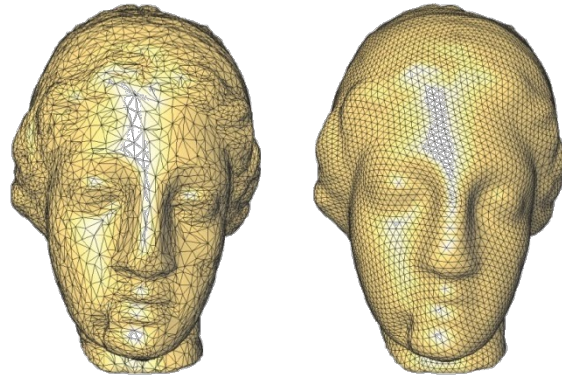
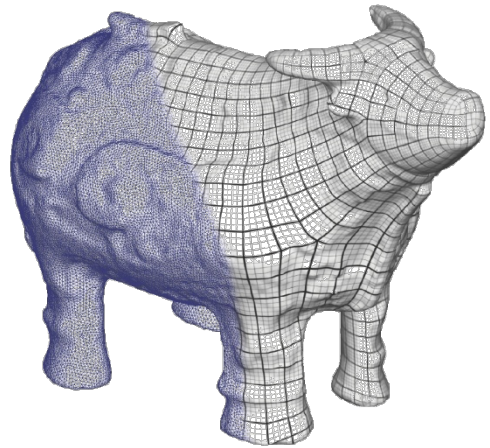


CS348a: Computer Graphics -- Geometric Modeling and Processing



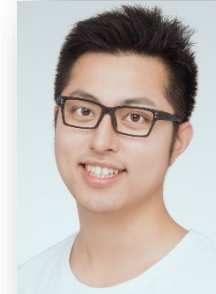
Leonidas Guibas
Computer Science Department
Stanford University



The Class

The Principals

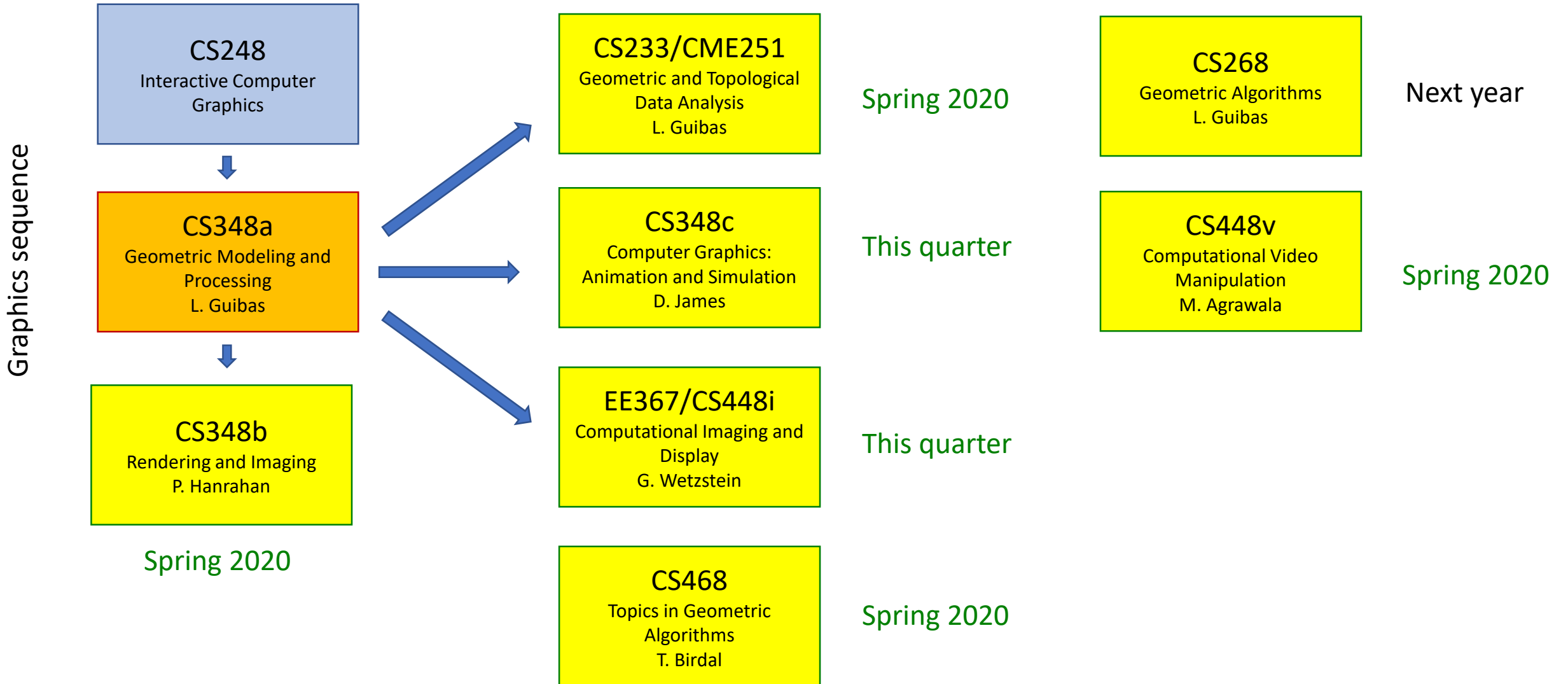
- Leonidas (Leo) Guibas (CS & EE)
 - Instructor (Clark S293)
- Jingwei Huang (CS)
 - Course Assistant (Clark S297)
- Carrie Petersen
 - Admin (Gates 150)



<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

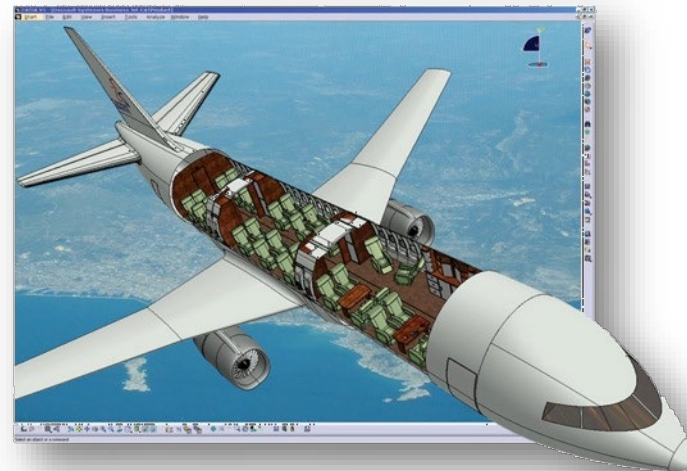
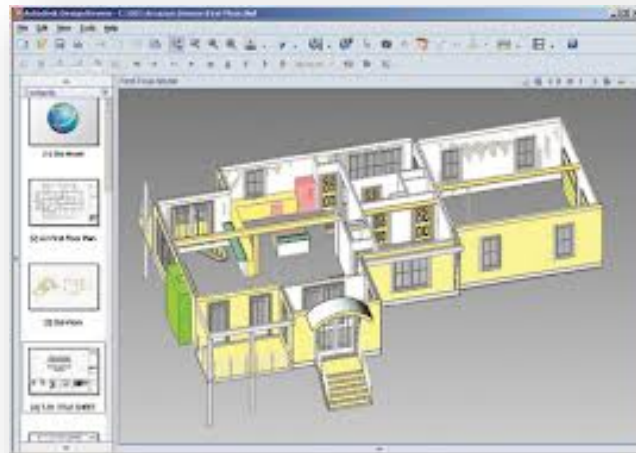
History of Geometric Modeling / Processing

