# Introduction To Geometric Modelling

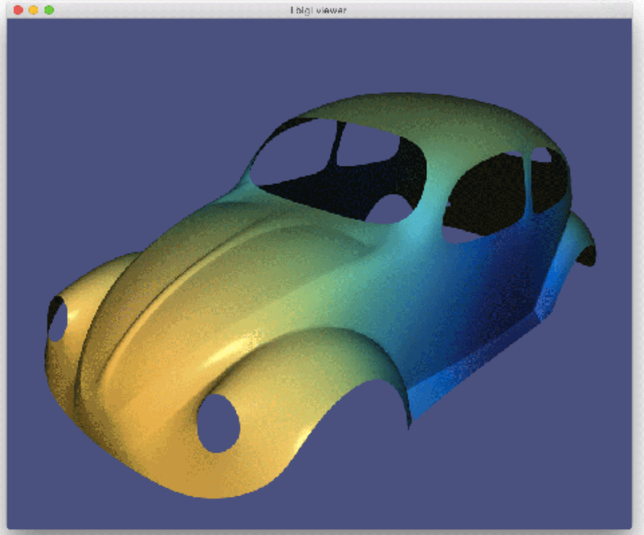


*Acknowledgements: Olga Sorkine-Hornung and Daniele Panozzo*

# Course Goals

- Learn how to design, program and analyze algorithms for **interactive 3D shape modeling** and **digital geometry processing**
- Theory and applications of 3D mesh processing
- Hands-on experience with shape modeling and geometry processing algorithms

# Geometric Modeling and Processing



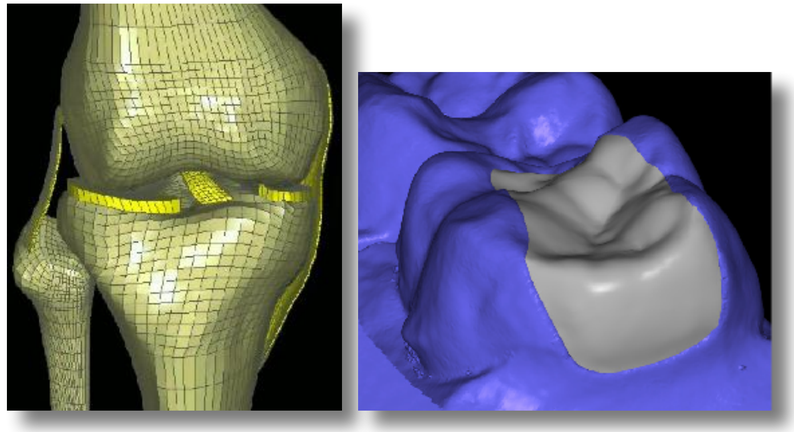
- The shape of an object is an important characteristic (not the only one…)

- Geometry processing: computerized modeling of 2D/ 3D geometry

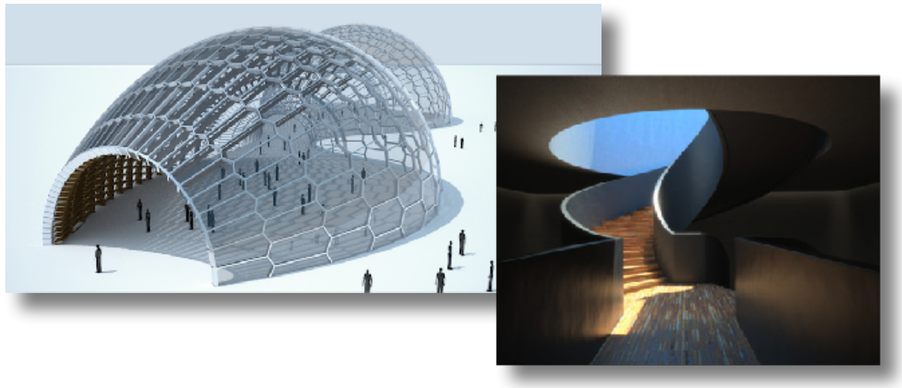
Copyright: Blender

# Applications

Product design and prototyping



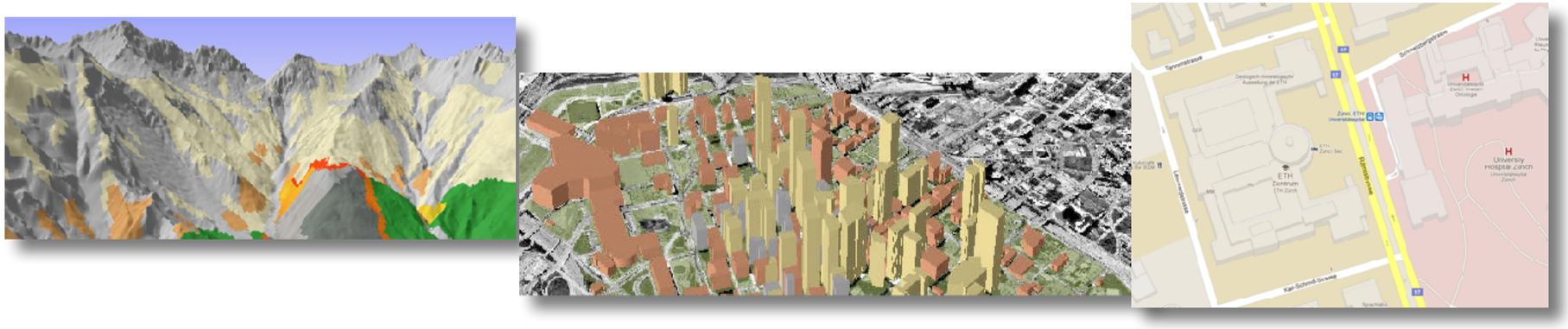
Medicine, prosthetics



Architecture

Cultural heritage

# Applications



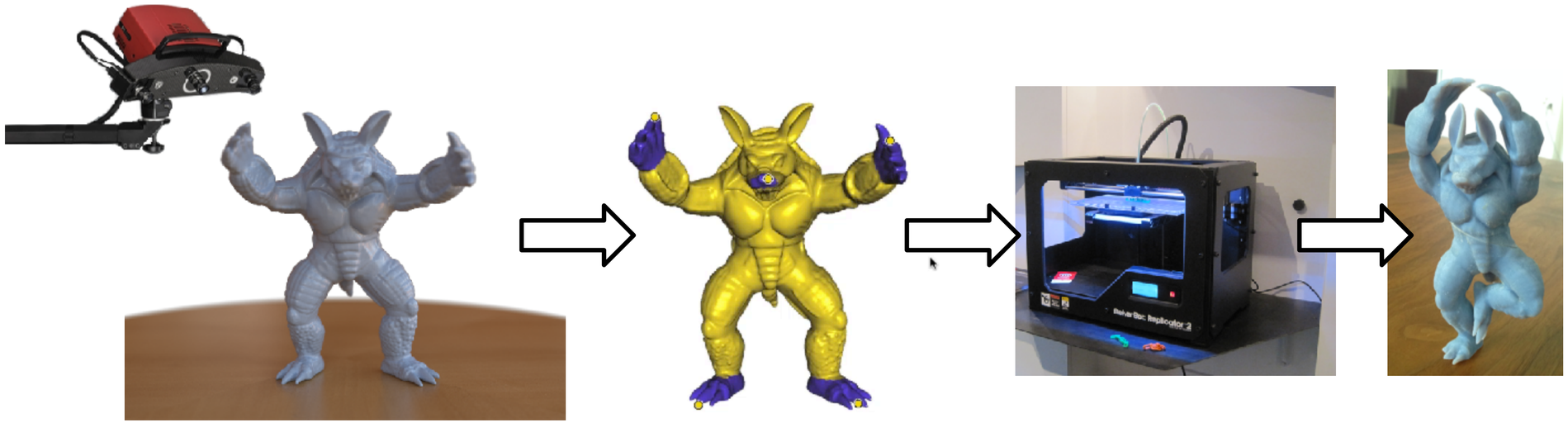
Geographical systems

[Bickel et al., ACM SIGGRAPH 2010]

