

Shape, Pose and Resolution Invariant Correspondences for Non-rigid Articulated Objects



Aggeliki Tsoli and Michael Black

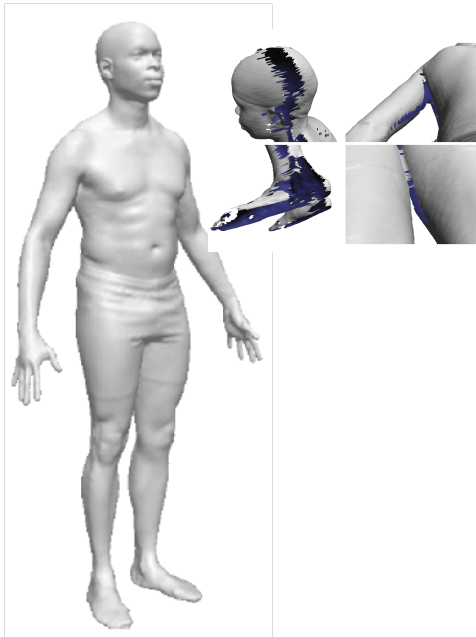


MAX-PLANCK-GESELLSCHAFT

Max Planck Institute for Intelligent Systems
Perceiving Systems Department

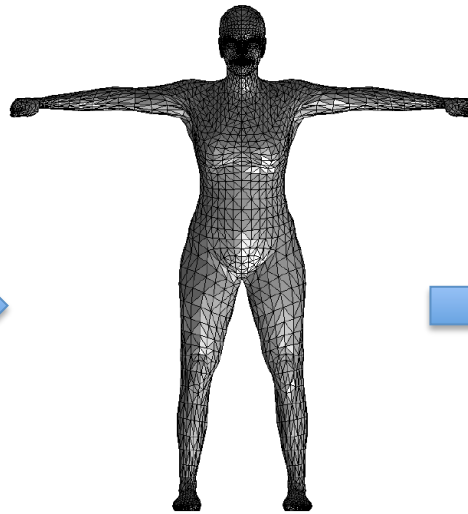
Motivation:

Align 3D model to laser scan data



[Allen et al. '03]

high-resolution scan
(~ 80000 points)

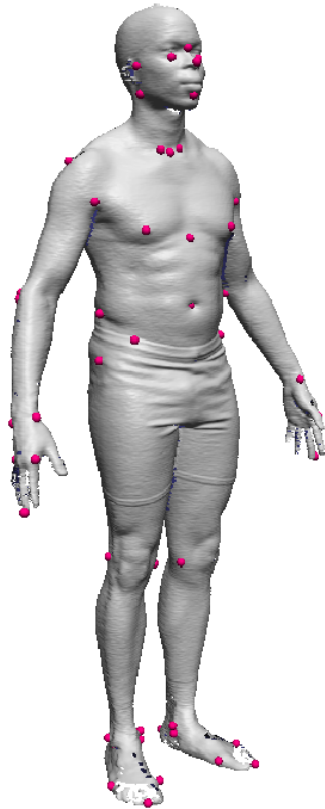


low-resolution model
(~ 5000 points)



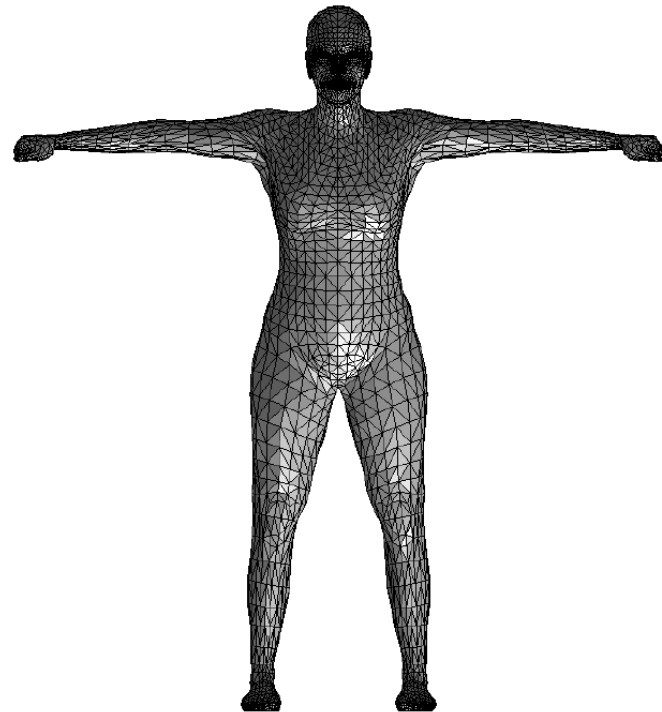
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Align 3D model to laser scan data



high-resolution 3D scan
(~ 80000 points)

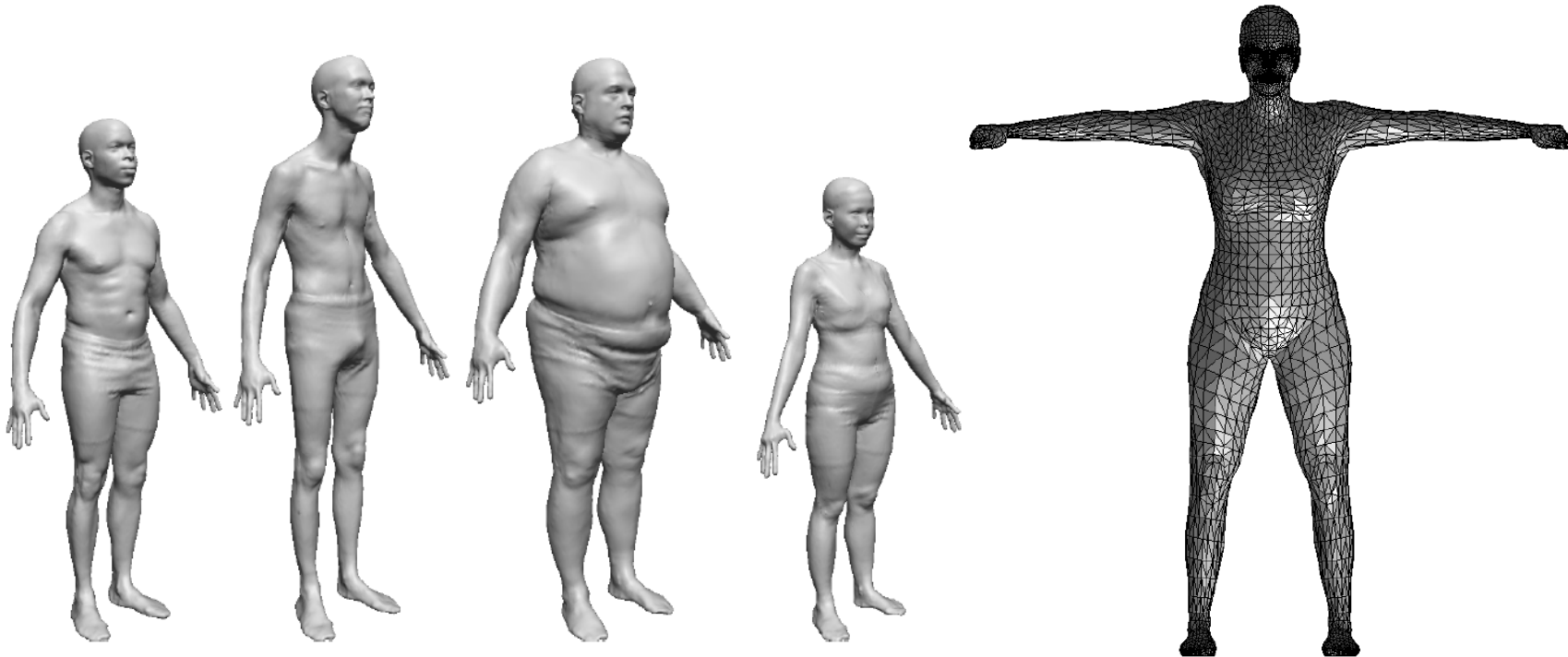
[Allen et al. '03]