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



Bézier curves

A Bézier curve is the path traced by the function $B(t)$, given

$$B(t) = (1-t)^2 P_0 + 2(1-t)t P_1 + t^2 P_2$$

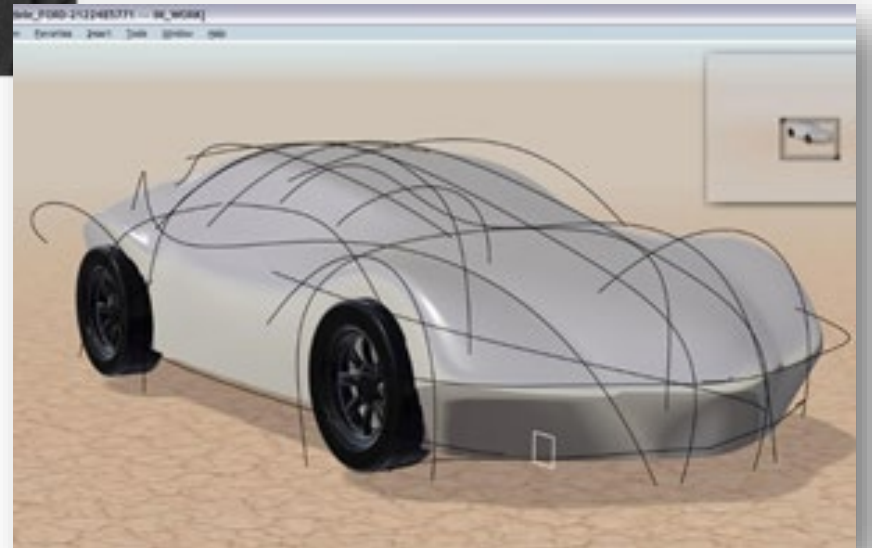
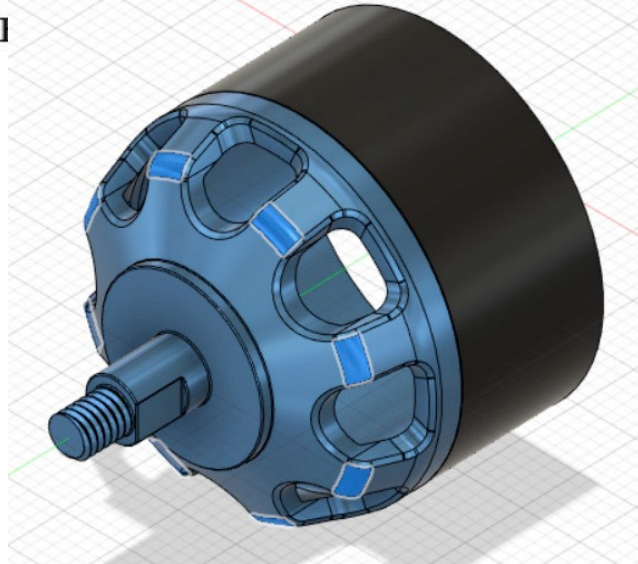
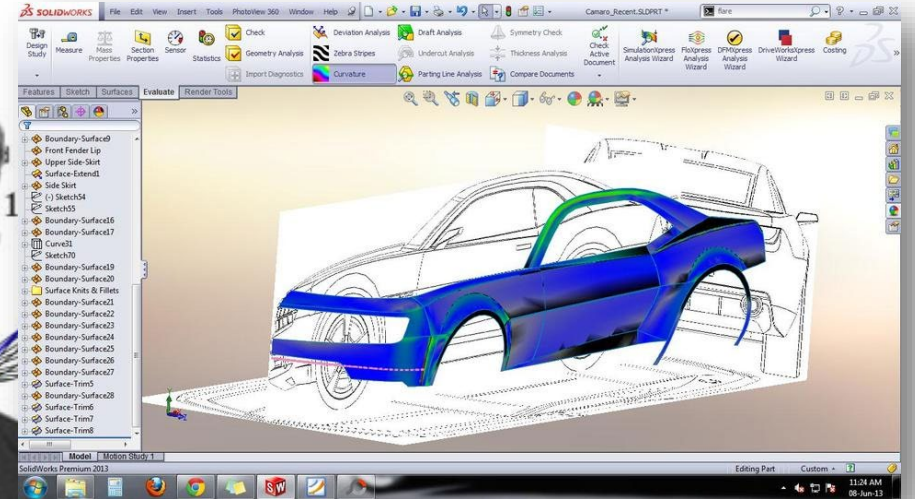
where P_0, P_1, P_2 are the control points.

$$B'(t) = 2(1-t)(P_1 - P_0) + 2t(P_2 - P_1)$$

The derivative of the Bézier curve with respect to t is

$$B'(t) = 2(1-t)(P_1 - P_0) + 2t(P_2 - P_1)$$

The derivative of the Bézier curve with respect to t tends to arrive at P_2 from the direction of P_1 .



Historical Role of 3D Modeling



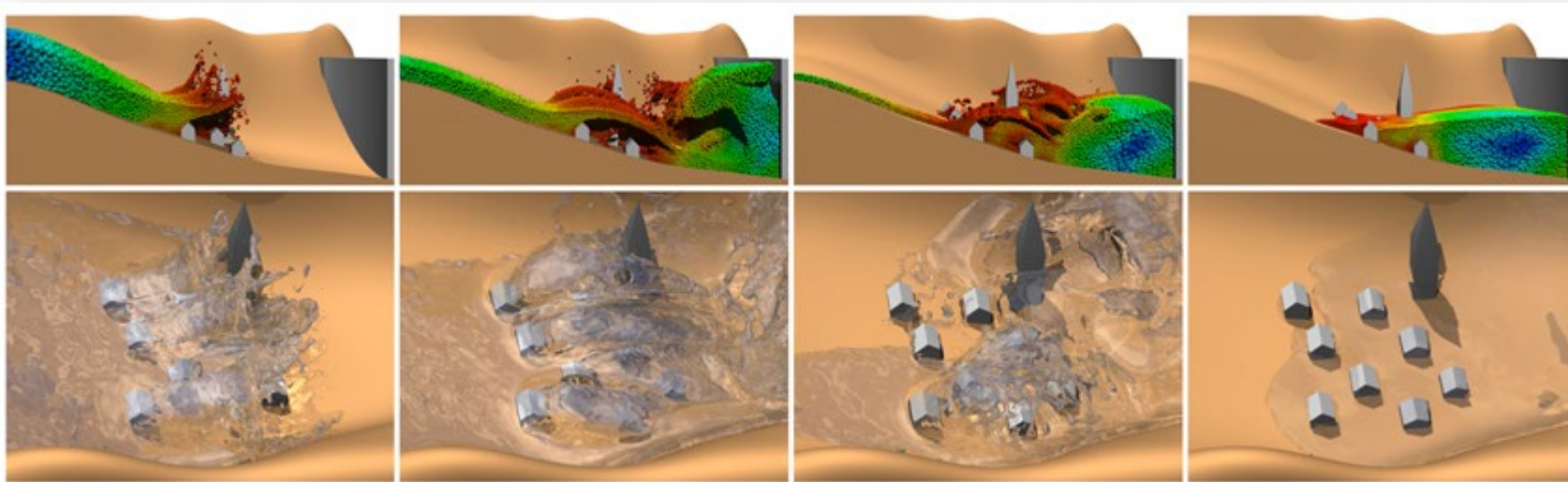
Beautiful synthetic imagery

Movie special effects

Computer games

Computer Graphics

Physically-based simulation



Science

Engineering

Personal 3D: Virtual / Augmented Reality



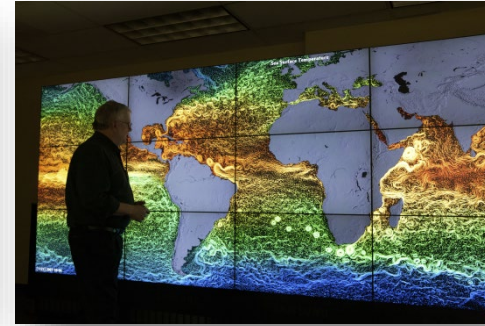
Digital 3D Geometry is Well-Established in Specialized Sectors



