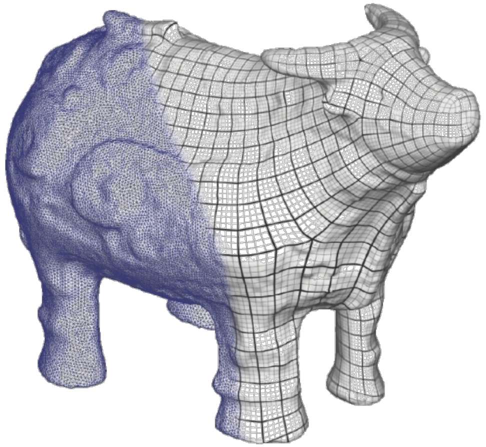
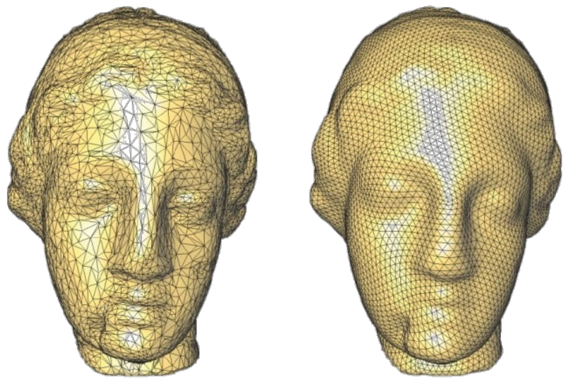
CS348a: Computer Graphics -- Geometric Modeling and Processing





Leonidas Guibas
Computer Science Department
Stanford University

Leonidas Guibas Laboratory
Geometric Computing

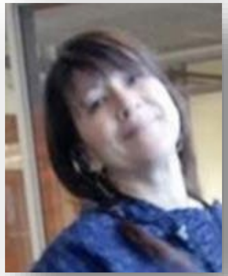
The Class

The Principals

- Leonidas (Leo) Guibas (CS & EE)
  - Instructor (Clark S293)

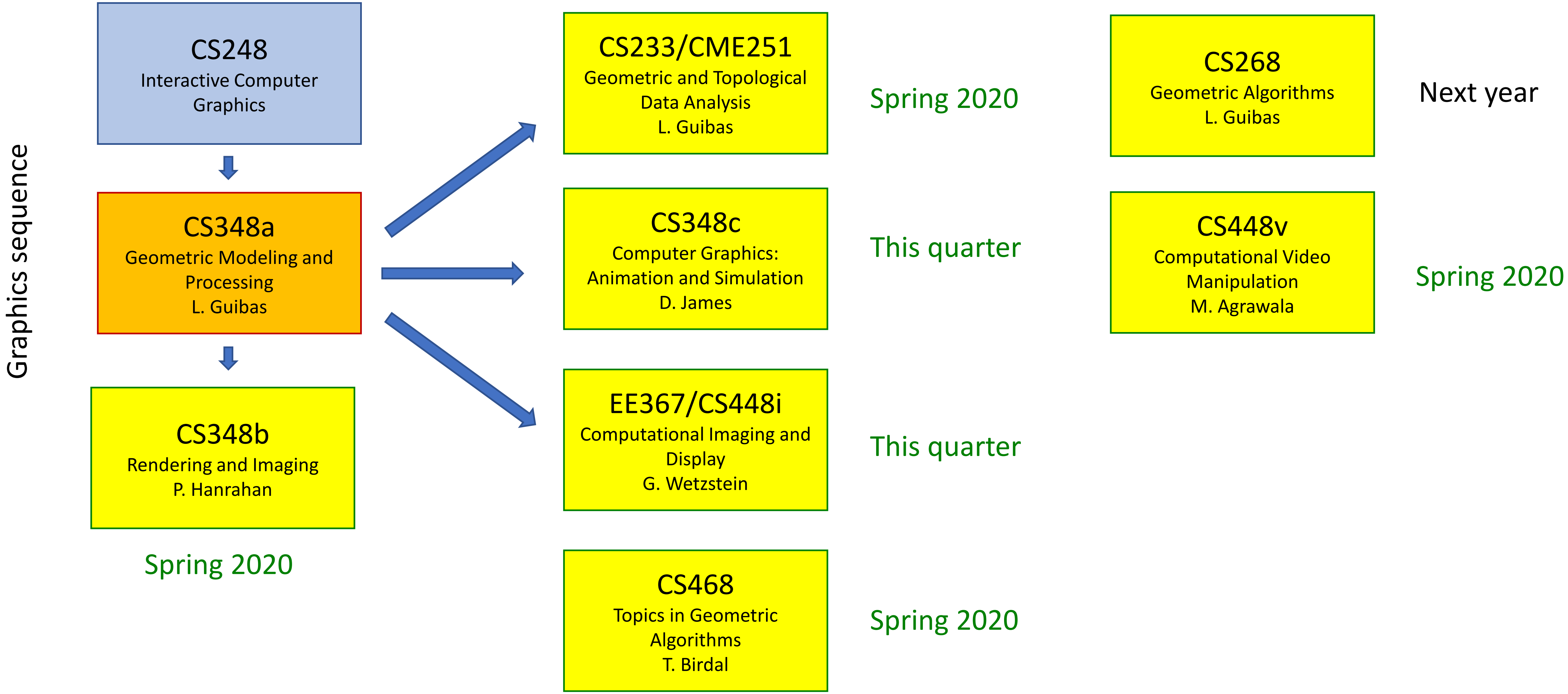
- Jingwei Huang (CS)
  - Course Assistant (Clark S297)

- Carrie Petersen
  - Admin (Gates 150)



http://cs348a.stanford.edu
http://graphics.stanford.edu/courses/cs348a-20-winter

Where CS348a Fits In



CS348a vs. CSxxx

- CS348a: Geometry modeling and processing
  - Tools: geometry, topology – shape representations, shape design, acquisition, and processing
- CS348b: Rendering / image formation
  - Tools: light transport, signal processing – how you make images once you have models
- CS233: Geometric and topological data analysis
  - Data-driven techniques --- high-level, semantic understanding of shape/motion in 2D (images) and 3D (scans)
- CS268: Geometric algorithms
  - Efficient data structures and algorithms for geometric data – algorithm analysis (more theoretical CS class)
- CS448i: Computational imaging and display
  - Display and imaging hardware, with the associated algorithms
- CS468: Topics in geometric algorithms
  - Offered in spring 2020. Riemannian Methods in Computer Vision & Biomedical Imaging

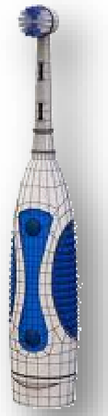
History of Geometric Modeling / Processing

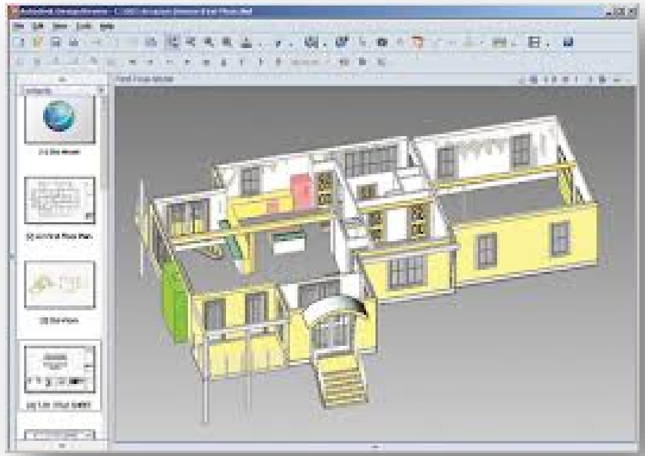
Geometric Modeling and Processing

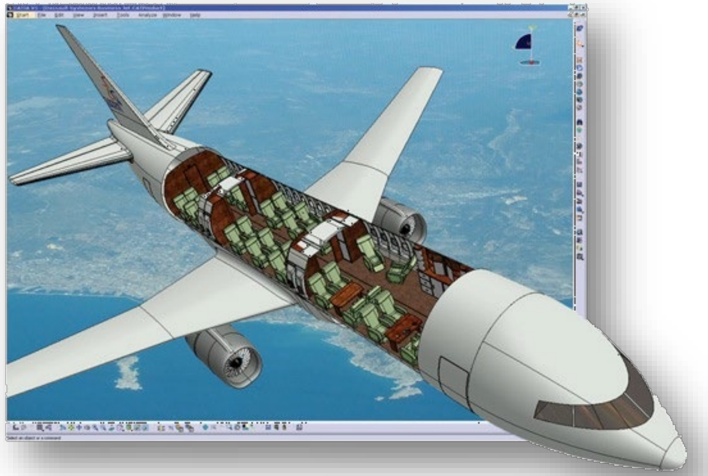
What is geometric modeling?

