RESEARCH CENTRE

Grenoble - Rhône-Alpes

2020
ACTIVITY REPORT

Project-Team

ELAN

modELing the Appearance of Nonlinear phenomena

IN COLLABORATION WITH: Laboratoire Jean Kuntzmann (LJK)

DOMAIN

Applied Mathematics, Computation and Simulation

THEME

Numerical schemes and simulations

Contents

Project-Team ELAN

Creation of the Project-Team: 2017 October 01

Keywords

Computer sciences and digital sciences

- A2.5. – Software engineering
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Other research topics and application domains

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- B3.3.1. – Earth and subsoil
- B5.5. – Materials
- B9.2.2. – Cinema, Television
- B9.5.3. – Physics
- B9.5.5. – Mechanics

1 Team members, visitors, external collaborators

Research Scientists

- Florence Descoubes [Team leader, Inria, Senior Researcher, HDR]
- Thibaut Metivet [Inria, Researcher]

Post-Doctoral Fellow

- Gauthier Rousseau [Inria, until Apr 2020]

PhD Students

- Raphael Charrondiere [Univ Grenoble Alpes]
- Mickael Ly [Inria]
- Nicolas Parent [Inria, from Oct 2020]
- Abdullah Haroon Rasheed [Inria]

Technical Staff

- Laurence Boissieux [Inria, Engineer]
- Victor Romero Gramegna [Inria, Engineer]

Interns and Apprentices

- Louis Guillet [Inria, until Jan 2020]
- Emile Hohnadel [École Normale Supérieure de Lyon, from Sep 2020]
- Jean Jouve [École normale supérieure de Rennes, until Jan 2020]

Administrative Assistant

- Julia Di Toro [Inria, from Oct 2020]

2 Overall objectives

ELAN is a young research team of Inria and Laboratoire Jean Kuntzmann (UMR 5224), with an original positioning across Computer Graphics and Computational Mechanics. The team is focussed on the design of predictive, robust, efficient, and controllable numerical models for capturing the shape and motion of visually rich mechanical phenomena, such as the buckling of an elastic ribbon, the flowing of sand, or the entangling of large fiber assemblies. Target applications encompass the digital entertainment industry (e.g., feature film animation, special effects), as well as virtual prototyping for the mechanical engineering industry (e.g., aircraft manufacturing, cosmetology); though very different, these two application fields require predictive and scalable models for capturing complex mechanical phenomena at the macroscopic scale. An orthogonal objective is the improvement of our understanding of natural physical and biological processes involving slender structures and frictional contact, through active collaborations with soft matter physicists. To achieve its goals, the team strives to master as finely as possible the entire modeling pipeline, involving a pluridisciplinary combination of scientific skills across Mechanics and Physics, Applied Mathematics, and Computer Science.

3 Research program

3.1 Discrete modeling of slender elastic structures

For the last 15 years, we have investigated new discrete models for solving the Kirchhoff dynamic equations for thin elastic rods [11, 12, 16]. All our models share a curvature-based spatial discretization, allowing them to capture inextensibility of the rod intrinsically, without the need for adding any kinematic constraint. Moreover, elastic forces boil down to linear terms in the dynamic equations, making them well-suited for implicit integration. Interestingly, our discretization methodology can be interpreted from two different points-of-views. From the finite-elements point-of-view, our strain-based discrete schemes can be seen as discontinuous Galerkin methods of zero and first orders. From the multibody system dynamics point of view, our discrete models can be interpreted as deformable Lagrangian systems in finite dimension, for which a dedicated community has started to grow recently [37]. We note that adopting the multibody system dynamics point of view helped us formulate a linear-time integration scheme [10], which had only be investigated in the case of multibody rigid bodies dynamics so far.