Games



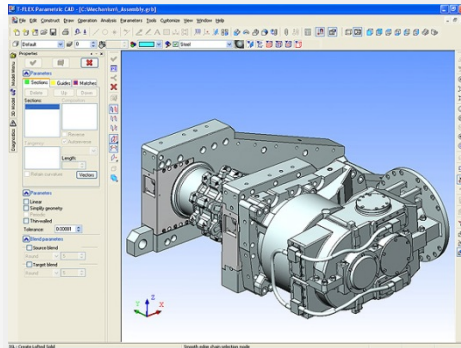
Virtual Worlds



Visualization



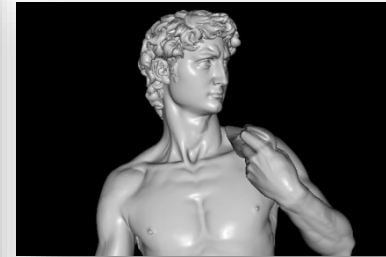
Design



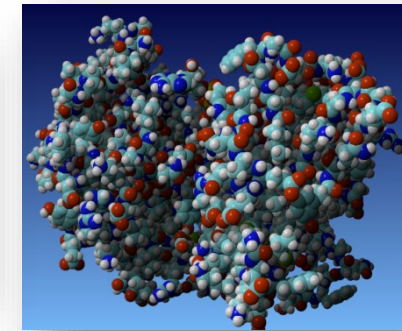
**Manufacturing/
CAD**



**Animation/Film/
Special Effects**

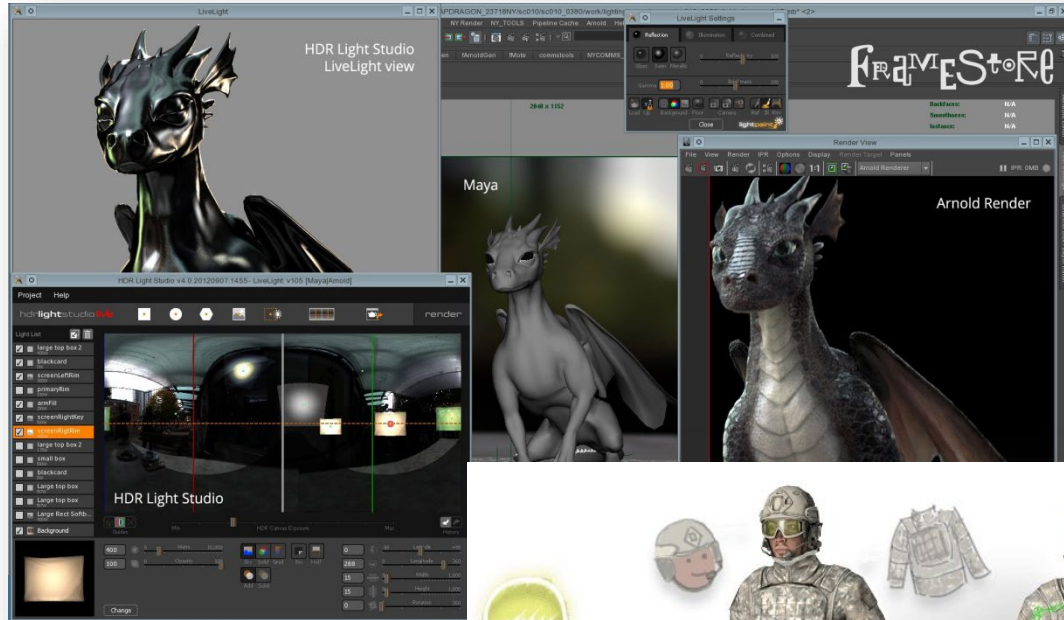


**Cultural
Preservation**



**Medicine
and Biology**

But, 3D Content Creation Has Been Hard



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

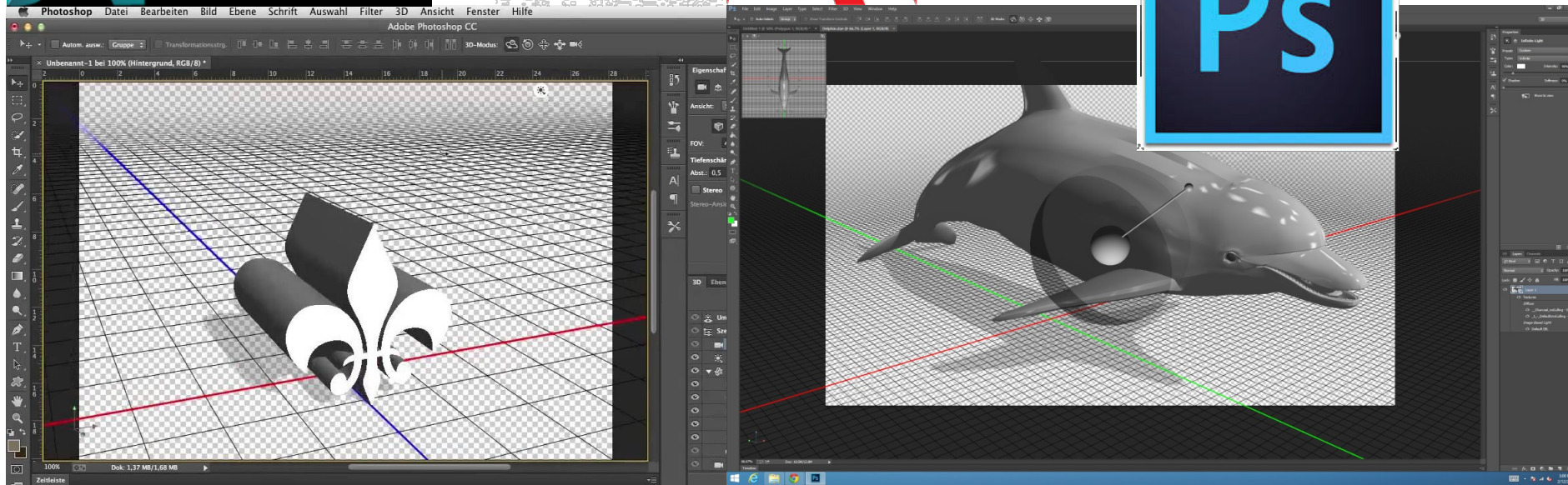
Simpler 3D Modeling Software



House in Istanbul Haluk Hatipoglu



www.hot4cad.com



Affordable 3D Scanners



Microsoft Kinect



Google Tango



iSense 3D for iPad



Intel RealSense

3D Printers



Machine Learning Approaches

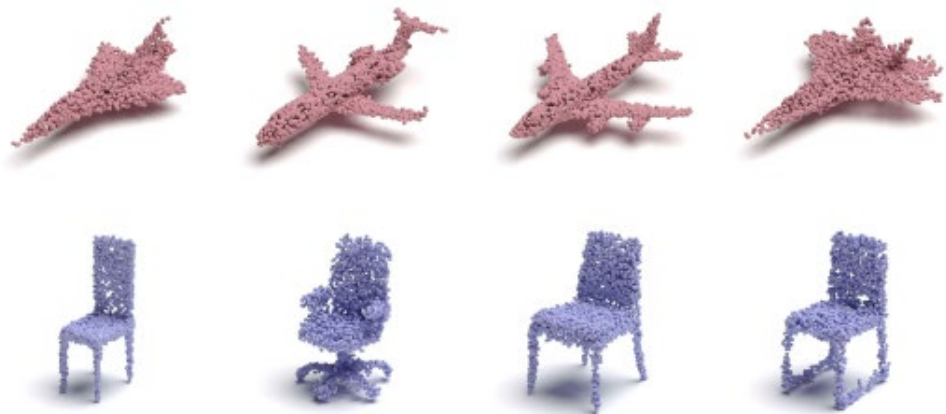
- Example: PointFlow

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

