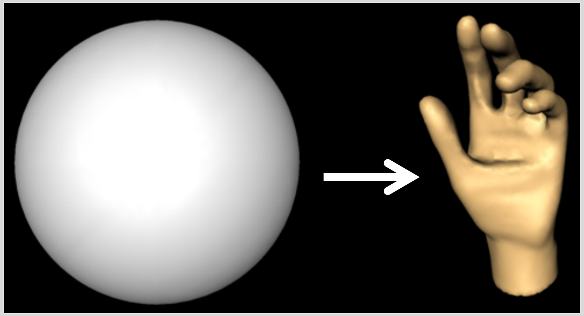
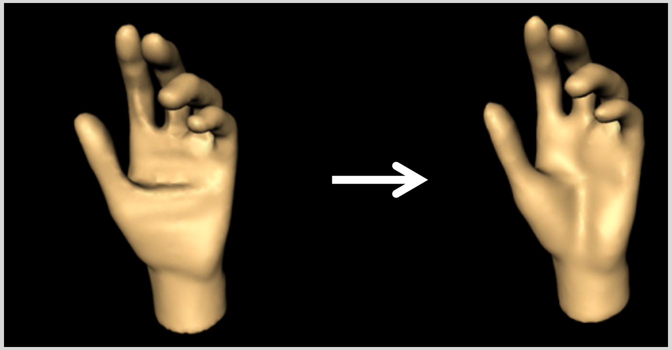
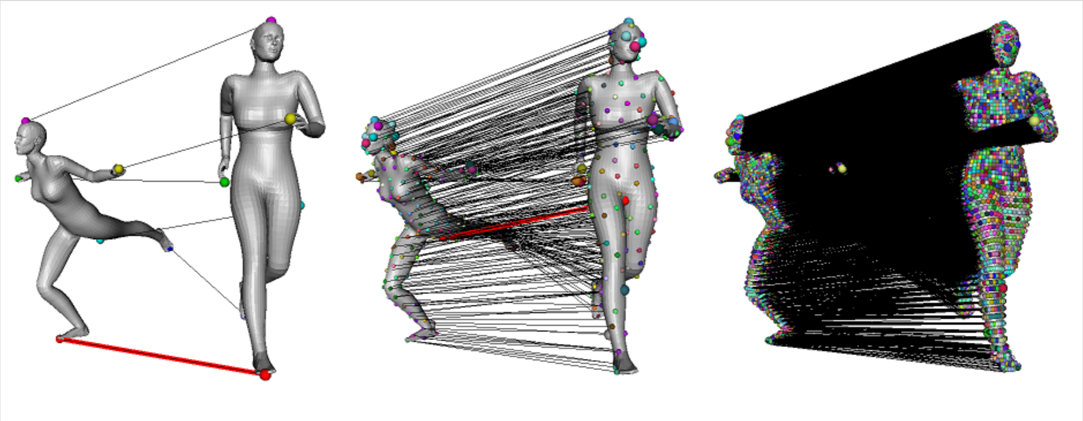
Mesh Processing:
From Creation to Comparison





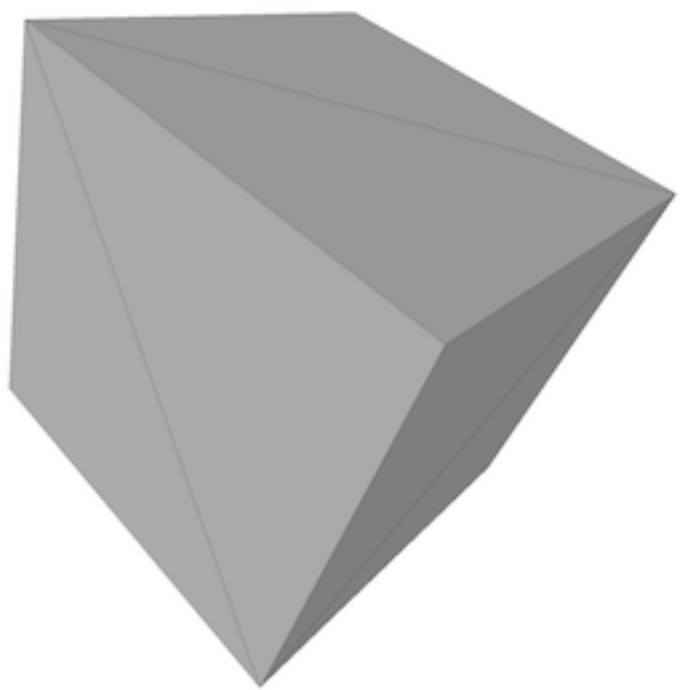


Assoc. Prof. Yusuf Sahillioğlu

Computer Eng. Dept. ORTA DOĞU TEKNİK ÜNİVERSİTESİ MIDDLE EAST TECHNICAL UNIVERSITY Turkey

Surface Mesh

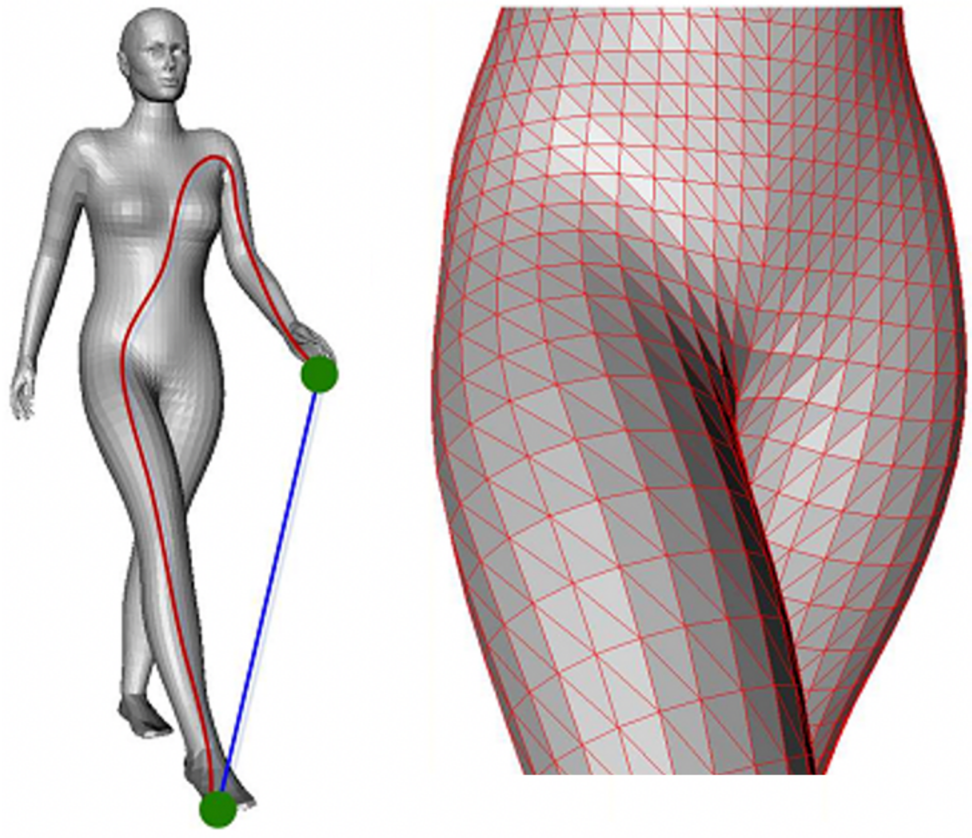
Representing geometry and topology as a polygon mesh.



```
v 1.000000 -1.000000 -1.000000
v 1.000000 -1.000000 1.000000
v -1.000000 -1.000000 1.000000
v -1.000000 -1.000000 -1.000000
v 1.000000 1.000000 -0.999999
v 0.999999 1.000000 1.000001
v -1.000000 1.000000 1.000000
v -1.000000 1.000000 -1.000000
f 2 3 4
f 8 7 6
f 5 6 2
f 6 7 3
f 3 7 8
f 1 4 8
f 1 2 4
f 5 8 6
f 1 5 2
f 2 6 3
f 4 3 8
f 5 1 8
```

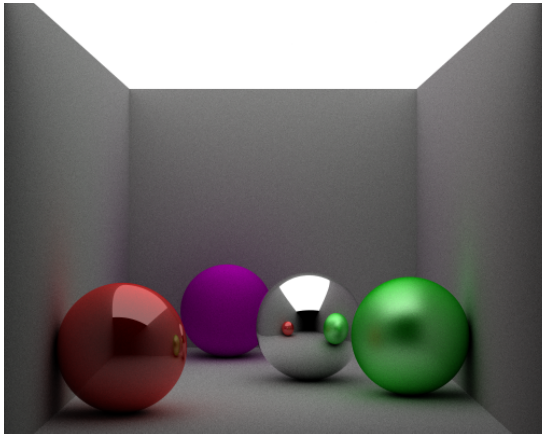
Surface Mesh

Representing geometry and topology as a polygon mesh.

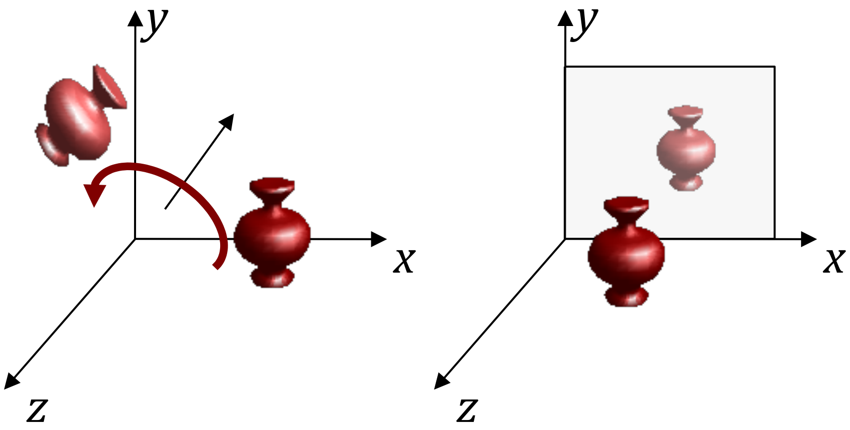


MP vs. CG

- Computer graphics //CENG 477
  - Rendering
    - Ray tracing
    - Rasterization

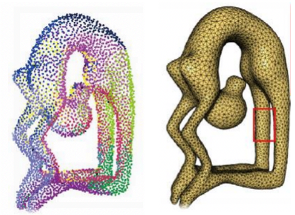


  - Transformations



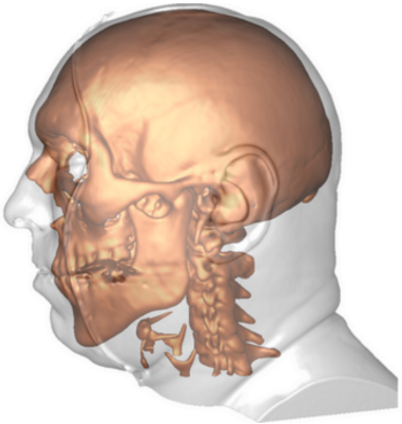
MP vs. CG

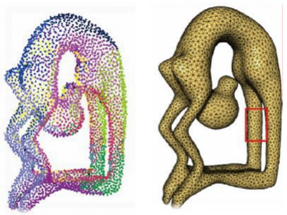
- Mesh Processing //CENG 789
  - Reconstruction