High-order spatial discretization schemes for rods, ribbons and shells Our goal is to investigate similar high-order modeling strategies for surfaces, in particular for the case of inextensible ribbons and shells. Elastic ribbons have been scarcely studied in the past, but they are nowadays drawing more and more the attention from physicists [26, 35]. Their numerical modeling remains an open challenge. In contrast to ribbons, a huge litterature exists for shells, both from a theoretical and numerical viewpoints (see, e.g., [30, 17]). However, no real consensus has been obtained so far about a unified nonlinear shell theory able to support large displacements. In [14] we have started building an inextensible shell patch by taking as degrees of freedom the curvatures of its mid-surface, expressed in the local frame. As in the super-helix model, we show that when taking curvatures uniform over the element, each term of the equations of motion may be computed in closed-form; besides, the geometry of the element corresponds to a cylinder patch at each time step. Compared to the 1D (rod) case however, some difficulties arise in the 2D (plate/shell) case, where compatibility conditions are to be treated carefully.

Numerical continuation of rod equilibria in the presence of unilateral constraints In Alejandro Blumentals' PhD thesis [13], we have adopted an optimal control point of view on the static problem of thin elastic rods, and we have shown that direct discretization methods [1] are particularly well-suited for dealing with scenarios involving both bilateral and unilateral constraints (such as contact). We would like to investigate how our formulations extend to continuation problems, where the goal is to follow a certain branch of equilibria when the rod is subject to some varying constraints (such as one fixed end being applied a constant rotation). To the best of our knowledge, classical continuation methods used for rods [27] are not able to deal with non-persistent or sliding contact.

3.2 Discrete and continuous modeling of frictional contact

Most popular approaches in Computer Graphics and Mechanical Engineering consist in assuming that the objects in contact are locally compliant, allowing them to slightly penetrate each other. This is the principle of penalty-based methods (or molecular dynamics), which consists in adding mutual repulsive forces of the form $k\,f(\delta)$, where δ is the penetration depth detected at current time step [18, 34]. Though simple to implement and computationally efficient, the penalty-based method often fails to prevent excessive penetration of the contacting objects, which may prove fatal in the case of thin objects as those may just end up traversing each other. One solution might be to set the stiffness factor k to a large enough value, however this causes the introduction of parasitical high frequencies and calls for very small integration steps [9]. Penalty-based approaches are thus generally not satisfying for ensuring robust contact handling.

In the same vein, the friction law between solid objects, or within a yield-stress fluid (used to model foam, sand, or cement, which, unlike water, cannot flow beyond a certain threshold), is commonly modeled using a regularized friction law (sometimes even with simple viscous forces), for the sake of

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[1] Within this optimal control framework, our previous curvature-based methods can actually be interpreted as a special case of direct single shooting methods.

simplicity and numerical tractability (see e.g., [36, 29]). Such a model cannot capture the threshold effect that characterizes friction between contacting solids or within a yield-stress fluid. The nonsmooth transition between sticking and sliding is however responsible for significant visual features, such as the complex patterns resting on the outer surface of hair, the stable formation of sand piles, or typical stick-slip instabilities occurring during motion.

The search for a realistic, robust and stable frictional contact method encouraged us to depart from those, and instead to focus on rigid contact models coupled to the exact nonsmooth Coulomb law for friction (and respectively, to the exact nonsmooth Drucker-Prager law in the case of a fluid), which better integrate the effects of frictional contact at the macroscopic scale. This motivation was the sense of the hiring of F. Bertails-Descoubes in 2007 in the Inria/LJK BIPOP team, specialized in nonsmooth mechanics and related convex optimization methods. In the line of F. Bertails-Descoubes's work performed in the BIPOP team, the ELAN team keeps on including some active research on the finding of robust frictional contact algorithms specialized for slender deformable structures.

