

IFT 6113

INTRODUCTION

<http://tiny.cc/ift6113>



Mikhail Bessmeltsev

TEAM

Instructor: Mikhail Bessmeltsev

Email: bmpix@iro.umontreal.ca

Office hour: Fri, 4:30–5:30 pm, Zoom or AA
3357

Web: <http://www-labs.iro.umontreal.ca/~bmpix/>

TA: Ivan Puhachov

Contact: via Piazza

FORMALITIES

Lectures: Tue 9.30-11.30

Thu 16.30-18.30

Web: <http://tiny.cc/ift6113>

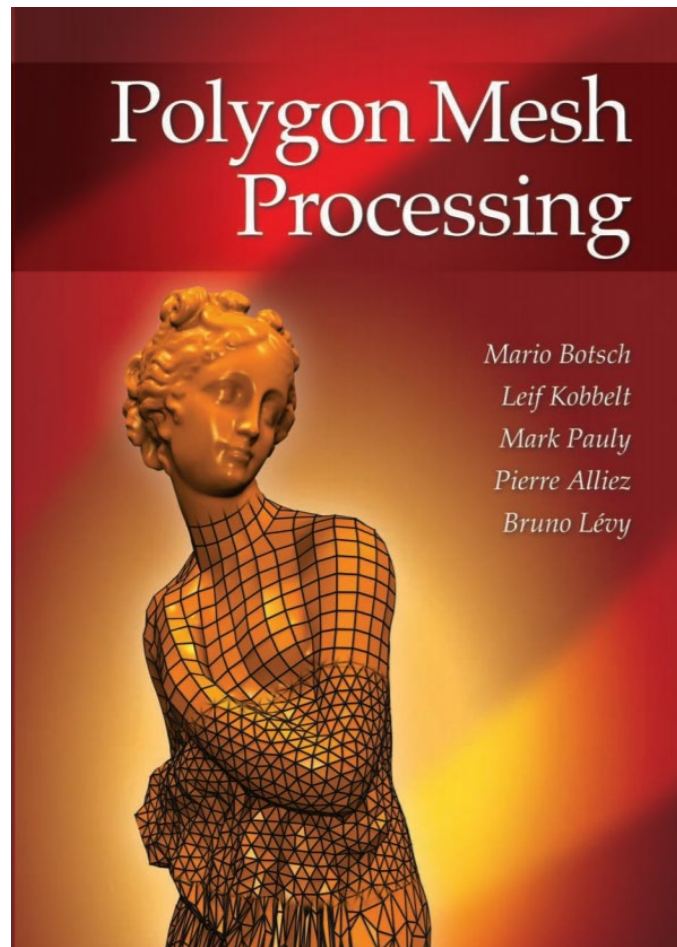
Use Piazza!

<http://piazza.com/umontreal.ca/fall2022/ift6113>

TEXTBOOK (OPTIONAL)

Polygon Mesh Processing by Botsch et al.

Free online at UdeM library



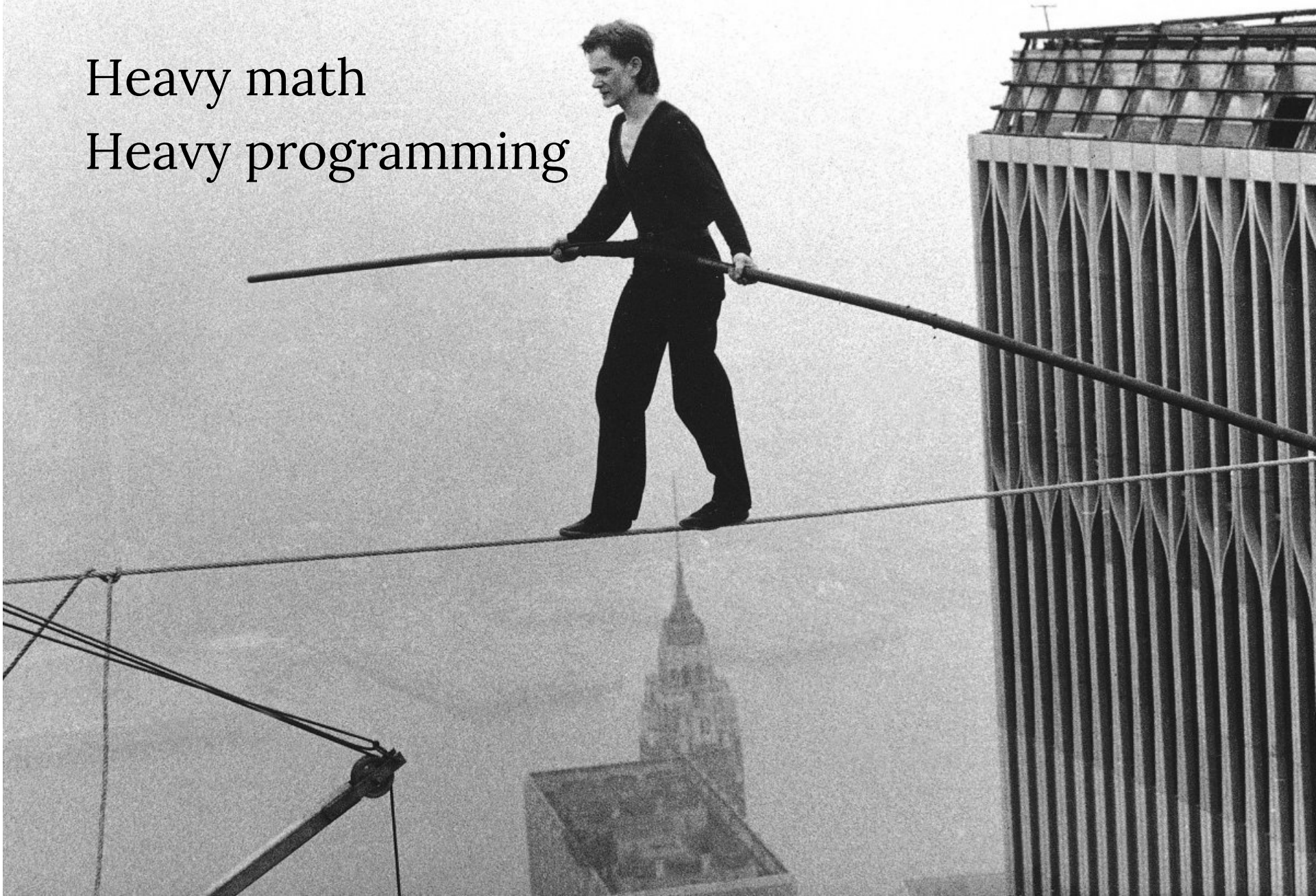
PREREQS

- For sure:
 - Calculus
 - Linear algebra
- Bonus (but not required):
 - Differential Geometry
 - Partial Differential Equations

THIS IS NOT AN EASY COURSE

Heavy math

Heavy programming



BUT INTERESTING

I will help
and be generous with grading

GRADING

Assignments (33%)		100%
Paper Presentation (25%)		
Participation (2%)		
Final Project (40%)		

FACE TO FACE GRADING

- Understand each line of your code
- Plagiarism policy

PAPER PRESENTATION (25%)

- Choose a SIGGRAPH paper on a related topic
 - Give a talk!
 - Others: ask questions
-
- Choose a paper (and post about it in Piazza) by **Oct 29th**

PARTICIPATION (2%)

- Classroom
- Questions/discussion at paper and project presentations

FINAL PROJECT (40%)

1. Choose a recent SIGGRAPH paper
2. Propose an improvement/modification
3. Implement
4. Present!

Important dates:

Project proposal: Oct 21st, by midnight

Final Presentation: Dec 8th, in class

NO EXAMS

WHAT YOU WILL LEARN

Fundamentals:

Mesh data structures
Discrete Differential Geometry
Discrete Laplacians
Vector Fields

Applications:

Shape Deformations
Surface Reconstruction
Mesh Parameterization
Remeshing
Animation/Sketch-based modeling/...
Learning geometry

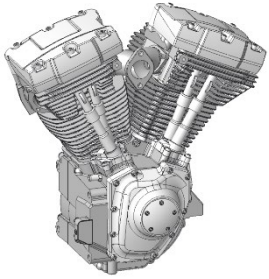
TODAY

1. Geometric modeling?
2. Shape analysis?
3. Studying shapes: what we need
4. Applications

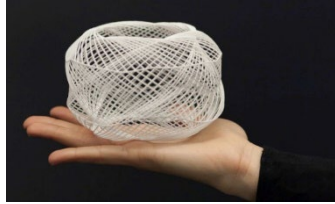
TODAY

- 1. Geometric modeling?**
- 2. Shape analysis?**
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WHAT IS GEOMETRIC MODELING?



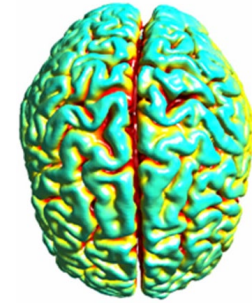
Mechanical Engineering



Fabrication



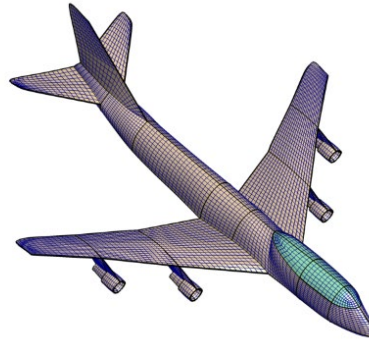
Architecture and civil engineering



Medical



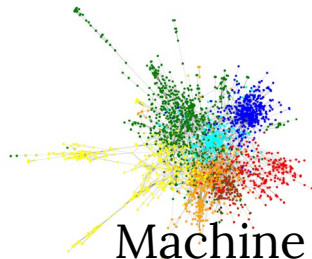
Computer Vision



Geometric Modeling



Computer Graphics



Machine Learning

$$\begin{aligned} & \min f(x) \\ & \text{s.t. } g(x) \leq 0 \\ & \quad h(x) = 0 \end{aligned}$$

Numerical Optimization



Augmented/Virtual Reality



Human-Computer Interaction (HCI)