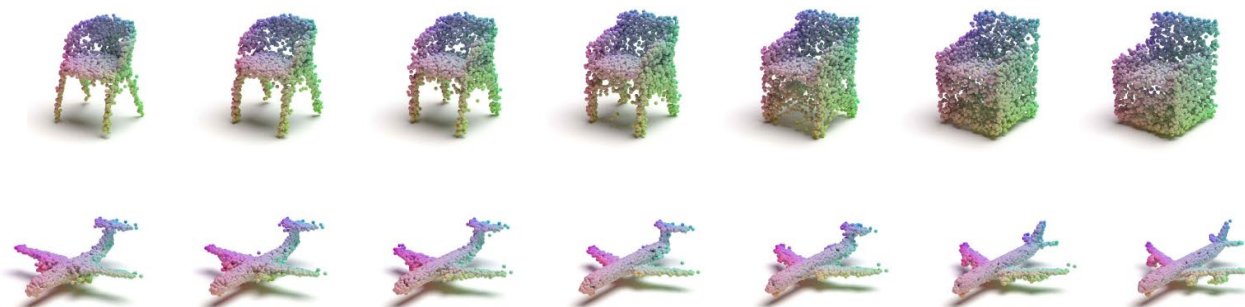
Shape generation flow



Free shape generation



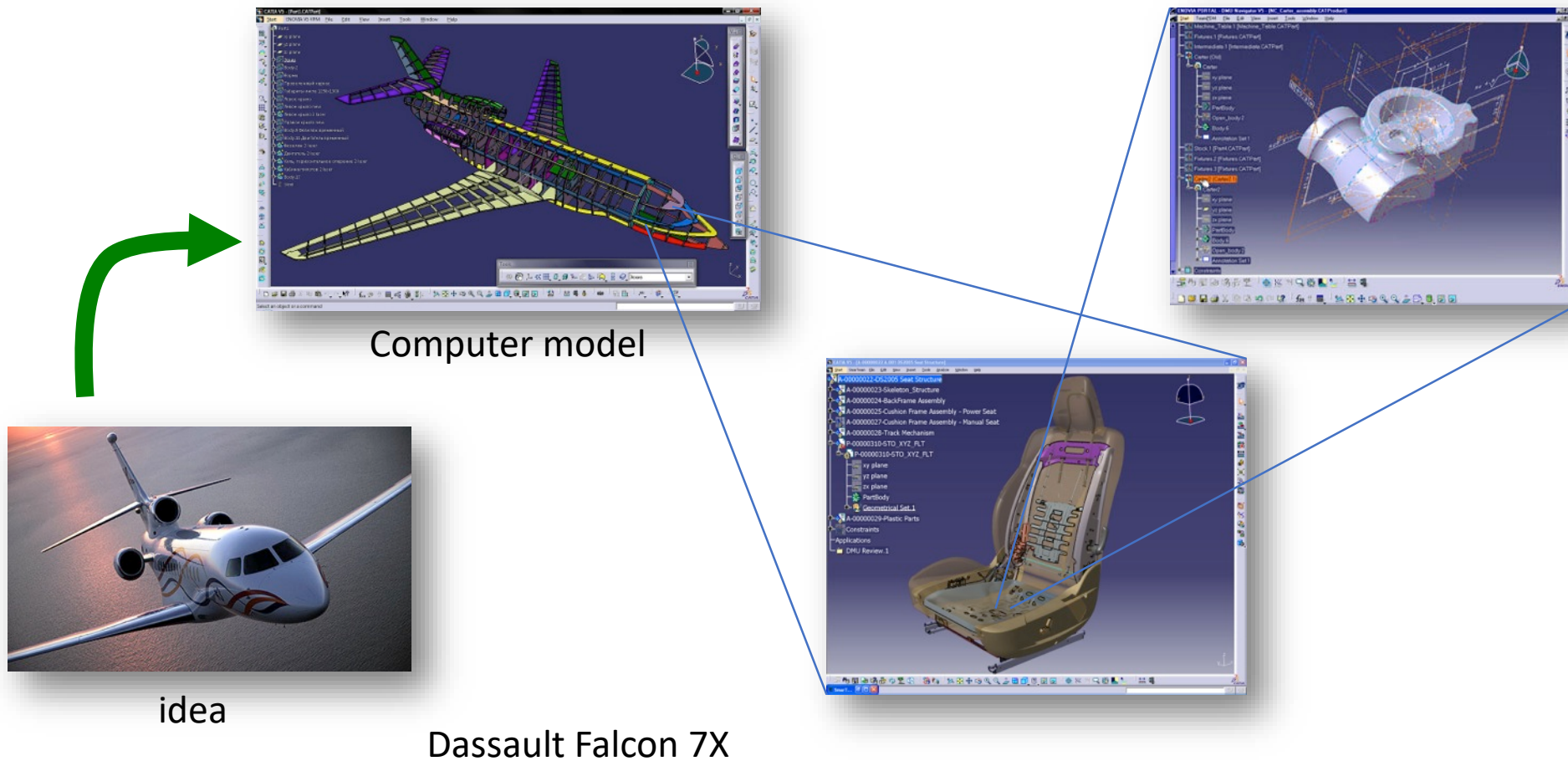
Shape interpolation



How are 3D Models Created?

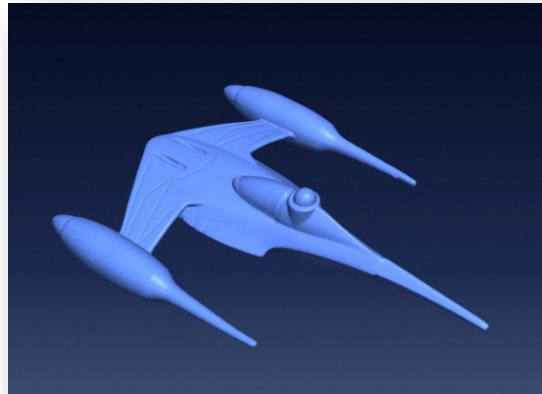
How Shape Models Arise

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



How Shape Models Arise

- Acquired shapes:



Live Body Scan
Data acquired in 0.01 seconds



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

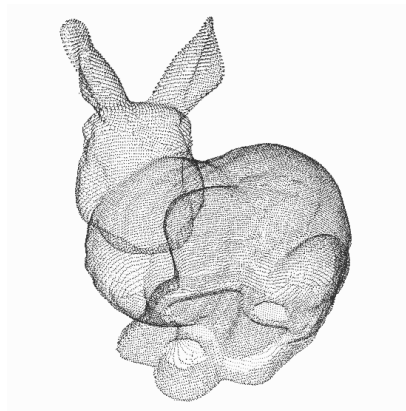
Shape Topology Optimization



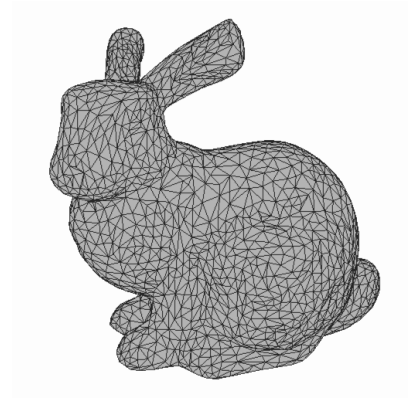
ML Challenge: Multiple 3D Representations



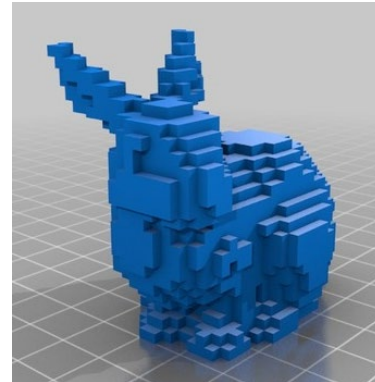
CAD Model



Point Cloud



Surface Mesh



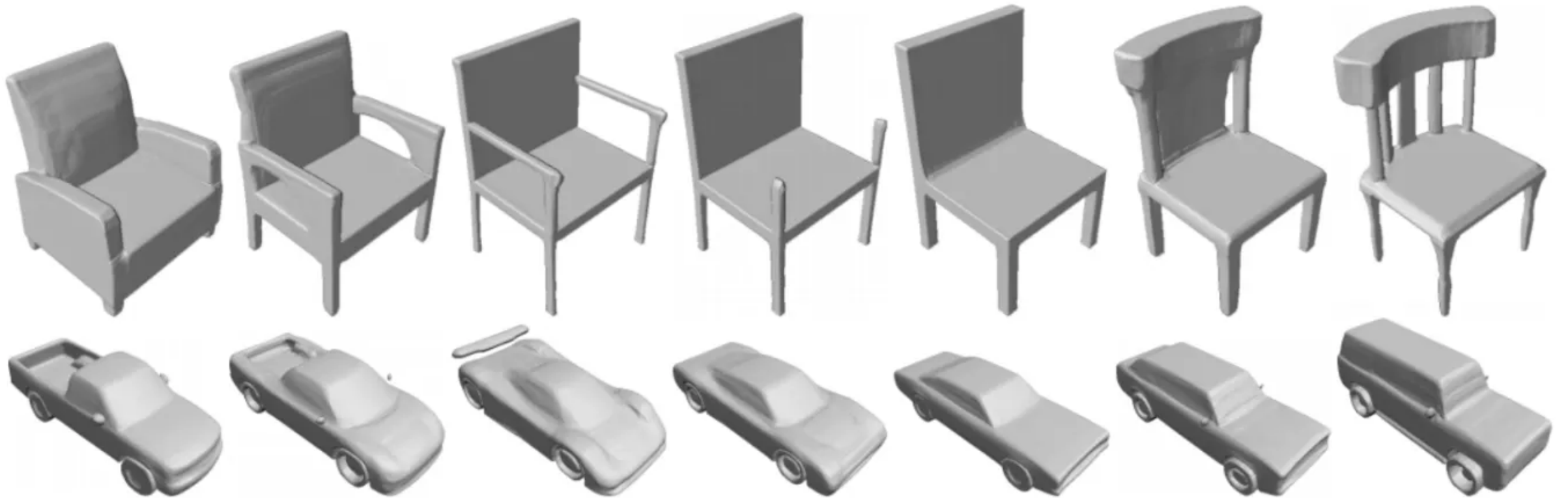
Volumetric



Multi-View Images

...