Optimized algorithms for large nodal systems in frictional contact In the fiber assembly case, the resulting mass matrix M is block-diagonal, so that the Delassus operator can be computed in an efficient way by leveraging sparse-block computations [20]. This justifies solving the reduced discrete frictional contact problem where primary unknowns are forces, as usually advocated in nonsmooth mechanics [32]. For cloth however, where primal variables (nodal velocities of the cloth mesh) are all interconnected via elasticity through implicit forces, the method developed above is computationally inefficient. Indeed, the matrix M (only block-sparse, but not block-diagonal) is costly to invert for large systems and its inverse is dense. Recently, we have leveraged the fact that generalized velocities of the system are 3D velocities, which simplifies the discrete contact problem when contacts occur at the nodes. Combined with a multiresolution strategy, we have devised an algorithm able to capture exact Coulomb friction constraints at contact, while retaining computational efficiency [33]. This work also supports cloth self-contact and cloth multilayering. How to enrich the interaction model with, e.g., cohesion, remains an open question. The experimental validation of our frictional contact model is also one of our goals in the medium run.

Continuum modeling of granular and fibrous media Though we have recently made progress on the continuum formulation and solving of granular materials in Gilles Daviet's PhD thesis [19, 22, 21], we are still far from a continuum description of a macroscopic dry fibrous medium such as hair. One key ingredient that we have not been considering in our previous models is the influence of air inside divided materials. Typically, air plays a considerable role in hair motion. To advance in that direction, we have started to look at a diphasic fluid representation of granular matter, where a Newtonian fluid and the solid phase are fully coupled, while the nonsmooth Drucker-Prager rheology for the solid phase is enforced implicitly [23]. This first approach could be a starting point for modeling immersed granulars in a liquid, or ash clouds, for instance.

A long path then remains to be achieved, if one wants to take into account long fibers instead of isotropic grains in the solid phase. How to couple the fiber elasticity with our current formulation remains a challenging problem.

3.3 Inverse design of slender elastic structures [ERC GEM]

With the considerable advance of automatic image-based capture in Computer Vision and Computer Graphics these latest years, it becomes now affordable to acquire quickly and precisely the full 3D geometry of many mechanical objects featuring intricate shapes. Yet, while more and more geometrical data get collected and shared among the communities, there is currently very little study about how to infer the underlying mechanical properties of the captured objects merely from their geometrical configurations.

An important challenge consists in developing a non-invasive method for inferring the mechanical properties of complex objects from a minimal set of geometrical poses, in order to predict their dynamics. In contrast to classical inverse reconstruction methods, our claim is that 1/ the mere geometrical shape of physical objects reveals a lot about their underlying mechanical properties and 2/ this property can be fully leveraged for a wide range of objects featuring rich geometrical configurations, such as slender structures subject to contact and friction (e.g., folded cloth or twined filaments).

In addition to significant advances in fast image-based measurement of diverse mechanical materials stemming from physics, biology, or manufacturing, this research is expected in the long run to ease considerably the design of physically realistic virtual worlds, as well as to boost the creation of dynamic human doubles.

To achieve this goal, we shall develop an original inverse modeling strategy based upon the following research topics:

Design of well-suited discrete models for slender structures We believe that the quality of the upstream, reference physics-based model is essential to the effective connection between geometry and mechanics. Typically, such a model should properly account for the nonlinearities due to large displacements of the structures, as well as to the nonsmooth effects typical of contact and friction.

It should also be parameterized and discretized in such a way that inversion gets simplified mathematically, possibly avoiding the huge cost of large and nonconvex optimization. In that sense, unlike concurrent methods which impose inverse methods to be compatible with a generic physics-based model, we instead advocate the design of specific physics-based models which are tailored for the inversion process.

More precisely, from our experience on fiber modeling, we believe that reduced Lagrangian models, based on a minimal set of coordinates and physical parameters (as opposed to maximal coordinates models such as mass-springs), are particularly well-suited for inversion and physical interpretation of geometrical data [25, 24]. Furthermore, choosing a high-order coordinate system (e.g., curvatures instead of angles) allows for a precise handling of curved boundaries and contact geometry, as well as the simplification of constitutive laws (which are transformed into a linear equation in the case of rods). We are currently investigating high-order discretization schemes for elastic ribbons and developable shells [14].