Manufacturing, 3D Printing

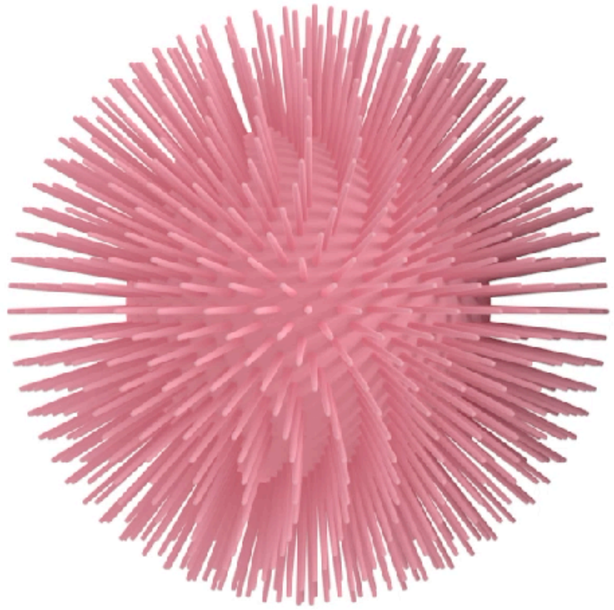
# Fabrication

- Modern scanning and 3D printing technologies allow replication and much more

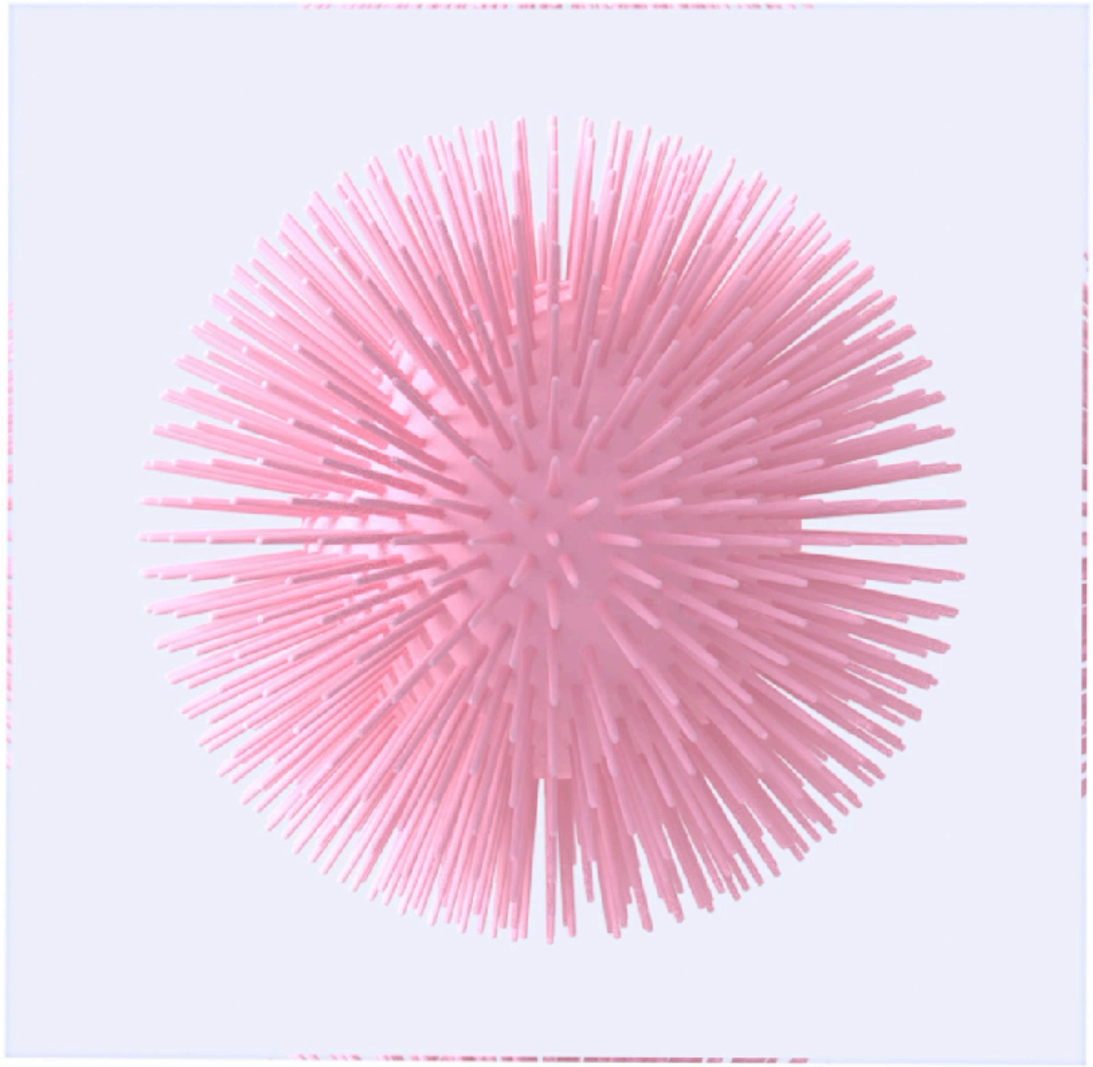


# Simulation

**IPC**



**tetrahedra: 2314K**
**contacts per step (max): 5.6K**
**dt: 0.001**
**$\mu$: 0**



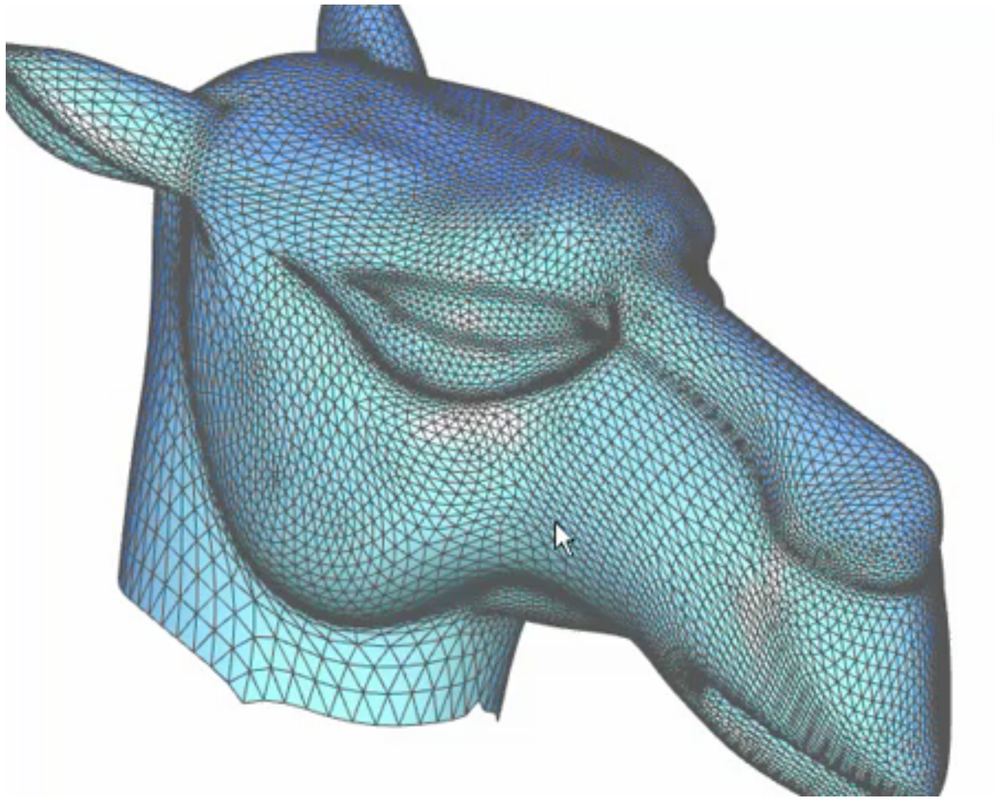
# Digital Geometry Processing (DGP)

- Processing of discrete surfaces/volumes
- Why discrete?
  - Representable by a computer
  - Efficiently rendered by graphics hardware
  - Input to most simulation/analysis tools
  - Easy to acquire(CT, MRI, LIDAR, Kinect…)

*Copyright: The Digital Michelangelo Project*

# Interactive Shape Modeling

- Tools for design, editing and animation of digital shapes
  - Interactive means fast algorithms
  - Intuitive – convenient interface and predictable outcome

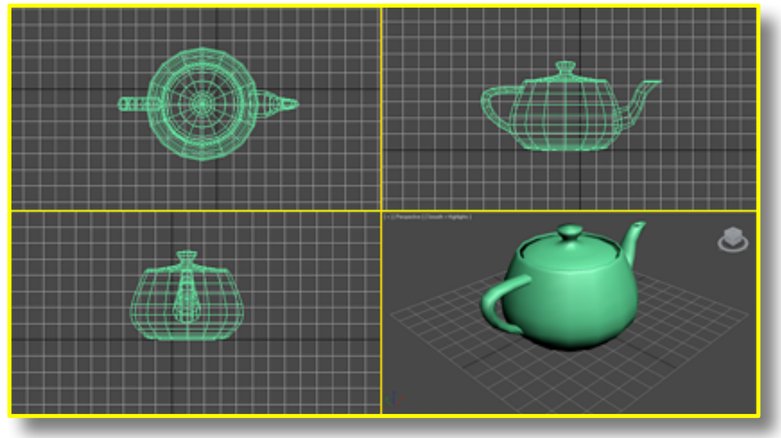


http://youtu.be/EMx6yNe23ug

# Digital Shape Modeling

- How do shapes find their way into computers?
  - Geometric modeling is difficult

Humans have no direct “video out”



“Translation” from 2D to 3D is hard

# Digital Shape Modeling

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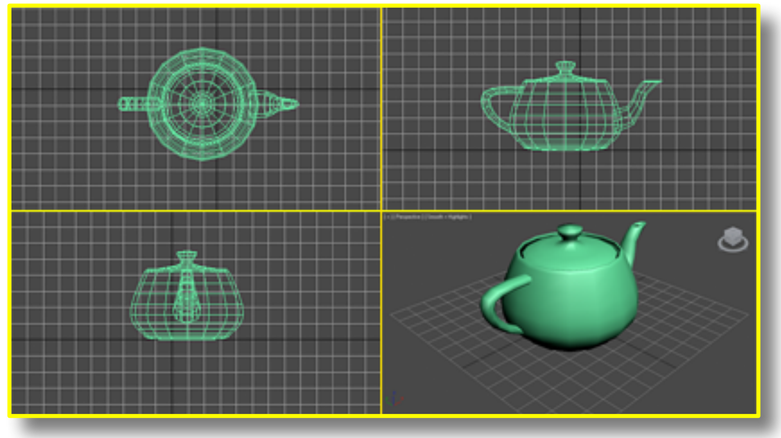
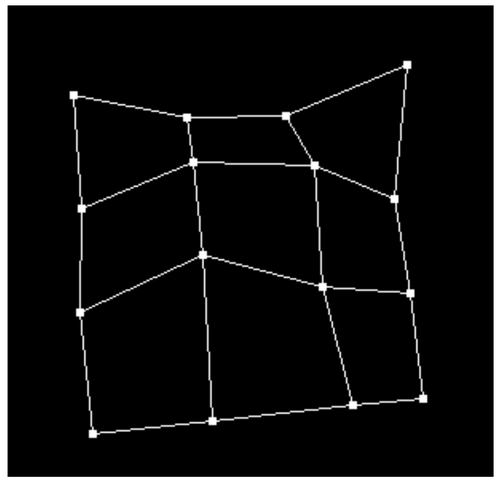
  - Geometric modeling is difficult



Use computation to compensate for lack of direct ability to convey visual information

# Computer-Aided Geometric Design

- Traditional pipeline for modeling shapes from scratch



User defines a layout of surface patches and control points

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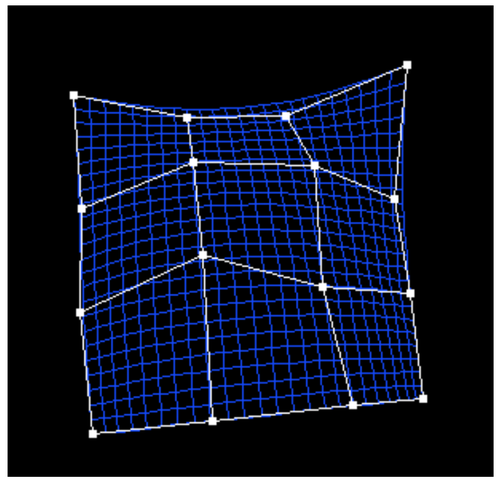

