

Digital Geometry -Introduction

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Spring 2021

<https://github.com/jjcao-school/dgp>

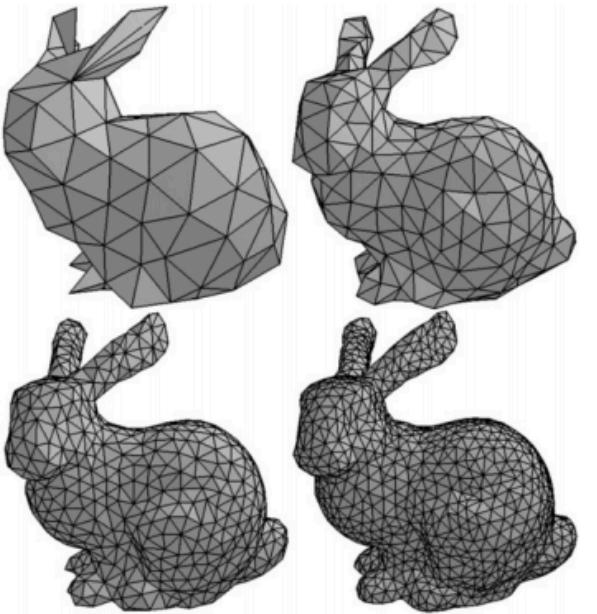
Pleasure may come from illusion, but happiness can come only of reality.

缘起：计算机图形学

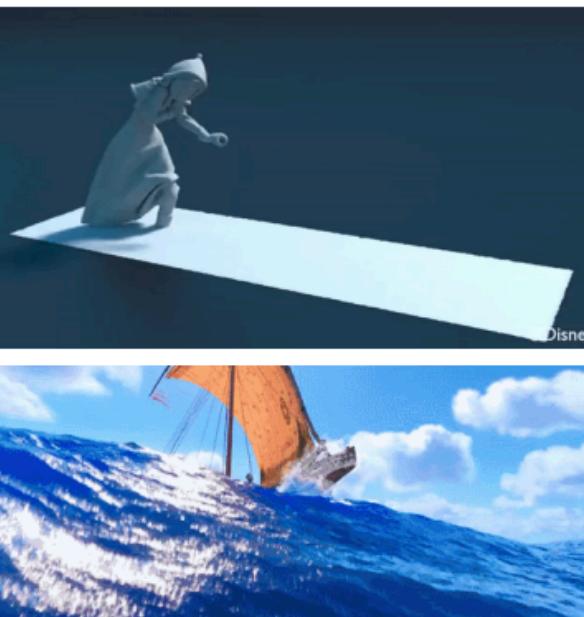


2013 年 8 月 8 日, 刘利刚

计算机图形学



建模（设计）
Modeling



动画（仿真）
Animation



渲染（绘制）
Rendering

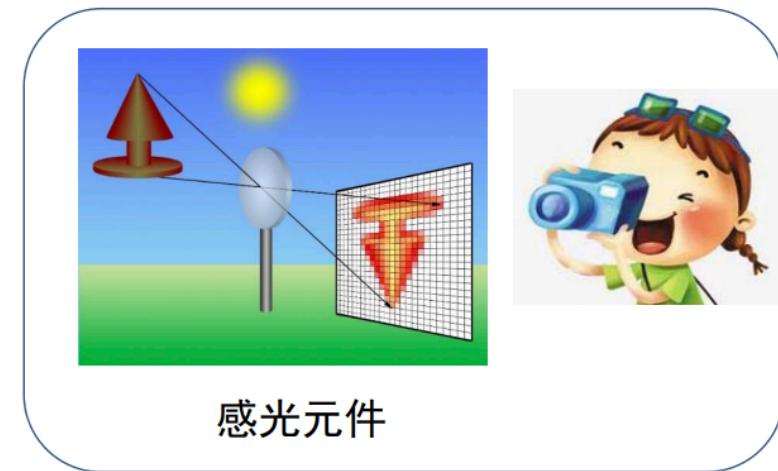
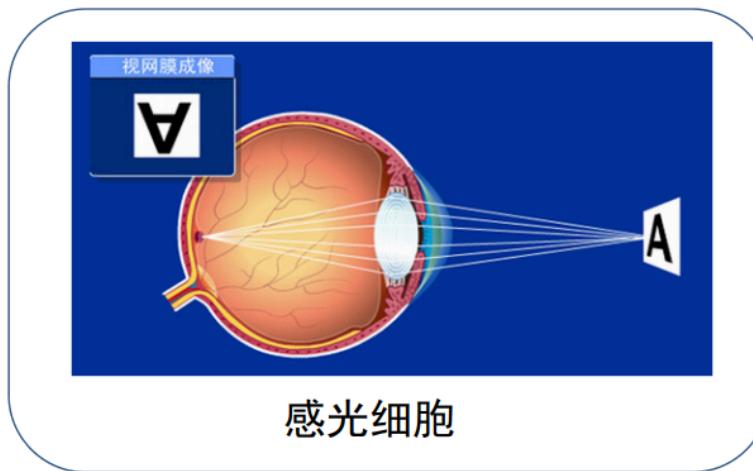
内容创建

内容仿真

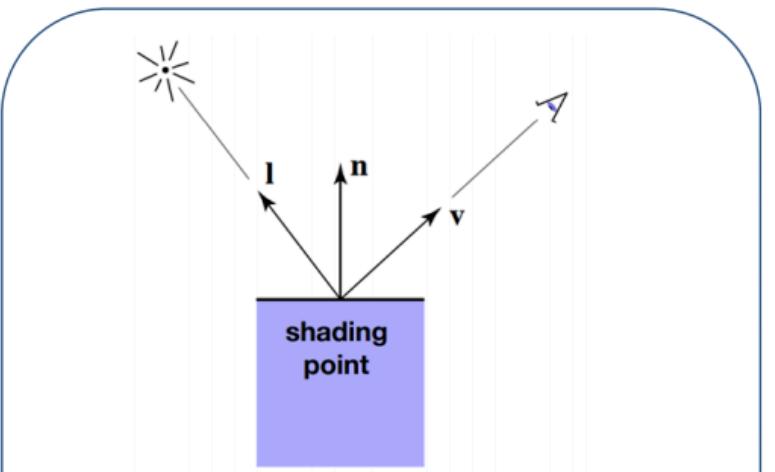
内容呈现

构建和创造（虚拟）平行世界

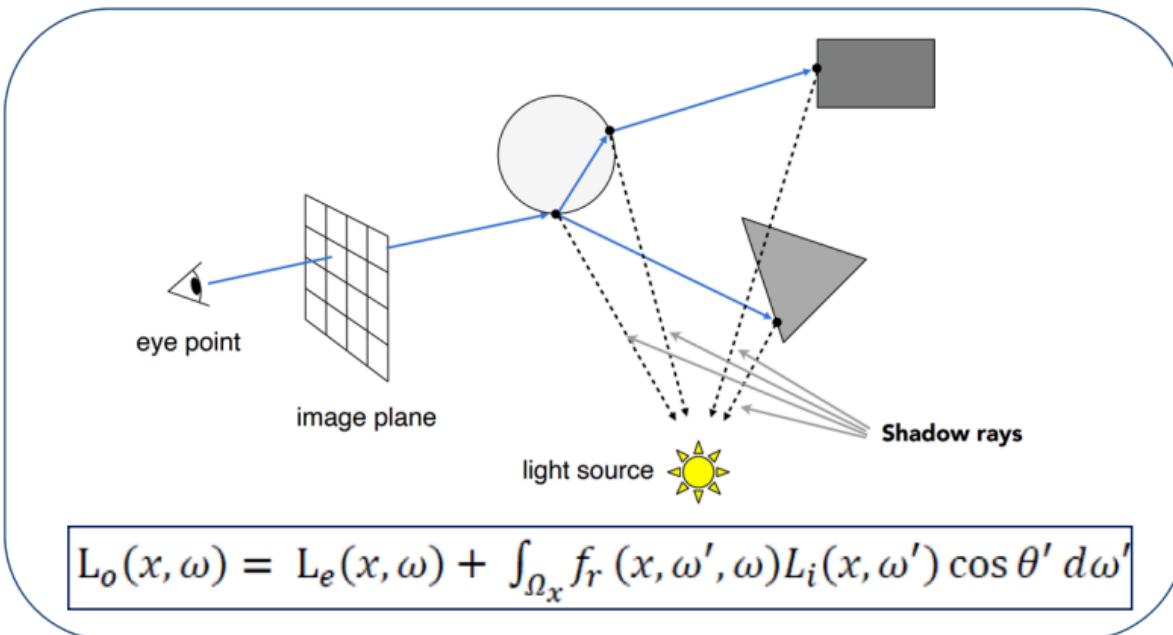
眼、画家、相机 如何感知3d真实世界？降维+离散



渲染成像：光的计算科学



$$L_d = k_d (I/r^2) \max(0, \mathbf{n} \cdot \mathbf{l})$$



$$L_o(x, \omega) = L_e(x, \omega) + \int_{\Omega_x} f_r(x, \omega', \omega) L_i(x, \omega') \cos \theta' d\omega'$$

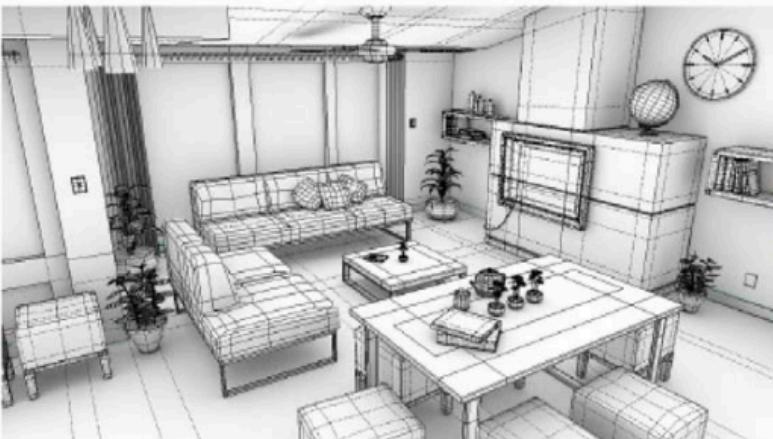
光源

几何

纹理

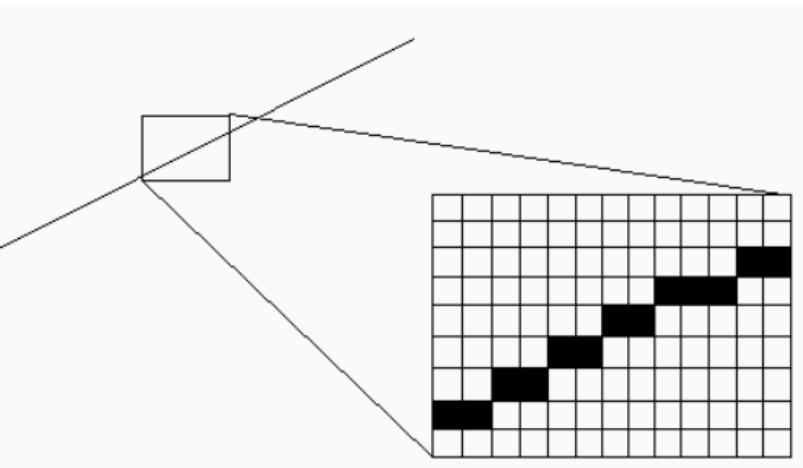
材质

...

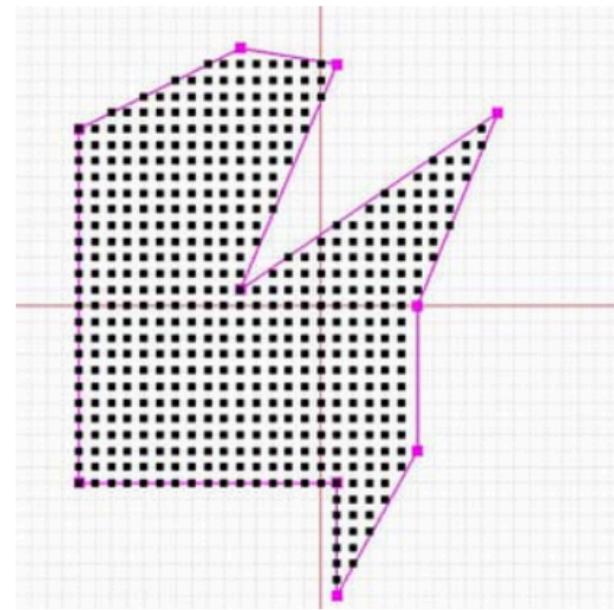


See more in GAMES 101

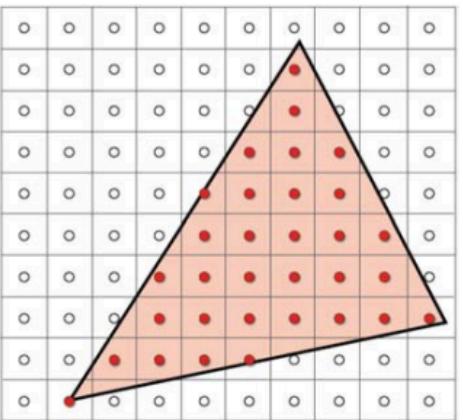
矢量图形的光栅化：扫描转化



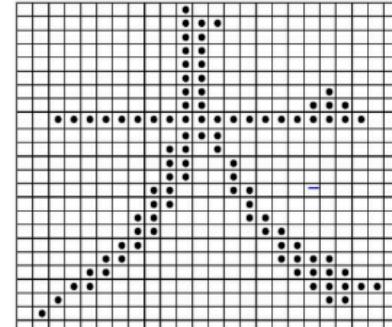
直线的光栅化



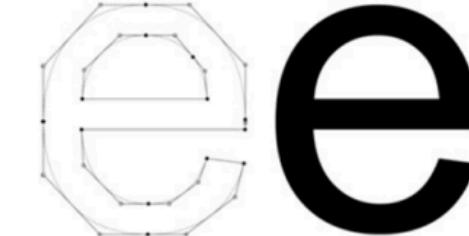
多边形的光栅化



三角形的光栅化

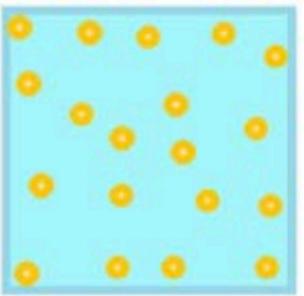


文字的光栅化

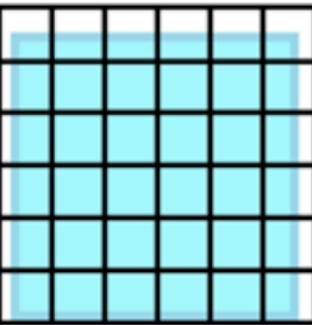


e

仿真动画：运动的计算科学

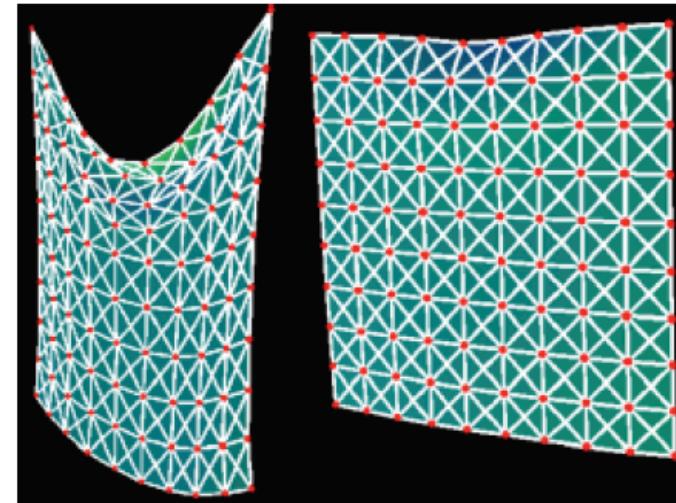


拉格朗日视角
(粒子采样)

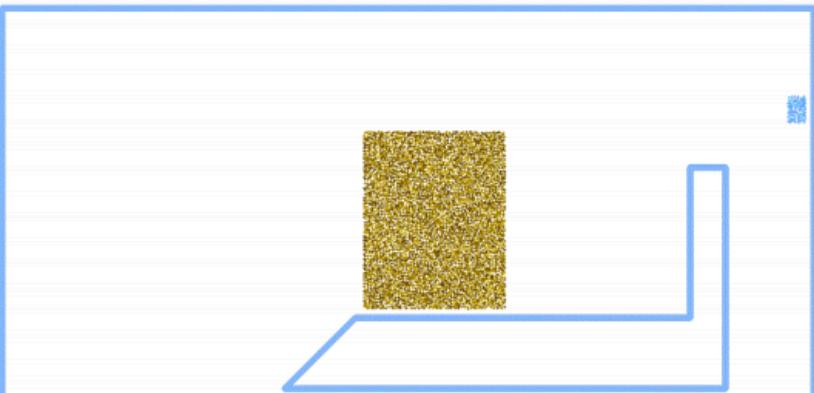


欧拉视角
(网格格点采样)

$$\rho(\mathbf{u}_t + \mathbf{u} \cdot \nabla \mathbf{u}) = -\nabla p + \mu \Delta \mathbf{u} + \mathbf{f},$$
$$\nabla \cdot \mathbf{u} = 0,$$



$$f_p = k_d \left(\frac{v_q - v_p}{r} \cdot \frac{x_q - x_p}{\|x_q - x_p\|} \right) \frac{x_q - x_p}{\|x_q - x_p\|}$$



See more in GAMES 201

What is computer graphics?

- The use of computers to synthesize and manipulate **visual information**.
- The use of computers to synthesize and manipulate **sensory information**.



(sound)



(touch)

Visual technology: digital imagery

- Intersection of visual depiction & computation

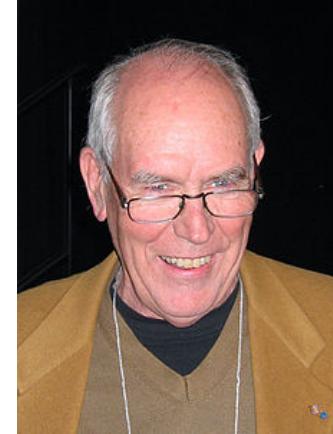


Ivan Sutherland, "Sketchpad" (1963)



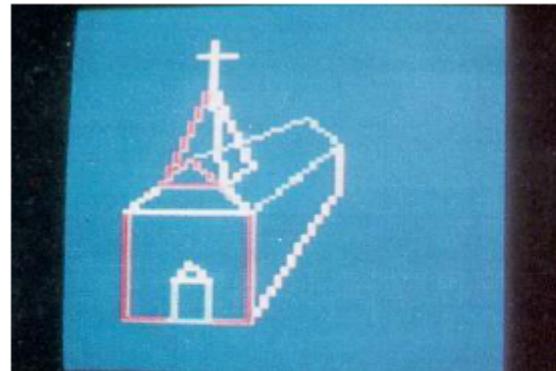
1. pop-up menus
2. constraint-based drawing
3. hierarchical modeling

- [Turing Award](#), 1988
- [human–computer interaction](#) (HCI)
- a major breakthrough in the development of [computer graphics](#) in general.
 - For example, the graphical user interface (GUI) was derived from the Sketchpad as well as modern **object oriented programming**.
- PhD thesis



What is Computer Graphics?