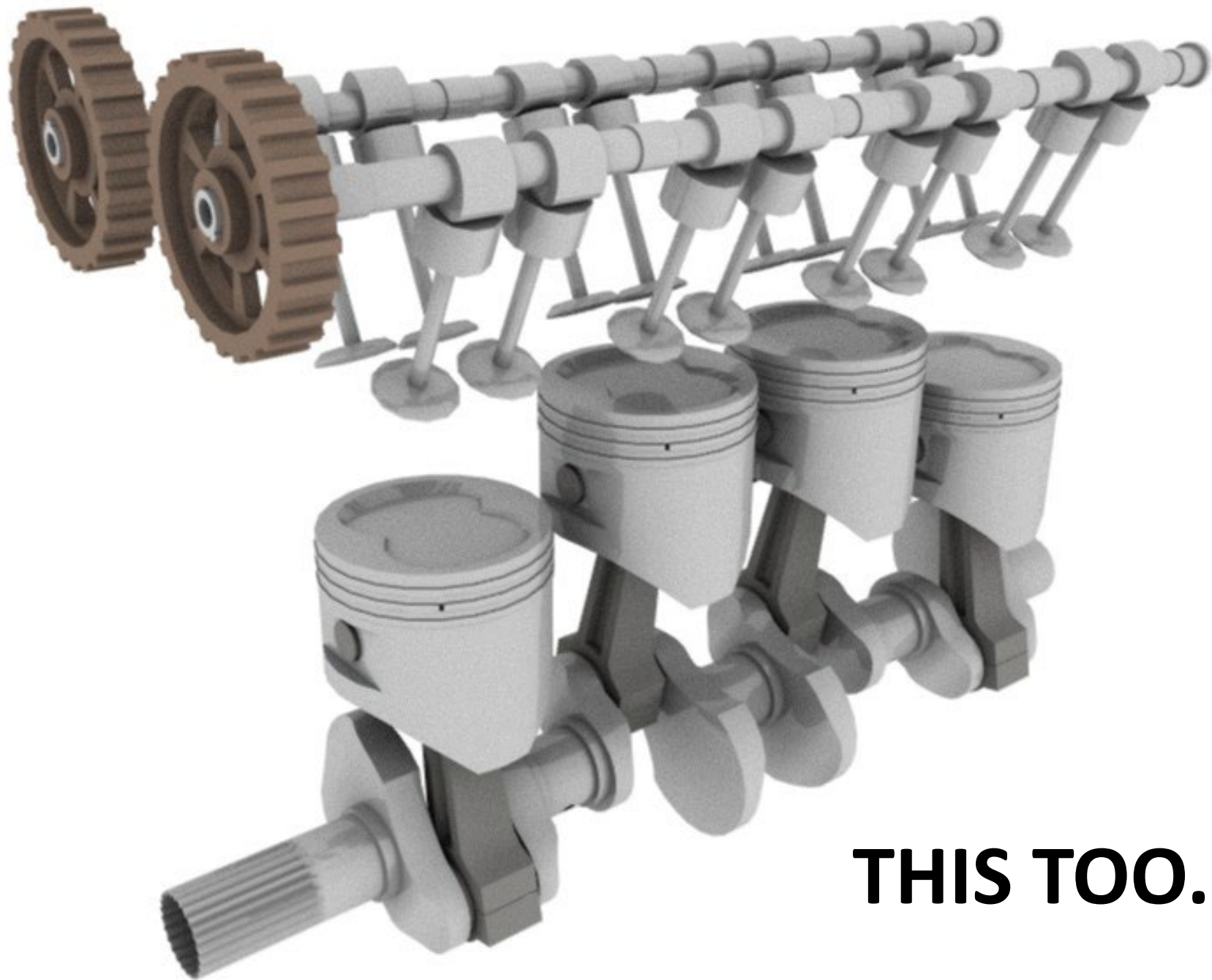




EVENT COVERAGE

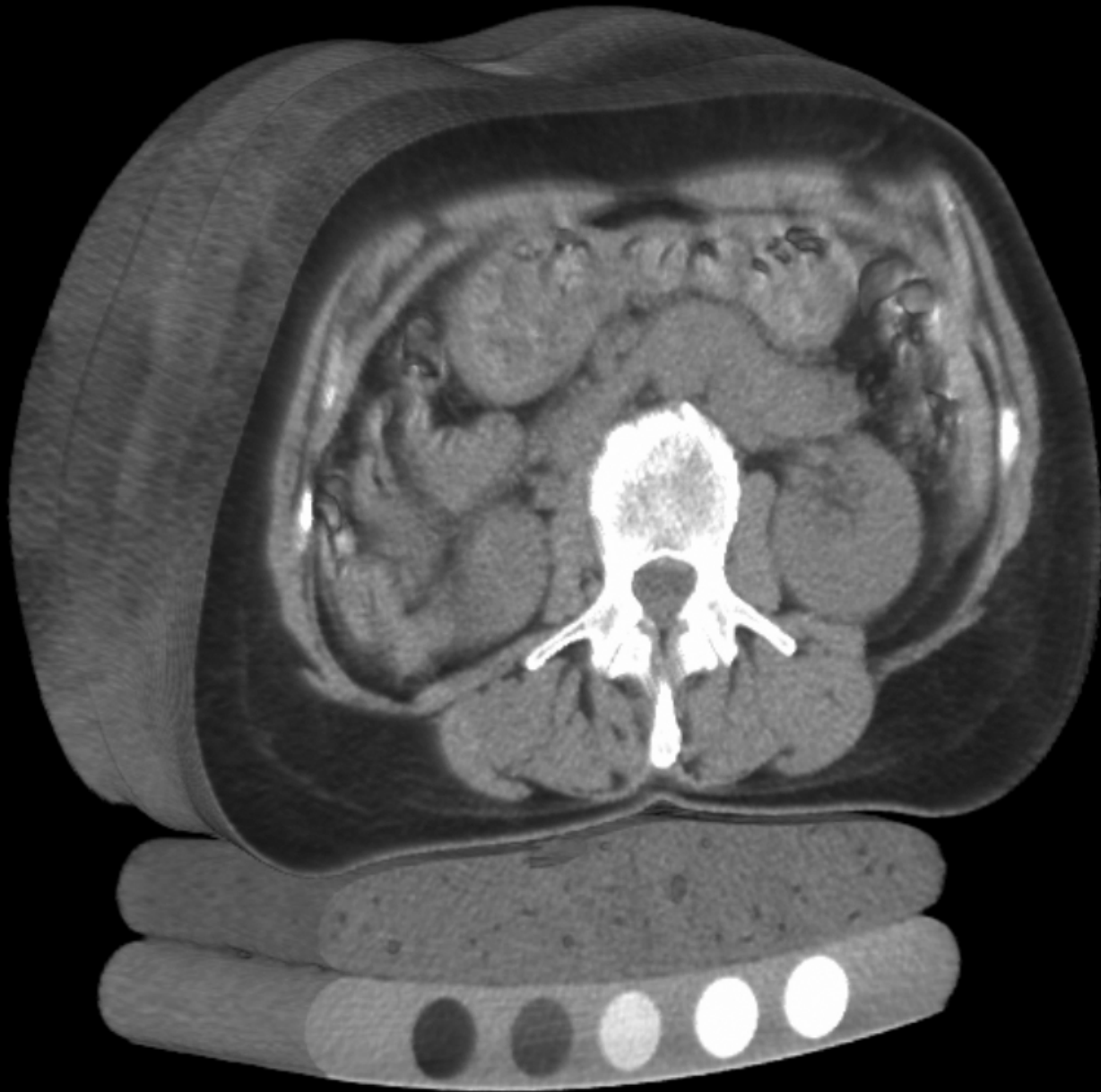
AND THIS.





THIS TOO.

AND EVEN THIS.

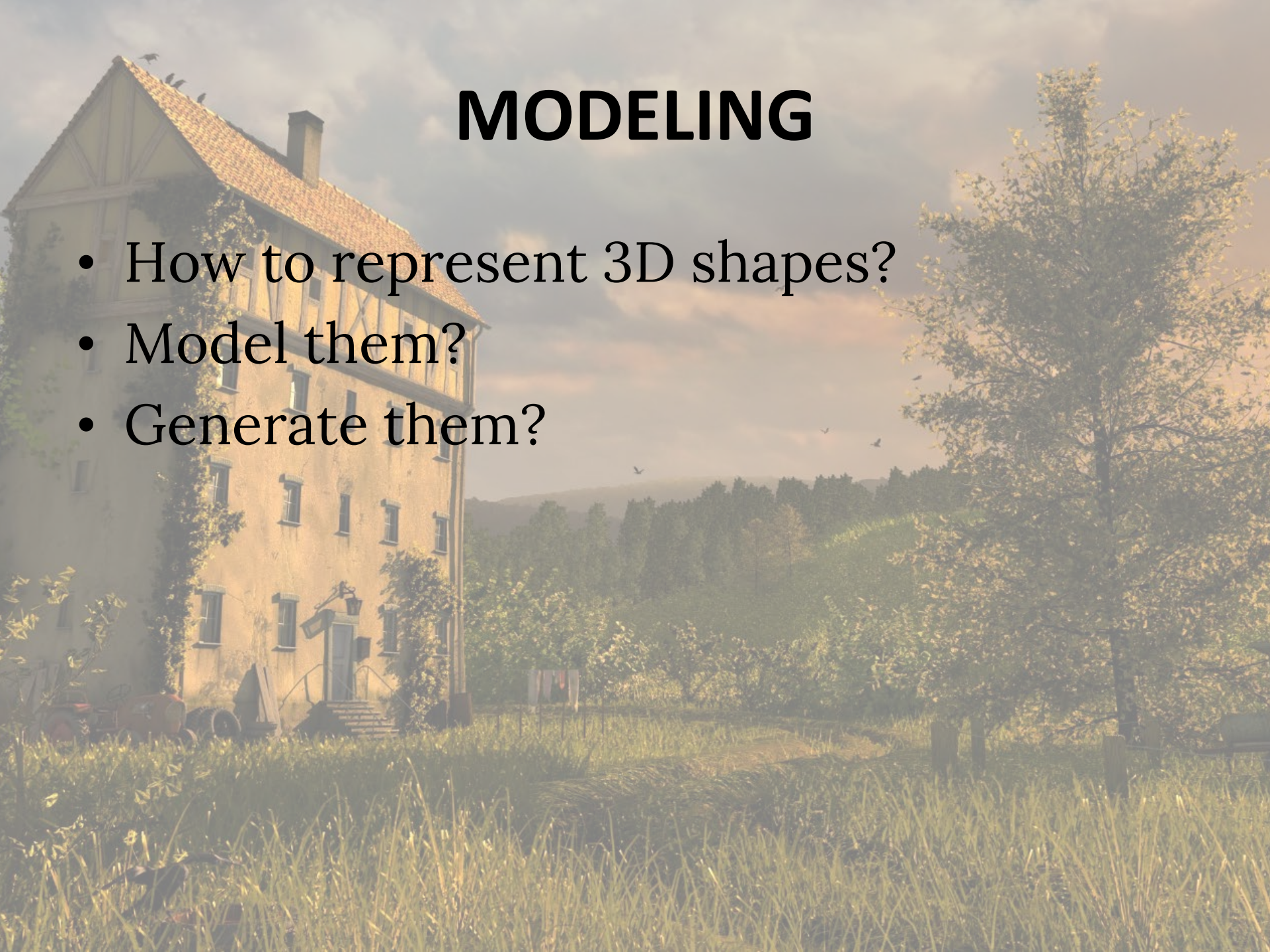


MODELING



MODELING

- How to represent 3D shapes?
- Model them?
- Generate them?



MODELING

- How to represent 3D shapes?
- Model them?
- Generate them?
- How to scan a building? An animal? A molecule?

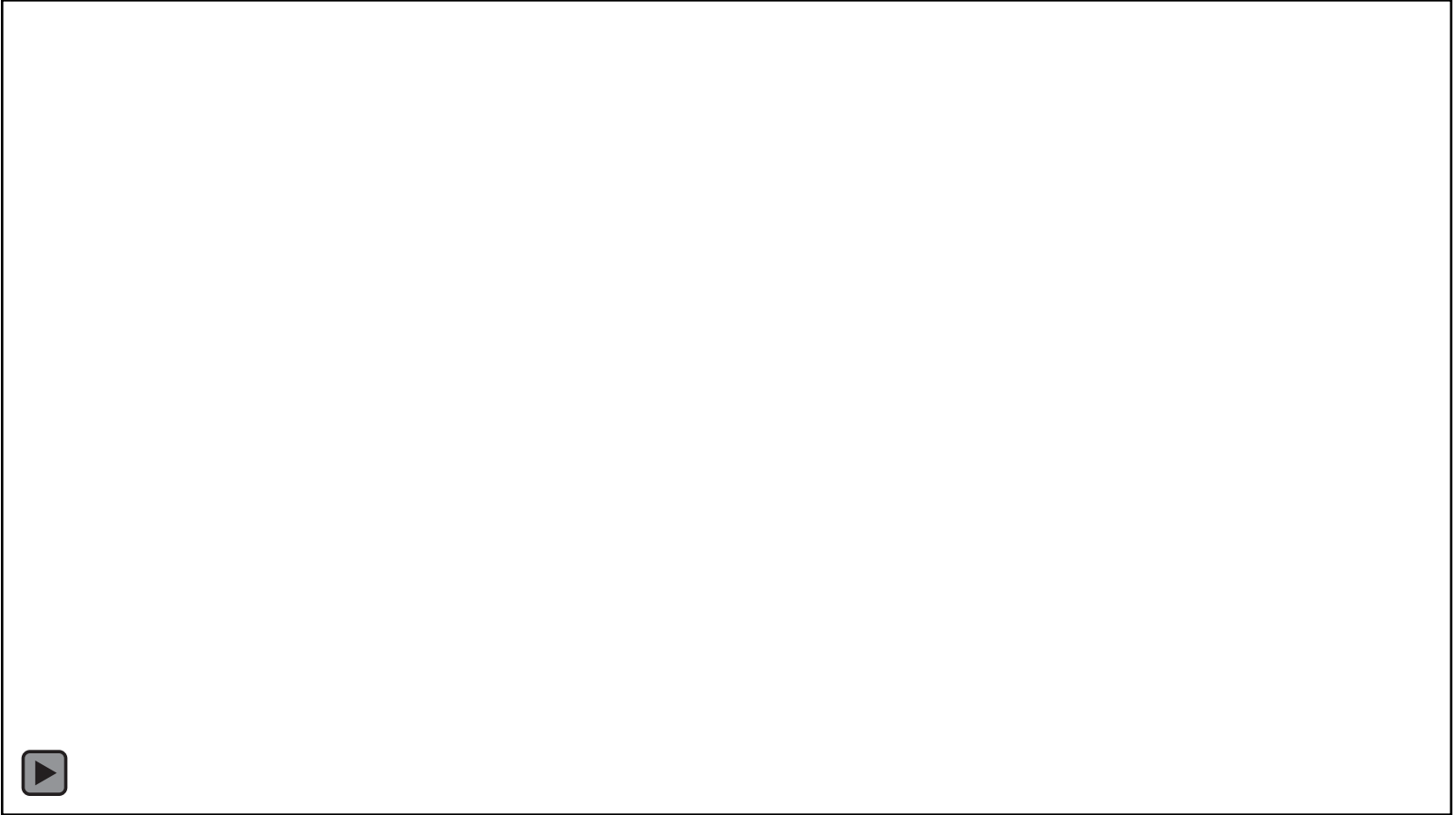
MODELING

- How to represent 3D shapes?
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- Generate them?
- How to scan a building? An animal? A molecule?
- How to deform a model?

MODELING

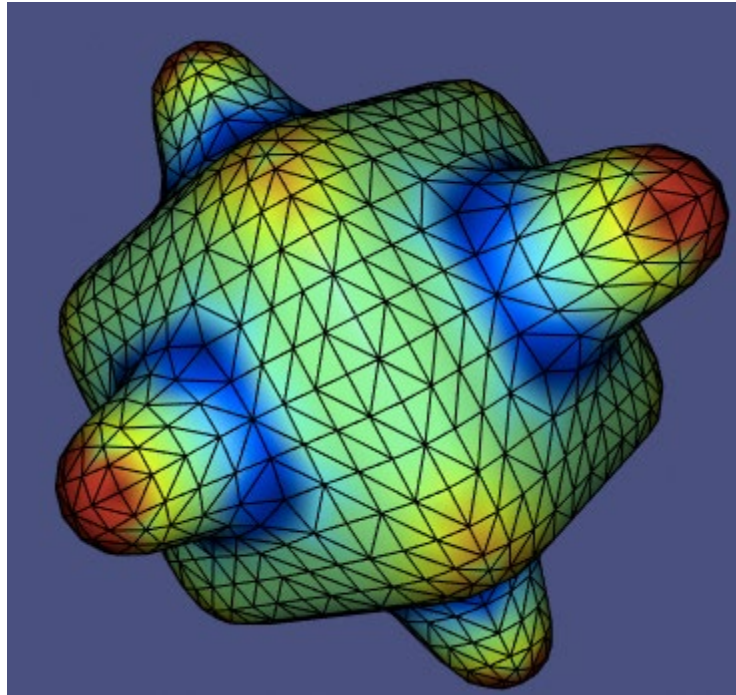
- How to represent 3D shapes?
- Model them?
- Generate them?
- How to scan a building? An animal? A molecule?
- How to deform a model?
- ...

MODELING SESSION



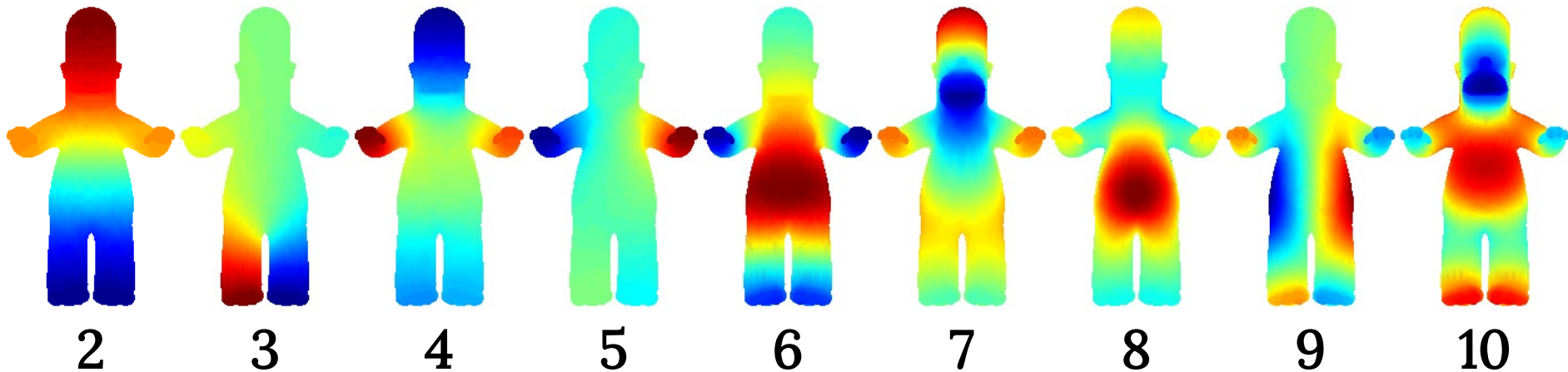
SHAPE ANALYSIS

Which parts of 3D shape are *interesting*?



SHAPE ANALYSIS

Can you **hear** the shape of a drum?



SHAPE ANALYSIS

How to create vector fields and how to use them?