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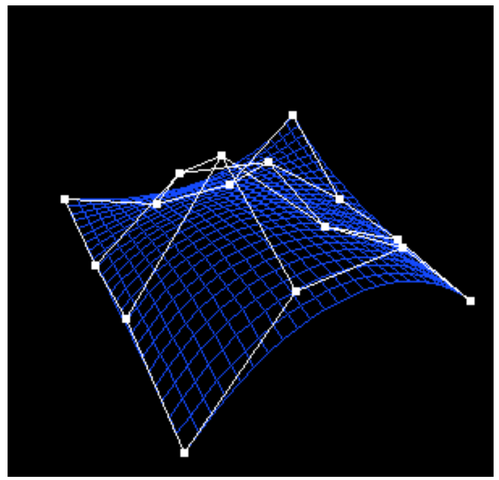

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Editing is performed by moving control points and/or prescribing tangents

# Computer-Aided Geometric Design

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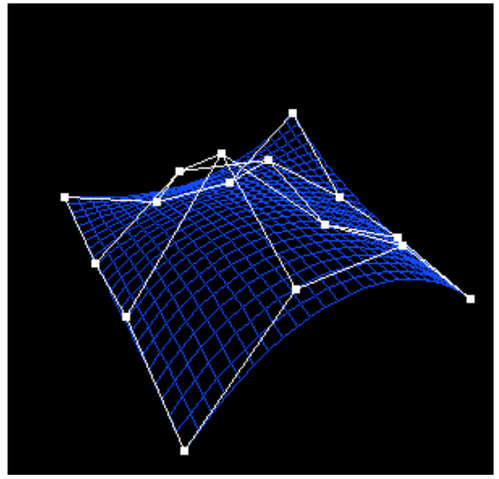

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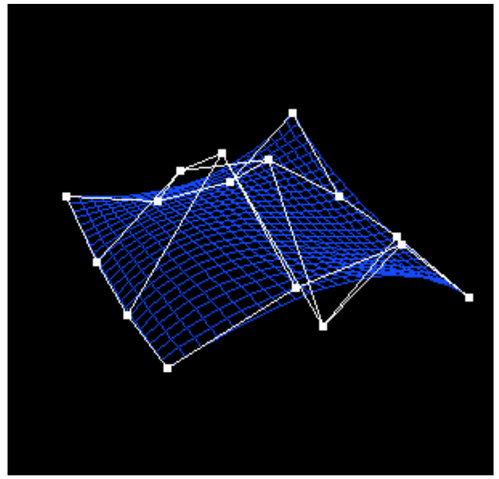

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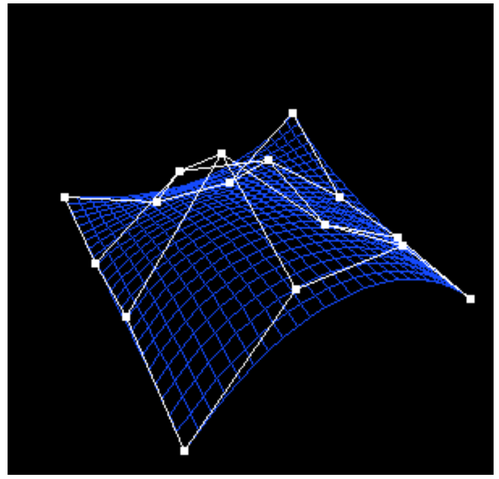

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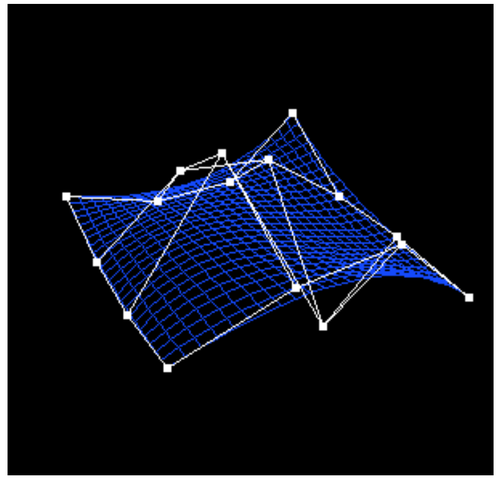

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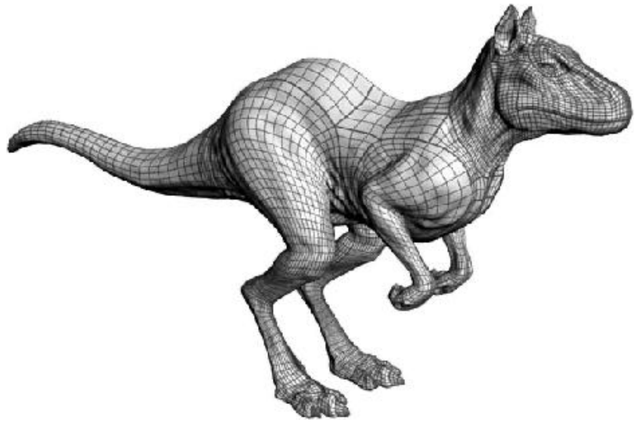
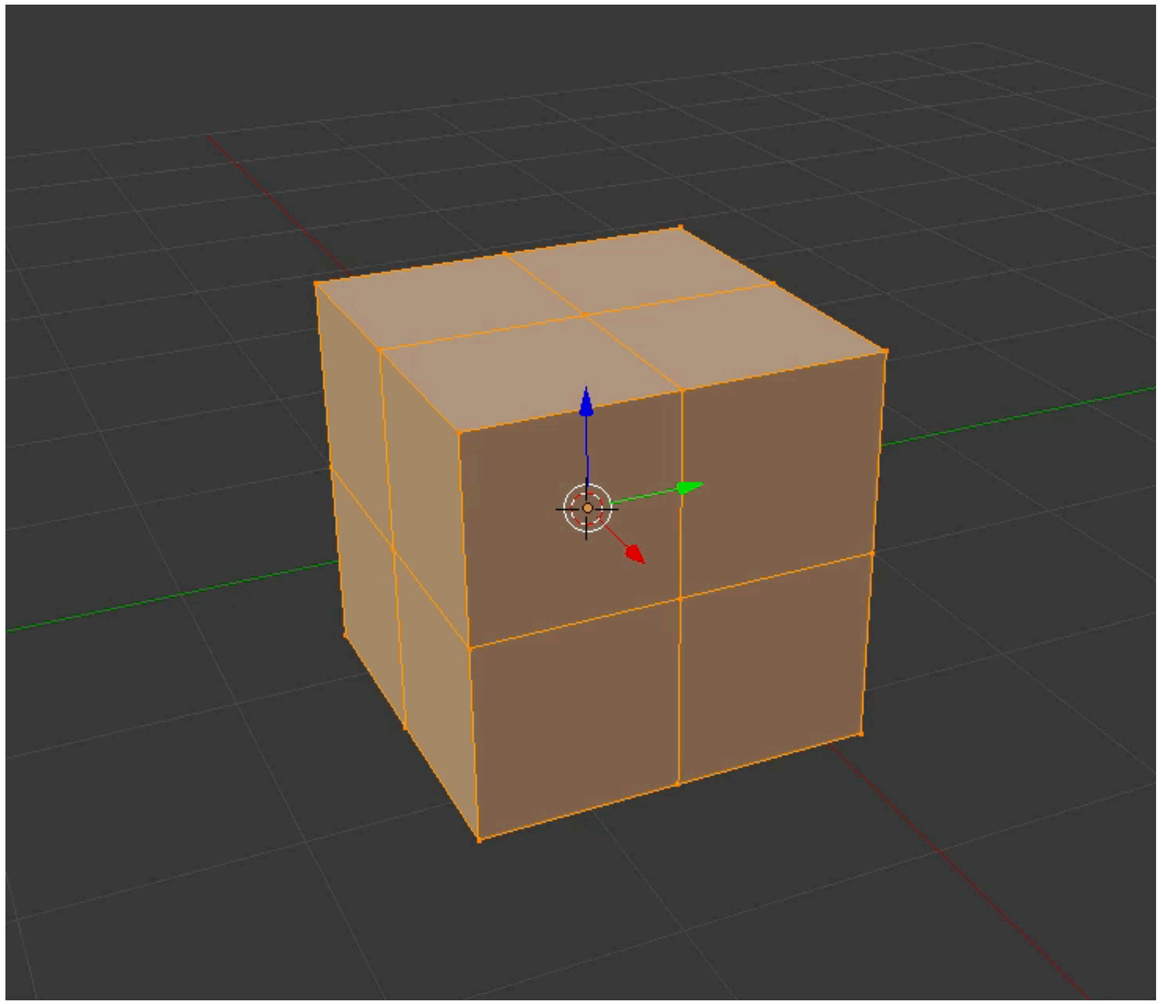