low-resolution model
(~ 5000 points)

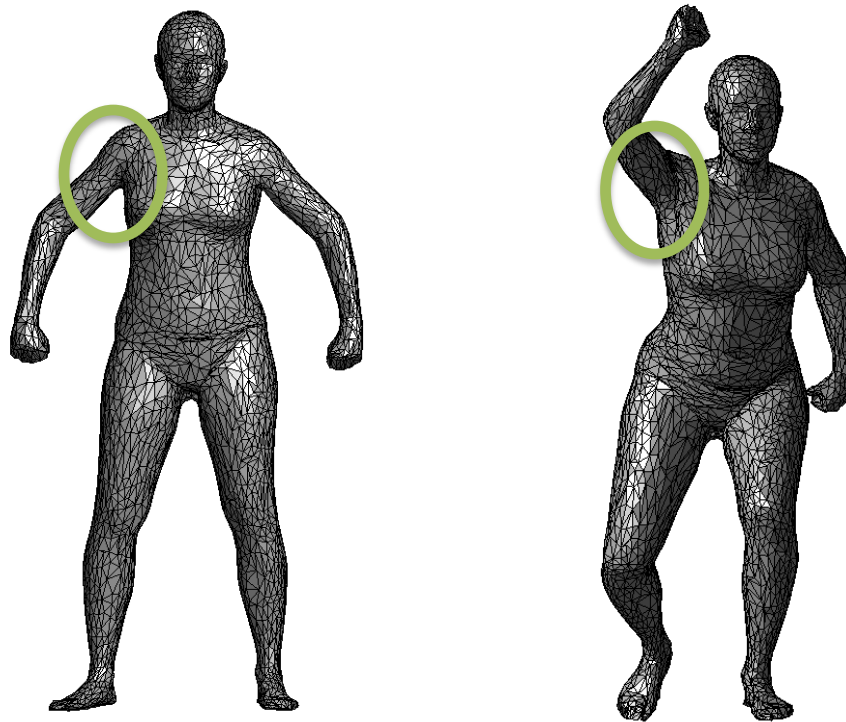
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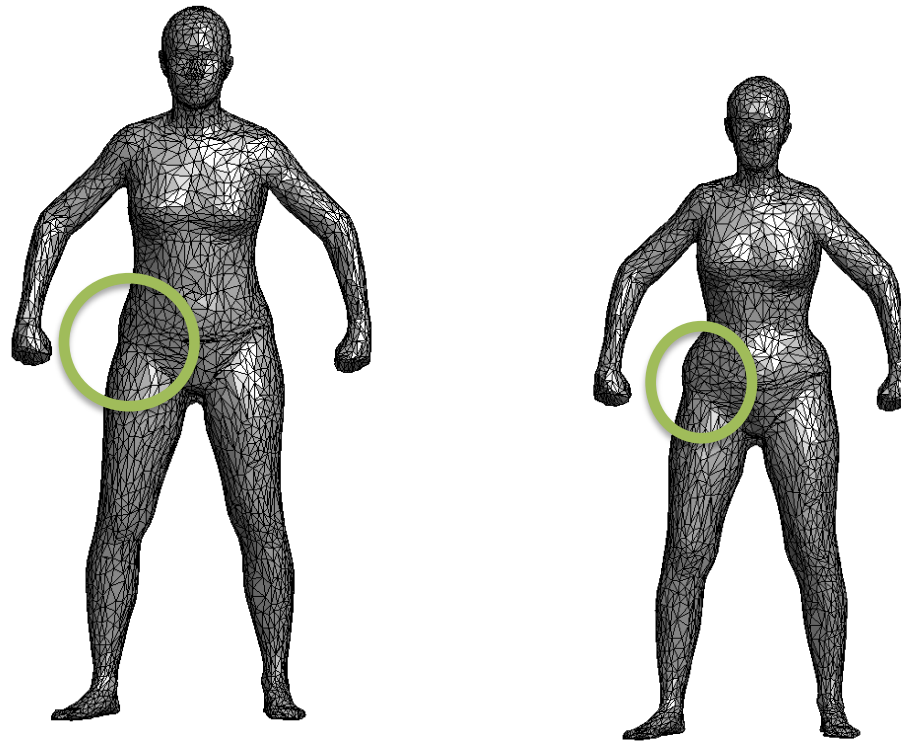
low-resolution model
(~ 5000 points)