Broad goal:

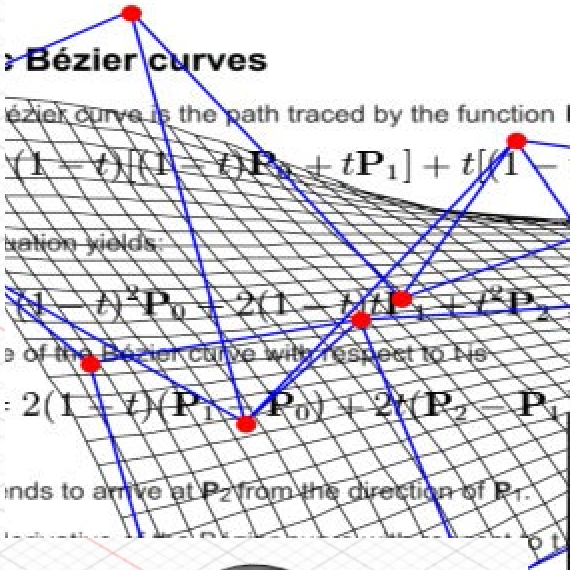
To create mathematical models and practical tools for the digital representation and manipulation of 2D/3D shapes.

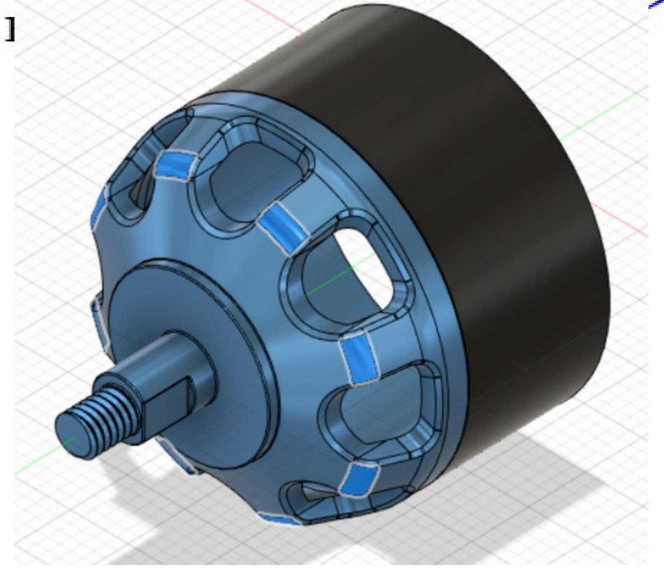


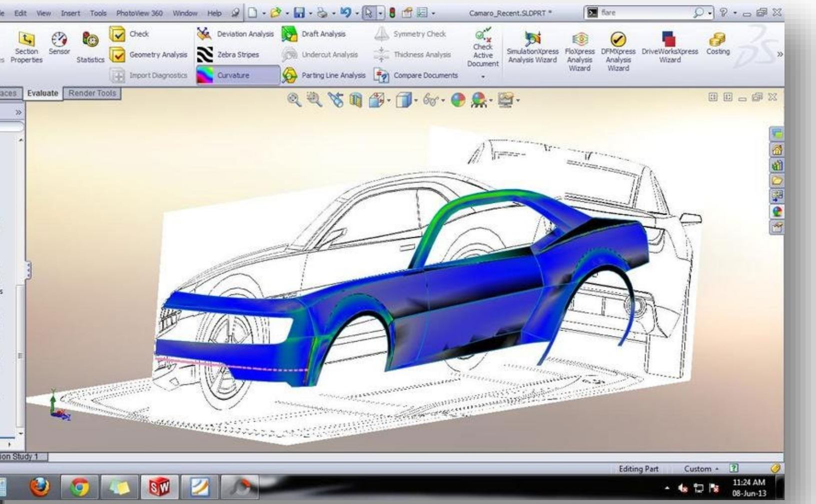


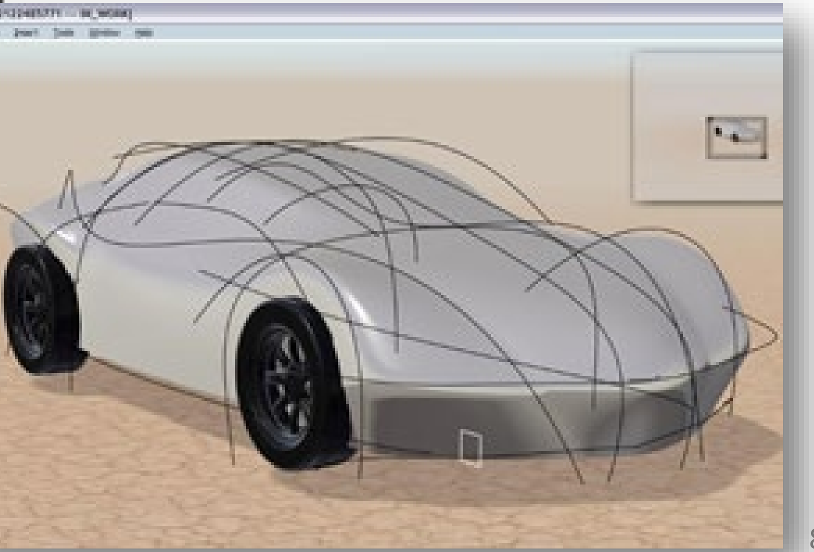


GM Originated in the CAD Industry ~1950









Historical Role of 3D Modeling

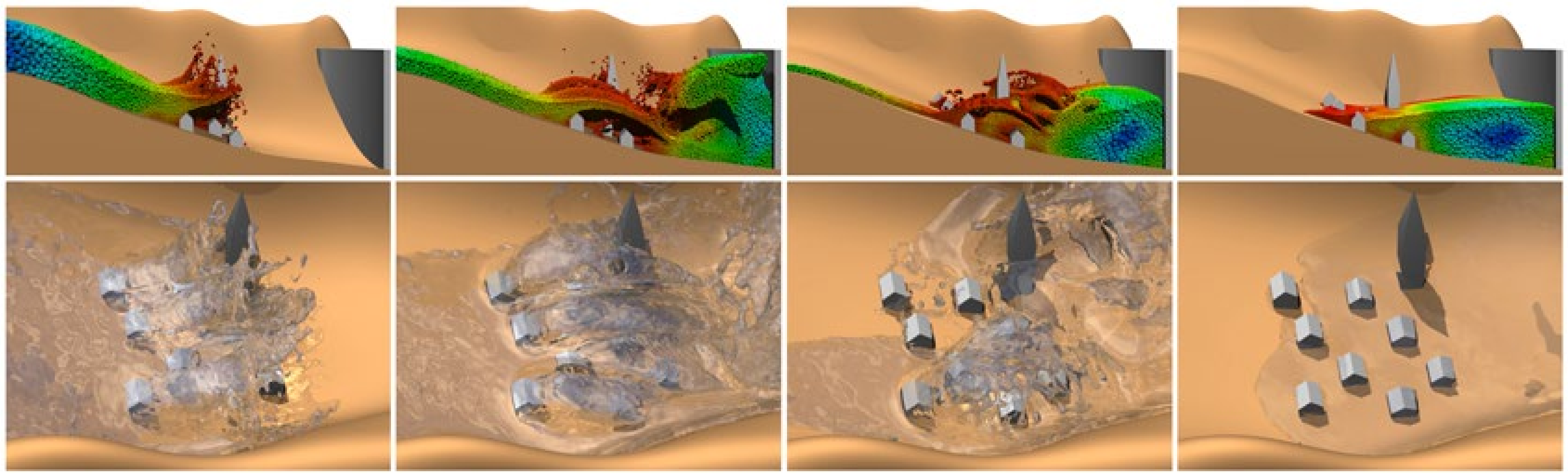
Beautiful synthetic imagery

Movie special effects

Computer games

Computer Graphics

Physically-based simulation



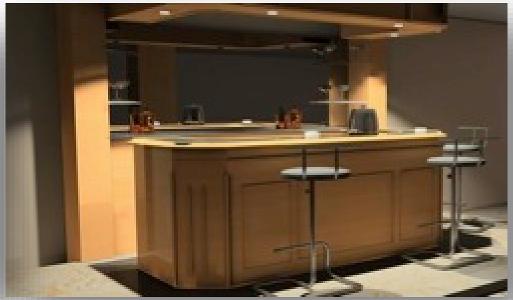
Science

Engineering

Personal 3D: Virtual / Augmented Reality

Digital 3D Geometry is Well-Established in Specialized Sectors

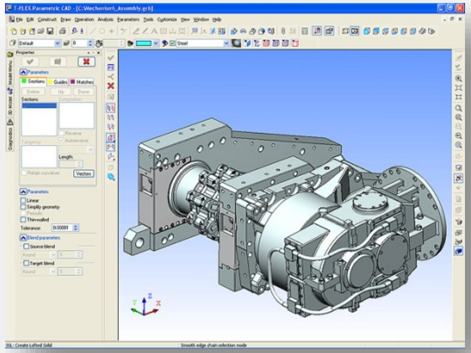
Games



Virtual Worlds

Visualization

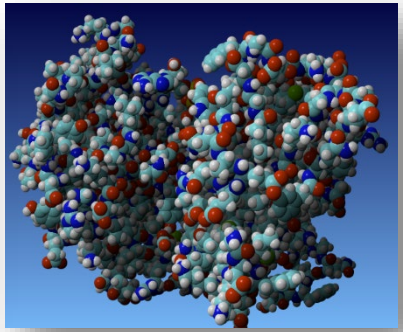
Design



Manufacturing/
CAD

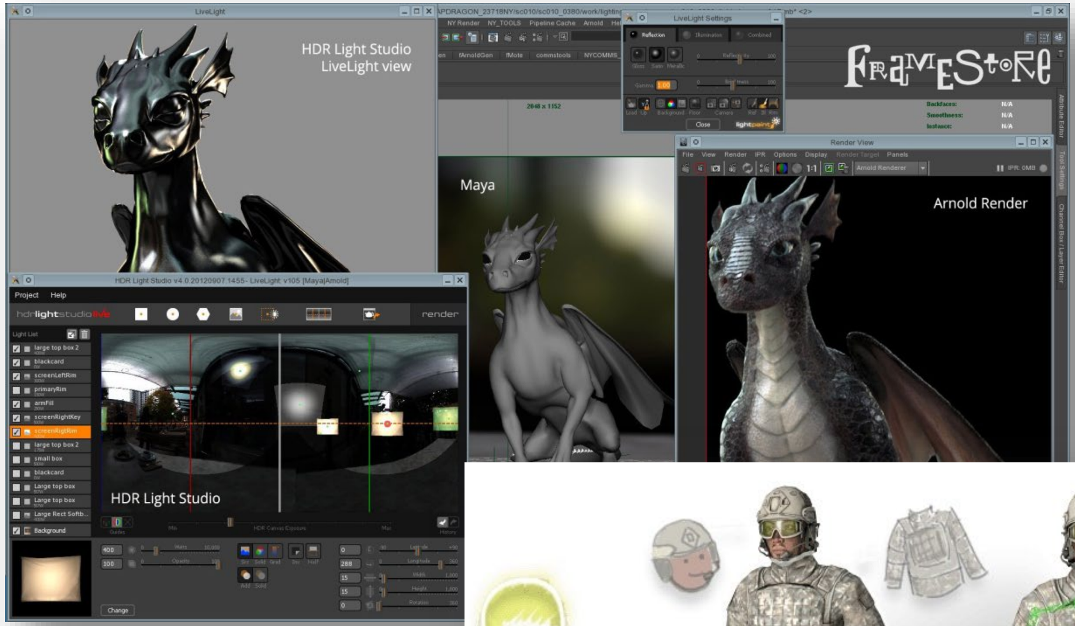
Animation/Film/
Special Effects

Cultural
Preservation



Medicine