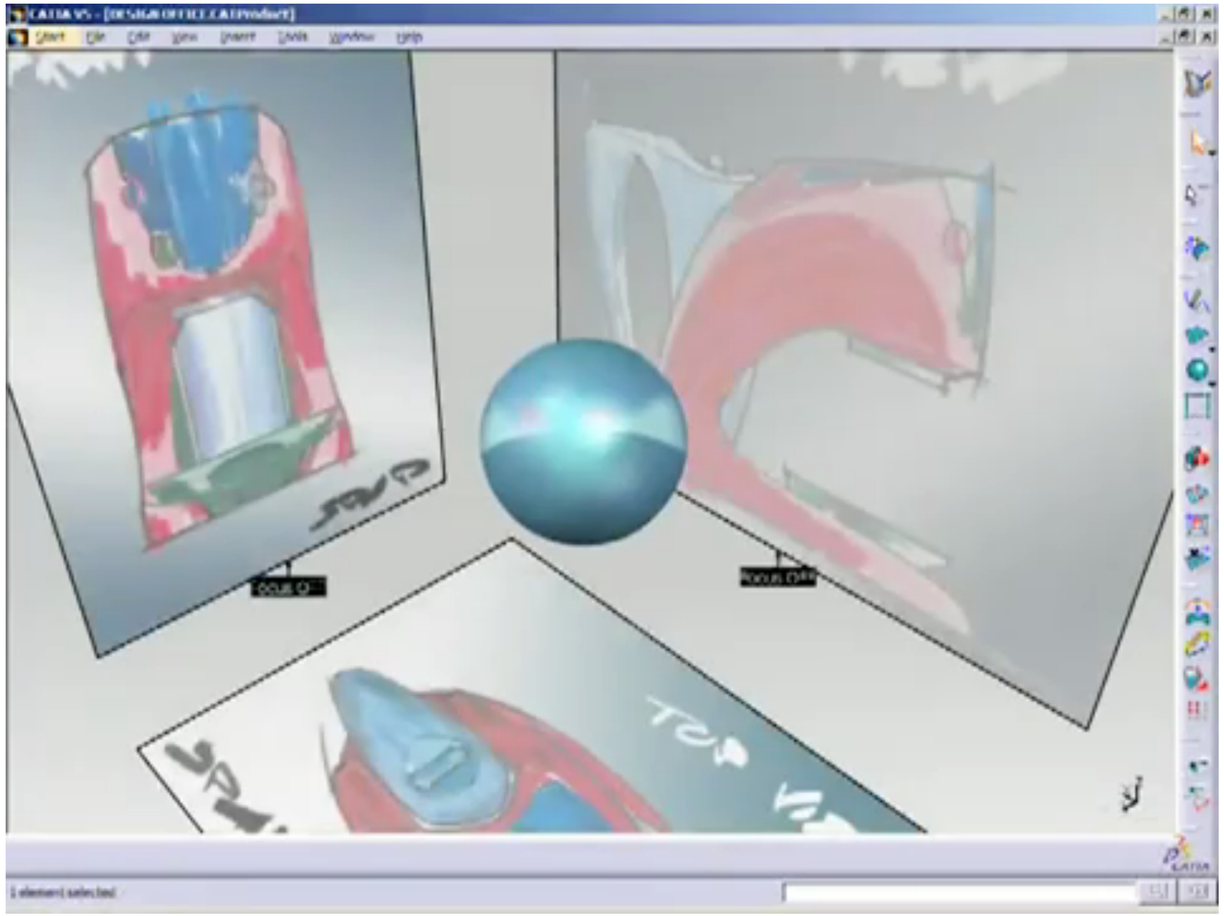
Patch-based construction of a surface

# Blender Demo



# Computer-Aided Geometric Design

- High-quality surfaces
- Constrained modeling
- Requires a specific idea of the object first
  - Not easy to experiment and explore alternatives
- Requires extensive training



CATIA, Dassault Systemes

http://youtu.be/gTC5zMktMr0

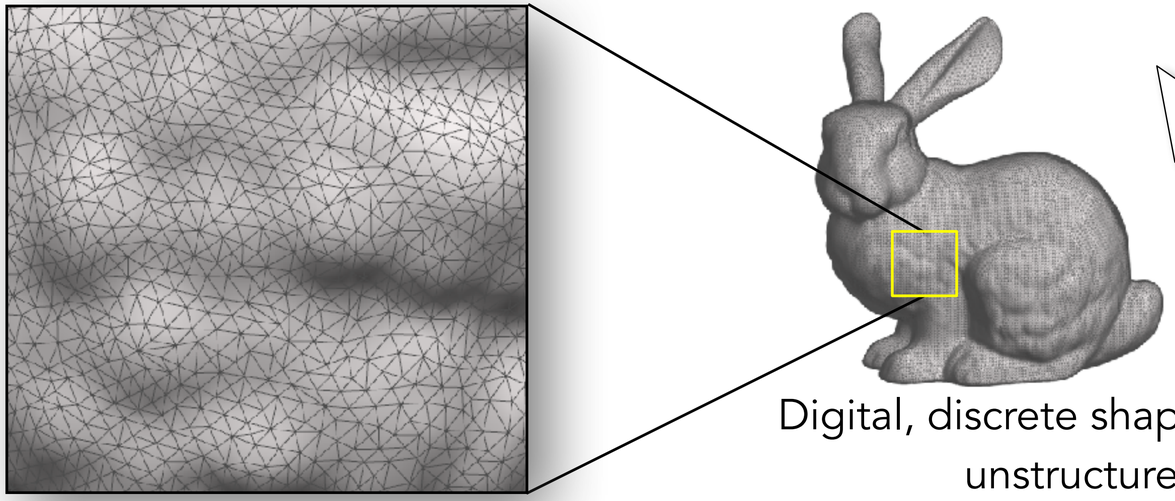
# Modern Geometry Acquisition Pipeline

Physical object

scanning

3D point samples, range images

DGP

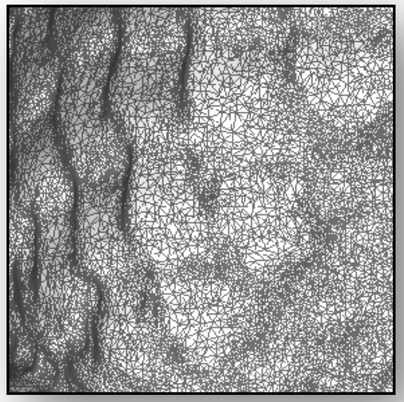


Digital, discrete shape representation:
unstructured mesh

The Stanford Bunny, Stanford 3D Scanning Repository

# Unstructured Digital Shapes

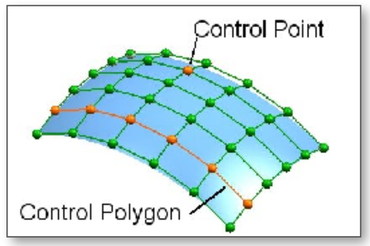
- How to **edit** and **animate**?
- How to convert to a **structured representation**?
- Computational challenge:
  very large amounts
  of data, yet modeling has to
  remain interactive



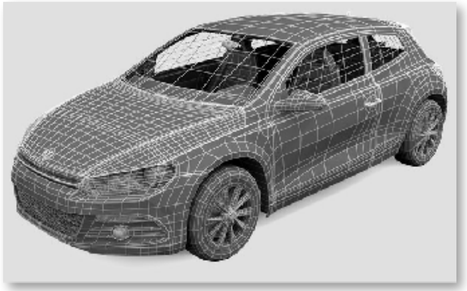
Thai statue, 10M triangles, Stanford 3D Scanning Repository

# Traditional CAD vs Modern Mesh Modeling

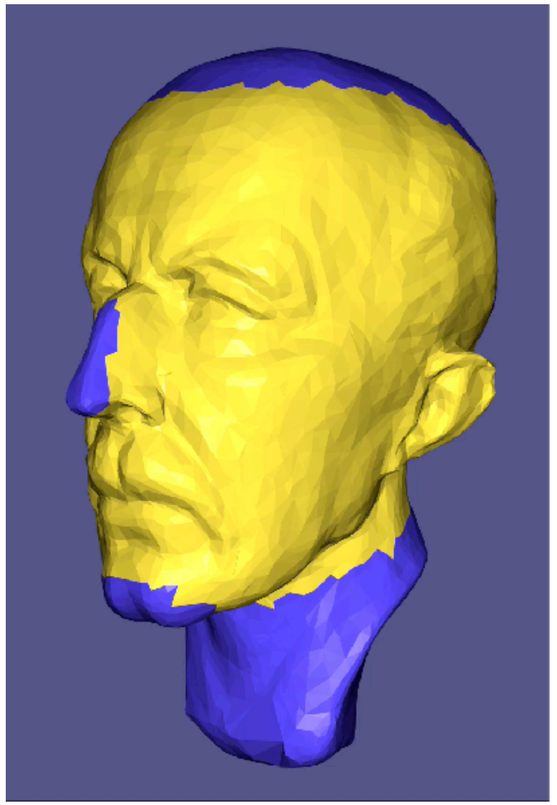
## Traditional CAD




$$\mathbf{x}(u,v) = \sum_{i,j} \mathbf{p}_{i,j} B_i(u) B_j(v)$$



## Modern mesh modeling

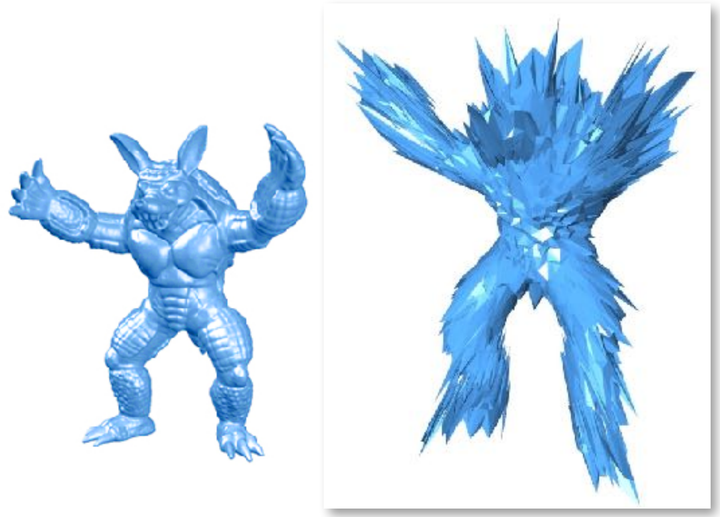


$$\min_{\mathbf{x}} \int_{\mathcal{S}} E(\mathbf{x}) \quad s.t. \; \mathbf{x}|_{\mathcal{C}} = \mathbf{x}_{\text{fixed}}$$

User has more freedom!
Select and manipulate arbitrary regions.

# Tools?

- Use techniques from both CS & Math
  - PDEs
  - Discrete differential geometry
  - Numerical linear algebra
  - Graph theory
  - ...
- ...combined with intuition and creativity ...
- work on real data = write/use code



# Prerequisites

- Linear Algebra
  - We **will not** cover the concepts that you need. If you are not familiar with basis, points, vectors, matrices, and linear systems, the course will be hard to follow.
- Python
  - We **will not** review the basic concepts of Python and Jupyter notebooks. There will be plenty of examples given, it should be easy to catch up if you never used it before.
  - Alternatively, you can use C++ for the assignments. However, no starting code will be provided.

