Voxels, Point Clouds, and Registration

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CMPT 464/764: Geometric Modeling in Computer Graphics

Lecture 3

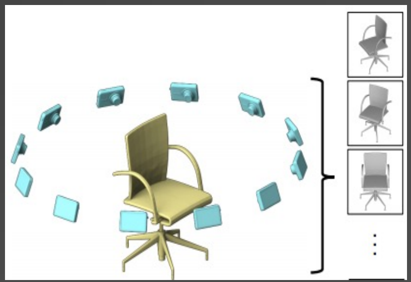
Outline

- Implicit representations
- Parametric representations
- Meshes (subdivision)
- Point clouds
- Voxels
- Multi-view representations

Smooth curves and surfaces

Discrete representations

2D → 3D



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- Voxels

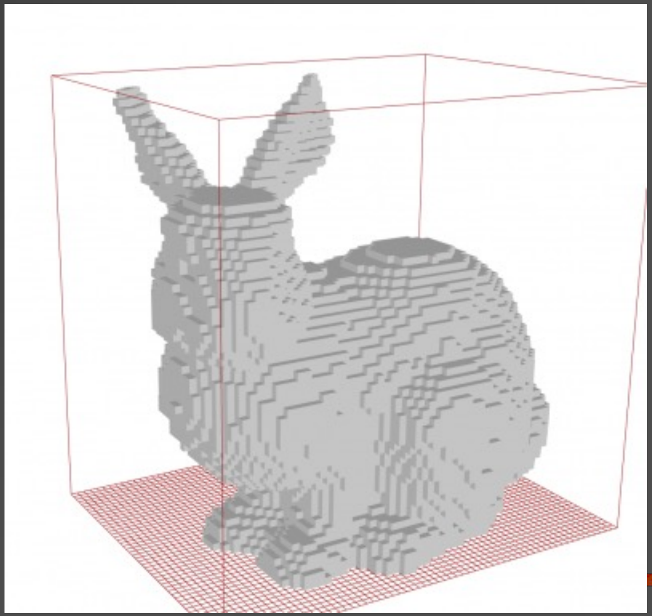
Discrete representations

- Multi-view representations

2D → 3D

Volumetric or voxel representations

- Embed 3D shape in a regular volumetric grid: 3D shape = set of all voxels that lie **on or inside** the shape
- Closely related to image and pixel representations: it is a **3D image**
- Closely tied to **implicit representations** and support similar operations
- Natural **"first choice" for neuralization** due to similarity to images (more next week)

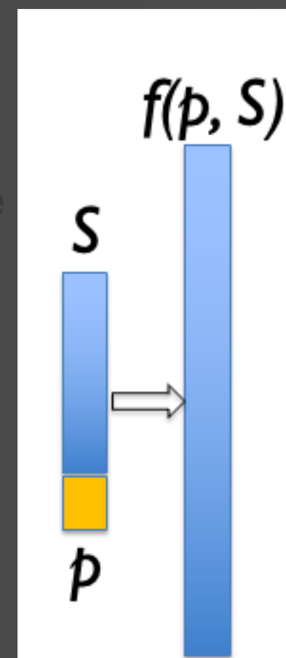


Voxels vs. implicit functions

- Voxels: intrinsically **discrete** representation, limited by resolutions
- Implicit functions: intrinsically **continuous** representation
  - There is an implicit field value for any (x, y, z)
  - When processing an implicit function (e.g., for rendering), one often need to discretize the function