Challenge 1: Local geometry changes with pose



pose variation

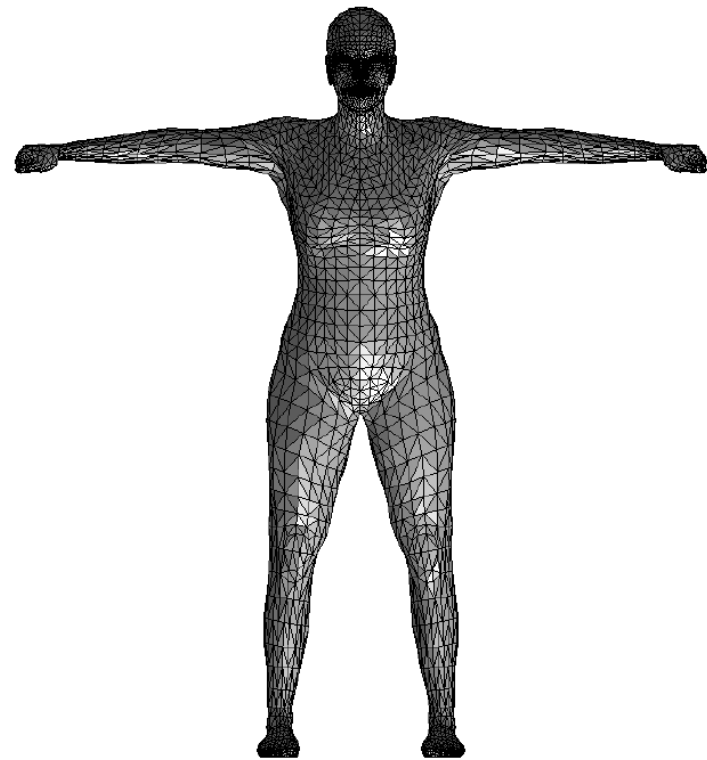
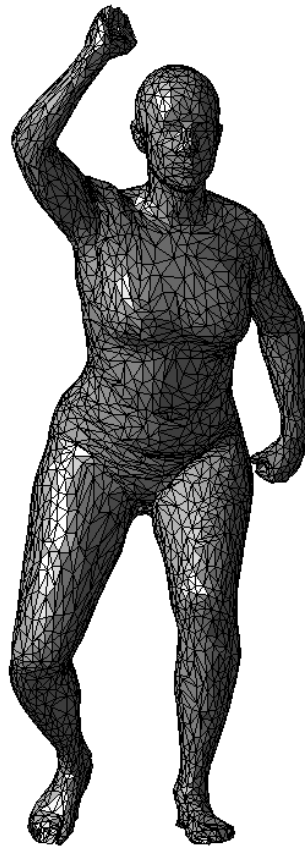
Challenge 2: Local geometry changes with shape



shape variation

Challenge 3:

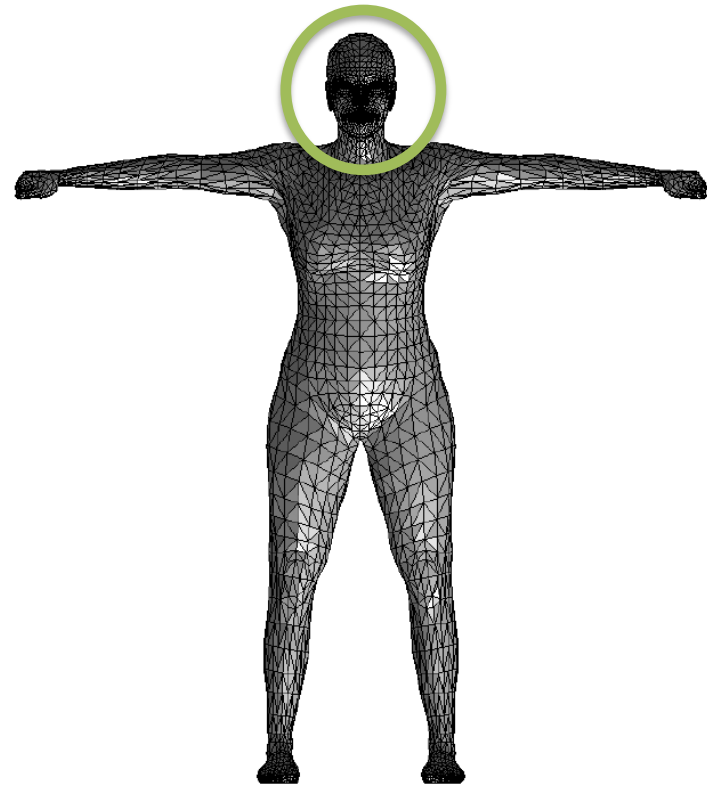
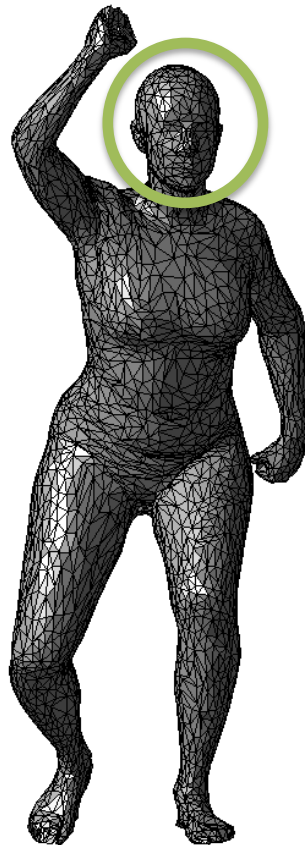
Correspondence between meshes with different resolution



Challenge 3:

Correspondence between meshes with
different resolution

almost uniform
resolution

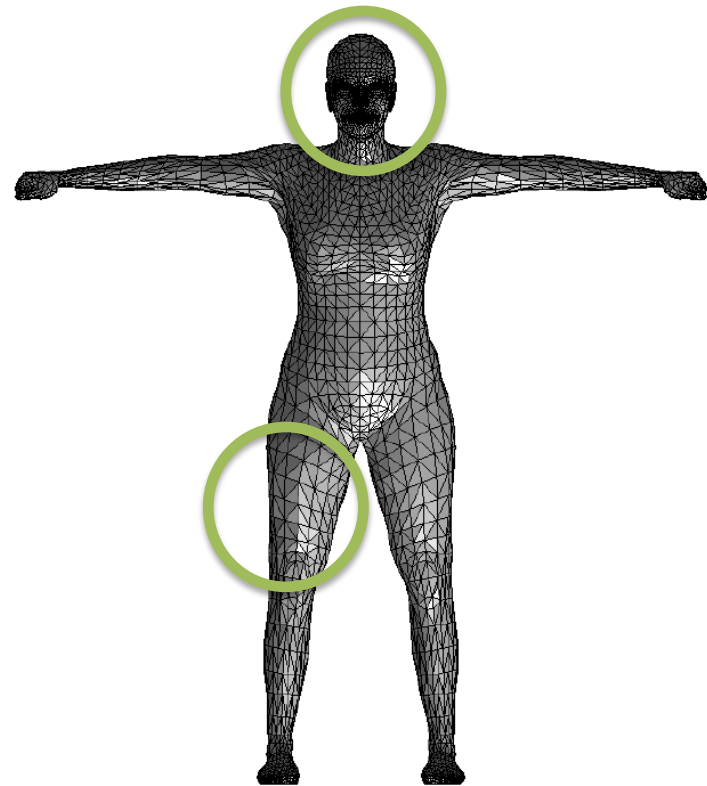
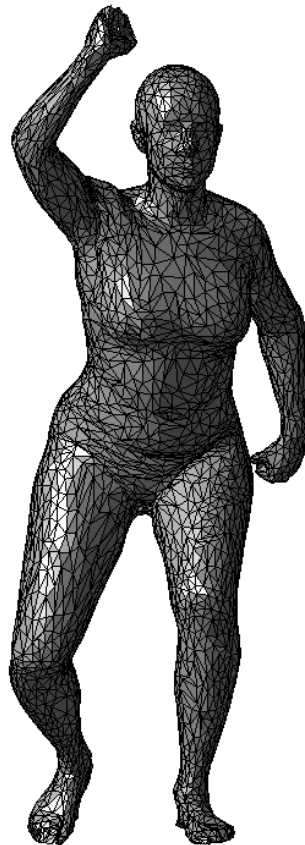