# Organization

- Course Website
- Weekly Lecture
- Office Hours
- MS Teams

# Organization

- Weekly live lectures
  - TWF 9:30am - 10:20am ECS 108
- Office hours:
  - Wednesdays 1:00pm- 2:00pm ECS 612
  - By appointment
- Use MS Teams

# Lectures

- I will upload the slides on the website, so that you can directly annotate them
- For every class, I will always add references in the end to the textbook and/or external resources
- You are encourage to take a look at the material **before** I present it in class

# Lectures

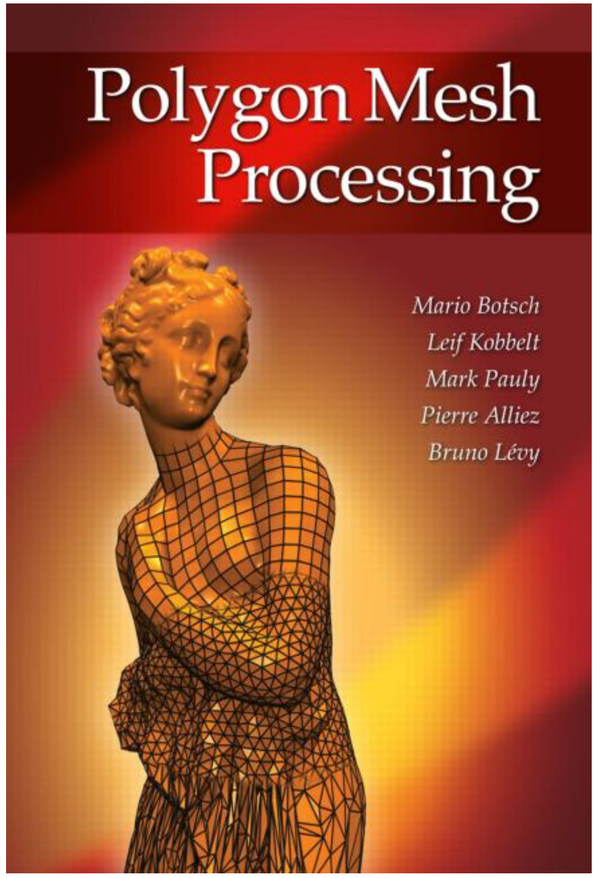
- **Please interrupt me at any time to ask questions**

# Final Coding Project

- Individual project, we will publish the rules later but you are essentially free to do whatever you want, as long as it requires geometry processing

- The project will be presented in a fast-forward session at the end of semester (3 minutes presentation per project)

# Material




**Polygon Mesh Processing**

https://libigl.github.io/libigl-python-bindings/

https://www.wikipedia.org

# Grading

- **Assignments 65% (70% Grad)**
  - **Late assignments count 70%**
- **Project or Exam: 35% (30% Grad)**
- There will be optional tasks, that will allow you to recover points lost in the assignments

# Policy

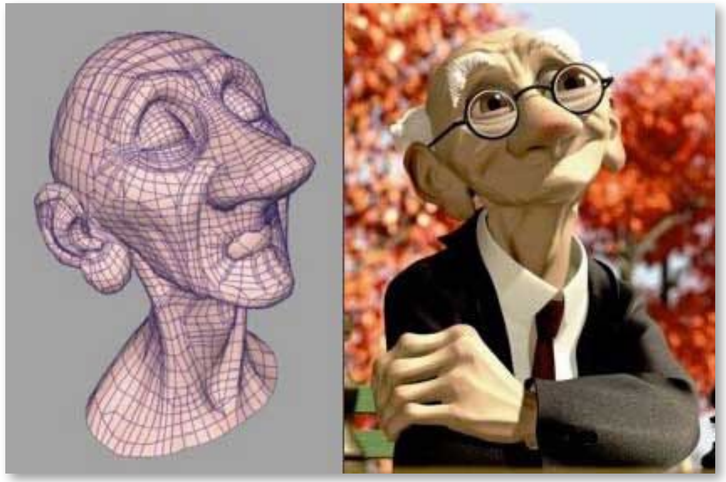
- You are encouraged to consult with your classmates/friends but collaboration in the assignments is **NOT** allowed.

- You are **NOT** allowed to copy code online or use external libraries (except those provided in the class) for the first 3 assignments.

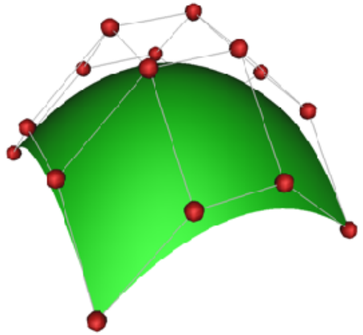
- We will use plagiarism tools to validate all homework. Plagiarism will be punished with a zero-tolerance policy: **the minimal penalty will be a score of 0 points on the assignment, the reduction of 1 letter grade in the final score, and a permanent ban on university-related jobs**.

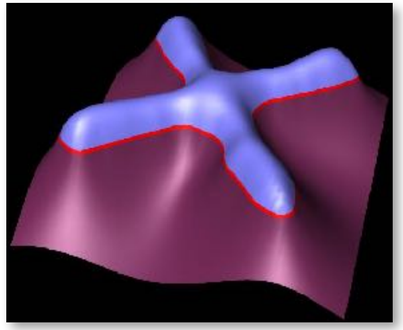
# Course Topics

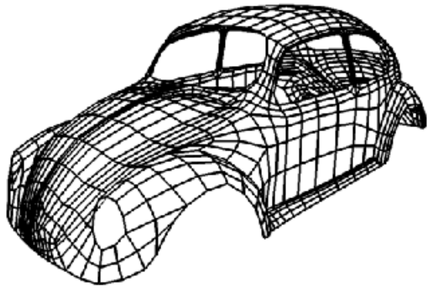
- Overview of shape representations
  - Parametric curves/surfaces
  - Implicits
  - Polygonal meshes