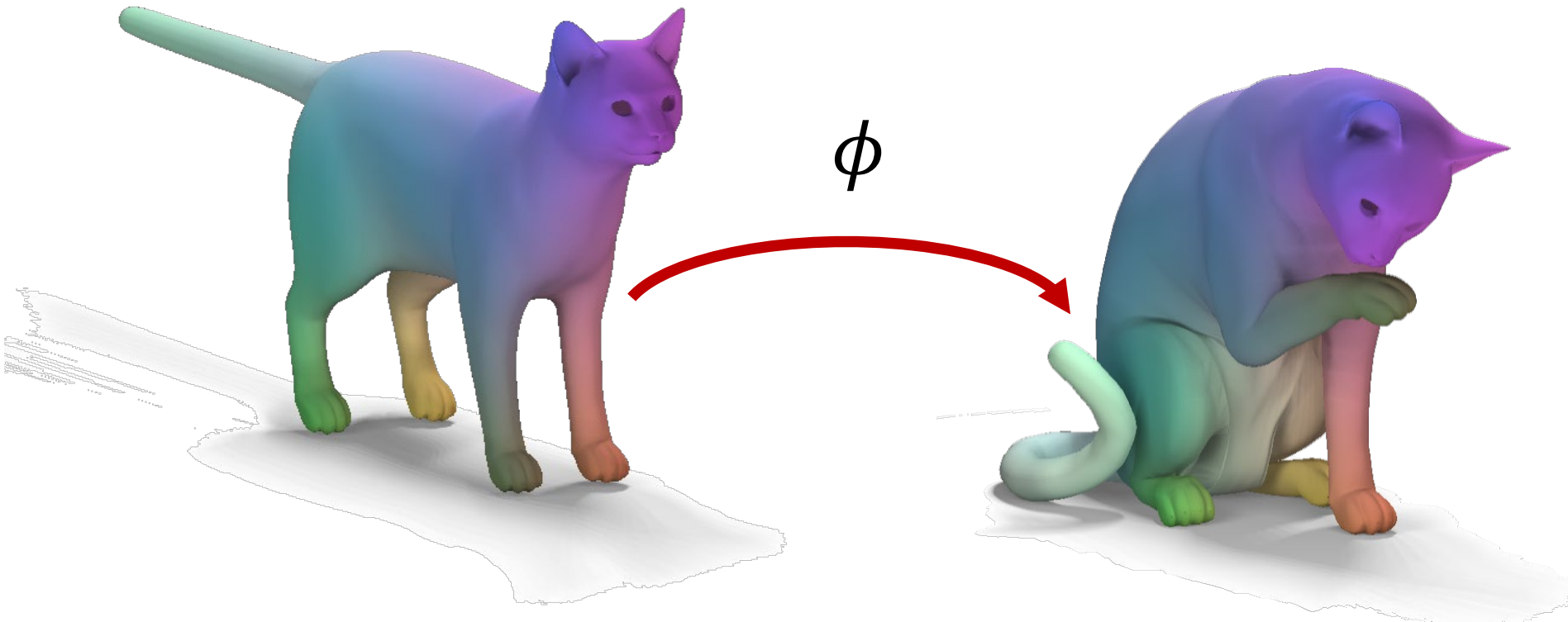
SHAPE ANALYSIS

How can we *compare* shapes?



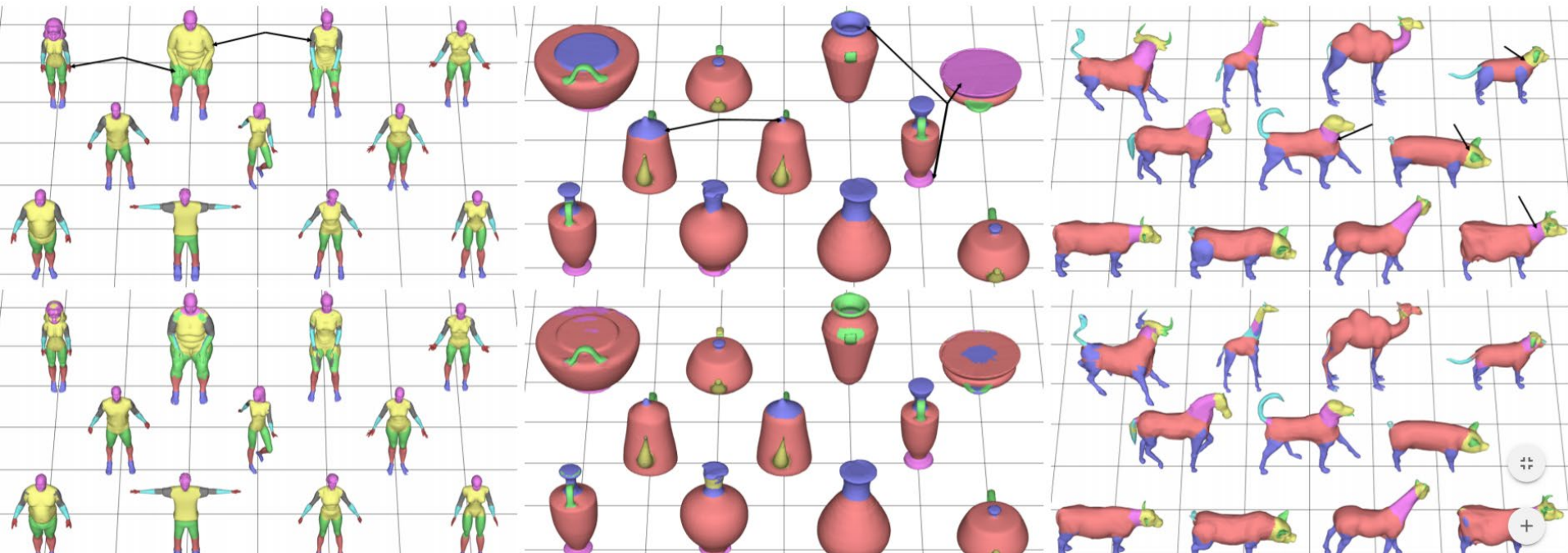
SHAPE ANALYSIS

- How can we *compare* shapes?
- How to map them onto each other?



SHAPE ANALYSIS

Segment shapes?



<https://arxiv.org/pdf/1705.11050.pdf>

ROADMAP

- Data Structures $\int dx$
- Recap of differential geometry $\iiint dx dy dz$
- Mesh Simplification & Saliency $\iint dx dy$
- Vector Fields $\iiint dx dy dz$
- Mesh Parameterization $\iint dx dy$
- Shape Deformation $\iint dx dy$
- 2D modeling $\int dx$
- Remeshing $\iint dx dy$
- Learning $\int dx$



SOURCES

Based on two courses:
Many slides are derived from theirs



6.838 (Justin Solomon)

MIT CSAIL

http://groups.csail.mit.edu/gdpgroup/6838_spring_2021.html



524 (Alla Sheffer)

UBC CS

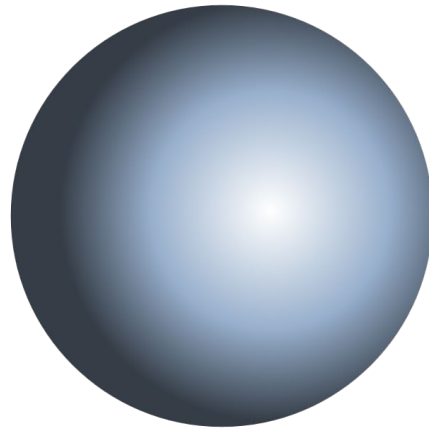
<https://www.cs.ubc.ca/~sheffa/dgp/>

TODAY

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2. Shape analysis?
- 3. Studying shapes: what we need**
4. Applications

WE WANT TO STUDY SHAPES

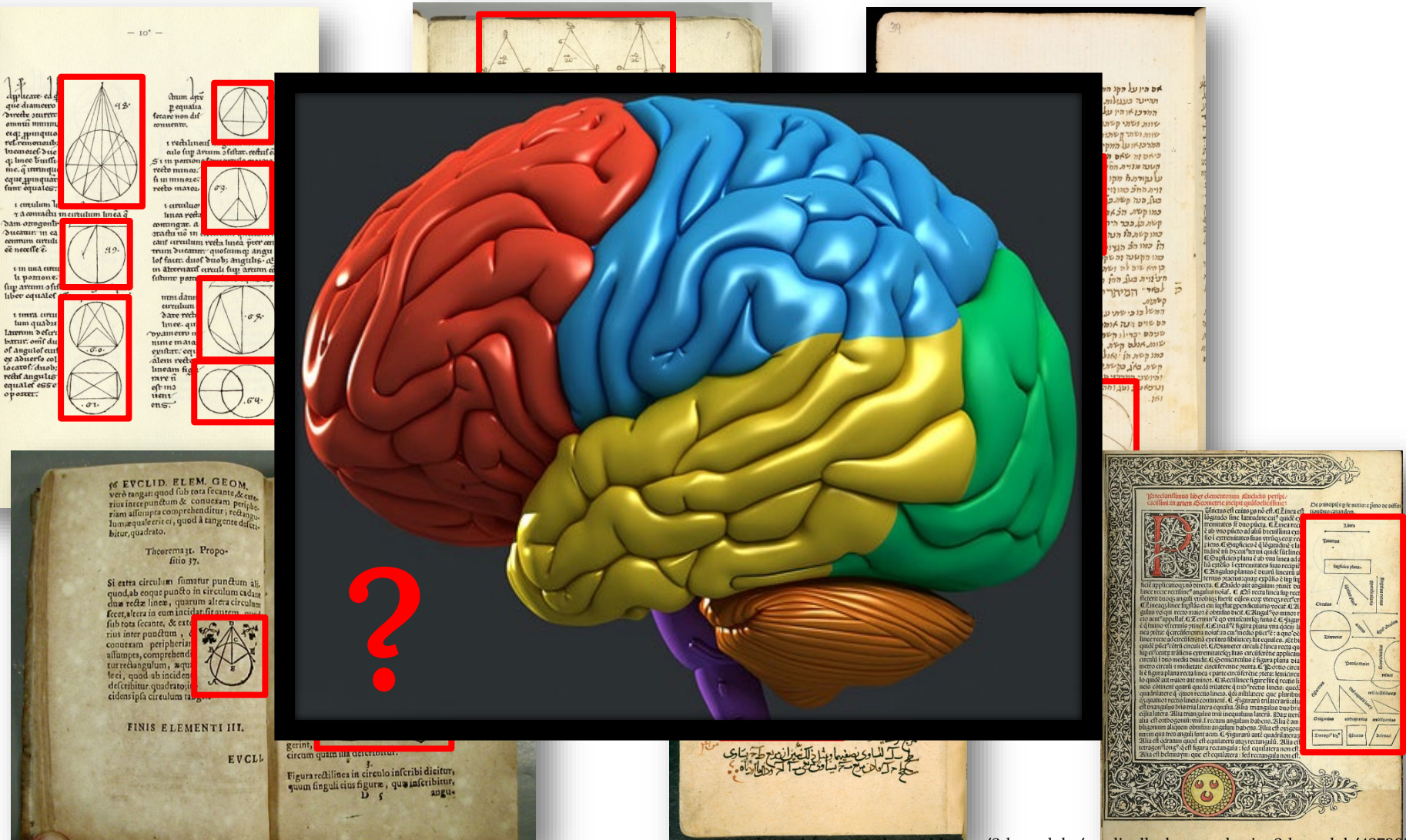
What (pure) mathematicians think:



EUCLIDEAN GEOMETRY

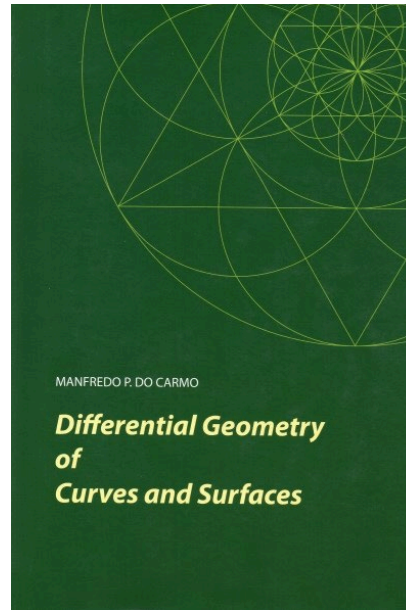


EUCLIDEAN GEOMETRY

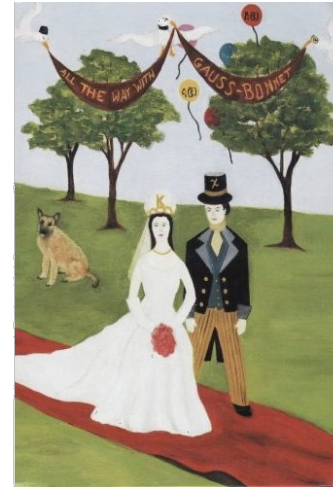
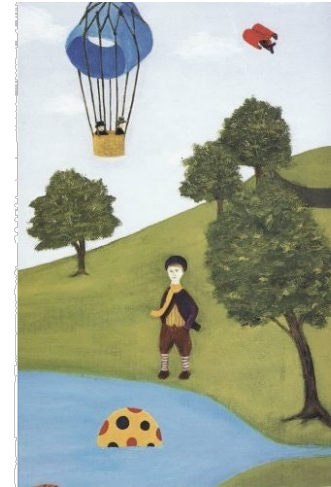
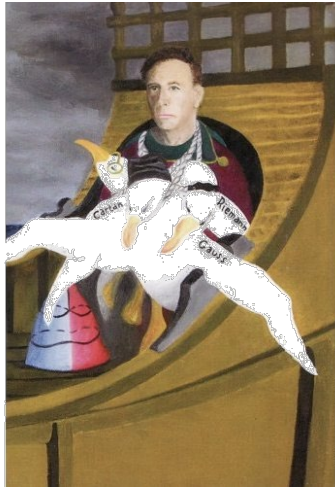


DIFFERENTIAL GEOMETRY

Easy intro:

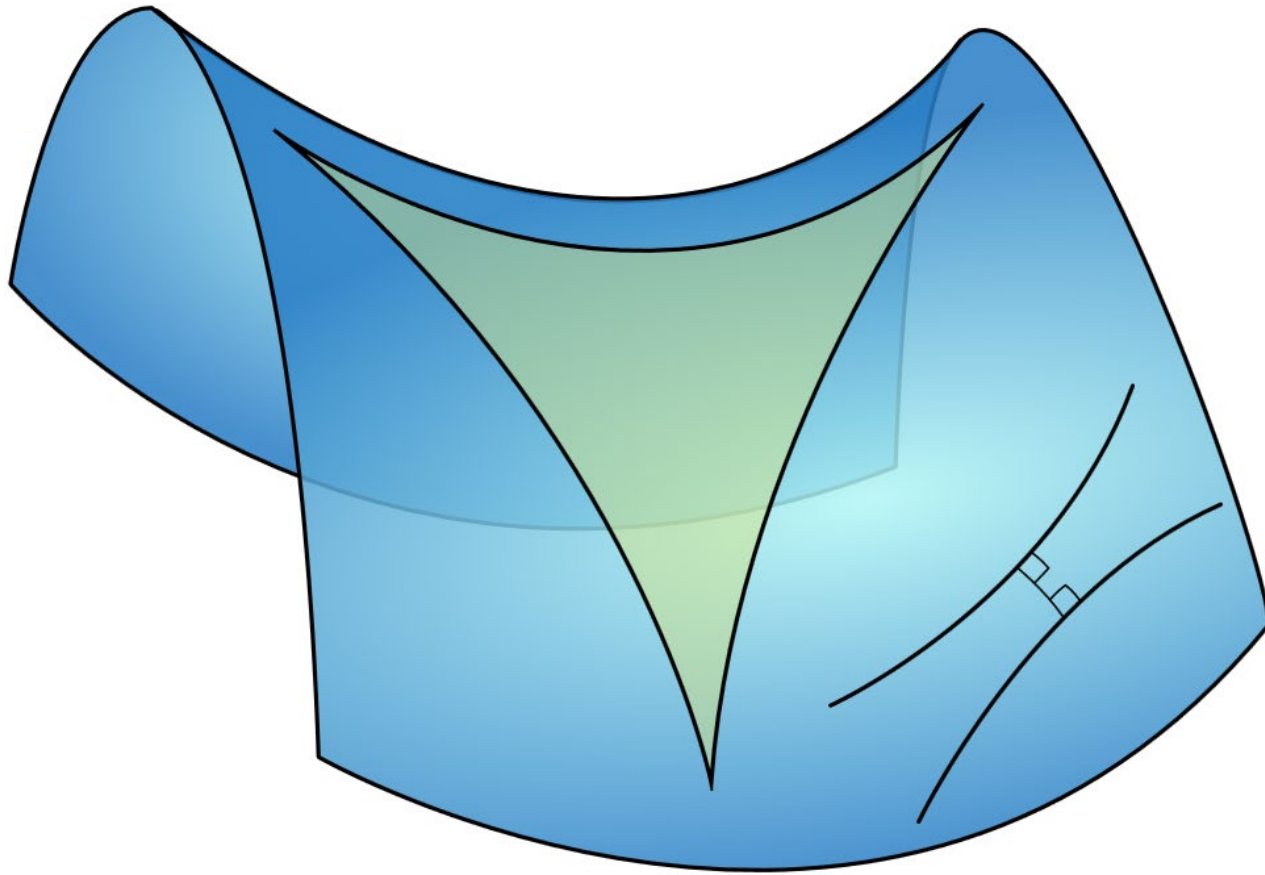


Harder intro (5 volumes):



Spivak: *A Comprehensive Introduction to Differential Geometry*

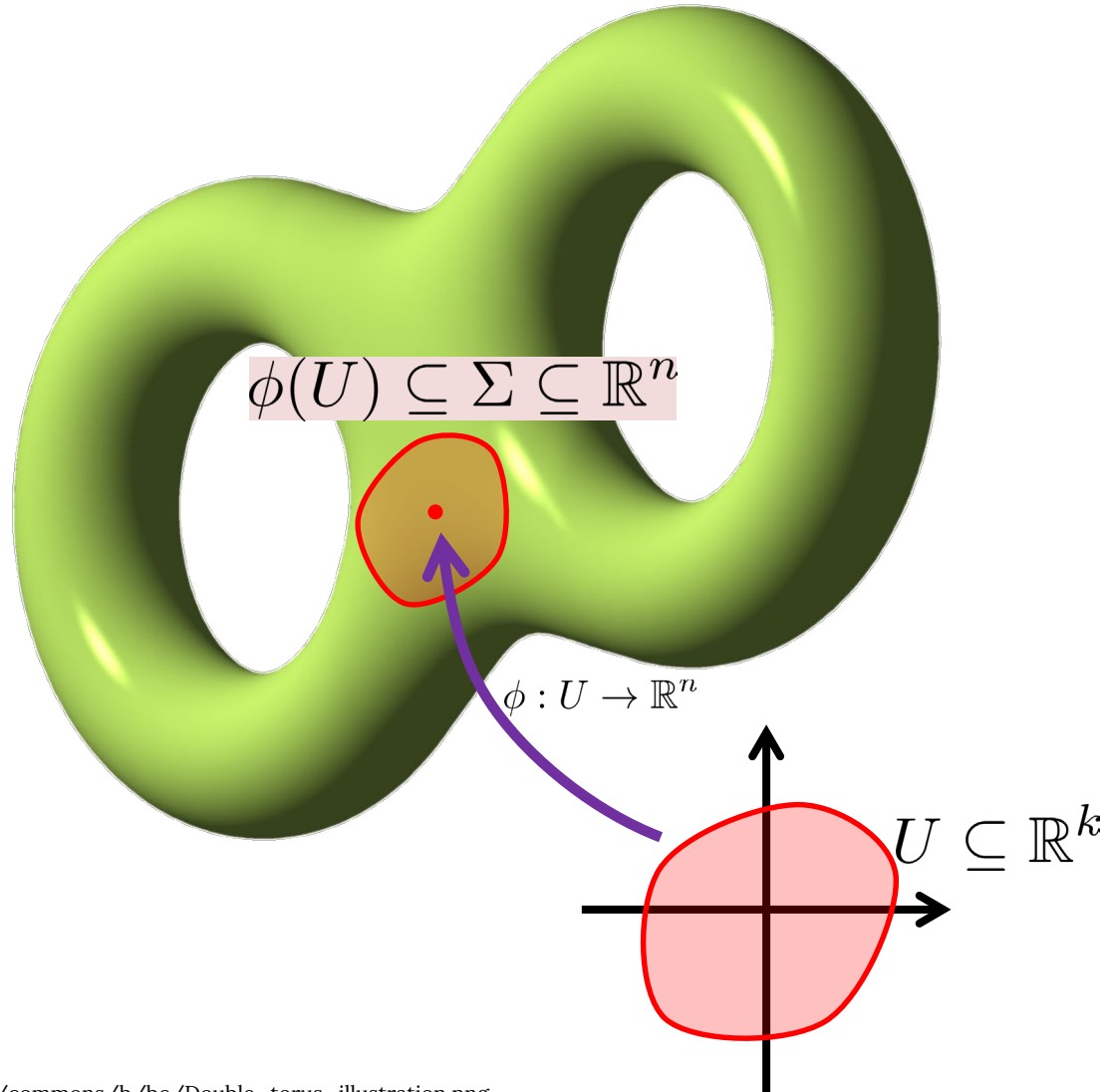
DIFFERENTIAL GEOMETRY



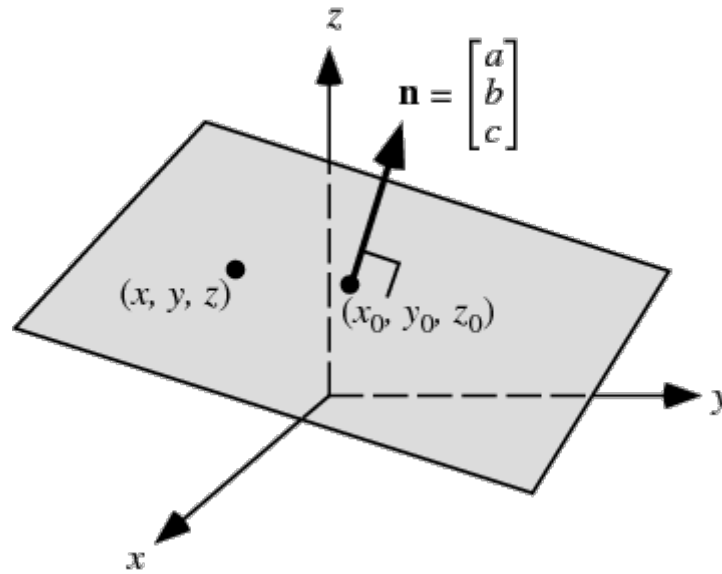
http://en.wikipedia.org/wiki/Differential_geometry

Study of smooth manifolds

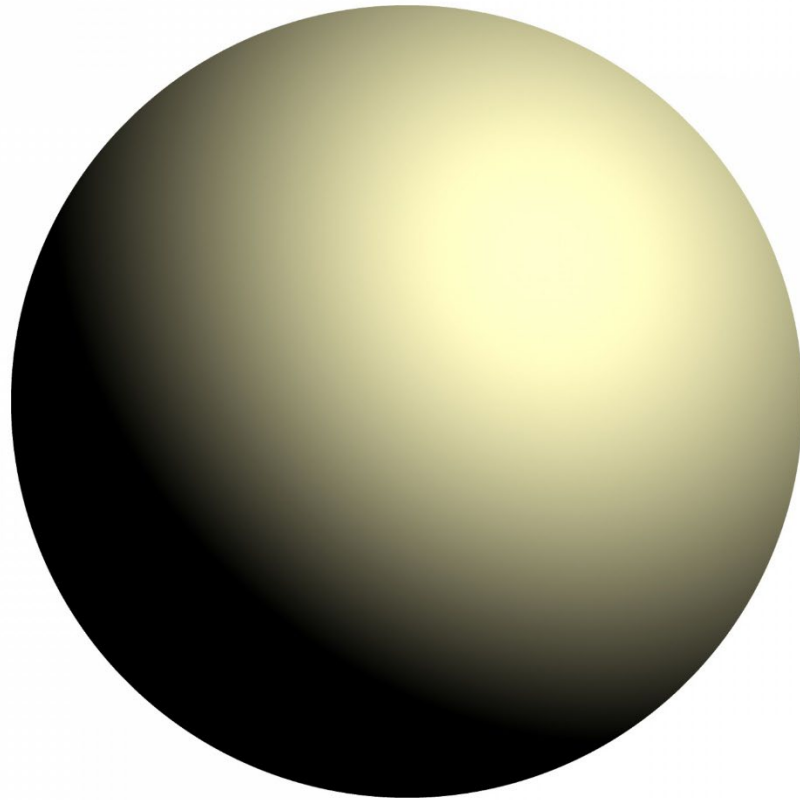
MANIFOLD



MANIFOLD?



MANIFOLD?



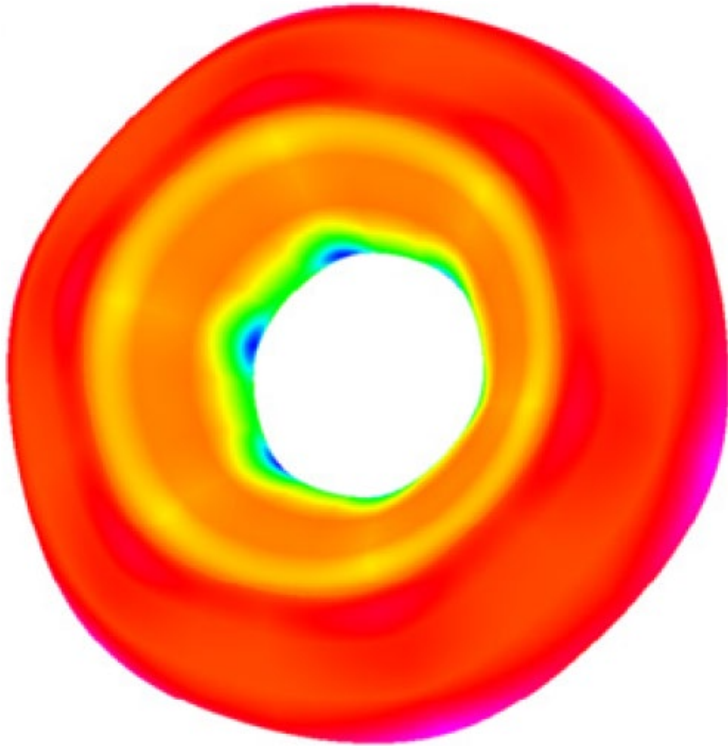
MANIFOLD?



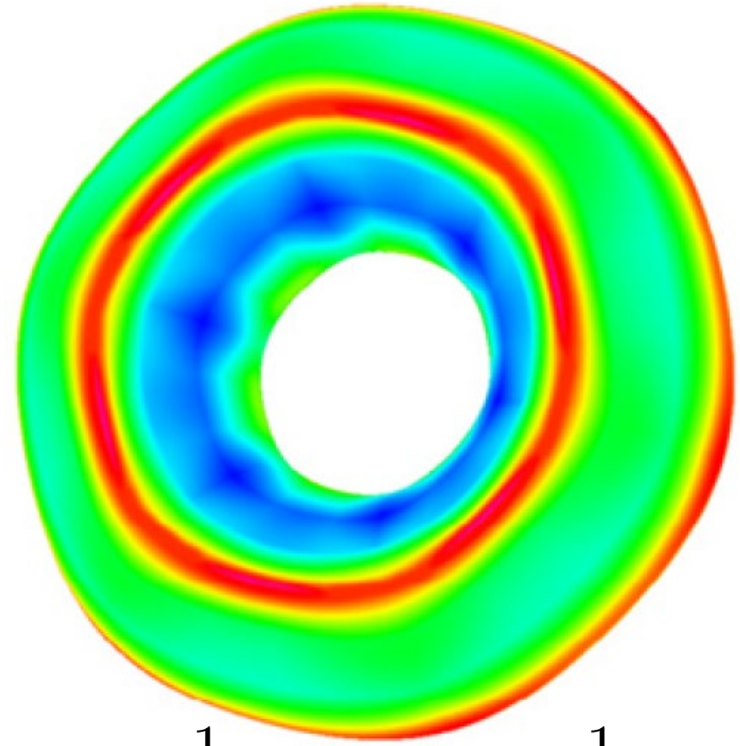
MANIFOLD?