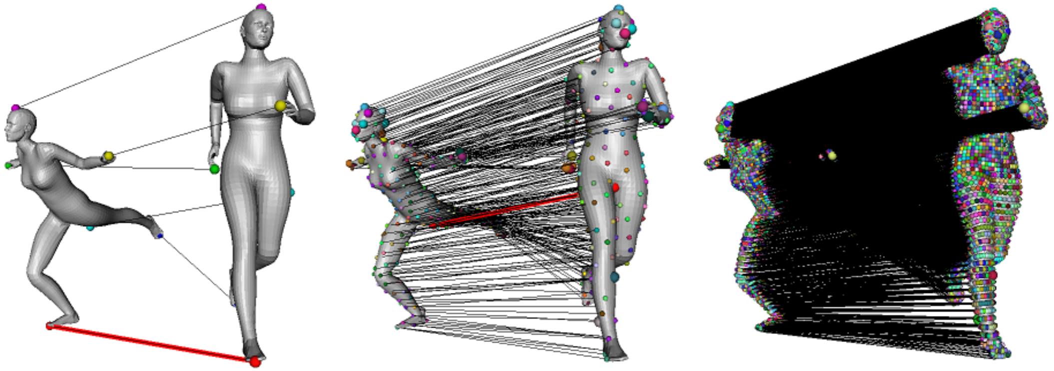
MP vs. CG

- Mesh Processing //CENG 789
  - Reconstruction



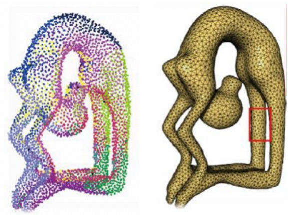


  - Analysis

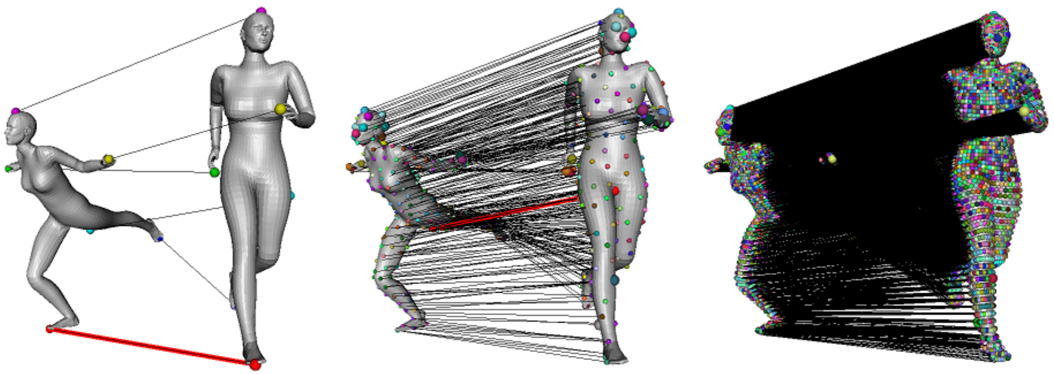


MP vs. CG

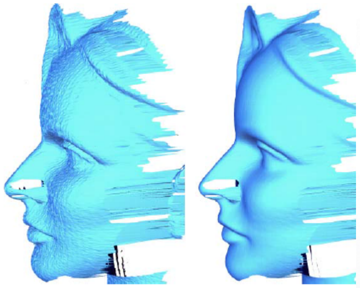
- Mesh Processing //CENG 789
  - Reconstruction

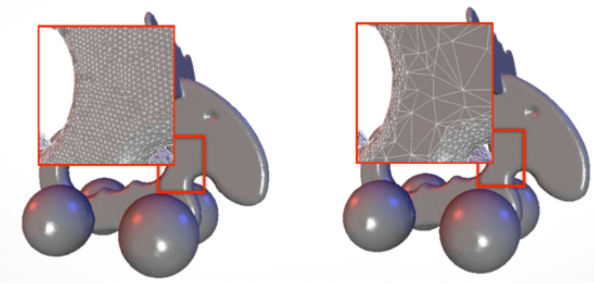


  - Analysis



  - Smoothing/Remeshing





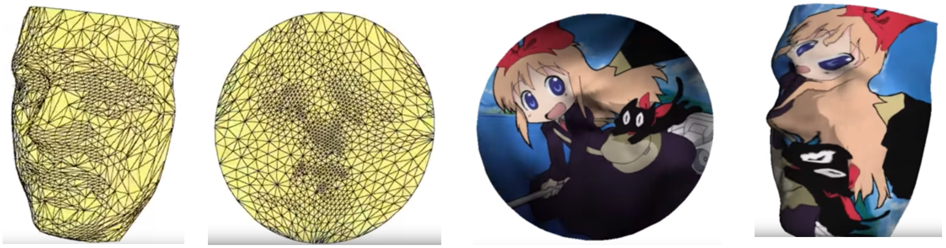
MP vs. CG

- Mesh Processing //CENG 789
  - Parameterization
  - Deformation
  - Registration
  - Fabrication

- I'll focus on my papers on Reconstruction and Analysis
  (Creation) (Comparison)

MP vs. CG

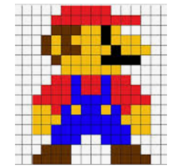
- Mesh Processing //CENG 789
  - Parameterization
  - Deformation
  - Registration
  - Fabrication

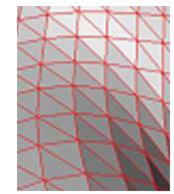


- I'll focus on my papers on Reconstruction and Analysis
  (Creation) (Comparison)

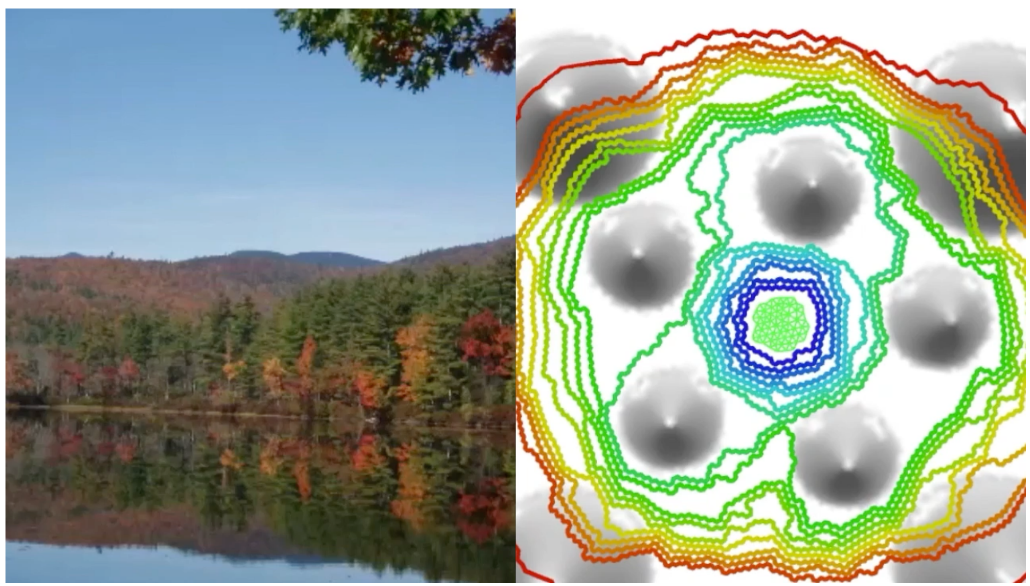
MP vs. IP

- Image Processing //CENG 466
  - Regularity
    - IP: Every pixel has 4 neighbors
    - MP: Every edge is incident to 2 faces





- Exchange of ideas IP → MP



Seam Carving for Content-Aware Image Resizing, S. Avaidan, A. Shamir, SIGGRAPH, 2007.
Geometry Seam Carving, E. Dekkers, L. Kobbelt, Computer-Aided Design, 2014.

MP vs. IP

- Image Processing //CENG 466
  - Regularity
    - IP: Every pixel has 4 neighbors
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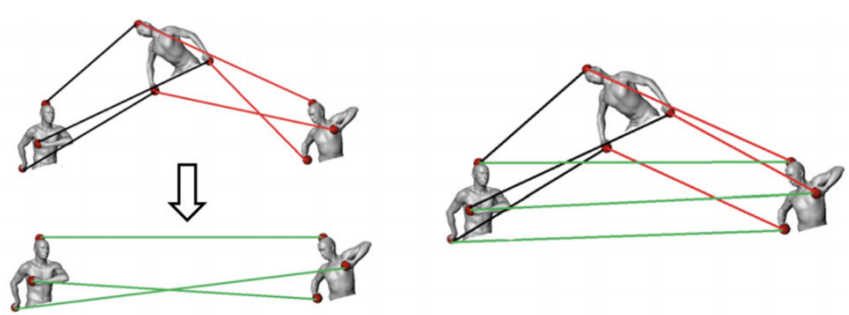
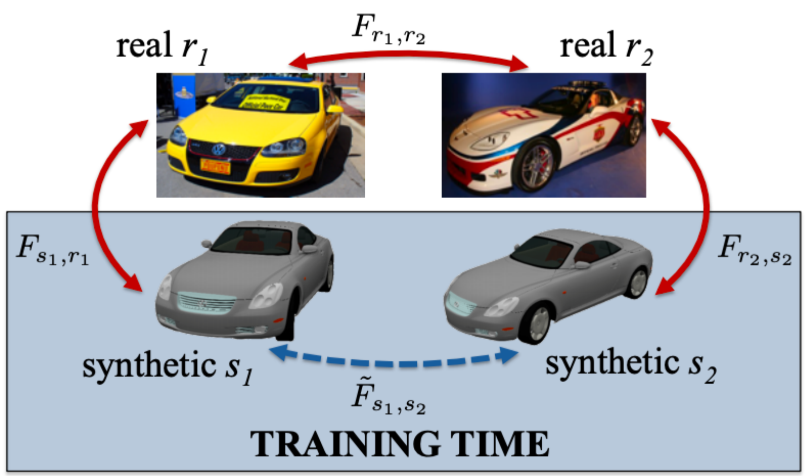
- Exchange of ideas MP → IP

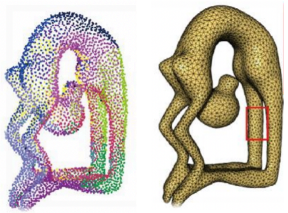




Multiple shape correspondence by dynamic programming, Y. S., Y. Yemez, Computer Graphics Forum, 2014.
Learning Dense Correspondence via 3D-guided Cycle Consistency, T. Zhou et al., CVPR, 2016.