DeepSDF: Shapes Created by a Neural Network



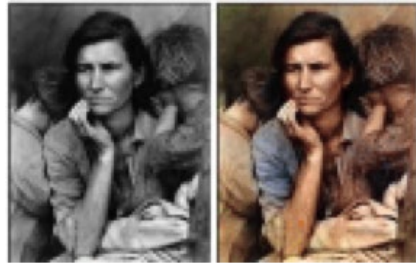
DeepSDF: Learning Continuous Signed Distance Functions for Shape Representation

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



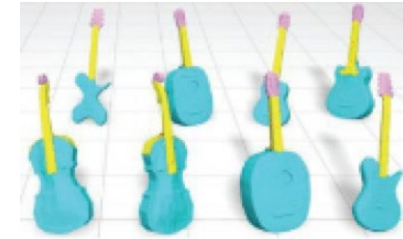
Sketch simplification



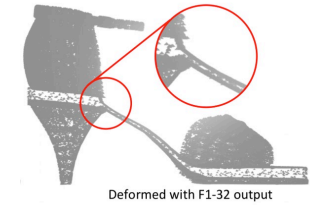
Colorization



Procedural modelling



Mesh segmentation



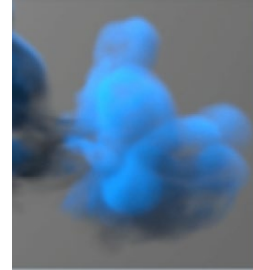
Learning deformations



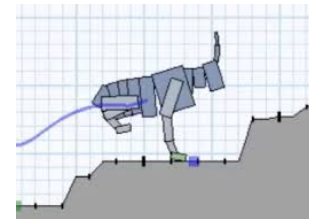
Real-time rendering



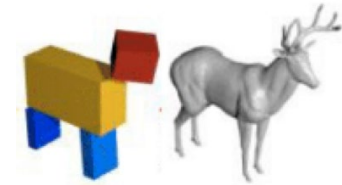
BRDF estimation



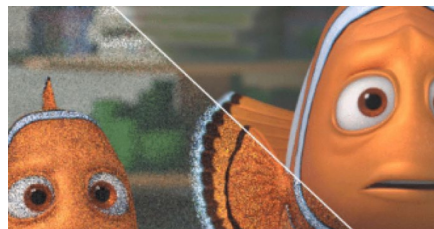
Fluid



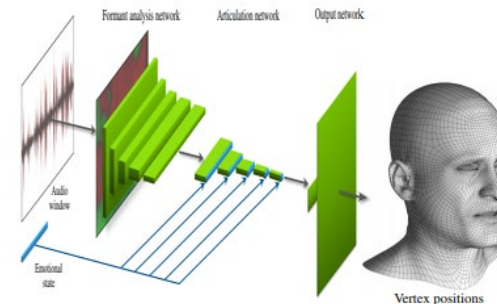
Animation



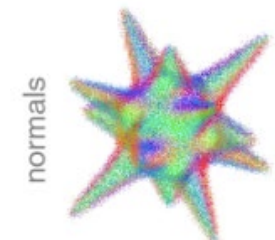
Boxification



Denosing



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

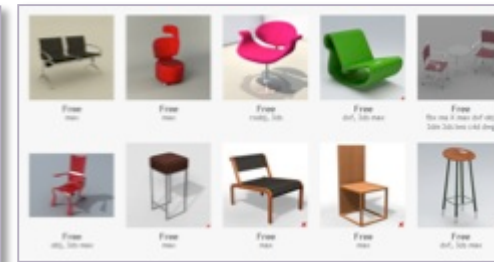
AIM@SHAPE Shape Repository ~ Search ~










Search Results:

< 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
> 708 Shapes found.

Show 24 models per page Sort by: Quality Current sort: .

 <p>Neptune category: ManifoldSurfaceMesh format: OFF file size: 18.7MB creator: M. Attene, L.Sa... uploader: INRIA date: 2006-11-13 14:27:12 download: 382 times Cryp downloads: 3756 times</p> <p>view group</p>	 <p>Neptune category: ManifoldSurfaceMesh format: OFF file size: 43.9MB creator: M. Attene, L.Sa... uploader: INRIA date: 2006-11-13 14:24:53 download: 245 times Cryp downloads: 3758 times</p> <p>view group</p>	 <p>Neptune category: ManifoldSurfaceMesh format: OFF file size: 103.9MB creator: M. Attene, L.Sa... uploader: INRIA date: 2006-11-08 17:37:25 download: 68 times Cryp downloads: 3582 times</p> <p>view group</p>
 <p>Neptune category: ManifoldSurfaceMesh format: OFF file size: 155.0MB creator: M. Attene, L.Sa... uploader: INRIA date: 2006-11-08 17:29:42 download: 161 times Cryp downloads: 3689 times</p> <p>view group</p>	 <p>Neptune category: ManifoldSurfaceMesh format: OFF file size: 17.7MB creator: Laurent_Sabot uploader: INRIA date: 2006-11-08 11:46:07 download: 370 times Cryp downloads: 3711 times</p> <p>view group</p>	 <p>Neptune category: ManifoldSurfaceMesh format: OFF file size: 161.3MB creator: Laurent_Sabot uploader: INRIA date: 2006-11-08 11:37:06 download: 289 times Cryp downloads: 3763 times</p> <p>view group</p>



 <p>Sports Car - Porsche by Antics A detailed 3D model of a... Download to SketchUp 6</p> <p>*****</p>	 <p>US Police Car by Antics A detailed 3D model of a US... Download to SketchUp 6</p> <p>*****</p>	 <p>Camaro Police Car by Sergio777 My entry for the cop car... Download to SketchUp 6</p> <p>*****</p>
 <p>Car by Coolade.Mercenary... Car cars car—Third... Download to SketchUp 6</p> <p>*****</p>	 <p>Car Audi avus quattro... by Marian87 Audi, avus, quattro,... Download to SketchUp 5</p> <p>*****</p>	 <p>VW Jetta Touring Car (Race...) by Dw26 Touring Car version of... Download to SketchUp 5</p> <p>*****</p>
 <p>Wooden Car by Jon A Heritage Mint, Ltd. wooden... Download to SketchUp 6</p> <p>*****</p>	 <p>Ferrari Velocita - Concept... by Shimmy With its Ferrari-Standard V12... History Download to SketchUp 8</p> <p>*****</p>	 <p>Car by Acorn I made this Caterham 7 kit... Download to SketchUp 7</p> <p>*****</p>

ShapeNet (>3M Models)

SHAPE NET Search Options Home About Download Statistics

chair
a seat for one person, with a support for the back; 'he put his coat over the back of the chair and sat down'
[ImageNet](#) [MetaData](#)

Choose a taxonomy:
ShapeNetCore

- airplane,aeroplane,plane(12,4501)
- aquarium,fish tank,marine museum(0,4)
- ashcan,trash can,garbage can,wastebin,ash bin(1,10)
- bag,travelling bag,travel bag,grip,suitcase(1,10)
- basket,handbasket(2,140)
- bathtub,bathing tub,bath,tub(0,932)
- bed(13,353)
- bench(5,1953)
- birdhouse(0,79)
- boat(12,1635)
- bookshelf(0,495)
- bottle(6,550)
- bowl(1,234)
- bus,autobus,coach,charabanc,double-decker,jack bus(1,10)
- cabinet(9,1644)
- camera,photographic camera(4,134)
- can,tin,tin can(2,108)
- cap(4,81)
- car,auto,automobile,machine,motorcar(18,244)
- cellular telephone,cellular phone,cellphone,cell phone(1,10)
- chair(23,7083)**
- chair(1,10)