DIFFERENTIAL GEOMETRY TOOLBOX



$$K := \kappa_1 \kappa_2 = \det \mathbb{II}$$



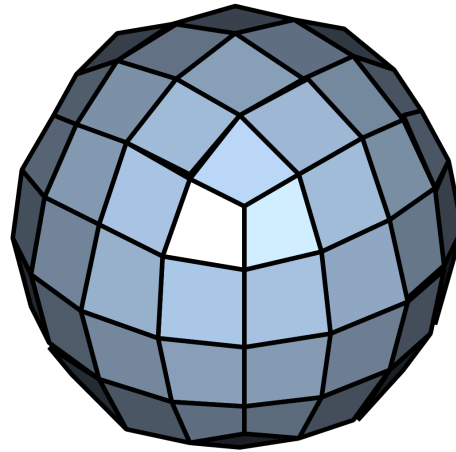
$$H := \frac{1}{2}(\kappa_1 + \kappa_2) = \frac{1}{2} \operatorname{tr} \mathbb{II}$$

<http://www.sciencedirect.com/science/article/pii/S0010448510001983>

Curvature and shape properties

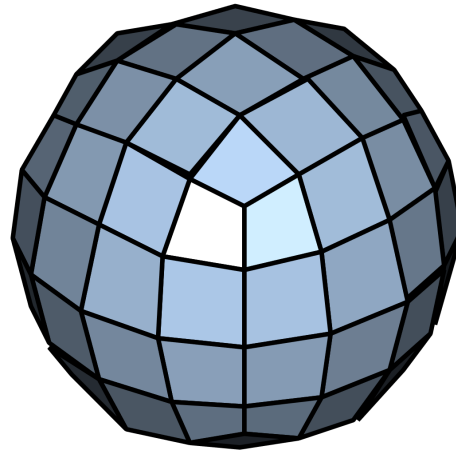
WE WANT TO STUDY SHAPES

What graphics people think:



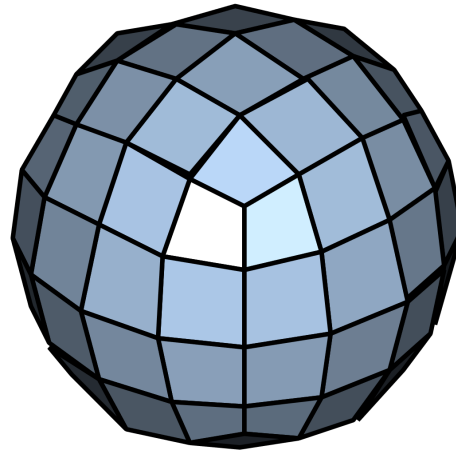
WE WANT TO STUDY SHAPES

- Collection of flat triangles/quads
- Approximates a smooth surface

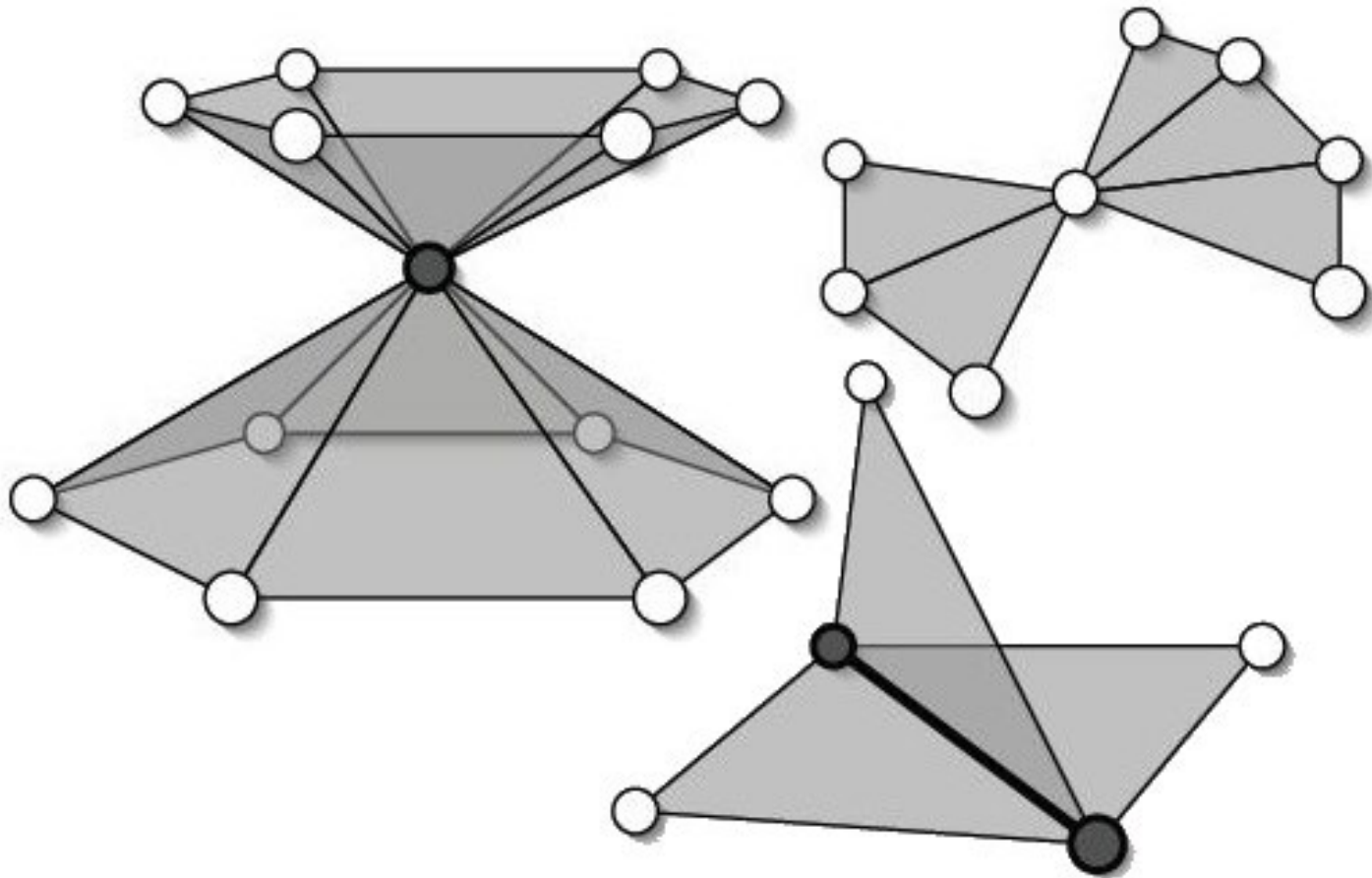


WE WANT TO STUDY SHAPES

- Can such a mesh have curvature?



MANIFOLD?

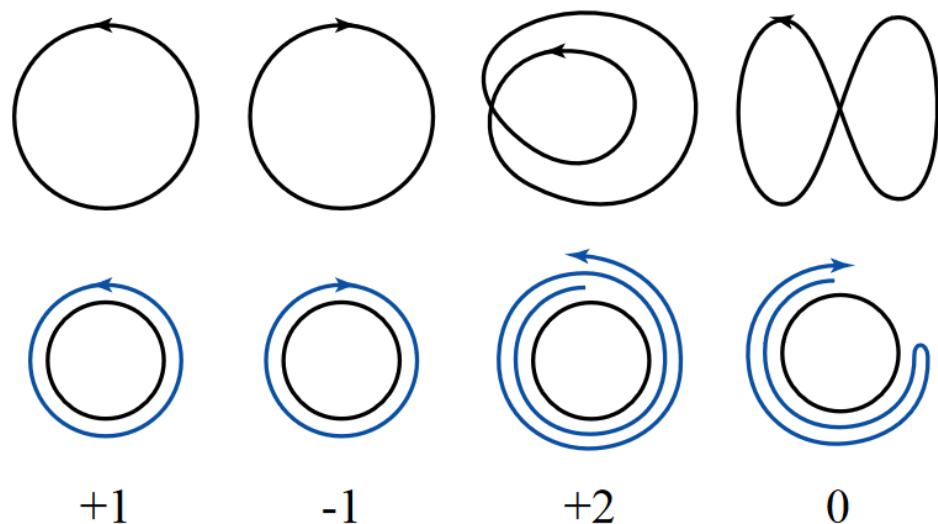


DISCRETE DIFFERENTIAL GEOMETRY

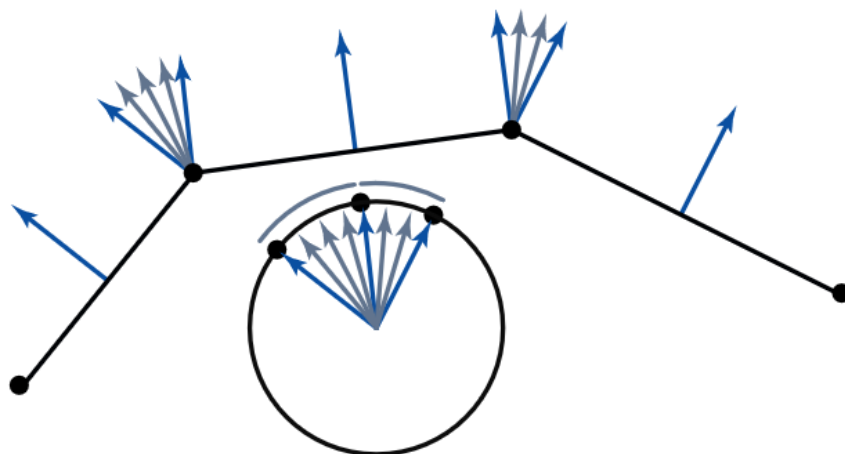
Structure preservation:

- Keeping properties from the continuous abstraction exactly true in a discretization.

EXAMPLE: TURNING NUMBERS



$$\int_{\Omega} \kappa ds = 2\pi k$$



$$\sum_i \alpha_i = 2\pi k$$

DISCRETE DIFFERENTIAL GEOMETRY

Eurographics Symposium on Geometry Processing (2007)
Alexander Belyaev, Michael Garland (Editors)

Discrete Laplace operators: No free lunch

Max Wardetzky¹

Saurabh Mathur²

Felix Kälberer¹

Eitan Grinspun² †

¹Freie Universität Berlin, Germany

²Columbia University, USA

the continuous setting. Building on the smooth setting, we present a set of natural properties for discrete Laplace operators for triangular surface meshes. We prove an important theoretical limitation: discrete Laplacians cannot satisfy all natural properties; retroactively, this explains the diversity of existing discrete Laplace operators.

operators for triangular surface meshes. We prove an important theoretical limitation: discrete Laplacians cannot satisfy all natural properties; retroactively, this explains the diversity of existing discrete Laplace operators. Finally, we present a family of operators that includes and extends well-known and widely-used operators.

1. Introduction

Discrete Laplace operators on triangular surface meshes span the entire spectrum of geometry processing applications, including mesh filtering, parameterization, pose transfer, segmentation, reconstruction, re-meshing, compression, simulation, and interpolation via barycentric coordinates [Tau00, Zha04, FH05, Sor05].

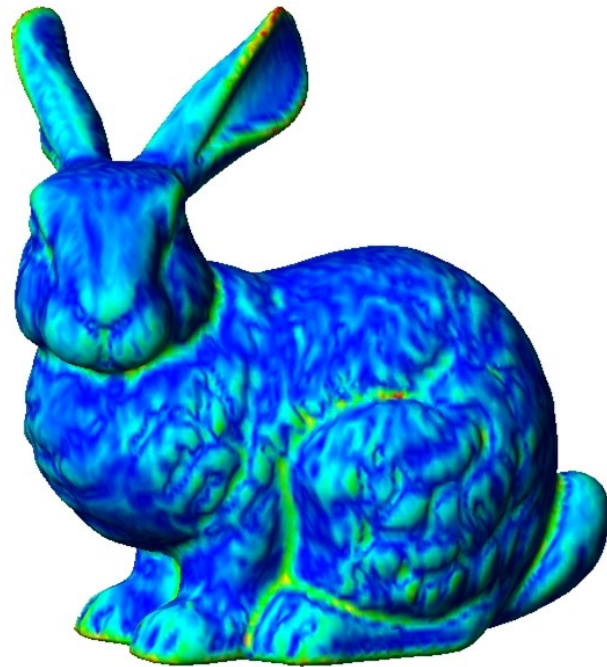
In applications one often requires certain structural prop-

1.1. Properties of smooth Laplacians

Consider a smooth surface S , possibly with boundary, equipped with a Riemannian metric, *i.e.*, an intrinsic notion of distance. Let the intrinsic L^2 inner product of functions u and v on S be denoted by $(u, v)_{L^2} = \int_S uv \, dA$, and let $\Delta = -\operatorname{div} \operatorname{grad}$ denote the intrinsic smooth Laplace-Beltrami operator [Ros97]. We list salient properties of this operator:

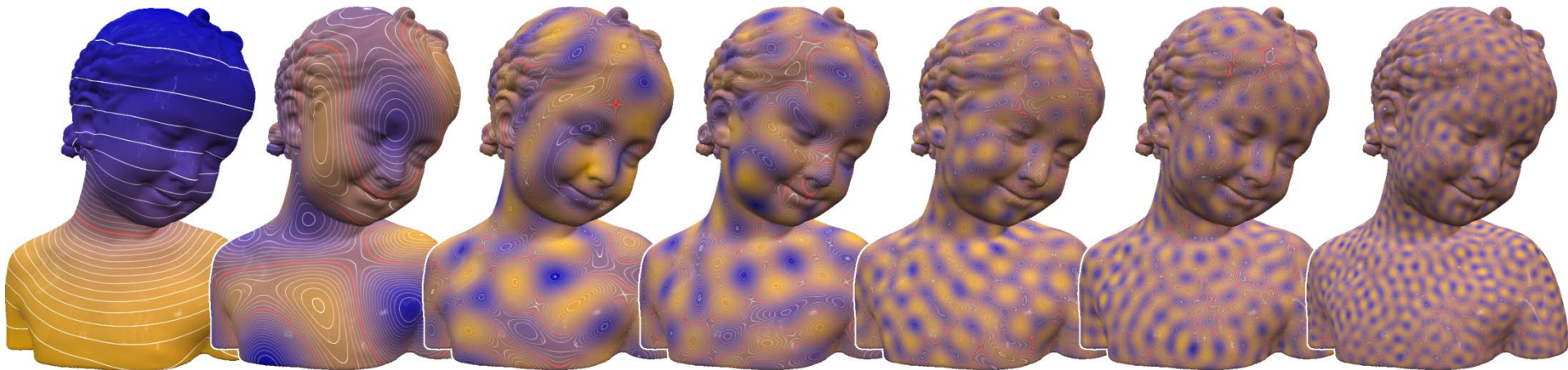
(NULL) $\Delta u = 0$ whenever u is constant.

THEORY: GRAD



THEORY: LAPLACIAN

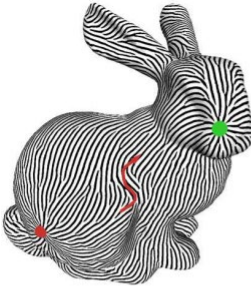
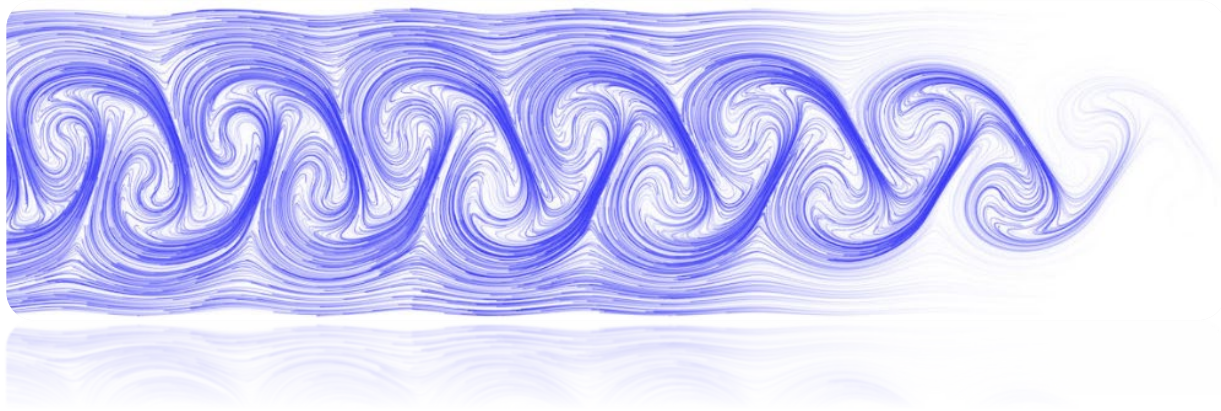
$$\Delta$$



Vallet and Lévy.
Spectral Geometry Processing with Manifold Harmonics.

