Level-of-Detail for Geometry Processing and Simulation

Jiayi Eris Zhang
Stanford University
Palo Alto, USA
eriszhan@stanford.edu

Hsueh-Ti Derek Liu
Roblox
Vancouver, Canada
hsuehtil@gmail.com

Abstract

Level-of-detail (LOD) is a concept we intuitively experience in everyday life—whether it is how our brains filter visual information or how digital maps adjust as we zoom. At its core, LOD is about allocating detail where it matters most, striking a balance between efficiency and precision. While originally developed to accelerate rendering in computer graphics, modern LOD techniques have evolved into a powerful framework for constructing hierarchical shape representations and designing multilevel solvers in geometry processing and simulation.

This course begins by highlighting the role of LOD not just in visualization, but also in numerical computation. We introduce key methods for constructing hierarchical structures, then dive into the design of multilevel solvers—focusing on how to transfer quantities and signals across levels, with emphasis on *surface self-parametrization* and *intrinsic prolongation.* We conclude with applications that showcase how these hierarchical frameworks enable efficient, accurate and scalable solutions to problems in geometry processing and physical simulation.

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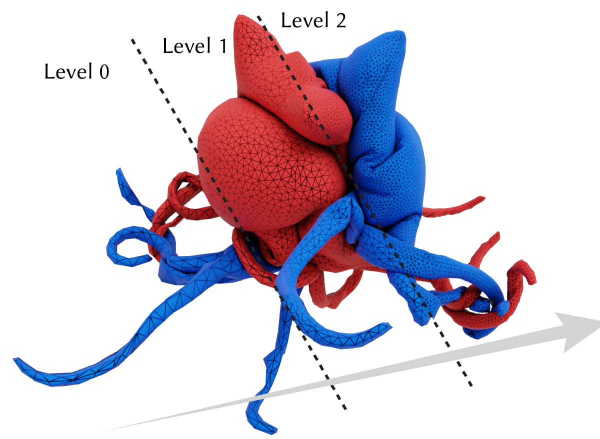

Figure 1: Level-of-Detail for Simulation: We apply Progressive Dynamics (PD) [Zhang et al. 2024] to simulate two inflated Octocat objects colliding, with details progressively emerging across resolution levels.

1 Introduction

Level of detail (LOD) is a concept that we encounter all the time in our daily life. Imagine using Google Maps—when you are zoomed out, only major cities, highways, and borders are visible. As you zoom in, more details gradually appear: local streets, buildings, landmarks. This progressive refinement approach enhances interactivity and responsiveness by adjusting detail to the current scale, simplifying both visual presentation and computation. Whether it's how our brain filters visual input or how digital maps adapt as we zoom in and out, LOD techniques are about prioritizing detail where it matters most—balancing efficiency and clarity.

LOD techniques have long been an important topic in computer graphics, initially developed to optimize rendering performance by dynamically adjusting geometric complexity based on viewing conditions [Luebke et al. 2002]. By simplifying distant or less noticeable objects while preserving detail where it is needed, these methods reduce computational cost through adaptive control of visual fidelity. Over time, LOD has evolved into a core strategy for managing complexity in real-time applications such as games, virtual reality, and large-scale visualizations. However, while LOD strategies are well established for visual rendering, their use in geometry processing and simulation is still an emerging area with many open challenges. The underlying spirit is much the same—adapting resolution to match the task at hand in order to improve efficiency and scalability—yet many core operations in geometry processing and simulation, such as solving partial differential equations (PDEs) over discretized domains, still largely rely on single-resolution representations that are often rigid, computationally intensive, and difficult to scale.

To fill in this gap, this course explores recent advancements in LOD techniques that extend these ideas beyond rendering and visualization, focusing on hierarchical representations and the successive computation of correspondences during multiscale construction. We demonstrate how such structures can support efficient, scalable, and accurate algorithms across applications in geometric modeling and physics-based simulation. Starting from the motivation for LOD in both visualization and computation, we introduce foundational techniques such as subdivision, mesh simplification, and progressive meshes, and build toward multilevel solvers with an emphasis on transferring quantities across resolutions. In particular, we highlight operator design challenges—such as surface

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self-parametrization and intrinsic prolongation—that are key to enabling truly hierarchical computation. We conclude by showcasing applications where hierarchical frameworks enable efficient, accurate, and scalable solutions, including attribute transfer, multigrid methods, detail reconstruction, and progressive simulation.