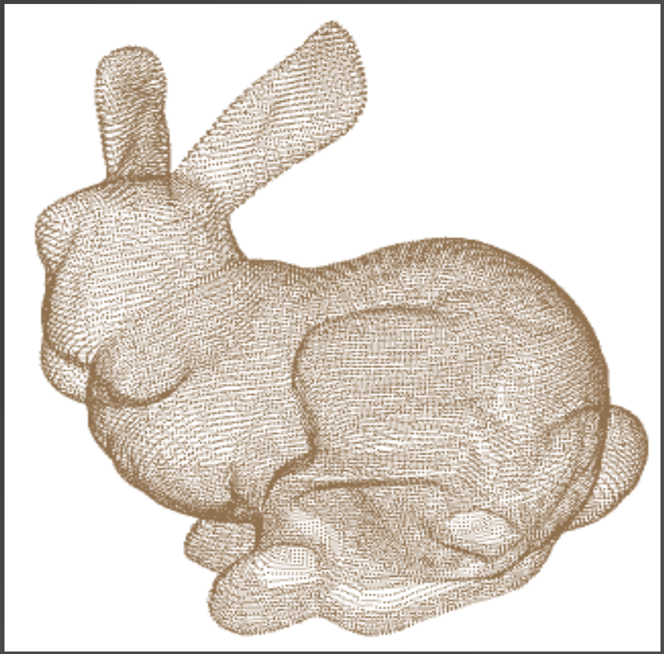
Voxels vs. implicit functions

- Voxels: intrinsically **discrete** representation, limited by resolutions
- Implicit functions: intrinsically **continuous** representation
  - There is a field value for any (x, y,
  - When processing an implicit function (e.g., for rendering), one need to discretize the function
- IM-Net (next week): trained on voxel inputs, e.g., on 64^3 voxels, but can learn **continuous** outputs, $\forall p \in R^3$

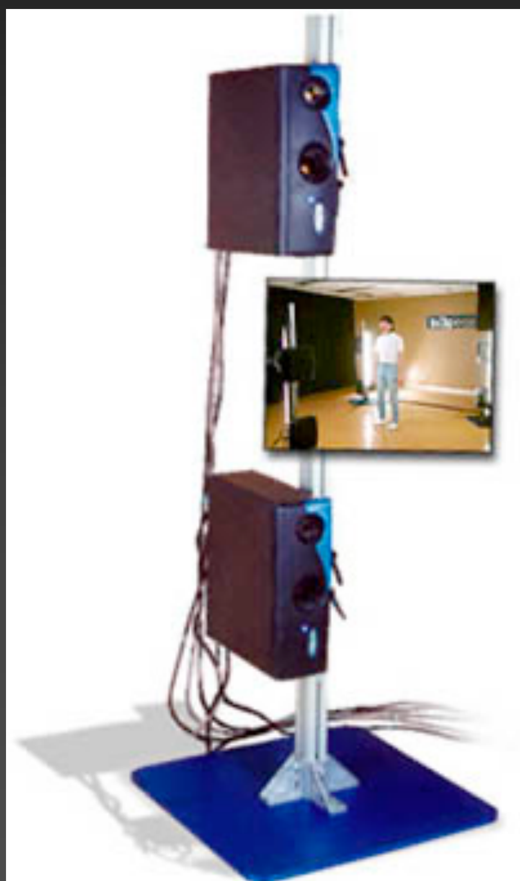


Point-based representation (PBR)

- A 3D surface model is represented using a set of **points near the surface**
- There is no (explicit) connectivity information between the points
- Typically need *k*NN – ***k*** **nearest neighbors** – during processing
- Point normals can also be specified or estimated for rendering



Point cloud acquisition



InSpeck

FastScan ($23K)