EG 2008

THEORY: VECTOR FIELDS AND FLOWS



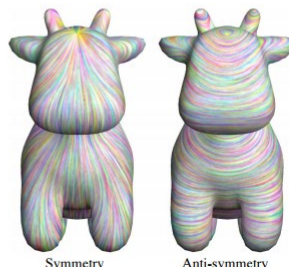
(a) [FSDH07]



(b) [BCBSG10]



(c) [KCPS13]

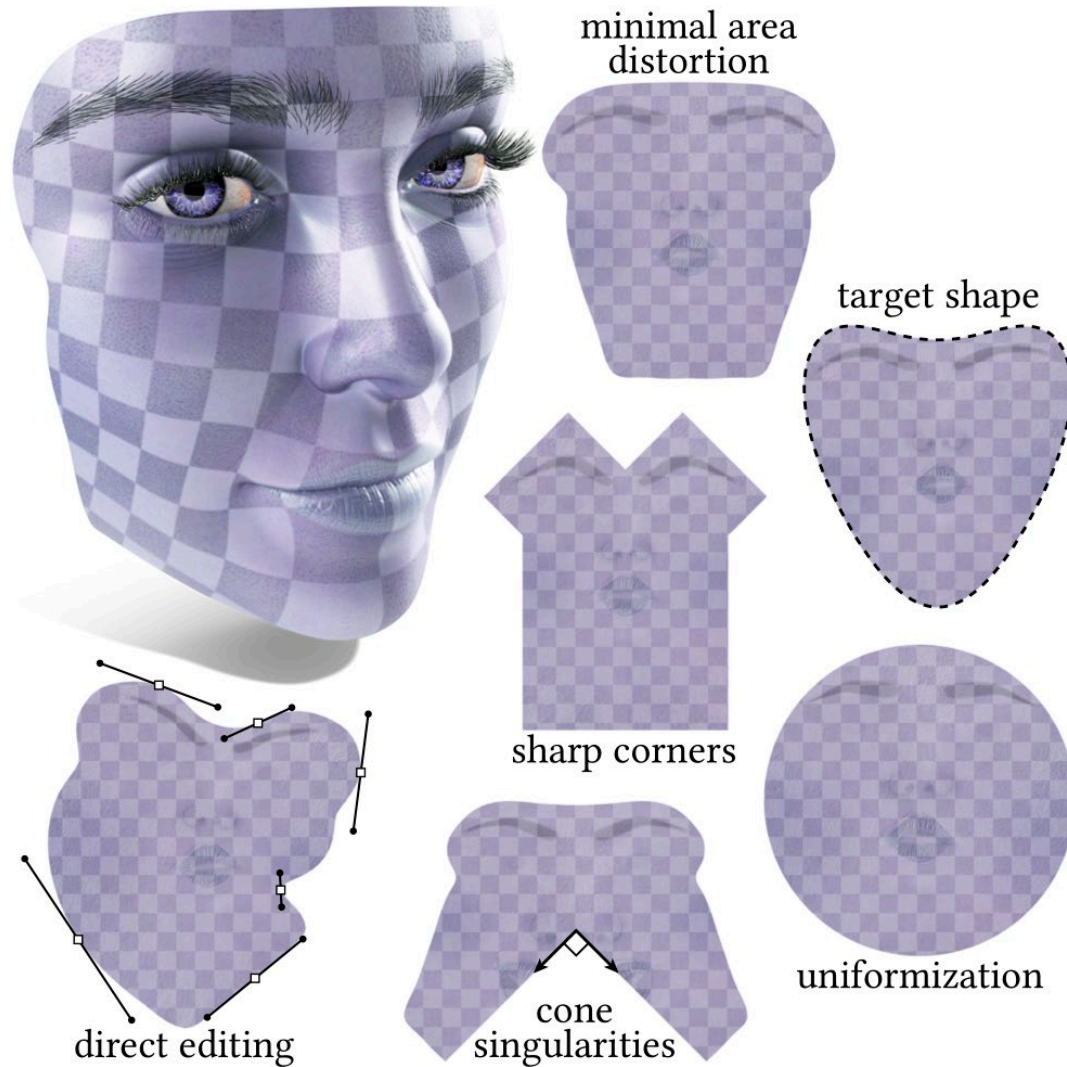


Symmetry Anti-symmetry

(d) [ABCCO13]

Vaxman et al.
Directional field synthesis, design, and processing. EG STAR 2016.

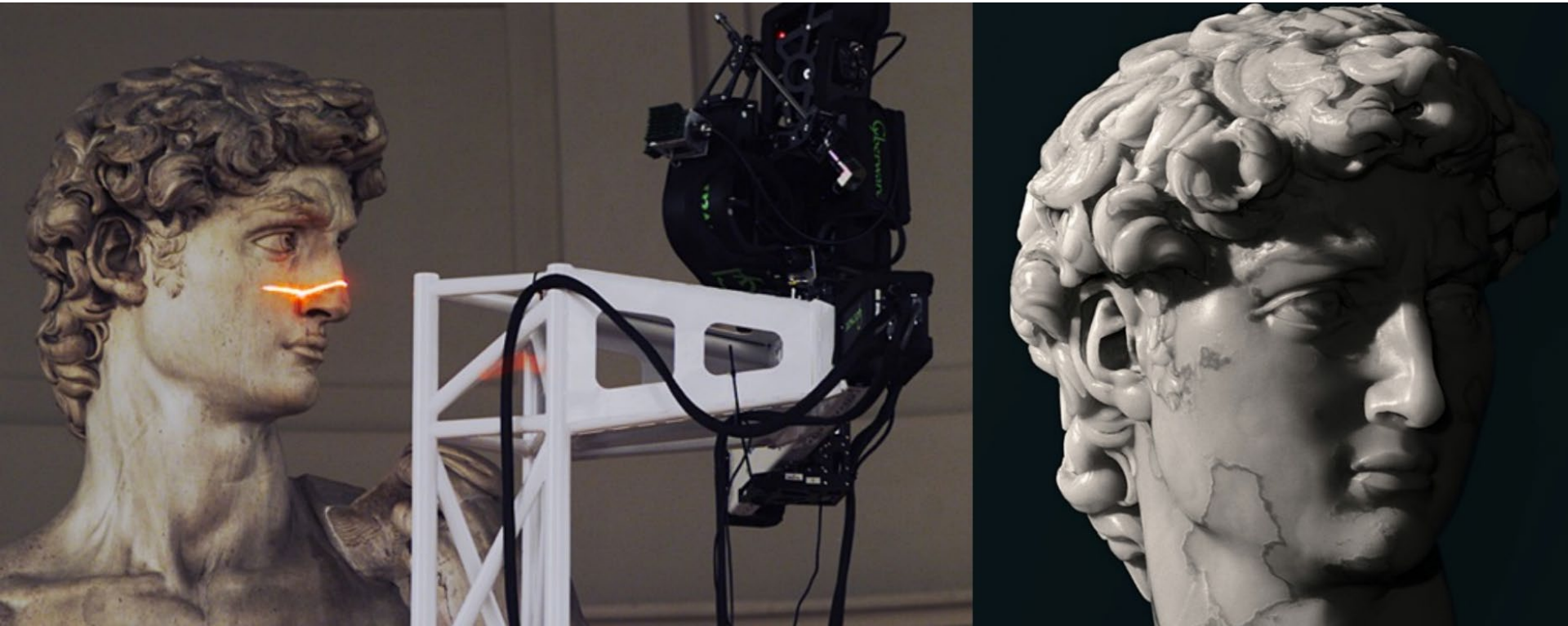
NUMERICS



TODAY

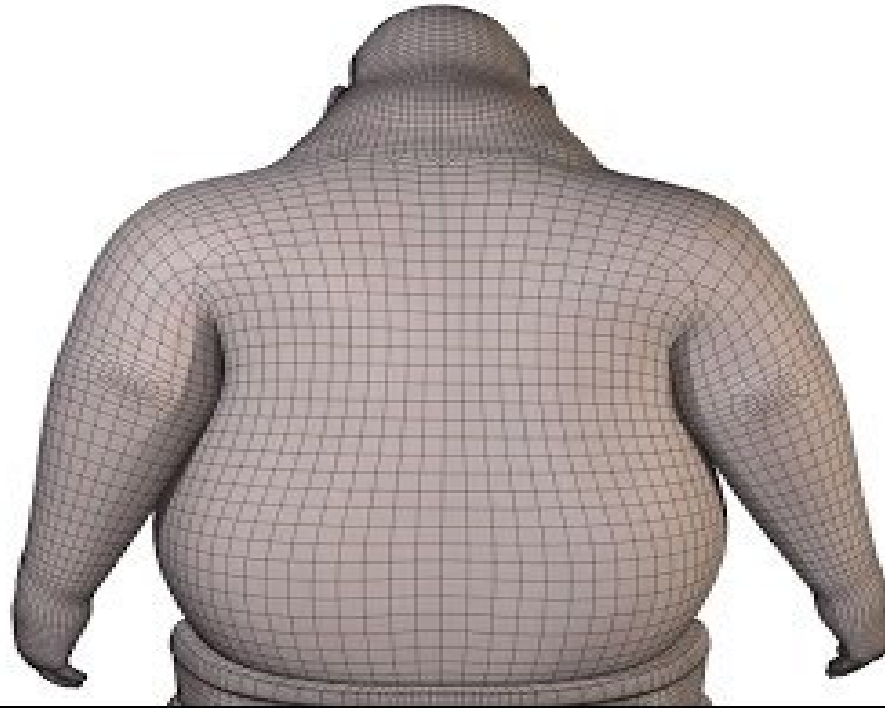
1. Geometric modeling?
2. Shape analysis?
3. Studying shapes: what we need
- 4. Applications**

APPLICATION: 3D RECONSTRUCTION



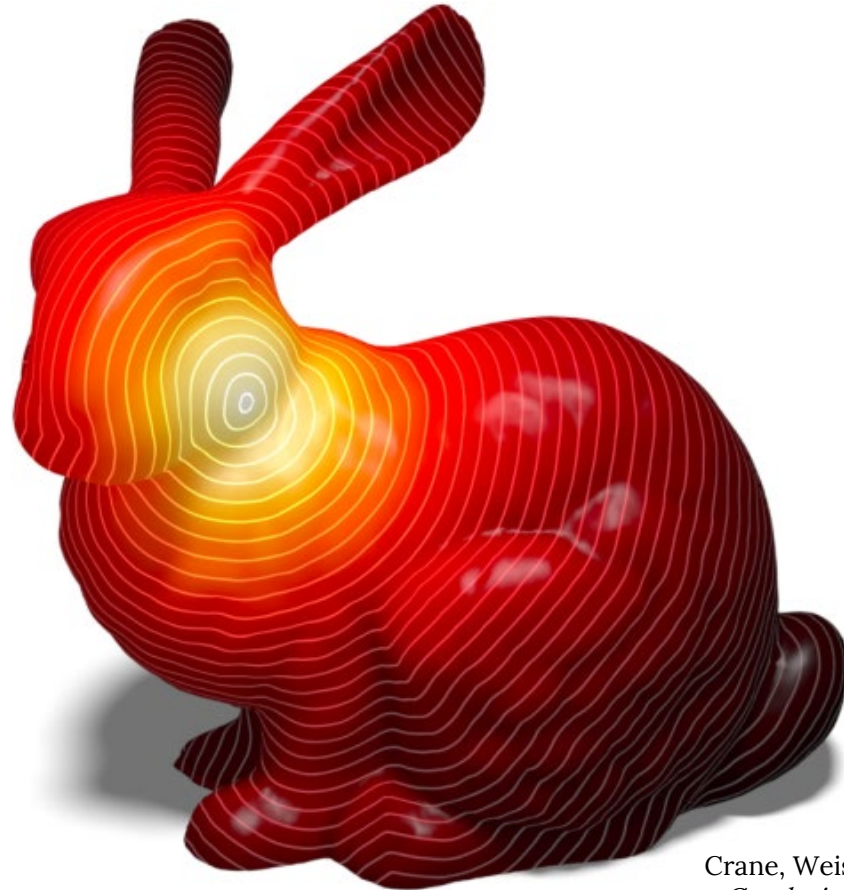
Depth maps $\xrightarrow{?}$ points $\xrightarrow{?}$ triangle mesh

APPLICATIONS: MESH DEFORMATION



How to propagate deformations to
unconstrained parts of shape?

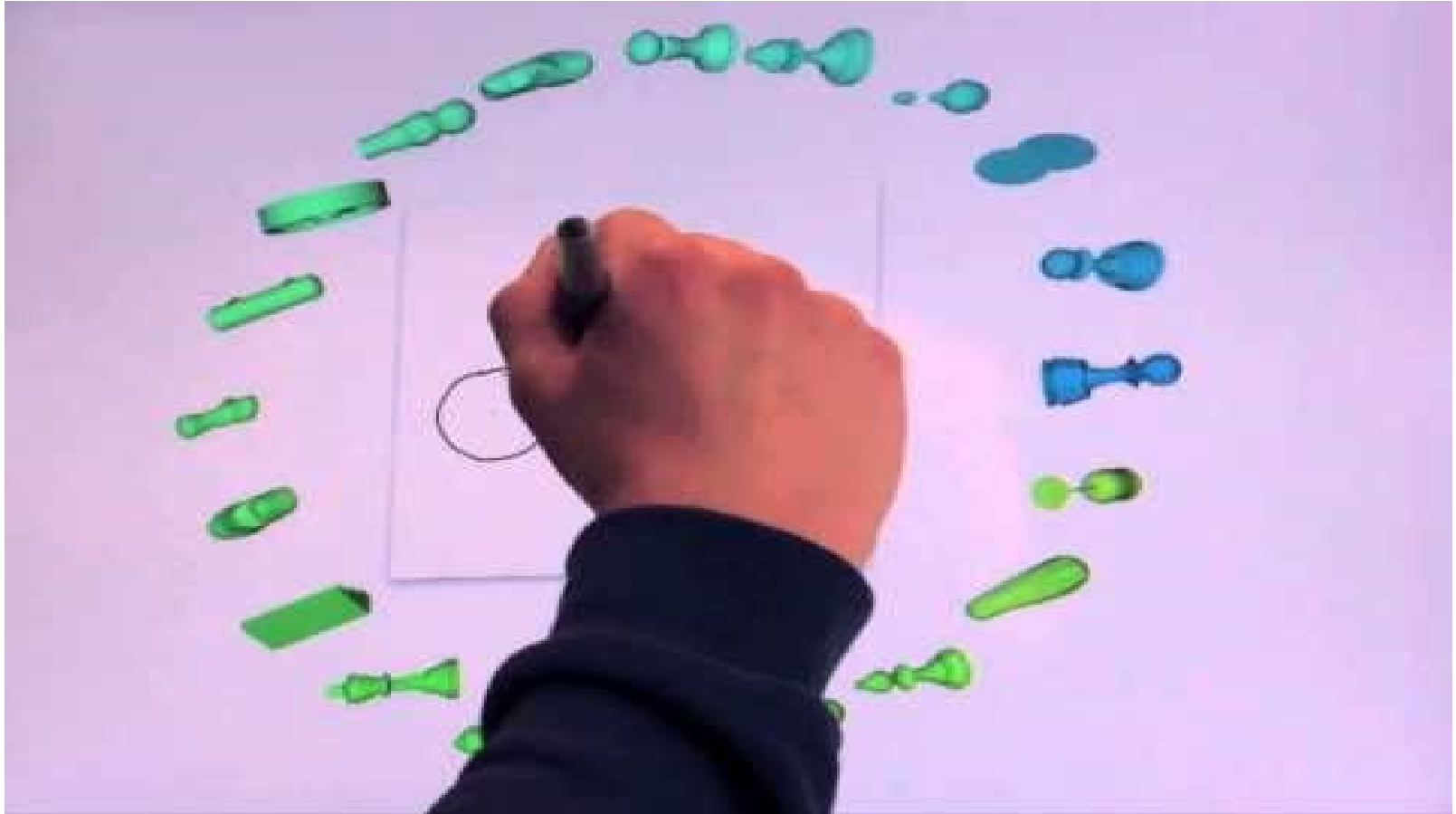
APPLICATIONS: HEAT AND GEODESICS



Crane, Weischedel, Wardetzky.
Geodesics in heat. TOG 2013.