- CG studies **visual/geometric** information using **computer & mathematics**.
- 3D graphics programming in 1979



approx. 25 triangles



approx. 50 x 100 pixels



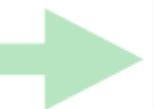
Computer Graphics



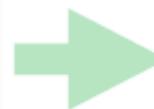
Action!



Story

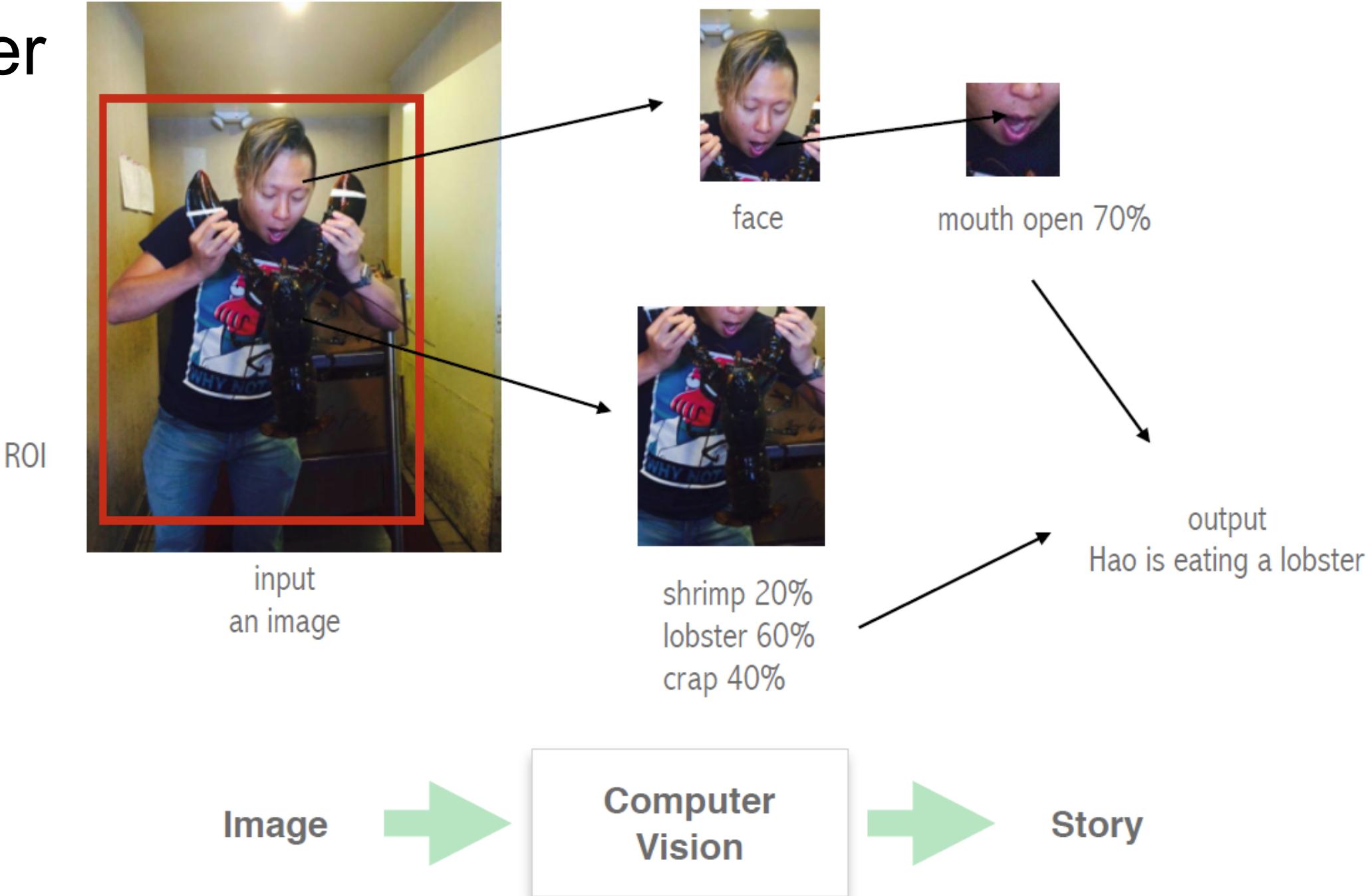


Computer
Graphics



Image

Computer Vision



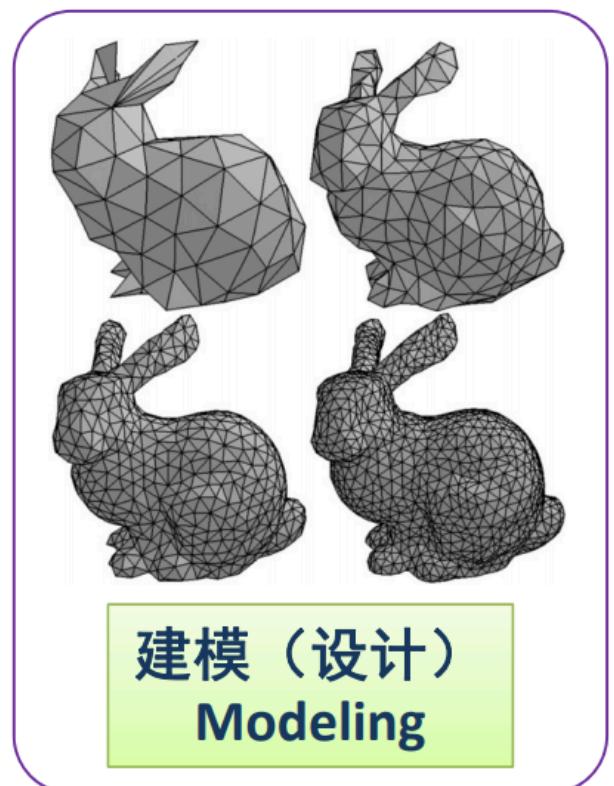
计算机图形学：“创造”虚拟世界



一个问题：数据从哪来？

制作三维数据

- 几何数据
- UV展开
- 贴图（纹理）
- 材质
- 灯光
- 动画
- ...



内容创建



内容仿真

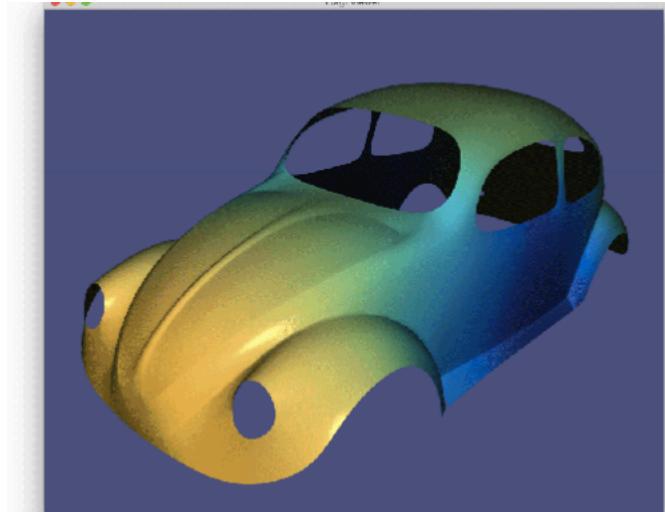


内容呈现

靠美工画？靠美工调？
几何内容的生成仍然是计算机图形学应用的瓶颈问题之一！

CG & Digital Geometry Processing

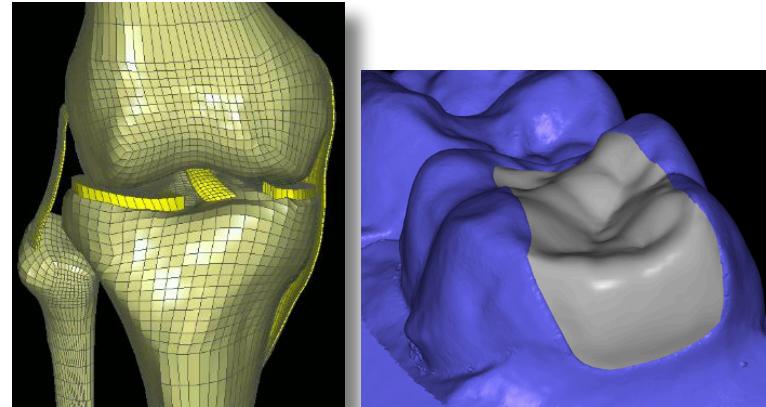
- The shape of an object is an important characteristic (not the only one...)
- DGP is a subdomain of CG without some traditional parts, like rendering, etc.
- DGP is for 2D/ 3D geometry modeling, analyzing and processing.



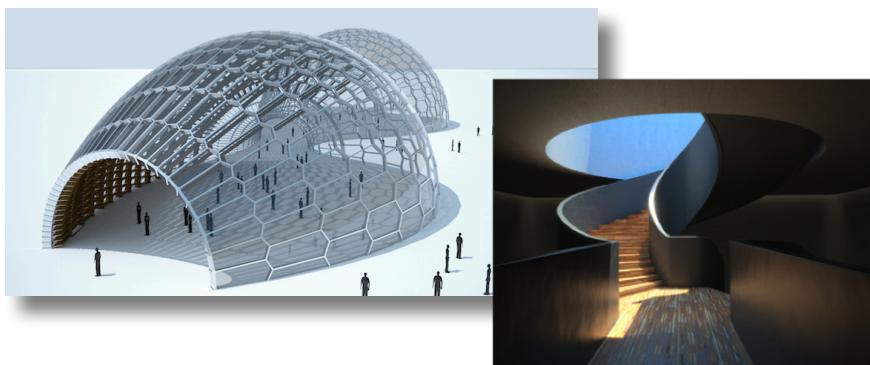
Applications



Product design and prototyping



Medicine, prosthetics



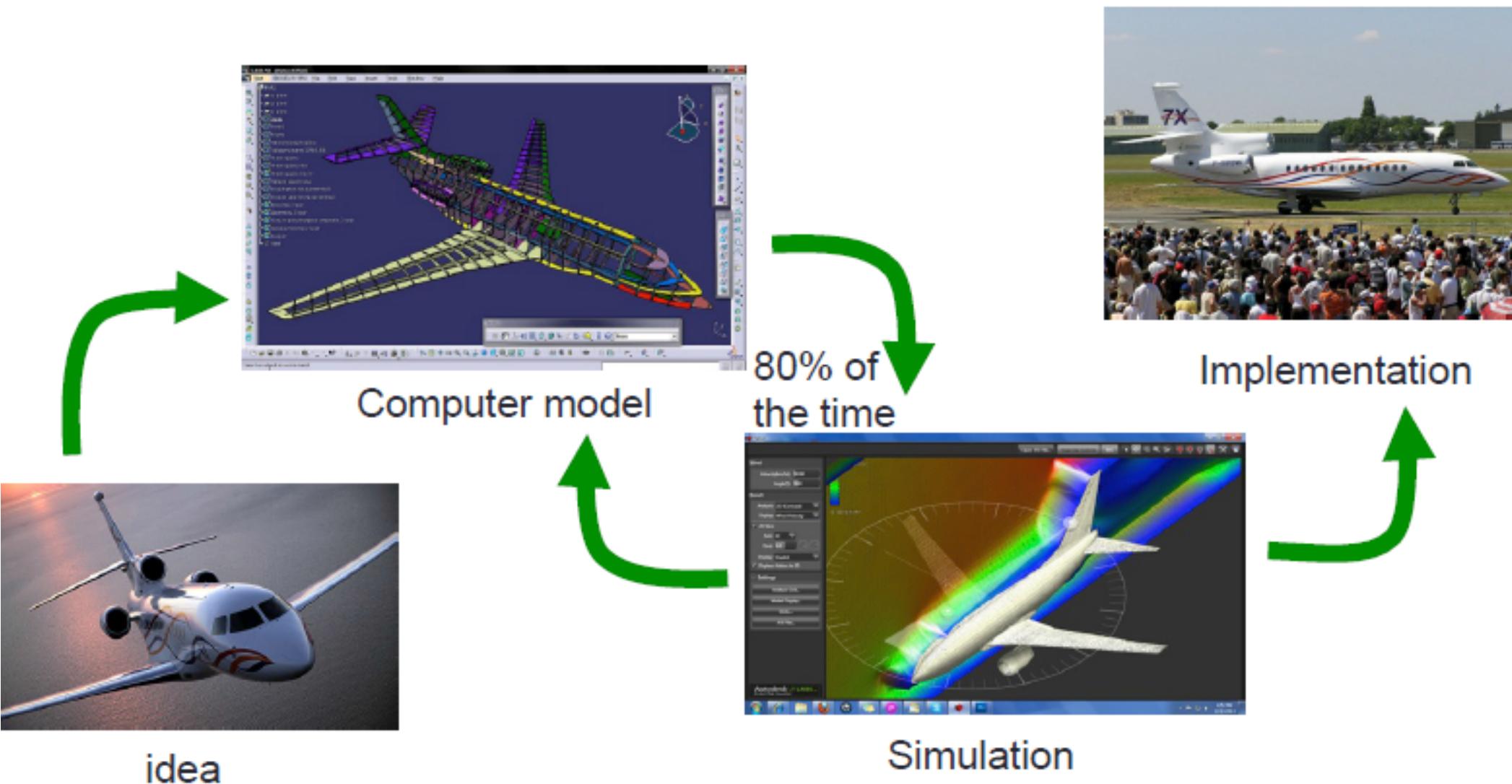
Architecture



Cultural heritage

Digital Models -- Industry

- ✓ Geometric objects in the world are digitally modeled (representation).



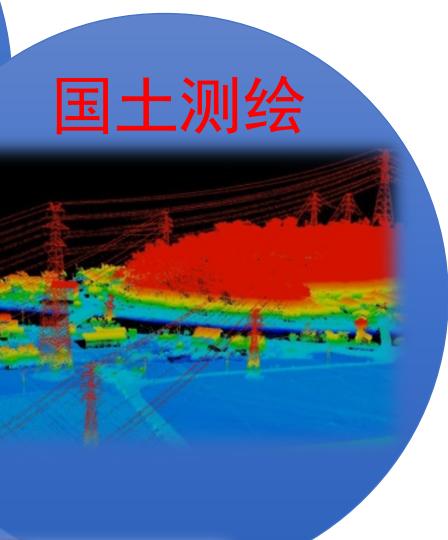
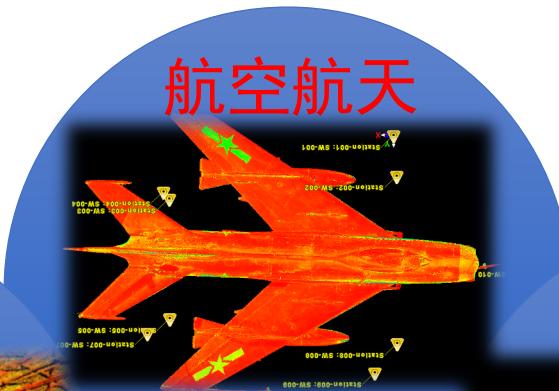
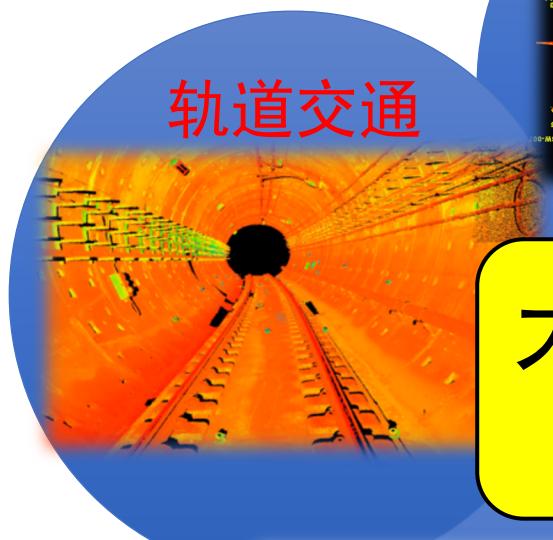
Geometric Digital Modeling -- Industry

- ✓ Geometric objects in the world are digitally modeled (representation) for
 - ✓ easy manipulation
 - ✓ easy repairing
 - ✓ easy comparison
 - ✓ easy synthesis
 - ✓ cheaper simulation

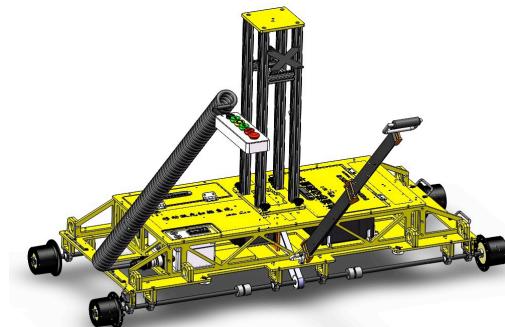
Digitally modeled
(designed on a computer)