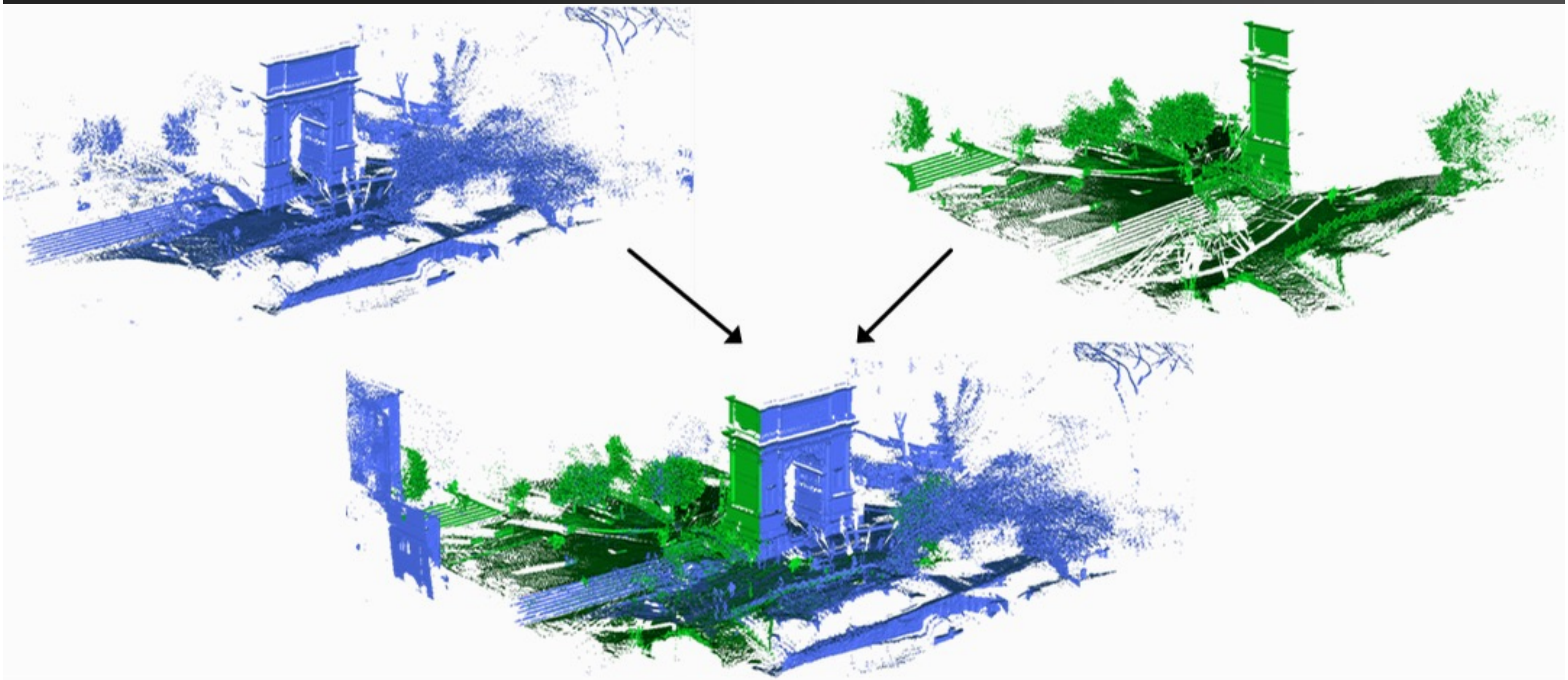
NextEngine (< $3K)

Cyberware

Roland DGA LPX-250 ($10K)

