CENG 789 – Digital Geometry Processing

14- Main DGP Tasks in a Nutshell

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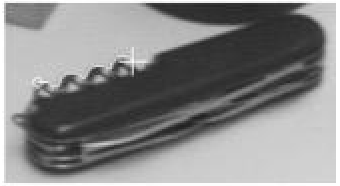
Shape/Mesh Processing Tasks

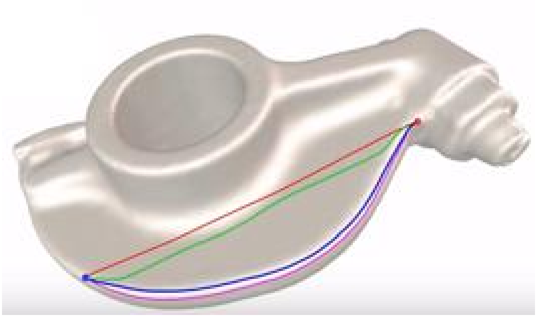
- ✓ Already covered some important tasks (check out previous lectures).
  - ✓ Shape descriptors, generation, reconstruction, registration.
  - ✓ Mesh deformation, parameterization, remeshing, repairing.
- ✓ Talk about some other prominent tasks today.
  - ✓ Shape segmentation.
  - ✓ Shape representation/approximation.
  - ✓ Shape correspondence.
  - ✓ Shape retrieval.
  - ✓ Groupwise alignment.
  - ✓ Human-centric shape analysis (indirect).
  - ✓ Shape interpolation/morphing.
  - ✓ Scene synthesis and labeling.
  - ✓ Slides in the sequel represent Potential Project Topics.

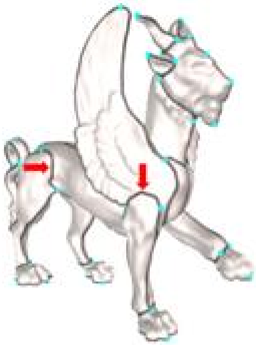
Shape Segmentation

- ✓ User-guided shape segmentation.
  - ✓ Live-wire interaction (well-known in image processing).



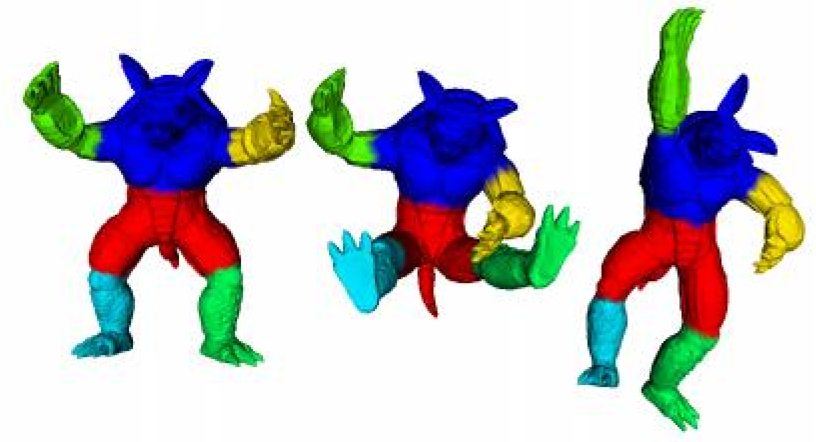
  - ✓ https://www.youtube.com/watch?v=XRj8AFlkZfY





Shape Segmentation

- ✓ Fully-automatic shape segmentation.



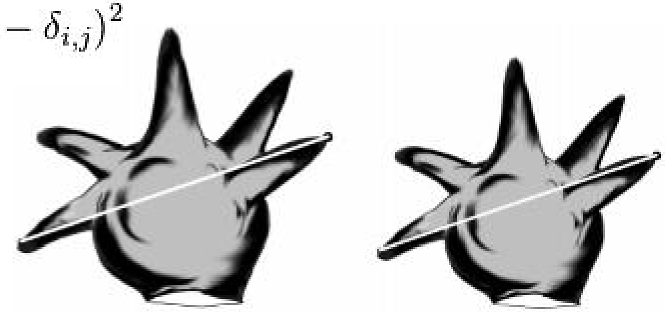
- ✓ Shape representation: MDS.
- ✓ Followed by k-means clustering algorithm.

Shape Segmentation

- ✓ Fully-automatic shape segmentation.

- ✓ Shape representation: MDS (bending-invariant).

$$\min_{x1,\ldots,x_I} \sum_{i<j} (\|x_i - x_j\| - \delta_{i,j})^2$$



Shape Segmentation

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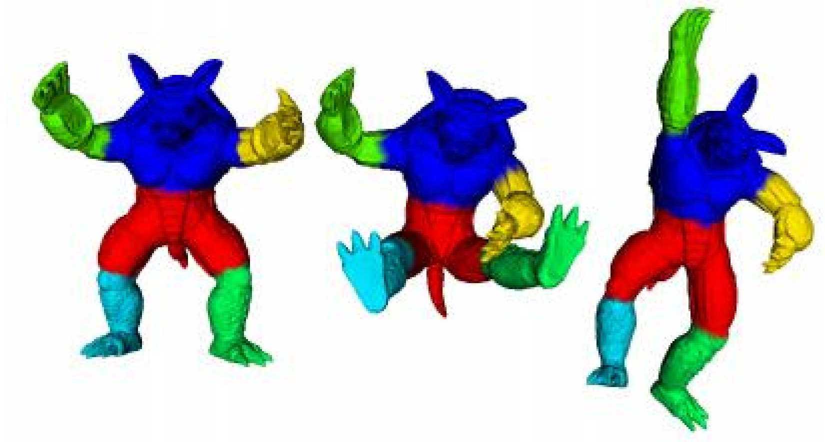
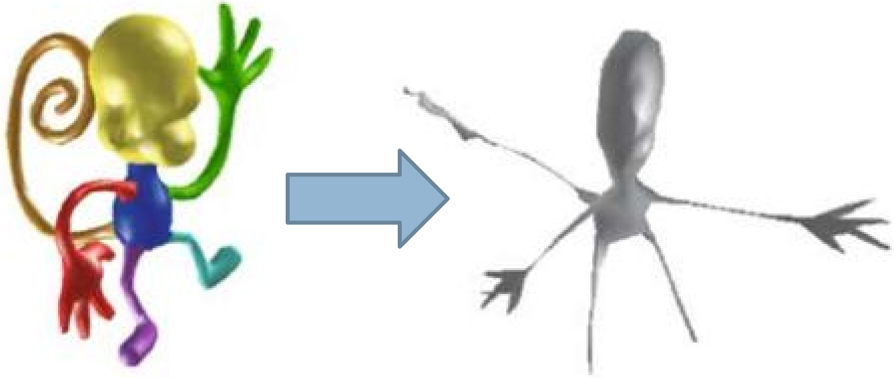
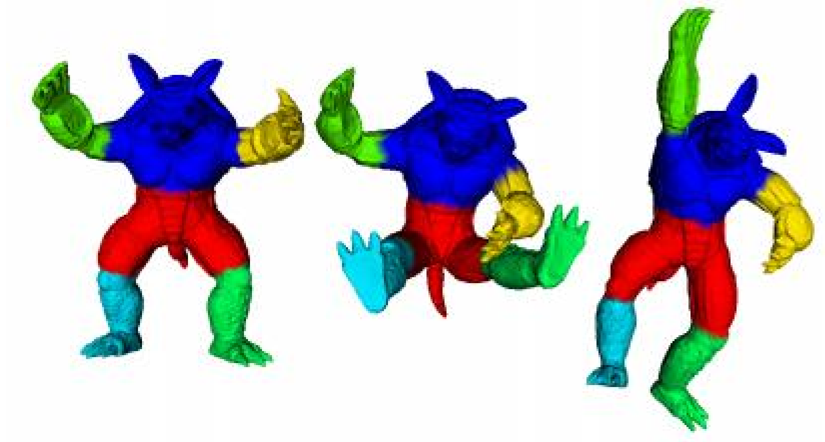


- ✓ Shape representation: MDS (bending-invariant).

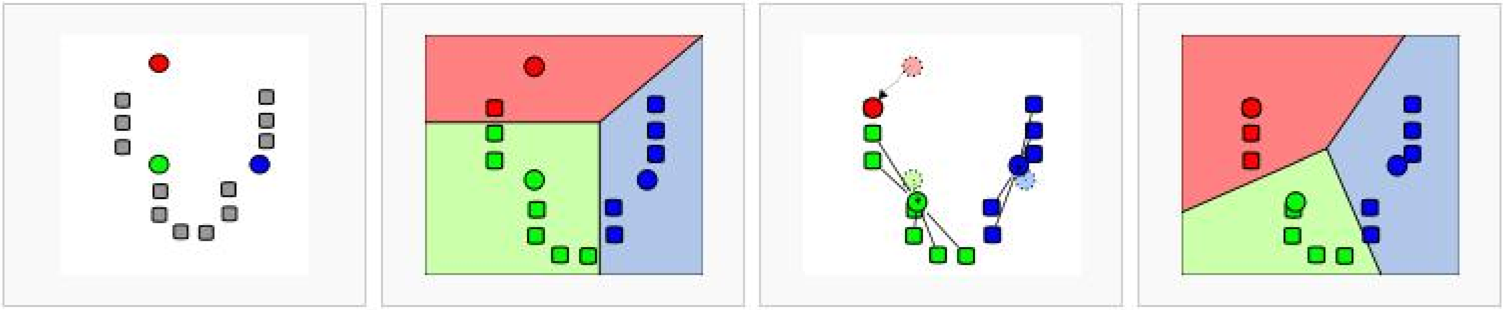


Shape Segmentation

✓ Fully-automatic shape segmentation.