Synset models

Displaying 1 to 40 of 7080

< 1 2 3 4 5 6 7 8 9 10 11 12 13 ... 177 >

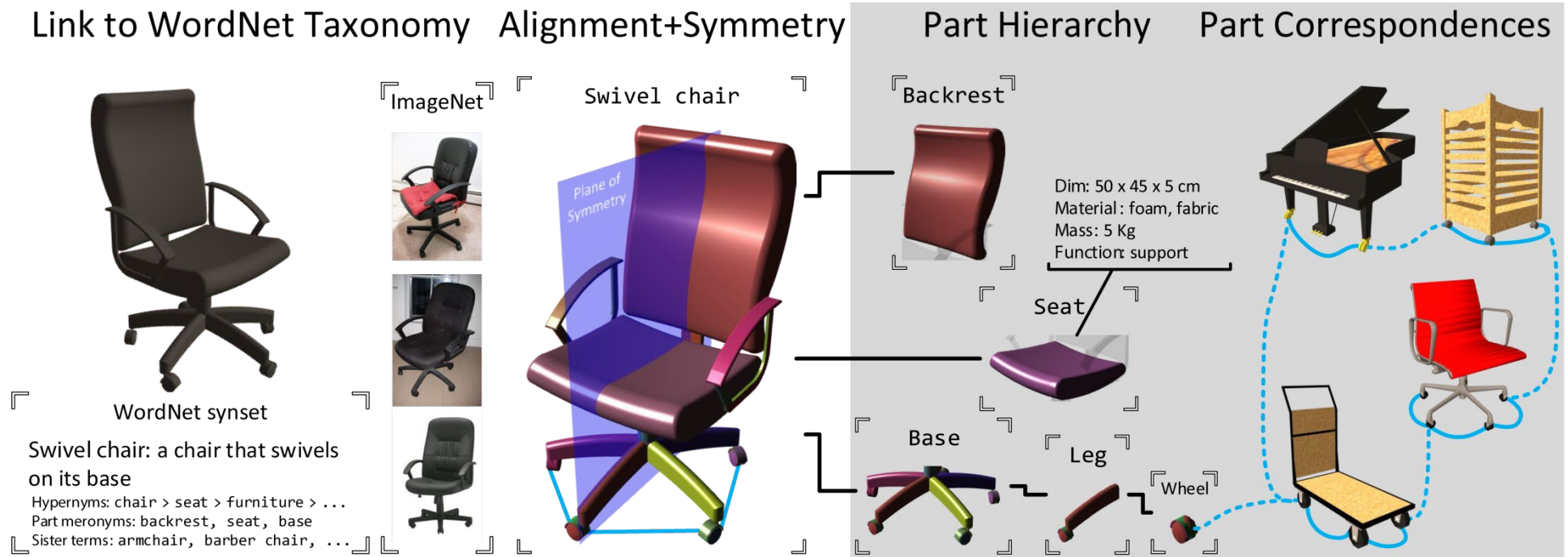
club chair cantilever chair armchair straight chair straight chair club chair deck chair rex chair

straight chair club chair club chair swivel chair butterfly chair armchair armchair club chair

recliner cantilever chair swivel chair swivel chair armchair folding chair rocking chair club chair