Point cloud acquisition

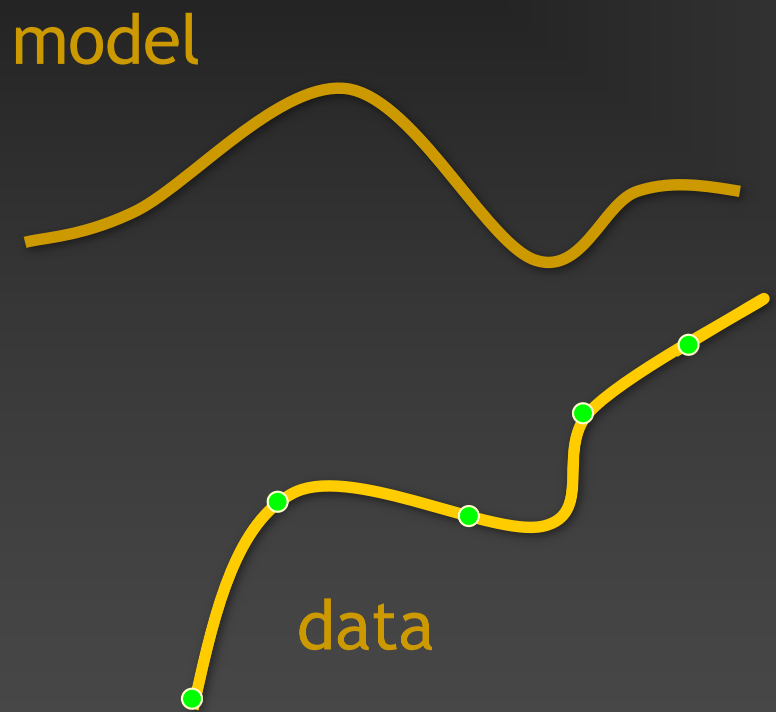
Point cloud registration



Iterative closest point (ICP) algorithm

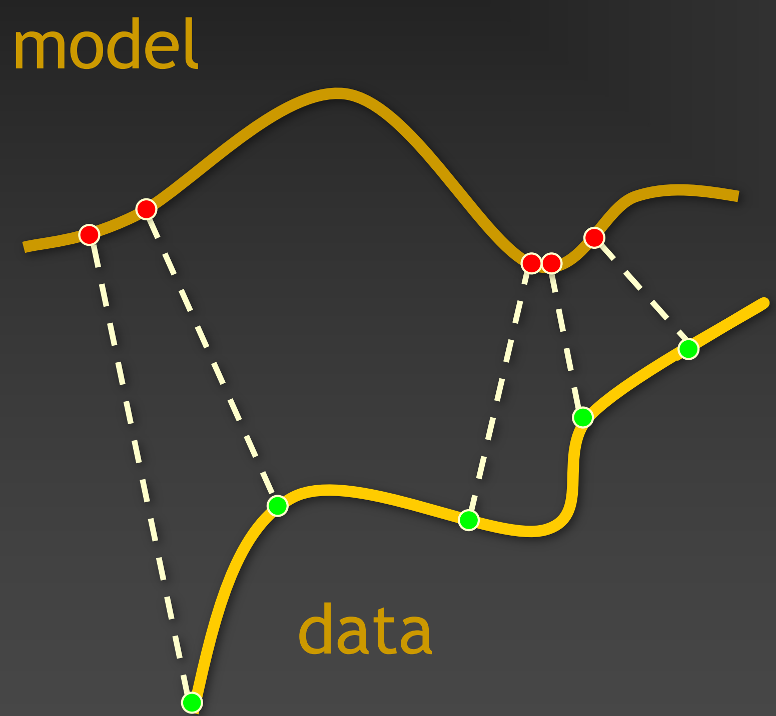
- A classic registration/correspondence schemes
- Input: **data** and **model shapes**
- Objective:
  - Rigid transform = rotation + translation
  - **Minimize mean squared error** from data points to closest points in model [Besl and Mckay 92]
- Correspondence obtained by Euclidean proximity

ICP algorithm



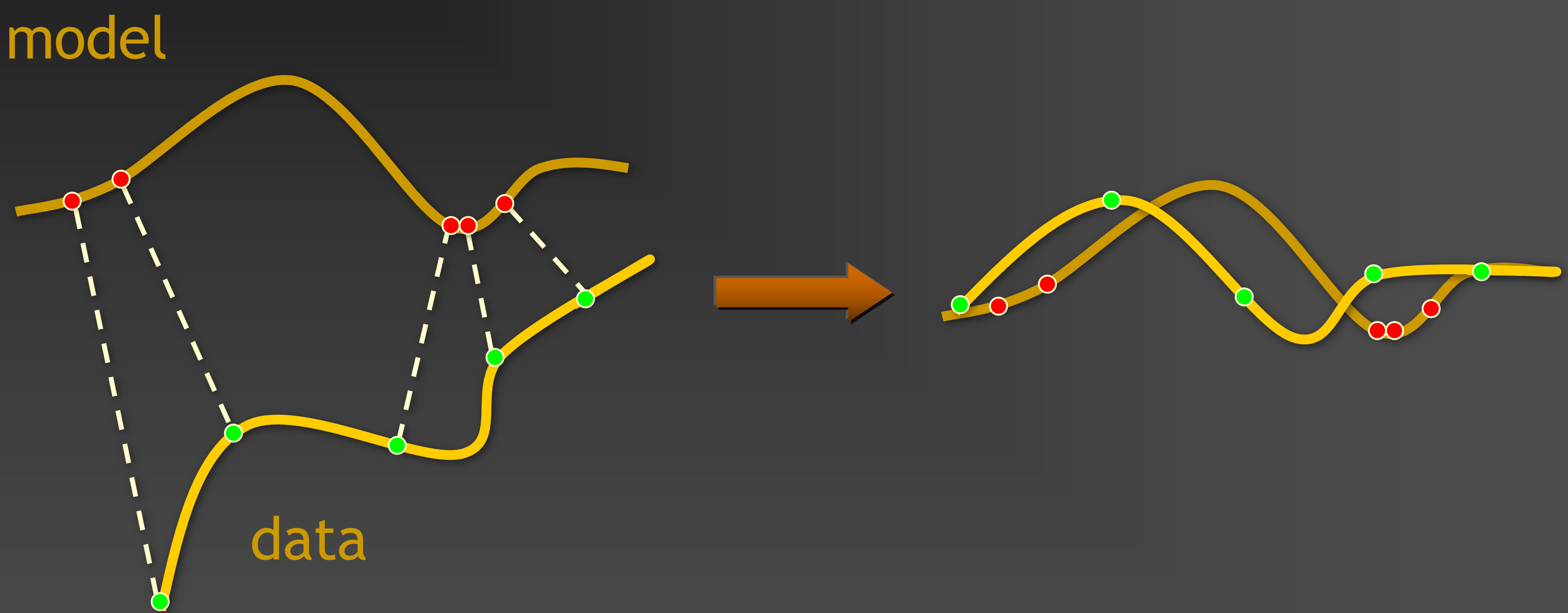
Model and data shapes (point samples)

