Geometry

3D Content Creation

How to make the 3D assets?

- Geometry Processing
- Surface Reconstruction
- Geometric Modeling
- Creative Generation

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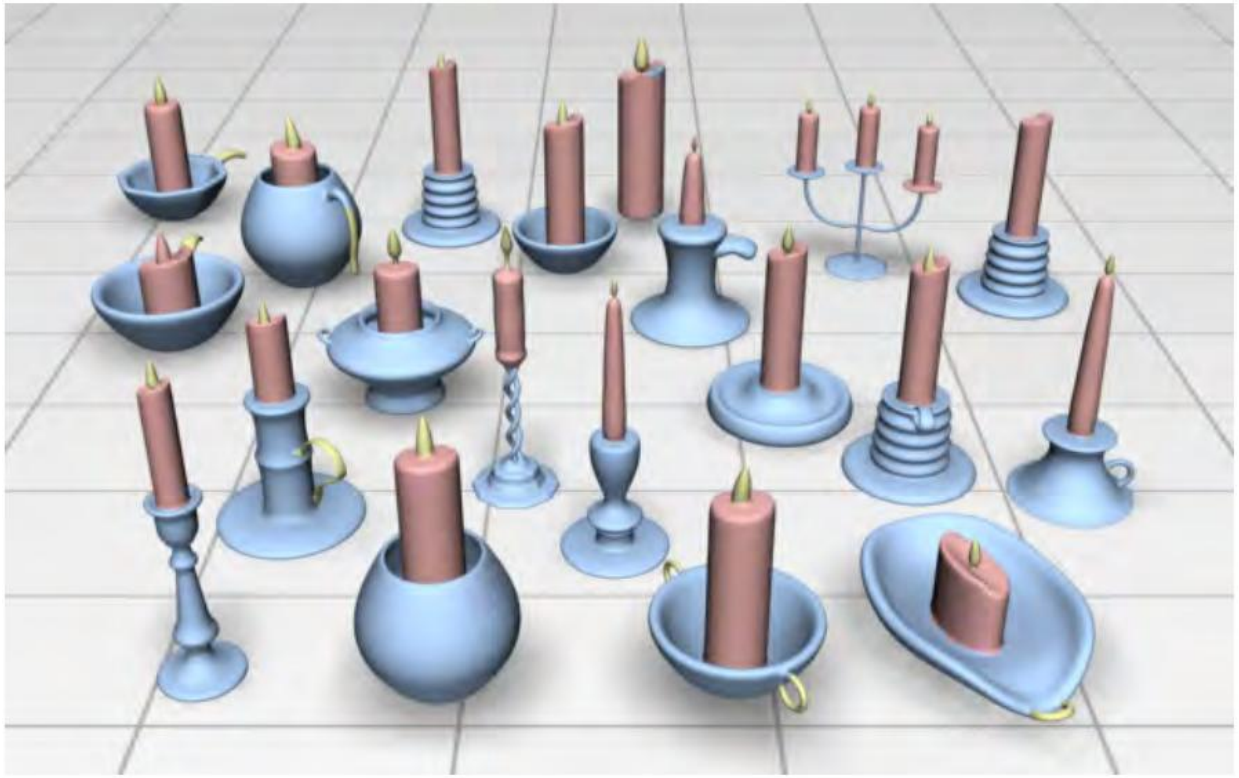


Shape Retrieval

Assuming a large dataset of 3D models, how to find the one we need?

A metric to measure the “similarity” between 3D shapes!

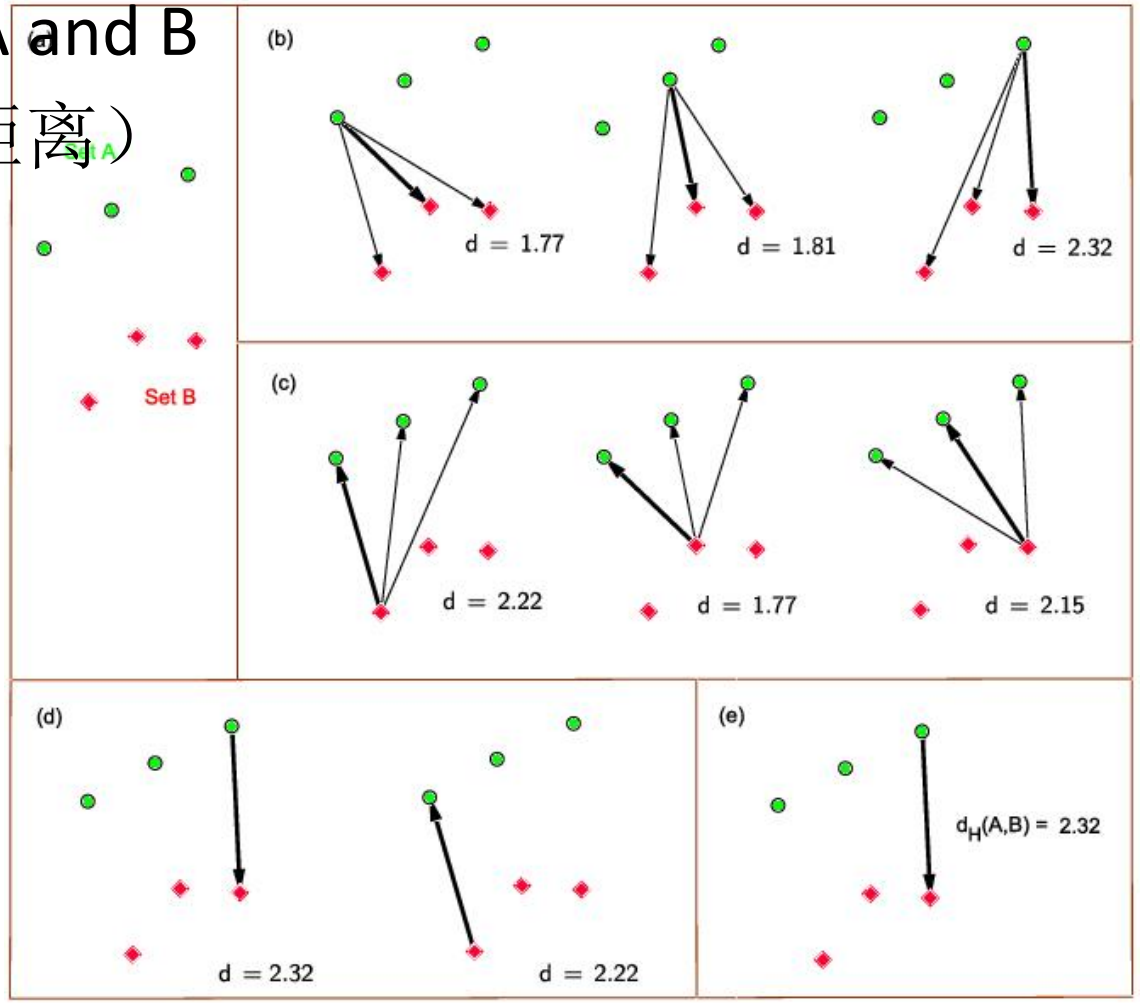
Distance Between Two Surfaces

Take 3D models as geometric surfaces A and B

- Hausdorff Distance（双向豪斯多夫距离）

$$H(A,B) = max(h(A,B), h(B,A))$$

$$\begin{cases} h(A,B) = \max_{a \in A} \min_{b \in B} ||a-b|| \\ h(B,A) = \max_{b \in B} \min_{a \in A} ||b-a|| \end{cases}$$