and Biology

But, 3D Content Creation Has Been Hard



But This Is Changing …
Better Software, Hardware, and Machine Learning

Simpler 3D Modeling Software

House in Istanbul Haluk Hatipoglu

SketchUp

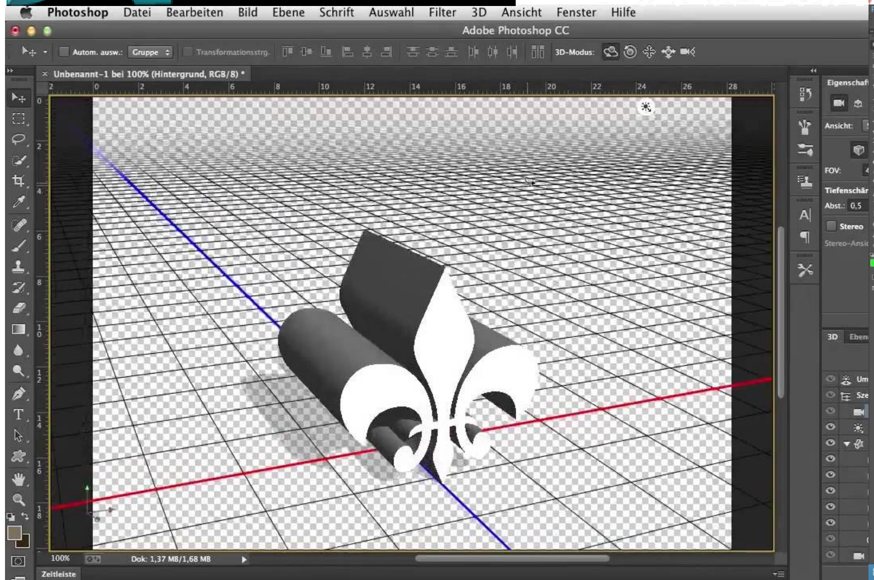
Trimble

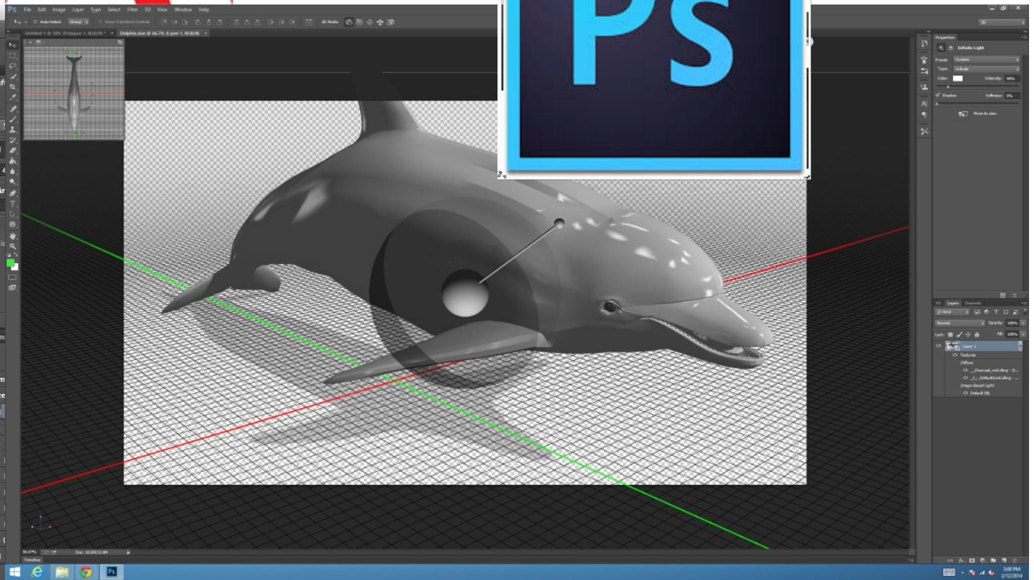
MAYA

AUTODESK

Adobe

Ps





Affordable 3D Scanners

Microsoft Kinect

Google Tango

Intel RealSense

iSense 3D for iPad

3D Printers


OBJET 1000
OBJET


MakerBot
Automated Build Platform
Thing-O-Matic
MakerBot
INDUSTRIES

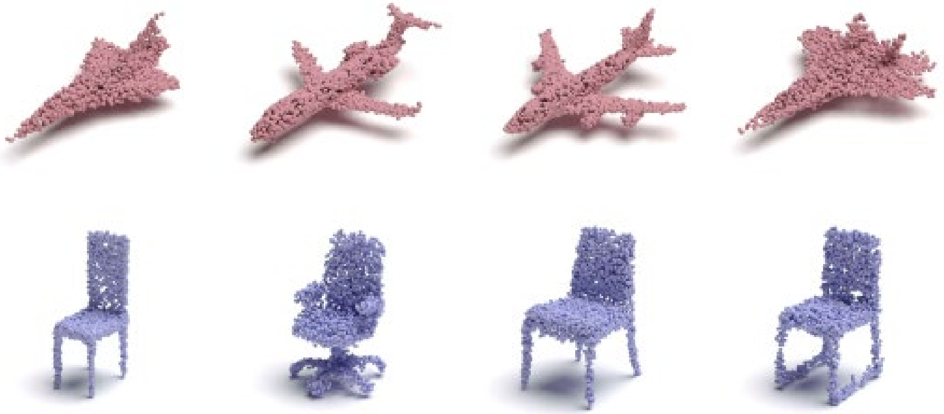
Machine Learning Approaches

- Example: PointFlow

Two flows: One to create the distribution of shape feature vectors, one for the distribution of points on a shape

Shape generation flow

Free shape generation



Shape interpolation

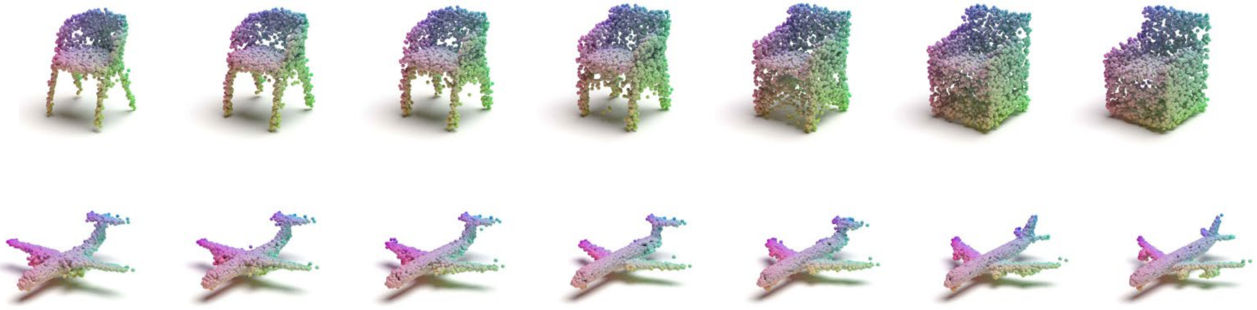
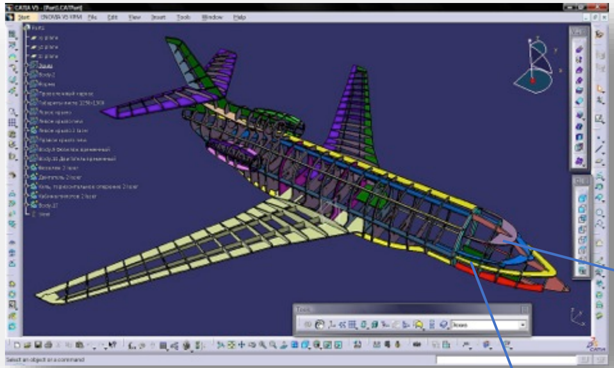


Image Credit: PointFlow: 3D Point Cloud Generation with Continuous Normalizing Flows, Yang et al.