ICP algorithm



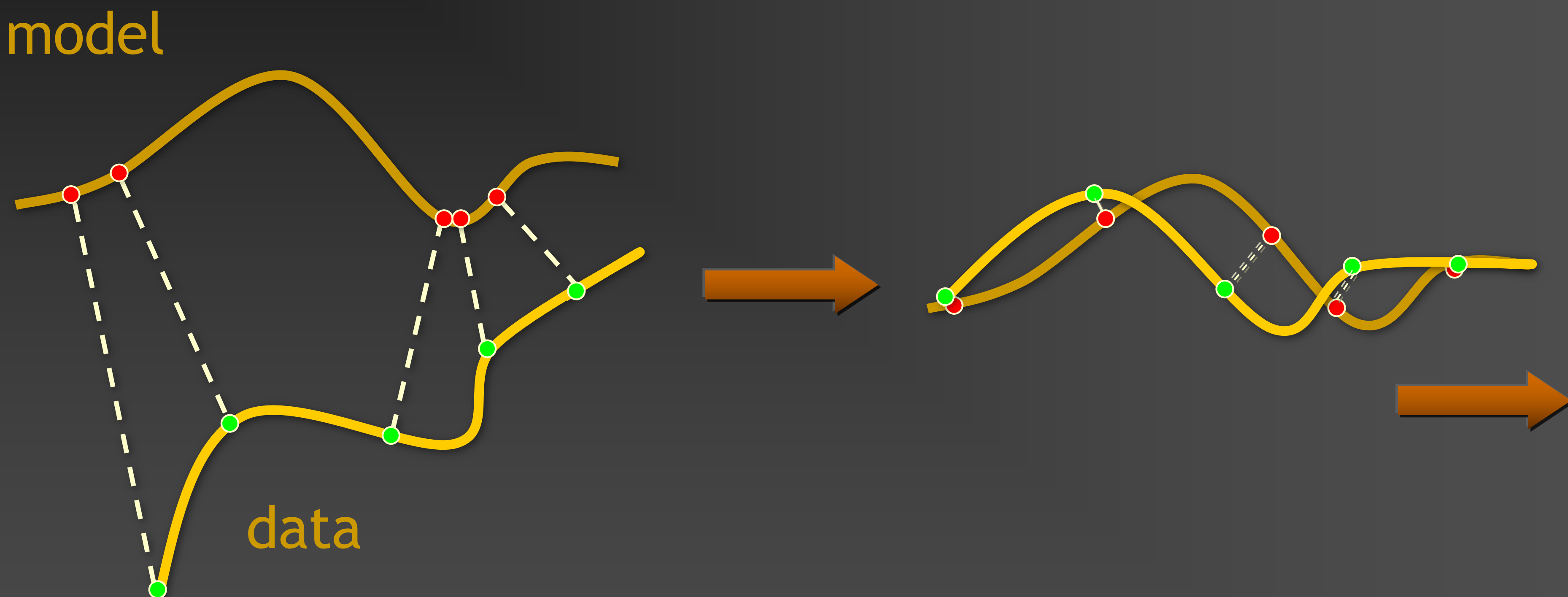
Find closest points from data to model

ICP algorithm



Find best rigid transform to align the corresponding points

ICP algorithm



Iterate ...

A historical note on PBRs

- “As the visual complexity of computer-generated scenes continue to increase, the use of classical modeling primitives (polygons) as display primitives becomes less appealing.”