Distance Between Two Surfaces

Take 3D models as geometric surfaces A and B

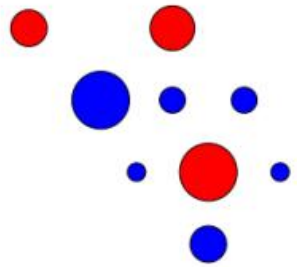
- Chamfer Distance（倒角距离）

$$d_{CD}(S_1, S_2) = \frac{1}{S_1} \sum_{x \in S_1} \min_{y \in S_2} ||x - y||_2^2 + \frac{1}{S_2} \sum_{y \in S_2} \min_{x \in S_1} ||x - y||_2^2$$

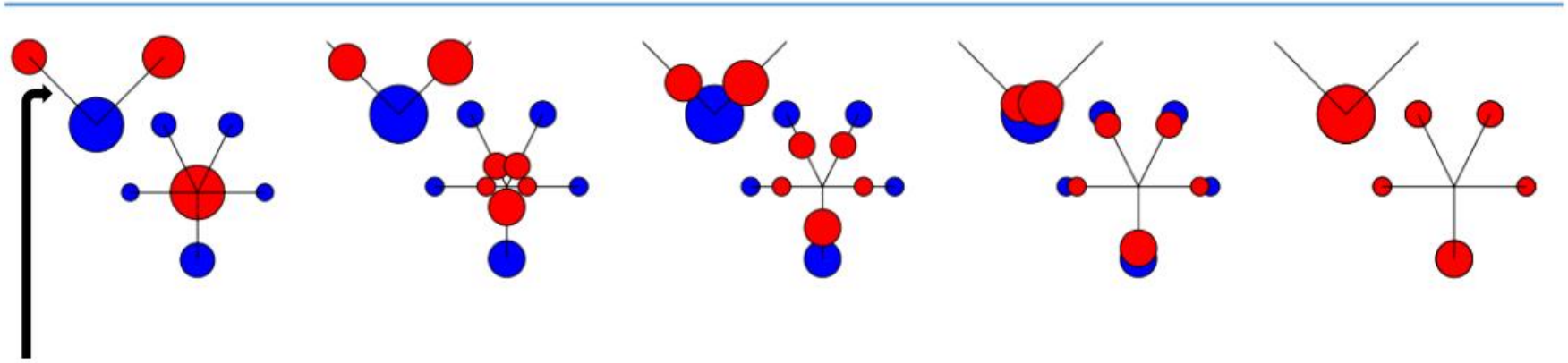
Distance Between Two Surfaces

Take 3D models as geometric surfaces A and B

- Earth Mover's Distance（推土机距离）



- red distribution: "dirt"
- blue distribution: "holes"



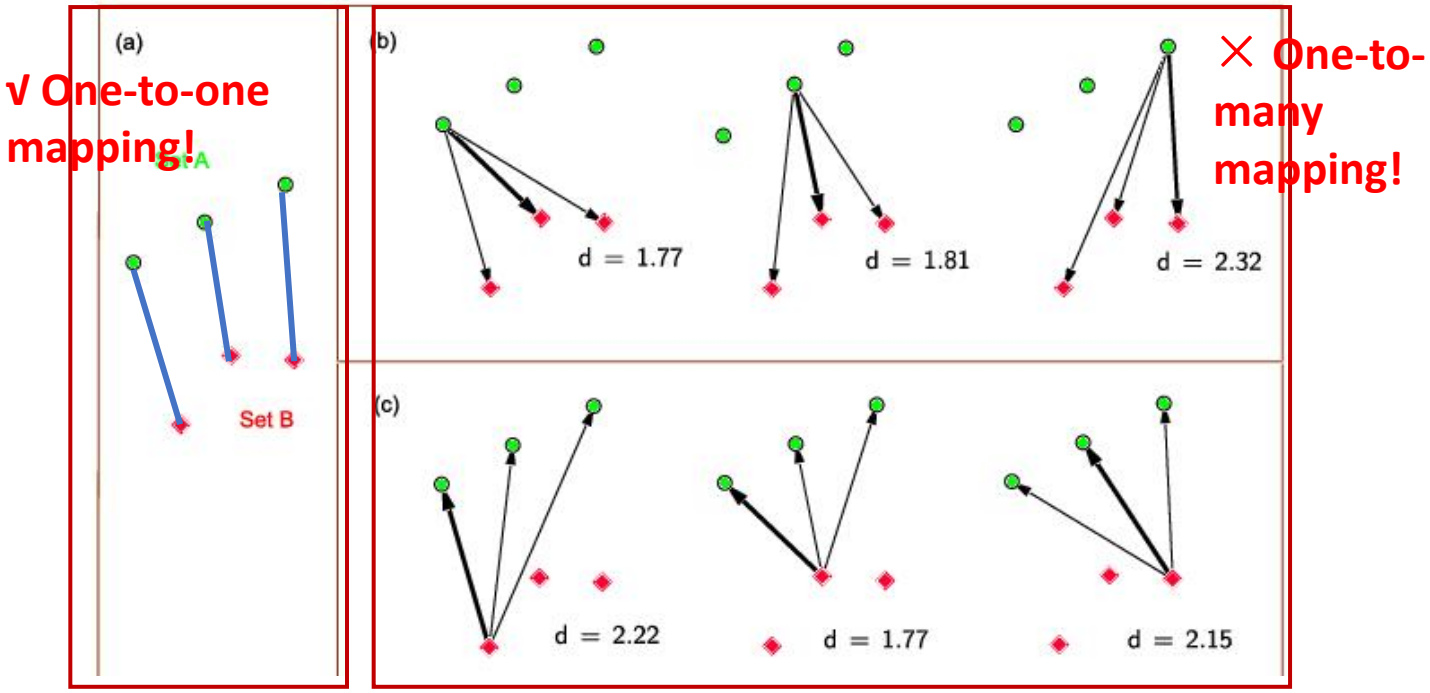
The distance between points (ground distance) can be Euclidean distance, Manhattan…

Distance Between Two Surfaces

Take 3D models as geometric surfaces A and B

- Earth Mover's Distance（推土机距离）

$$d_{EMD}(S_1, S_2) = \min_{\phi: S_1 \to S_2} \sum_{x \in S_1} ||x - \phi(x)||_2, \phi : S_1 \to S_2 \text{为一个双射}$$



√ One-to-one mapping!

× One-to-many mapping!