Static inversion of physical objects from geometrical poses We believe that pure static inversion may by itself reveal many insights regarding a range of parameters such as the undeformed configuration of the object, some material parameters or contact forces.

The typical settings that we consider is composed of, on the one hand, a reference mechanical model of the object of interest, and on the other hand a single or a series of complete geometrical poses corresponding each to a static equilibrium. The core challenge consists in analyzing theoretically and practically the amount of information that can be gained from one or several geometrical poses, and to understand how the fundamental under-determinacy of the inverse problem can be reduced, for each unknown quantity (parameter or force) at play. Both the equilibrium condition and the stability criterion of the equilibrium are leveraged towards this goal. On the theoretical side, we have recently shown that a given 3D curve always matches the centerline of an isotropic suspended Kirchhoff rod at equilibrium under gravity, and that the natural configuration of the rod is unique once material parameters (mass, Young modulus) are fixed [1]. On the practical side, we have recently devised a robust algorithm to find a valid natural configuration for a discrete shell to match a given surface under gravity and frictional contact forces [3]. Unlike rods however, shells can have multiple inverse (natural) configurations. Choosing among the multiple solutions based on some selection criteria is an open challenge. Another open issue, in all cases, is the theoretical characterization of material parameters allowing the equilibrium to be stable.

Dynamic inversion of physical objects from geometrical poses To refine the solution subspaces searched for in the static case and estimate dynamic parameters (e.g., some damping coefficients), a dynamic inversion process accounting for the motion of the object of interest is necessary.

In contrast to the static case where we can afford to rely on exact geometrical poses, our analysis in the dynamic case will have to take into account the imperfect quality of input data with possible missing parts or outliers. One interesting challenge will be to combine our high-order discretized physics-based model together with the acquisition process in order to refine both the parameter estimation and the geometrical acquisition.

Experimental validation with respect to real data The goal will be to confront the theories developed above to real experiments. Compared to the statics, the dynamic case will be particularly involving as it will be highly dependent on the quality of input data as well as the accuracy of the motion predicted by our physics-based simulators. Such experiments will not only serve to refine our direct and inverse models, but will also be leveraged to improve the 3D geometrical acquisition of moving objects. Besides, once validation will be performed, we shall work on the setting up of new non-invasive measurement protocols to acquire physical parameters of slender structures from a minimal amount of geometrical configurations.

4 Application domains

4.1 Mechanical Engineering

Many physicists and mathematicians have strived for centuries to understand the principles governing those complex mechanical phenomena, providing a number of continuous models for slender structures, granular matter, and frictional contact. In the XX^{th} century, industrial applications such as process automatization and new ways of transportation have boosted the fields of Mechanical Engineering and Computer-Aided Design, where material strength, reliability of mechanisms, and safety, standed for the main priorities. Instead, large displacements of structures, buckling, tearing, or entanglement, and even dynamics, were long considered as undesirable behaviors, thus restraining the search for corresponding numerical models.

Only recently, the engineering industry has shown some new and growing interest into the modeling of dynamic phenomena prone to large displacements, contact and friction. For instance, the cosmetology industry is more and more interested in understanding the nonlinear deformation of hair and skin, with the help of simulation. Likewise, auto and aircraft manufacturers are facing new challenges involving buckling or entanglement of thin structures such as carbon or optical fibers; they clearly lack predictive, robust and efficient numerical tools for simulating and optimizing their new manufacturing process, which share many common features with the large-scale simulation scenarii traditionally studied in Computer Graphics applications.