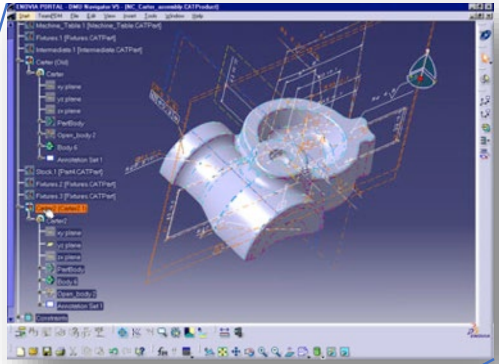
How are 3D Models Created?

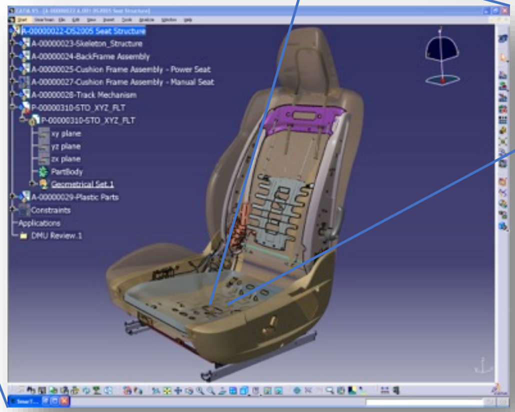
How Shape Models Arise

- Designed shapes: CAGD (Computer-Aided Geometric Design)



Computer model



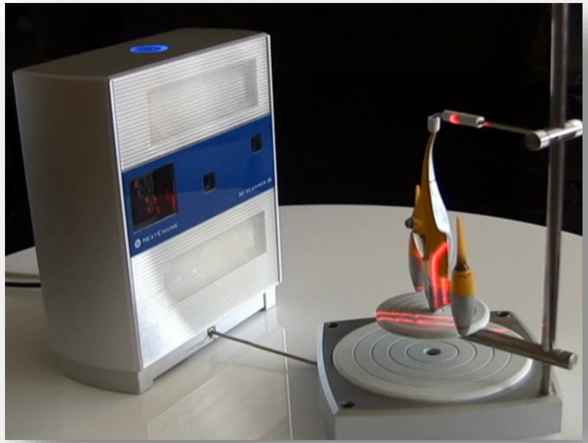


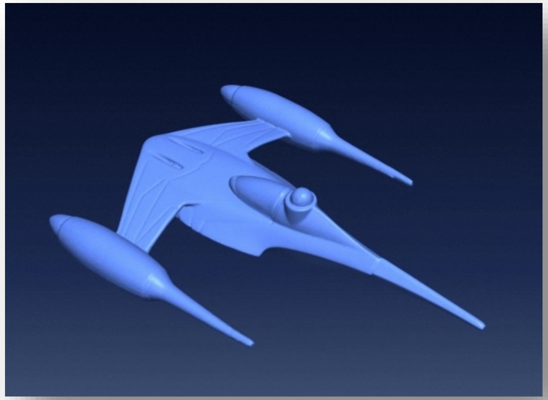
idea

Dassault Falcon 7X

How Shape Models Arise

- Acquired shapes:





Why Geometric Modeling?

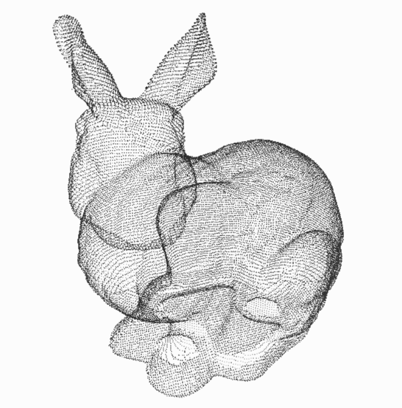
Among all digital representations of physical objects, a 3D model is closest to the physical artifact.

- A digital model allows easy manipulation
- Digital simulation is much cheaper than building the real object
- Model optimization and repair is possible
- Detailed comparison across models is possible
- Creation of new models from other ones is relatively easy

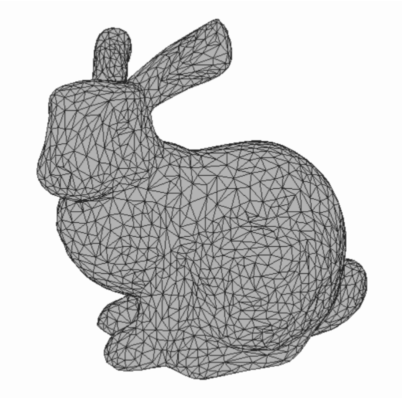
Shape Topology Optimization

ML Challenge: Multiple 3D Representations

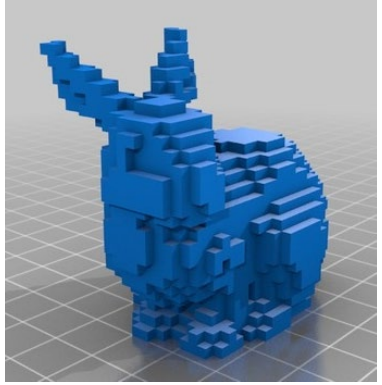
CAD Model



Point Cloud



Surface Mesh

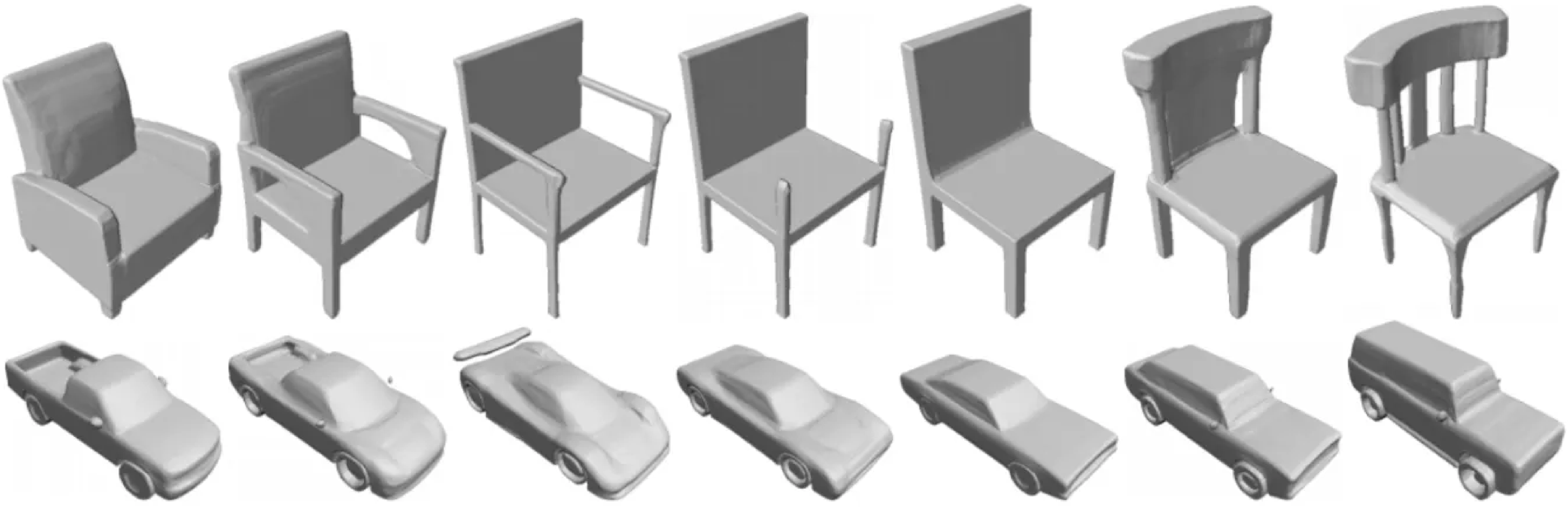


Volumetric

Multi-View Images

…

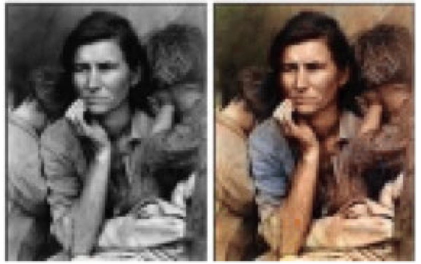
DeepSDF: Shapes Created by a Neural Network



DeepSDF: Learning Continuous Signed Distance Functions for Shape Representation
Jeong Joon Park, Peter Florence, Julian Straub, Richard Newcombe, Steven Lovegrove; The IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2019