chair chair chair chair chair chair chair chair chair chair

Models, with Semantic Annotations

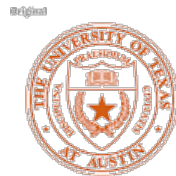


A repository of 3D models organized according to the WordNet taxonomy, with

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



Leonidas Guibas
Pat Hanrahan
Silvio Savarese

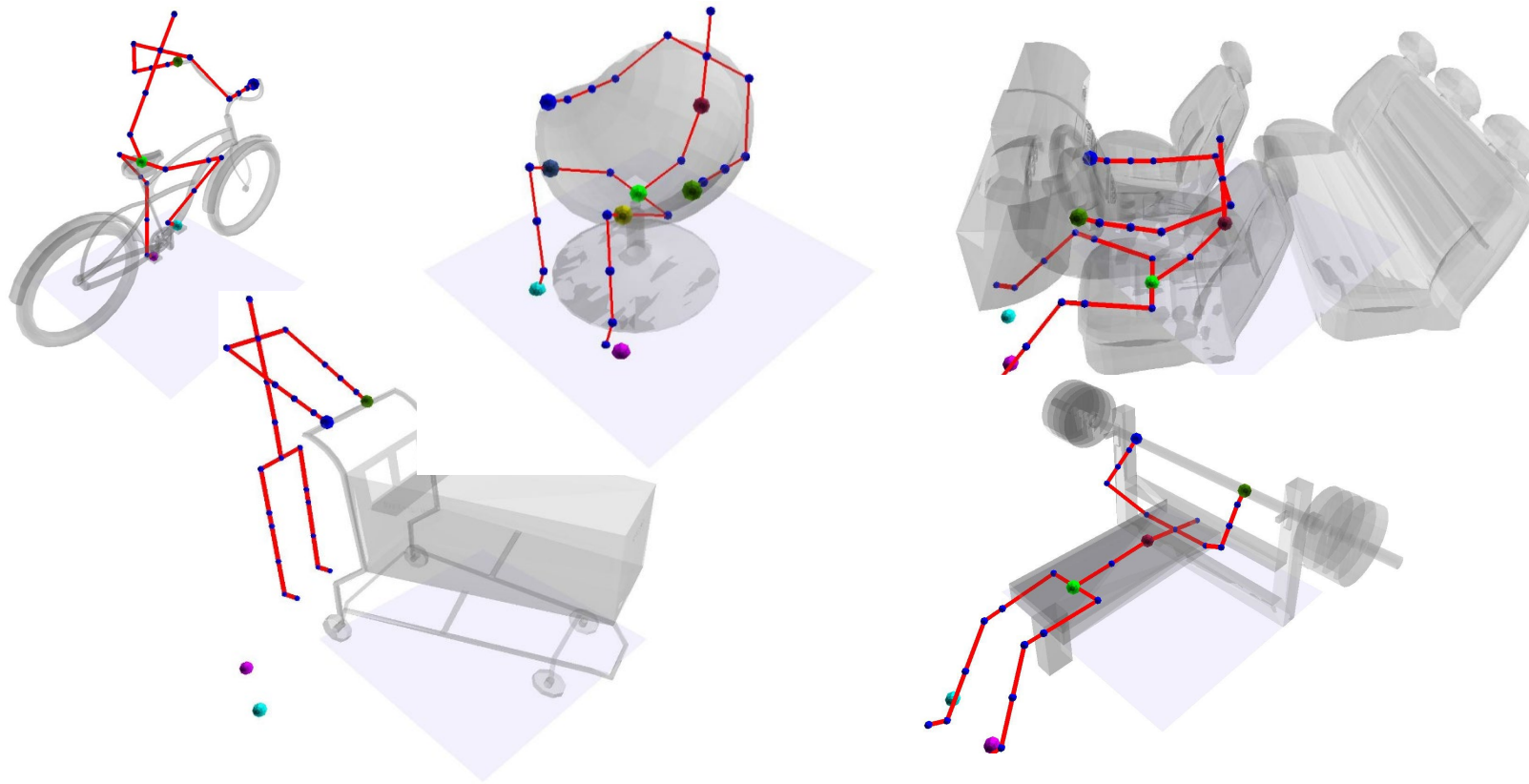


Qixing Huang

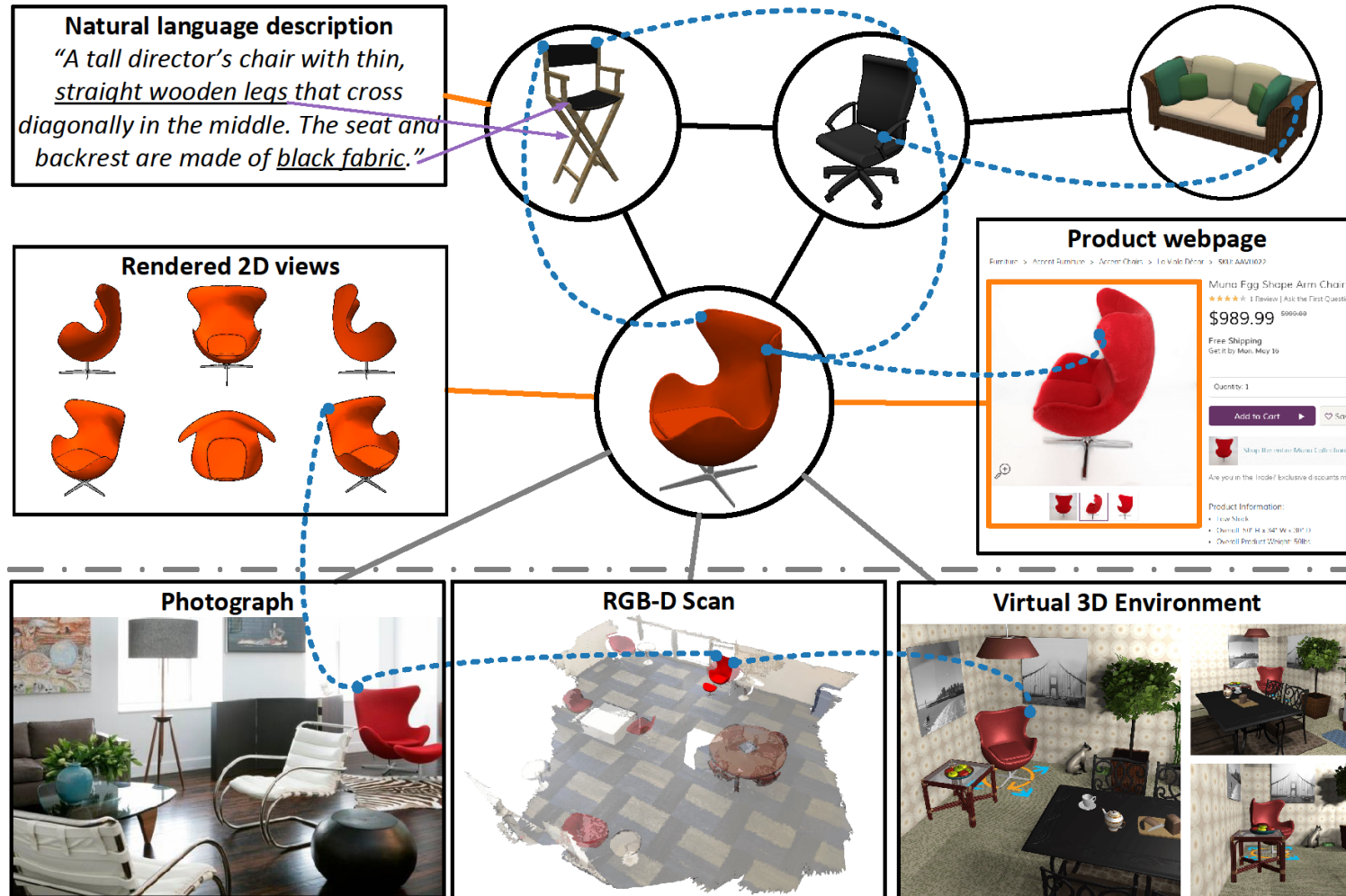


Tom Funkhouser
Jianxiong Xiao

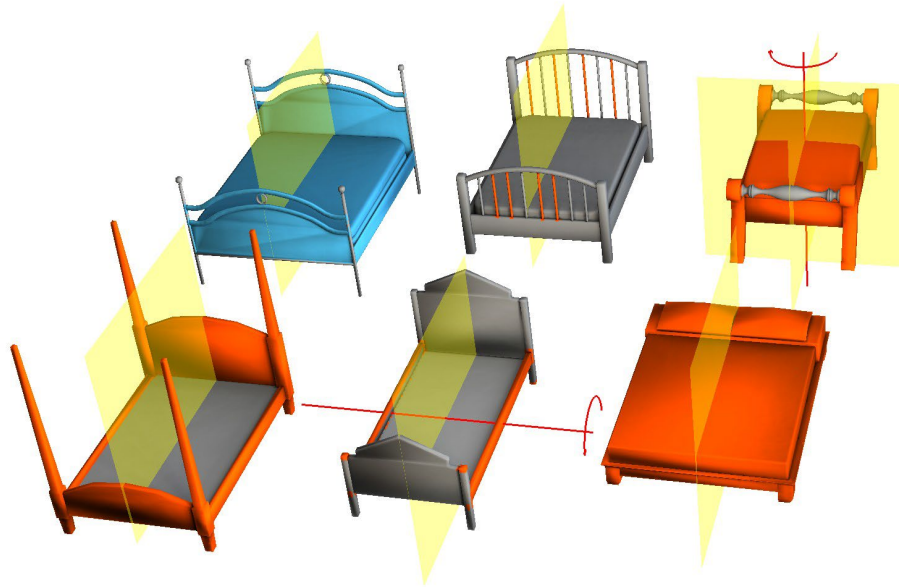
Shape Affordances



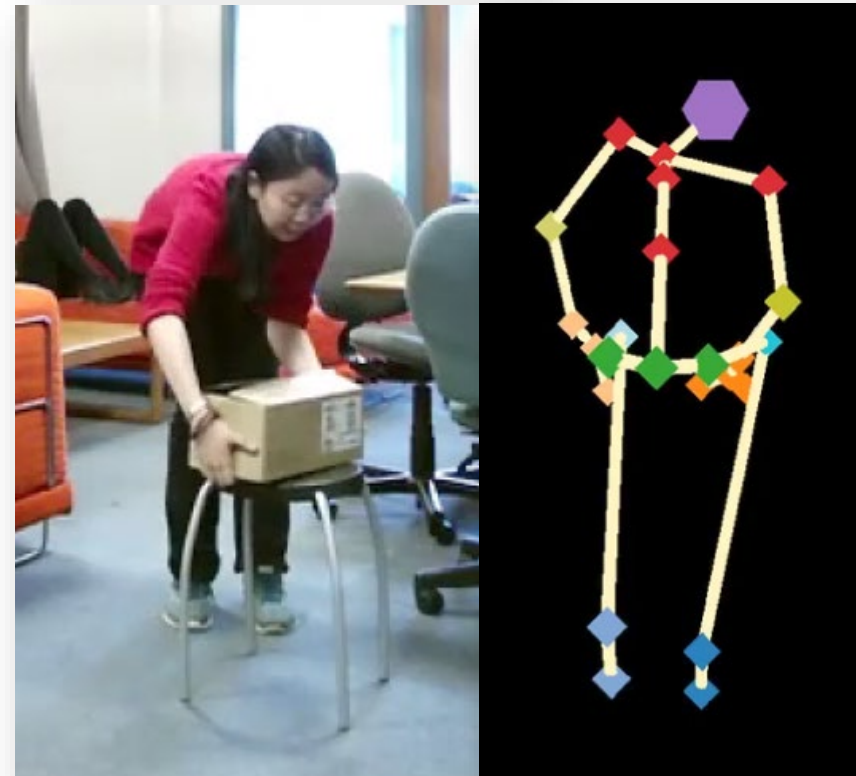
Connections



High-Level Semantic Properties

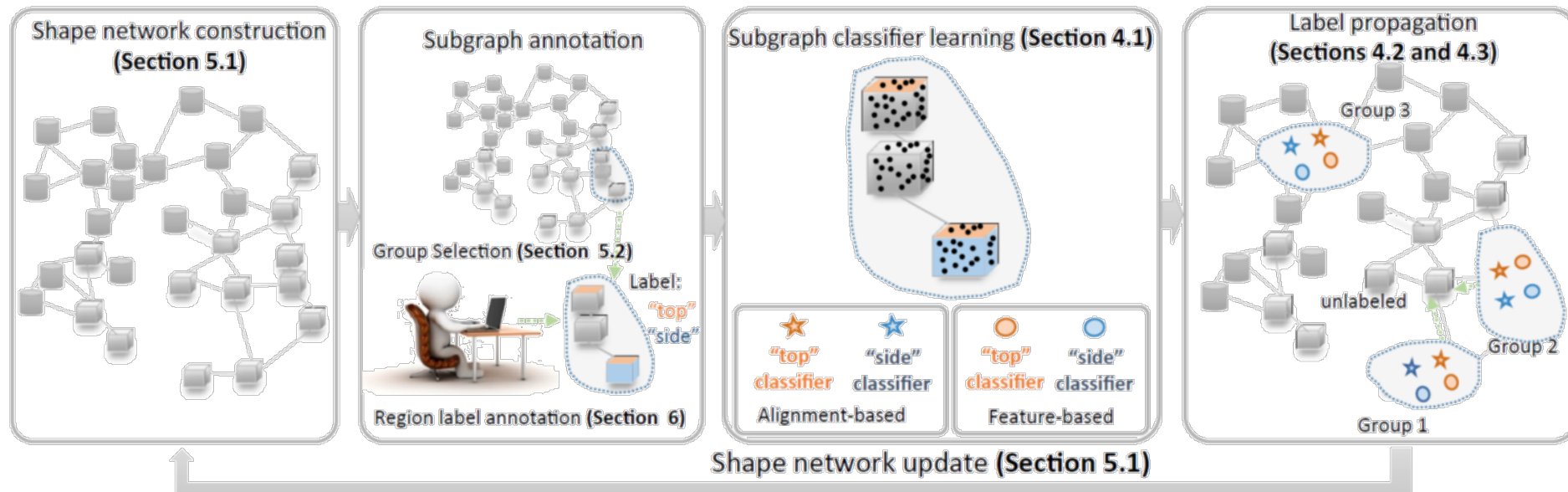


Object symmetries

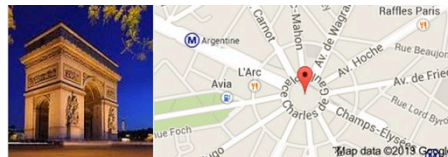


Object weight / grasps

Annotation Pipeline: Humans + Algorithms



3D at the Center



Arc de Triomphe

Directions

The Arc de Triomphe de l'Étoile is one of the most famous monuments in Paris. It stands in the centre of the Place Charles de Gaulle, at the western end of the Champs-Élysées. [Wikipedia](#)

Construction started: August 15, 1806

Opened: 1806

Height: 164' (50 m)

Address: Place Charles de Gaulle, 75008 Paris, France

Architectural style: Neoclassicism

Architect: Jean Chalgrin

YouTube arc de triomphe About 40,100 results

Arc de Triomphe pour la 100ème Arrivée Tour de France
by [vincent GERMAIN](#) · 1 week ago · 6,461 views
21 juillet 2013 Jeux de lumière.
HD

Arc de Triomphe, Paris [HD]
by [WorldSiteGuides](#) · 2 years ago · 27,509 views
Arc de Triomphe - HD footage, information and facts on the Arch of Triumph.
Arc de Triomphe is one of France's most famous ...
HD CC

[Arc de Triomphe - Wikipedia, the free encyclopedia](#)
https://en.wikipedia.org/wiki/Arc_de_Triomphe

The **Arc de Triomphe** de l'Étoile is one of the most famous monuments in Paris. It stands in the centre of the Place Charles de Gaulle (originally named Place de ...
[Arc de Triomphe du Carrousel - Arch of Triumph \(Pyongyang\) - Champs-Élysées](#)

Arc De Triomphe

www.arcdetriompheparis.com/

Arc de Triomphe Paris information in amazing detail with breathtaking photos. Everything you need to know about one of Paris' top attractions - **Arc de Triomphe**.