4.2 Computer Graphics

In contrast, Computer Graphics, which has emerged in the 60's with the advent of modern computers, was from the very beginning eager to capture such peculiar phenomena, with the sole aim to produce spectacular images and create astonishing stories. At the origin, Computer Graphics thus drastically departed from other scientific fields. Everyday-life phenomena such as cloth buckling, paper tearing, or hair fluttering in the wind, mostly ignored by other scientists at that time, became actual topics of interest, involving a large set of new research directions to be explored, both in terms of modelling and simulation. Nowadays, although the image production still remains the core activity of the Computer Graphics community, more and more research studies are directed through the virtual and real prototyping of mechanical systems, notably driven by a myriad of new applications in the virtual try on industry (e.g., hairstyling and garment fitting). Furthermore, the advent of additive fabrication is currently boosting research in the free design of new mechanisms or systems for various applications, from architecture design and fabrication of metamaterials to the creation of new locomotion modes in robotics. Some obvious common interests and approaches are thus emerging between Computer Graphics and Mechanical Engineering, yet the two communities remain desperately compartmentalized.

4.3 Soft Matter Physics

From the physics-based viewpoint, since a few decades a new generation of physicists became interested again in the understanding of such visually fascinating phenomena, and started investigating the tight links between geometry and elasticity [2]. Common objects such as folded or torn paper, twined

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[2] In France this new trend was particularly stimulated by the work of Yves Pomeau, who convinced many young scientists to study the nonlinear physics of common objects such as paper, plants, or hair [28].

plants, coiled honey threads, or human hair have thus regained some popularity among the community in Nonlinear Physics [3]. In consequence, phenomena of interest have become remarkably close to those of Computer Graphics, since scientists in both places share the common goal to model complex and integrated mechanical phenomena at the macroscopic scale. Of course, the goals and employed methodologies differ substantially from one community to the other, but showcase some evident complementarity: while computer scientists are eager to learn and understand new physical models, physicists get more and more interested in the numerical tools, in which they perceive not only a means to confirm predictions afterwards, but also a support for testing new hypothesis and exploring scenarios that would be too cumbersome or even impossible to investigate experimentally. Besides, numerical exploration starts becoming a valuable tool for getting insights into the search for analytic solutions, thus fully participating to the modeling stage and physical understanding. However, physicists may be limited to a blind usage of numerical black boxes, which may furthermore not be dedicated to their specific needs. According to us, promoting a science of modeling in numerical physics would thus be a promising and rich avenue for the two research fields. Unfortunately, very scarce cooperation currently exists between the two communities, and large networks of collaboration still need to be set up.

5 Social and environmental responsibility

5.1 Footprint of research activities

The ELAN team is environment-sensitive. Since its creation in 2017, 100% of its research staff moves daily from home to the lab using soft transportation means (biking, public transportation). Intercontinental missions are limited while train is the preferred mode of transportation in Europe.

5.2 Impact of research results

A large part of the research conducted in the team is of fundamental level. Direct applications lie in numerical arts, cloth design, sports, and environmental studies, all of these being of limited negative impact for the environment. Collaborations with industry leading specially harmful activities to the environment are avoided.

6 New software and platforms

6.1 New software

6.1.1 Feel++

Keywords: High order finite elements, Discontinuous Galerkin, High-Performance Computing

Functional Description: Feel++ is a high-performance C++ library for the resolution of general variational formulations, including continuous and discontinuous Galerkin methods, finite element or spectral element methods, reduced basis formulations, etc. It features a high-level domain specific embedded language (DSEL) for Galerkin methods, space dimension-agnostic computation kernels and seamless and automatic parallelism. It also includes applicative toolboxes to solve physics problems in fluid mechanics, solid mechanics, thermal conduction, and the corresponding multi-physics coupling.

Release Contributions: - Enable adaptive remeshing - Optimisation of automatic parallelism (for export and degrees of freedom management) - Add automatic computation of simulation statistics

URL: `http://www.feelpp.org`

Contact: Thibaut Metivet

Partners: Université de Strasbourg, UGA, Inria

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[3] It is however amusing to observe that research in these areas is quite successful in obtaining the IG Nobel prize [8, 31], thus still being considered as an exotic research topic by physicists.

6.1.2 ProjectiveFriction

Name: Projective Dynamics with Dry Frictional Contact

Keywords: Physical simulation, Frictional contact, Real time

Functional Description: Simulation based on the Projective Dynamics method that accurately reproduce dry frictional contact while keeping the high performance brought by the Projective Dynamics method. This is possible thanks to the iterative solve of an approximated discrete frictional contact problem at the local step of Projective Dynamics.