Distance Between Two Surfaces

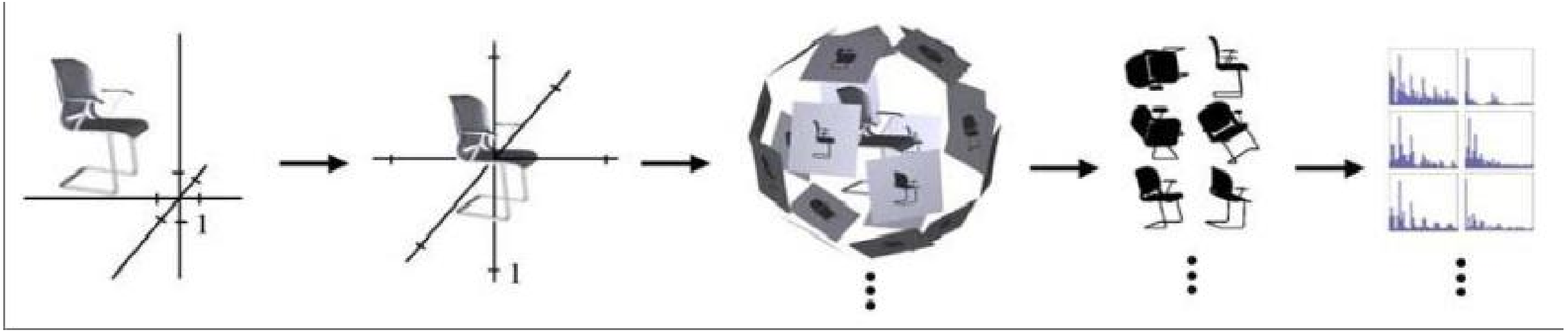
Only measures the geometric similarity

No pose invariance!

Distance Between Two Shapes

Shape descriptors to capture the primary feature

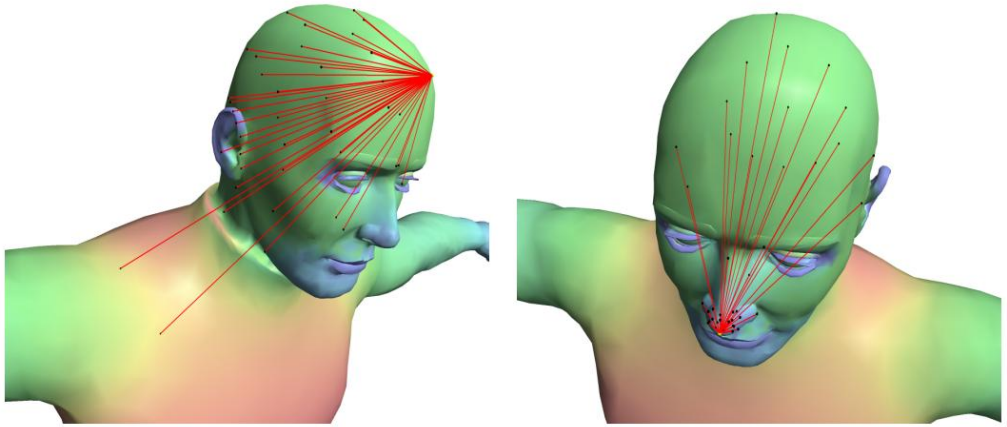
- Light Field Discriptor (LFD)