Different resolution between scan and model

Challenge 3:

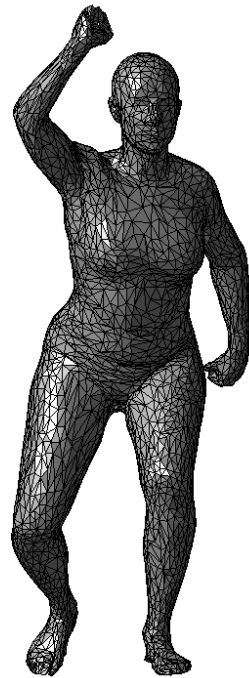
Correspondence between meshes with
different resolution

almost uniform
resolution

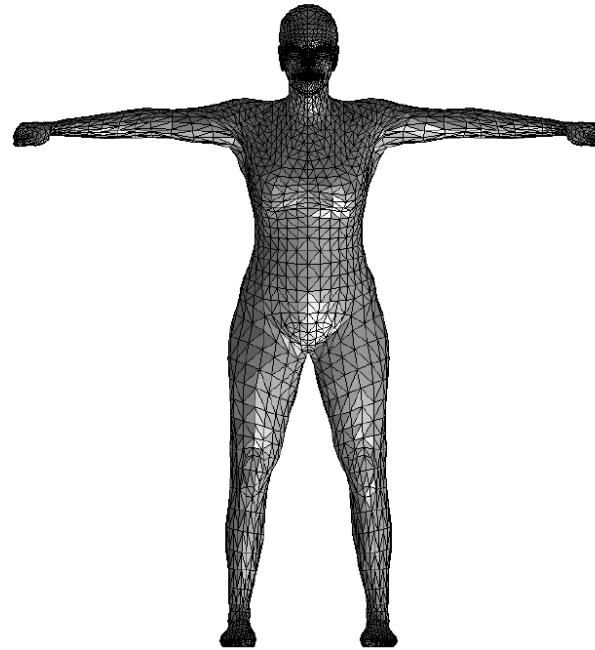


Different resolution within model

Challenge 4: Exponential space of correspondences



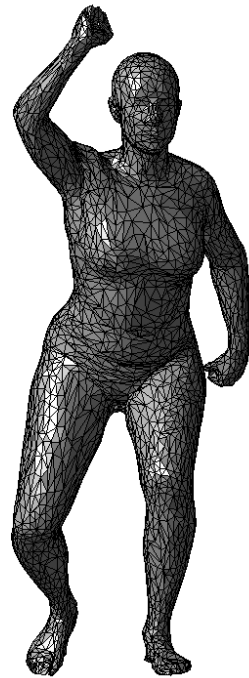
M vertices



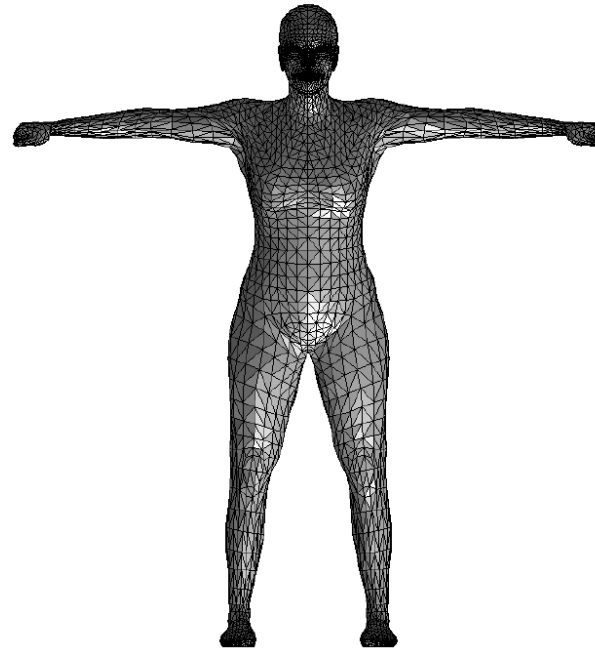
N vertices

- approximately N^M possible correspondences

Challenge 4: Exponential space of correspondences



4000 vertices



2000 vertices

- approximately 3000^{4000} possible correspondences!
=> Search may end up in local minima

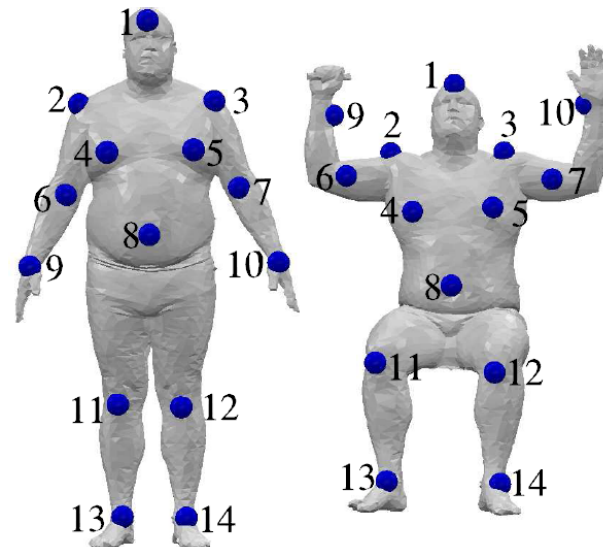
Question

*“How do we **search** for correspondences between **non-rigid articulated objects** with significant variation in **pose**, **shape** and **resolution**?”*

Previous work:

Correlated Correspondence (CC) [Anguelov et al. '04]

- Probabilistic framework
 - loose pairwise geodesic constraints
 - geometric local descriptors (spin images [Johnson 1997])