Publication: hal-02563307

Contact: Florence Bertails Descoubes

Participants: Florence Bertails Descoubes, Laurence Boissieux, Mickael Ly, Jean Jouve

7 New results

7.1 Static simulation of thin elastic ribbons

Participant Raphaël Charrondière, Florence Bertails-Descoubes, Victor Romero.

In collaboration with Sébastien Neukirch (Sorbonne Université, Institut Jean le Rond d'Alembert), we have proposed a robust and efficient numerical model to compute stable equilibrium configurations of thin elastic ribbons featuring arbitrarily curved natural shapes. Our spatial discretization scheme relies on elements characterized by a linear normal curvature and a quadratic geodesic torsion with respect to arc length. Such a high-order discretization allows for a great diversity of kinematic representations, while guaranteeing the ribbon to remain perfectly inextensible. Stable equilibria are calculated by minimizing gravitational and elastic energies of the ribbon, under a developability constraint. This work, numerically and experimentally validated, has been published in Mechanics [4].

7.2 Video-based measurement of the friction coefficient between cloth and a substrate

Participant Haroon Rasheed, Victor Romero, Florence Bertails-Descoubes.

In collaboration with Arnaud Lazarus (Sorbonne Université, Institut Jean le Rond d'Alembert), Jean-Sébastien Franco and Stefanie Wuhrer (Inria, Morphéo team), we have investigated a first non-invasive measurement network for estimating cloth friction at contact with a substrate. Our network was trained on data exclusively generated by the solver ARGUS co-developed by the ELAN team, which we have carefully validated against real experiments under controlled conditions. We have shown promising friction measurement results on multiple real cloth samples contacting various kinds of substrates, by comparing our estimations based on a simple video acquisition protocol against standard measurements. This work has been published and selected for an oral at IEEE CVPR 2020 [7], and an extension incorporating new results on cloth-cloth friction has been submitted to a Computer Vision journal.

7.3 Willmore flow simulation with diffusion-redistanciation numerical schemes

Participant Thibaut Metivet.

In collaboration with Arnaud Sengers (Université Claude Bernard , Emmanuel Maitre (Laboratoire Jean Kuntzmann, Grenoble INP) and Mourad Ismail (Laboratoire Interdisciplinaire de Physique, UGA), we have proposed original diffusion-redistanciation numerical schemes to compute the static shapes of elastic membranes with bending stiffness under constant area and volume constraints. This numerical method relies on an implicit representation of the surface which is used as an initial condition for diffusion-like equations. This allows to circumvent the usual difficulties pertaining to the high geometrical order and non-linearities of the bending energy and to benefit from the robustness of discretised diffusion operators. The resulting numerical schemes provide very a good stability behaviour thanks to their inherent diffusive nature and demonstrate a convergence order close to the optimal one, which is a nive achievement in regards of the low-order geometrical discretisation used. We have implemented the schemes within the finite-element library Feel++ and provided efficient and parallel solvers for the resolution of the diffusion equation and the redistanciation of the implicit surface representation. We have validated our method using comparative benchmarks computed with standard approaches. This work has led to a recent publication in Computational Physics [6].

7.4 Fast frictional contact solver

Participant Mickaël Ly, Jean Jouve, Laurence Boissieux, Florence Bertails-Descoubes.

Inspired by the recent projective dynamics algorithm [15], which computes the dynamics of elastic structures in an efficient way thanks to a progressive update of elastic forces, we have designed a new frictional contact solver which perfectly fits in with the projective dynamics global/local steps framework. Assuming that contacts apply to nodes only, the key is to split the global matrix into a diagonal and a positive matrix, and use this splitting in the local step so as to make a good prediction of frictional contact forces at next iteration. Each frictional contact force is refined independently in the local step, while the original efficient structure of the global step is left unchanged. We apply our algorithm to cloth simulation and show that contact and dry friction can be captured at a reasonable precision within a few iterations only, hence one order of magnitude faster compared to global implicit contact solvers of the literature. This work has been published at ACM Siggraph 2020 [5], and we plan to release the source code in 2021.