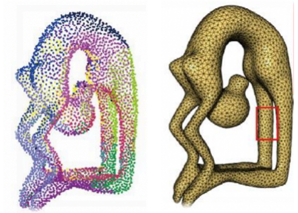
Reconstruction

- Input: 3D point samples
- Output: Surface fit to the point samples



- 3D point samples can be acquired passively or actively
  - Stereoscopic images
  - Multiple silhouettes
  - Emitters
    - LIDAR, Laser Scanner, Kinect, ToF

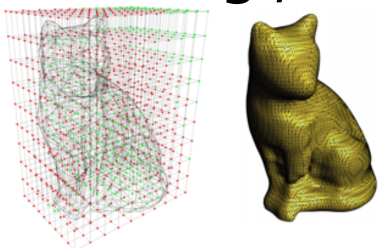
Reconstruction

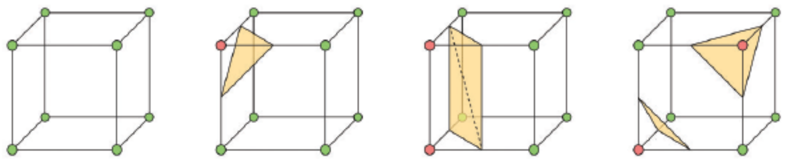


- Input: 3D point samples
- Output: Surface fit to the point samples

- 3D point samples can be acquired passively or actively
  - Stereoscopic images
  - Multiple silhouettes
  - Emitters
    - LIDAR, Laser Scanner, Kinect, ToF

- Alternative input: Scalar field defined over a 3D grid (CT)
  - Defines surface implicitly
  - Implicit methods, e.g., Marching Cubes, to extract the surface.

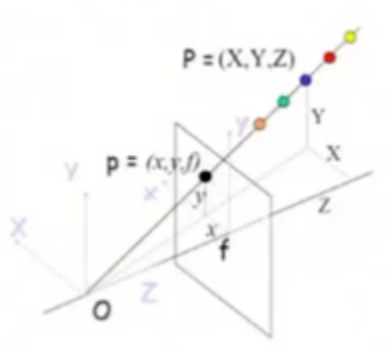




Reconstruction

- Input: 3D point samples; how to get them?

- Stereoscopy

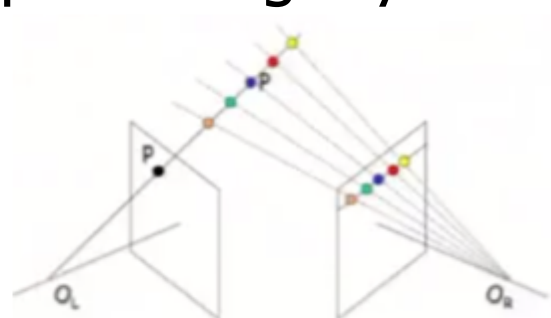


$$x = \frac{fX}{Z} = \frac{fkX}{kZ}$$

$$y = \frac{fY}{Z} = \frac{fkY}{kZ}$$

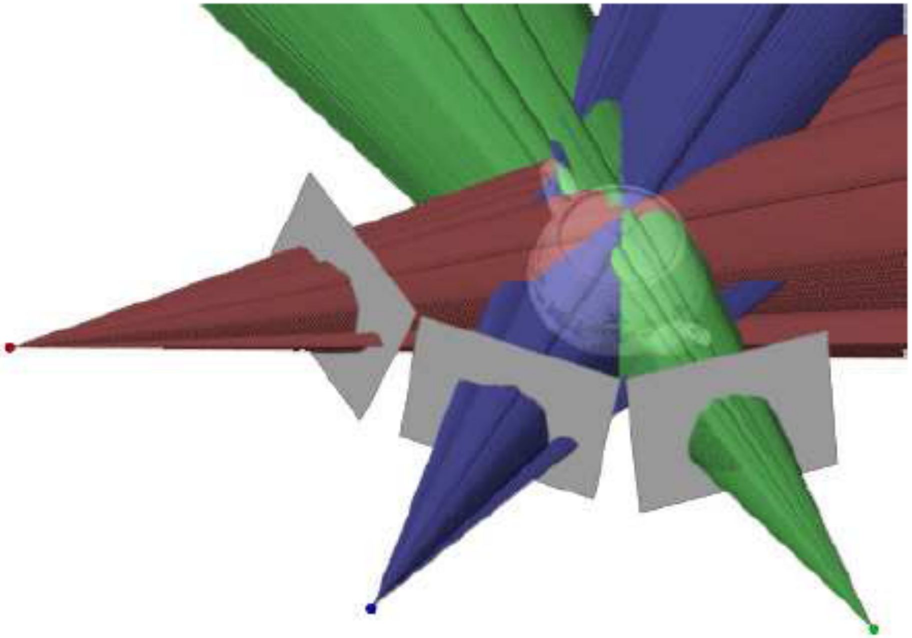
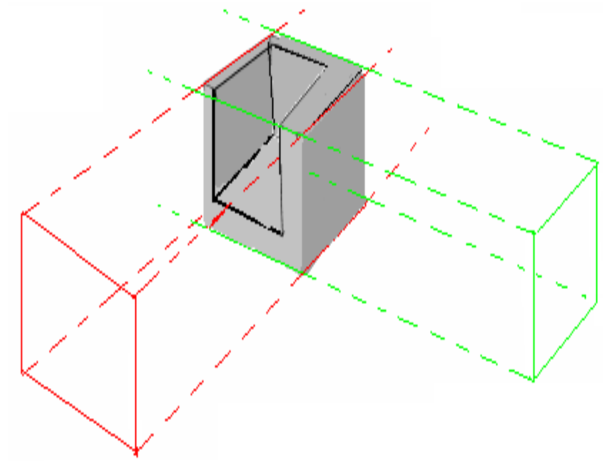
For any $k \neq 0$

Depth ambiguity handled by a second image



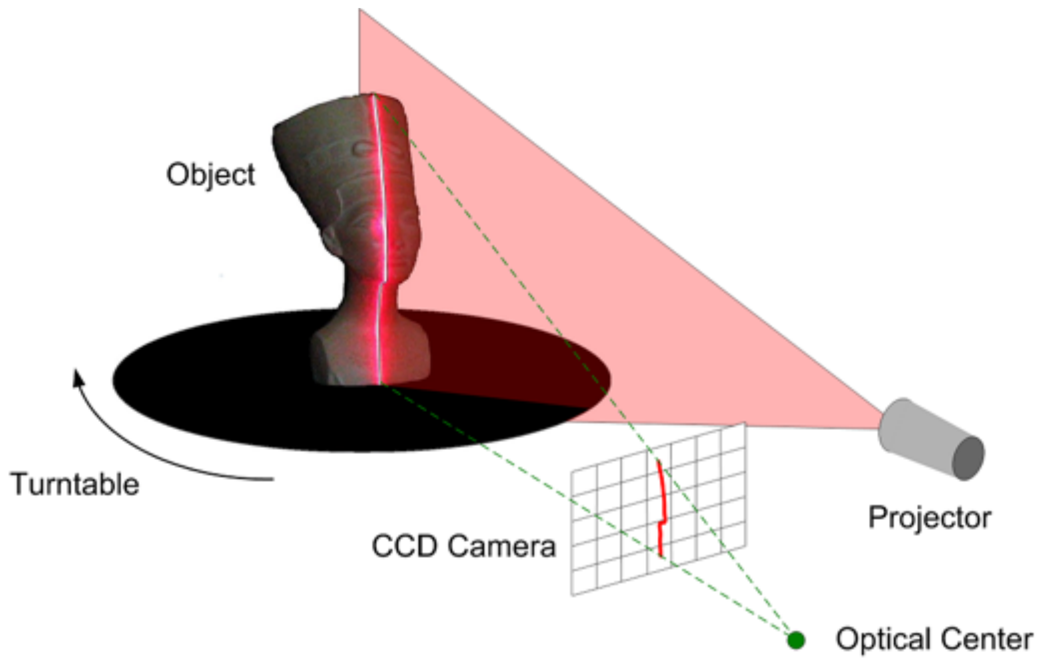
Reconstruction

- Input: 3D point samples; how to get them?
- Silhouettes

Idea	***Weakness***
	 Hidden Concavity

Reconstruction

- Input: 3D point samples; how to get them?
- Structured light

<table>
<tr><th>Idea</th><th>Weakness</th></tr>
<tr><td>


</td><td>

Occlusion
</td></tr>
</table>

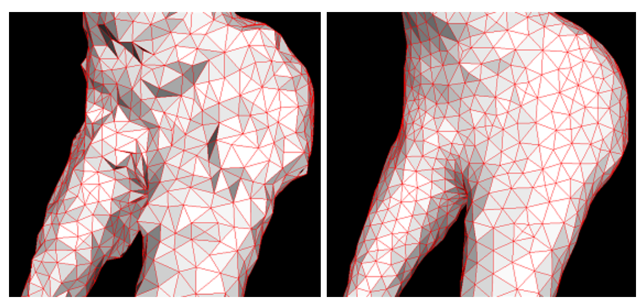
Reconstruction

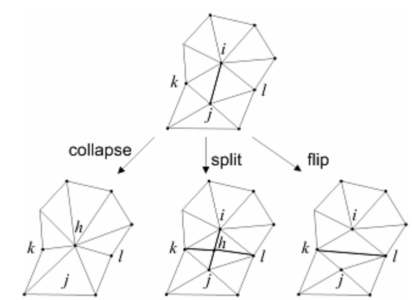
- Input: 3D point samples
- Output: Surface; how to get it?

Iterate

- Move each vertex P with v(P, B) in the direction of its normal N(P), as Fext suggests: $\mathbf{F}_{ext}(P,B) = v(P,B) \cdot \mathbf{N}(P)$
- Regularize the mesh by Fint
- Collapse edges with length smaller than εmin
- Split edges with length exceeding εmax = 2εmin
- Flip edges where necessary, favoring the vertices with valences close to 6