2 Course Presenters

2.1 Jiayi Eris Zhang

Jiayi Eris Zhang is a fourth-year PhD 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. Her research primarily focuses on developing intelligent algorithms, models, and tools to enhance creativity and productivity in design, animation, and simulation. She is a Stanford Reed-Hodgson Fellow, a Young Researcher at the Heidelberg Laureate Forum, an MIT EECS Rising Star, and a recipient of the Roblox Graduate Fellowship and the Nvidia Graduate Fellowship. She has also interned at Adobe over multiple summers, collaborating closely with Dr. Danny Kaufman.

2.2 Hsueh-Ti Derek Liu

Hsueh-Ti Derek Liu is a Senior Research Scientist at Roblox Research working on digital geometry processing and geometric machine learning. His research focuses on developing easy-to-use 3D content creation tools and level-of-detail methods for processing geometric data at scale. He received his PhD from University of Toronto advised by Prof. Alec Jacobson. He completed his M.S. with Profs. Keenan Crane and Levent Burak Kara at Carnegie Mellon University, and his B.S.E. at National Taiwan University.

3 Course Format

This 3-hour course is presented by two speakers who alternate between topics. The session is structured to provide a balance between foundational theory, practical techniques, and hands-on learning. It includes:

- Overview of Level-of-Detail (LOD) in Computer Graphics *by Eris*
  - Traditional LOD for computer rendering
  - LOD in Numerical Computation
- Introduction to Mesh Simplification *by Derek*
  - Quadric Error Mesh Simplification
  - The Devil is in the Details: Towards High Quality LOD
- Surface Hierarchies with Successive Parameterization *by Derek*
  - Overview of Self-Parameterization
  - Extrinsic Parameterization
  - Intrinsic Parameterization
- Break (10 minutes)
- LOD Computations in Geometry Processing *by Eris*
  - E.g., Multigrid Methods
- LOD Computations in Physical Simulation *by Eris*
  - E.g., Progressive Simulation
- Q&A and Hands-on Coding Demo (15 minutes)

4 Course Description

This course summarizes recent advancements in modern LOD techniques, with focuses on successively computing correspondences throughout the LOD construction. We highlight how they enhance computational efficiency, scalability, and accuracy across a wide range of applications, from geometric modeling to physically-based simulation.

This course begins by motivating the importance of LOD in visualization and, most critically, geometry computation. We then move on to the construction of hierarchical representations, covering key techniques such as quadric error mesh simplification [Garland and Heckbert 1997] and successive mappings [Cohen et al. 1997; Lee et al. 1998]. We emphasize on *intrinsic* surface parameterization [Liu et al. 2023, 2020, 2021] and its applications to multilevel solvers, such as the design of operators operators for transferring quantities and signals across resolutions. Building on this foundation, we introduce *progressive simulation* [Zhang et al. 2023, 2022, 2024], a hierarchical simulation framework offering efficient coarse-to-fine simulation with consistent simulations across multiple resolutions. We showcase how these hierarchical structures enable efficient solutions to key challenges in computations, addressing both intrinsic and extrinsic problem domains.

This course contributes to the SIGGRAPH community by providing a comprehensiveperspective on computational LOD as a fundamental tool in geometry processing and simulation. By presenting recent advancements, open challenges, and hands-on coding exercises alongside our 3-hour lecture, we aim to inspire new research directions and practical innovations. Attendees will leave with a deeper understanding of how LOD methodologies can be effectively applied to complex geometric and simulation problems, equipping them with the knowledge and resources to jump-start their work in this area.

5 Intended Audience

This course is intended for graduate students, researchers, and industry practitioners who seek to learn both the foundational principles and recent advancements in computational Level-of-Detail (LOD) techniques. It is particularly suited for those with a background in computer graphics, geometry processing, or numerical simulation who are interested in hierarchical representations, multilevel solvers, and scalable computation.

6 Prerequisites and Learning Objectives

While prior experience in geometry processing and simulation is beneficial, no specific background in LOD techniques is required. This course provides a structured introduction to key concepts, offering foundational intuition while exploring state-of-the-art developments and practical applications.

This course is especially valuable for those looking to engage with ongoing research and contribute to the field, whether by advancing recent developments, tackling open problems, or integrating LOD techniques into real-world applications. By the end, participants will have a solid starting point to further explore computational LOD in geometry processing and physical simulation.

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