7.5 Validation of simulators for slender elastic structures and frictional contact

Participant Victor Romero, Mickaël Ly, Haroon Rasheed, Raphaël Charrondière, Florence Bertails-Descoubes.

In collaboration with Arnaud Lazarus and Sébastien Neukirch (Sorbonne Université, Institut Jean le Rond d'Alembert), we have set up a new framework for validating simulators of slender elastic structures (rods and plates) and frictional contact. To this aim we leverage and enrich a set of protocols from the Soft Matter Physics community, initially devised for measuring elasticity and frictional properties of slender elastic structures. These retained tests, that we experimentally validate, are characterized by scaling laws which only depend on a few dimensionless parameters, making them ideal for benchmarking robustly a large diversity of codes across different physical regimes, without having to worry about scales or dimensions. We have passed a number of popular codes of Computer Graphics through our benchmarks by defining a rigorous, consistent, and as fair as possible methodology. Our results show that while some popular simulators for plates/shells and frictional contact fail even on the simplest scenarios, more recent ones, as well as well-known codes for rods, generally perform well and sometimes even better than some reference commercial tools of Mechanical Engineering. Our benchmarking study has been conditionally accepted for publication at ACM SIGGRAPH 2021.

8 Partnerships and cooperations

8.1 European initiatives

8.1.1 FP7 & H2020 Projects

8.1.2 GEM

- Title: from GEometry to Motion, inverse modeling of complex mechanical structures
- Programm: H2020
- Type: ERC
- Duration: September 2015 - February 2022
- Coordinator: Inria
- Inria contact: Florence BERTAILS-DESCOUBES
- With the considerable advance of automatic image-based capture in Computer Vision and Computer Graphics these latest years, it becomes now affordable to acquire quickly and precisely the full 3D geometry of many mechanical objects featuring intricate shapes. Yet, while more and more geometrical data get collected and shared among the communities, there is currently very little study about how to infer the underlying mechanical properties of the captured objects merely from their geometrical configurations. The GEM challenge consists in developing a non-invasive method for inferring the mechanical properties of complex objects from a minimal set of geometrical poses, in order to predict their dynamics. In contrast to classical inverse reconstruction methods, my proposal is built upon the claim that 1/ the mere geometrical shape of physical objects reveals a lot about their underlying mechanical properties and 2/ this property can be fully leveraged for a wide range of objects featuring rich geometrical configurations, such as slender structures subject to frictional contact (e.g., folded cloth or twined filaments). To achieve this goal, we shall develop an original inverse modeling strategy based upon a/ the design of reduced and high-order discrete models for slender mechanical structures including rods, plates and shells, b/ a compact and well-posed mathematical formulation of our nonsmooth inverse problems, both in the static and dynamic cases, c/ the design of robust and efficient numerical tools for solving such complex problems, and d/ a thorough experimental validation of our methods relying on the most recent capturing tools. In addition to significant advances in fast image-based measurement of diverse mechanical materials stemming from physics, biology, or manufacturing, this research is expected in the long run to ease considerably the design of physically realistic virtual worlds, as well as to boost the creation of dynamic human doubles.

8.2 National initiatives

8.2.1 National Collaborations

- Long-term collaboration with Arnaud Lazarus and Sébastien Neukirch (Institut Jean le Rond d'Alembert, Sorbonne Université).
- Long-term collaboration with Christophe Prud'homme and Vincent Chabannes (Université de Strasbourg and Centre de modélisation et de simulation de Strasbourg).
- New collaboration with Olivier Pouliquen and Joël Marthelot (IUSTI, Aix-Marseille University).
- Starting collaboration with Philippe Peyla, Aurélie Dupont (LIPhy, Université Grenoble-Alpes) and Christian Graff (LPNC, Université Grenoble-Alpes). Submission of a project proposal for ANR AAPG 2021.