Till convergence

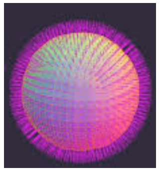




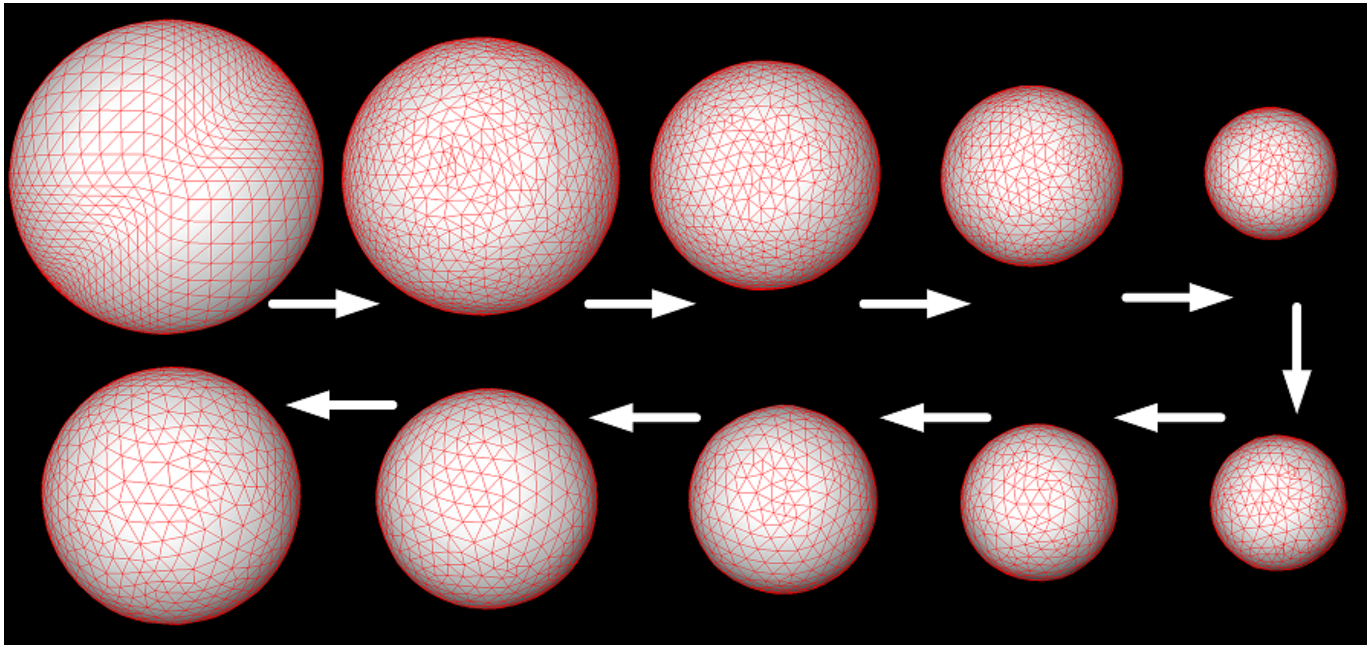
Coarse-to-Fine Surface Reconstruction from Silhouettes and Range Data Using Mesh Deformation, Y. S., Y. Yemez, CVIU, 2010.

Reconstruction

- Input: 3D point samples
- Output: Surface; how to get it?



Fext: constant external force (F(P) = −εmin/2 * N(P))

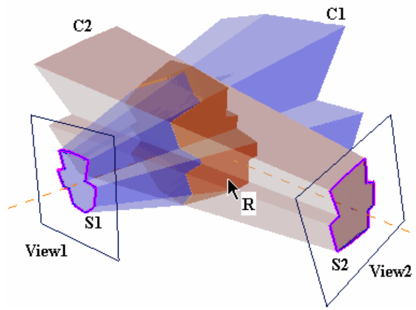


Coarse-to-Fine Surface Reconstruction from Silhouettes and Range Data Using Mesh Deformation, Y. S., Y. Yemez, CVIU, 2010.

Reconstruction

- Input: 3D point samples
- Output: Surface; how to get it?

```
Fext: force based on silhouettes
```



$$\mathbf{F}_{ext}(P,B) = v(P,B) \cdot \mathbf{N}(P)$$

$$v(P) = \varepsilon_{\min} f(P) = \varepsilon_{\min} \min_{n} \left\{ G\left[\mathrm{Proj}_{I_n}(P) \right] - 0.5 \right\}$$

$$G(x', y') = (1-\alpha)((1-\beta)I(\lfloor x' \rfloor, \lfloor y' \rfloor) + \beta I(\lfloor x' \rfloor, \lfloor y' \rfloor + 1))$$
$$+ \alpha((1-\beta)I(\lfloor x' \rfloor + 1, \lfloor y' \rfloor) + \beta I(\lfloor x' \rfloor + 1, \lfloor y' \rfloor + 1))$$

Coarse-to-Fine Surface Reconstruction from Silhouettes and Range Data Using Mesh Deformation, Y. S., Y. Yemez, CVIU, 2010.

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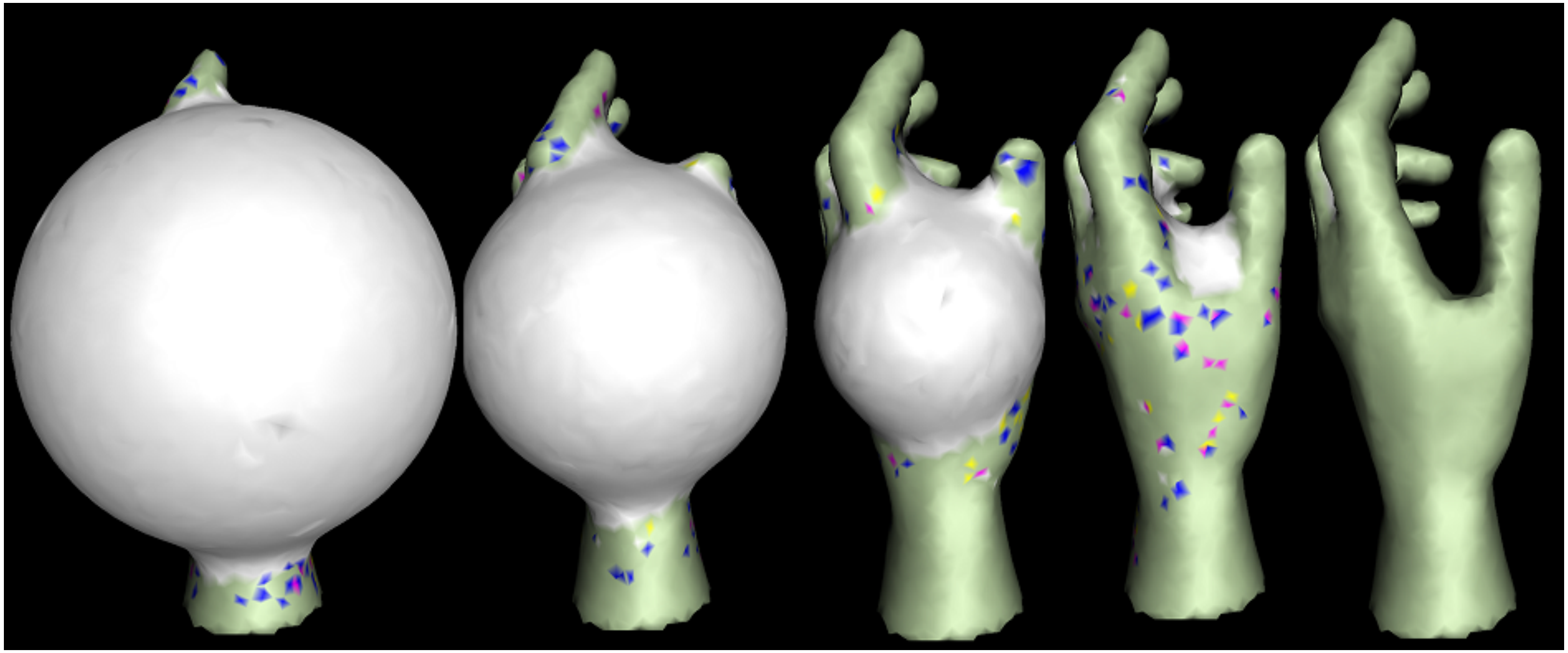

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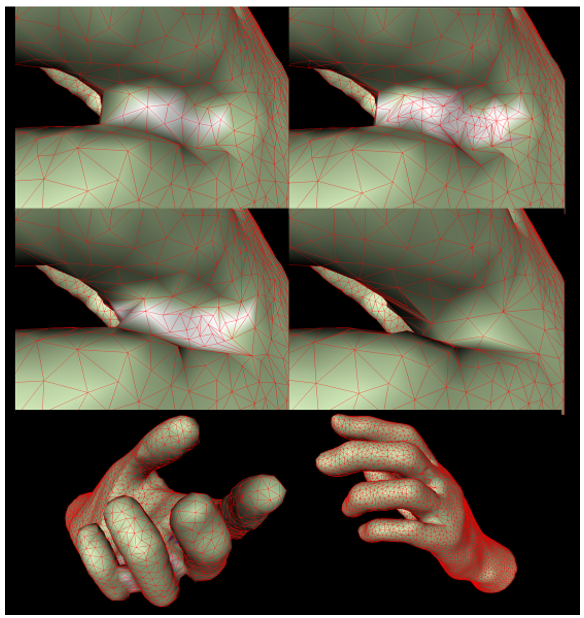
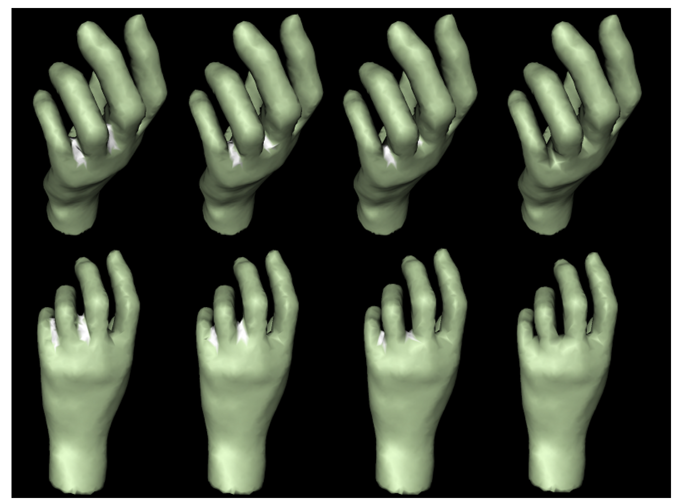
`Fext: force based on silhouettes`





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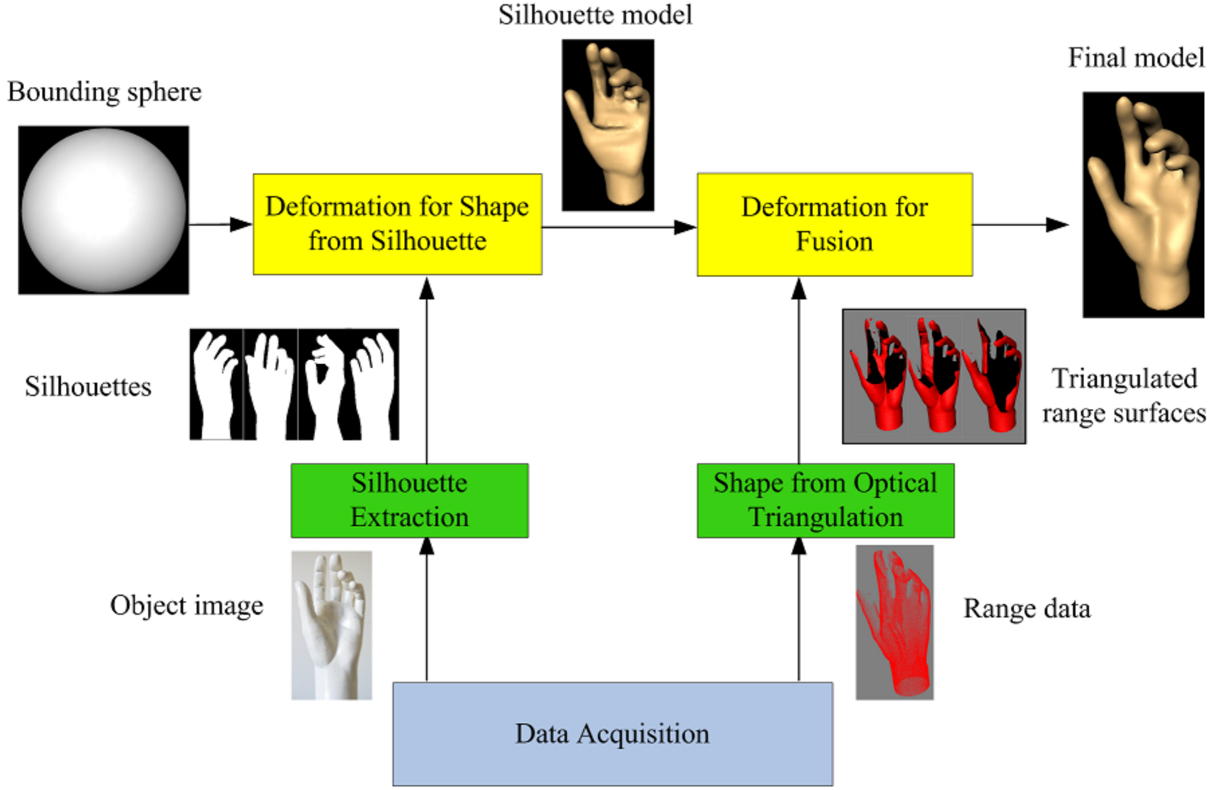
Reconstruction