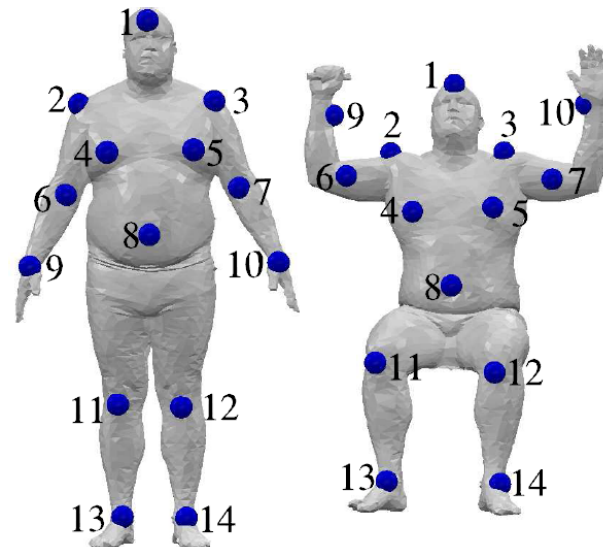


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X only for high-res scans



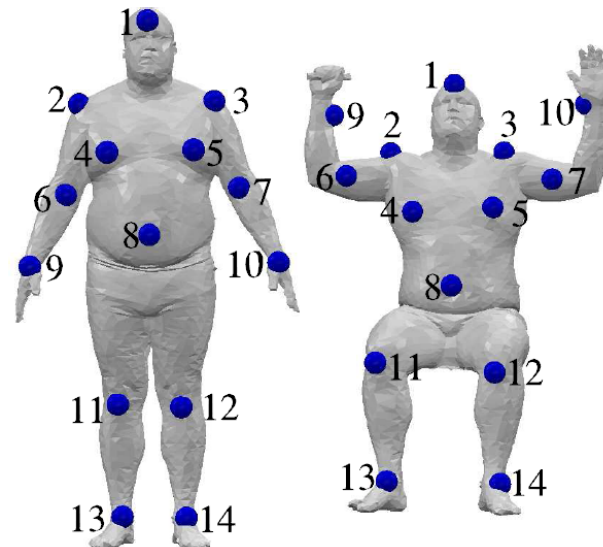
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X only for high-res scans

X small shape variation



Previous work:

Generalized Multidimensional Scaling (GMDS)

[Bronstein et al. '06]

- Root Mean Squared (RMS) error between geodesic distances on surfaces Z, X



surface Z



surface X

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X Local minima



surface Z



surface X

Contributions

X HIGH-res to HIGH-res
meshes
X small shape variation
X sensitive to local
minima

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X HIGH-res to HIGH-res
meshes
X small shape variation
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minima

- Strict geodesic constraints
- Pose/shape/res invariant local descriptors

Contributions

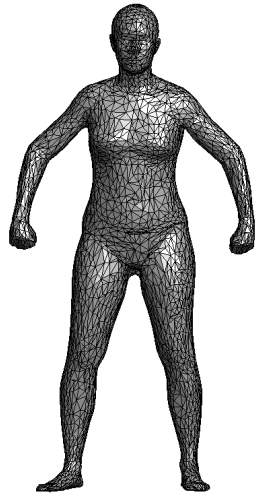
X HIGH-res to HIGH-res
meshes
X small shape variation
X sensitive to local
minima



✓ HIGH-res to HIGH/LOW-
res meshes
✓ large shape/pose
variation
✓ more meaningful
correspondences

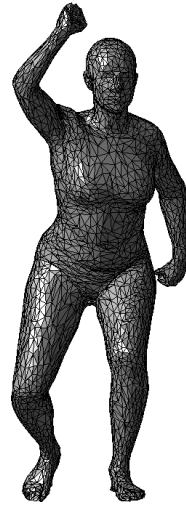
Problem Statement

Input:



Data mesh

$$Z = (V^Z, E^Z)$$
$$V^Z = (z_1, \dots, z_{N^Z})$$

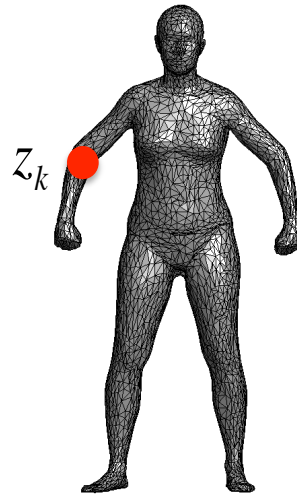


Model mesh

$$X = (V^X, E^X)$$
$$V^X = (x_1, \dots, x_{N^X})$$

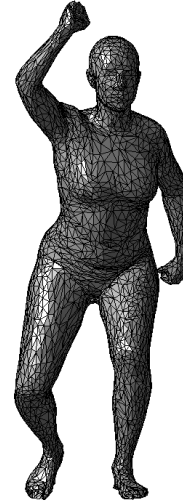
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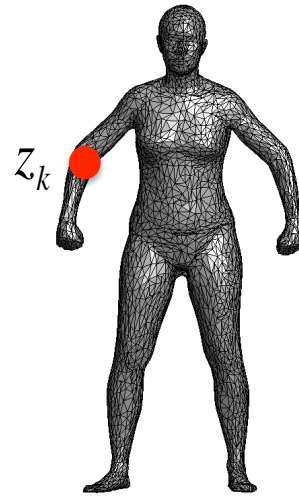


Model mesh

$$X = (V^X, E^X)$$
$$V^X = (x_1, \dots, x_{N^X})$$

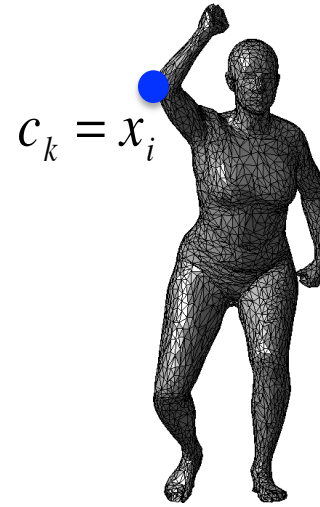
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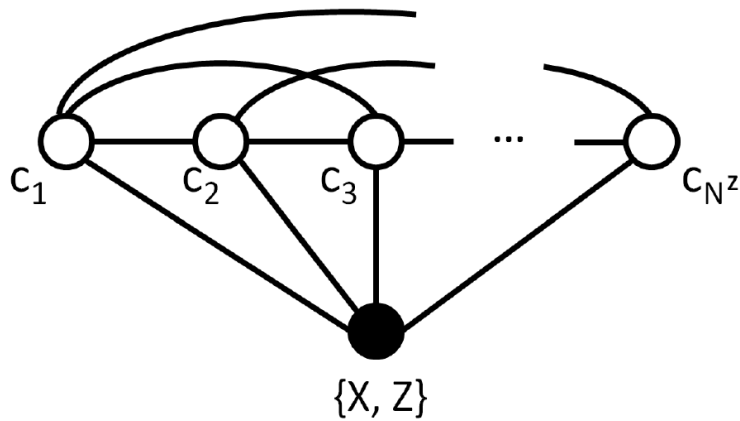
Model mesh