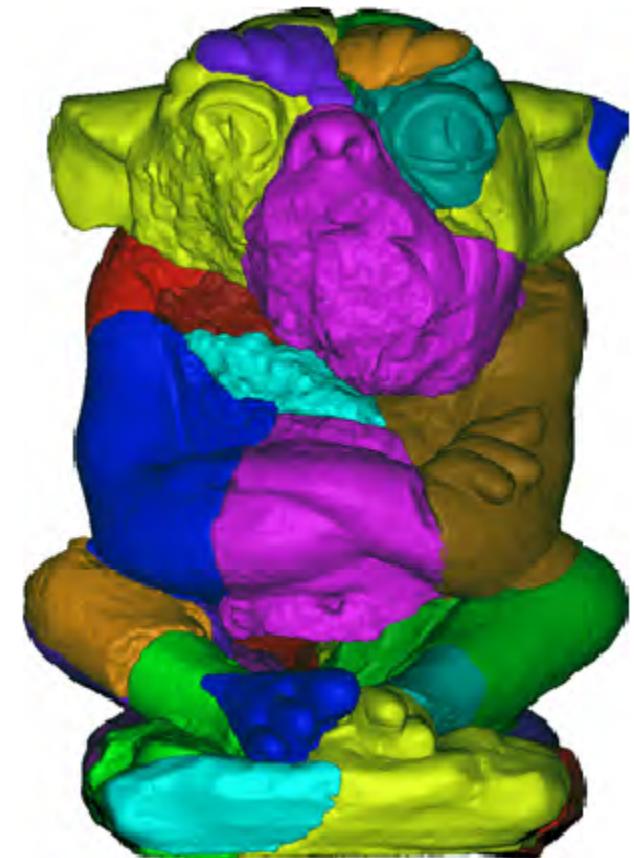


Detection and Analysis -- Industry



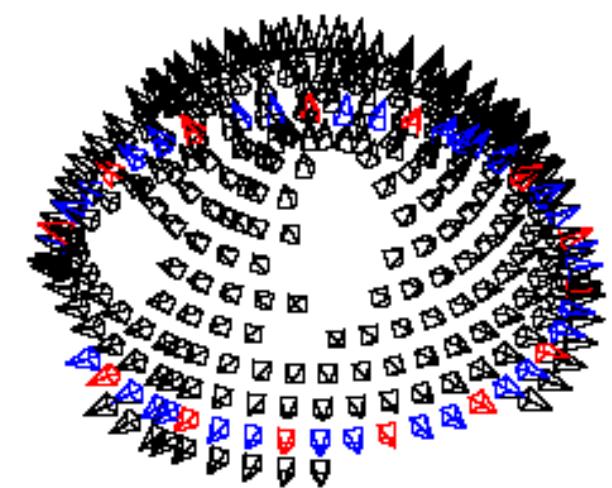
大规模点云
数据处理





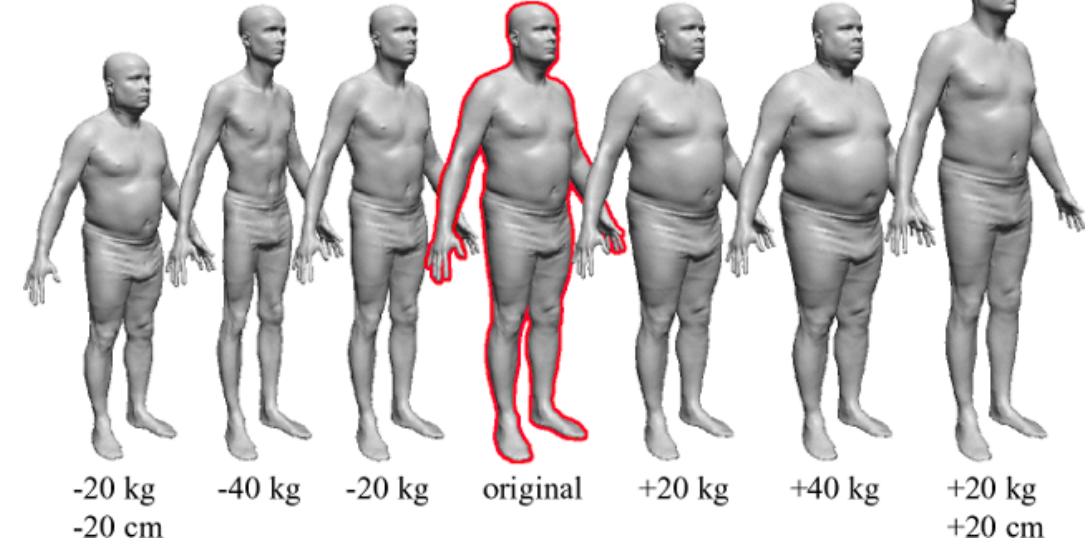
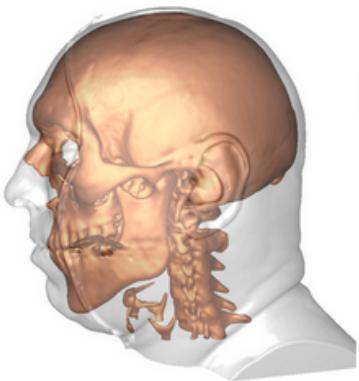
Reassembling a gargoyle statue: photo (bottom left) and 3D models (top left) of the fragments, final assembly (right).

Multi-View Stereo

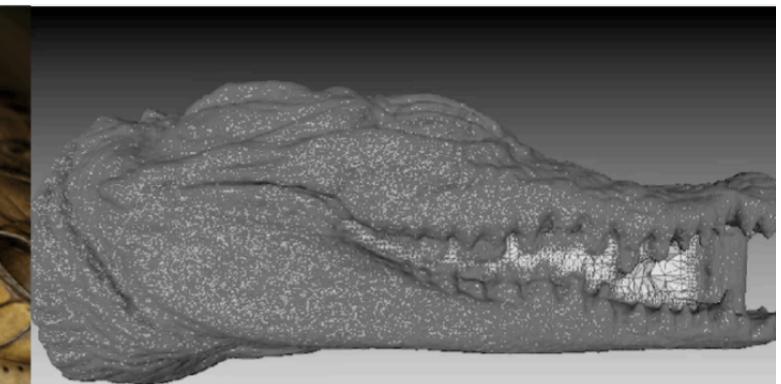


Digital Models

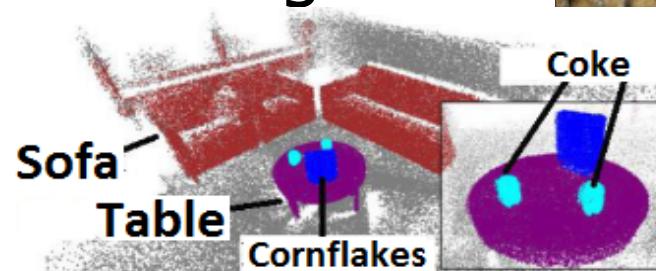
- medicine, esthetics



- Evolutionary Biology

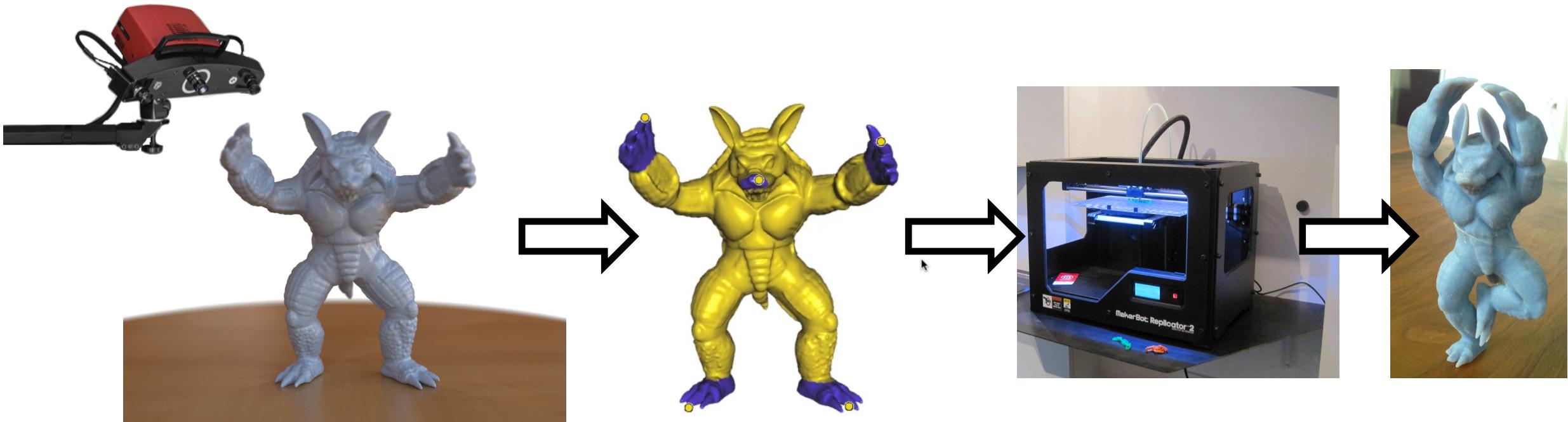


- Robotics, autonomous driving

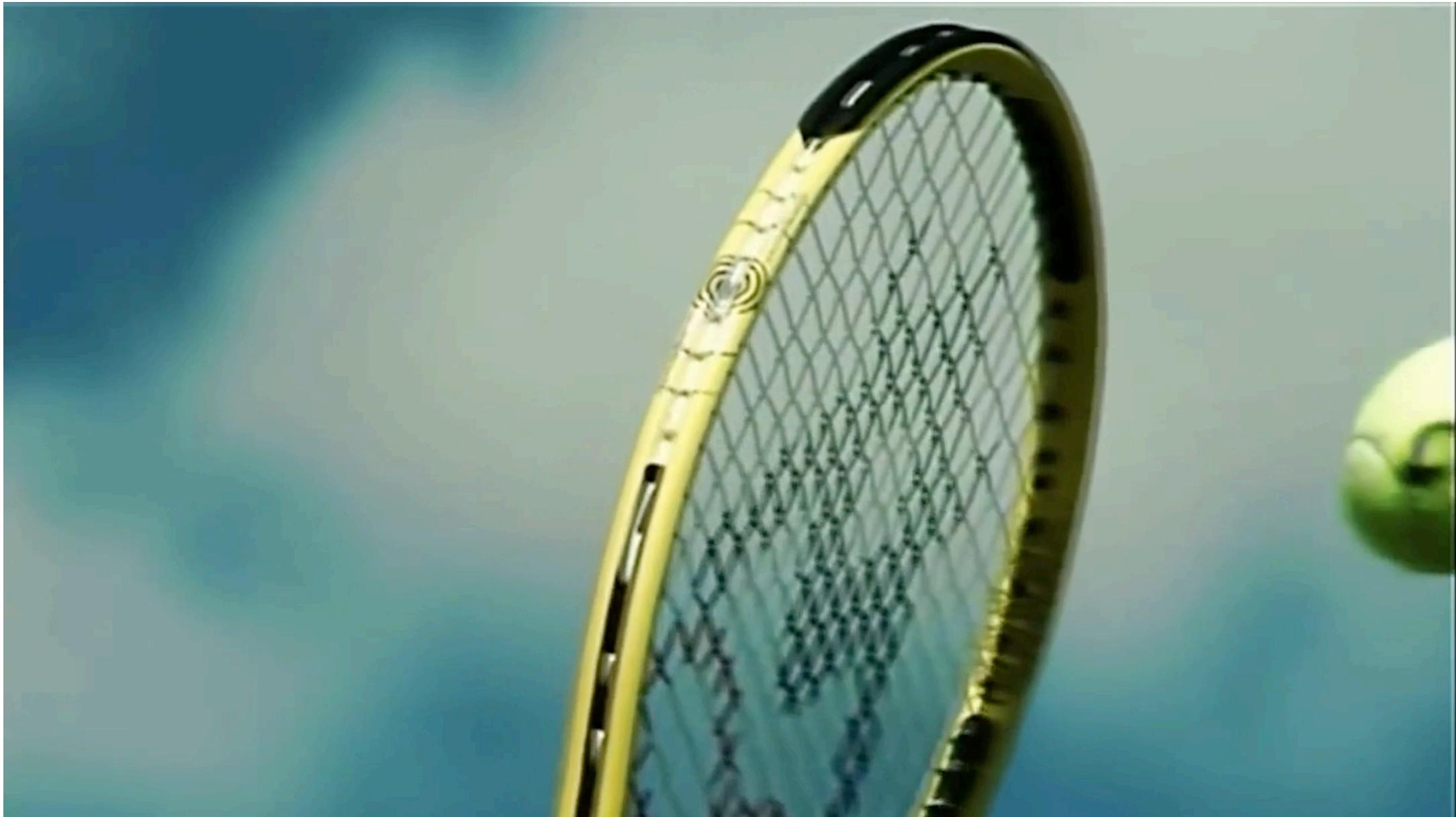


Fabrication

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



Simulation



Contents

- What is DGP
- Motivations
- **Pipeline**
- About the course

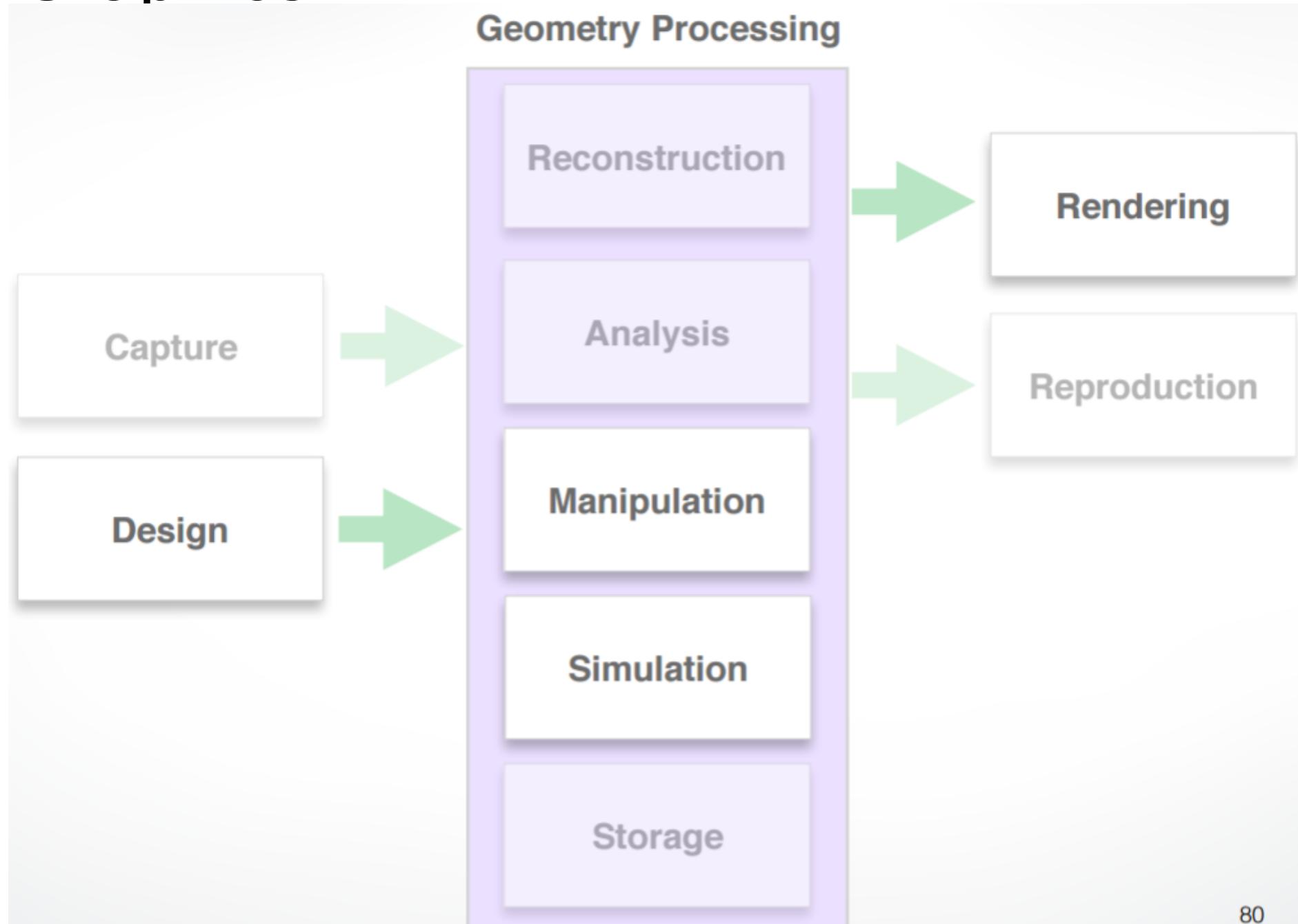
What is graphics?

- **Creation**, display, storage, and animation of visual content

First step, perhaps least well known: content creation



Classic Graphics

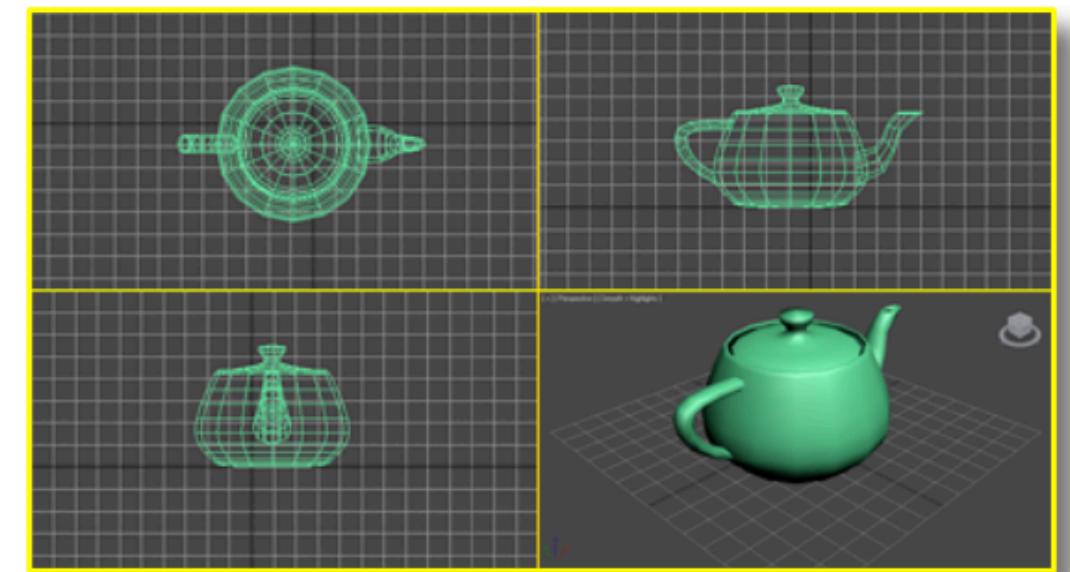


Digital Shape Modeling

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



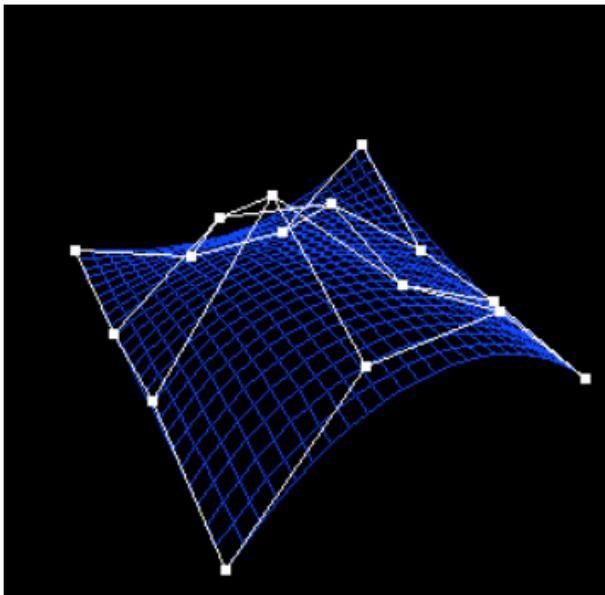
Humans have no
direct “video out”