9 Dissemination

9.1 Promoting scientific activities

9.1.1 Scientific events: selection

Member of the conference program committees

- Florence Bertails-Descoubes was member of the ACM SIGGRAPH 2021 Technical Program Committee.

9.1.2 Journal

Reviewer - reviewing activities

- Florence Bertails-Descoubes was reviewer in 2020 for ACM SIGGRAPH 2020, 2021, ACM SIGGRAPH Asia 2020, ACM Transactions on Graphics, and International Journal of Solids and Structures.
- Thibaut Metivet was reviewer in 2020 for ACM SIGGRAPH 2021.

9.1.3 Invited talks

- January 2021: Florence Bertails-Descoubes was Semi-plenary Speaker at WCCM-ECCOMAS 2020.

9.2 Teaching - Supervision - Juries

9.2.1 Teaching

- Licence: Nicolas Parent, TD Algèbre linéaire MAT202, 44 éq. TD, L1 PCMM, Université Grenoble Alpes.
- Licence: Raphaël Charrondière, CM Validation d'algorithmes, 27h éq. TD, L3 Miage, Université Grenoble Alpes.
- Licence: Raphaël Charrondière, TD Validation d'algorithmes, 18h éq. TD, L3 Miage, Université Grenoble Alpes.
- License: Thibaut Metivet, Analyse, 33h éq TD, L3, ENSIMAG 1A, Grenoble INP.
- License: Thibaut Metivet, Méthodes Numériques de Base, 16.5h éq TD, ENSIMAG 1A, Grenoble INP.
- Master: Raphaël Charrondière, Complexité Algorithmique Des Problèmes, 15h éq TD, M1, Université Grenoble Alpes.
- Master: Florence Bertails-Descoubes, Special Course for M2 at École Normale Supérieure de Lyon, entitled "Numerical Mechanics: From Lagrangian mechanics to simulation tools for computer graphics", 19h éq TD.
- Master: Mickaël Ly, Special Course for M2 at École Normale Supérieure de Lyon, entitled "Numerical Mechanics: From Lagrangian mechanics to simulation tools for computer graphics", 14h éq TD.

9.2.2 Supervision

- PhD in progress : Mickaël Ly, 01 octobre 2017, Florence Bertails-Descoubes and Mélina Skouras (EPI ANIMA).
- PhD in progress : Haroon Rasheed, 01 novembre 2017, Florence Bertails-Descoubes, Jean-Sébastien Franco, and Stefanie Wuhrer (EPI MORPHEO)
- PhD in progress : Raphaël Charrondière, 01 septembre 2018, Florence Bertails-Descoubes and Sébastien Neukirch (Institut Jean le Rond d'Alembert, Sorbonne Université).

- PhD in progress : Nicolas Parent, since 19 October 2020, Florence Bertails-Descoubes, Thibaut Metivet and Mélina Skouras (EPI ANIMA).

9.2.3 Juries

- Florence Bertails-Descoubes was member (Examinatrice) of the Ph.D. Thesis committee of Xavier Tellier (8 March 2019), Université Paris-Est (directeurs de thèse : O. Baverel et L. Hauswirth).

9.3 Popularization

9.3.1 Interventions

- October 2020: Seminar on the ethical aspects of research for PhD students at Inria Grenoble Rhône-Alpes, together with Edmond Boyer (EPI MORPHEO).

10 Scientific production

10.1 Major publications

[1] F. Bertails-Descoubes, A. Derouet-Jourdan, V. Romero and A. Lazarus. 'Inverse design of an isotropic suspended Kirchhoff rod: theoretical and numerical results on the uniqueness of the natural shape'. In: *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences* 474.2212 (Apr. 2018), pp. 1–26. DOI: `10.1098/rspa.2017.0837`. URL: `https://hal.inria.fr/hal-01827887`.

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