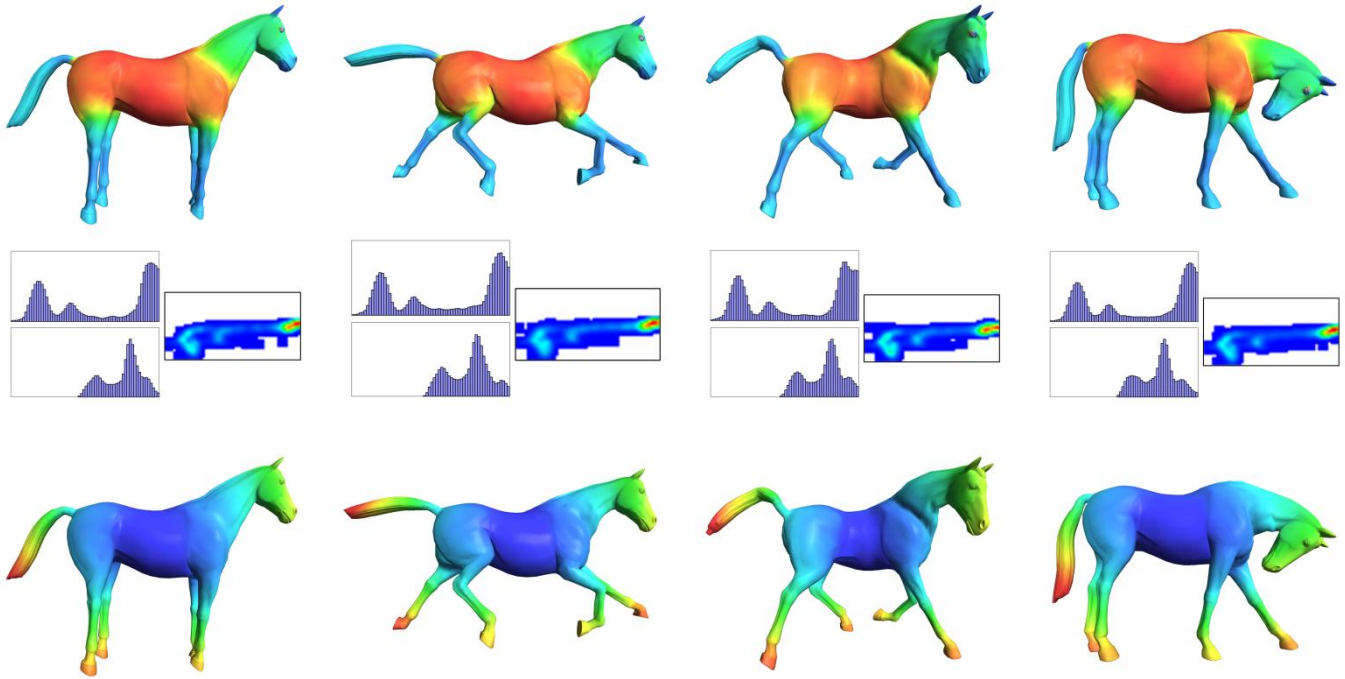
Distance Between Two Shapes

Shape descriptors to capture the primary feature

- Shape Diameter (SD) Signature



cone of rays shot to the opposite side

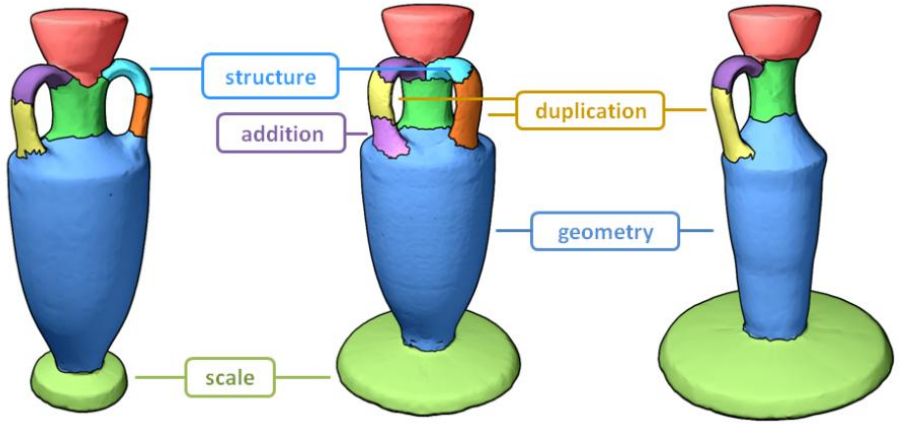


Point-wise SD distribution

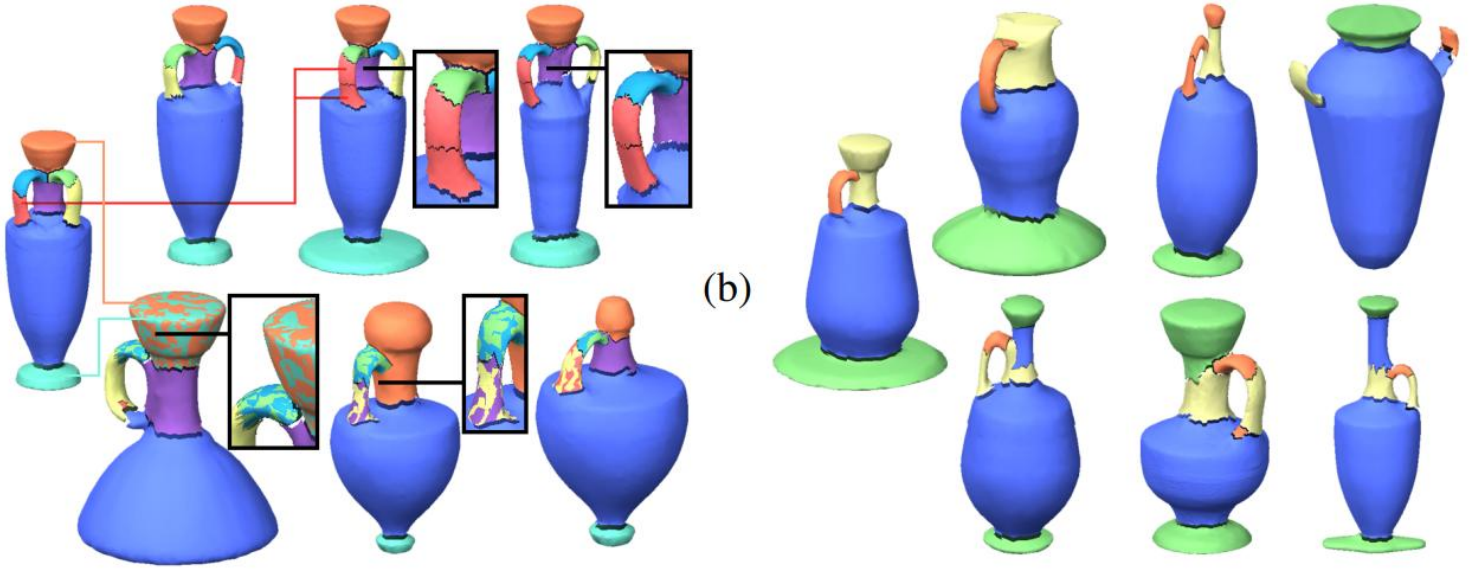
Distance Between Two Shapes

Shape descriptors to capture the primary feature

- SHape Edit Distance (SHED)



shape editing operations



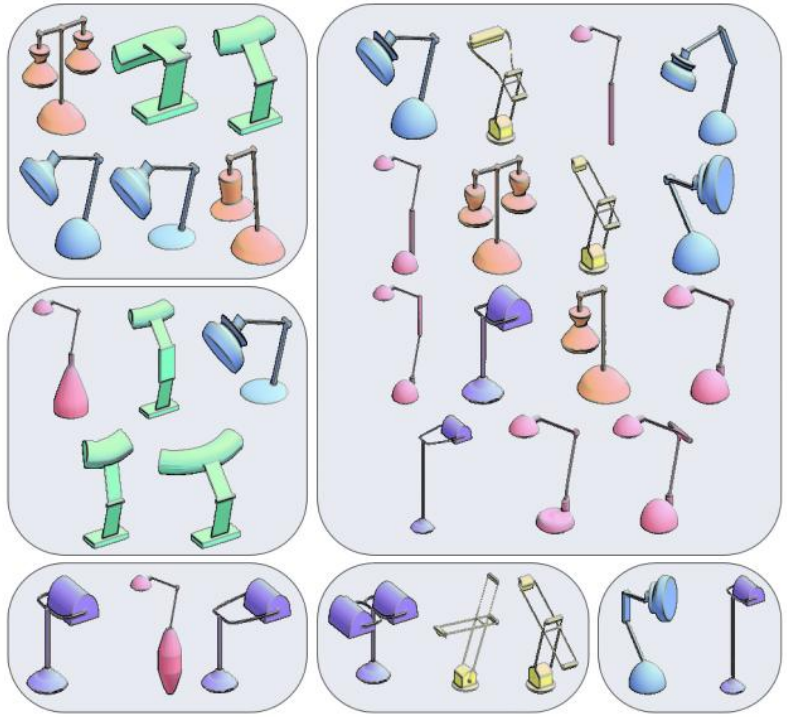
shape retrieval results

Distance Between Two Shapes

From surface to pose-invariant shapes

More and more semantics!

SHED



LFD

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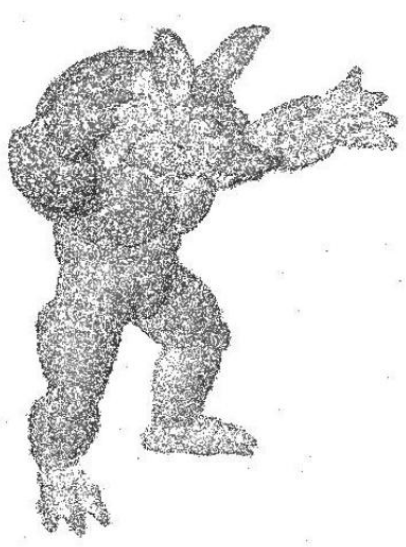
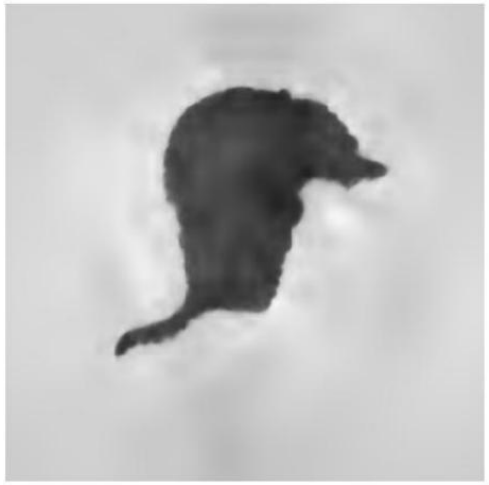
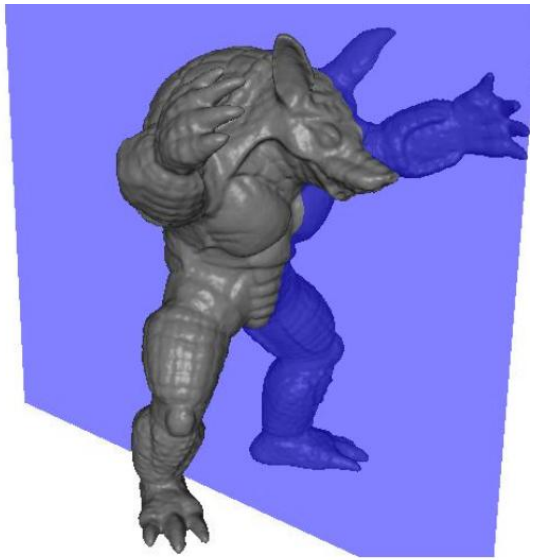
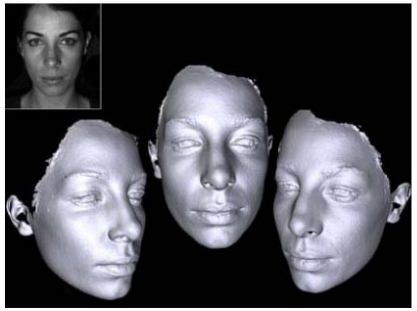