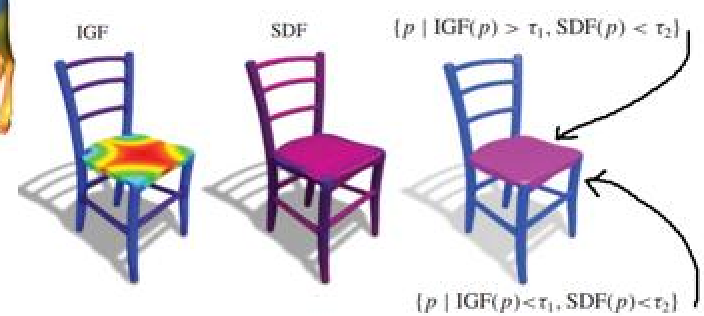
✓ K-means clustering.



Shape Segmentation

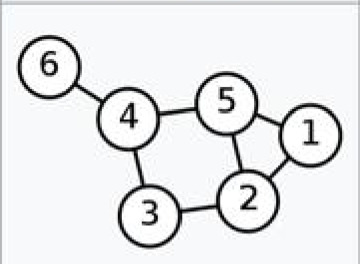
- ✓ Fully-automatic shape segmentation.

- ✓ More sophisticated data-driven segmentation methods exist.
  - ✓ Hierarchical decomposition.
  - ✓ Randomized cuts.
  - ✓ Core extraction.
  - ✓ Fitting primitives.
  - ✓ Shape diameter function (SDF).
  - ✓ Intrinsic girth function (IGF).

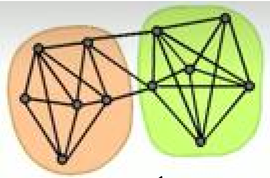


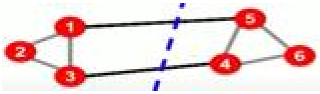
Shape Segmentation

- ✓ Fully-automatic shape segmentation via spectral clustering.
- ✓ Spectrum (eigvals) of a matrix, the Laplacian Matrix = Degree – Adj.

Labelled graph	Degree matrix	Adjacency matrix	Laplacian matrix
	$\begin{pmatrix} 2&0&0&0&0&0\\ 0&3&0&0&0&0\\ 0&0&2&0&0&0\\ 0&0&0&3&0&0\\ 0&0&0&0&3&0\\ 0&0&0&0&0&1 \end{pmatrix}$	$\begin{pmatrix} 0&1&0&0&1&0\\ 1&0&1&0&1&0\\ 0&1&0&1&0&0\\ 0&0&1&0&1&1\\ 1&1&0&1&0&0\\ 0&0&0&1&0&0 \end{pmatrix}$	$\begin{pmatrix} 2&-1&0&0&-1&0\\ -1&3&-1&0&-1&0\\ 0&-1&2&-1&0&0\\ 0&0&-1&3&-1&-1\\ -1&-1&0&-1&3&0\\ 0&0&0&-1&0&1 \end{pmatrix}$

- ✓ $Lx = 0$ for all const vectors, e.g., $x=[1\ 1\ ..\ 1]^T$. Eigval = 0, eigvec = c.
- ✓ 2nd smallest eigval is more useful; it comes with the Fiedler eigenvector.
- ✓ This eigval/vec, call it x2, approximates the sparsest cut of a graph.
  - ✓ Eigvecs orthogonal: x1 is constant, so to make dot prodct 0, x2 has +ve and –ve components. These 2 sets of components are clusters.

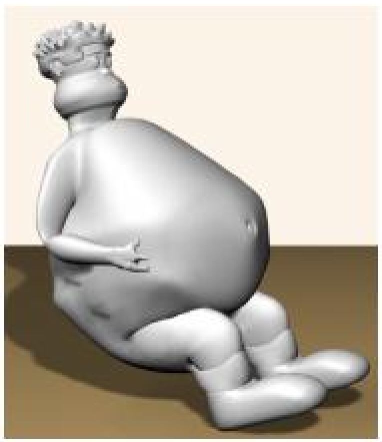




- ✓ Not directly applicable to Mesh Segmentation as mesh graph is regular.

Shape Segmentation

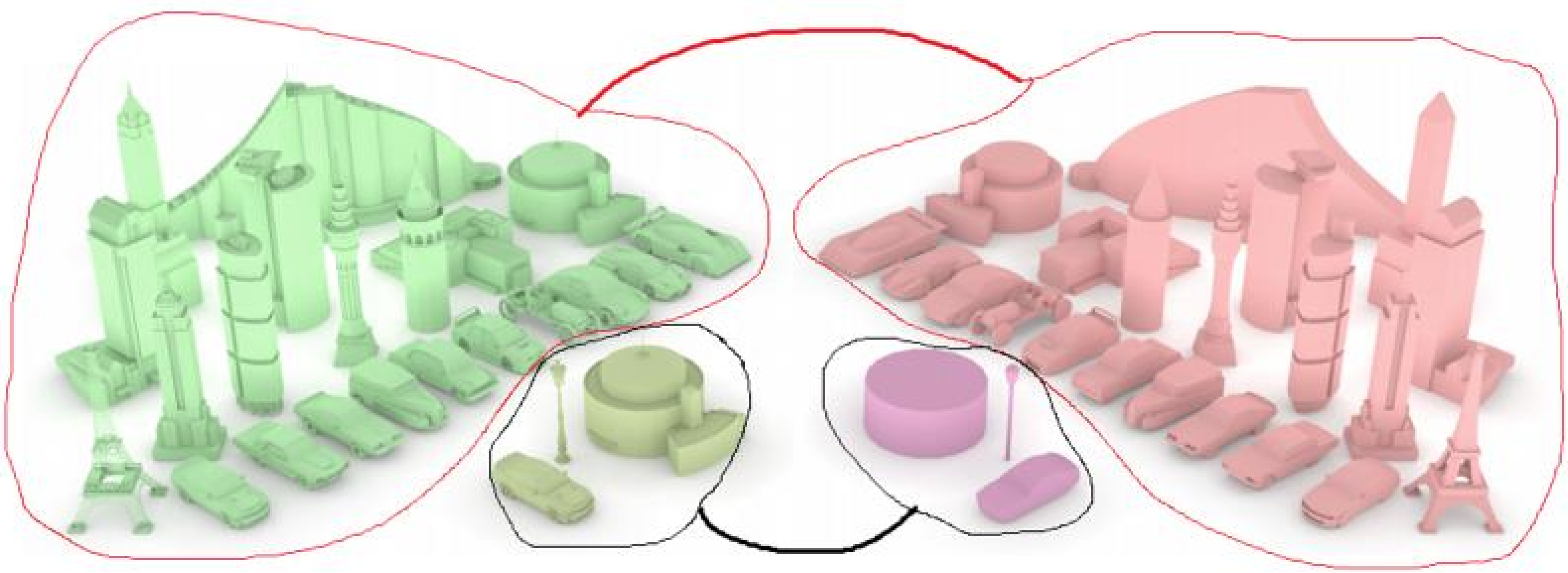
- ✓ Why segment? Once you have the parts, you can go wild, e.g., collage




- ✓ Collection understanding through part-level correspondences, ..

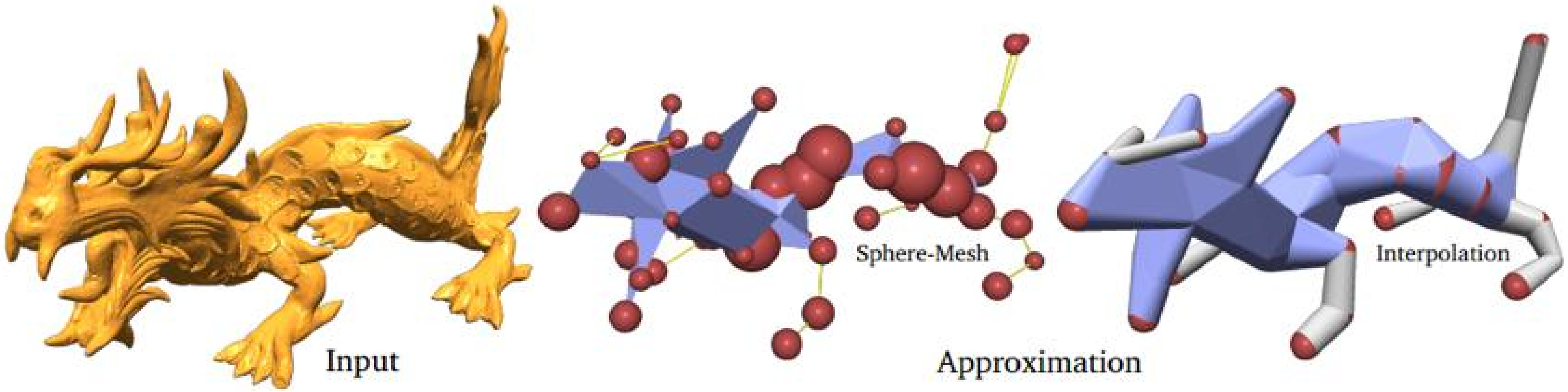
Shape Approximation

- ✓ Computing simple geometric descriptions for dense surfaces.
  - ✓ Mesh decimation (minimal elements; already covered).
  - ✓ Mesh decimation based on context. See https://youtu.be/62_1CQirnzM



