning for change detection from remote sensing images.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Organisation

10.1.1.1. Member of the Organizing Committees

- Pierre Alliez: advisory committee of the EUROGRAPHICS annual conference 2018.
- Yuliya Tarabalka: Scientific Advisory Committee of the 2nd International Electronic Conference on Remote Sensing.

10.1.2. Scientific Events Selection

10.1.2.1. Chair of Conference Program Committees

Pierre Alliez is full paper co-chair of

- EUROGRAPHICS 2019 conference, organized in Genova, May 2019.
- Solid and Physical Modeling 2019, organized in Vancouver, June 2019.

10.1.2.2. Member of the Conference Program Committees

- Pierre Alliez: EUROGRAPHICS Symposium on Geometry Processing, International Conference on Geometric Modeling and Processing, Shape Modeling International, EUROGRAPHICS Workshop on Graphics and Cultural Heritage.
- Florent Lafarge: Area chair of Asian Conference on Computer Vision (ACCV)
- Yuliya Tarabalka: SPIE in Remote Sensing conference, ACIVS conference.

10.1.3. Journal

10.1.3.1. Member of the Editorial Boards

- Pierre Alliez: associate editor of Computer Graphics Forum, Computer-Aided Geometric Design and Graphical Models. He is also a member of the editorial board of the CGAL open source project.
- Florent Lafarge: associate editor of The Visual Computer since 2015.
- Yuliya Tarabalka: associate editor for IEEE Transactions on image processing since 2018, Springer journal Sensing and Imaging since 2017, the International Journal of Computing since 2017 and journal Remote Sensing since 2017.

10.1.3.2. Reviewer - Reviewing Activities

- Pierre Alliez: reviewer for ACM Transactions on Graphics, ACM Siggraph conference, ACM Siggraph Asia conference, Computer Graphics Forum, CAGD, CAD, Symposium on Geometry Processing, Eurographics workshop on cultural heritage, Geometric Modeling and Processing, Shape Modeling International.
- Florent Lafarge: reviewer for the ISPRS journal of Remote Sensing and Photogrammetry.
- Yuliya Tarabalka: reviewer for the journals IEEE PAMI, IEEE TIP, IEEE TGRS, conferences IEEE IGARSS (student competition selection committee), ACIVS, SPIE, ECRS.

10.1.4. Invited Talks

- Pierre Alliez: invited talk at the Einstein Workshop on Geometry and Physics in Computer Graphics, organized in Berlin.
- Yuliya Tarabalka: keynote at the ACIVS 2018 conference (Advanced Concepts for Intelligent Vision Systems, Poitiers), TERRADATA workshop (Paris, 2018), conference "Challenges for imaging and modeling complex media and processes: The Earth's interior and earthquake rupture" (Sophia Antipolis, 2018). She also gave an invited tutorial on machine learning at IEEE IGARSS 2018 conference.

10.1.5. Leadership within the Scientific Community

Pierre Alliez is a member of the Steering Committees of the EUROGRAPHICS Symposium on Geometry Processing, EUROGRAPHICS Workshop on Graphics and Cultural Heritage and Executive Board Member for the Solid Modeling Association.

10.1.6. Scientific Expertise

- Pierre Alliez: reviewer for the European commission (two EU projects), ERC, evaluator for the French ANR, Belgium FNRS, Innovation Fund Denmark.
- Yuliya Tarabalka: expert evaluator for the ANR proposals and "Make Our Planet Great Again" CampusFrance proposals.

10.1.7. Research Administration

- Pierre Alliez: member of the scientific committee of the 3IA Côte d'Azur proposal.
- Yuliya Tarabalka: member of the scientific committee of the Academy 3 of the University Cote d'Azur since 2017.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

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

Master: Pierre Alliez and Florent Lafarge, Ingeniérie 3D, 21h, M2, university Nice Sophia Antipolis, France.

Master: Pierre Alliez and Florent Lafarge, Interpolation, 60h, M1, university Nice Sophia Antipolis, France.

Master: Pierre Alliez and Florent Lafarge, Mathématiques pour la géométrie, 30h, M1, EFREI, France.

Master: Florent Lafarge, Traitement d'images numériques, 6h, M2, university Nice Sophia Antipolis, France.

Master: Yuliya Tarabalka, Discrete inference and learning, 12h, M2 MVA, ENS Paris-Saclay & CentraleSupelec, France.

Master: Yuliya Tarabalka, Mathematical methods, 25h, MSc in data sciences and business analytics ESSEC-CS, CentraleSupelec, France.

Licence: Yuliya Tarabalka, Advanced algorithms, 28.5h, L2 Networks and Telecoms, IUT Nice Côte d'Azur, France.

10.2.2. Supervision

PhD defended:

Jean-Dominique Favreau, Compact image vectorization by stochastic approaches, Université Côte d'Azur, defended March 15 [11], Florent Lafarge and Adrien Bousseau.