$$X = (V^X, E^X)$$
$$V^X = (x_1, \dots, x_{N^X})$$

Output: correspondence variables $C = (c_1, \dots, c_{N^Z})$

$$c_k \in \{1, \dots, N^X\}$$

Conditional Random Field (CRF) model

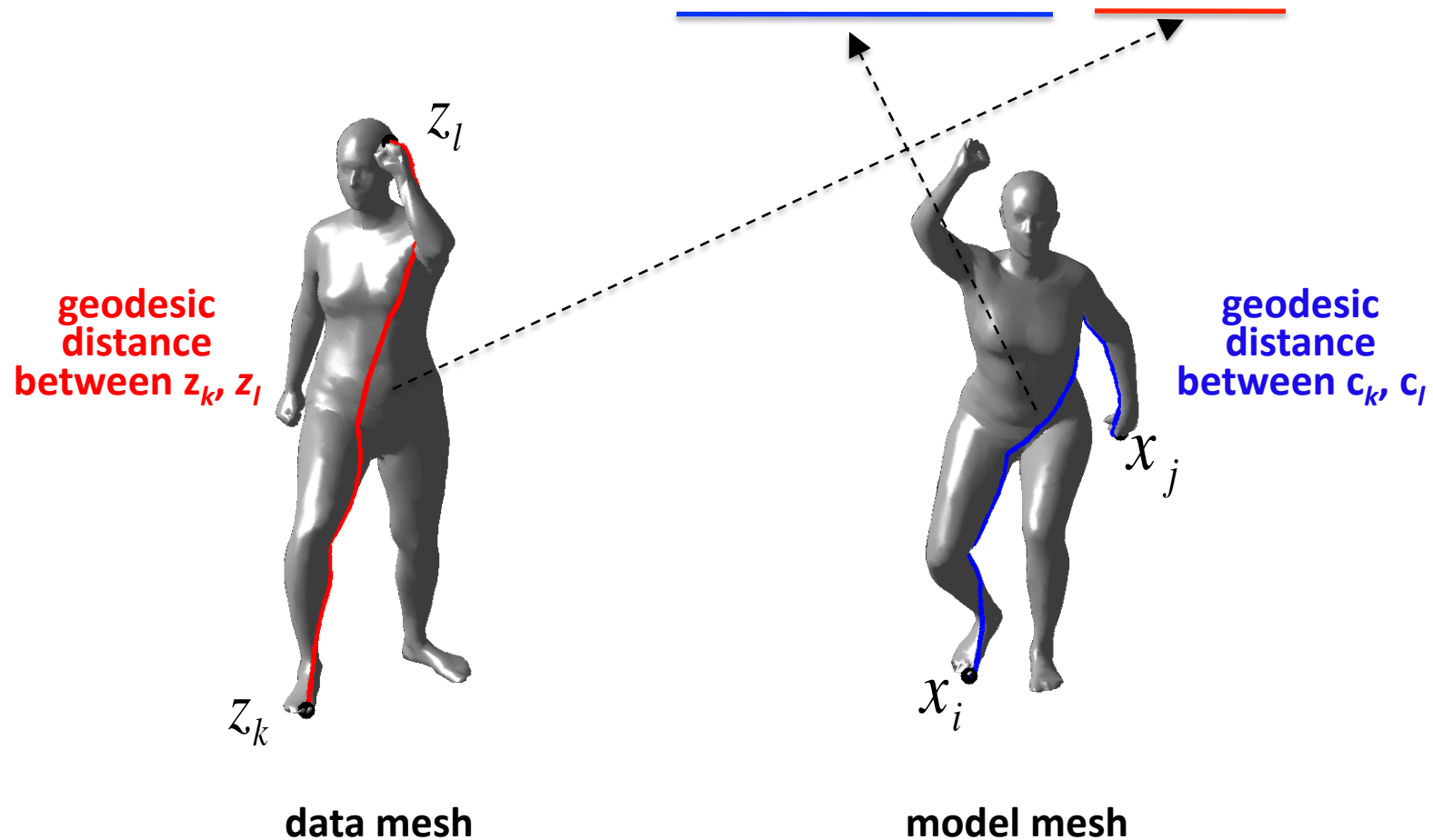


$$\arg \max_C p(C | X, Z)$$

$$p(C | X, Z) \propto \prod_k \underbrace{\phi(c_k, X, Z)}_{\text{geodesic signature potential}} \prod_{k,l} \underbrace{\psi(c_k, c_l, X, Z)}_{\text{pairwise geodesic potential}}$$