[Visitor information](#) - [Facts](#) - [History](#) - [Arc de Triomphe Gallery](#)

News - Arc de triomphe - Centre des monuments nationaux
arc-de-triomphe.monuments-nationaux.fr/en/ · [Translate this page](#)

Come and visit the **Arc de Triomphe** at Place de l'Étoile at the top of the Champs-Élysées. A symbol of the French nation, it links old and new Paris, standing on ...

Arc de triomphe - Centre des monuments nationaux
arc-de-triomphe.monuments-nationaux.fr/ · [Translate this page](#)

Présentation du monument et informations pratiques par le Centre des monuments nationaux. Paris (75), France.

4.4 ★★★★★ 215 Google reviews · [Write a review](#)

Place Charles de Gaulle 75008 Paris, France
+33 1 55 37 73 77



3D Warehouse Results Sorted by relevance



Arc de Triomphe
by [Google 3D Warehouse](#)
Standing at the end of the...
[View in Google Earth](#)

★★★★★



The Arch of Triumph in...
by [rafa](#)
The Arch of Triumph in...
[View in Google Earth](#)

★★★★★



Arc de Triomphe d'Orange
by [José Manuel](#)
L'Arc de triomphe dit de...
[View in Google Earth](#)

★★★★★



Arc De Triomphe Montpellier...
by [SpasherProductionFB](#)
Montpellier - Ecuson - Arc...
[View in Google Earth](#)

★★★★★



Germania Triumph Arch
by [Generalfeldmarschall](#)
Germania Triumph Arch, also...
[Download to SketchUp 6](#)

★★★★★

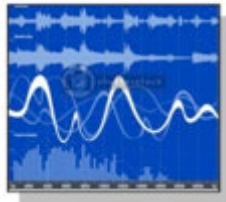


Arc de Triomphe - Paris, France
by [giotis](#)
The Arc de Triomphe (Arc de...
[View in Google Earth](#)

★★★★★

The Time is Now for 3D + ML

- New forms of media are constantly being acquired



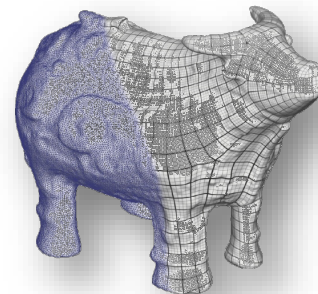
sound



images



video



scanned 3D geometry



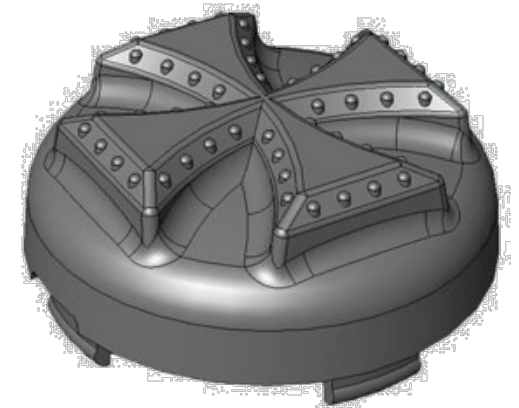
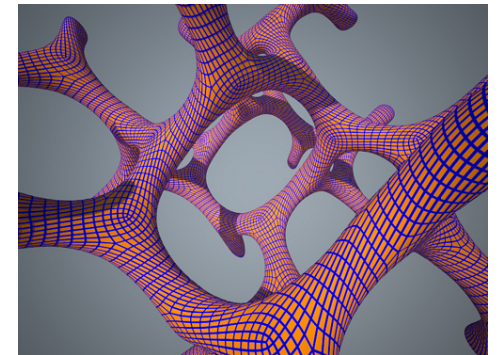
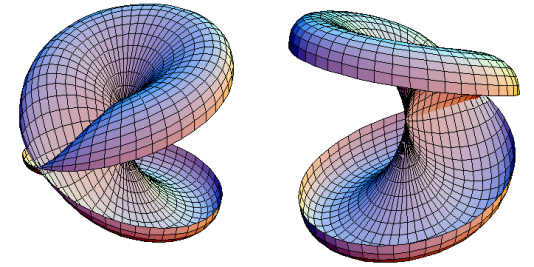
ML generated geometry

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

Course Content

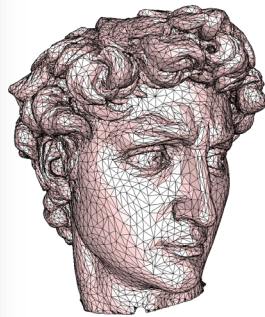
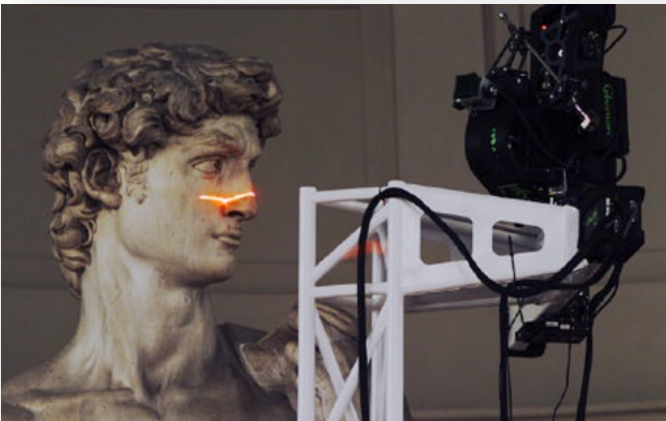
The Course Content I

- 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 Polynomials 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