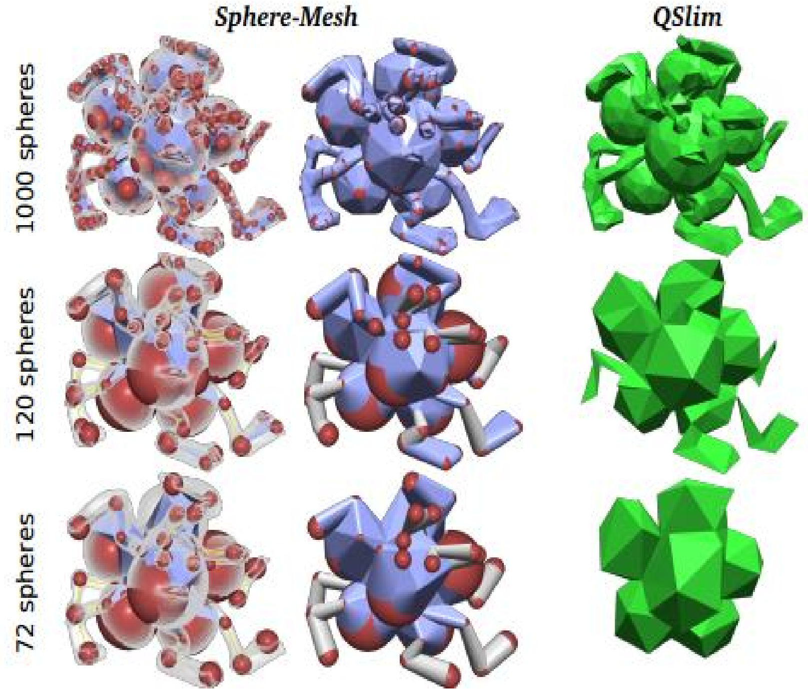
Shape Approximation

- ✓ Computing simple geometric descriptions for dense surfaces.
  - ✓ Mesh decimation (minimal elements; already covered).
  - ✓ Mesh decimation based on volume.
    - ✓ At extreme simplification levels, model the volumetric extent of the original shape. See https://youtu.be/Jz09SAeBWI0



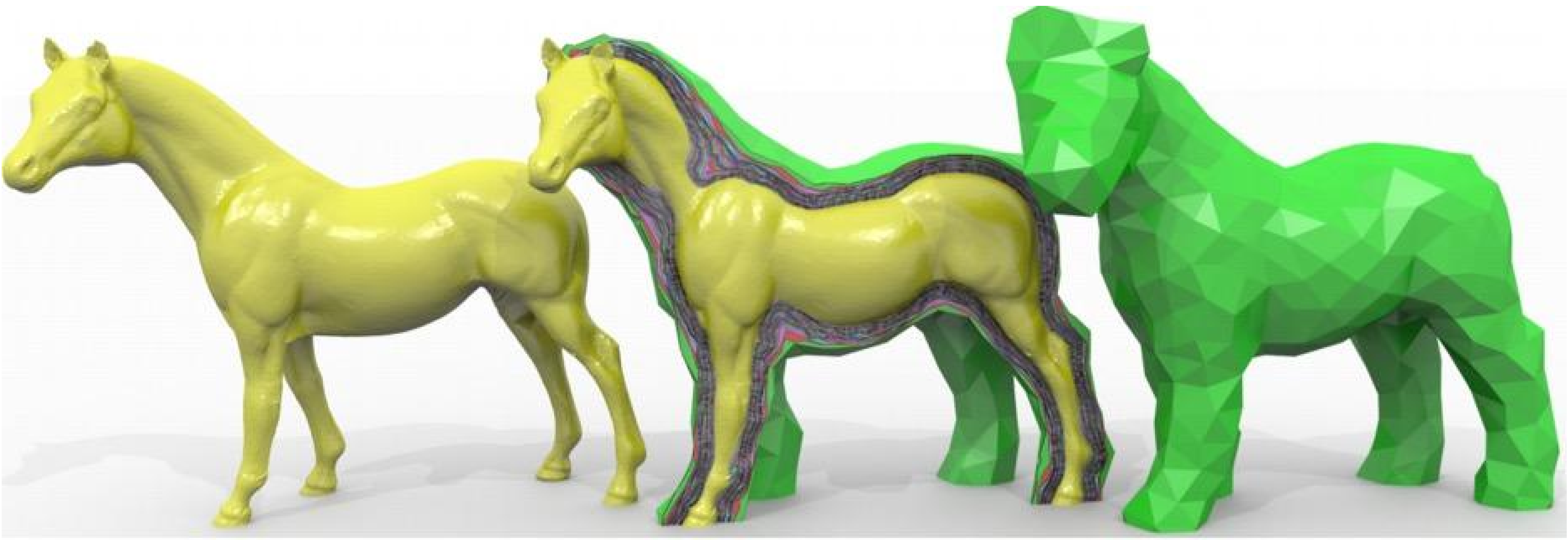
Shape Approximation

- ✓ Computing simple geometric descriptions for dense surfaces.
  - ✓ Mesh decimation (minimal elements; already covered).
  - ✓ Mesh decimation based on volume.
    - ✓ Sphere interpolation replacing classic point interpolation.



Shape Approximation

- ✓ Computing simple geometric descriptions for dense surfaces.
  - ✓ Mesh decimation (minimal elements; already covered).
  - ✓ Mesh decimation based on level.
    - ✓ Nested cages for faster collision detection and deformation.



Shape Approximation

- ✓ Computing simple geometric descriptions for dense surfaces.
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    - ✓ Nested cages. Shrink, re-inflate. See https://youtu.be/tTEGDPHv_AI

Shape Approximation

- ✓ Computing simple geometric descriptions for dense surfaces.
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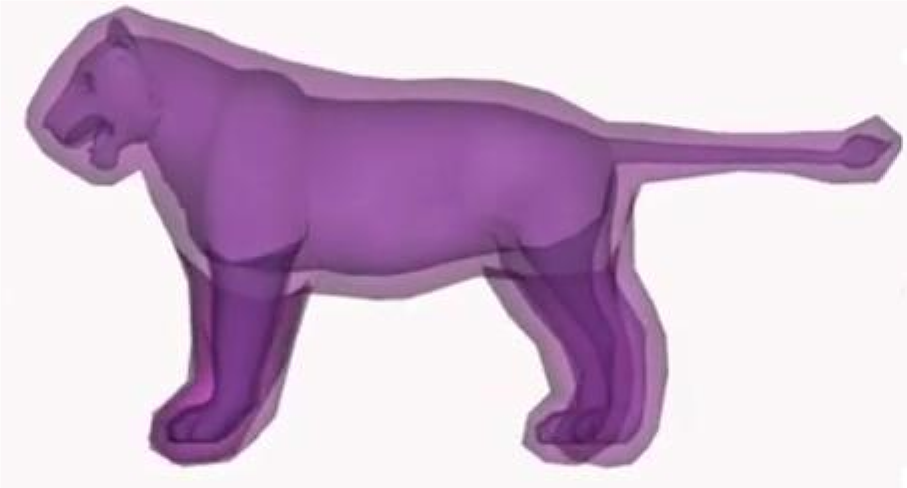
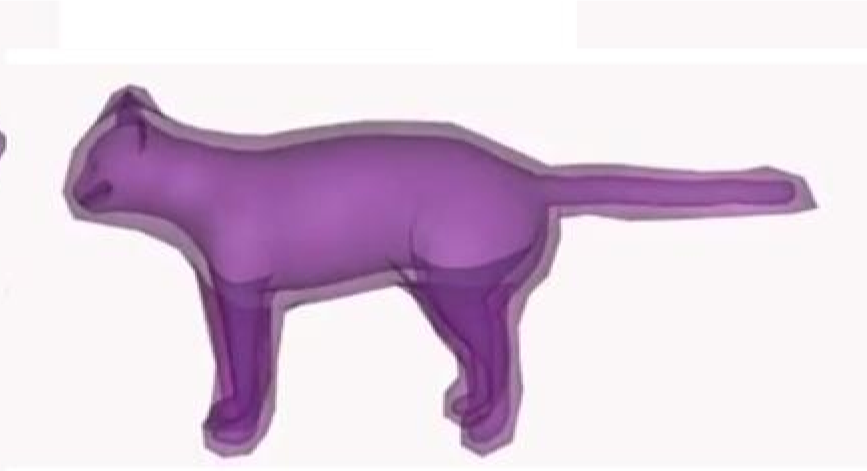
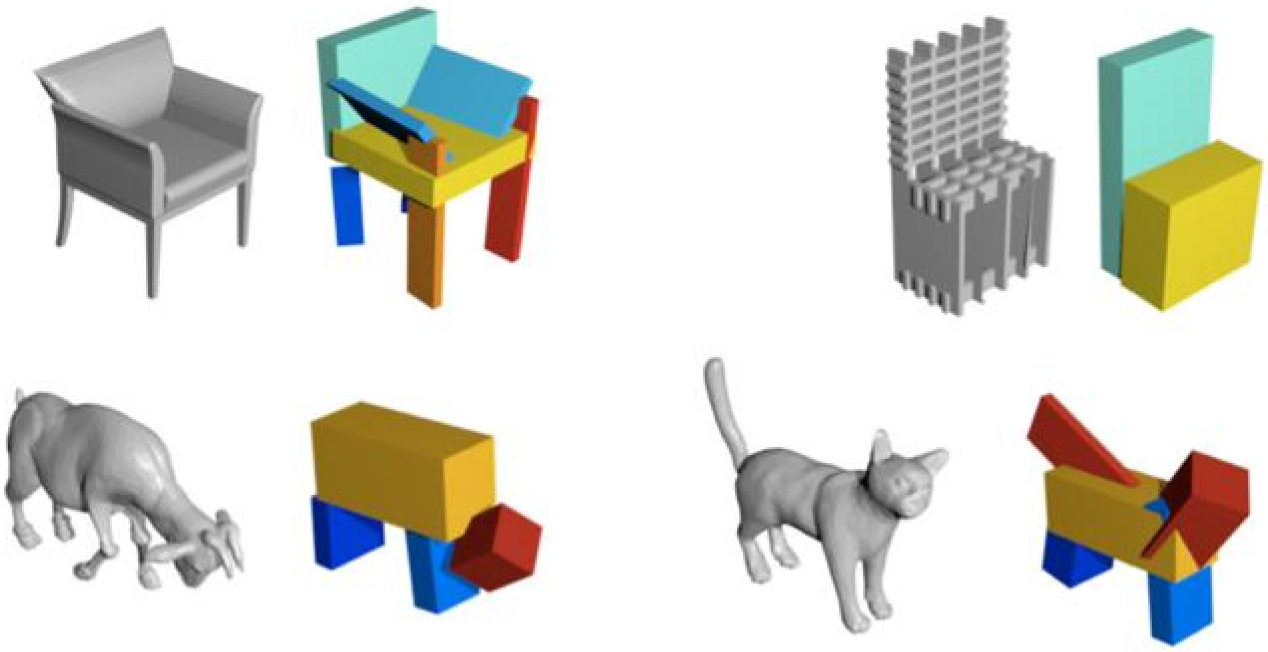
  - ✓ Mesh decimation based on level.
    - ✓ Nested cages. Shrink, re-inflate. See https://youtu.be/tTEGDPHv_AI
    - ✓ Cage-based deformations. Read
      - ✓ Spatial Deformation Transfer. https://youtu.be/ayeKItDliUc
      - ✓ Embedded Deformation. https://youtu.be/BEEN7Dmo9vI