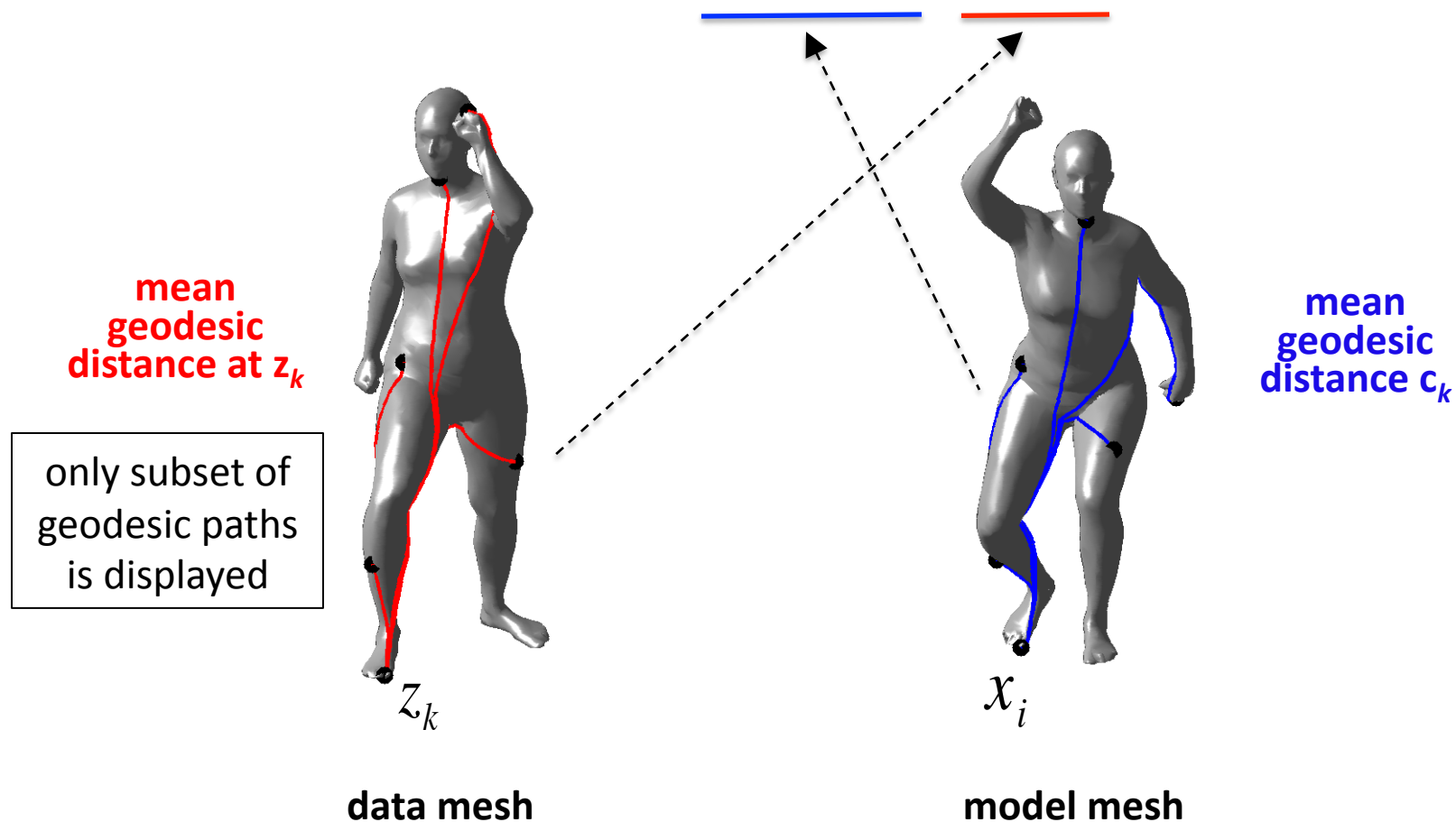
Pairwise geodesic potential

$$\psi(c_k = x_i, c_l = x_j, X, Z) = N(h(c_k = x_i, c_l = x_j; X), h(x_i, x_j; Z), \sigma_{kl}^2)$$

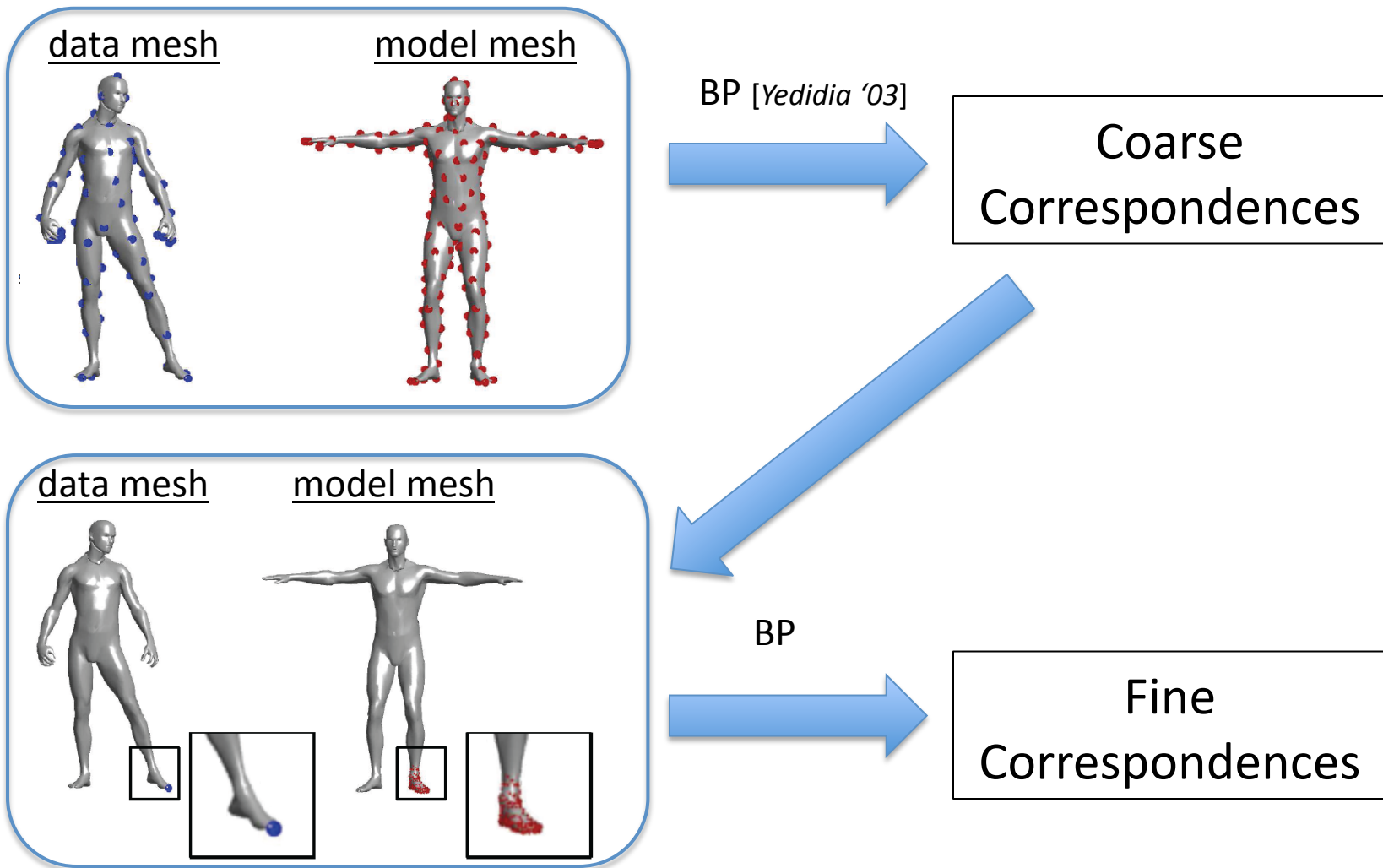


Geodesic signature potential

$$\psi(c_k = x_i, X, Z) = N(\underbrace{g(c_k = x_i; X)}_{\text{blue}}, \underbrace{g(k; Z)}_{\text{red}}, \sigma_k^2)$$