PhDs in progress:

Hao Fang, Scale-space understanding in urban scenes, since March 2016, Florent Lafarge.

Jean-Philippe Bauchet, City modelling from high resolution satellite images, since October 2016, Florent Lafarge.

Lionel Matteo: From Pleiades images to very high resolution topography in complex zones, since September 2017, Yuliya Tarabalka and Isabelle Manighetti.

Onur Tasar, Using deep learning approaches to devise an efficient representation for large-scale satellite images, since October 2017, Yuliya Tarabalka and Pierre Alliez.

Nicolas Girard, How to structure satellite data, since November 2017, Yuliya Tarabalka.

Flora Quilichini, Geometry Compression, since January 2018, Pierre Alliez and Guillaume Lavoué (INSA Lyon).

Muxingzi Li, Image-based 3D reconstruction of indoor environments, since February 2018, Florent Lafarge and Renaud Marlet (ENPC).

Vincent Vadez, Geometric simplification of satellites for thermal simulation, since August 2018, Pierre Alliez.

10.2.3. Juries

Pierre Alliez:

- Thesis committee and president: Arnaud Bletterer (I3S Sophia Antipolis).
- HDR committee and president: Stefanie Wuhrer (Inria Grenoble).
- Comité de suivi doctoral: Simon Rodriguez (Inria Sophia Antipolis).
- Comité de suivi doctoral: Julien Renaudeau (Schlumberger).
- Comité de suivi doctoral: Oussama Ennafii (IGN).

Florent Lafarge:

- Thesis reviewer: Hassan Bouchiba (Ecole des Mines Paristech).

Yuliya Tarabalka:

- Thesis committee: Hariprasad Kannan (University Paris-Saclay), Nicolas Audebert (University Bretagne Sud and ONERA).
- Thesis reviewer: Praveer Singh (University Paris-Est), Lloyd Windrim (University of Sydney).

10.3. Popularization

Yuliya Tarabalka gave a seminar for the academic-industrial event “Les rendez-vous Université Côte d’Azur-Entreprise”, May 2018.

10.3.1. Internal or external Inria responsibilities

Pierre Alliez is head of science of the Inria Sophia Antipolis Center since September 2018, and member of the Inria evaluation committee.

10.3.2. Interventions

- Pierre Alliez gave a seminar and demo for the “fête de la science”, October 7th.

11. Bibliography

Major publications by the team in recent years

[1] D. Bommes, M. Campen, H.-C. Ebke, P. Alliez, L. Kobbelt. *Integer-Grid Maps for Reliable Quad Meshing*, in "ACM Transactions on Graphics", July 2013, vol. 32, n^{o} 4, https://hal.inria.fr/hal-00862648

[2] L. DUAN, F. LAFARGE. *Towards large-scale city reconstruction from satellites*, in "European Conference on Computer Vision (ECCV)", Amsterdam, Netherlands, October 2016, https://hal.inria.fr/hal-01352466

[3] J.-D. FAVREAU, F. LAFARGE, A. B. BOUSSEAU. *Photo2ClipArt: Image Abstraction and Vectorization Using Layered Linear Gradients*, in "ACM Transactions on Graphics", 2017, vol. 36, n^{o} 6, https://hal.inria.fr/hal-01581981

[4] S. GIRAUDOT, D. COHEN-STEINER, P. ALLIEZ. *Noise-Adaptive Shape Reconstruction from Raw Point Sets*, in "Computer Graphics Forum, Proceedings of EUROGRAPHICS Symposium on Geometry Processing", 2013, vol. 32, n^{o} 5, pp. 229-238 [*DOI :* 10.1111/CGF.12189], https://hal.inria.fr/hal-00844472

[5] F. LAFARGE, P. ALLIEZ. *Surface Reconstruction through Point Set Structuring*, in "Computer Graphics Forum (Proceedings of Eurographics 2013)", May 2013, vol. 32, n^{o} 2, pp. 225-234, https://hal.inria.fr/hal-00822763

[6] E. MAGGIORI, Y. TARABALKA, G. CHARPIAT, P. ALLIEZ. *High-Resolution Semantic Labeling with Convolutional Neural Networks*, in "IEEE Transactions on Geoscience and Remote Sensing", December 2017, https://hal.inria.fr/hal-01393279

[7] E. MAGGIORI, Y. TARABALKA, G. CHARPIAT. *Improved Partition Trees for Multi-Class Segmentation of Remote Sensing Images*, in "2015 IEEE International Geoscience and Remote Sensing Symposium - IGARSS 2015", Milan, Italy, IEEE, July 2015, https://hal.inria.fr/hal-01182772

[8] M. MANDAD, D. COHEN-STEINER, L. KOBBELT, P. ALLIEZ, M. DESBRUN. *Variance-Minimizing Transport Plans for Inter-surface Mapping*, in "ACM Transactions on Graphics", 2017, vol. 36, 14 p. [*DOI :* 10.1145/3072959.3073671], https://hal.inria.fr/hal-01519006

