Introduction to Optimization Time Integration for Solids and Fluids

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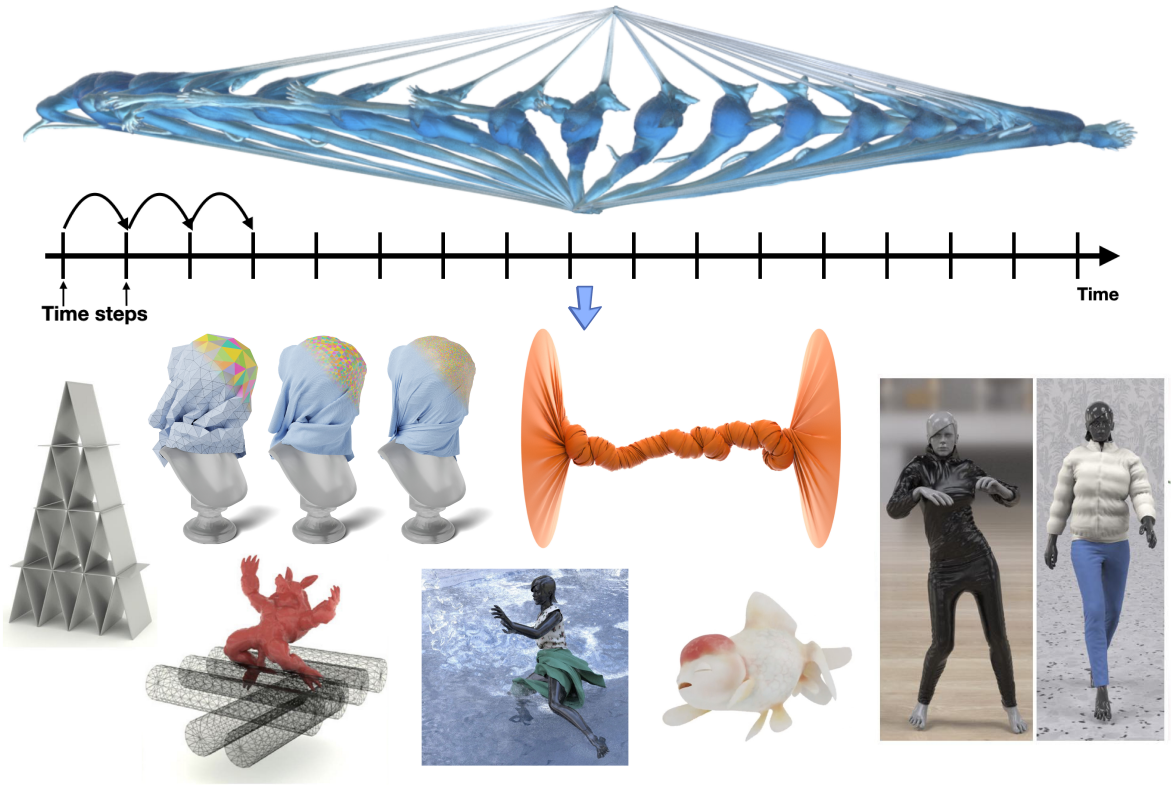

Figure 1: *Overview image for the tutorial.*

Abstract

Second-order optimization methods, such as Newton's Method, are critical not only in geometry processing for applications like shape deformation and mesh parameterization but also in the robust and accurate simulation of solid and fluid dynamics. In the first part of this course, we will provide a high-level overview of optimization time integration methods, starting from a geometric perspective focused on distortion minimization. Participants will learn how to extend distortion minimization methods to an elastodynamic simulation framework and will explore methods for simulating a variety of materials and phenomena, including cloth, hair, stiff objects, contacts, and fluids. The session also links to a comprehensive online book and a set of illustrative Python examples for the elastodynamic contact part to enhance understanding. In the second part of the course, we will show how various recent advancements in elastodynamic simulation are rooted in such a shared framework. This framework readily supports extensions like subspace methods for fast simulations, enhancements to rig-based animations with physical secondary motion, and the integration of multilevel methods for rapid previews and enhanced user interactivity, among many other applications. By the end of this course, attendees will gain a deeper insight into the close connection between geometry processing and physics-based simulation.

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1. Presenter details

1.1. Contact information

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1.2. Presenter roles

- **Jiayi (Eris) Zhang**: Co-organizer and primary presenter for sections on geometric distortion minimization, optimization-based time integration for elastodynamics, and connections between geometry processing and simulation.
- **Minchen Li**: Co-organizer and primary presenter for sections on robust second-order methods in solid and fluid dynamics, contact-rich simulation, and practical implementation aspects for large-scale systems.