*Pixar*

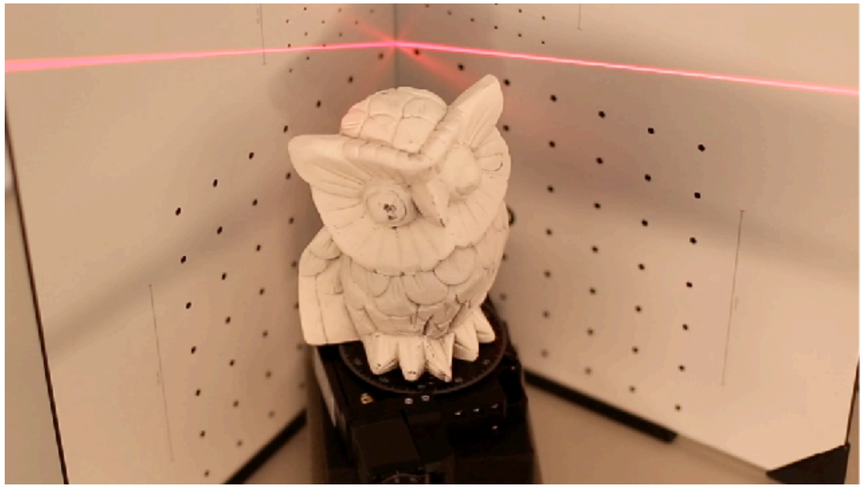


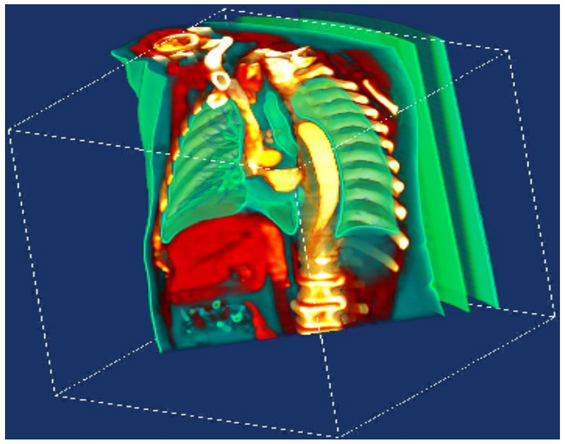


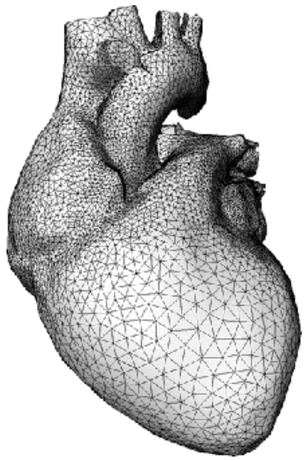


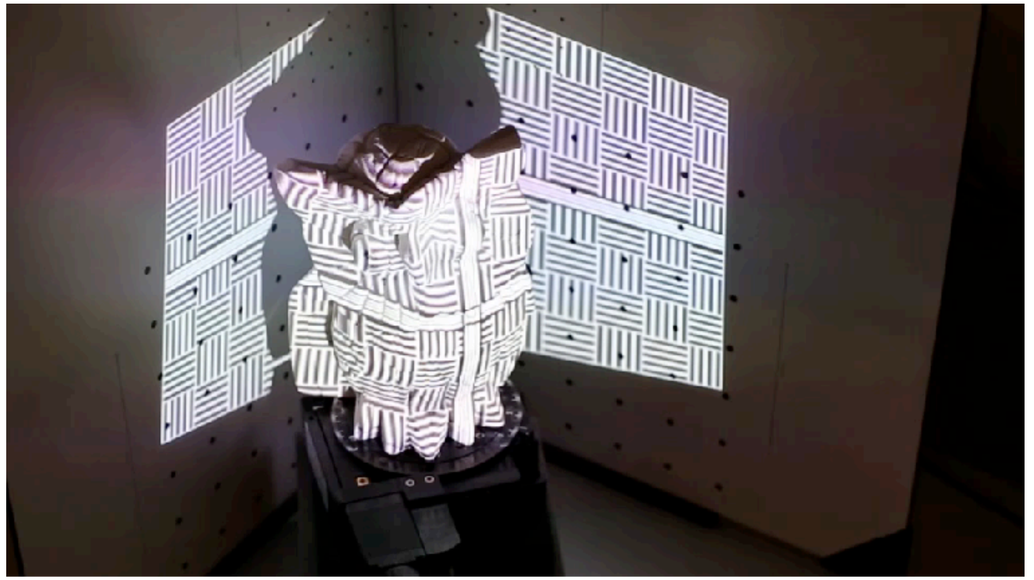
# Course Topics

- Shape acquisition
  - Scanning/imaging
  - Reconstruction



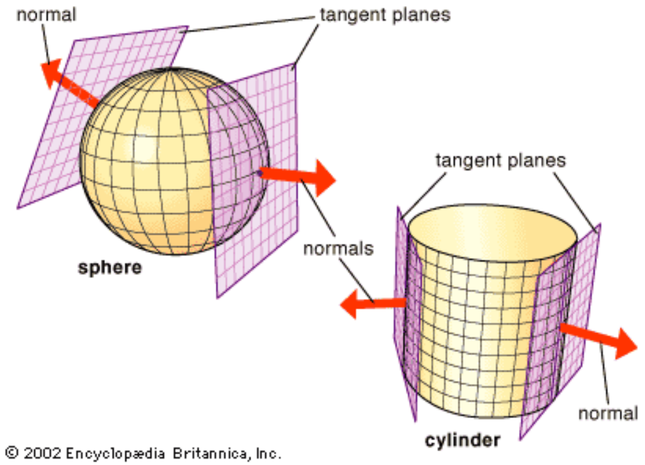


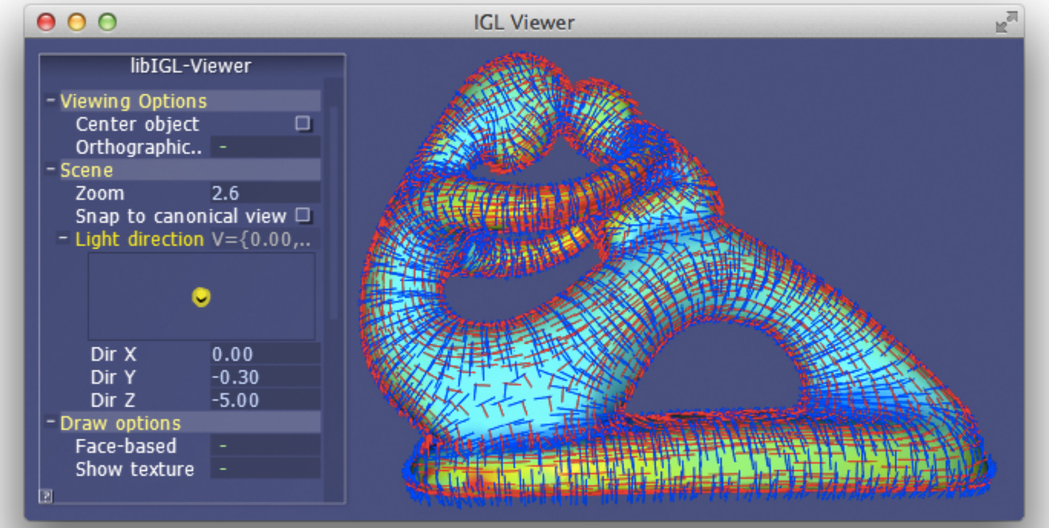




# Course Topics

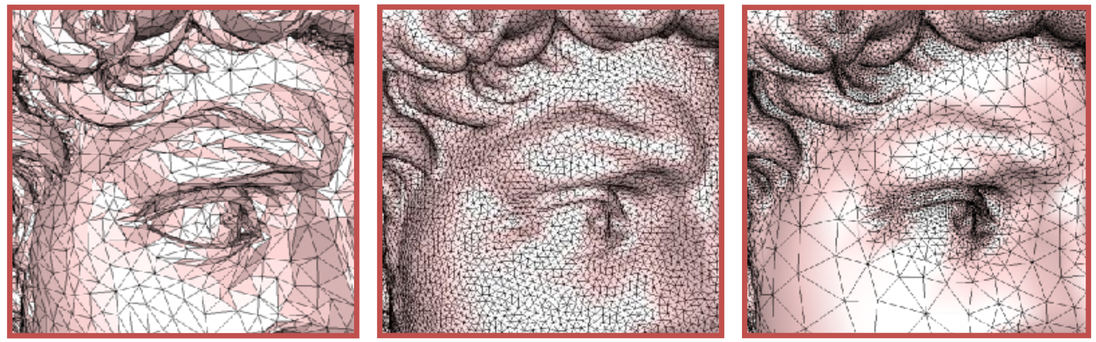
- Differential geometry
  - Continuous and (mostly) discrete
  - Powerful tool to analyze and model shapes

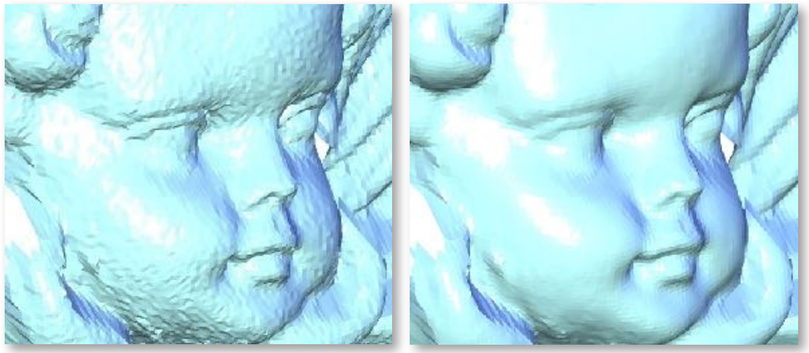


# Course Topics

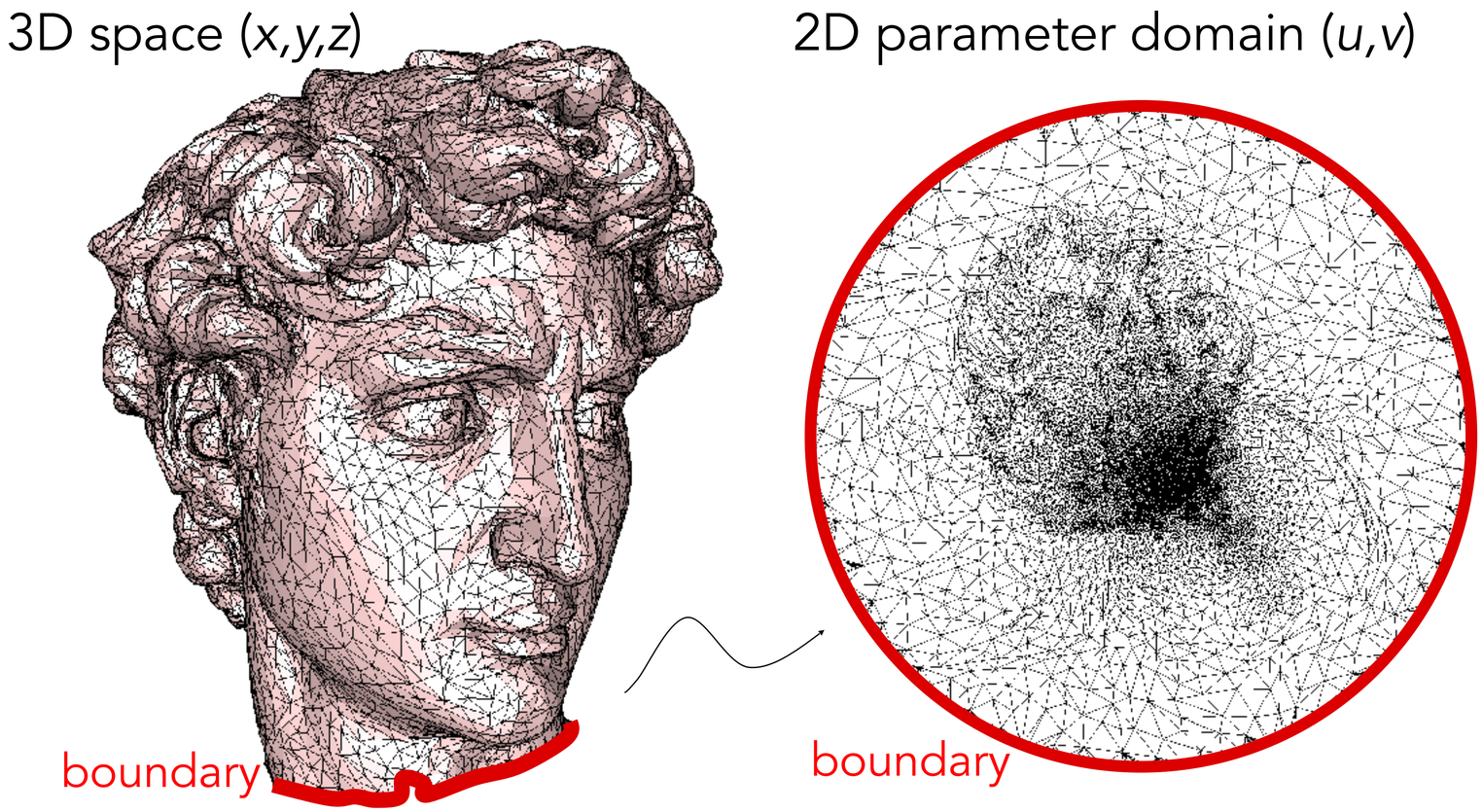
- Digital geometry processing
  - Denoising, smoothing, simplification, remeshing, parameterization, compression