More examples of ML Use in Computer Graphics

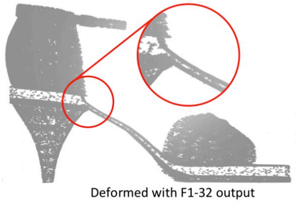
Sketch simplification



Colorization

Procedural modelling

Mesh segmentation

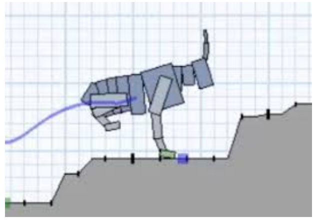


Learning deformations

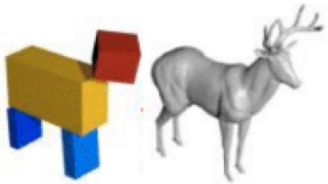
Real-time rendering

BRDF estimation

Fluid

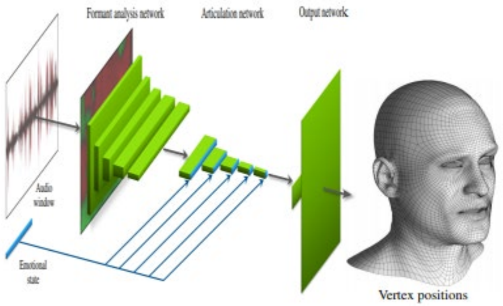


Animation

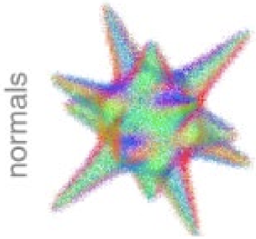


Boxification

Denoising



Facial animation



PCD processing

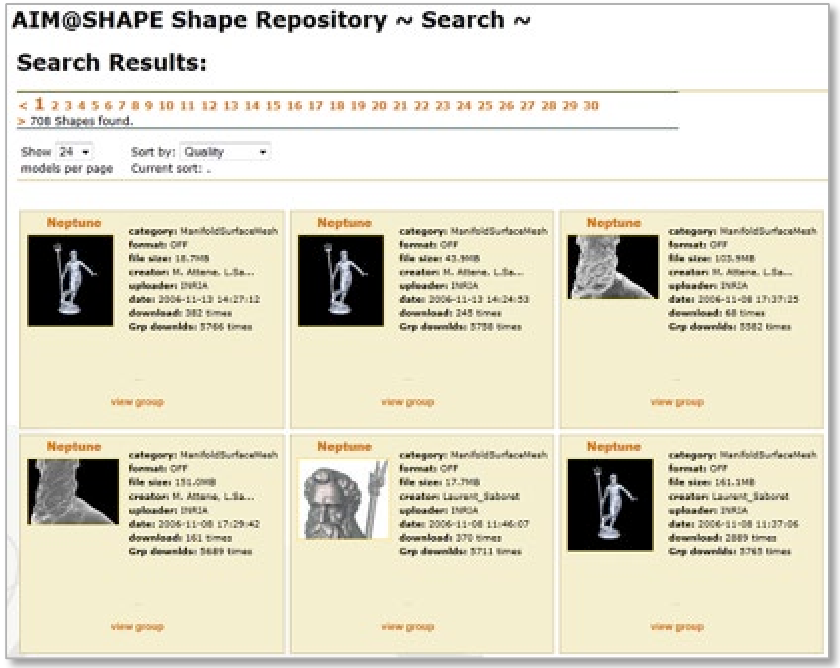
3D for Encoding Knowledge

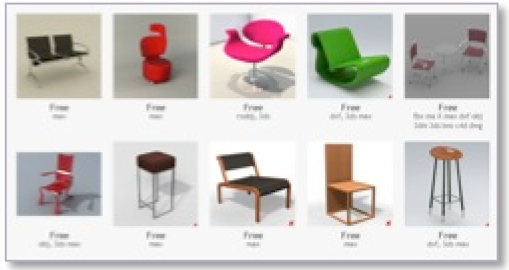
3D for Encoding Knowledge

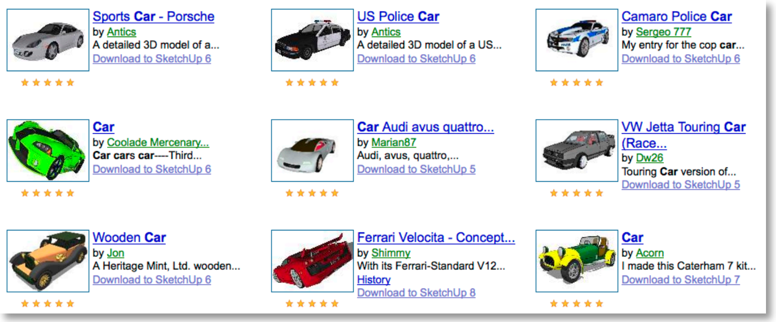
Among all digital representations we have of a real artifact, 3D is the most faithful to the actual physical object