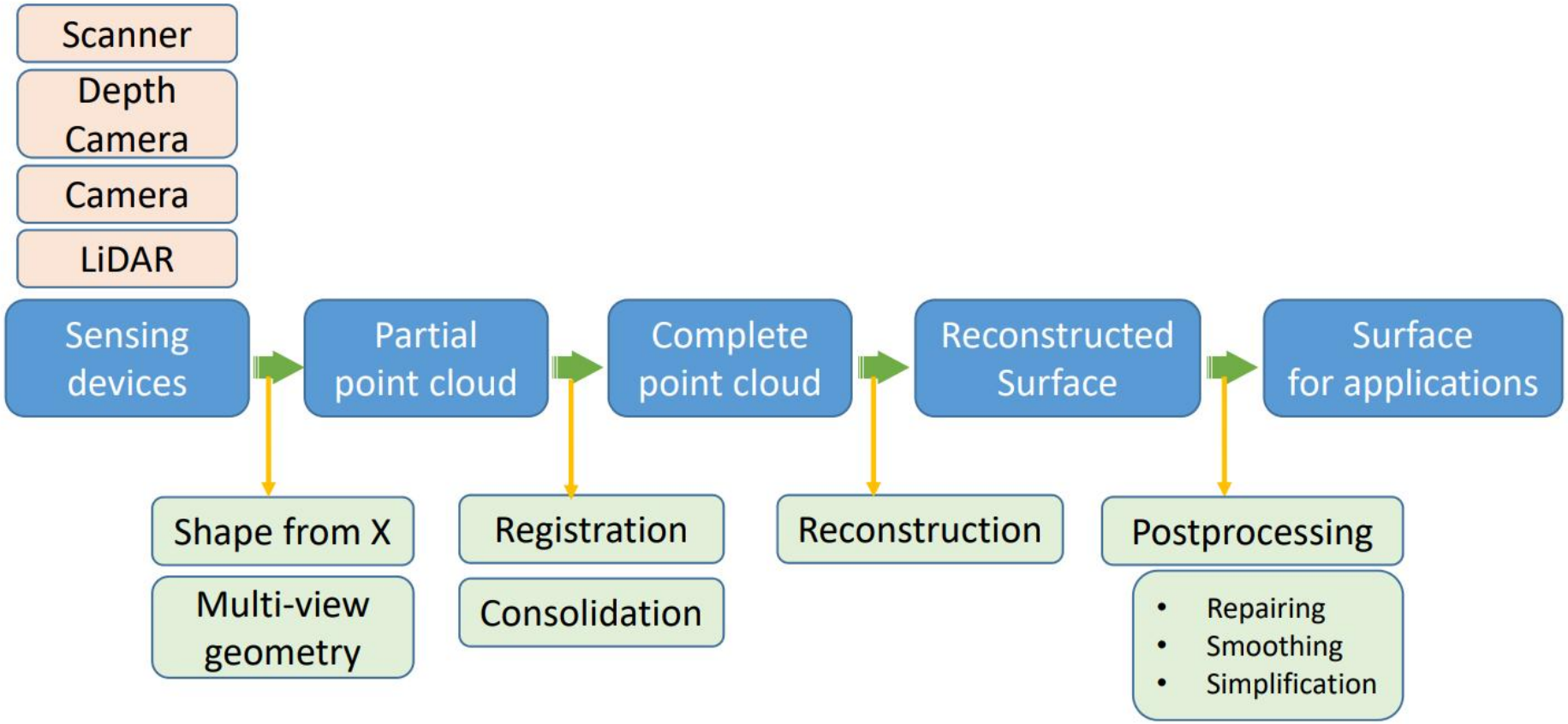


Surface Reconstruction

- Reverse engineering, Scanning, etc...



Outline

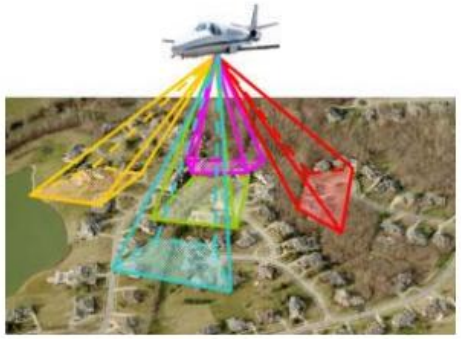

Scanner
Depth Camera
Camera
LiDAR
Sensing devices
Partial point cloud
Complete point cloud
Reconstructed Surface
Surface for applications
Shape from X
Multi-view geometry
Registration
Consolidation
Reconstruction
Postprocessing
Repairing
Smoothing
Simplification