# Course Topics

- Parameterization



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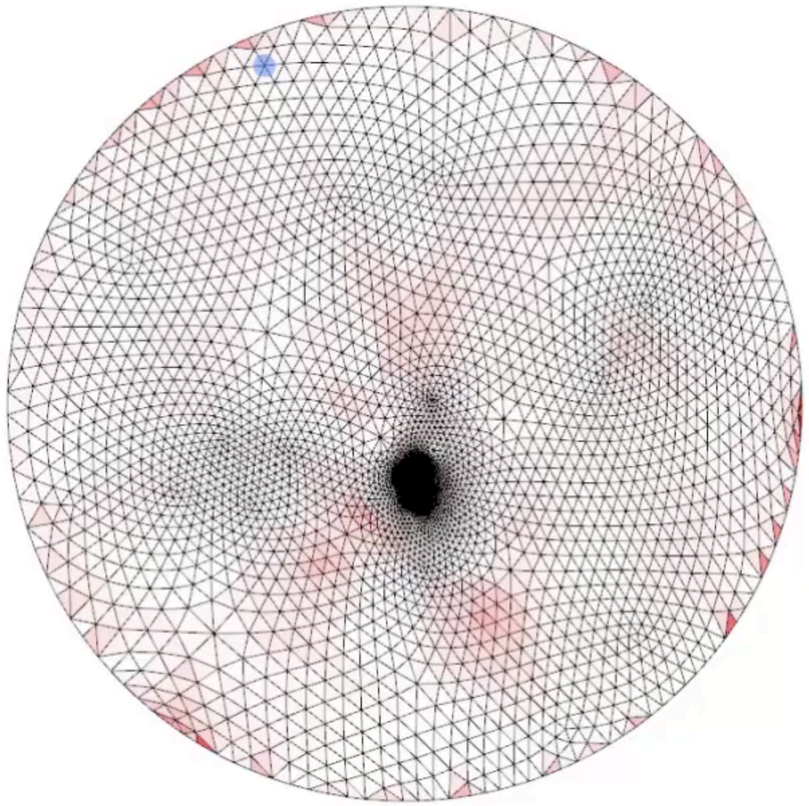
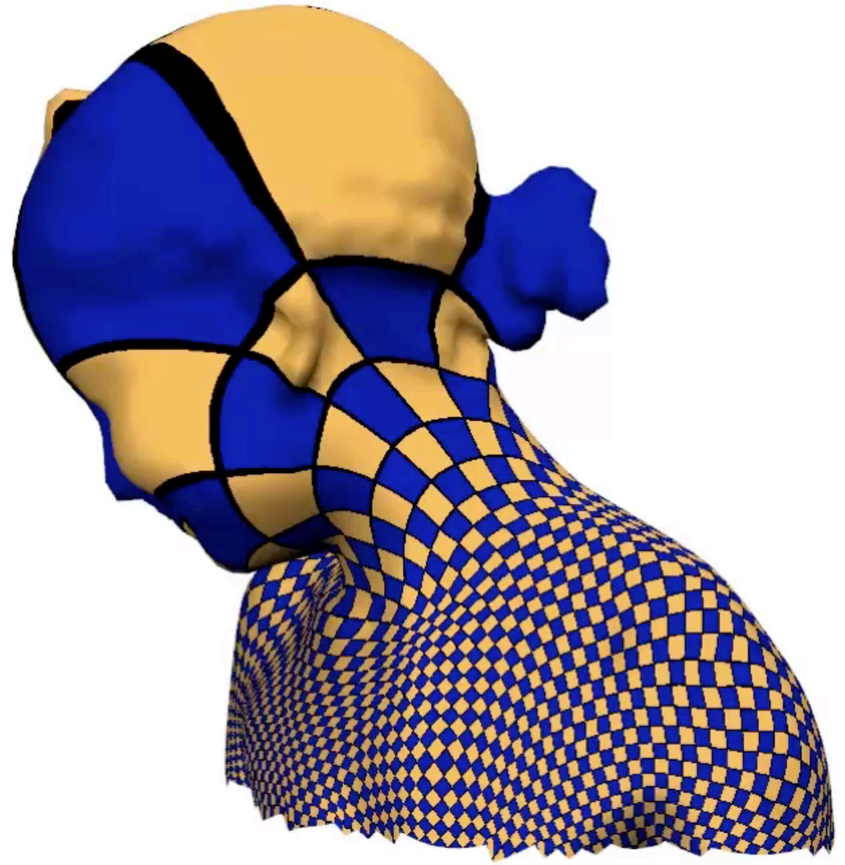
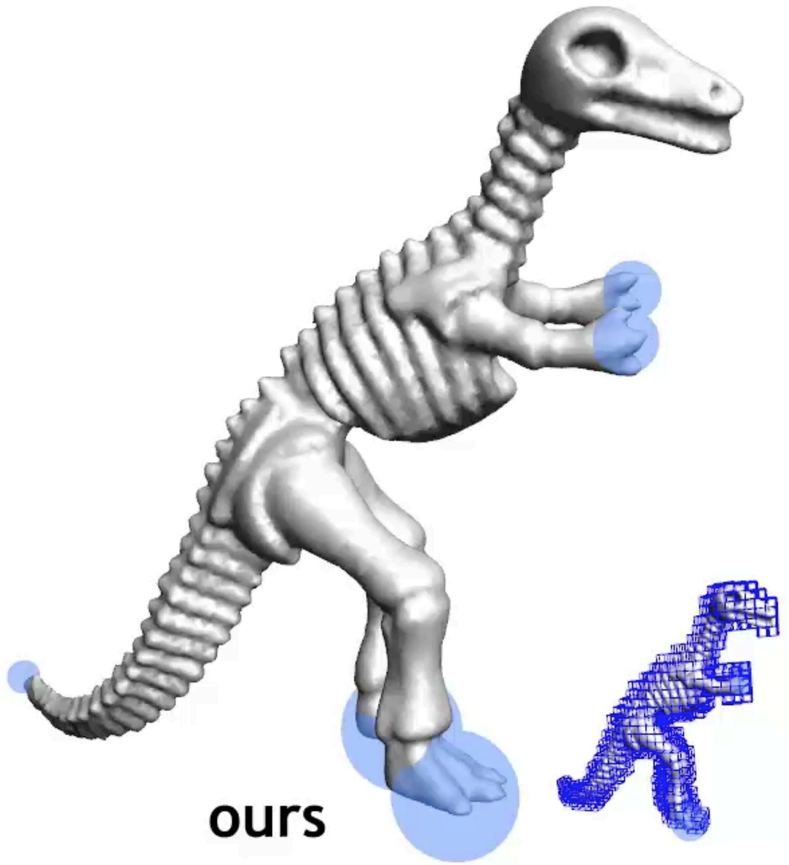




# Course Topics

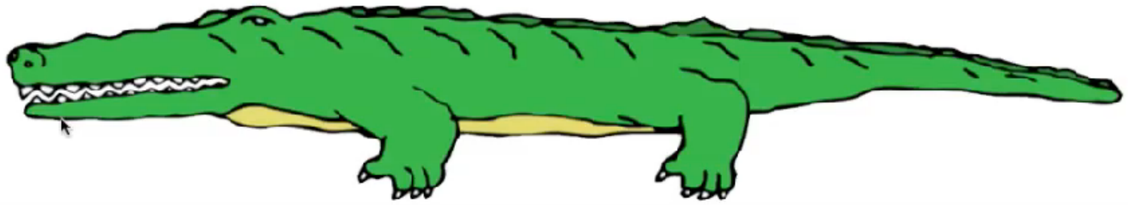
- Shape creation and editing

http://youtu.be/W0XGkS7zebo



# Course Topics

- Skinning, animation



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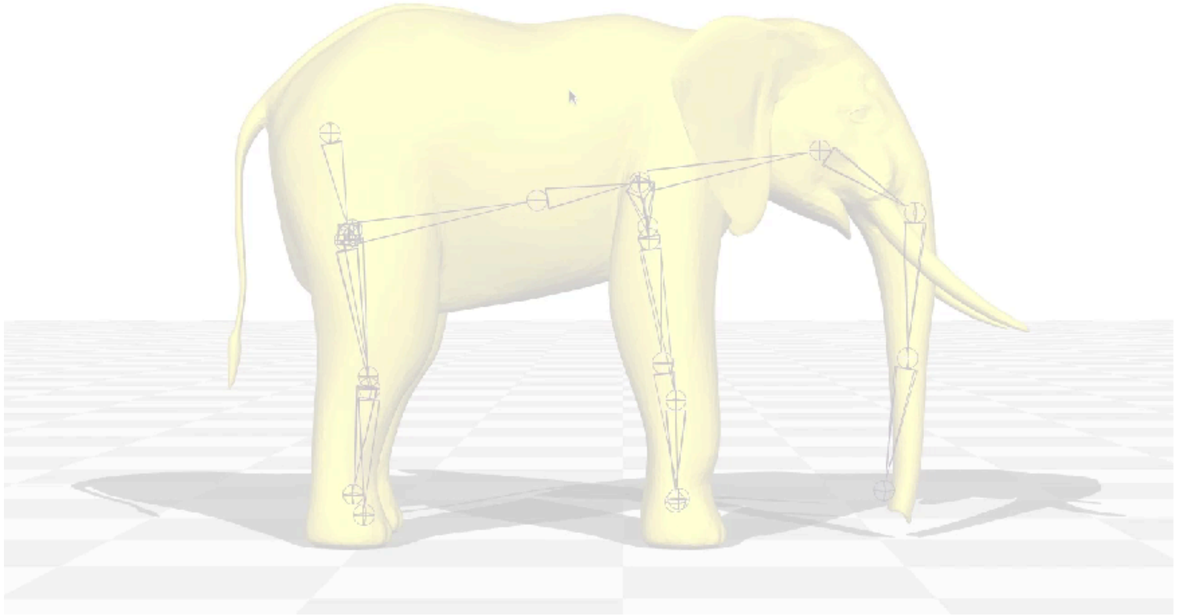
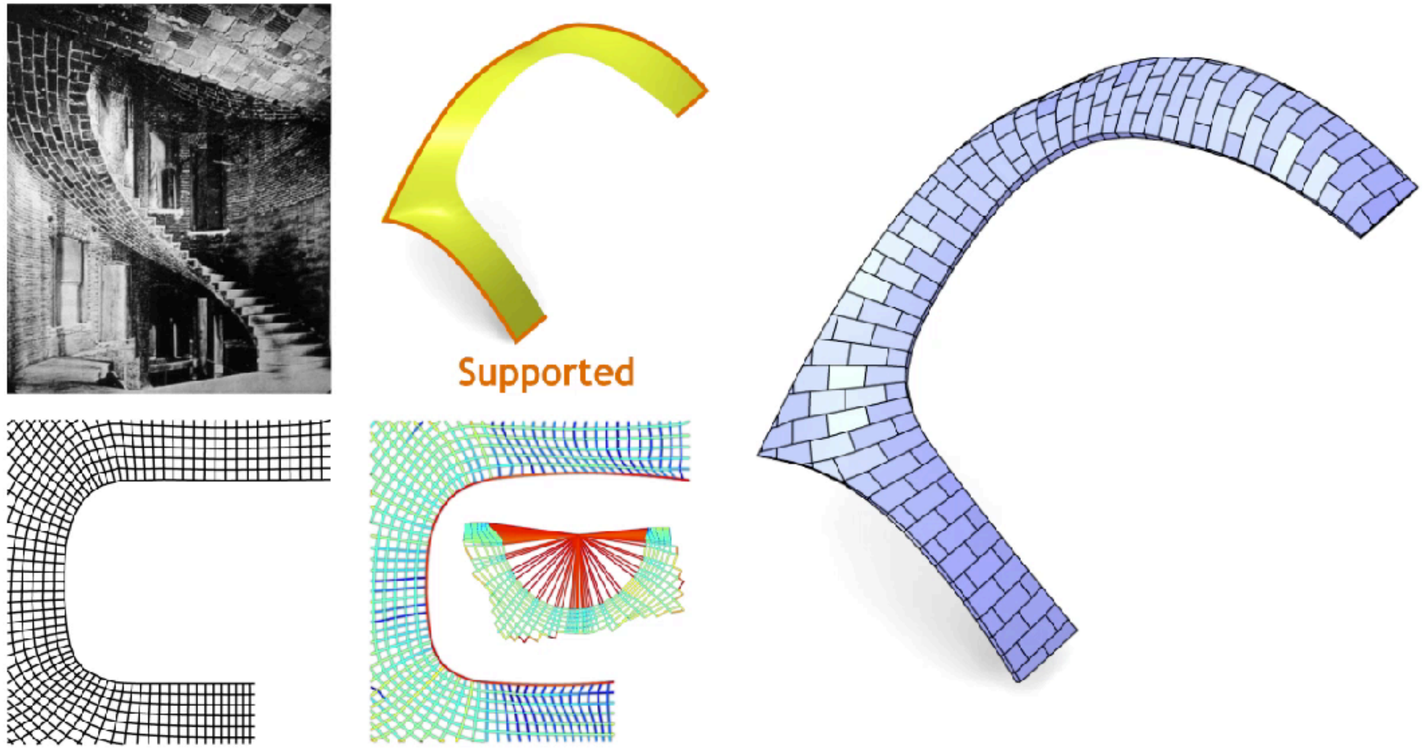