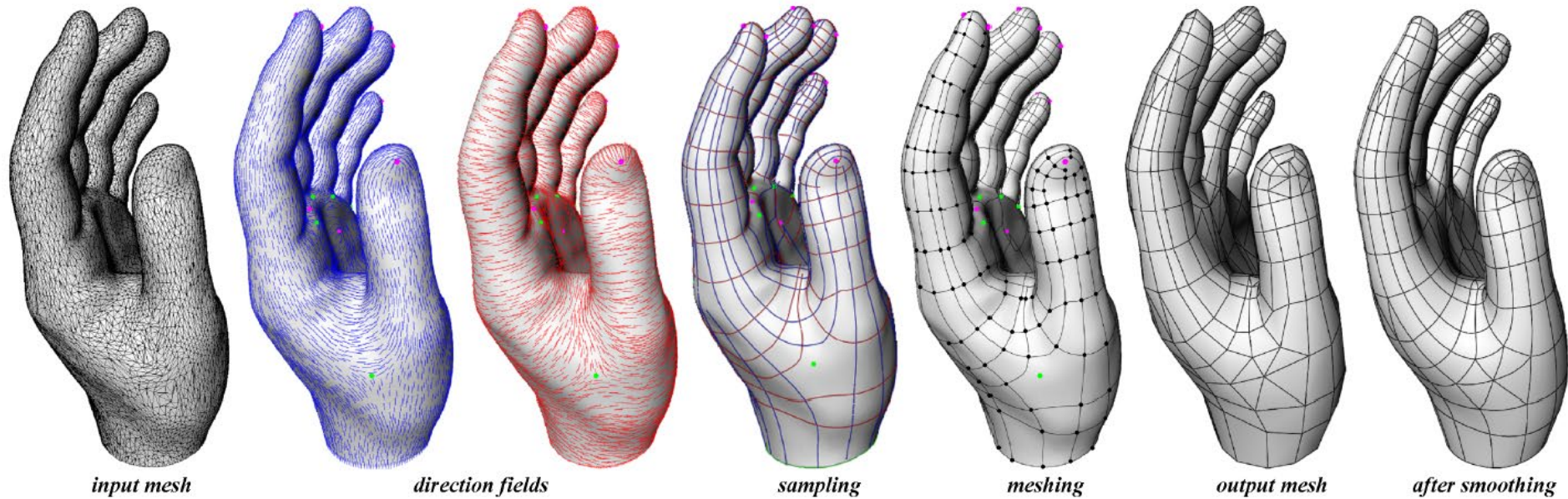
How to compute distances
between points on a surface?

APPLICATIONS: RETRIEVAL



How to compare shapes of
different modalities?

APPLICATIONS: REMESHING



Pierre Alliez, David Cohen-Steiner, Olivier Devillers, Bruno Lévy, and Mathieu Desbrun. 2003. Anisotropic polygonal remeshing. ACM Trans. Graph. 22, 3 (July 2003)

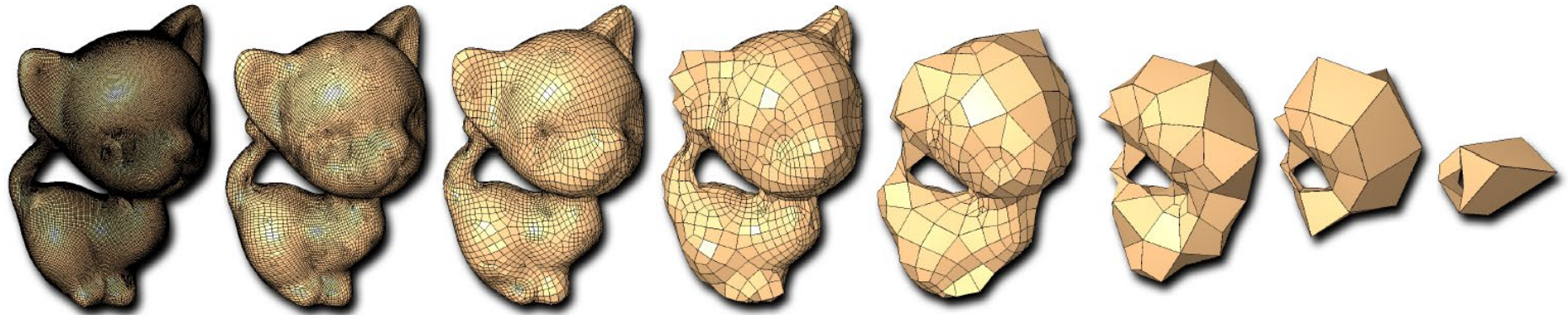
How to **convert** any mesh
into a **nice** one?

APPLICATIONS: QUADMESHING



How to make a **mesh** out of **quads**?

APPLICATIONS: MESH SIMPLIFICATION

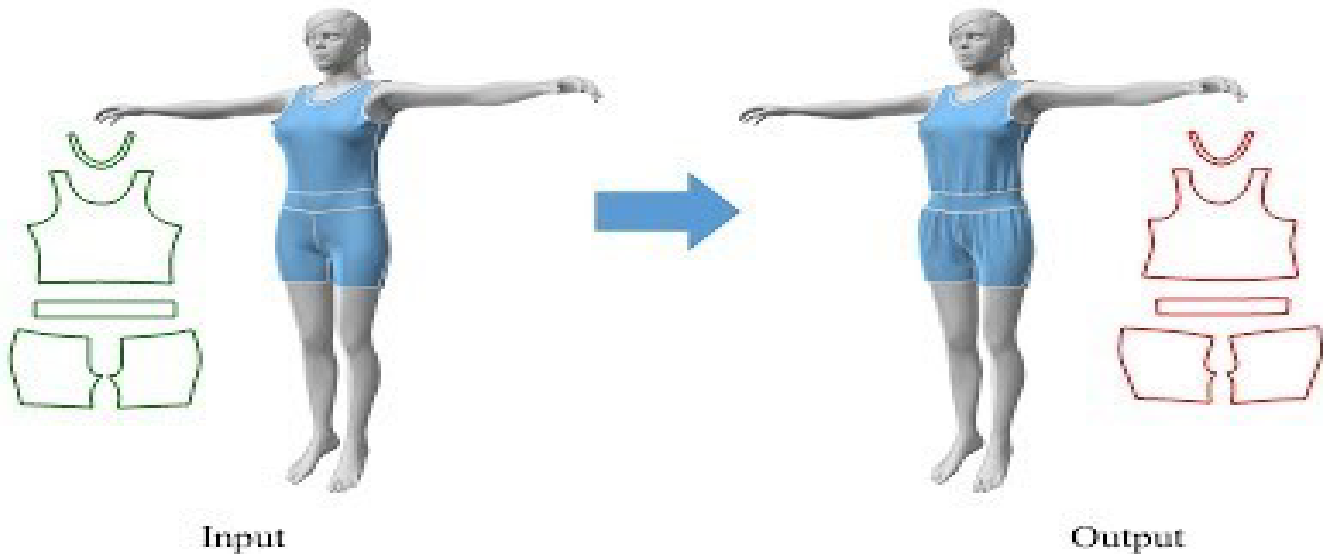


Joel Daniels, Cláudio T. Silva, Jason Shepherd, and Elaine Cohen. 2008. Quadrilateral mesh simplification. *ACM Trans. Graph.* 27, 5, Article 148 (December 2008)

How to **compress** geometry?

APPLICATIONS: CLOTH MODELING

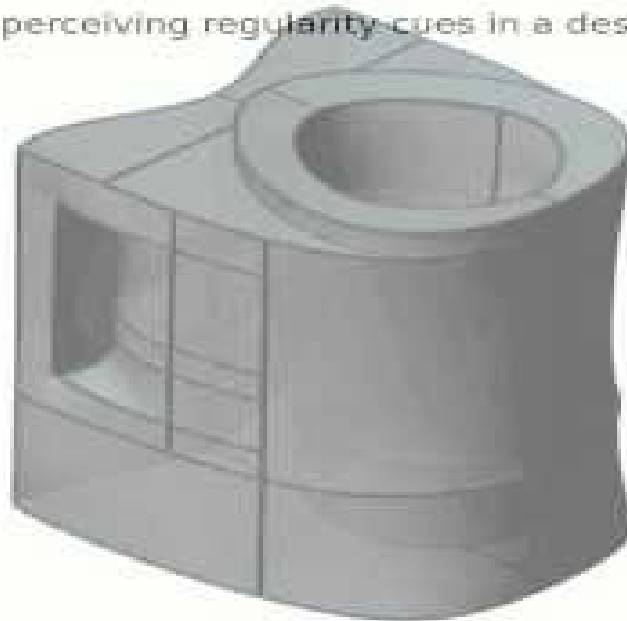
FoldSketch



APPLICATIONS: SKETCH-BASED MODELING

...perceptual validation

#1 Humans are consistent in perceiving regularity cues in a design sketch.