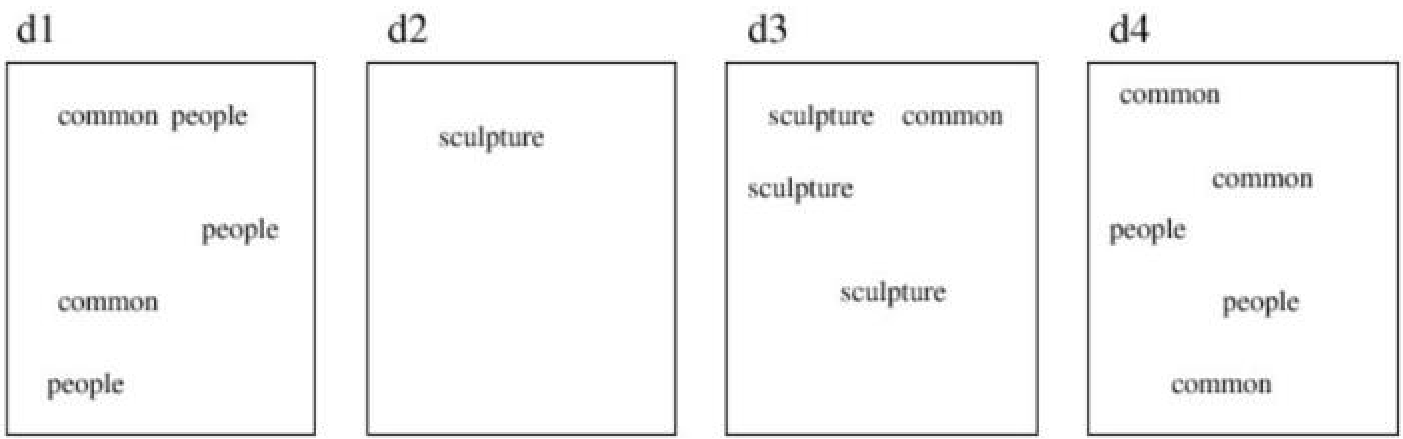
Shape Approximation

- ✓ Computing simple geometric descriptions for dense surfaces.
  - ✓ Assemble of volumetric primitives.



Shape Representation

- ✓ Computing simple geometric descriptions for dense surfaces.
  - ✓ Bag-of-words (bag-of-features) shape representation.

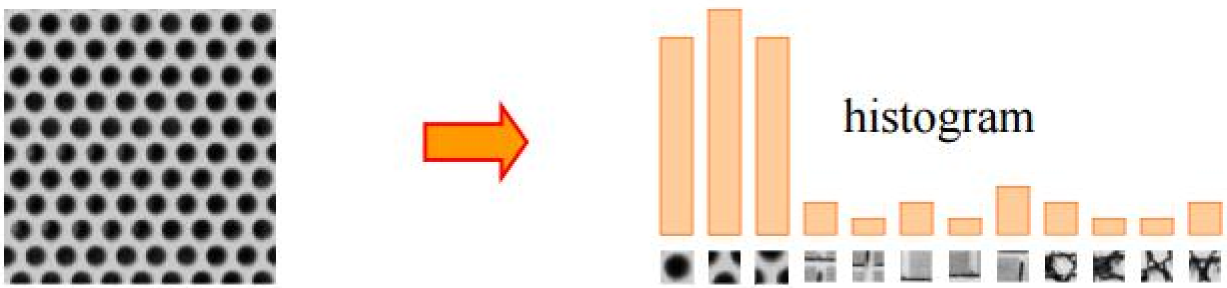


Bag-of-words

Common	2	0	1	3
People	3	0	0	2
Sculpture	0	1	3	0
…	…	…	…	…

Shape Representation

- ✓ Computing simple geometric descriptions for dense surfaces.
  - ✓ Bag-of-words (bag-of-features) shape representation.
  - ✓ Need a visual vocabulary for shape (not text) processing.



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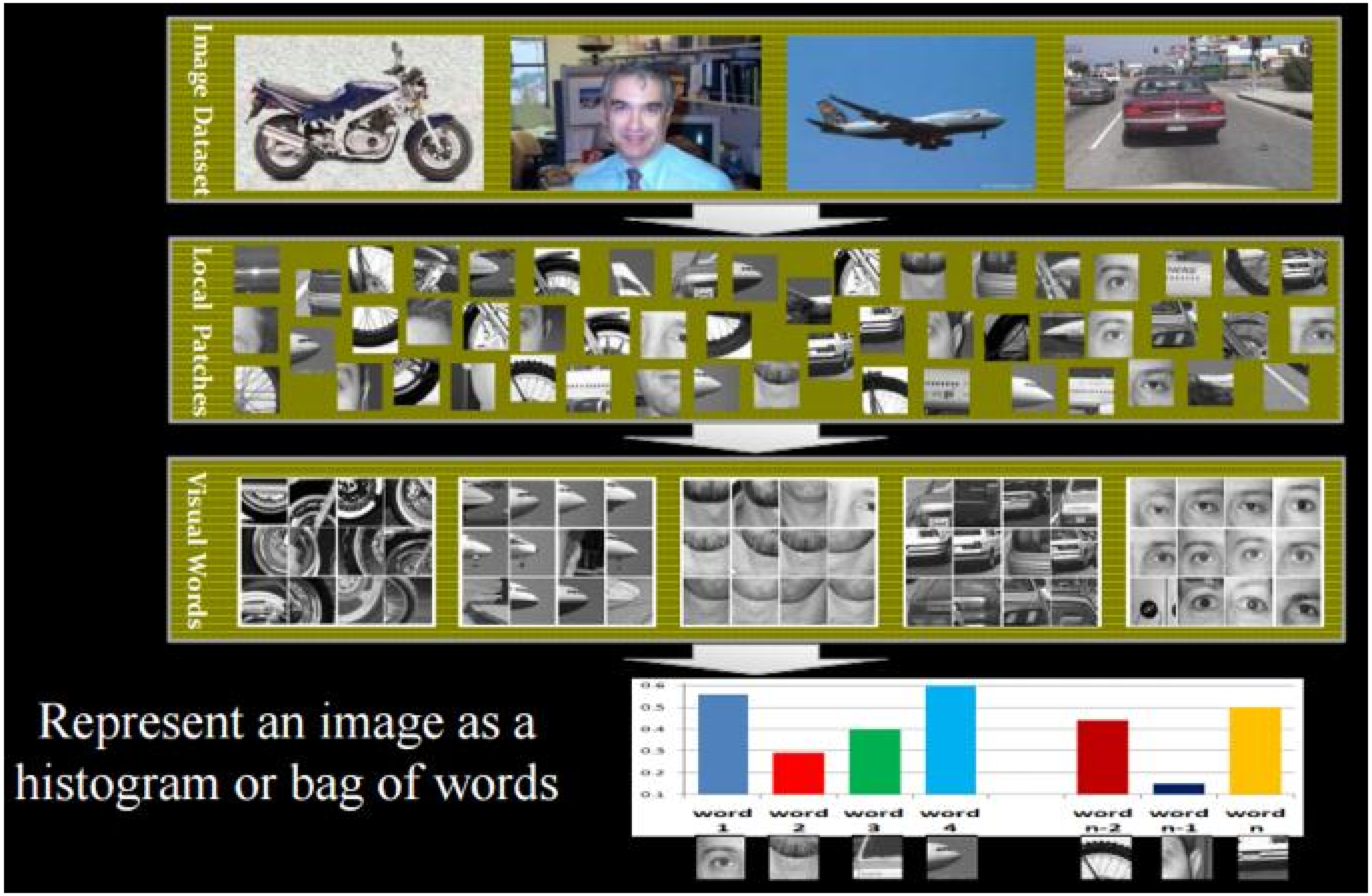
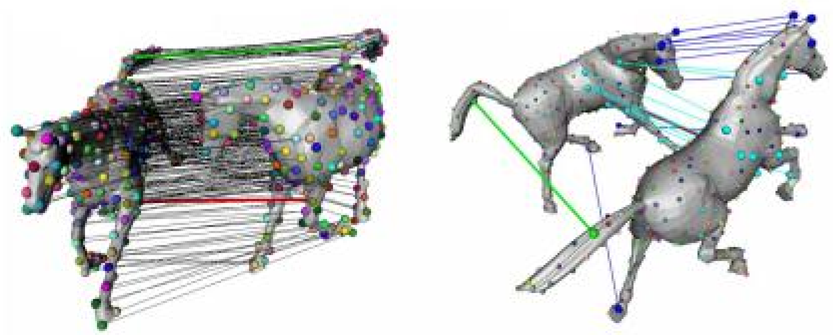


Shape Correspondence

- ✓ Define a map-distortion function that quantifies how good a given map is.
- ✓ Combinatorial search on space of maps.
  - ✓ Use the map minimizing the distortion function.