Data Acquisition

单个相机

深度相机

车载激光扫描仪



倾斜摄影

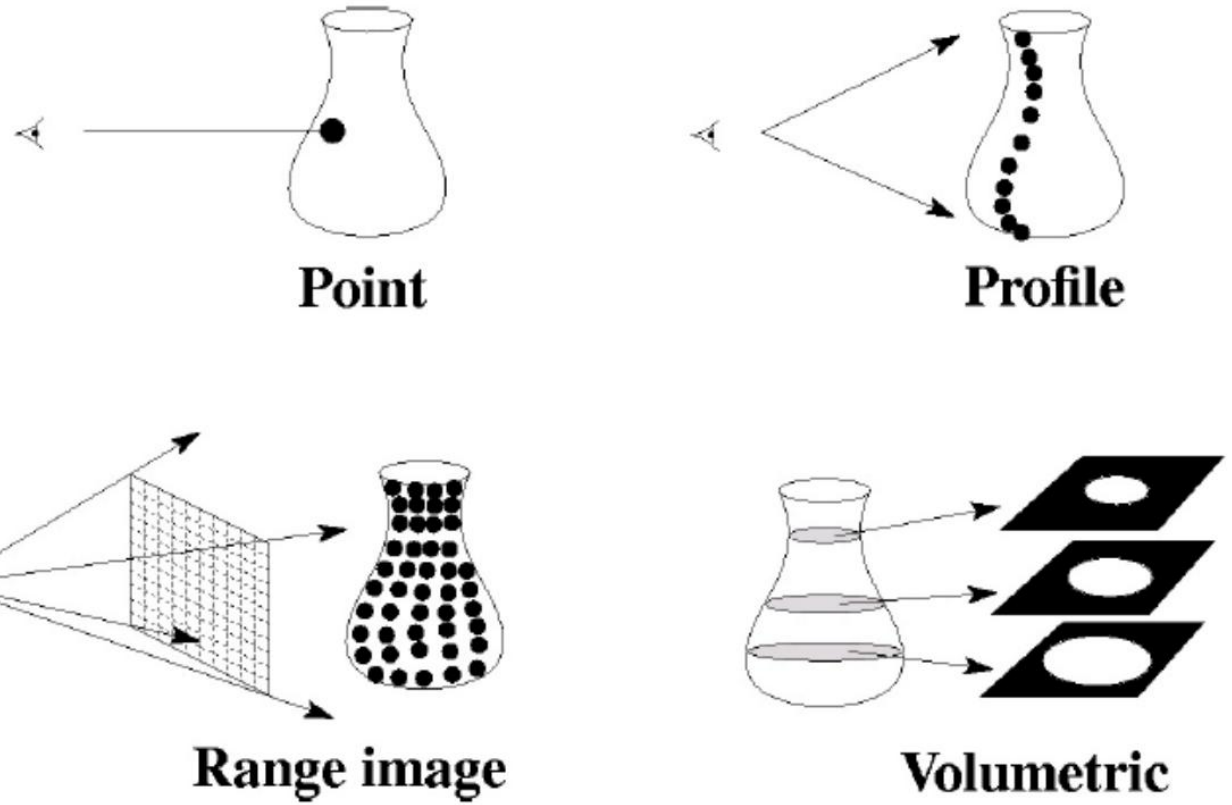
多个相机

激光扫描仪(LiDAR)

全站仪

遥感

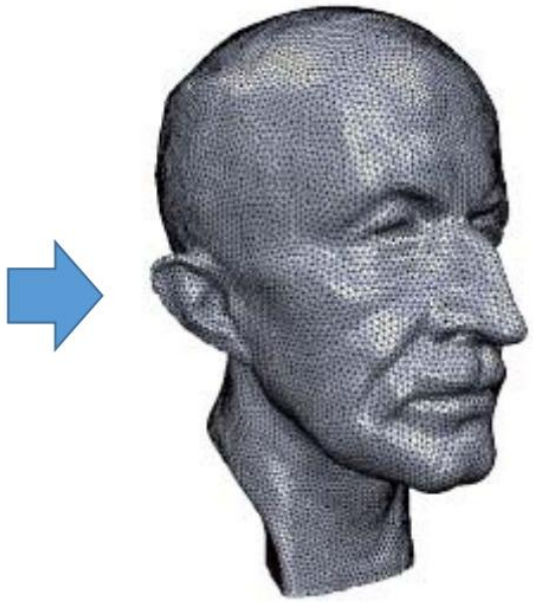
Data Acquisition



Registration

- Reconstruction from scanes

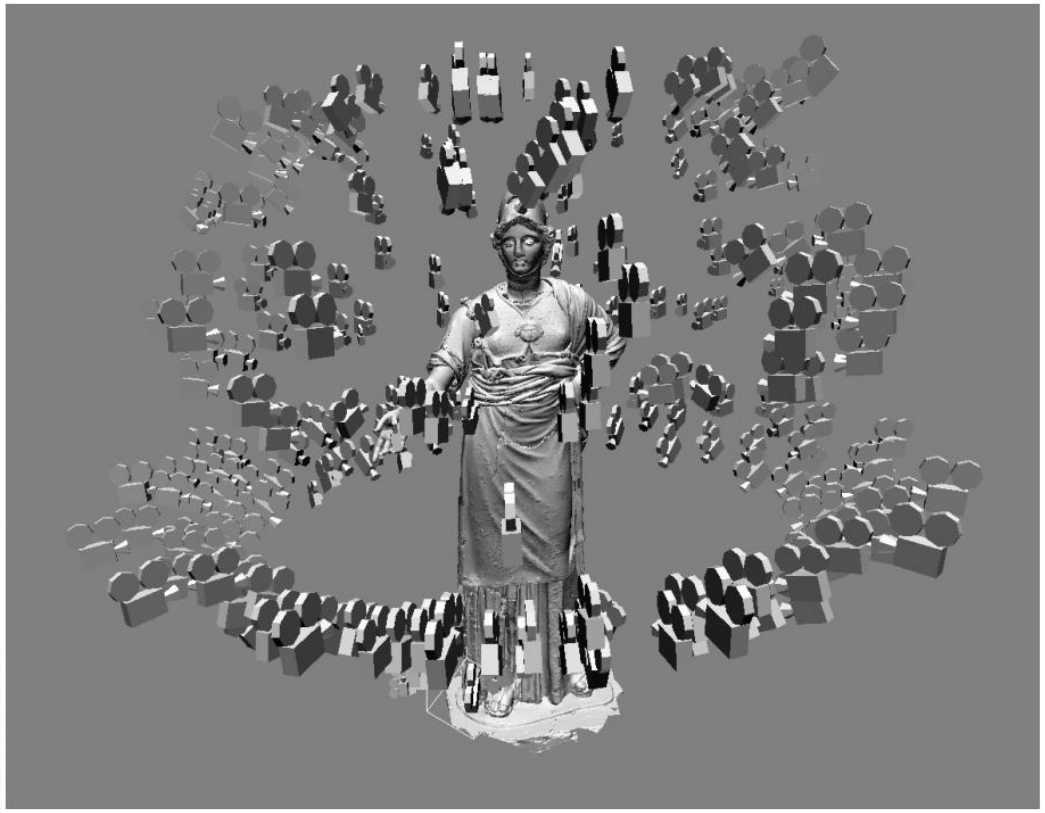
Set of raw scan data



Reconstruction

Registration

- Reconstruction from scanes



Selecting the set of views is not easy

Registration

- Iterative Closest Point Algorithm

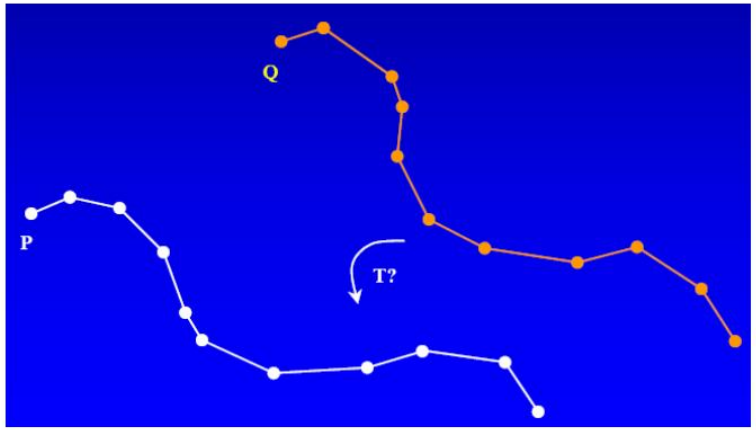
- **Step 1:** find correspondences using closest points for fixed transformation