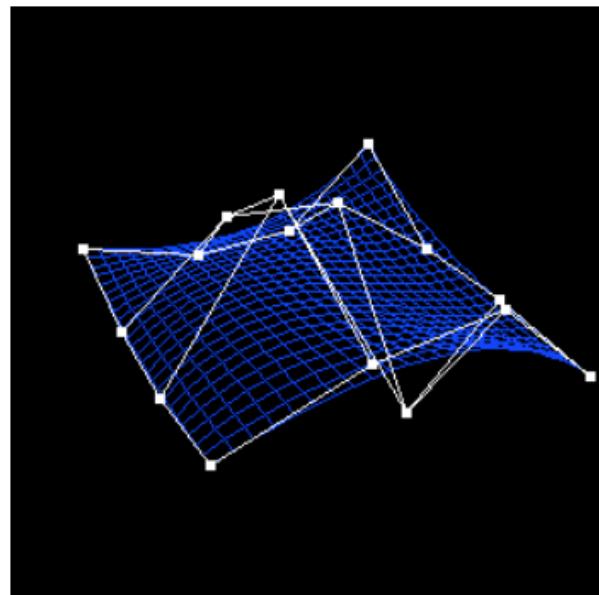
“Translation” from 2D
to 3D is hard

Computer-Aided Geometric Design

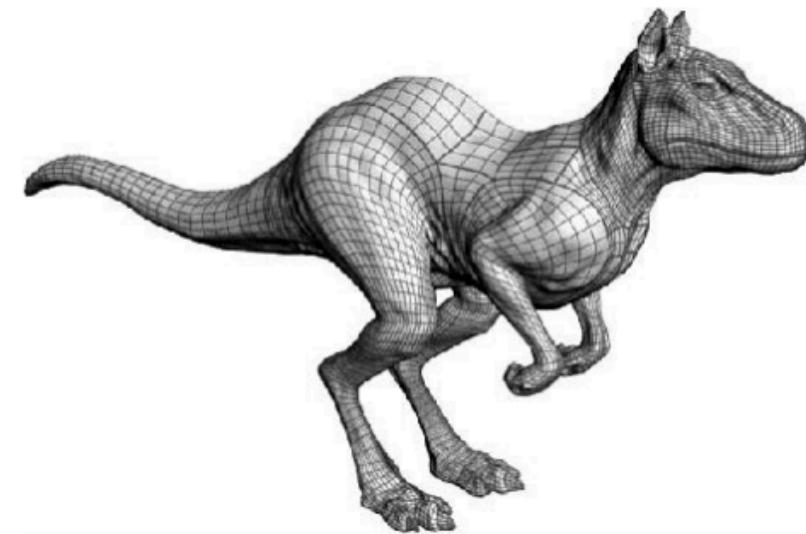
- Traditional pipeline for modeling shapes from scratch
 - Requires a specific idea of the object first
 - Not easy to experiment and explore alternatives
 - Requires training, skill and tedious work



User defines a layout
of surface patches and
control points

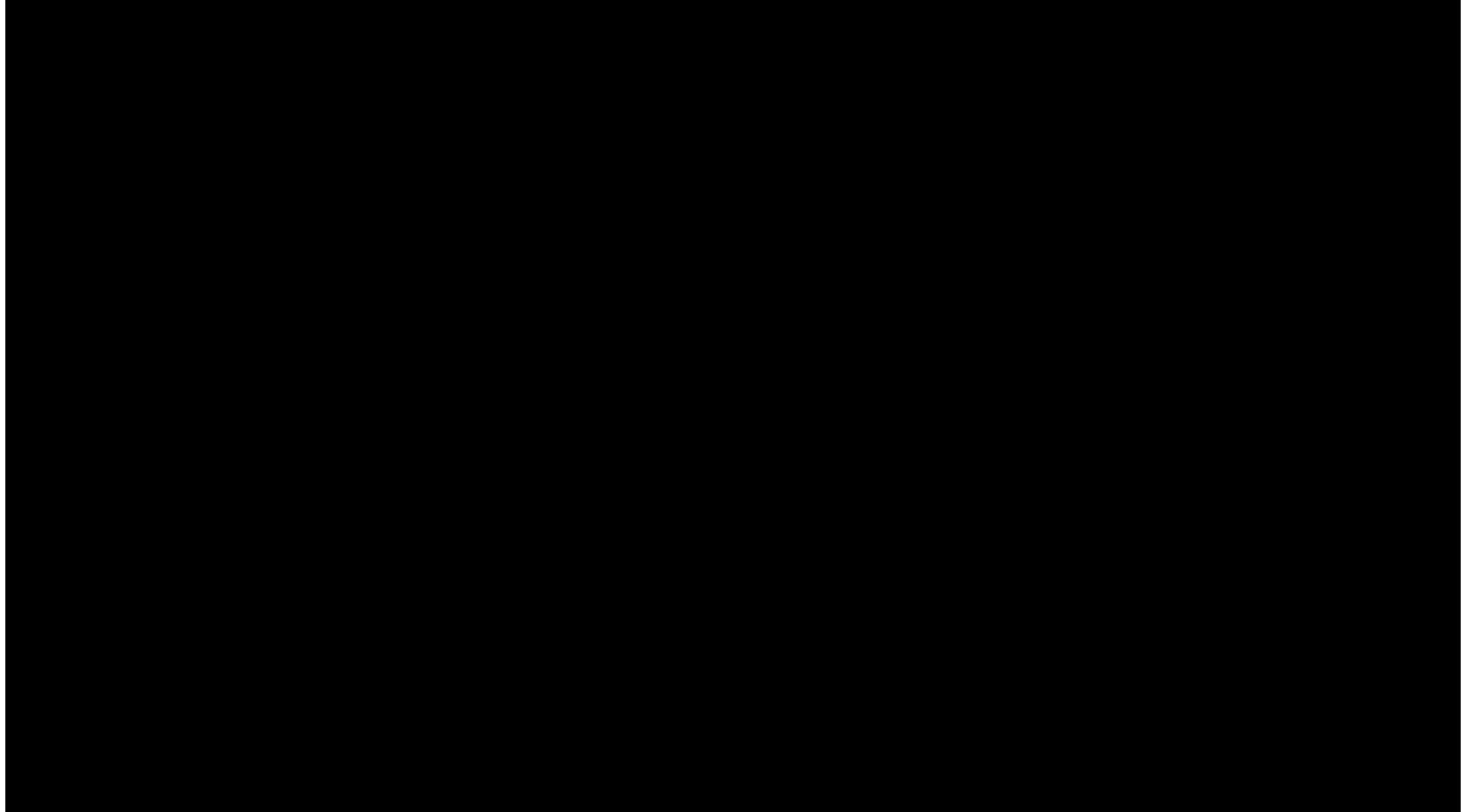


Editing is performed
by moving control
points and/or
prescribing tangents



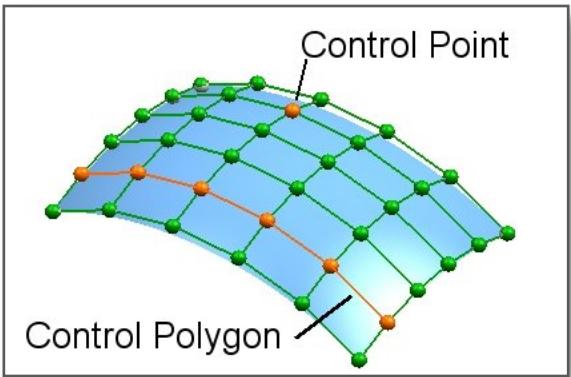
Patch-based construction
of a surface

A Demo

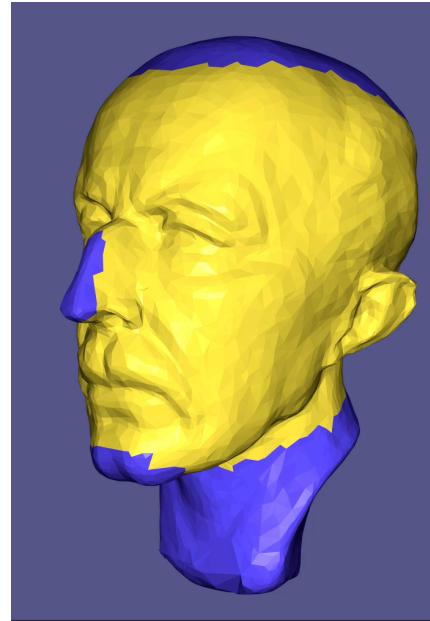
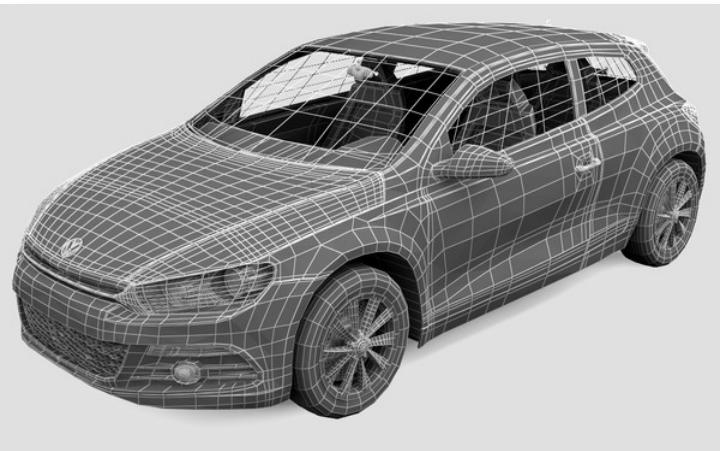


<https://www.youtube.com/embed/OnGHXARp-Hk>

Traditional CAD vs Modern Mesh Modeling

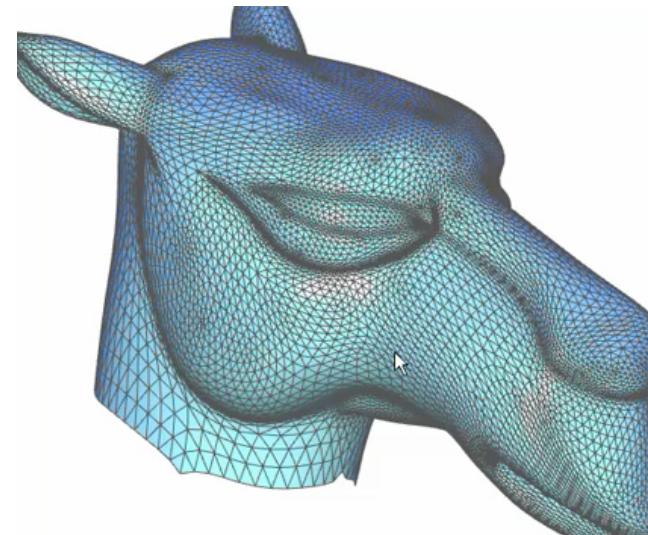


$$\mathbf{x}(u, v) = \sum_{i,j} \mathbf{p}_{i,j} B_i(u) B_j(v)$$



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

User has more freedom!
Select and manipulate
arbitrary regions.



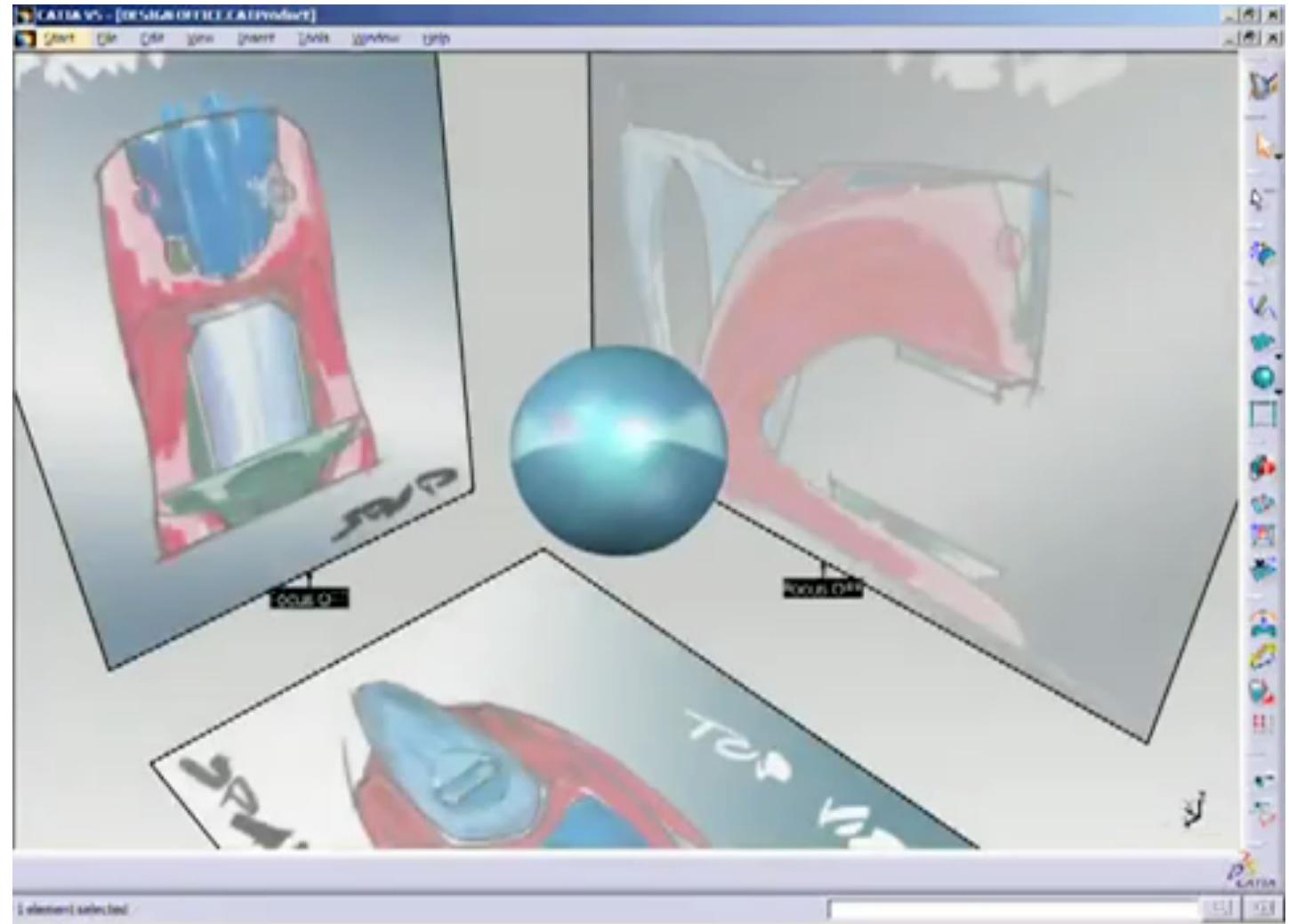
Interactive modeling by ZBrush



<https://www.youtube.com/watch?v=uSo5ZnkPxVc>

Computer-Aided Geometric Design

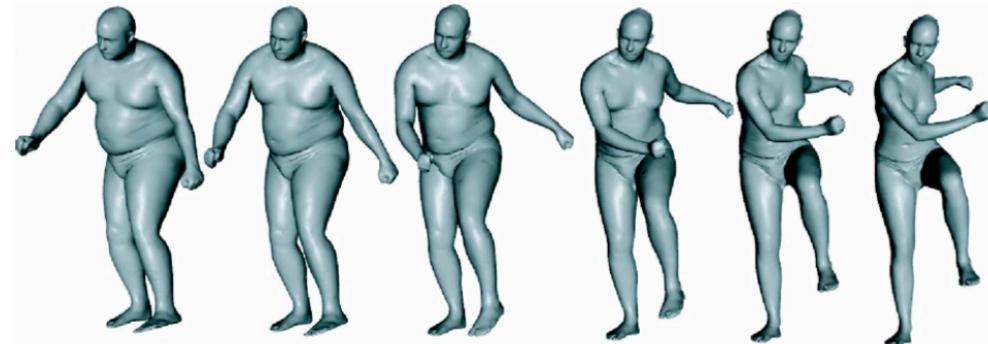
- High-quality surfaces
- Constrained modeling
- Requires a specific idea of the object first
 - Not easy to experiment and explore alternatives
- Requires training, skill and tedious work



