Geometric Potential and Geometric Predicates for Unconditionally Robust Elastodynamics Simulation

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Abstract

The numerical solution of partial differential equations (PDE) is ubiquitously used for physical simulation in scientific computing and engineering. Ideally, a PDE solver should be opaque: the user provides as input the domain boundary, boundary conditions, and the governing equations, and the code returns an evaluator that can compute the value of the solution at any point of the input domain. This is surprisingly far from being the case for all existing open-source or commercial software, despite the research efforts in this direction and the large academic and industrial interest. To a large extent, this is due to lack of robustness in geometric algorithms used to create the discretization, detect collisions, and evaluate element validity.

I will present an interior point simulation approach, which provides strong robustness guarantees in simulation codes, ensuring, for the first time, validity of the trajectories accounting for floating point rounding errors over an entire elastodynamic simulation with contact, building on the Incremental Potential Contact (IPC) framework [6]. The algorithm assumes a valid initial state void of intersections or inverted elements, and guarantees that these properties will hold for the entire trajectory while accounting for floating point rounding error. The two major building blocks of this approach are the conversion of time stepping into an unconstrained minimization of a set of continuous potentials (modeling elastic, contact, and friction forces), and a robust, conservative line-search to check for collisions between geometric primitives and for ensuring validity of the deforming elements over linear trajectories.

I will introduce the general framework first [6], then dive into the definition of a smooth geometric contact potential for barrier-based contact handling [3], and finally introduce algorithms to automatically construct robust geometric predicates for collisions and inversions from a high-level specification [8, 7]. The overall system enables simulations of scenes with unprecedented geometric and contact complexity which appear in structural mechanics, microscopy, and biomechanics, including traction force estimation on a live zebrafish and efficient modeling and simulation of fibrous materials. The formulation is a naturally differentiable solver [5], opening the door to exciting geometric optimization problems such as the discovery of optimal shock-absorbing microstructures for elastic metamaterials [4], robotics grippers optimized via soft pneumatic actuator design [1], and deformable sensors based on capacitive stretch sensing [2].

Bio

Daniele Panozzo is a Full Professor of Computer Science and Vice-Dean of Academic Affairs at the Courant Institute School of Mathematics, Computing, and Data Science. Prior to joining NYU he was a postdoctoral researcher at ETH Zurich (2012–2015). Daniele earned his PhD in Computer Science from the University of Genova (2012) and his doctoral thesis received the EUROGRAPHICS Award for Best PhD Thesis (2013). He received the EUROGRAPHICS Young Researcher Award in 2015, the NSF CAREER Award in 2017, and a Sloan Research Fellowship in 2020. Daniele's research group is leading the development of PolyFEM (`https://polyfem.github.io`), a simple and robust finite element library, and wild meshing (`https://github.com/wildmeshing`), a 2D and 3D robust meshing library. Daniele initiated the Graphics Replicability Stamp (`http://www.replicabilitystamp.org`), which is an initiative to promote reproducibility of research results and to allow scientists and practitioners to immediately benefit from state-of-the-art research results. His research interests are in finite element simulation, digital fabrication, and geometry processing.

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