  Levoy and Whitted,
  “The Use of Points as a Display Primitive”, 1985

- Use of points traces back to modeling of smoke, fire, and cloud around the late 70’s [Csuri et al. 79, Blinn 82]

First renewed interest

- PBR was witnessing a revival around 2002 - 2006
- Points are directly available via **laser scanning**
  - Substantial advances in 3D digitizing and laser scanning and acquisition technology
  - High quality points (color and texture) easily obtained
  - Relatively inexpensive laser scanners available

Point-based Graphics Resource

Symposium on Point-Based Graphics

Symposium on Point-Based Graphics 2006 (On-line Papers) NEW
Symposium on Point-Based Graphics 2006 (On-line Papers)
Symposium on Point-Based Graphics 2005 (On-line Papers)
Symposium on Point-Based Graphics 2004 (On-line Papers)

Books

Point-Based Graphics
Edited By Markus Gross, Swiss Federal Institute of Technology (ETH), Zurich, Switzerland Hanspeter Pfister, MERL (Mitsubishi Electric Research Laboratories), Cambridge, Massachusetts, U.S.A.

Tutorials/Course Notes/Survey

Point-Based Computer Graphics
Marc Alexa, Markus Gross, Mark Pauly, Hanspeter Pfister, Marc Stamminger, Matthias Zwicker
SIGGRAPH 2004 Course Notes

Point-Based Computer Graphics
Marc Alexa, Carsten Dachsbacher, Markus Gross, Mark Pauly, Jeroen van Baar, Matthias Zwicker
Eurographics 2003 Tutorial Notes

Point-Based Computer Graphics
Marc Alexa, Markus Gross, Mark Pauly, Hanspeter Pfister, Marc Stamminger, Matthias Zwicker
Eurographics 2002 Tutorial Notes

A Survey of Point-Based Techniques in Computer Graphics
Leif Kobbelt, Mario Botsch
to appear in Computers & Graphics

Dissertation/Thesis

Point-Based Modeling, Animation and Rendering of Dynamic Objects
Bart Adams
PhD Thesis, Katholieke Universiteit Leuven, May 2006

Point-Based Multi-Resolution Rendering
Michael Wand
PhD Thesis, University of Tubingen, Department of Computer Science and Cognitive Science, 2004

Dynamic Point Samples as Primitives for Free-Viewpoint Video
Stephan Wurmlin
PhD Thesis, ETH Zurich, 2004

Reconstruction and Rendering of Implicit Surfaces from Large Unorganized Point Sets
Patrick Reuter
PhD Thesis, LaBRI - Universite Bordeaux-1, 2003

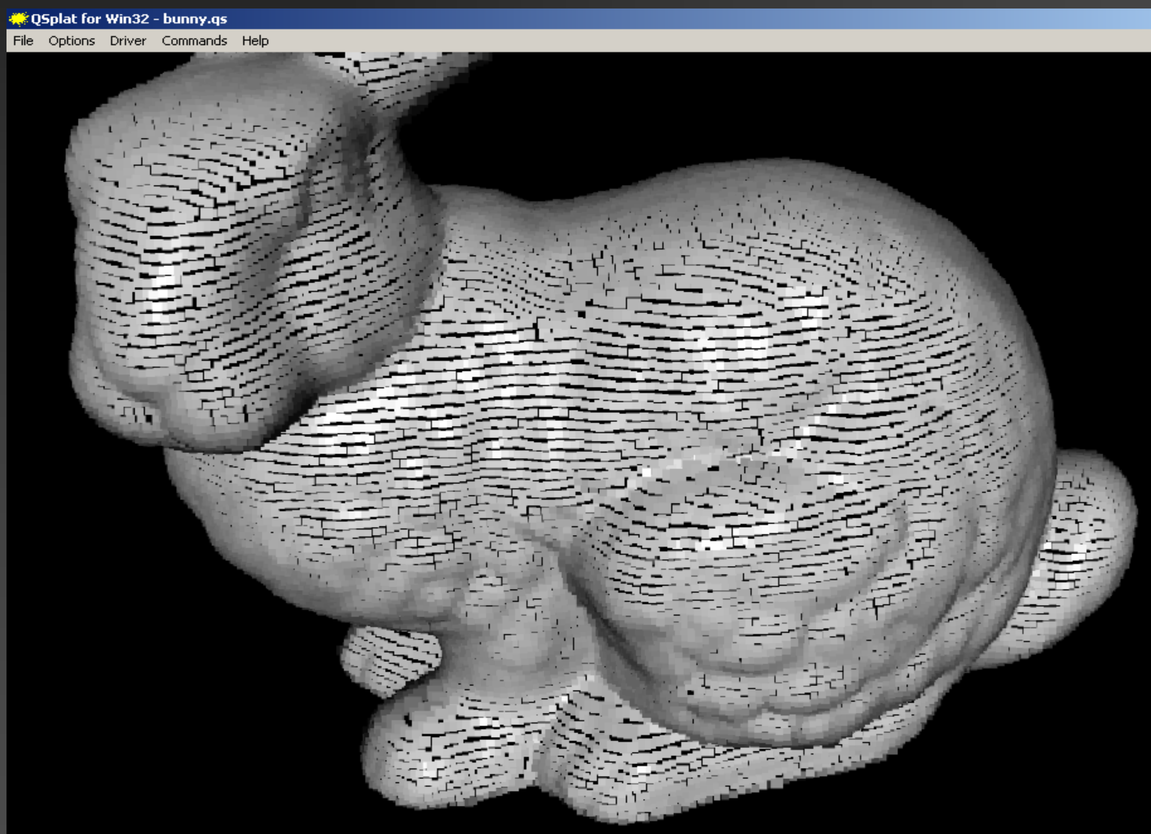
Point Primitives for Interactive Modeling and Processing of 3D Geometry
Mark Pauly
PhD Thesis, ETH Zurich, 2003