[9] Y. VERDIE, F. LAFARGE, P. ALLIEZ. *LOD Generation for Urban Scenes*, in "ACM Transactions on Graphics", 2015, vol. 34, n^{o} 3, 15 p. , https://hal.inria.fr/hal-01113078

[10] Y. VERDIE, F. LAFARGE. *Detecting parametric objects in large scenes by Monte Carlo sampling*, in "International Journal of Computer Vision", January 2014, vol. 106, n^{o} 1, pp. 57-75 [*DOI :* 10.1007/s11263-013-0641-0], https://hal.inria.fr/hal-00843022

Publications of the year

Doctoral Dissertations and Habilitation Theses

[11] J.-D. FAVREAU. *Compact image vectorization by stochastic approaches*, Université Côte d'Azur, March 2018, https://tel.archives-ouvertes.fr/tel-01818515

Articles in International Peer-Reviewed Journals

[12] L. FENG, P. ALLIEZ, L. BUSÉ, H. DELINGETTE, M. DESBRUN. *Curved Optimal Delaunay Triangulation*, in "ACM Transactions on Graphics", August 2018, vol. 37, n^{o} 4 [*DOI :* 10.1145/3197517.3201358], https://hal.inria.fr/hal-01826055

[13] P. GHAMISI, E. MAGGIORI, S. LI, R. SOUZA, Y. TARABALKA, G. MOSER, A. DE GIORGI, L. FANG, Y. CHEN, M. CHI, S. B. SERPICO, J. A. BENEDIKTSSON. *Frontiers in Spectral-Spatial Classification of Hyperspectral Images*, in "IEEE geoscience and remote sensing magazine", September 2018, vol. 6, n^{o} 3, pp.

10-43, This is a preprint, to read the final version please go to IEEE Geoscience and Remote Sensing Magazine on IEEE XPlore [*DOI :* 10.1109/MGRS.2018.2854840], https://hal.archives-ouvertes.fr/hal-01854061

Invited Conferences

[14] N. GIRARD, Y. TARABALKA. *End-to-End Learning of Polygons for Remote Sensing Image Classification*, in "IEEE International Geoscience and Remote Sensing Symposium – IGARSS 2018", Valencia, Spain, July 2018, https://hal.inria.fr/hal-01762446

International Conferences with Proceedings

[15] J.-P. BAUCHET, F. LAFARGE. *KIPPI: KInetic Polygonal Partitioning of Images*, in "IEEE Conference on Computer Vision and Pattern Recognition (CVPR)", Salt Lake City, United States, June 2018, https://hal.inria.fr/hal-01740958

[16] H. FANG, F. LAFARGE, M. DESBRUN. *Planar Shape Detection at Structural Scales*, in "IEEE Conference on Computer Vision and Pattern Recognition (CVPR)", Salt Lake City, United States, 2018, https://hal.inria.fr/hal-01741650

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[19] O. TASAR, E. MAGGIORI, P. ALLIEZ, Y. TARABALKA. *Polygonization of binary classification maps using mesh approximation with right angle regularity* , in "IEEE International Geoscience and Remote Sensing Symposium - IGARSS 2018", Valencia, Spain, July 2018, https://hal.inria.fr/hal-01765155

[20] A. ZAMPIERI, G. CHARPIAT, N. GIRARD, Y. TARABALKA. *Multimodal image alignment through a multiscale chain of neural networks with application to remote sensing*, in "European Conference on Computer Vision (ECCV)", Munich, Germany, V. FERRARI, M. HEBERT, C. SMINCHISESCU, Y. WEISS (editors), Computer Vision – ECCV 2018, Springer International Publishing, September 2018, pp. 679-696, https://hal.inria.fr/hal-01849389

Conferences without Proceedings

[21] N. GIRARD, G. CHARPIAT, Y. TARABALKA. *Aligning and Updating Cadaster Maps with Aerial Images by Multi-Task, Multi-Resolution Deep Learning*, in "Asian Conference on Computer Vision (ACCV)", Perth, Australia, December 2018, https://hal.archives-ouvertes.fr/hal-01923568

[22] S. LEFÈVRE, O. TASAR, D. SHEEREN. *Combining multiple segmentations through a flexible framework*, in "GEOBIA 2018 - From pixels to ecosystems and global sustainability ", Montpellier, France, Centre d'Etudes Spatiales de la BIOsphère (CESBIO) and Office national d'études et de recherches aérospatiales (ONERA) and Espace pour le développement (ESPACE DEV) and Société T.E.T.I.S, June 2018, http://hal.univ-reunion.fr/hal-01958983

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Other Publications

[24] O. ENNAFII, A. LE-BRIS, F. LAFARGE, C. MALLET. *Semantic evaluation of 3D city models*, September 2018, working paper or preprint, https://hal.archives-ouvertes.fr/hal-01875781

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