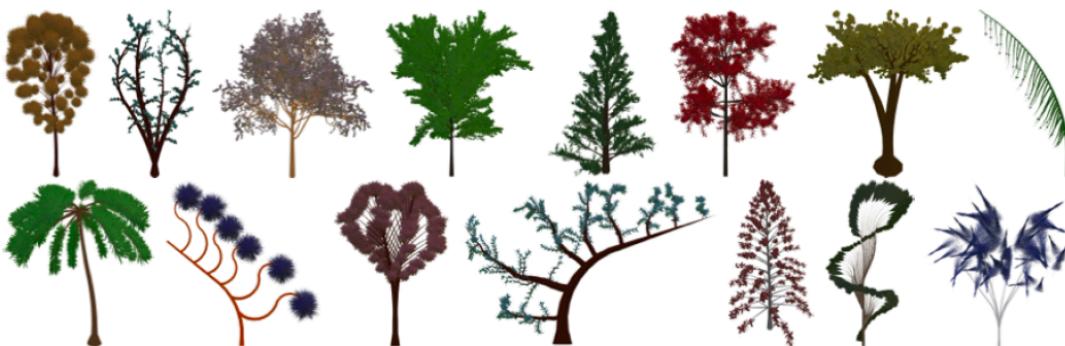
CATIA, Dassault Systemes

<http://youtu.be/gTC5zMktMr0>

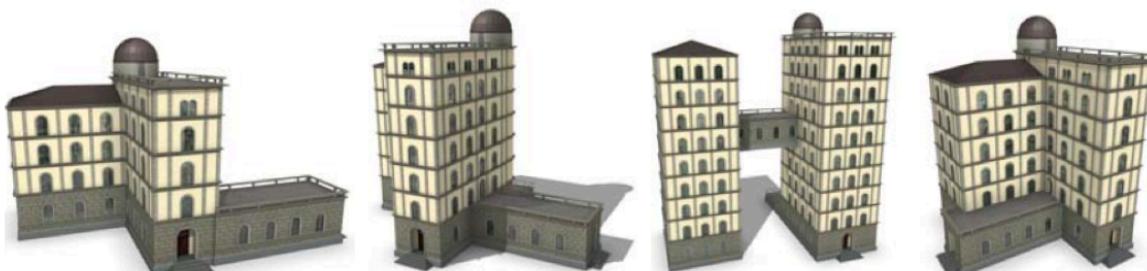
3D Content Creation



Template



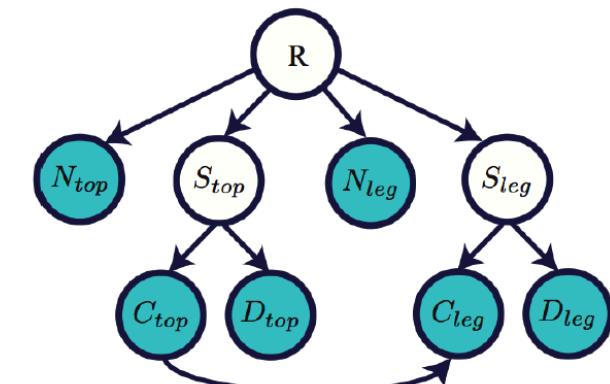
Procedure



Grammar

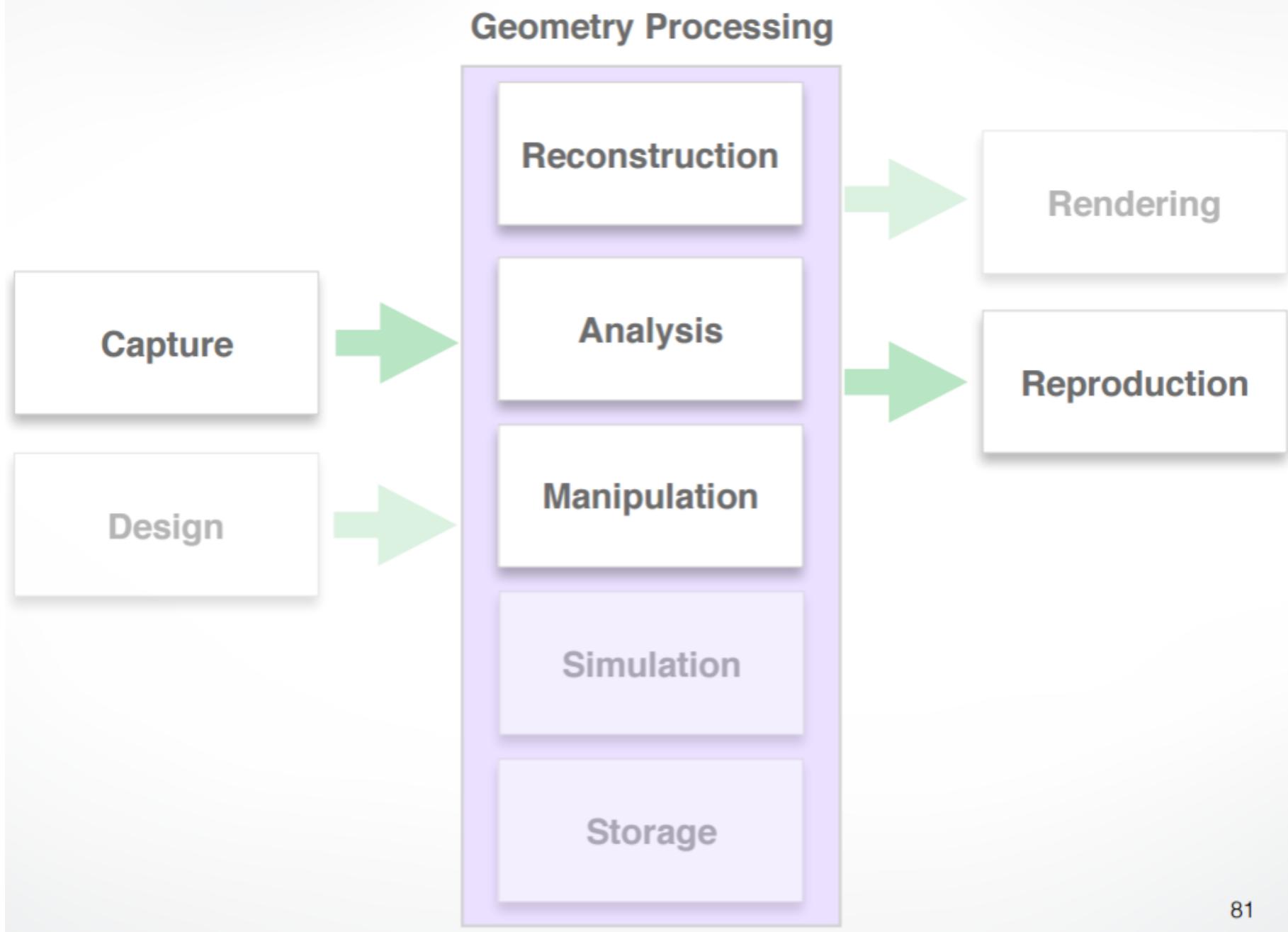


Exemplars



Probabilistic Graphical Model

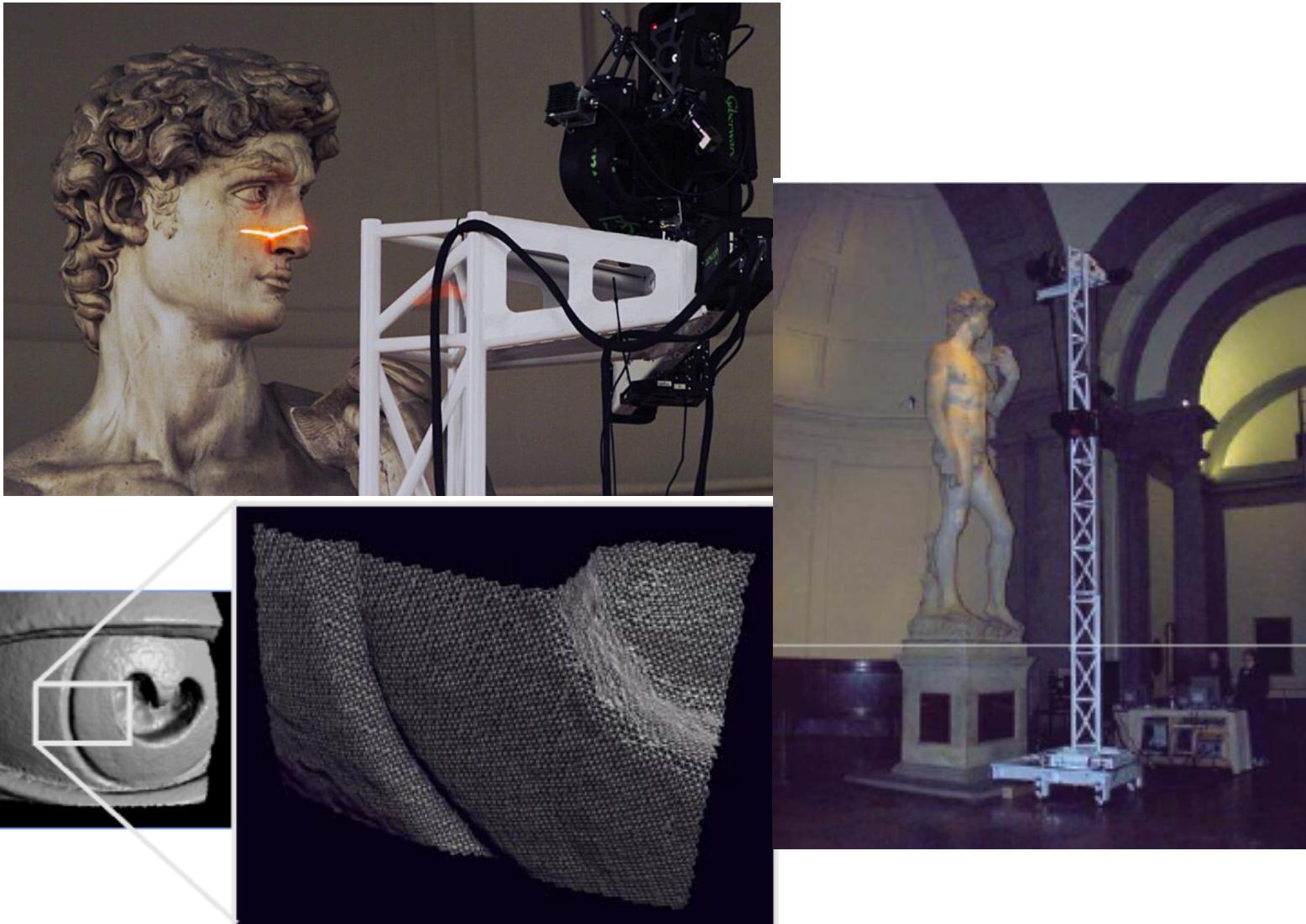
Modern Graphics/Vision



The Digital Michelangelo Project

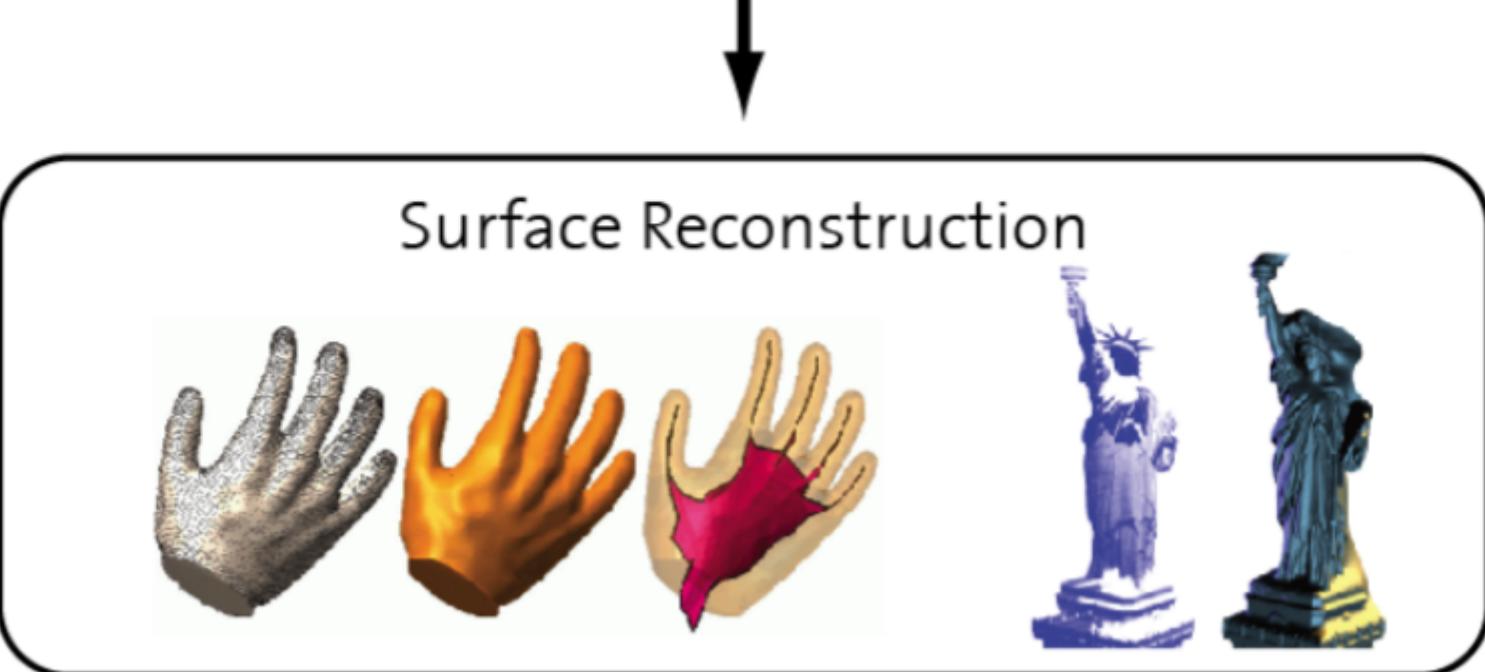
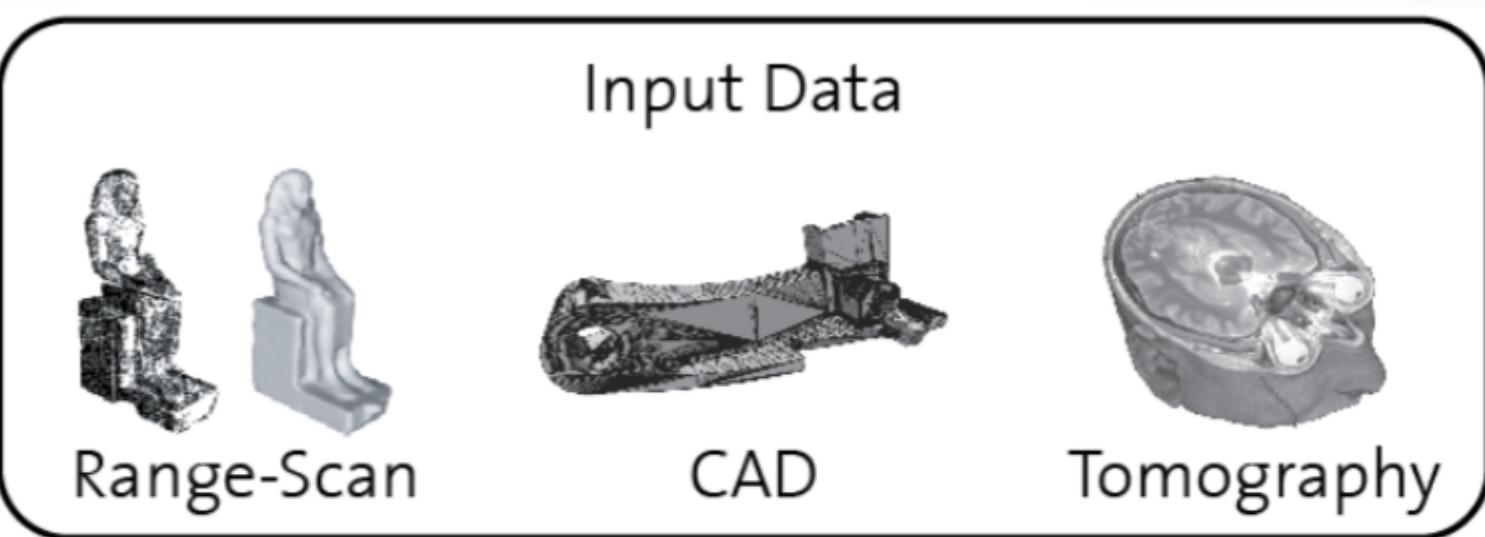
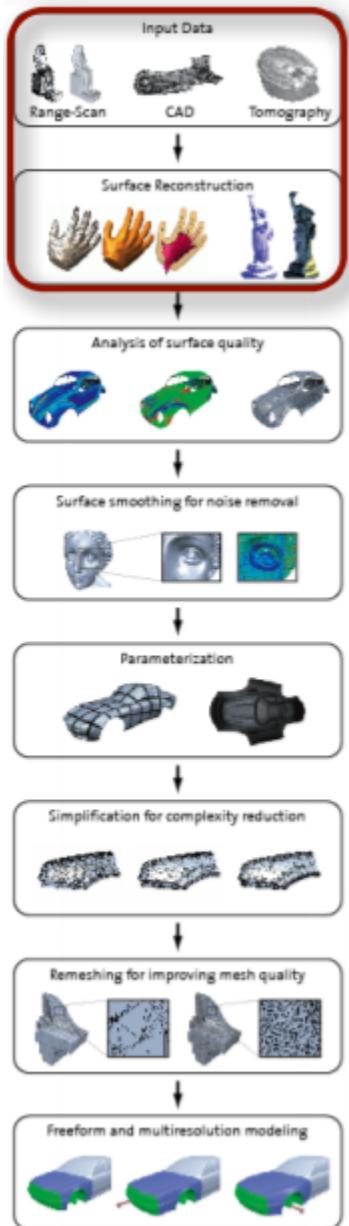
David:

- Resolution 0.29 mm
- 480 million polygons
- 2,000 color images
- 32 gigabytes
- **30 nights of scanning**
- **22 people**

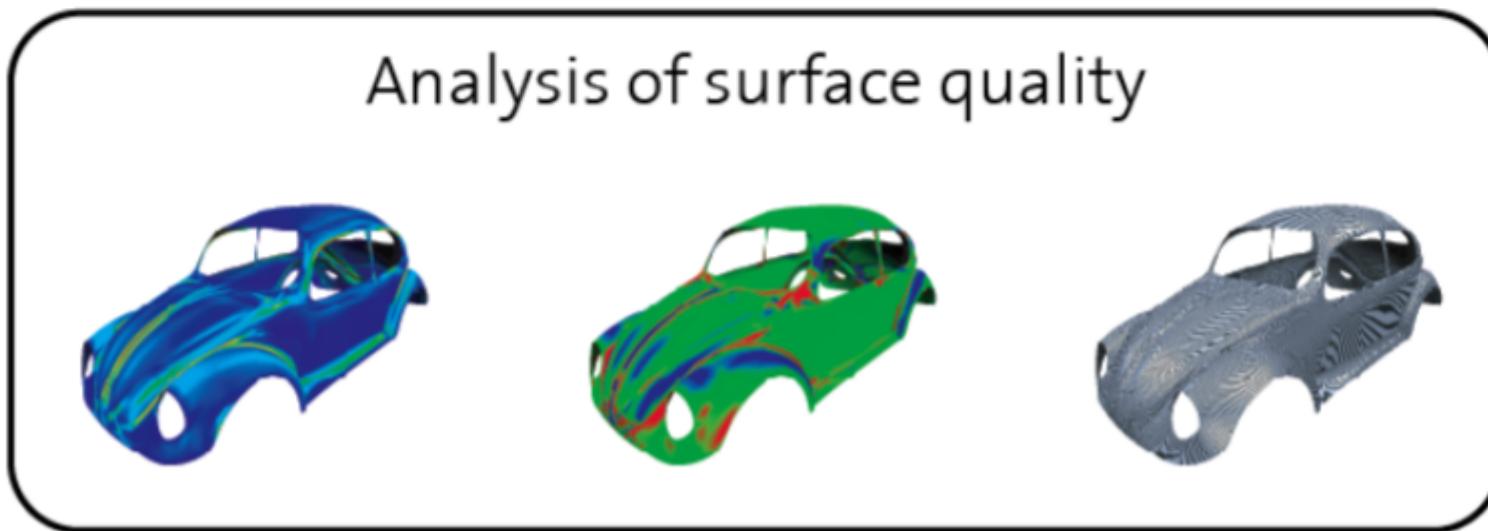
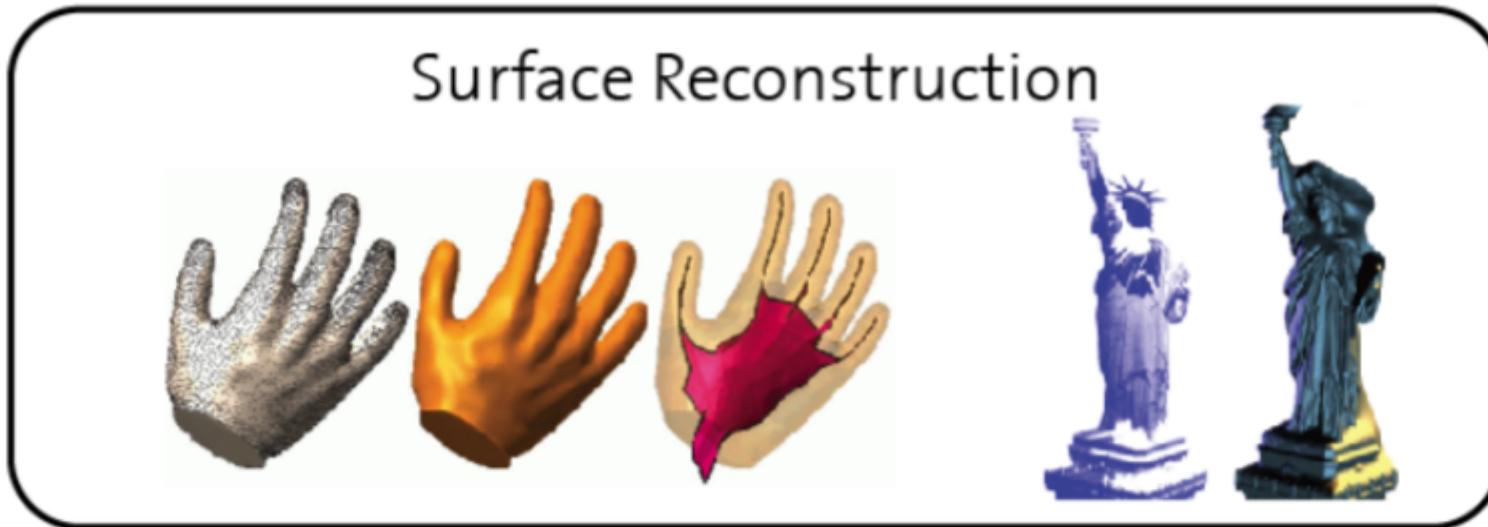
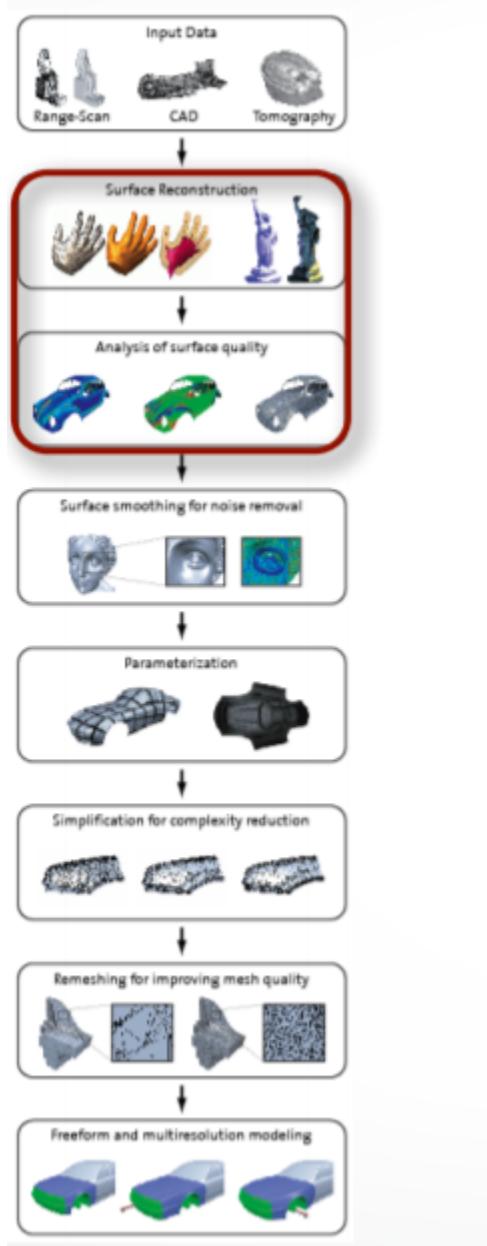