Continuous Reconstruction, Rendering, and Editing of Point-Sampled Surfaces
Matthias Zwicker
PhD Thesis, ETH Zurich, 2003

Point Set Surfaces
Shachar Fleishman
PhD Thesis, 2003

https://www.realtimerendering.com/kesen/PointBasedPaper.html

PBR rendering via splatting: QSplat



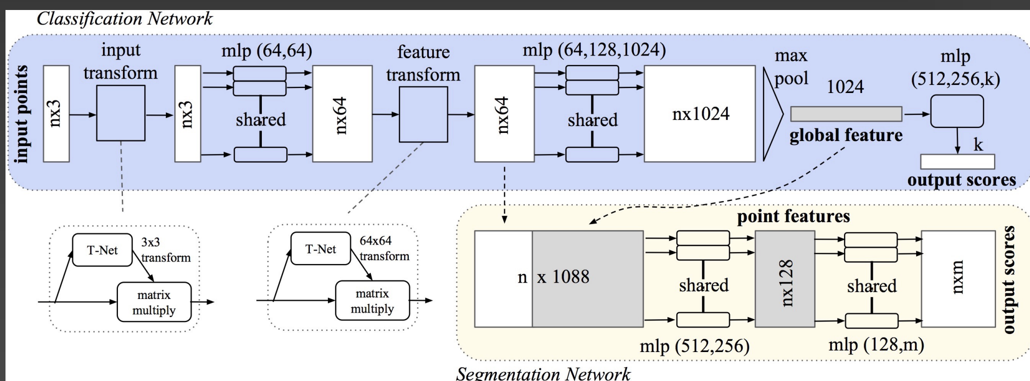
Splat = OpenGL points

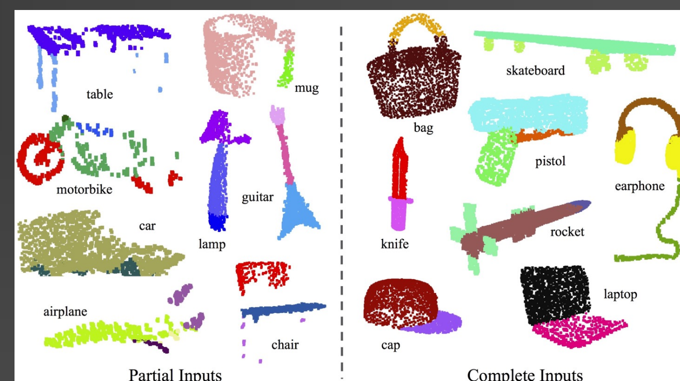
PBR rendering via splatting: QSplat

Splat = circles

Second revival: deep learning

- PointNet and PointNET++, since 2016/17
- Deep neural network to **encode and aggregate point features** for shape recognition, segmentation, etc. (more next week)