  → efficient data structures

Iterate until convergence

- **Step 2:** find best rigid transformation for fixed correspondences

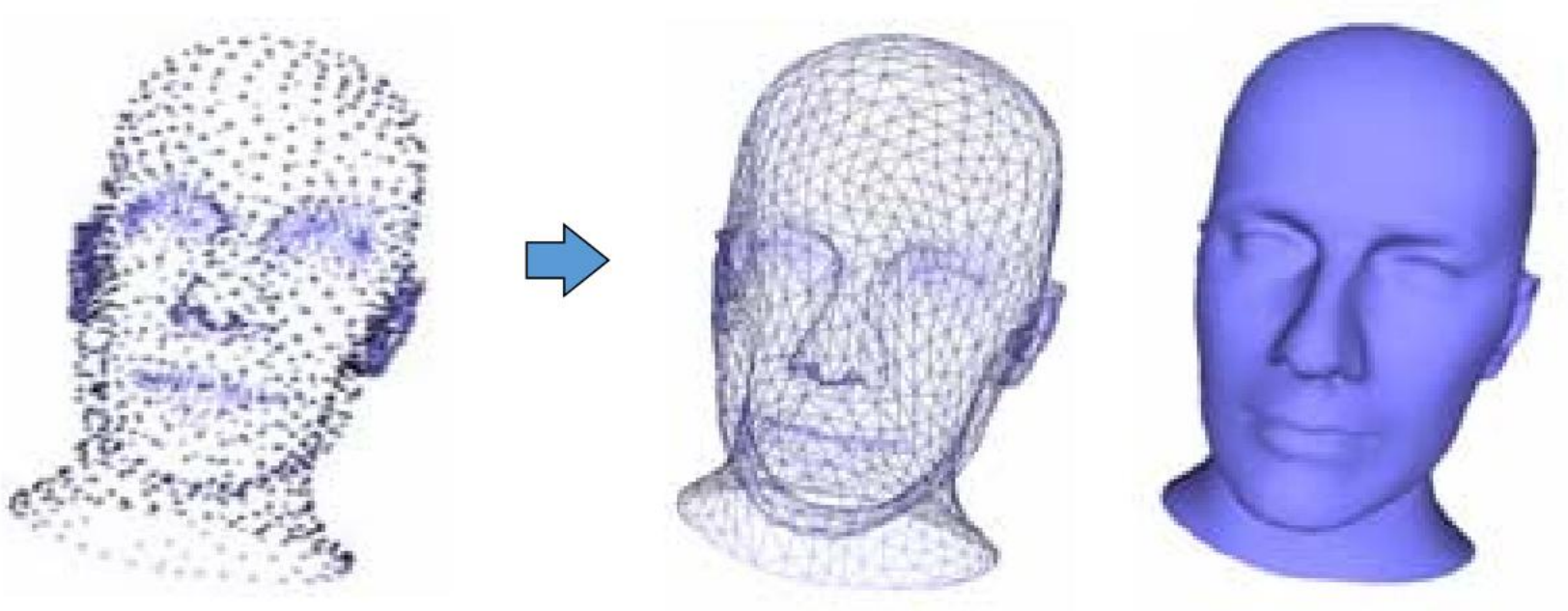
  → closed form solution



$$E = \sum_{i}^{N_P} \left\| Tq_i - p_i \right\|^2$$

Reconstruction

- Input: A set of points in 3D that sampled from a model surface
- Output: A 2D manifold mesh surface that closely approximates the surface of the original mode



Reconstruction

Approximation methods: Constructing continuous functions (Scattered data interpolation schemes)

- NURBS surfaces
- Signed distances [Hoppe et al. 1992]
- Radial basis function reconstruction [Carr et al. 2001]
- Poisson reconstruction [Kazhdan et al. 2006]

Discrete methods: Constructing triangle meshes directly

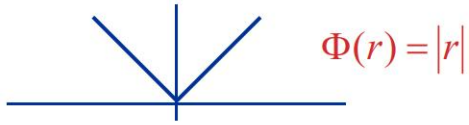
- [Amenta & Bern 1998]
- Power-crust [Amenda et al. 2001]
- Cocone [Dey & Giesen 2001]
- [Cazals & Giesen 2006]

An Approximation Method: RBF Reconstruction

- RBF function:

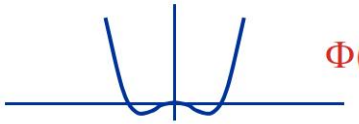
$$f(x) = \sum_{i=1}^{n} w_i \Phi\left(\left\| x - x_i \right\|\right)$$

- Φ is a radially symmetric function
- The trivial solution is wi=0



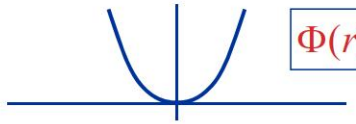
$\Phi(r) = |r|$

Minimizes 2nd derivative in 3D



$\Phi(r) = r^2 \log r$

Minimizes 2nd derivative in 2D



$\boxed{\Phi(r) = r^3}$

Minimizes 3nd derivative in 3D

An Approximation Method: RBF Reconstruction

- RBF function:

$$f(x) = \sum_{i=1}^{n} w_i \Phi\left(\|x - x_i\|\right)$$

Unknowns to compute

$$\left(A_{NxN}\right)\left(W\right) = \left(f\right)$$

Function values

Matrix dependent on the locations of the data points

An Approximation Method: RBF Reconstruction

- RBF function:

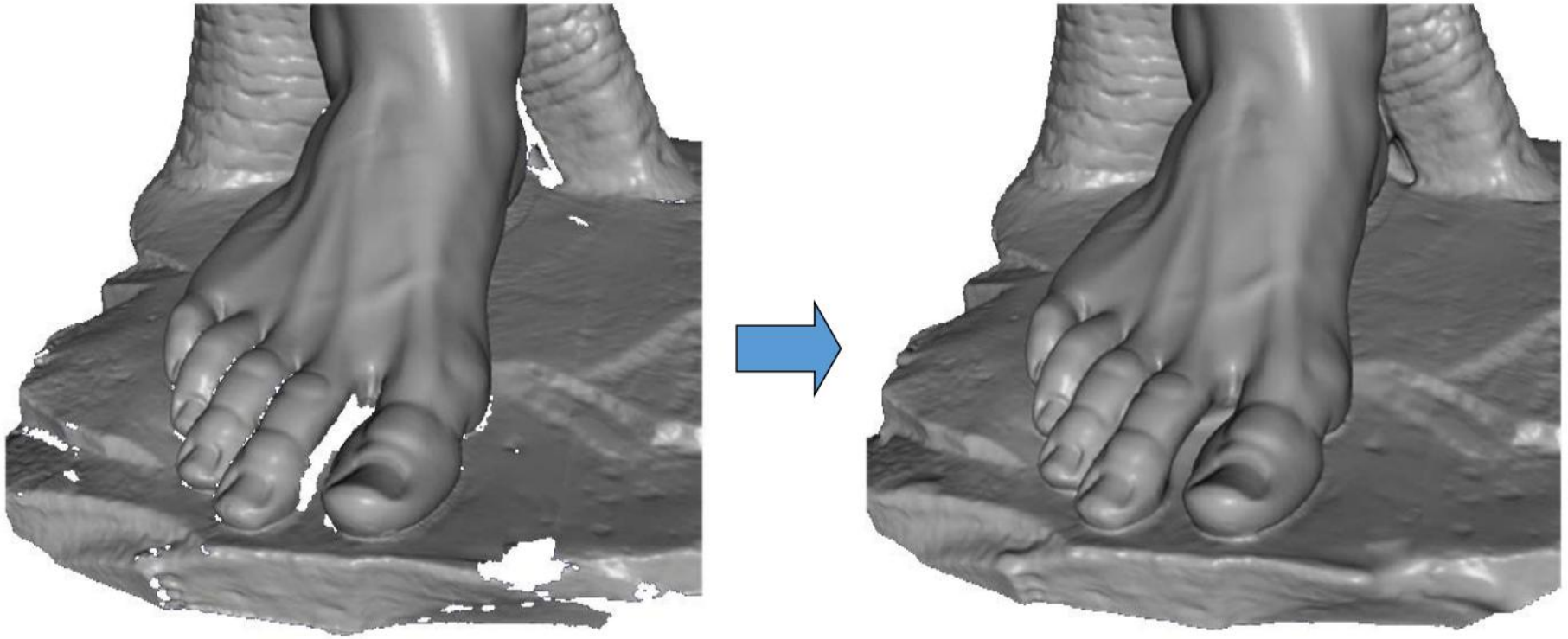
$$f(x) = \sum_{i=1}^{n} w_i \Phi\left(\|x - x_i\|\right)$$

$$\begin{pmatrix} \Phi(\|x_1 - x_1\|) & \Phi(\|x_2 - x_1\|) & \cdots & \Phi(\|x_N - x_1\|) \\ \Phi(\|x_1 - x_2\|) & \Phi(\|x_2 - x_2\|) & & \Phi(\|x_N - x_2\|) \\ \vdots & & & \vdots \\ \Phi(\|x_1 - x_N\|) & \Phi(\|x_2 - x_N\|) & \cdots & \Phi(\|x_N - x_N\|) \end{pmatrix} \begin{pmatrix} W_1 \\ W_2 \\ \vdots \\ W_N \end{pmatrix} = \begin{pmatrix} f_1 \\ f_2 \\ \vdots \\ f_N \end{pmatrix}$$

Solve the equations

Post-Processing

- Repairing, denoising, smoothing, simplification…



Repairing (completion, hole-filling, restoration)

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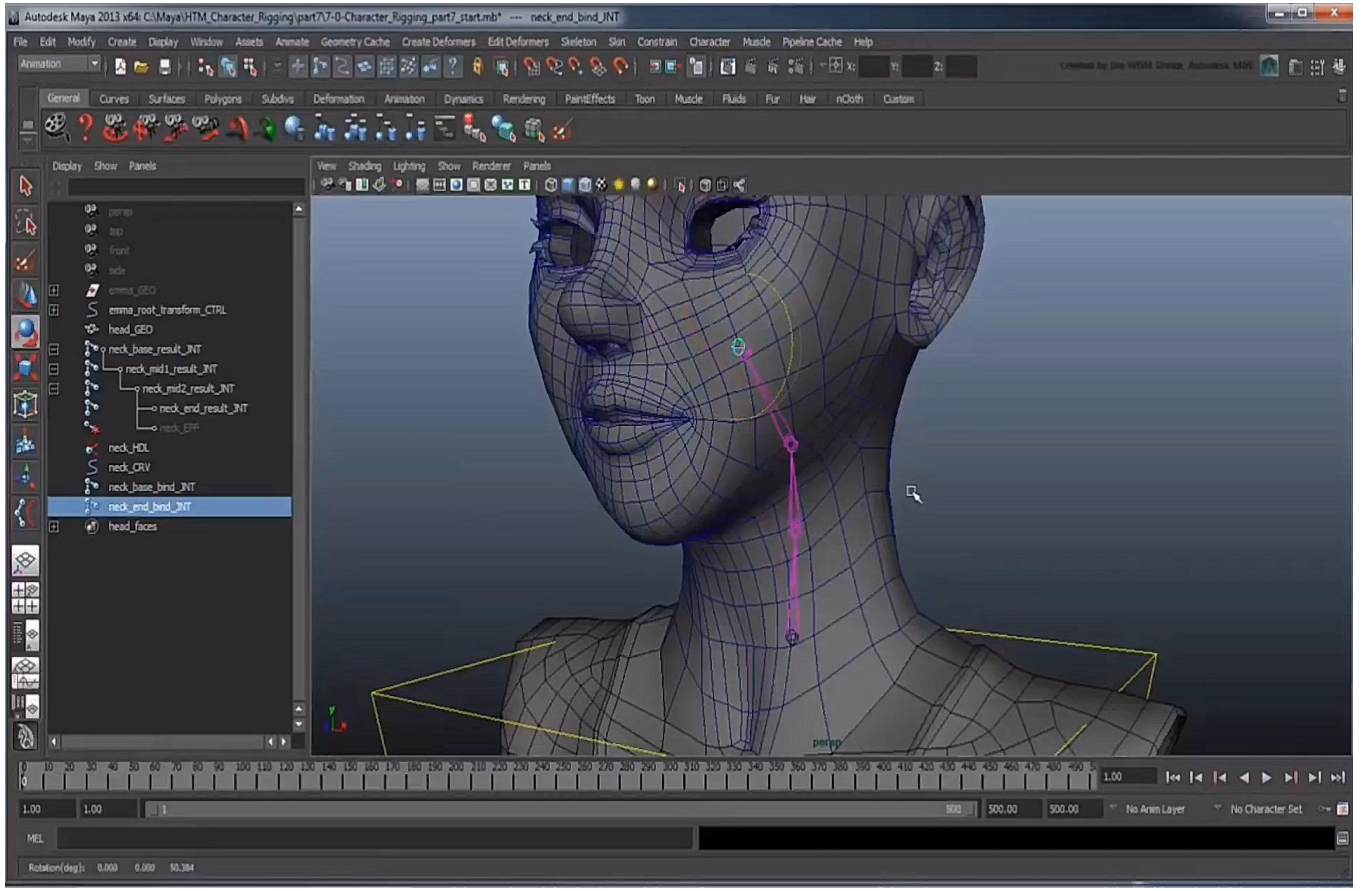

Autodesk, Maya, AutoCAD, Zbrush, etc...

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Thank you