"The Digital Michelangelo Project: 3D Scanning of Large Statues" [Levoy et al. 2000]

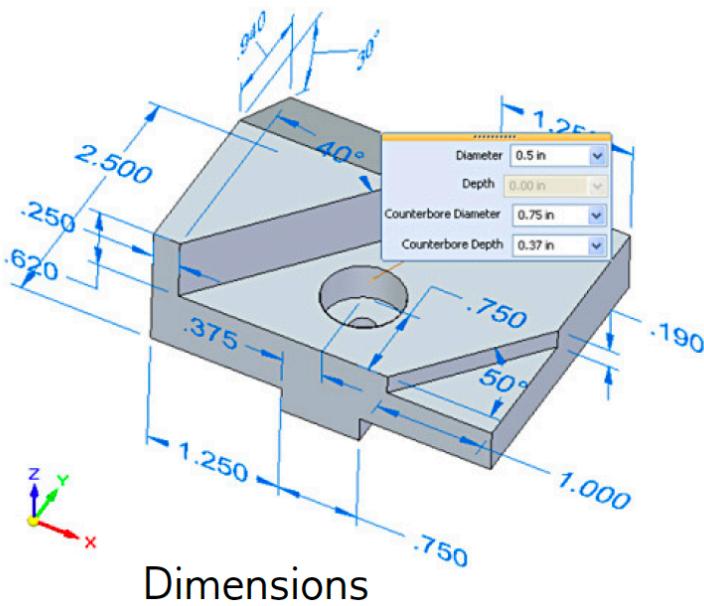
Geometry Processing Pipeline



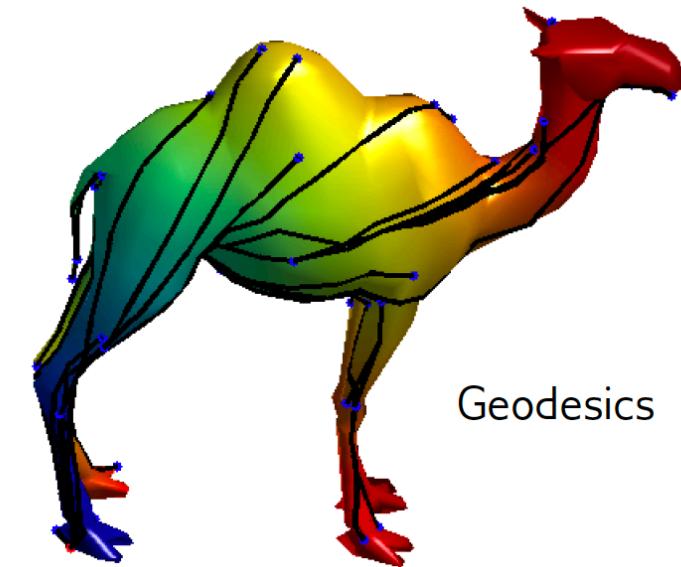
Geometry Processing Pipeline



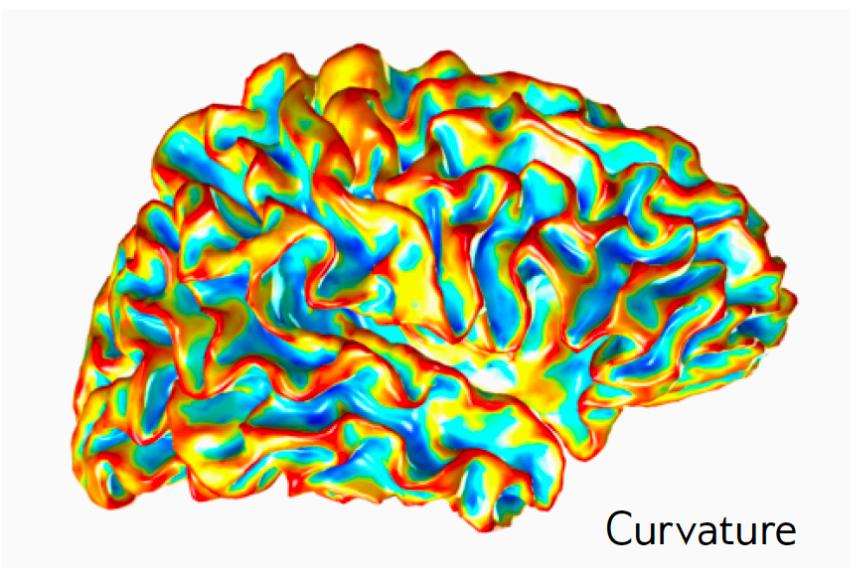
Basic Geometric Analysis



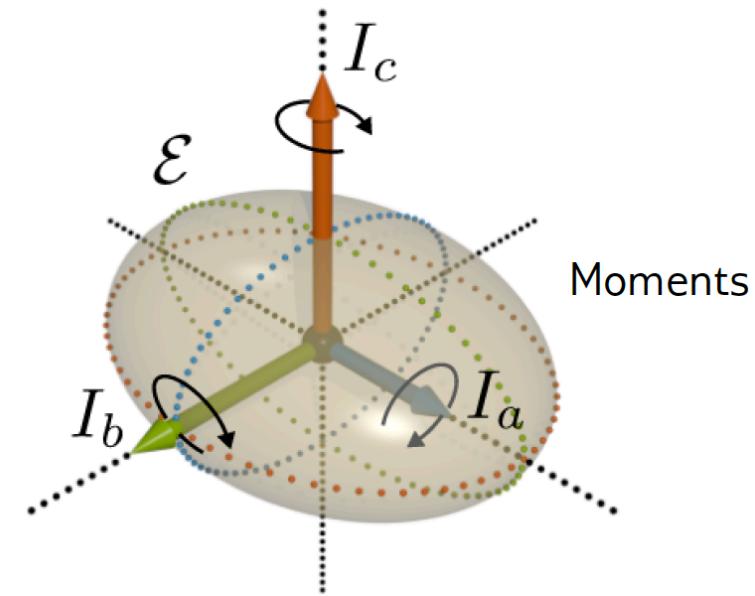
Dimensions



Geodesics

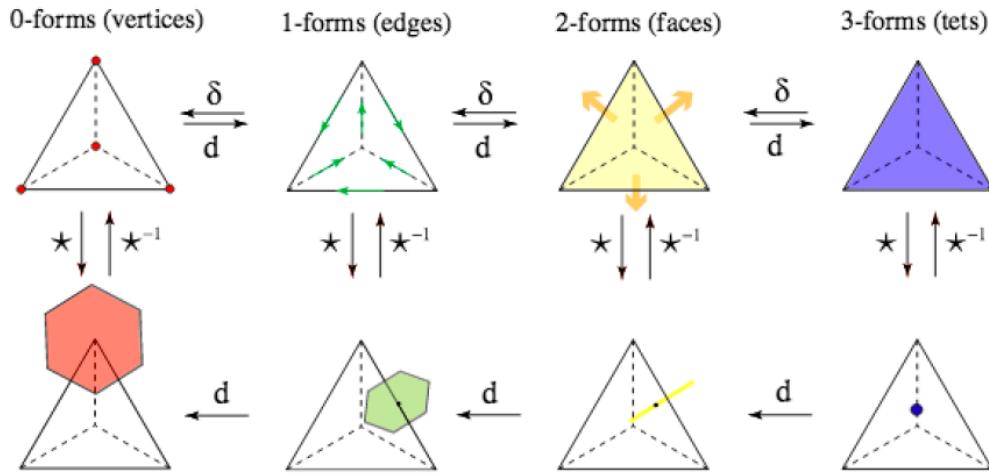


Curvature

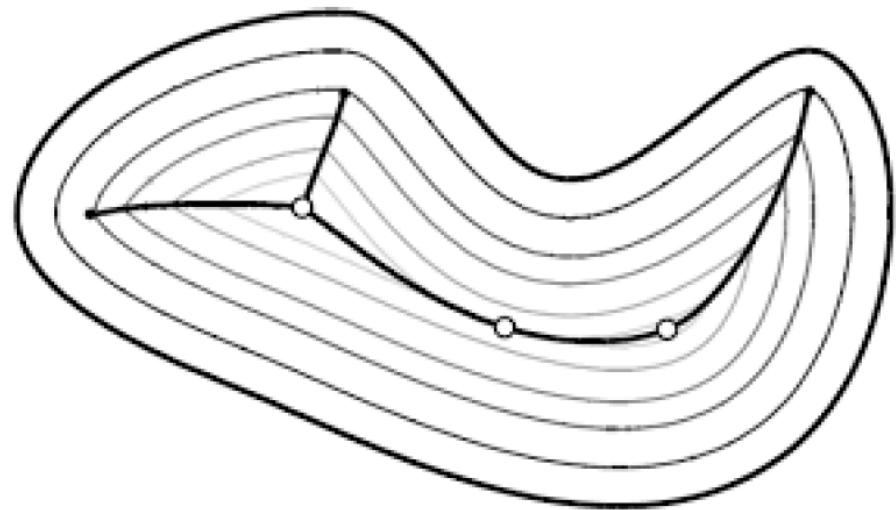


Moments

Advanced Geometric Analysis



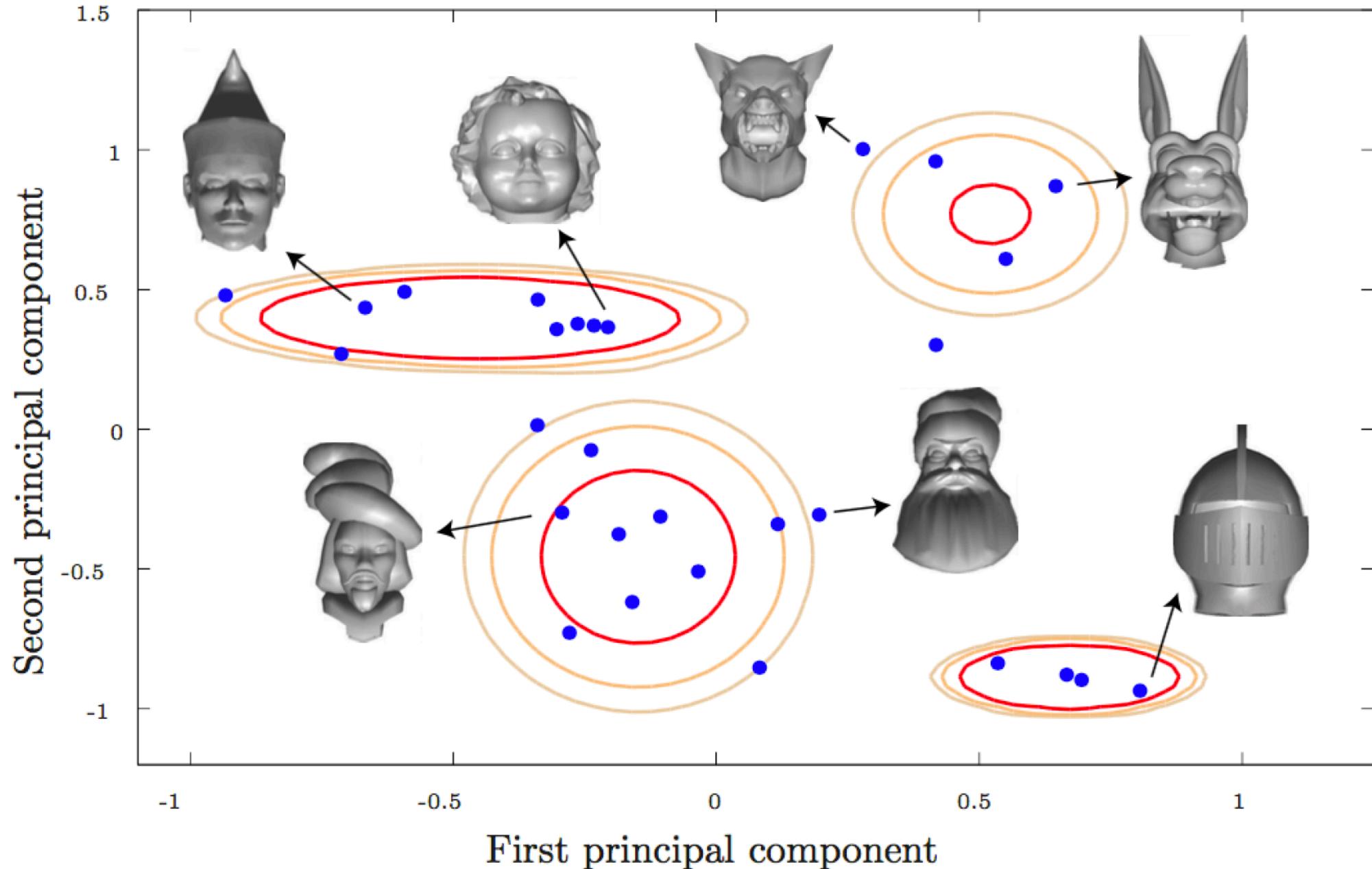
Discrete Differential Geometry



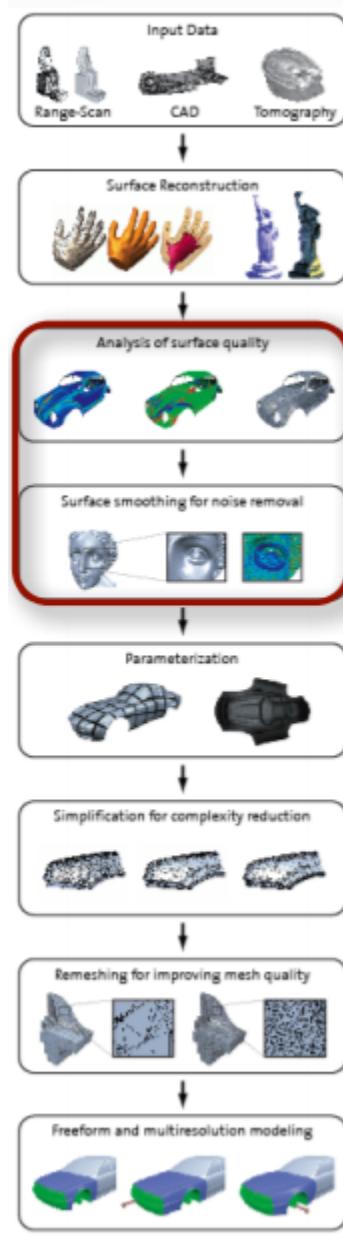
Medial Axis Transform



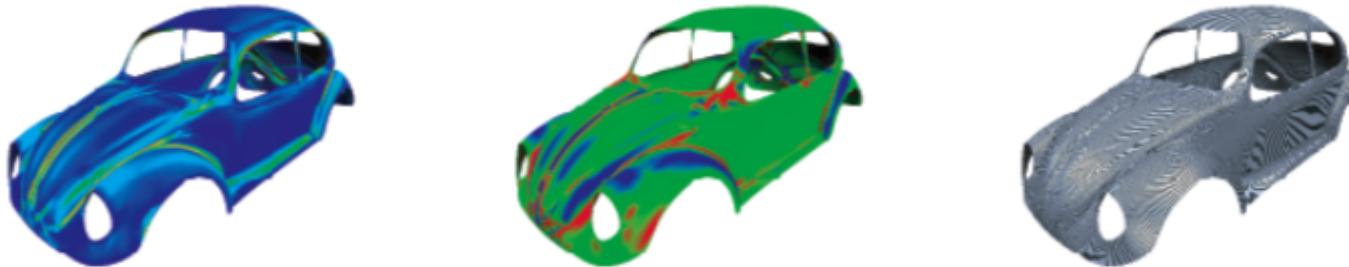
Global Shape Features



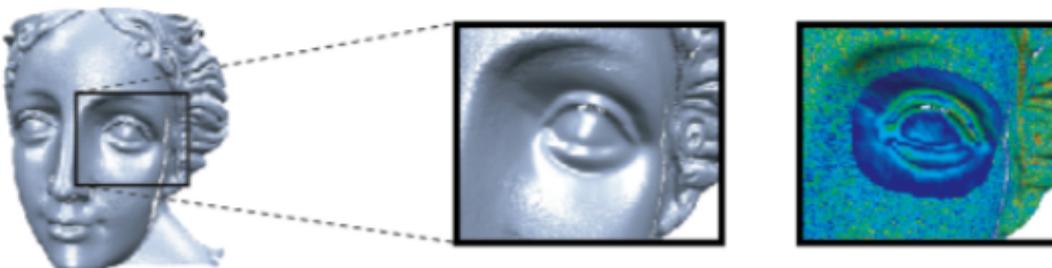
Geometry Processing Pipeline



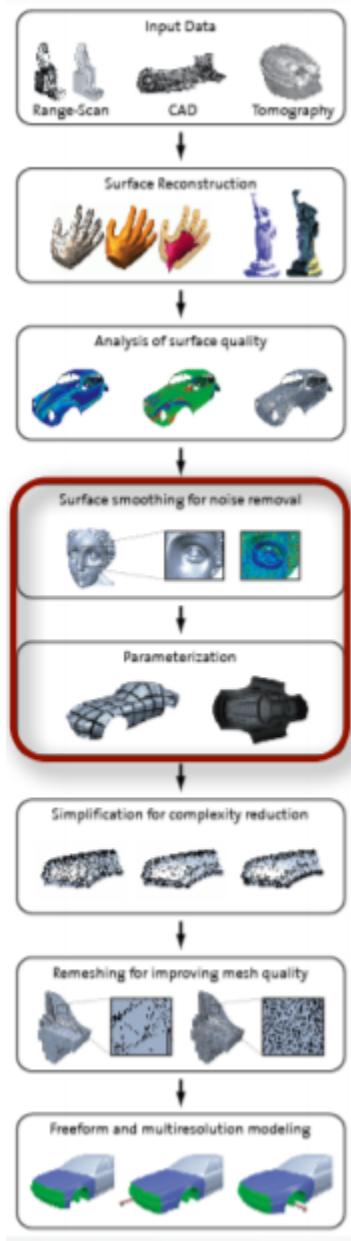
Analysis of surface quality



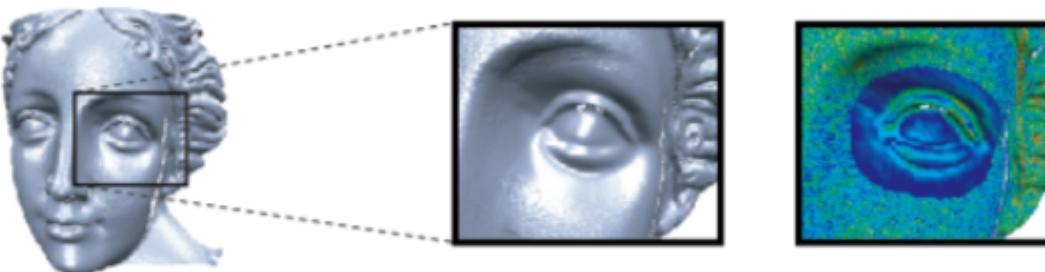
Surface smoothing for noise removal



Geometry Processing Pipeline