Shape Correspondence

- ✓ Define a map-distortion function that quantifies how good a given map is. Many variants in the literature; see
  - ✓ Coarse-to-Fine Combinatorial Matching For Dense Isometric Shape Correspondence (C2FCM)
  - ✓ Scale Normalization for Isometric Shape Matching
  - ✓ Non-rigid registration under isometric deformations
  - ✓ Blended intrinsic maps
  - ✓ Generalized multidimensional scaling
- ✓ Cast the problem as matching between function values, not points: Functional Maps (not covered here).
  - ✓ By the author: https://youtu.be/l9pqyo85nFE?t=884
  - ✓ A good function. Laplace-Beltrami eigenfunctions: https://youtu.be/CpdJVcXQte4?t=502

Isometric Distortion

- ✓ Given $\S : S \to T$, measure its isometric distortion (from C2FCM):

$$D_{\text{iso}}(\S) = \frac{1}{|\S|} \sum_{(s_i,t_j)\in\S} d_{\text{iso}}(s_i,t_j)$$

$$d_{\text{iso}}(s_i,t_j) = \frac{1}{|\S'|} \sum_{(s_l,t_m)\in\S'} |g(s_i,s_l) - g(t_j,t_m)|$$

$\S' = \S - \{(s_i,t_j)\}$ in the most general setting.

$g(.,.)$: normalized geodesic distance b/w two vertices.

- ✓ $O(N^2)$ for a map of size N.

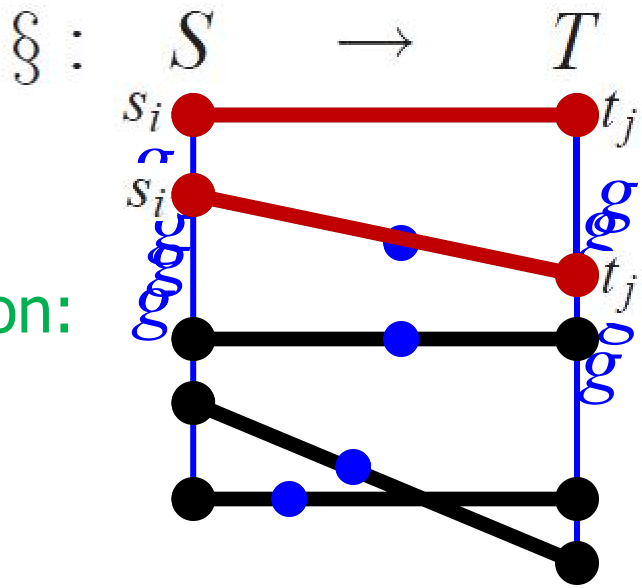
Isometric Distortion Illustration

$$D_{\text{iso}}(\S) = \frac{1}{|\S|} \sum_{(s_i,t_j)\in\S} d_{\text{iso}}(s_i,t_j)$$

$$d_{\text{iso}}(s_i,t_j) = \frac{1}{|\S'|} \sum_{(s_l,t_m)\in\S'} |g(s_i,s_l) - g(t_j,t_m)|$$

$$\S' = \S - \{(s_i,t_j)\}$$

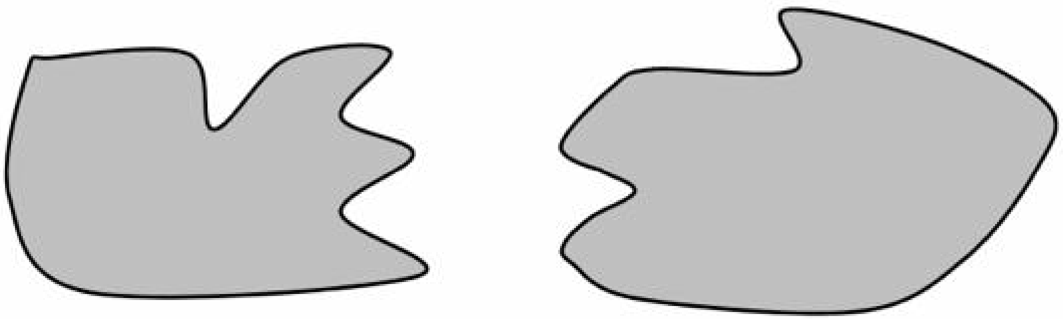
in action:



$$\left.\begin{array}{l} d_{\text{iso}}(s_i,t_j) = \;>0 + 0 + >0 + 0 \\ d_{\text{iso}}(s_i,t_j) = .. \\ \vdots \end{array}\right\} \text{average for } D_{\text{iso}}(\S).$$

Shape Correspondence

- ✓ Well-studied for isolated pair of X shapes.
- ✓ X =
  - ✓ Isometric or non-rigid
  - ✓ Rigid
  - ✓ Non-isometric
- ✓ At its infancy for collection analysis.
  - ✓ Use context info to improve results.



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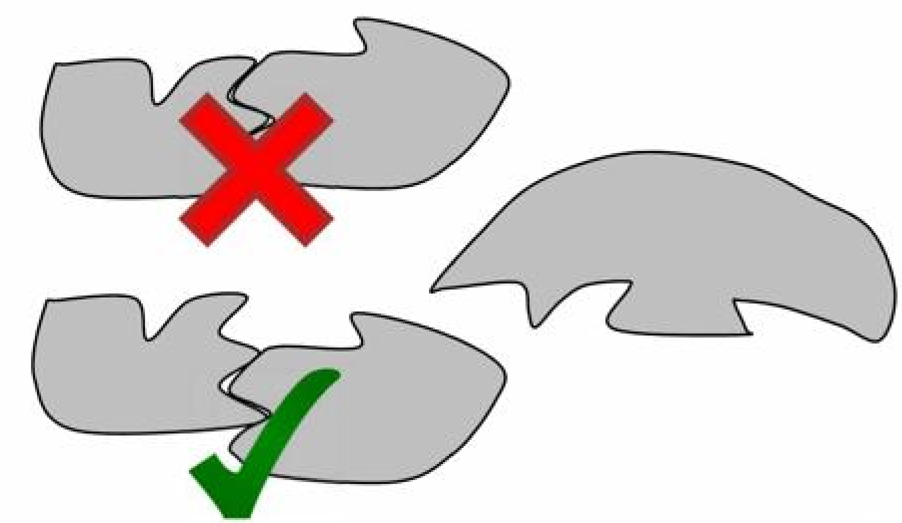
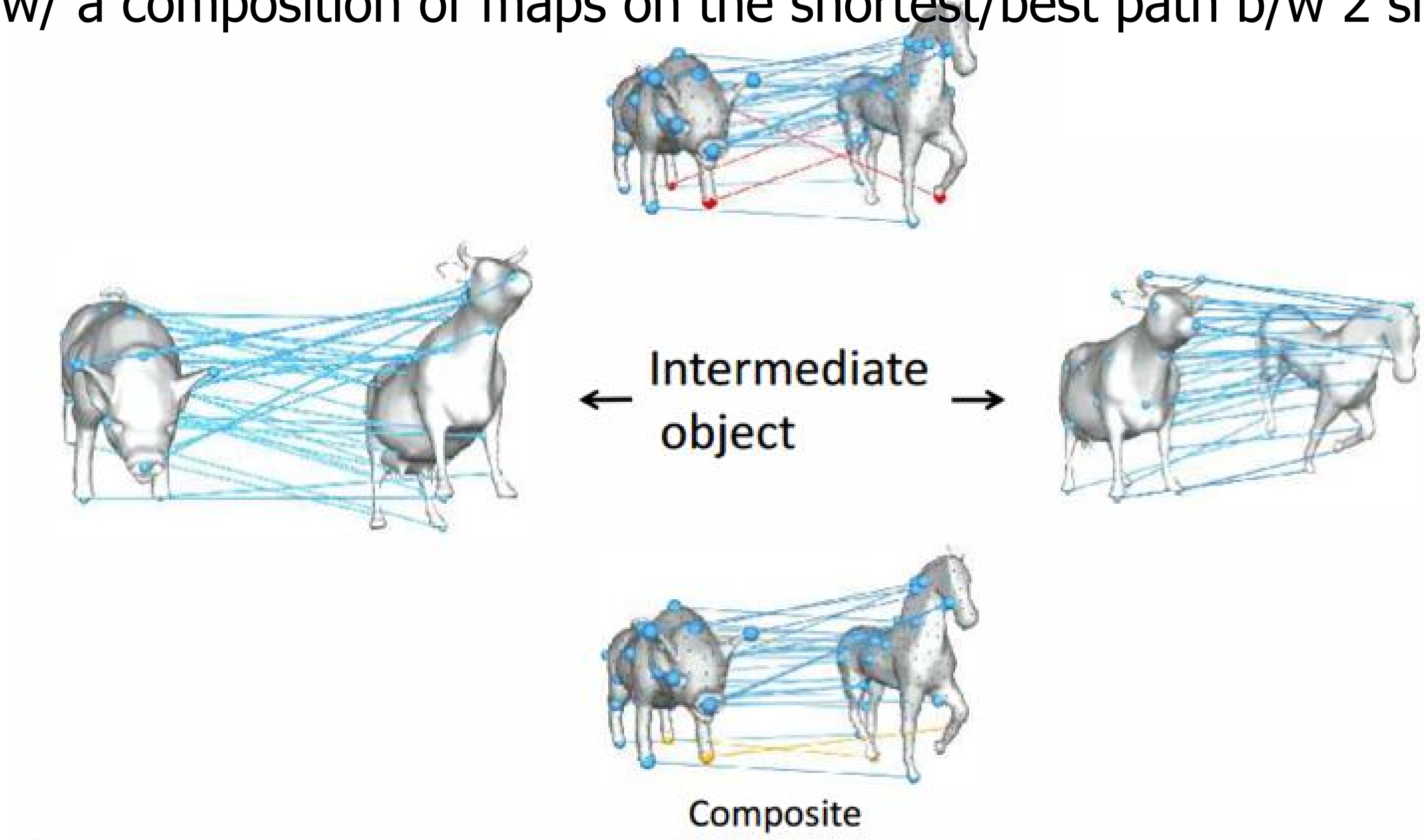