Geometry Repositories

Shape collections are becoming widely available

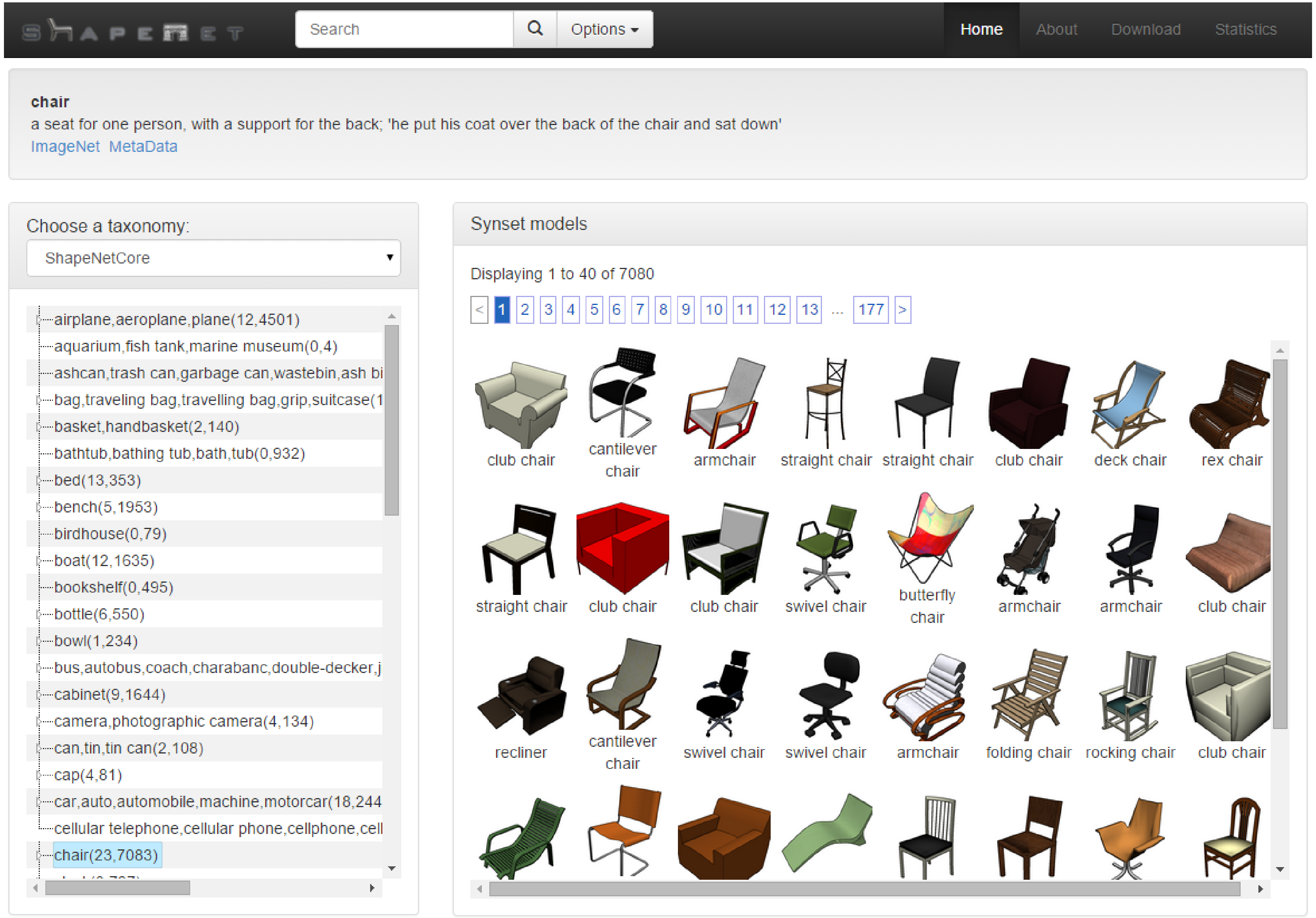




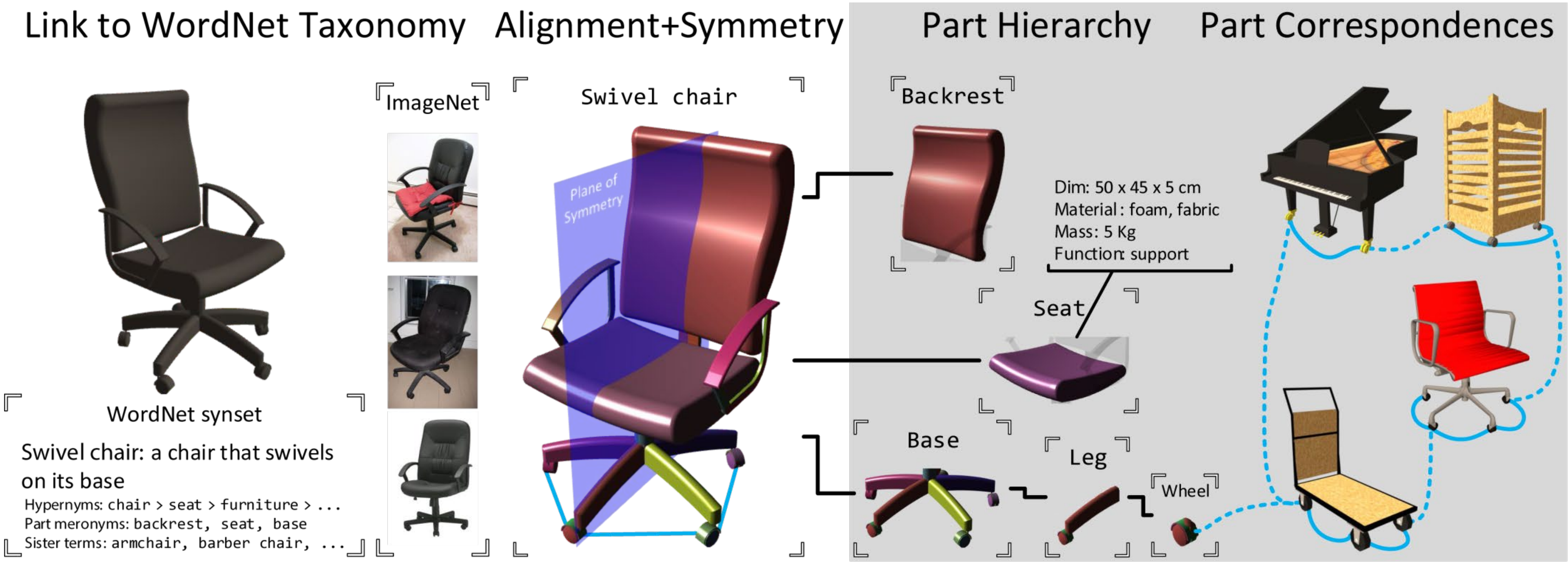


Trimble. 3D Warehouse
powered by Google

ShapeNet (>3M Models)



Models, with Semantic Annotations



A repository of 3D models organized according to the WordNet taxonomy, with

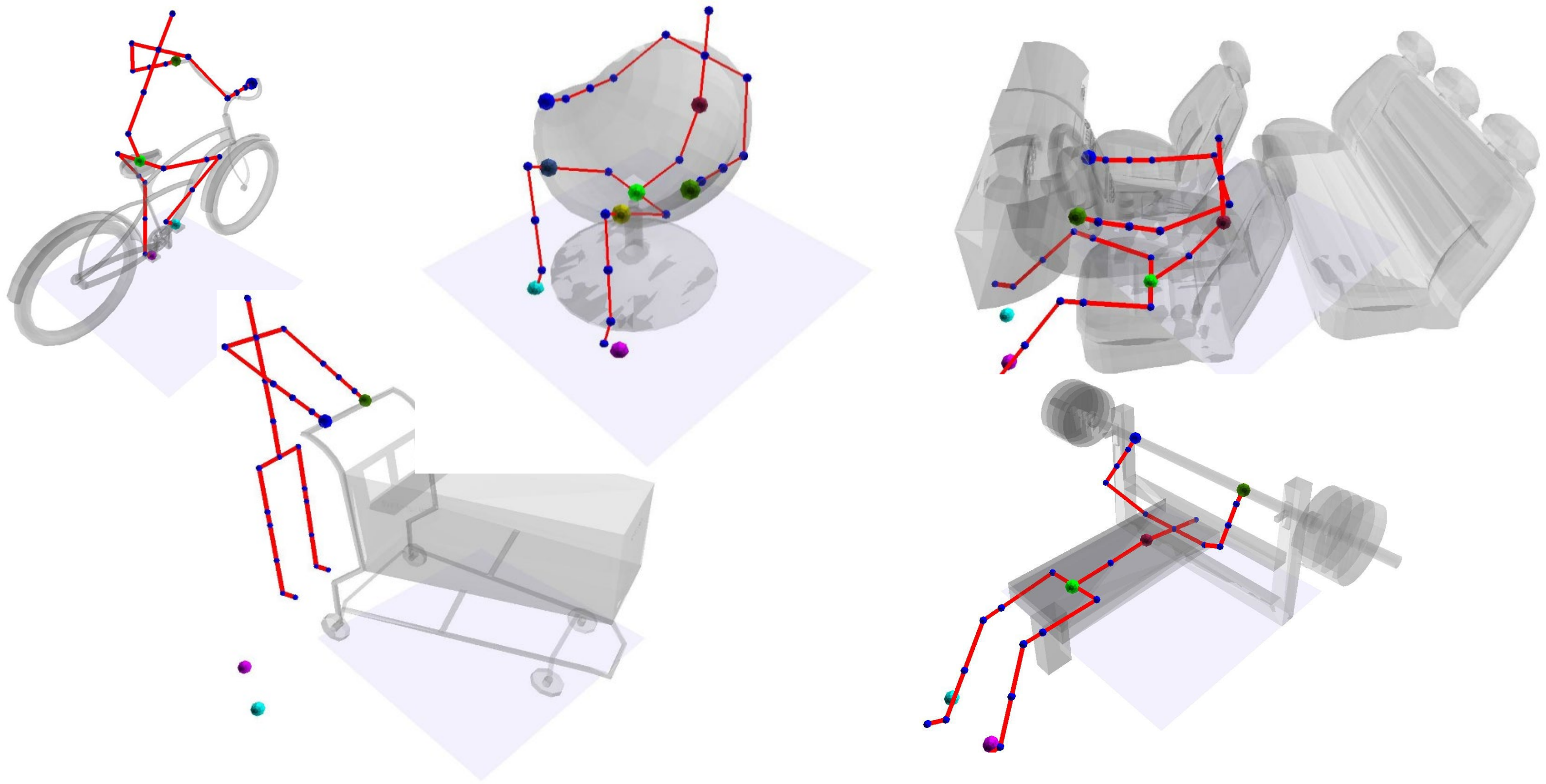
- geometric info (parts, symmetries)
- semantic info (keywords, part names, affordances, functionality)