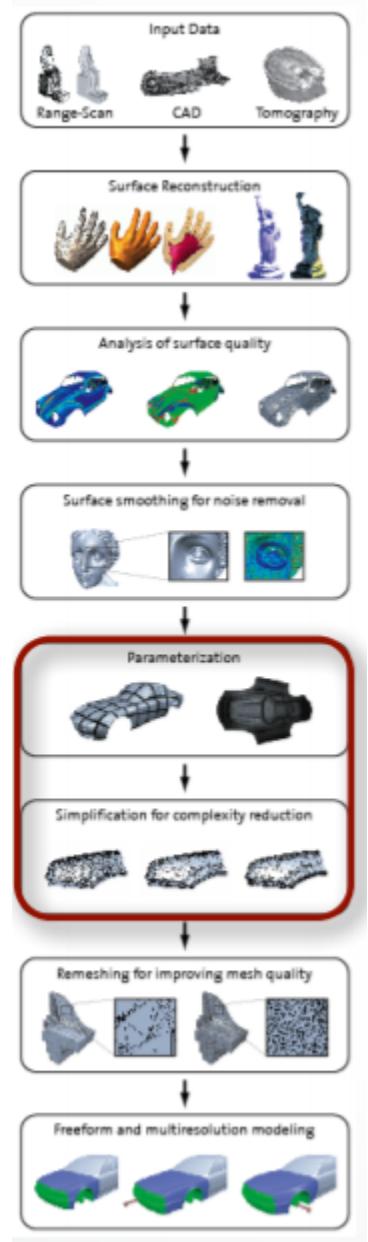
Surface smoothing for noise removal



Parameterization



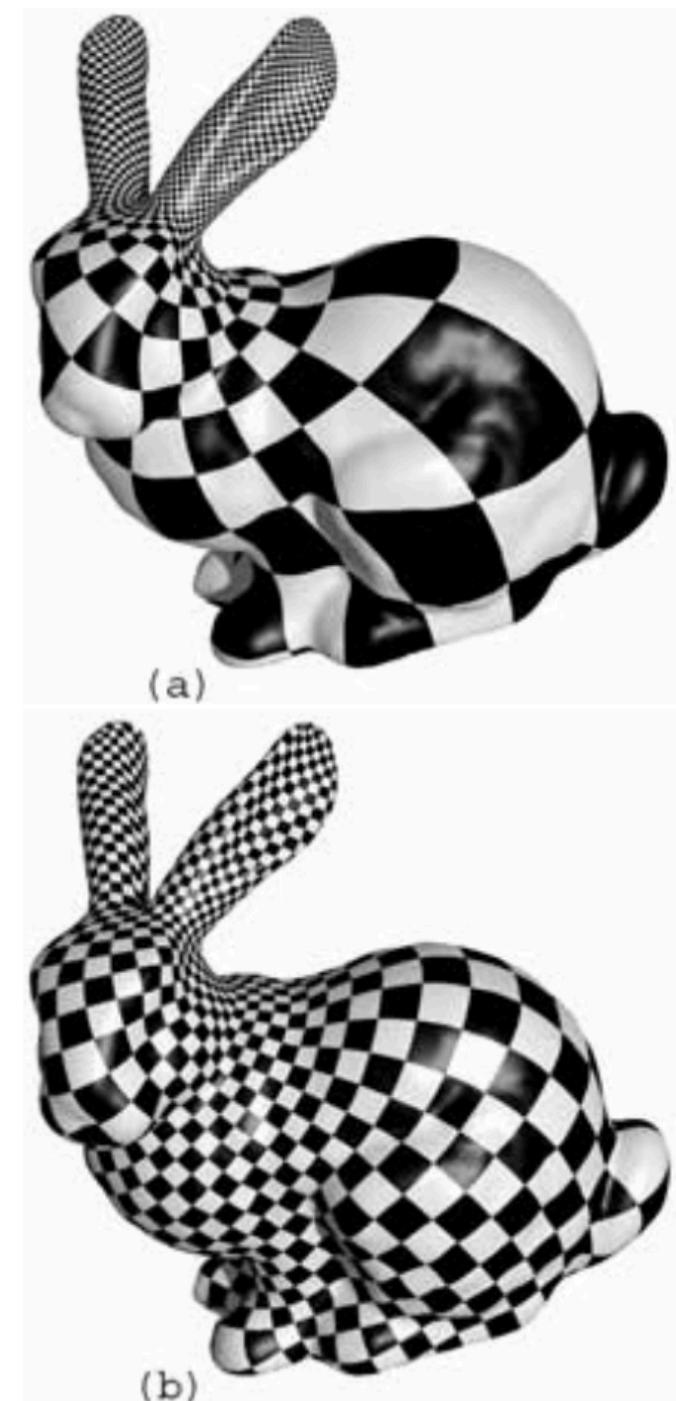
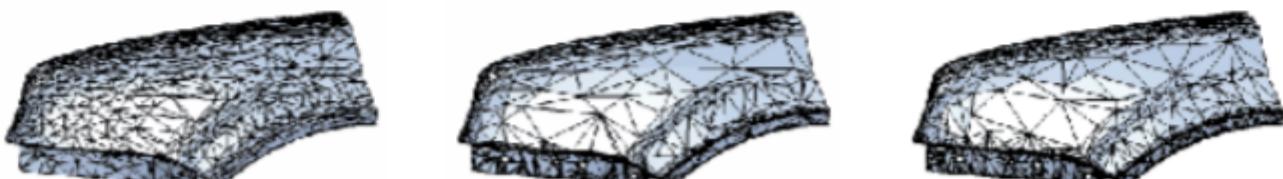
Geometry Processing Pipeline



Parameterization



Simplification for complexity reduction



Computational archaeology



Eg14_Content-Aware Surface Parameterization for Interactive Restoration of Historical Documents

Computational thermoforming (计算热成型)

Computational Thermoforming

Christian Schüller¹ Daniele Panozzo¹ Anselm Grundhöfer²
Henning Zimmer² Evgeni Sorkine¹
Olga Sorkine-Hornung¹

¹ ETH Zurich

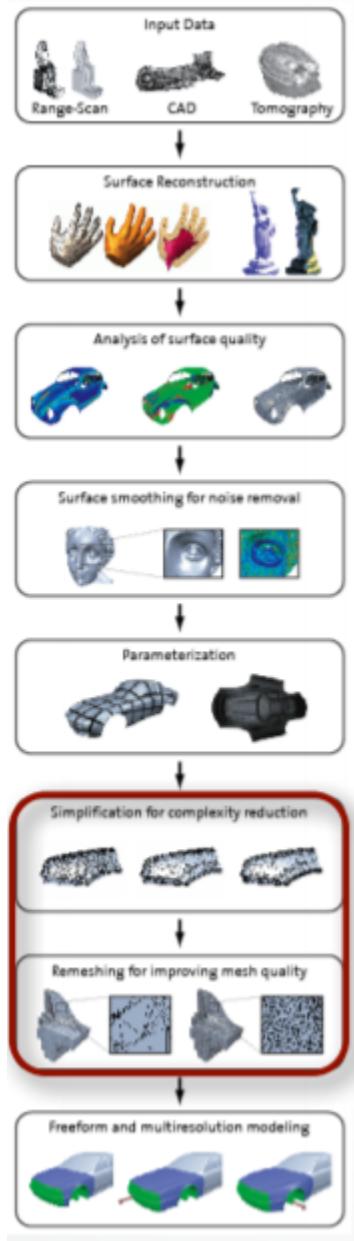
² Disney Research



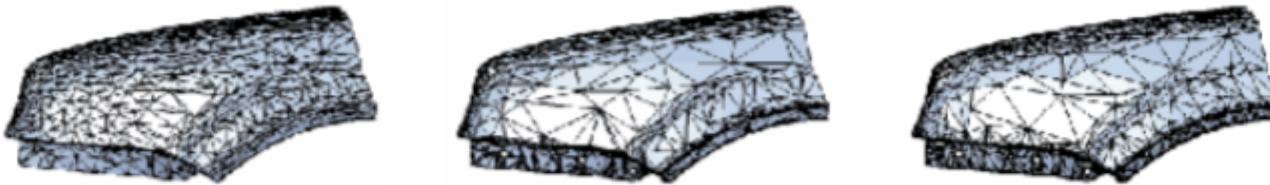
This video contains audio

texture mapping, parameterization

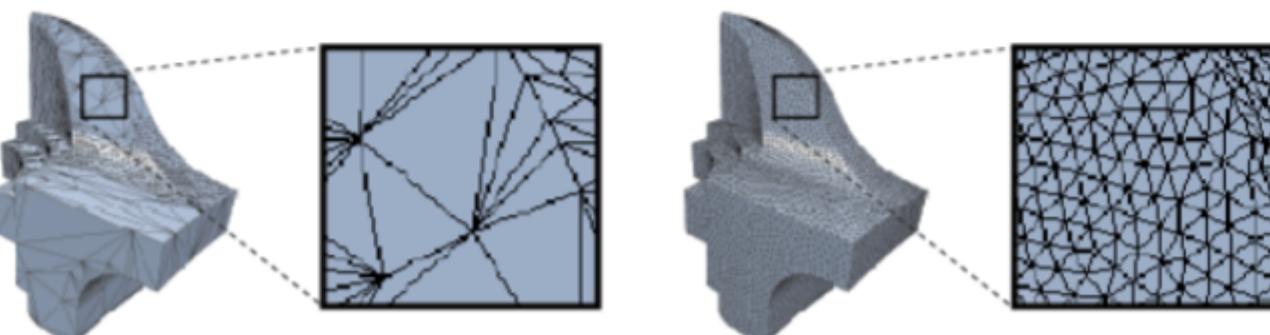
Geometry Processing Pipeline



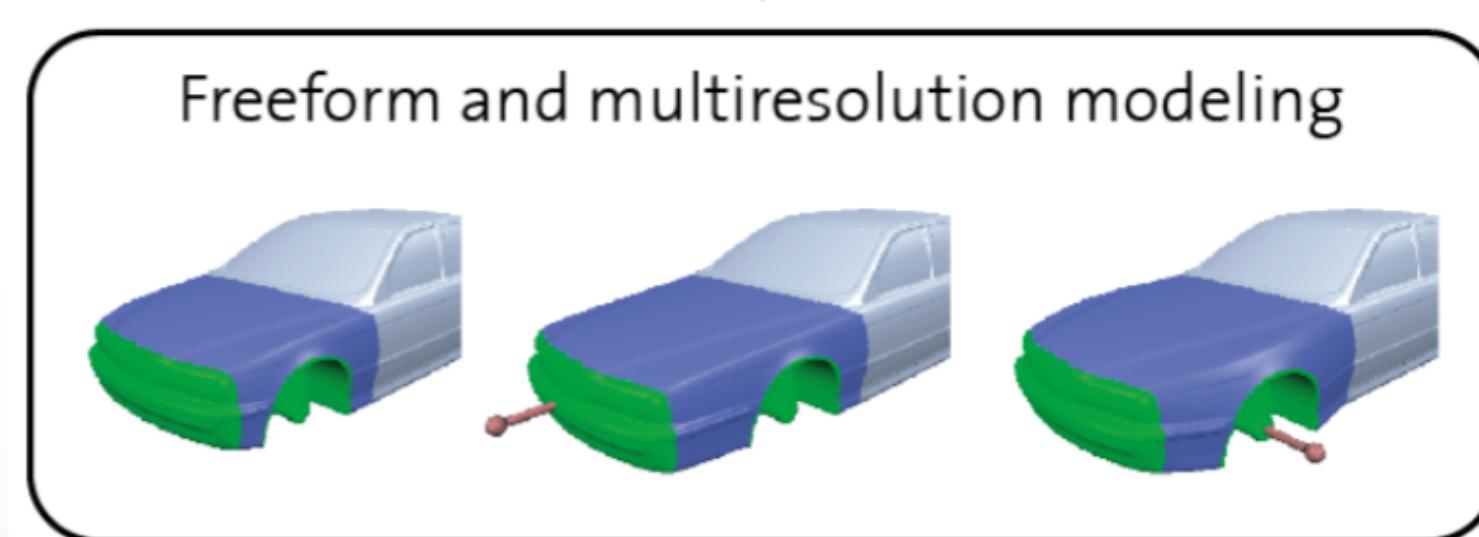
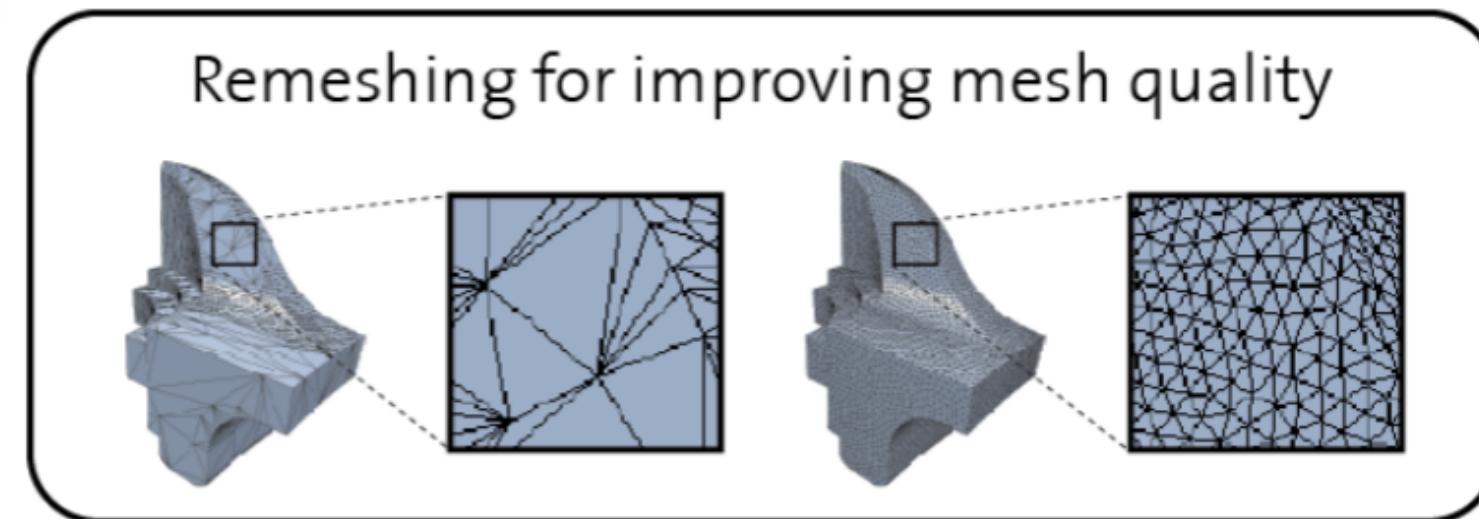
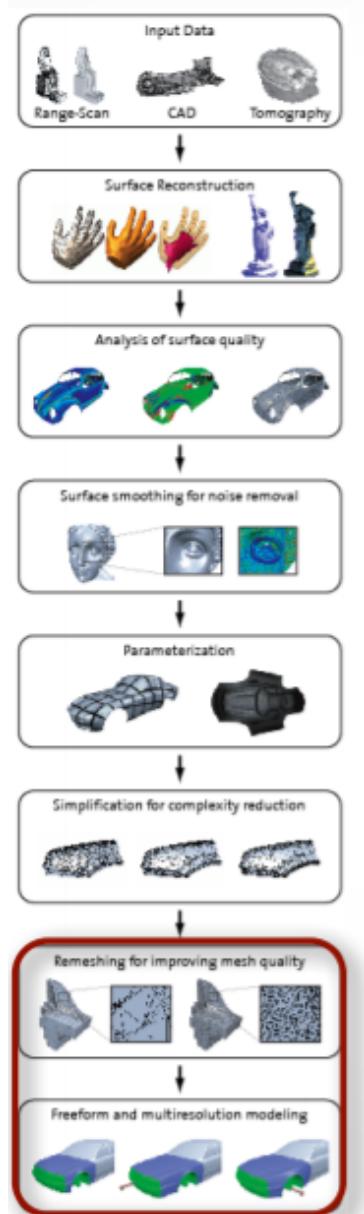
Simplification for complexity reduction