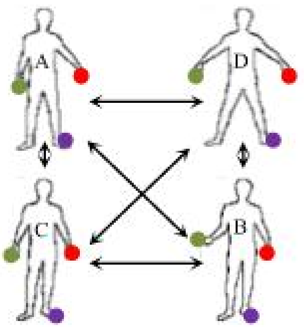
Shape Correspondence

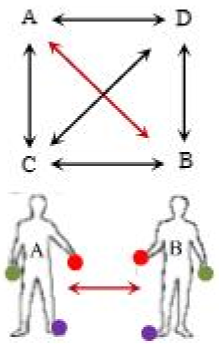
- ✓ At its infancy for collection analysis.
- ✓ Replace a (bad) map w/ a composition of (better) maps.
- ✓ = w/ a composition of maps on the shortest/best path b/w 2 shapes.



Shape Correspondence

- ✓ At its infancy for collection analysis.
- ✓ Consistent (left) vs. inconsistent (right) maps.

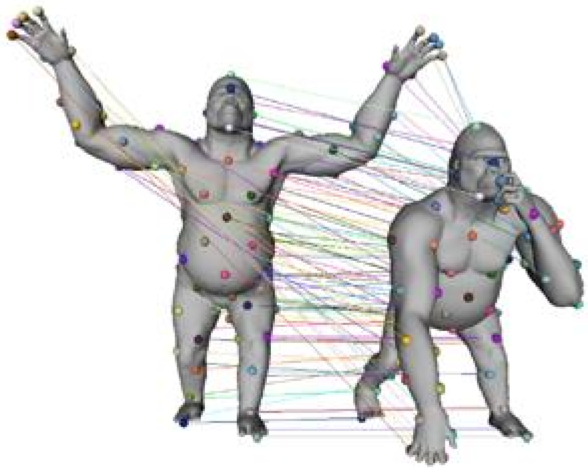




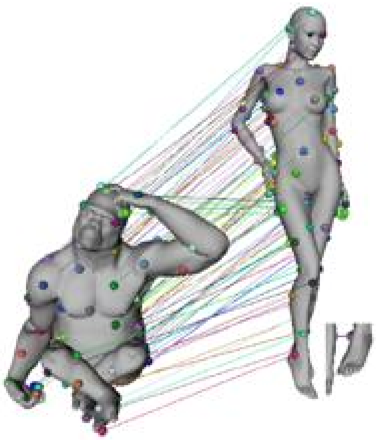
- ✓ Read
  - ✓ An optimization approach to improving collections of shape maps
  - ✓ Multiple shape correspondence by dynamic programming

Shape Correspondence

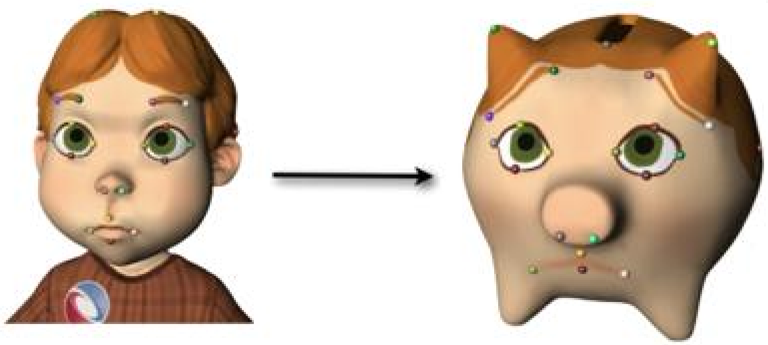
- ✓ Non-isometric case harder due to stretching.



vs.



- ✓ Idea: Interpolate a few predefined correspondences on landmarks
  - ✓ Weighted averages on surfaces. See https://youtu.be/tlMsB6tBO2w



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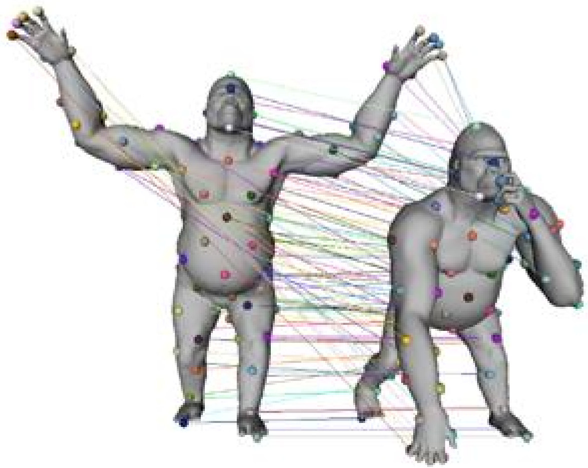

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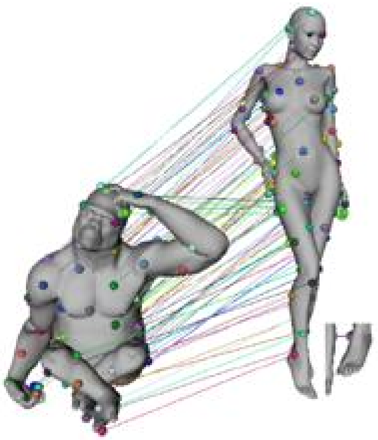
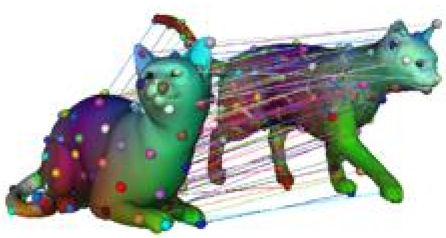
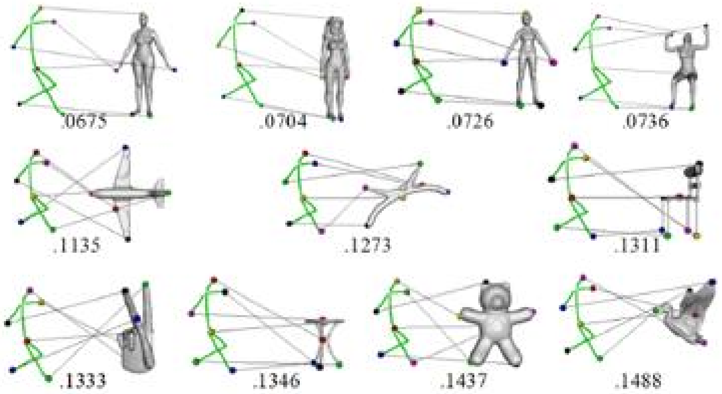


- ✓ Idea: Interpolate a few predefined correspondences on landmarks
  - ✓ Blended intrinsic maps.
  - ✓ Non-smooth blend:



Shape Retrieval

- ✓ Query-by-text.
  - ✓ Google search.
  - ✓ Shape adaptation: DB needs to be manually tagged ☹
- ✓ Query-by-example.
  - ✓ Shape adaptation: User provides a 3D model; popular but hard to come up with a 3D model ☹.
- ✓ Query-by-sketch.
  - ✓ Shape adaptation: User simply draws; easy for user but not so accurate due to view and drawing differences ☹.
  - ✓ Articulated:



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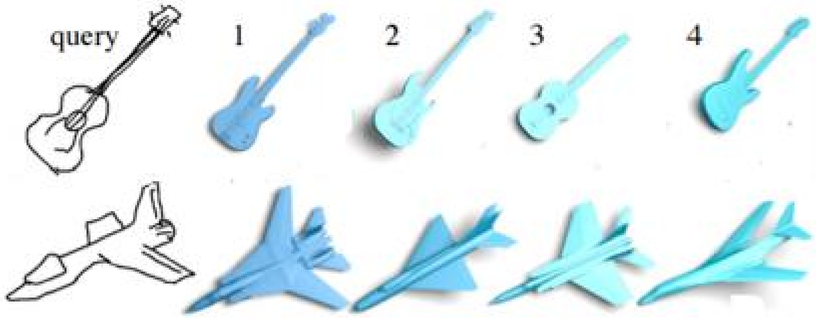
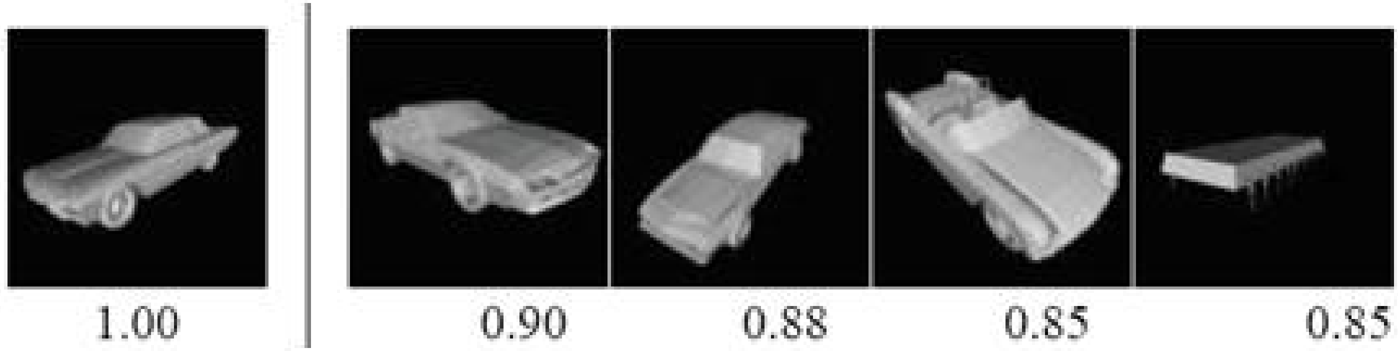
  - ✓ Shape adaptation: User simply draws; easy for user but not so accurate due to view and drawing differences ☹.
  - ✓ Non-articulated: See https://youtu.be/lVszERiVaJI



Shape Retrieval

- ✓ Index database models with
  - ✓ Features.
  - ✓ Bending-invariant representations.
  - ✓ Bag-of-words.
  - ✓ ..
- ✓ Convert to query model into that index.
  - ✓ Retrieve the most compatible model according to the indexing.

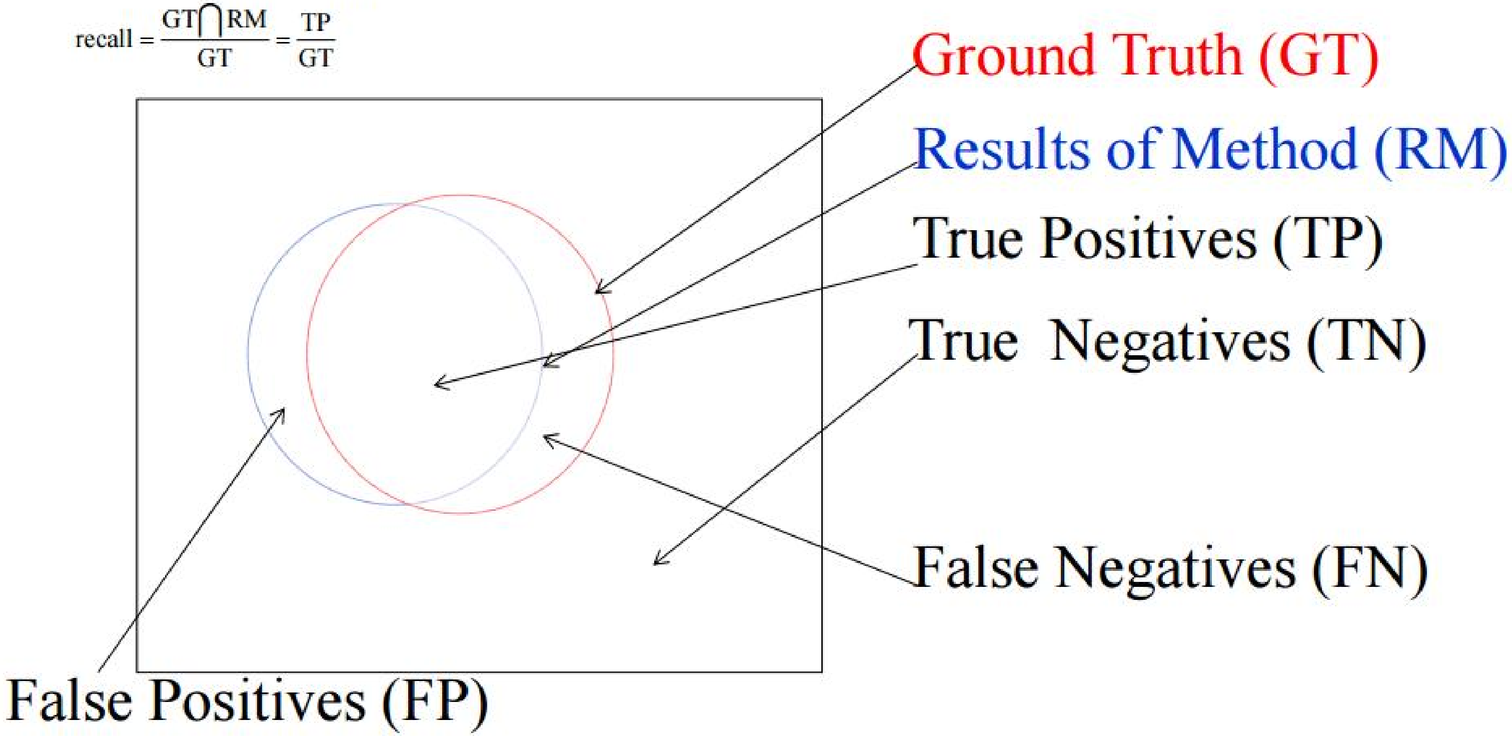


Shape Retrieval

- ✓ Evaluation of shape retrieval performance.
- ✓ Precision-recall plots.

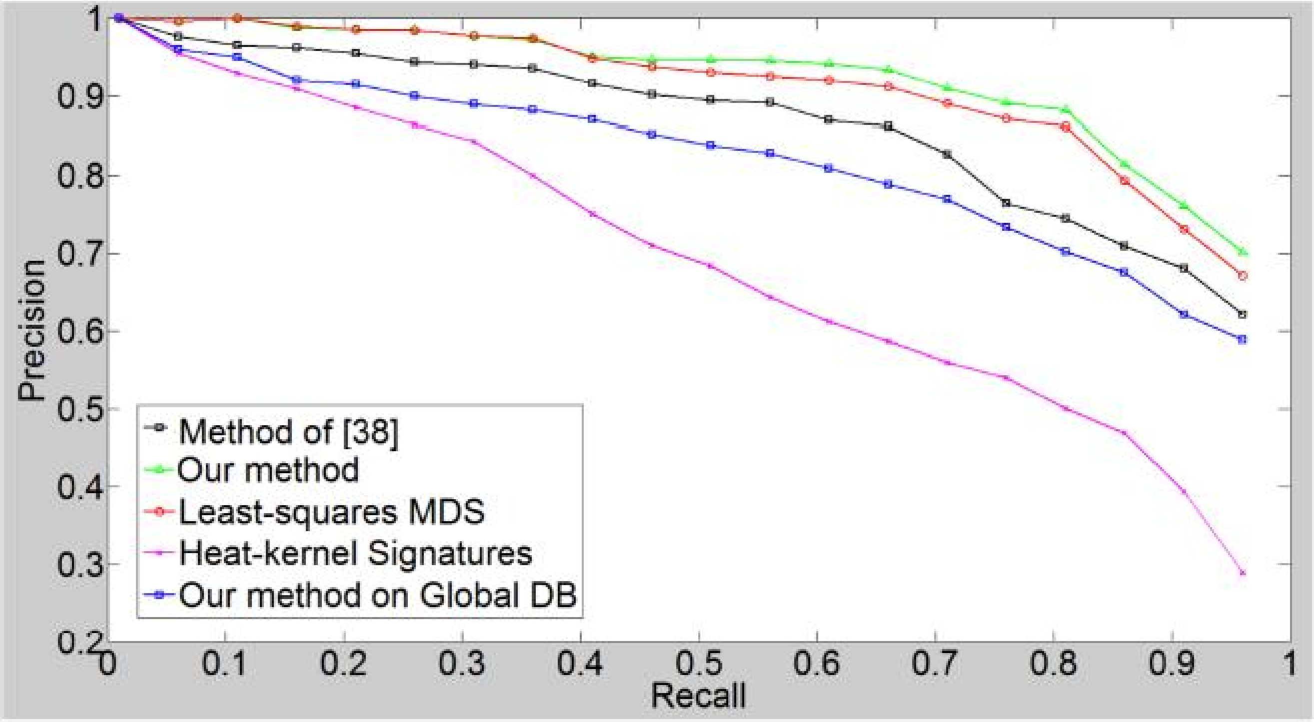
$$\text{precision} = \frac{GT \cap RM}{RM} = \frac{TP}{RM}$$

$$\text{recall} = \frac{GT \cap RM}{GT} = \frac{TP}{GT}$$



Shape Retrieval

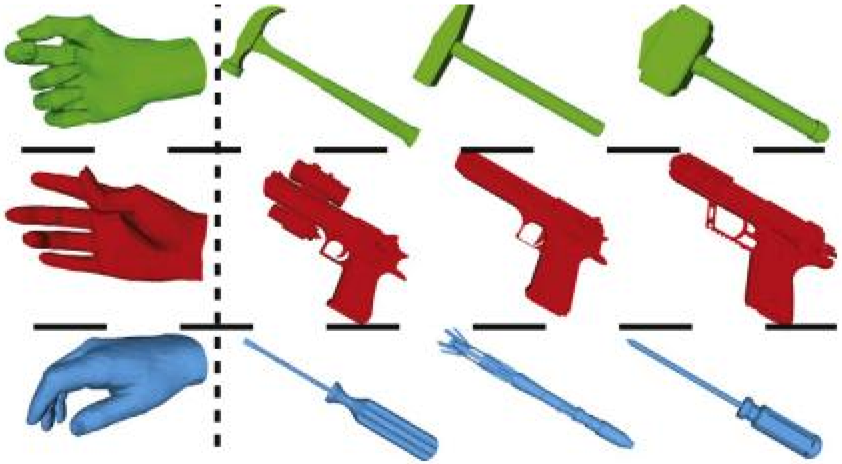
- ✓ Evaluation of shape retrieval performance.
- ✓ Precision-recall plots.
  - ✓ Ideally this curve should be a horizontal line at unit precision.