- Input: 3D point samples
- Output: Surface; how to get it?
- Hidden concavity problem solved using range/laser surface



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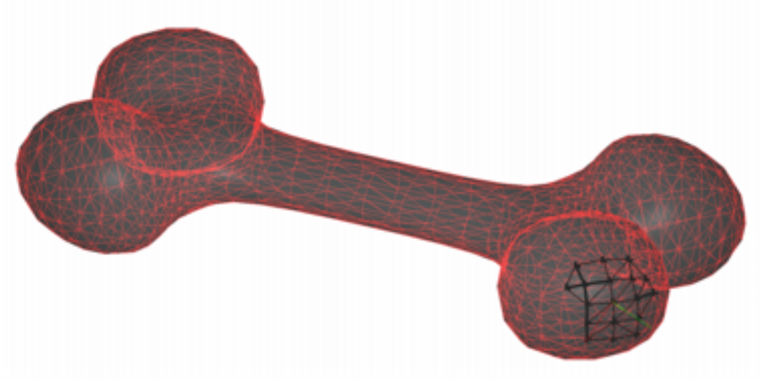
Coarse-to-Fine Surface Reconstruction from Silhouettes and Range Data Using Mesh Deformation, Y. S., Y. Yemez, CVIU, 2010.

Reconstruction

- Input: 3D point samples
- Output: Surface; how to get it?
- Mesh up laser point cloud as follows

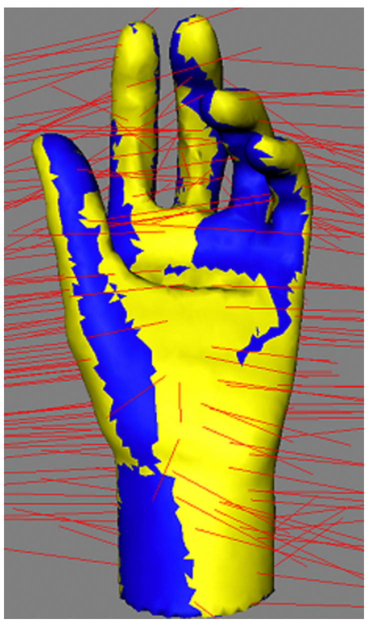
- Find local neighborhood Li of each point in the 3D point cloud input
- For each Li compute tangent plane using PCA
- Project all points in Li to the tangent plane and compute their 2D Delaunay triangulation
- Merge all these local triangulations into a global one

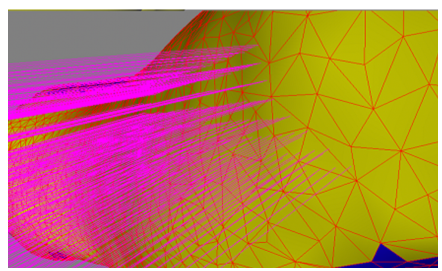


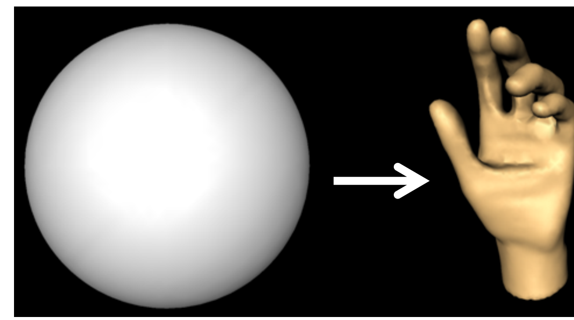
Coarse-to-Fine Surface Reconstruction from Silhouettes and Range Data Using Mesh Deformation, Y. S., Y. Yemez, CVIU, 2010.

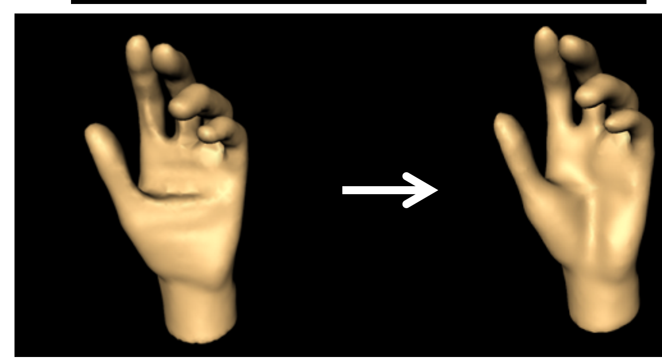
Reconstruction

- Input: 3D point samples
- Output: Surface; how to get it?
- Refine the silhouette-based mesh using an updated `Fext(P)` based on carvers assigned to triangles that share the vertex `P`





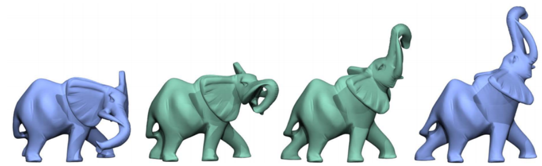




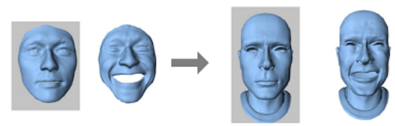
Coarse-to-Fine Surface Reconstruction from Silhouettes and Range Data Using Mesh Deformation, Y. S., Y. Yemez, CVIU, 2010.

Comparison/Correspondence

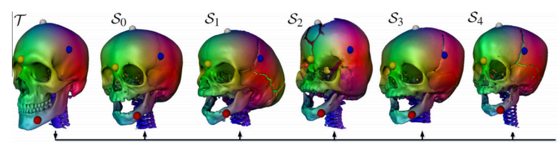
- Once we have the meshes (reconstruction), we want to relate them with each other to enable nice apps, such as
- Shape interpolation:



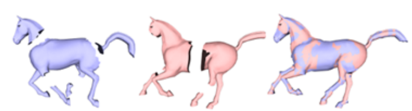
- Deformation transfer:



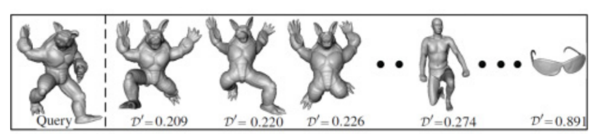
- Attribute transfer:



- Shape registration:



- Shape matching:



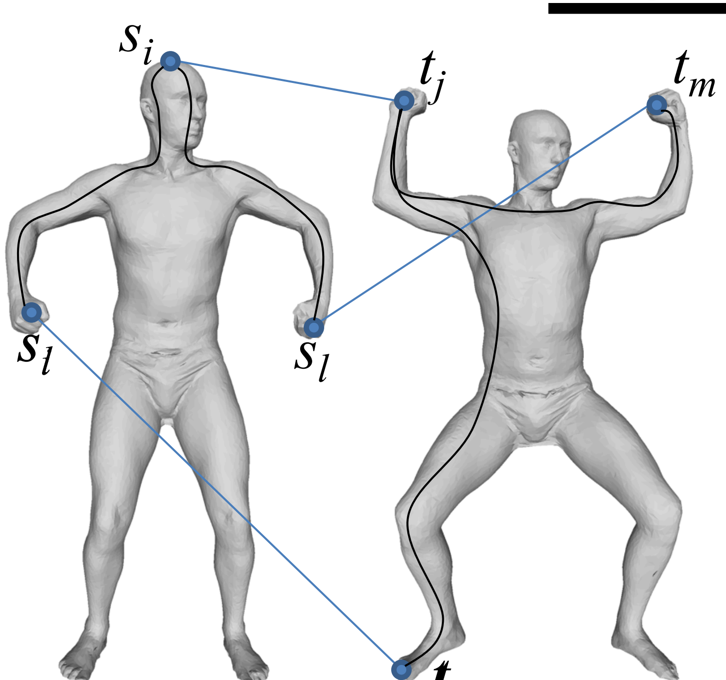
- Statistical analysis:

Correspondence

- Solution idea
  - Quantify the quality of a given map
  - Then search the map space using this metric

$$\mathcal{D}_{\text{iso}}(\phi) = \frac{1}{|\phi|} \sum_{(s_i,t_j)\in\phi} \left(\frac{1}{|\phi'|} \sum_{(s_l,t_m)\in\phi'} |d_g(s_i,s_l) - d_g(t_j,t_m)| \right)$$

|.34 - .98| = .64 ☹

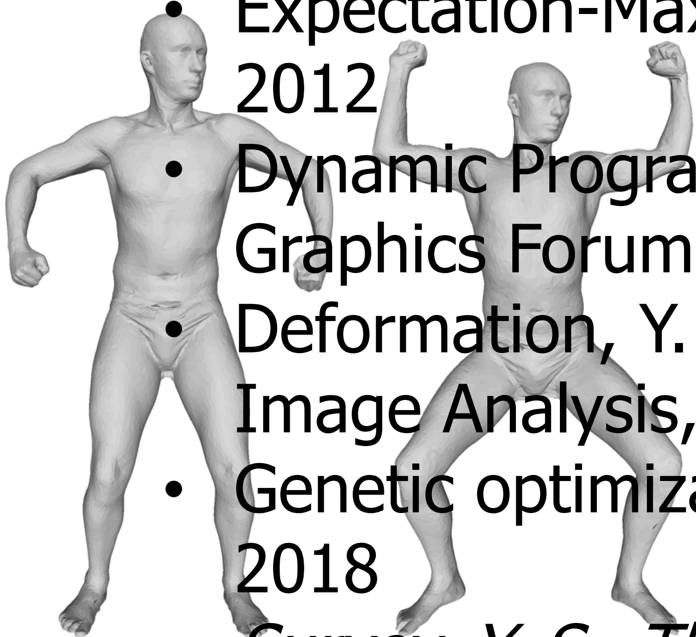


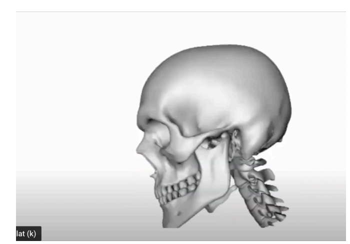
A bad/high-distortion map.