2. Tutorial details

2.1. Title

Introduction to Optimization Time Integration for Solids and Fluids

2.2. Keywords

optimization time integration, second-order methods, elastodynamics, solids and fluids, geometry processing, distortion minimization

2.3. Duration

Half-day tutorial (2×90 minutes)

3. Course outline

3.1. Session 1 (90 min): From Geometry Processing to Optimization-Based Elastodynamics

- Second-order optimization in geometry processing (shape deformation, parameterization).
- Distortion minimization viewpoint and its extension to time integration.
- Optimization-based elastodynamic framework.
- Applications: cloth, hair, stiff objects, contact, and fluids.
- Pointers to the online book and Python examples for elastodynamic contact.

3.2. Session 2 (90 min): Unified Framework, Fast Methods, and Applications

- Recent elastodynamic methods within a shared optimization framework.
- Subspace/model-reduced methods for fast simulation and previews.
- Enhancing rig-based animations with physical secondary motion.
- Multilevel methods for rapid previews and interactive workflows.
- Outlook and discussion: bridging geometry processing and physics-based simulation.

4. Background and target audience

4.1. Necessary background

We assume attendees have:

- Basic familiarity with linear algebra, numerical methods, and differential equations.
- Introductory exposure to computer graphics, computational mechanics, or scientific computing.
- Some experience with simulation or geometry-processing tools (e.g., FEM, MPM, or physics engines) is helpful but not strictly required.

Throughout the tutorial we emphasize intuition, design patterns, and implementation strategies. Mathematical details are supported by visual examples, conceptual diagrams, and accessible Python code.

4.2. Target audience

The tutorial is intended for:

- Researchers and graduate students in computer graphics, geometry processing, computational mechanics, and robotics who want a unified view of optimization time integration.
- Practitioners from VFX, games, digital content creation, and related industries who design or maintain simulation and deformation tools.
- Developers of numerical libraries and infrastructure interested in adopting optimization-based integrators and modern second-order methods for solids and fluids.

5. Brief resumes of the presenters

5.1. Jiayi (Eris) Zhang

Jiayi (Eris) Zhang is a fifth-year Ph.D. candidate at Stanford University, advised by Prof. Doug James. She earned her undergraduate degree in Computer Science and Mathematics from the University of Toronto, where she conducted research under the supervision of Prof. Alec Jacobson. She works on physical simulation, geometry processing and numerical optimization, with a primary focus on developing intelligent algorithms, models and tools for enhancing user creativity and productivity in design, animation and simulation. She is a Stanford Reed-Hodgson Fellow, a WiGRAPH rising star, an MIT EECS Rising Star, and a recipient of the Adobe

Women in Technology Scholarship, the Roblox Graduate Fellowship and the Nvidia Graduate Fellowship. She has also interned at Adobe and NVIDIA over multiple summers, working closely with Dr. Danny Kaufman.

5.2. Minchen Li

Minchen is an Assistant Professor in the Computer Science Department at Carnegie Mellon University since 2023. Since 2025, he has also served as an advisor to Genesis AI. Previously, he was an Assistant Adjunct Professor at the UCLA Department of Mathematics, within the AIVC Lab. He completed his Ph.D. in 2020 from the SIG Center for Computer Graphics at the University of Pennsylvania, advised by Chenfanfu Jiang. Minchen's research accomplishments have been recognized with several prestigious awards, including the SCA Early Career Researcher Award (2024), the ACM SIGGRAPH Outstanding Doctoral Dissertation Award (2021), etc. He is an active member of the research community, regularly serving as a program committee member for conferences such as ACM SIGGRAPH, Eurographics, and SCA, as well as a reviewer for journals including ACM TOG, IEEE TVCG, and CMAME.

6. Previous or related tutorials

A closely related tutorial was given at SGP 2024 (Graduate School Day) in a single 1.5 hour slot, with approximately 120 attendees. Because of the tight schedule, many technical details, especially on optimization based time integration, connections to modern elastodynamic methods, and practical implementation aspects, had to be significantly abstracted or omitted.

Optimization based geometry processing and elastodynamic simulation is a central and increasingly important topic in computer graphics, supporting robust geometry processing and state of the art physics-based simulation used in animation, VFX, and interactive applications. In this new half day, 3 hour format (two 90 minute sessions), we aim to substantially expand the material with deeper technical coverage, richer examples, and more time for discussion and Q&A. The longer format will allow us to more clearly develop the shared optimization framework underlying recent advances, better illustrate links between geometry processing and simulation, and provide attendees with more actionable insight for both research and production use.