# Course Topics

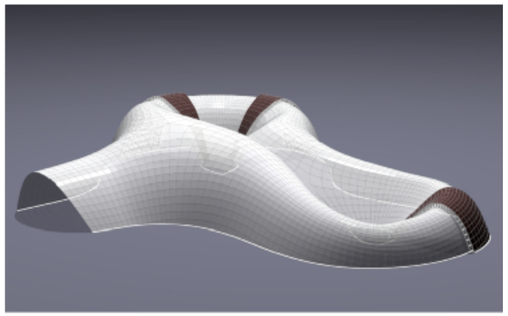
- Architectural geometry and structure-aware modeling

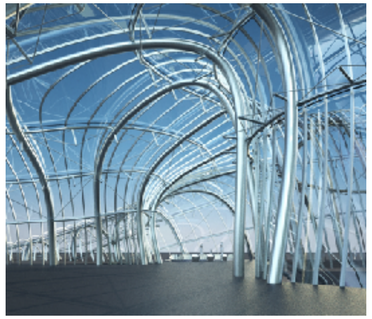



Panozzo et al. SIGGRAPH 2013

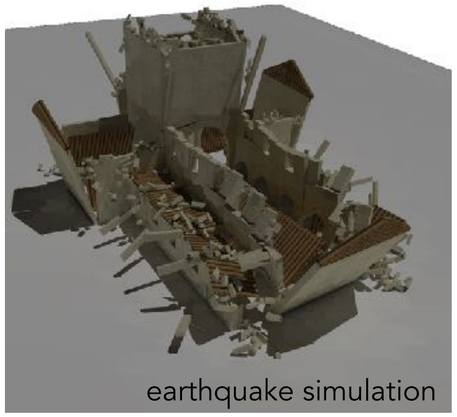
# Course Topics

- Architectural geometry and structure-aware modeling



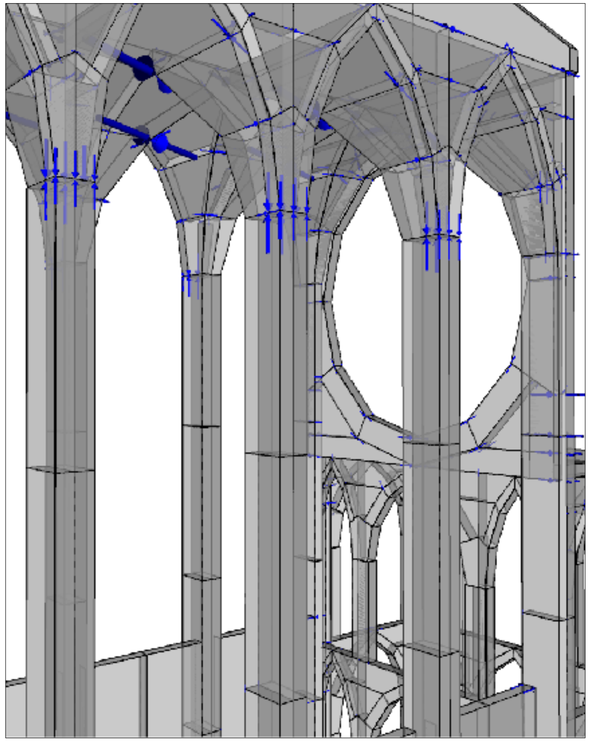


[Pottmann 08]
http://www.dmg.tuwien.ac.at/pottmann/2008/panels08/panels.html



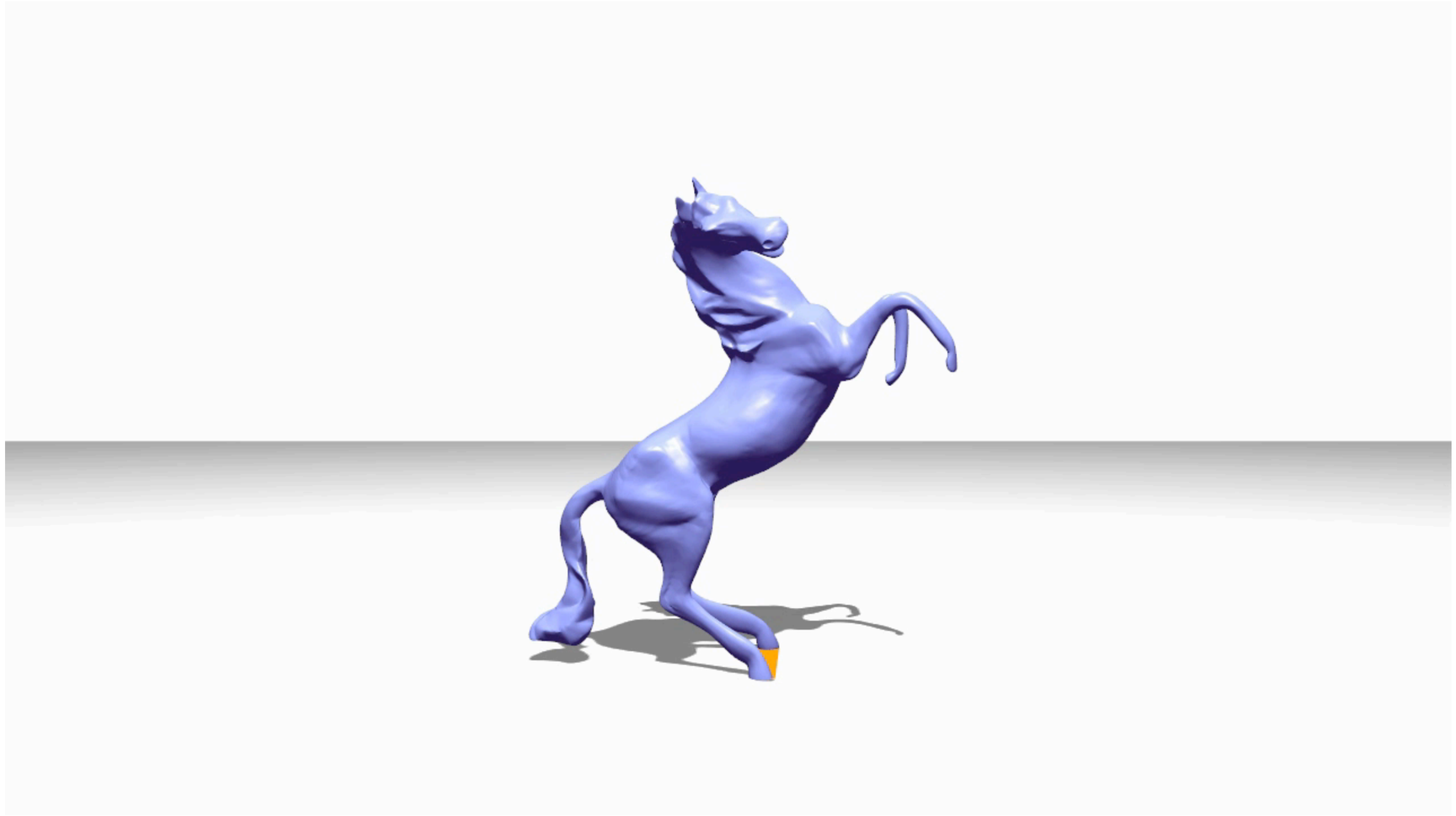
earthquake simulation

[Whiting 09]
http://www.inf.ethz.ch/personal/whitinge/projects/siggasia09.html



# Course Topics

- 3D fabrication-aware shape modeling



# Course Topics

- 3D fabrication-aware shape modeling

# Thank you