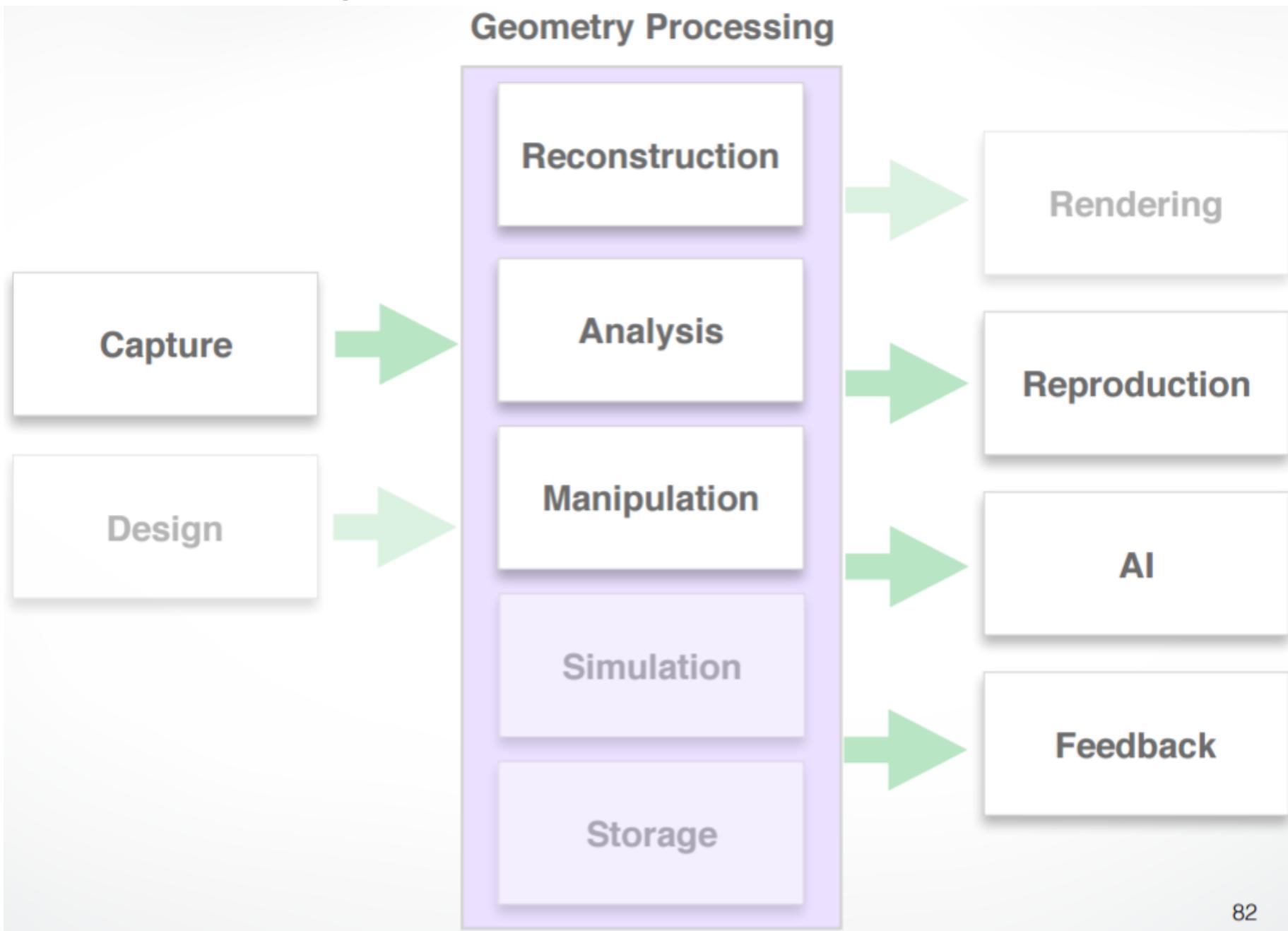
Remeshing for improving mesh quality



Geometry Processing Pipeline



The Future: Big Data / Robotics



About the course

<https://github.com/jjcao-school/dgp>

Course Objectives

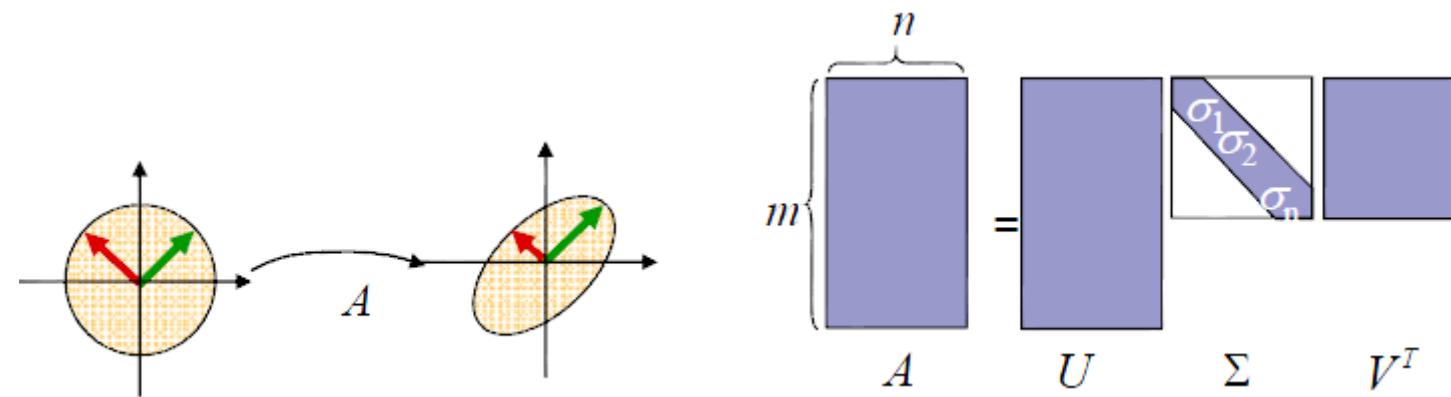
- **Basic concepts**, for 3D shape modeling / digital geometry processing
- **Basic coding training: Design and implement** individual components of geometric modeling system
- **Apply** the proposed methods in your own work

Target Audience

- PhD students, MSc students, Advanced undergraduates
- **Computer Science**, Computer Engineering, **Mathematics**, Physics, Game Program, Biomedicine, Bioengineering, etc.
- Computer Graphics, Computer Vision, Robotics, Machine Learning, Signal and Image Processing, Medical Imaging

Prerequisites

- Differential Geometry
- Linear algebra: transformations, spectral decomposition, PCA, SVD
- Graph theory
- ...



- Combined with a lot of intuition ...
- Work on real data = Write/use a lot of code!

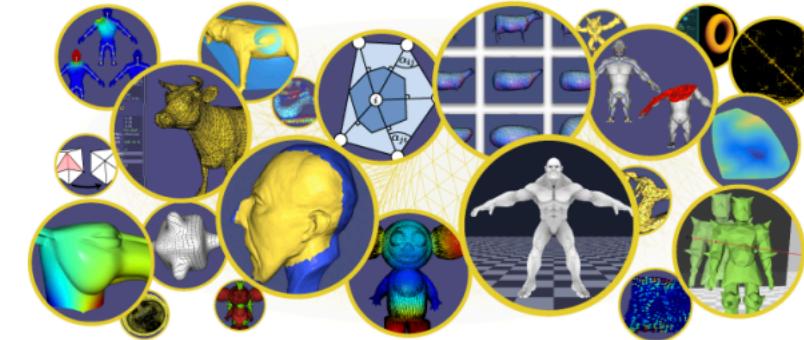
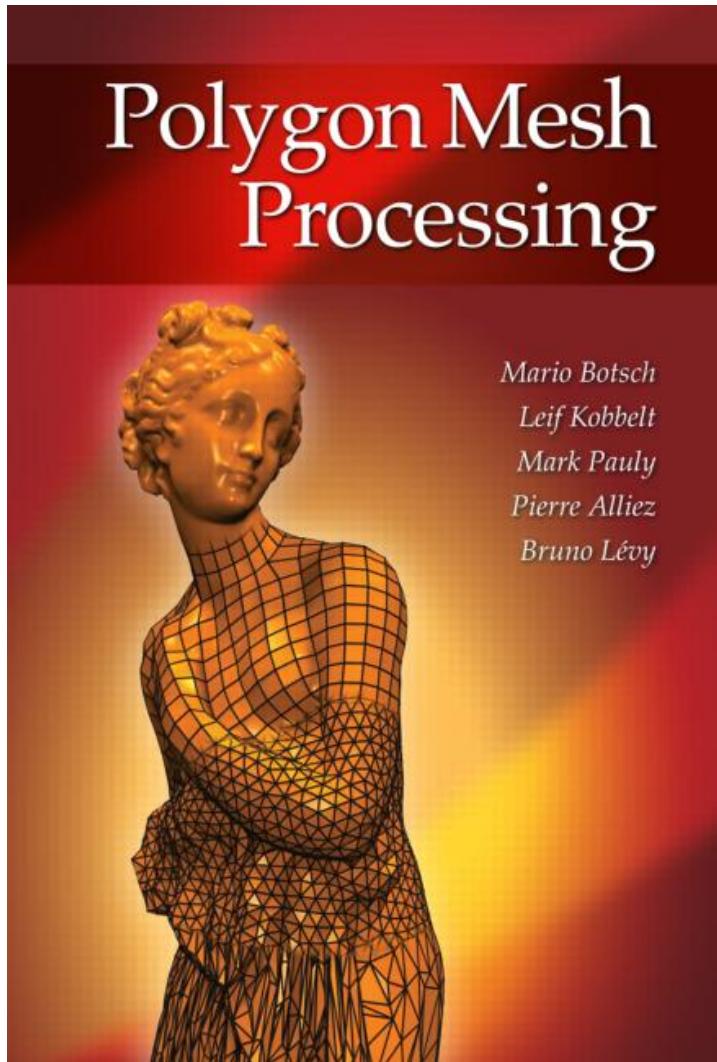
Prerequisites

- Capability to search Google and forums for useful information
- Python / C++ coding skills

Coding is very import in this area!

**If you can not program, you will
study nothing in this subject!**

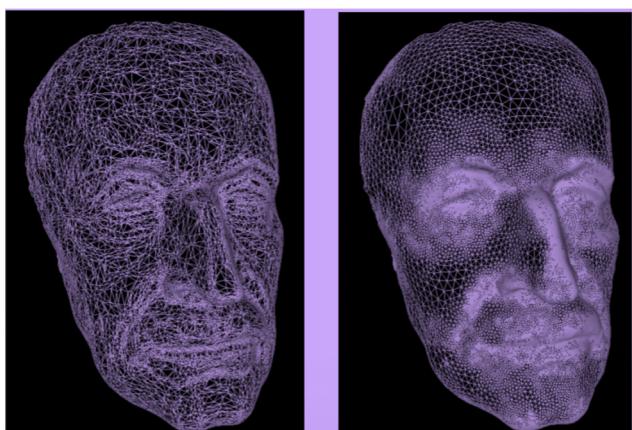
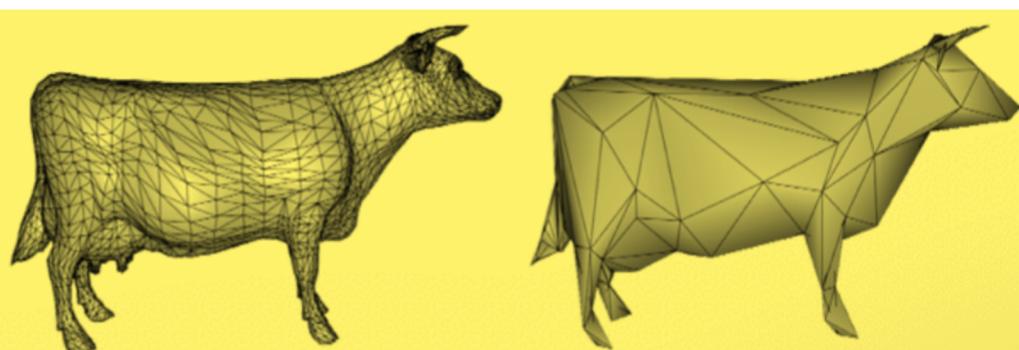
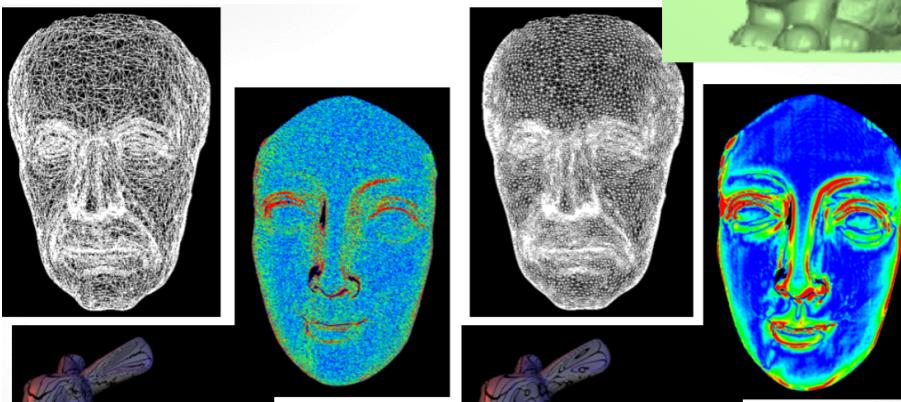
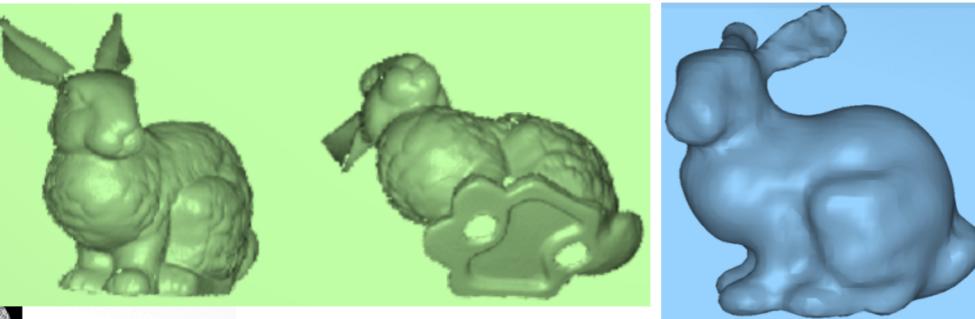
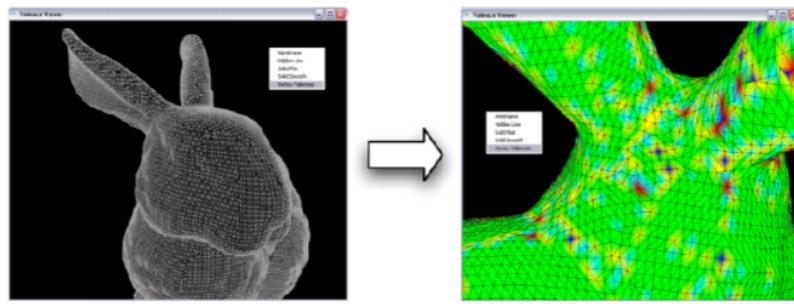
Material



<https://libigl.github.io/libigl/tutorial/tutorial.html>

Assignments

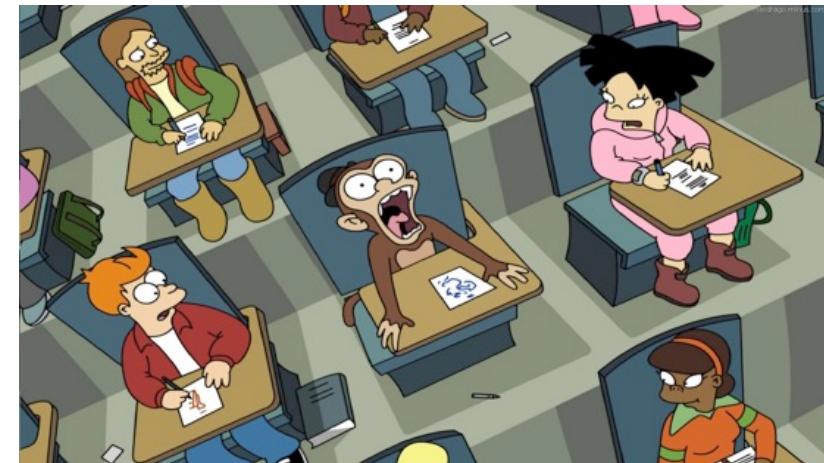
1. Hello world (display mesh)
2. Registration
3. Implicit Surface Reconstruction
4. Surface Smoothing
5. Mesh Decimation
6. Remeshing
7. Deformation



Grading

- Homework
 - **Contribute to 80% of the final grade :**
 - Functions 60 + Document 20 + Compliable code 10 + Executable file 10
 - 2-registration,3-reconstruction,4-smoothing, 5-decimation,6-remeshing
- Oral Reports:
 - 20%
- Final project
 - implement a recent geometric/vision paper in the style of a [libigl tutorial]
 - 认可后，可以忽略其他任务完成情况，给予满分！
- 2 or 3 students a team

Code & Document in Jupyter notebook.



Code in electronic:

- I can open *.sln and build it successfully and without modify setting and anything outside the folder.
- Compress whole folder into a zip
- Run **packing.bat** before compression
- Good function name and proper comments

Exe in electronic:

- A folder with exe, dll, and input data.
- Compress whole folder into a zip.

Related courses @ dlut math

- C++ <http://jjcao.github.io/cPlusPlus/>
- Computer Graphics <http://jjcao.github.io/ComputerGraphics/>
- Computer Vision <http://jjcao.github.io/ComputerVision/>
- 2120040081, Digital Media Processing, 数字媒体处理方法选讲
- 3120033010, New Topics in Computational Geometry, 计算几何新专题

SIGGRAPH & SIGGRAPH Asia



ACMSIGGRAPH

- Main computer graphics event
- Twice a year
- up to 30K attendees
- Academia, industry, artists



Video demo

- Technical Papers Preview SIGGRAPH 2020

Acknowledgements

- **Course material taught at:**
 - University of Southern California, Hao Li
 - Yusuf Sahillioğlu, CENG 789 – Digital Geometry Processing
 - Games 102 from Ligang Liu
 - CSCI-GA.3033-018 - Geometric Modeling, *Daniele Panozzo*