Correspondence

- Looking at all N! permutations is infeasible
- Minimize this metric (or its variants) using:

  - Greedy optimization, Y. S., Y. Yemez, CVPR, 2010
  - Combinatorial optimization, Y. S., Y. Yemez, Computer Graphics Forum, 2011, 2012, 2013, 2014
  - Expectation-Maximization (EM), Y. S., Y. Yemez, PAMI, 2012
  - Dynamic Programming, Y. S., Y. Yemez, Computer Graphics Forum, 2014
  - Deformation, Y. S., L. Kavan, Medical Image Analysis, 2015
  - Genetic optimization, Y. S., Transactions on Graphics 2018
  - *Survey, Y. S., The Visual Computer, 2020*





Correspondence

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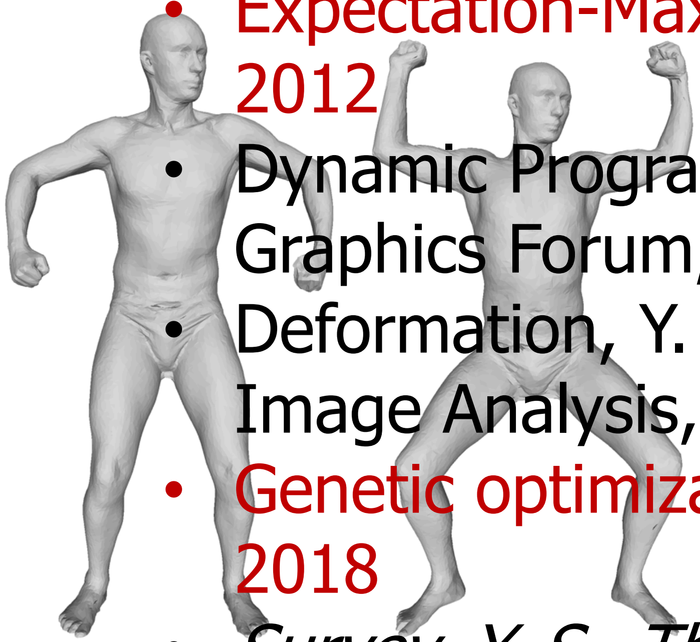
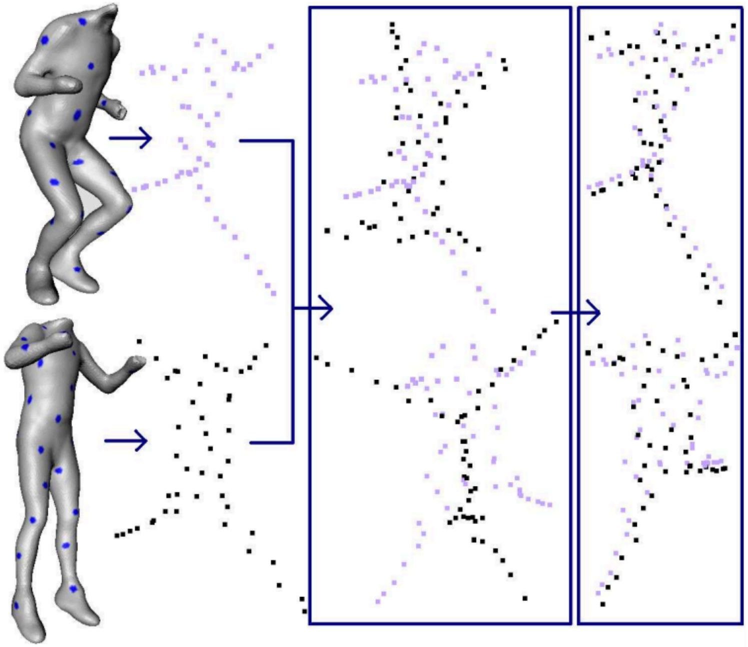
  - Greedy optimization, Y. S., Y. Yemez, CVPR, 2010
  - Combinatorial optimization, Y. S., Y. Yemez, Computer Graphics Forum, 2011, 2012, 2013, 2014
  - Expectation-Maximization (EM), Y. S., Y. Yemez, PAMI, 2012
  - Dynamic Programming, Y. S., Y. Yemez, Computer Graphics Forum, 2014
  - Deformation, Y. S., L. Kavan, Medical Image Analysis, 2015
  - Genetic optimization, Y. S., Transactions on Graphics 2018
  - *Survey, Y. S., The Visual Computer, 2020*

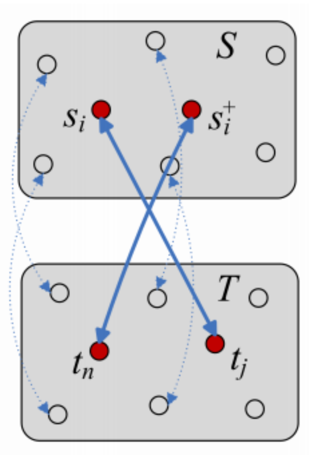


Correspondence

- Looking at all N! permutations is infeasible
- Minimize this metric (or its variants) using:

- Initial correspondence via MDS (left) is refined by greedy optimization based on neighbor voting (right).



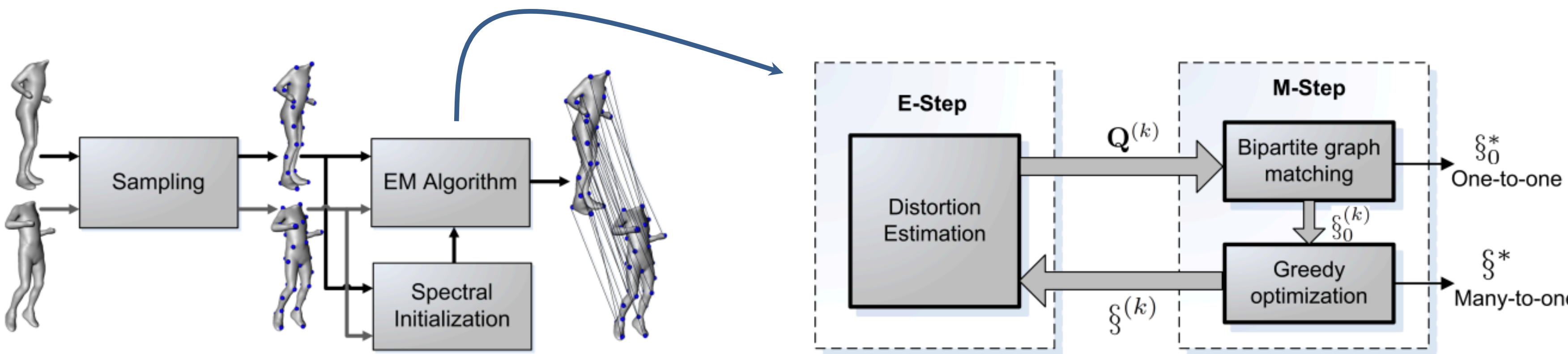


3D Shape Correspondence by Isometry-Driven Greedy Optimization, Y. S., Y. Yemez, CVPR, 2010.
Detail-Preserving Mesh Unfolding for Nonrigid Shape Retrieval, Y. S., L. Kavan, Transactions on Graphics, 2016.

Correspondence

- Looking at all N! permutations is infeasible
- Minimize this metric (or its variants) using:

- Isometric cost of matching si to tj for all pairs (Q matrix in E-Step) guides graph matching and refinement which results in a better map to estimate Q (M-step). Repeat.

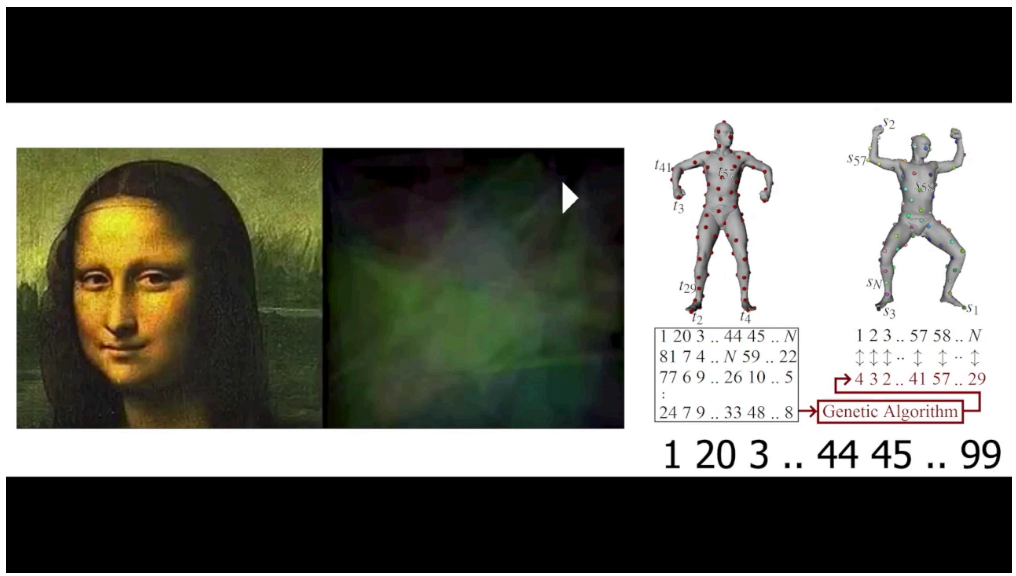


Minimum-Distortion Isometric Shape Correspondence Using EM Algorithm, Y. S., Y. Yemez, PAMI, 2012.

Correspondence

- Looking at all N! permutations is infeasible
- Minimize this metric (or its variants) using:

- Represent a permutation as a chromosome and evolve many of them into the fittest one that yields the min-distortion map

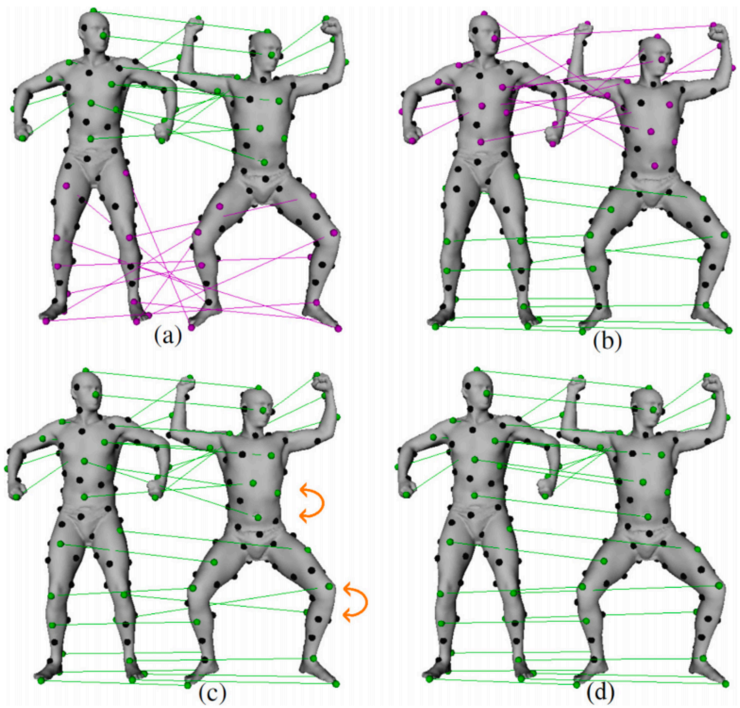


A Genetic Isometric Shape Correspondence Algorithm with Adaptive Sampling, Y. S., Transactions on Graphics, 2018.