Leonidas Guibas
Pat Hanrahan
Silvio Savarese

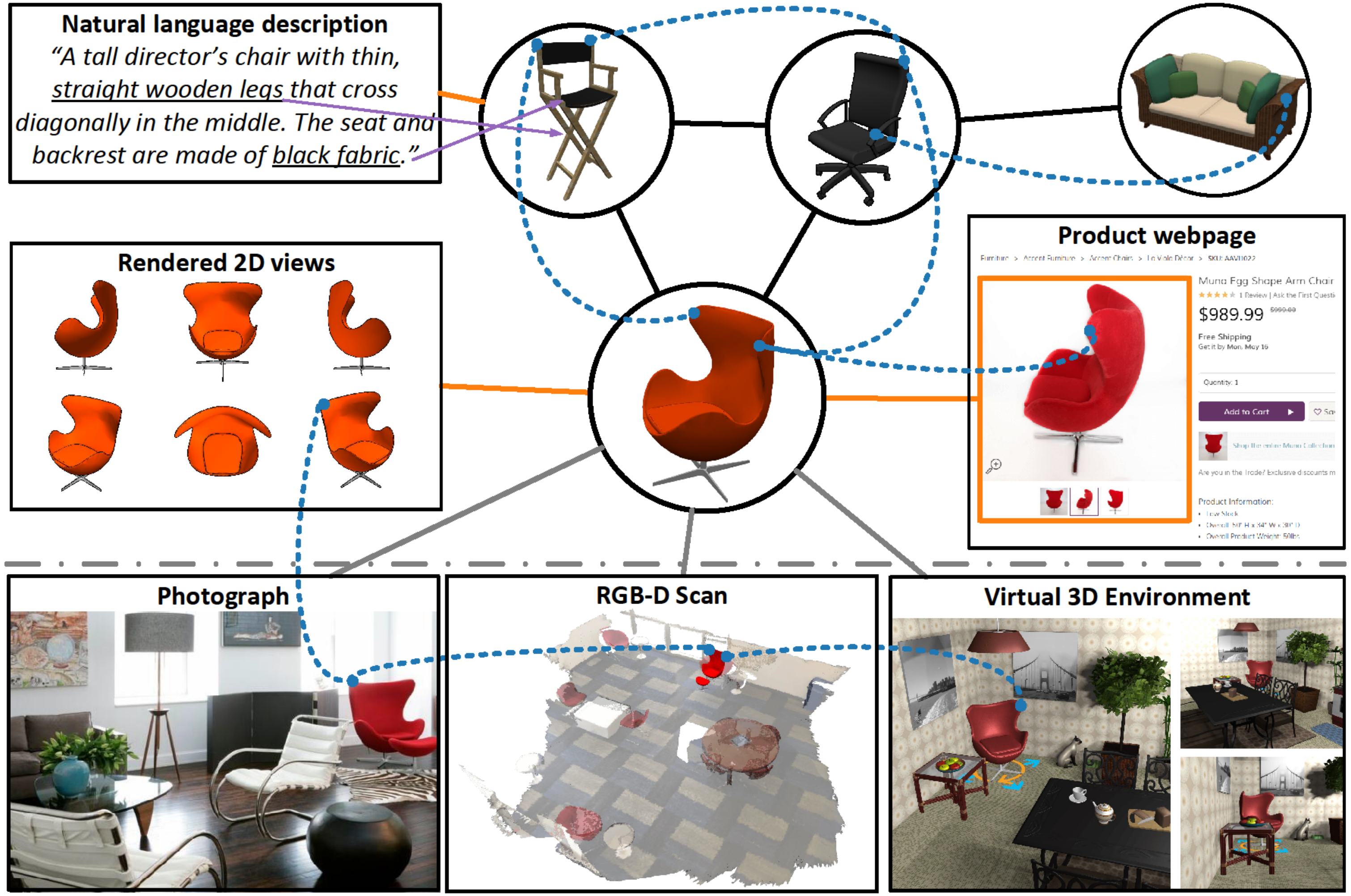
Qixing Huang

Tom Funkhouser
Jianxiong Xiao

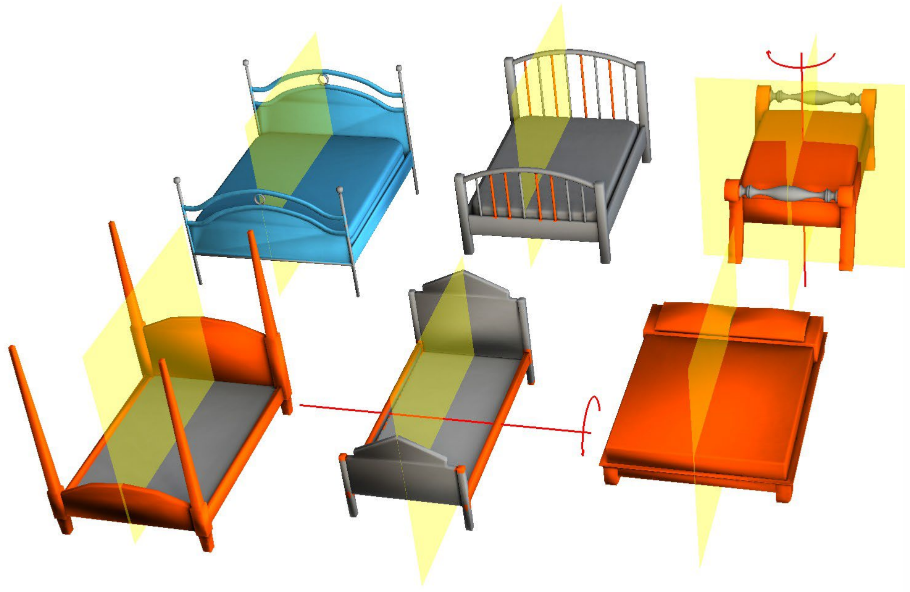
Shape Affordances



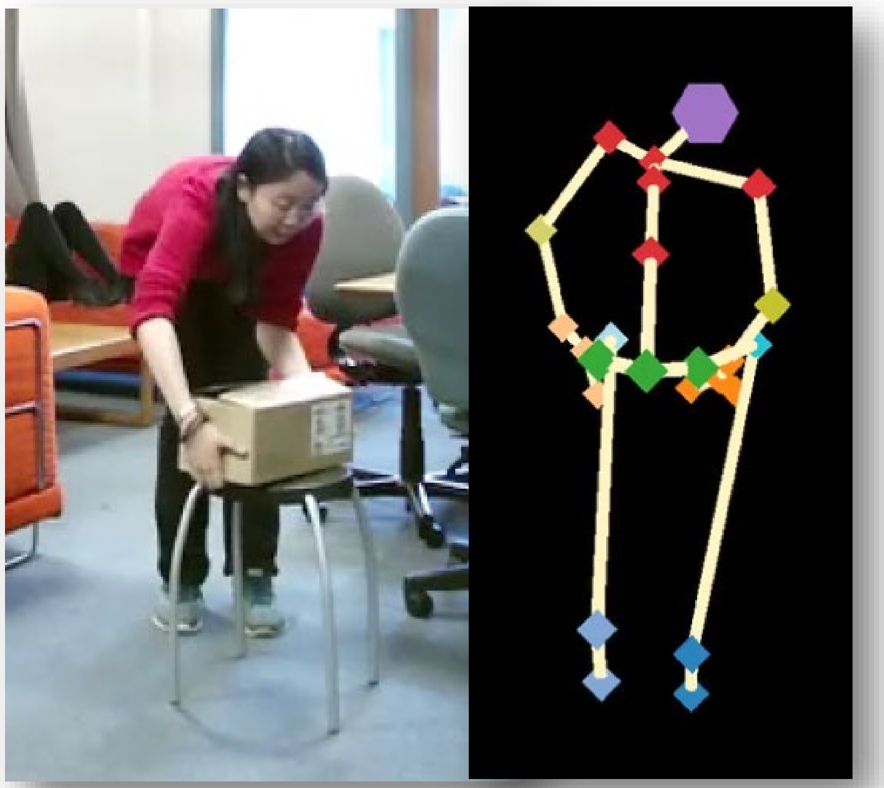
Connections



High-Level Semantic Properties

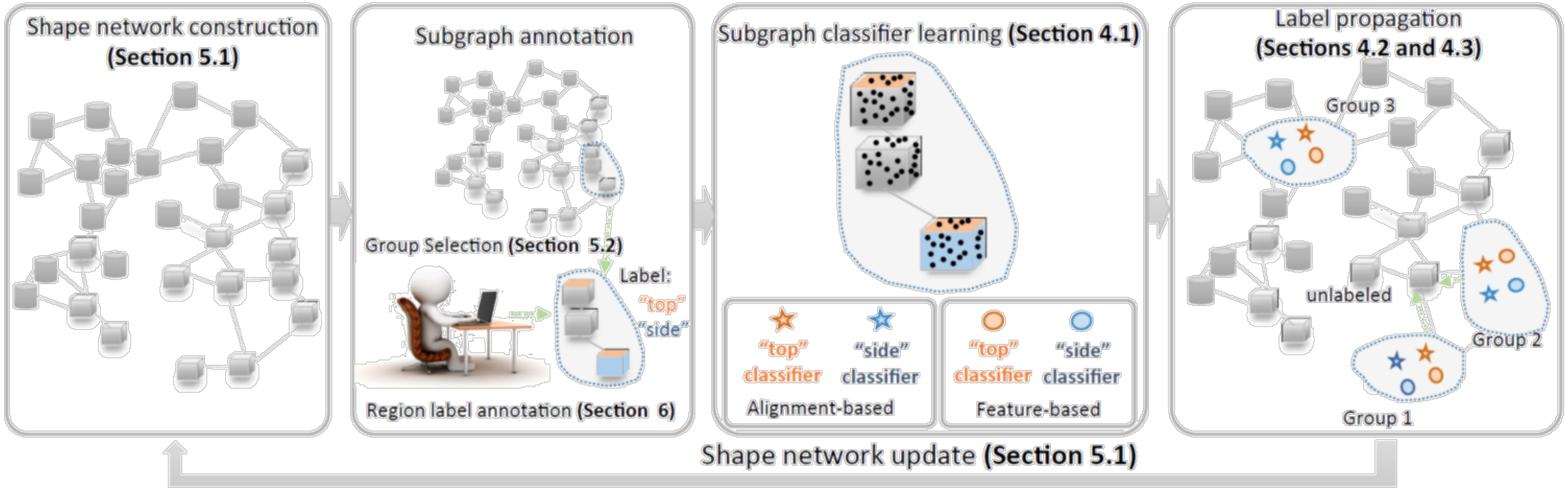


Object symmetries

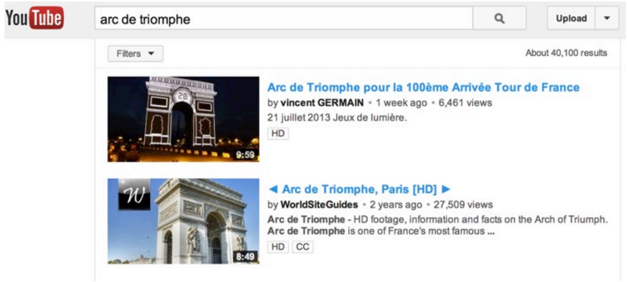


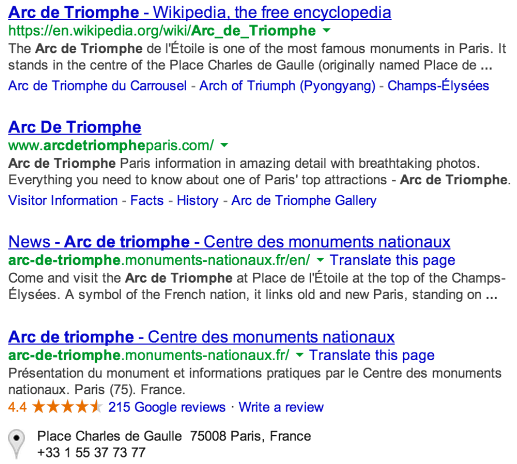
Object weight / grasps

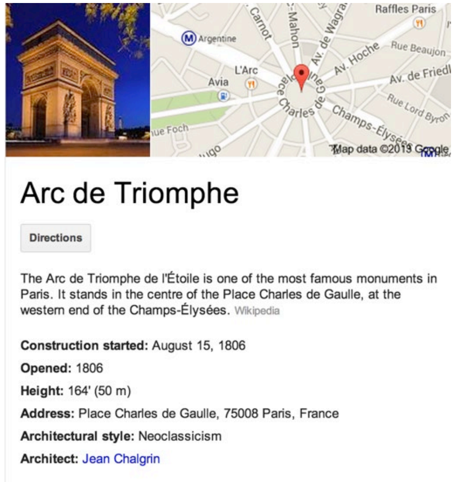
Annotation Pipeline: Humans + Algorithms