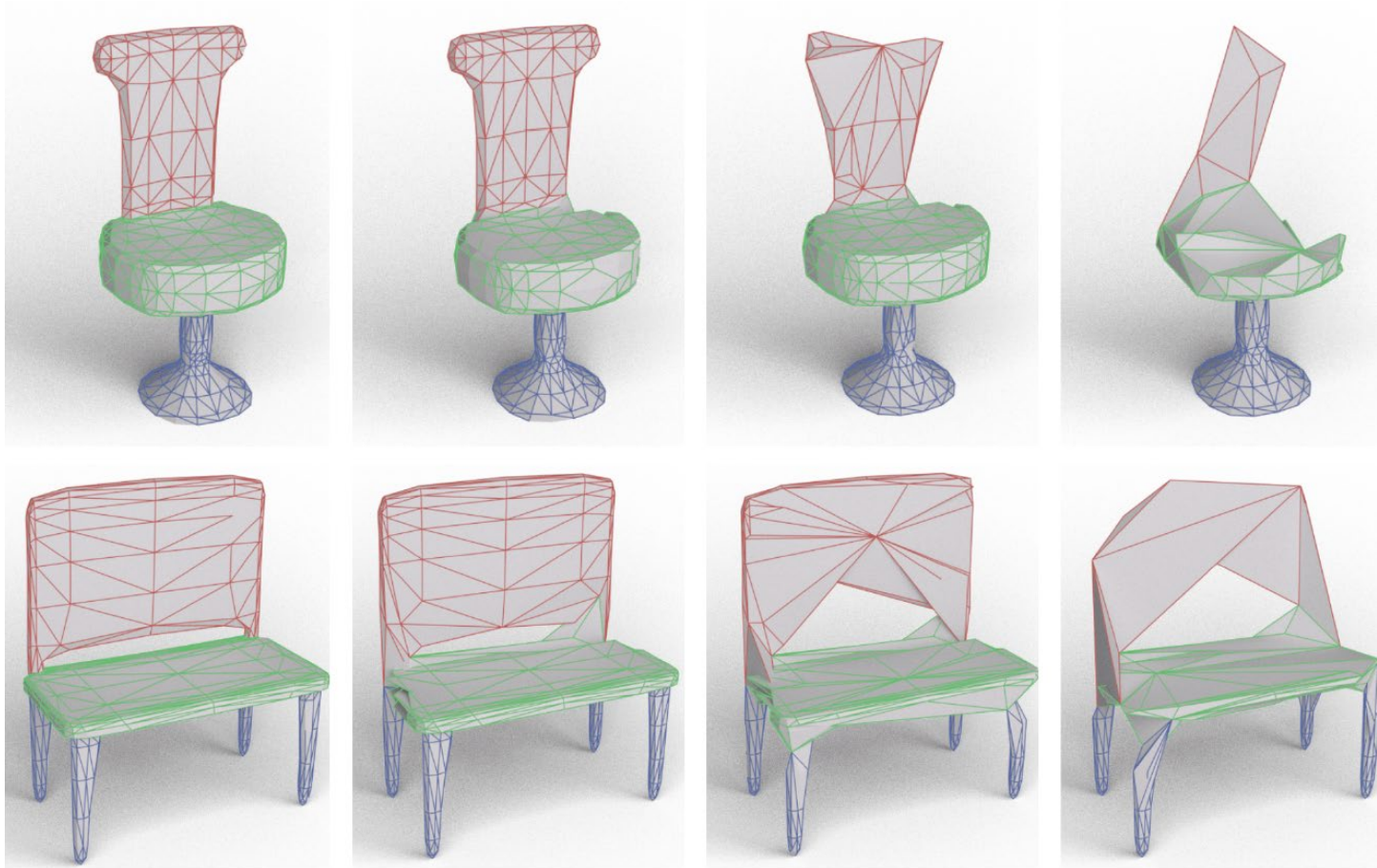
APPLICATIONS: SKETCH-BASED MODELING AND POSING



APPLICATIONS: LEARNING



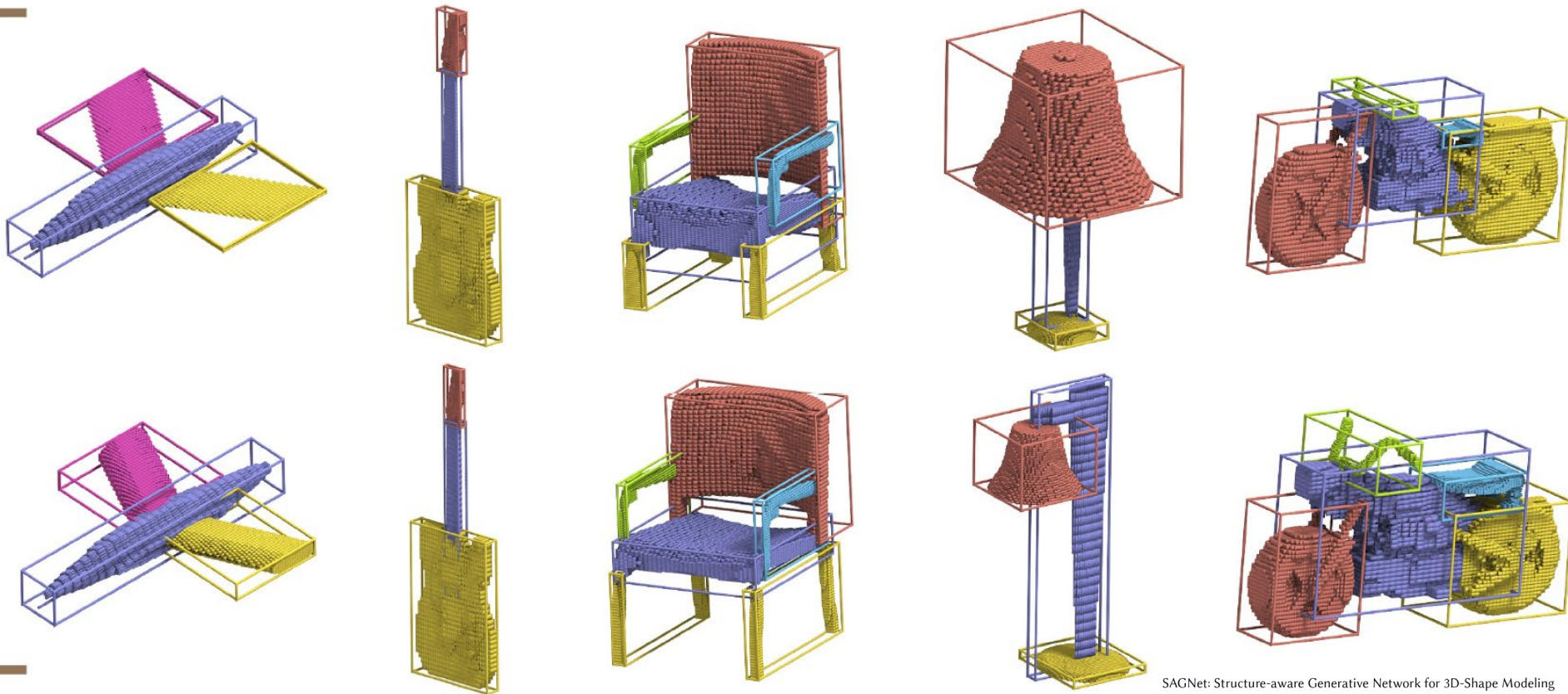
APPLICATIONS: LEARNING



"MeshCNN: A Network with an Edge" by Rana Hanocka, Amir Hertz, Noa Fish, Raja Giryes, Shachar Fleishman, Daniel Cohen-Or, SIGGRAPH 2019

How to bring **learning** approaches
from images to 3D geometry?

APPLICATIONS: LEARNING



SAGNet: Structure-aware Generative Network for 3D-Shape Modeling

ZHIJIE WU, Shenzhen University
XIANG WANG, Shenzhen University
DI LIN, Shenzhen University
DANI LISCHINSKI, The Hebrew University of Jerusalem
DANIEL COHEN-OR, Shenzhen University
HUI HUANG^{*}, Shenzhen University

How to bring **learning** approaches
from images to **3D geometry**?

</INTRO>

<http://tiny.cc/ift6113>

Piazza!

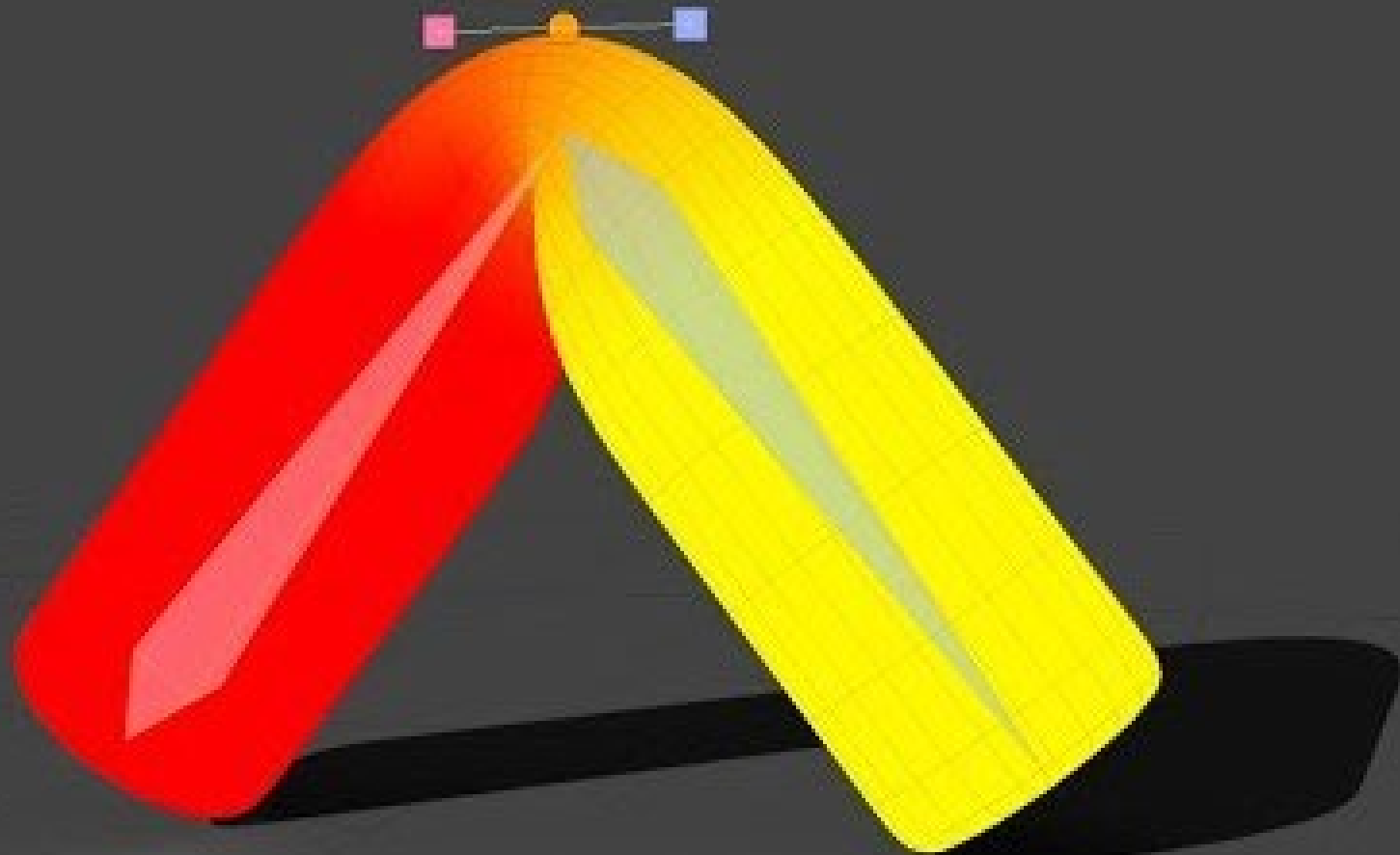
Office hour: Fri, 4:30-5:30 pm,
Zoom/AA3357



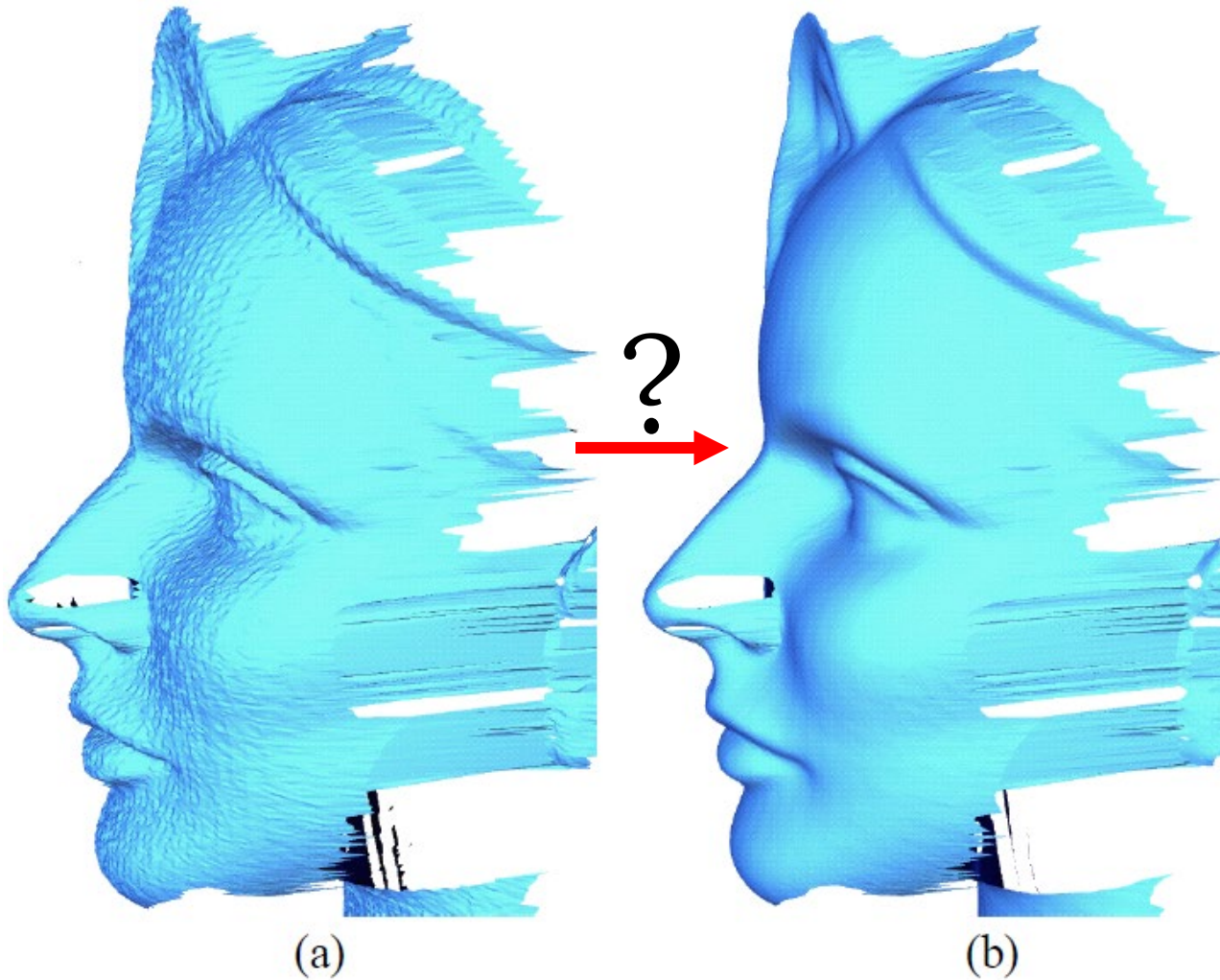
WARM-UP PROBLEMS



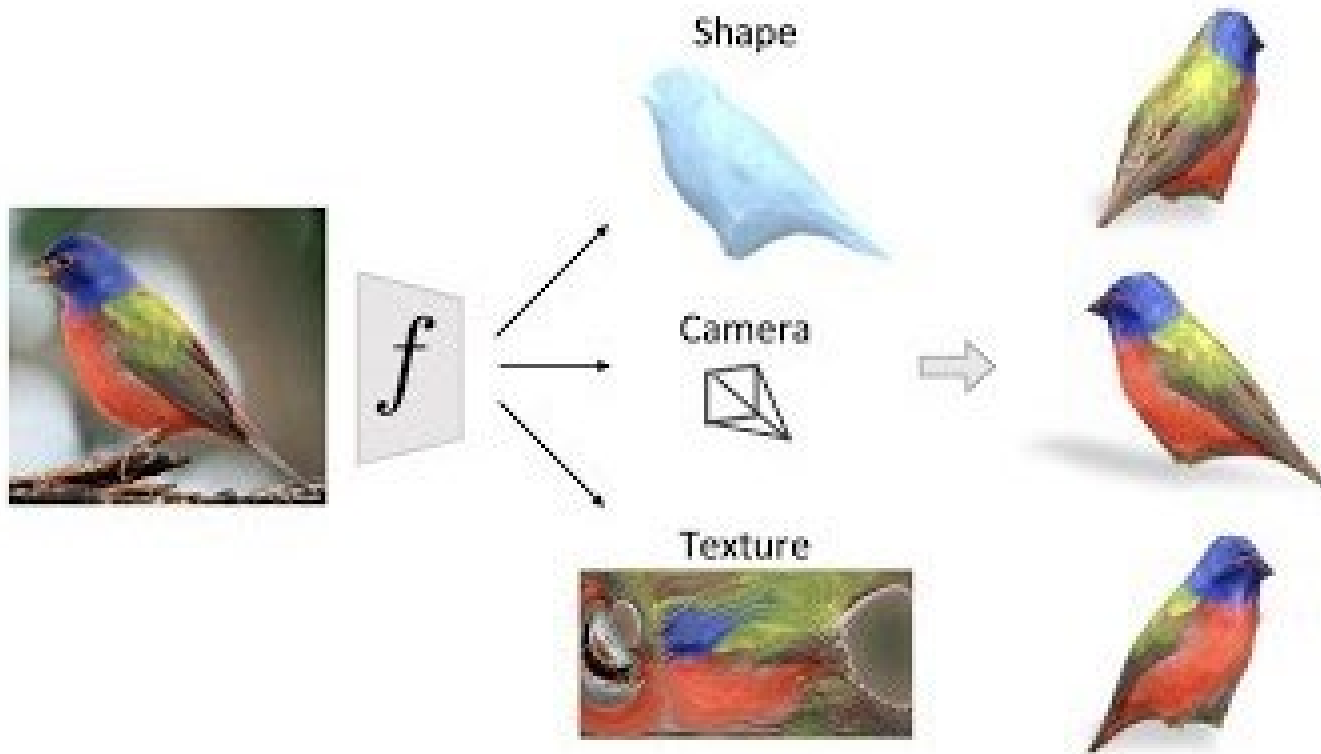
1



WARM-UP PROBLEMS



WARM-UP PROBLEMS



LIBIGL & EIGEN

- Eigen: a linear algebra library
- libigl: geometry processing library