Human-centric Shape Analysis

- ✓ Recognize/classify/segment objects based on their interaction with human agents.
  - ✓ Human body.

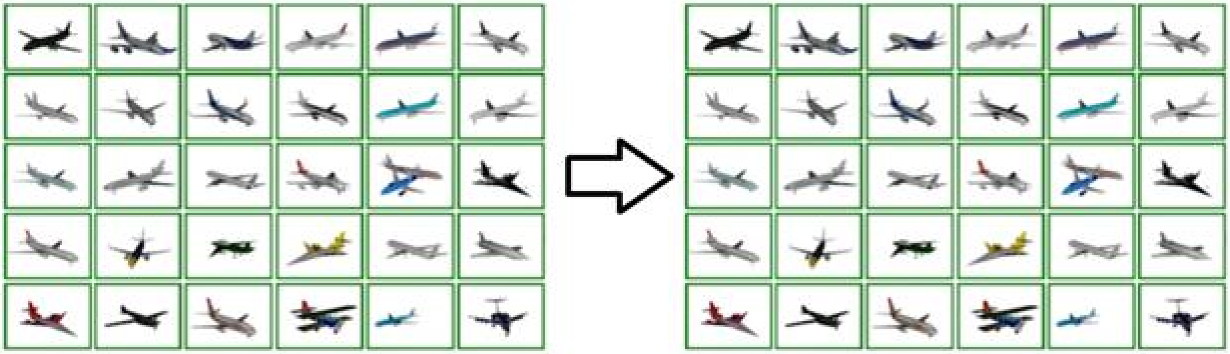
  - ✓ Human hand.



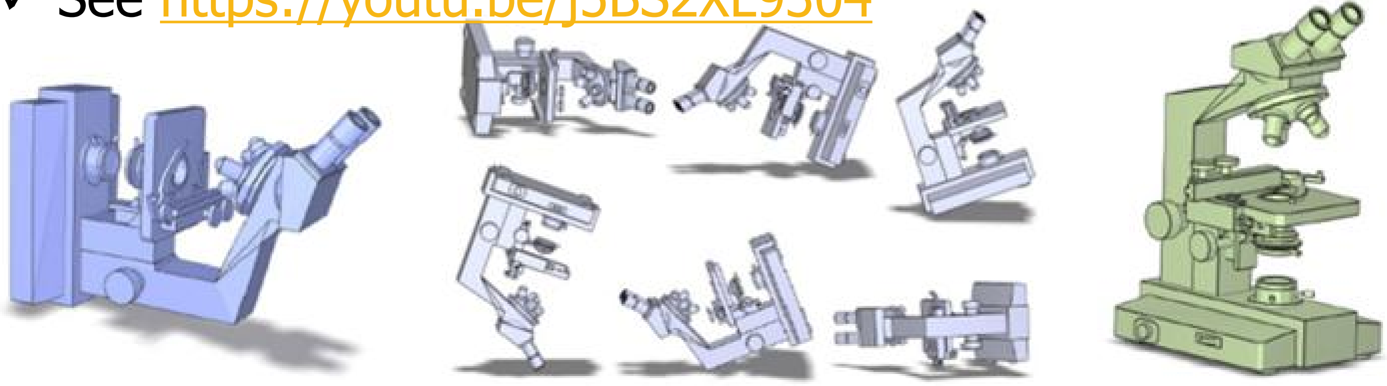
  - ✓ ..

Groupwise Shape Alignment

- ✓ Make every shape in collection look right.
  - ✓ See https://youtu.be/m584yqGtlCE

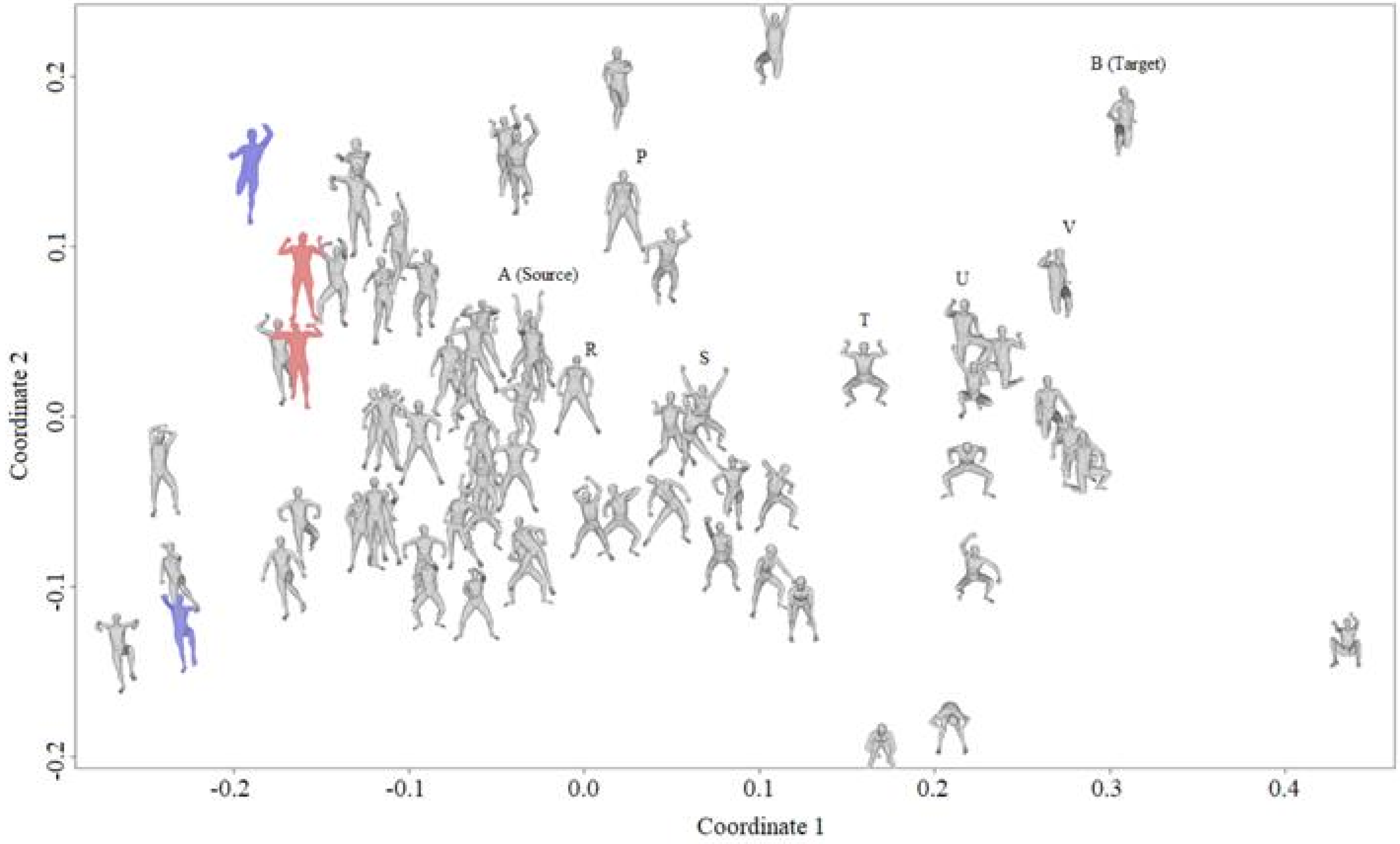


- ✓ Put every shape in collection in upright orientation.
  - ✓ See https://youtu.be/j5BS2XL9304



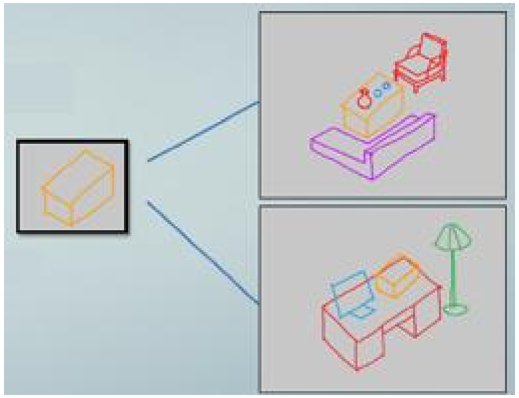
Shape Interpolation

✓ Instead of interpolating directly from A to B, create a path of shapes in data-driven fashion: A→R→S→T→U→V. Connecting more similar shapes along the path is bound to give better results.



Scene Synthesis

✓ An intuitive approach is to keep the user in the loop via sketches.



Scene Segmentation and Labeling

- ✓ In order to issue this command to a robot: Get me the **mug** on **table**, need segmentation & labels on scene point cloud (acquired by a depth sensor).

- ✓ User guidance might help for segmentation: https://youtu.be/z_TcWC7yjj0
- ✓ Pairwise analysis might help for labeling.