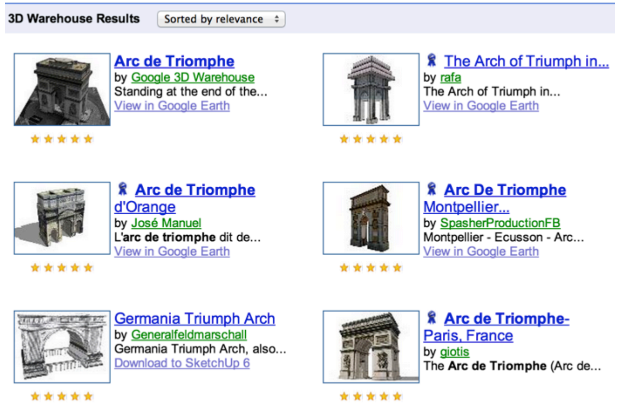


3D at the Center





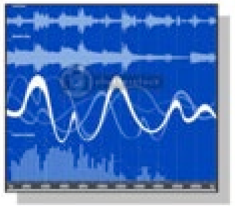




The Time is Now for 3D + ML

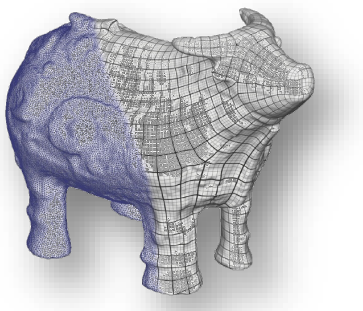
- New forms of media are constantly being acquired

'70 '80 '90 '00 '10 '20


sound


images


video


scanned 3D geometry

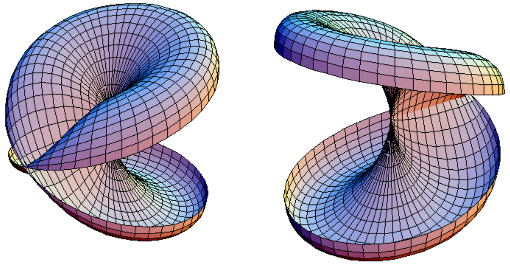

ML generated geometry

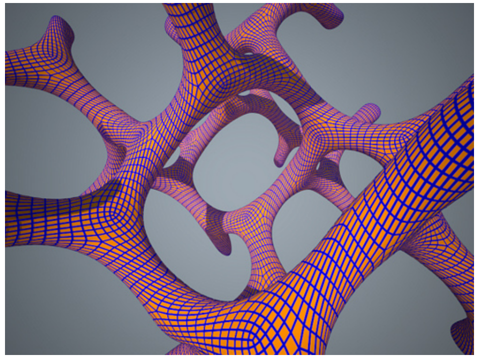
- Growing demand for acquisition, processing and analysis of 3D geometric data

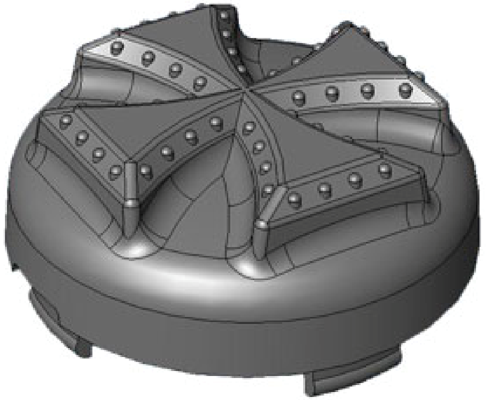
Course Content

The Course Content I

- Projective geometry and projective spaces
- Some linear algebra: matrices and transformations
- Polynomial algebra
- Algebraic tricks: homogenization and polarization
- 2D and 3D smooth shape models: splines
- Basic topology and mesh representations for shapes

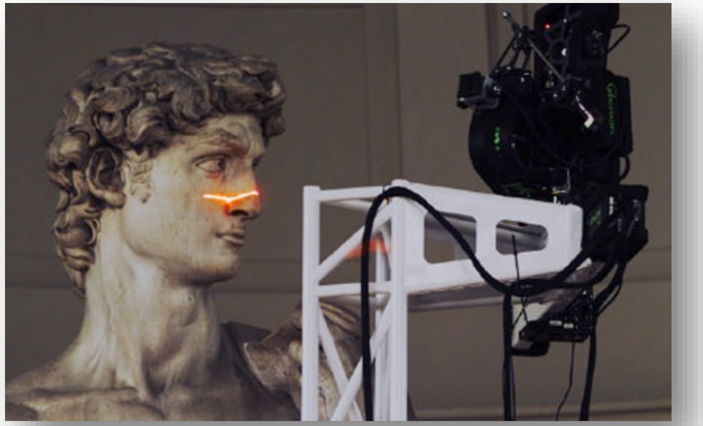


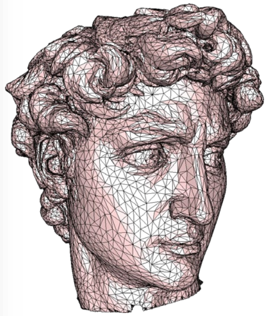




The Course Content II

- 3D reconstruction from scanner data
- Geometry processing (remeshing, smoothing)
- Mesh parametrization
- Mesh simplification





- Machine Learning Approaches to Shape Analysis
- Generative Models Based on Learned Shape Representations and Applications

Course Schedule I

CS348a Class Schedule, Winter Quarter 2019-20

Below are the key dates for the class.

Monday	Wednesday
January 06	**January 08**
Class Introduction; Homogeneous Coordinates; The Projective Plane and Space Read: Lecture Slides Read: N08, N15, N16; Chapters 1 and 2 of Stolfi's thesis	**Oriented Projective Geometry; Euclidean, Affine and Projective Transformations; Matrix Representations** Read: Lecture Slides Read: N09, N11
January 13	**January 15**
Rotations and Quaternions Read: N12, N13, N17	**Shape Modeling: Parametric and Implicit Representations; Classification of Parametric Cubics** Homework 1 out Read: Lecture Slides Read: N18 (Section 5), N19, N20; for parametric/implicit see also the Hoffmann report/slides

January 20	**January 22**
Martin Luther King, Jr., Day (holiday, no classes)	**Polar Forms of Plynomials** Read: N19, N20, N21
January 27	**January 29**
Derivatives and Polar Forms; Continuity Constraints Read: N22, N23, N24, N27	**Splines and B-Splines** Homework 1 due; Homework 2 out Read: N22, N23, N24, N27
February 03	**February 05**
Rational Curves Read: N25 Taubin paper	**Subdivision Curves** Read: Siggraph 99 Notes

Course Schedule II

February 10	February 12
Tensor-Product and Total Degree Parametric Surfaces Read: N25, N26, Lecture Slides1, Lecture Slides2	**Triangle Meshes and their Representation; the Quad-Edge Data Structure** Homework 2 due; Homework 3 out Read: N30, N31
February 17	**February 19**
Presidents' Day (holiday, no classes)	**Introduction to Geometry Processing** In-class Midterm; Homework 4 out Read: Lecture Slides

February 24	February 26
In-class Midterm	**Scan Alignment and Registration; Surface Reconstruction** Homework 3 due Read: Lecture Slides Read: BeslMcKay, ChenMedioni, PottmanHofer,MitraEtAl
March 02	**March 04**
Learned Shape Representations Read: Lecture Slides	**Mesh Simplification** Read: L08, L12, L13, L15
March 09	**March 11**
Building and Improving Meshes Read: Lecture Slides	**Mesh Parametrization; Course Summary** Homework 4 due Read:Lecture Slides

Course Mechanics

- Course web page: http://cs348a.stanford.edu, http://graphics.stanford.edu/courses/cs348a-20-winter
- No formal required text – we'll use class notes from previous course offerings
- Recommended:
  - Gerald Farin, Curves and Surfaces for CAGD, Fifth Edition: A Practical Guide, Morgan Kaufmann, 2001
  - Mario Botsch, Leif Kobbelt, Mark Pauly, Pierre Alliez, Bruno Levy, Polygon Mesh Processing, A K Peters, 2010
- Homeworks: a combination of paper-and-pencil (math) in the first half, some programming and a project assignment in the second half – four in total
- There will be a late midterm, but no final
- We'll use Piazza (www.piazza.com) as the class discussion forum

Course Recitation

- Recitation section: Gates B21, Fridays, 4:00 – 5:00 pm (starting 20 January 2020)

On to the Nitty-Gritty

Homogeneous Coordinates and Real Projective Spaces