Correspondence

- Looking at all N! permutations is infeasible
- Minimize this metric (or its variants) using:

- Represent a permutation as a chromosome and evolve through genetic operators xover and mutation



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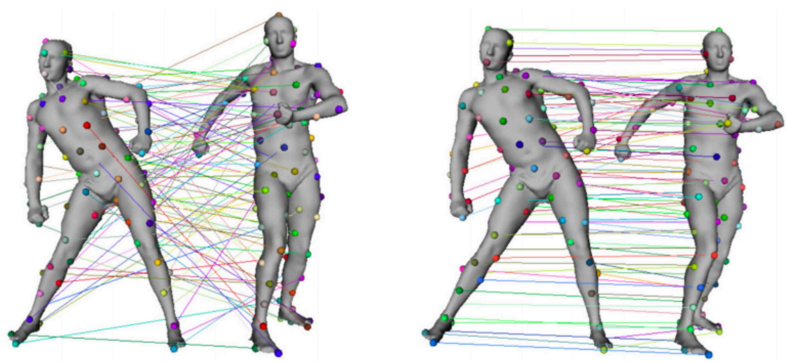
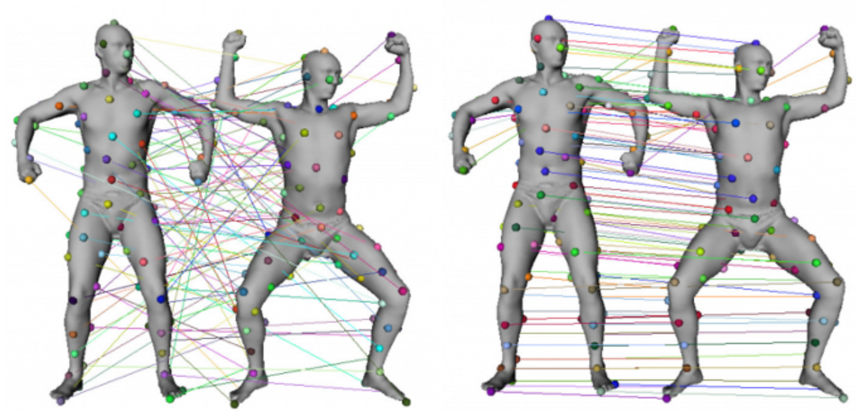


$(\mathcal{D}_{\text{iso}}, \mathcal{D}_{\text{grd}}, \#\,\text{Generations}, \text{Seconds}) = (.2125, .3299, 1, 0)$ (a)

$(0.311, 0.418, 170, 8.1)$ (d)

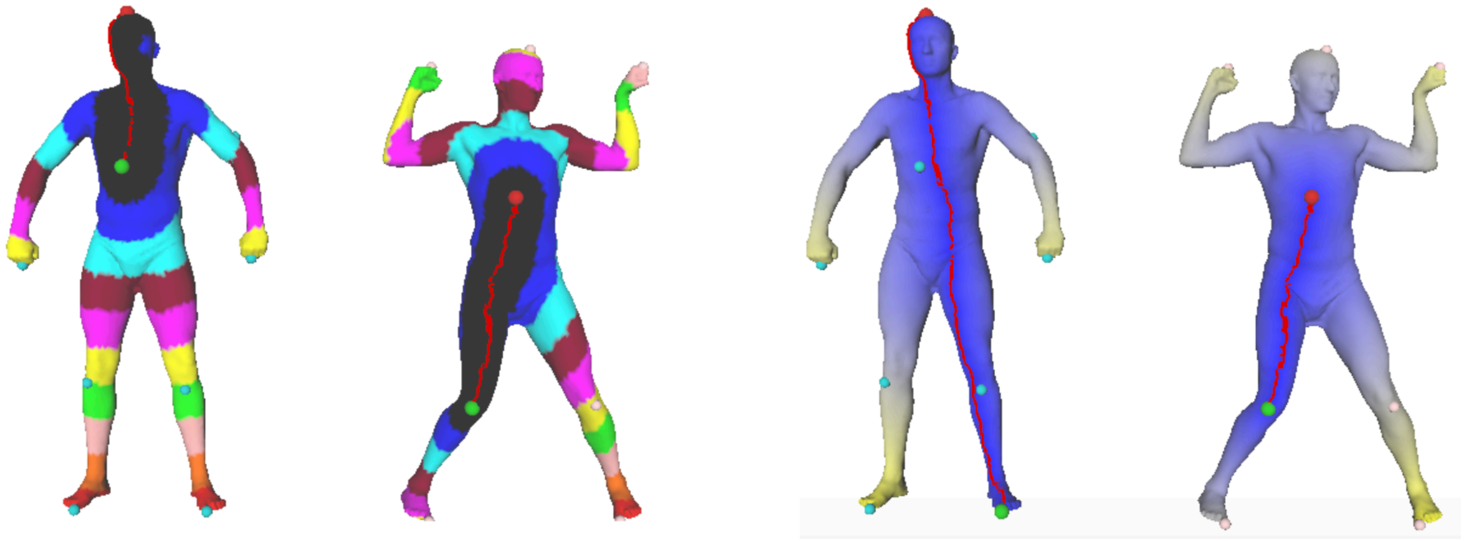


A Genetic Isometric Shape Correspondence Algorithm with Adaptive Sampling, Y. S., Transactions on Graphics, 2018.

Correspondence

- Looking at all N! permutations is infeasible
- Minimize this metric (or its variants) using:

- Improved bilateral maps: scale-invariance, fuzzy voting.



Bilateral Maps for Partial Matching, O. van Kaick., H. Zhang, G. Hamarneh, Computer Graphics Forum, 2013.

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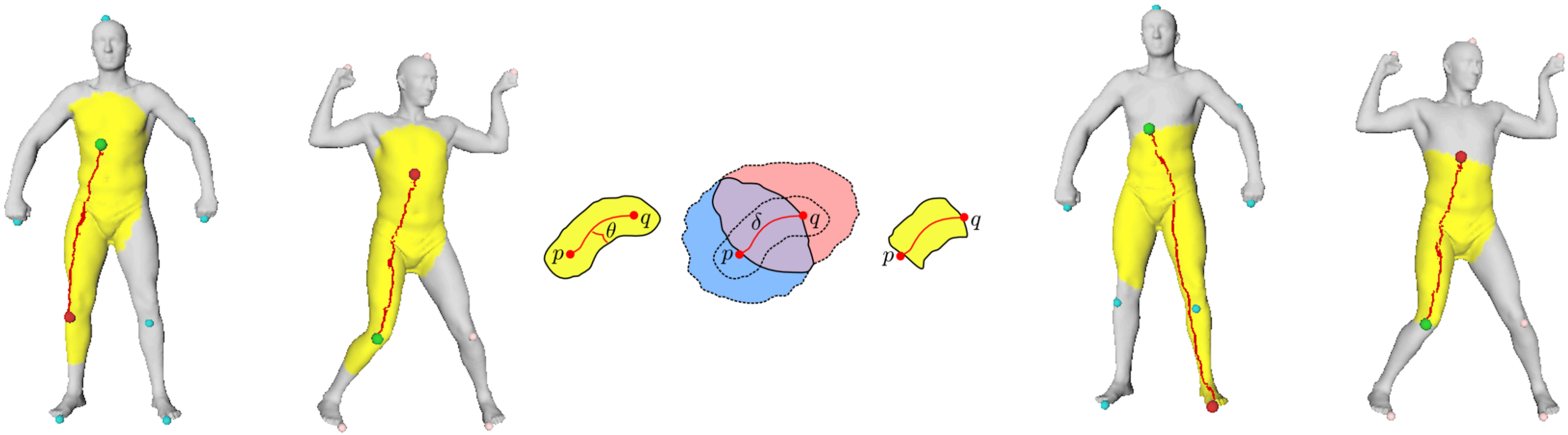

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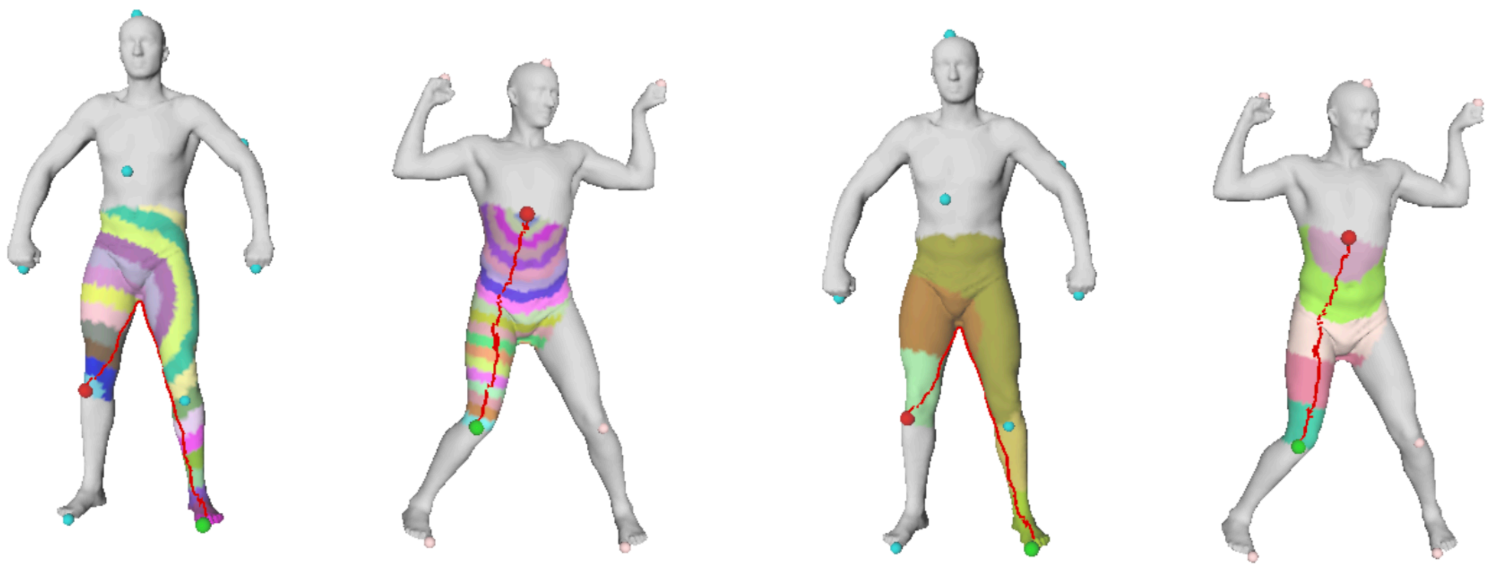