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TITLE	CITED BY	YEAR
Pointnet: Deep learning on point sets for 3d classification and segmentation CR Qi, H Su, K Mo, LJ Guibas Proceedings of the IEEE conference on computer vision and pattern …	21564	2017
Pointnet++: Deep hierarchical feature learning on point sets in a metric space CR Qi, L Yi, H Su, LJ Guibas Advances in neural information processing systems 30	16028	2017
Shapenet: An information-rich 3d model repository AX Chang, T Funkhouser, L Guibas, P Hanrahan, Q Huang, Z Li, ... arXiv preprint arXiv:1512.03012	7141	2015
The earth mover's distance as a metric for image retrieval Y Rubner, C Tomasi, LJ Guibas International journal of computer vision 40 (2), 99-121	7138	2000
Kpconv: Flexible and deformable convolution for point clouds H Thomas, CR Qi, JE Deschaud, B Marcotegui, F Goulette, LJ Guibas Proceedings of the IEEE/CVF international conference on computer vision …	3725	2019
Frustum pointnets for 3d object detection from rgb-d data CR Qi, W Liu, C Wu, H Su, LJ Guibas Proceedings of the IEEE conference on computer vision and pattern …	3184	2018
A point set generation network for 3d object reconstruction from a single image H Fan, H Su, LJ Guibas Proceedings of the IEEE conference on computer vision and pattern …	3014	2017

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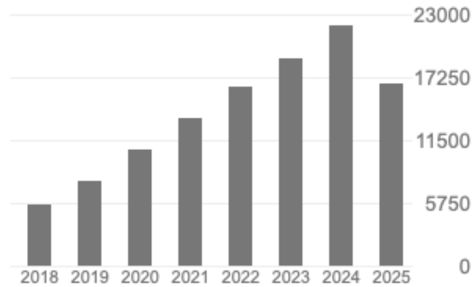

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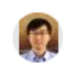

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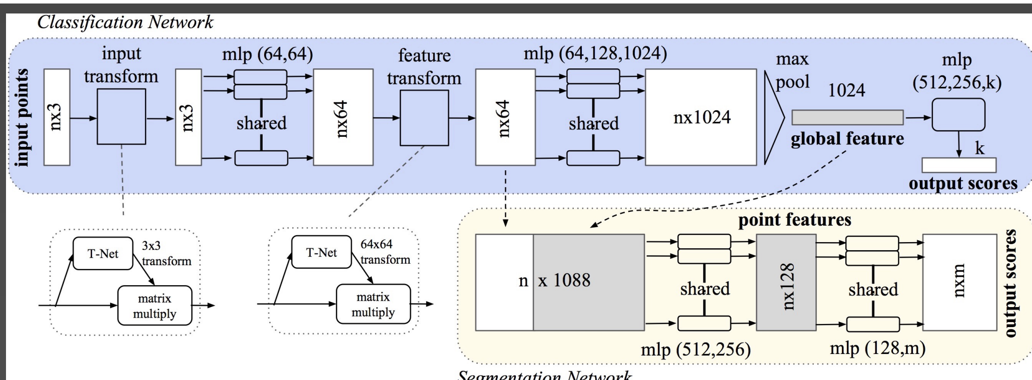

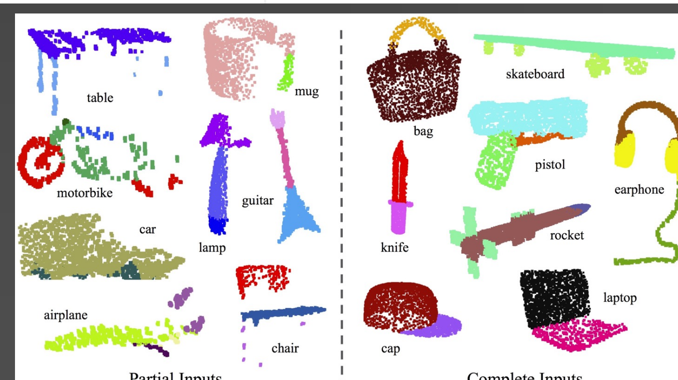

Third revival: 3D Gaussian splatting (3DGS)

- 3DGS [Kerbl et al. SIG 2023] superseding NeRF (2000) – more later