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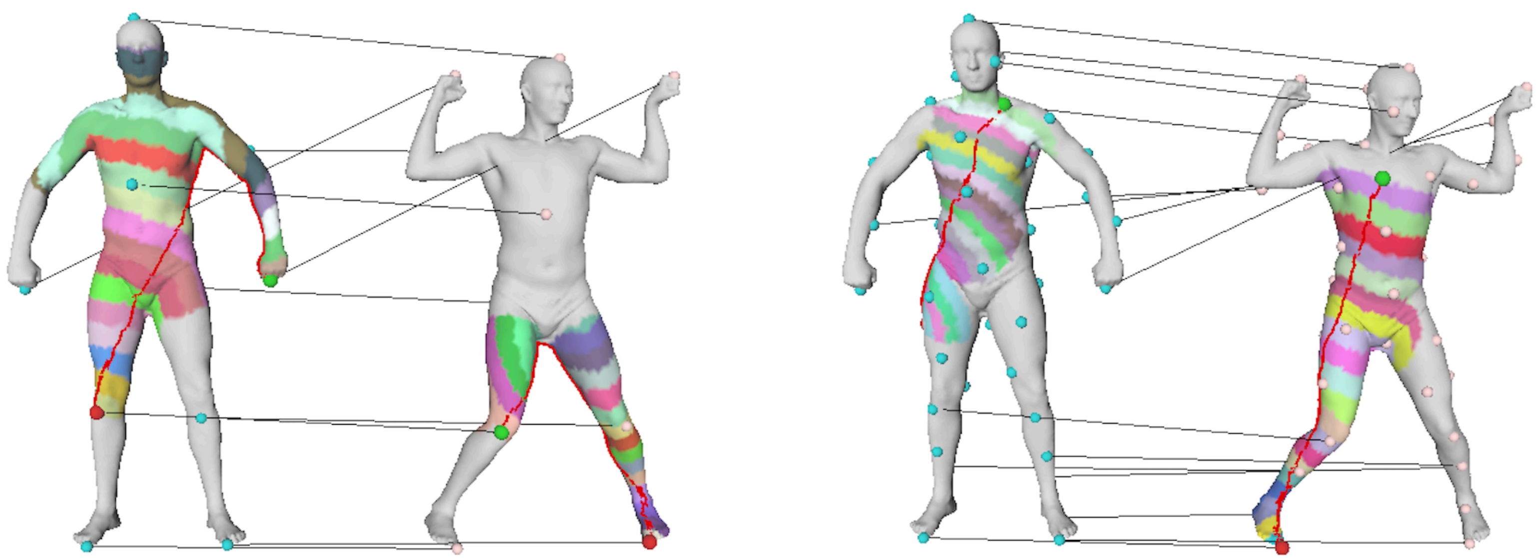
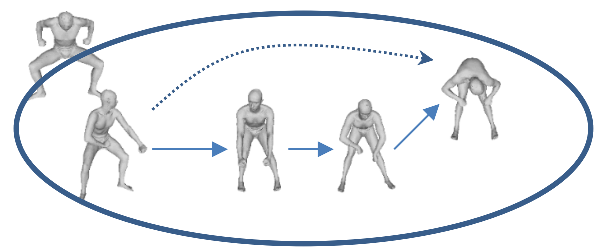
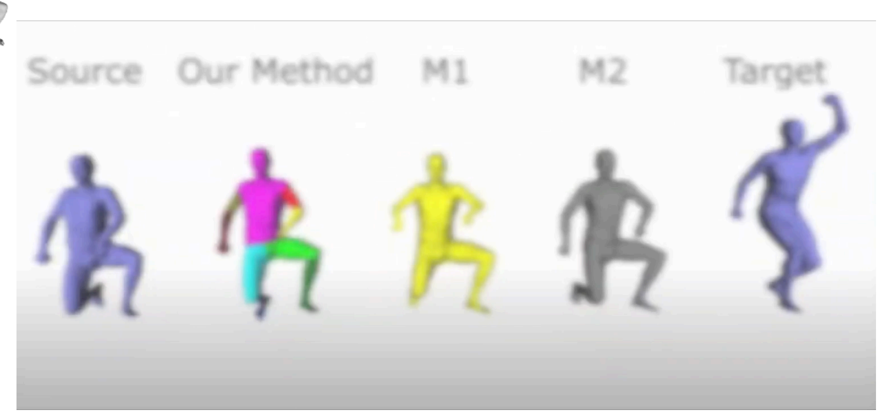


Bilateral Maps for Partial Matching, O. van Kaick., H. Zhang, G. Hamarneh, Computer Graphics Forum, 2013.

Interpolation

- Correspondence in action: shape interpolation
- Interpolate through the shortest path of inter-shapes



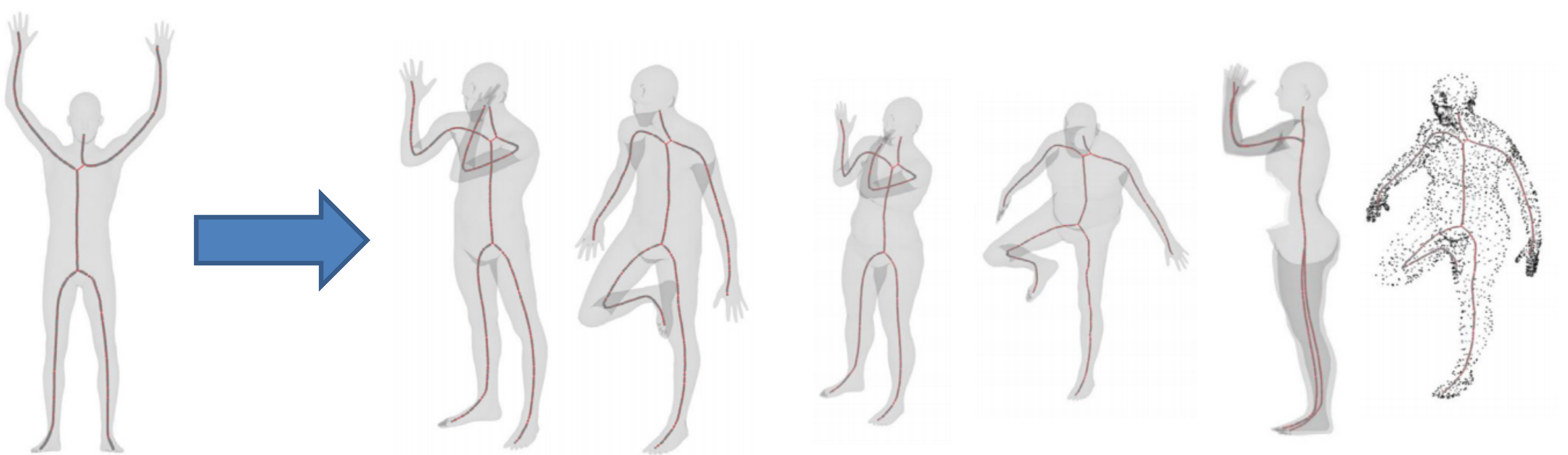


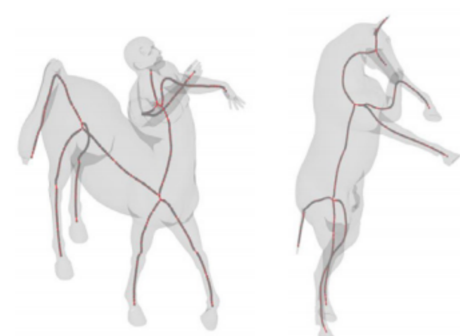
$$v^k_{\text{result}}(\alpha) = \sum_{i=0}^{m} v^k_i b_{i,m}(\alpha), \quad b_{i,m}(\alpha) = \binom{m}{i}\alpha^i(1-\alpha)^{m-i}$$

Part-Based Data-Driven 3D Shape Interpolation, M. Aydınlılar., Y. S., Computer-Aided Design, 2020.

Skeleton

- Correspondence in action: skeleton extraction/transfer
- Transfer the skeleton in source mesh to the target mesh using surface mesh correspondences

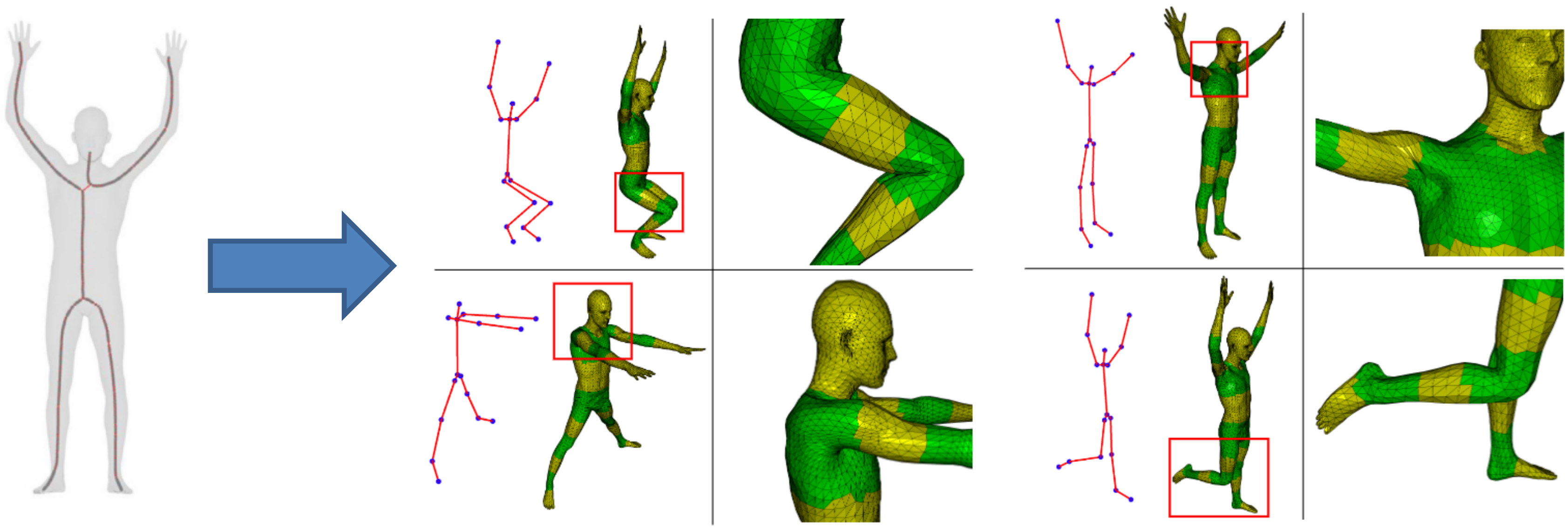




3D Skeleton Transfer for Meshes and Clouds, Ç. Seylan., Y. S., Graphical Models, 2019.

Skeleton

- Correspondence in action: inverse problem, skin extract
- Transfer the source mesh to the target skeleton using skeleton correspondences



XXX, Ç. Seylan., Y. S., under revision, 2020.

Thanks

Papers, codes, executables, lectures, ..: http://ceng.metu.edu.tr/~ys

Y. S., Assoc. Prof.