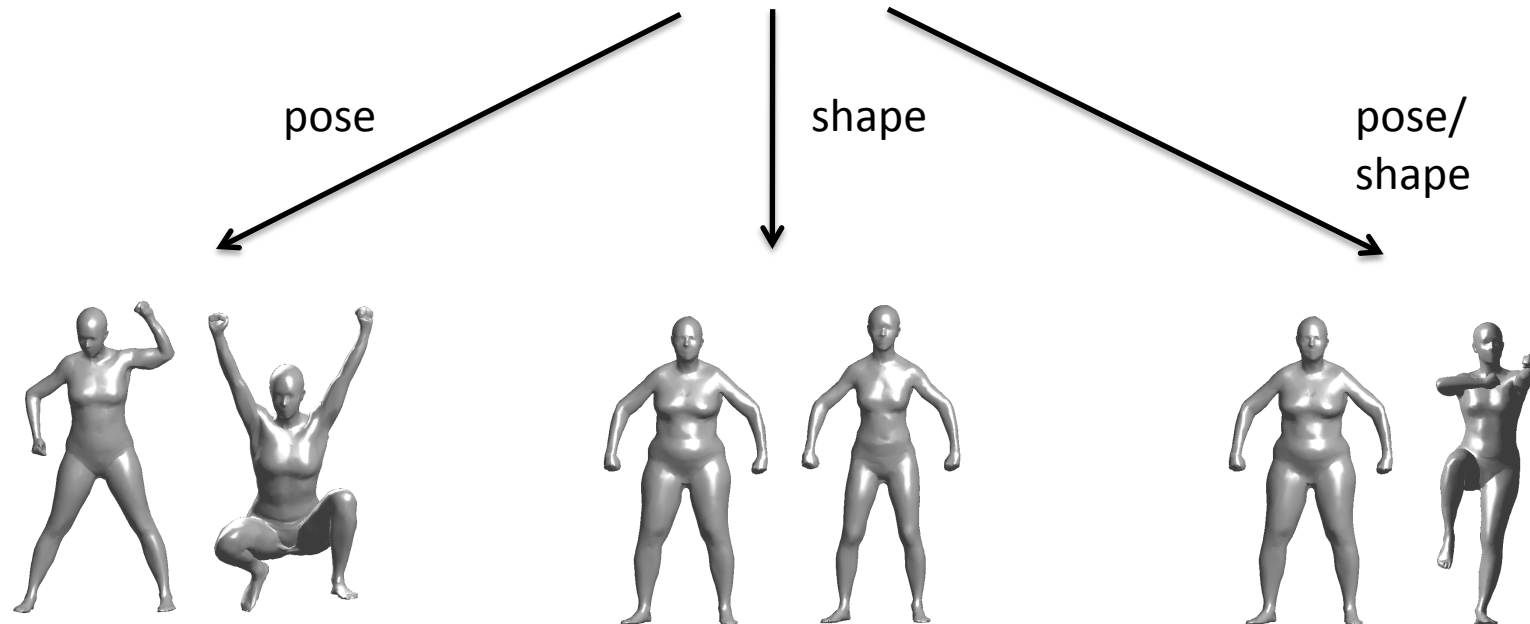


Our algorithm: Probabilistic Geodesic Surface Embedding (PGSE)



Dataset 1 – SCAPE bodies

- SCAPE model [Anguelov et al. '05]
 - pose and shape factorization



Dataset 2 – TOSCA nonrigid world

- 148 nonrigid objects (females, males, cats, dogs, horses etc.)
- only “pose” variation



http://tosca.cs.technion.ac.il/book/resources_data.html

Results – SCAPE bodies

GMDS



data mesh

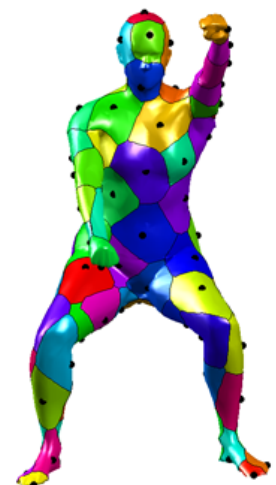


model mesh

PGSE



data mesh

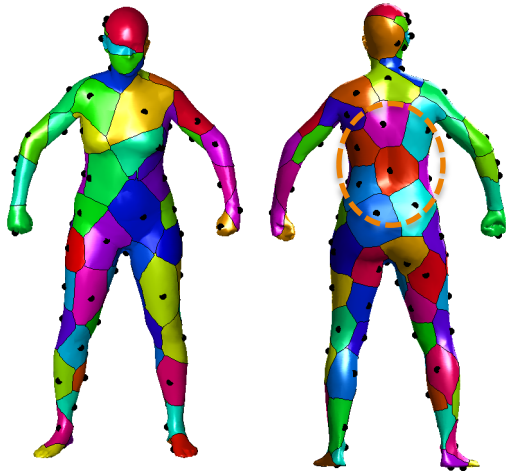


model mesh

Geodesic-based error metric

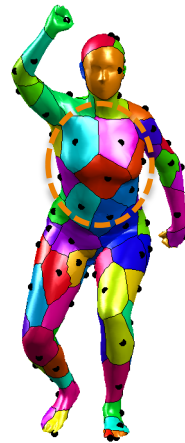
GMDS

data mesh



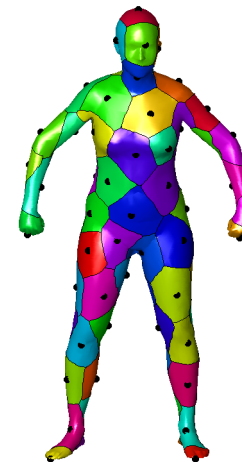
$$T_g = 0.043$$

model mesh

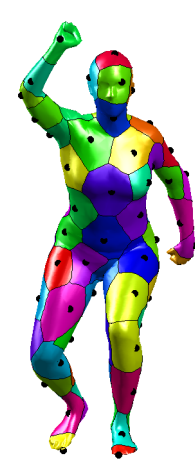


PGSE

data mesh



model mesh



$$T_g = 0.06$$

Low error
Bad fit

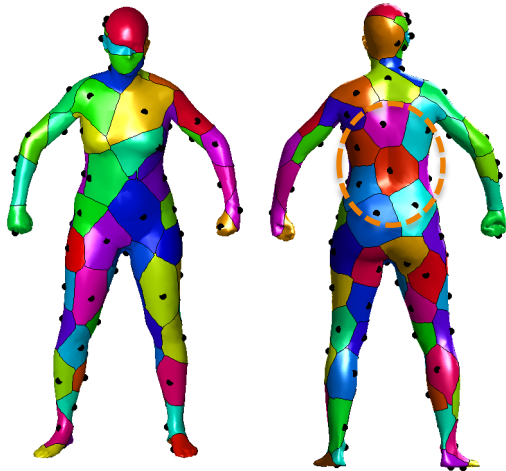
$$T_g = \text{mean} \left(\begin{array}{c} \text{geodesic} \\ \text{distances} \\ \text{in data mesh} \end{array} - \begin{array}{c} \text{corresponding} \\ \text{geodesic} \\ \text{distances} \\ \text{in model mesh} \end{array} \right)$$

Higher error
Better fit

Voronoi-based error metric

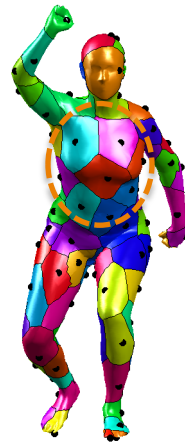
GMDS

data mesh



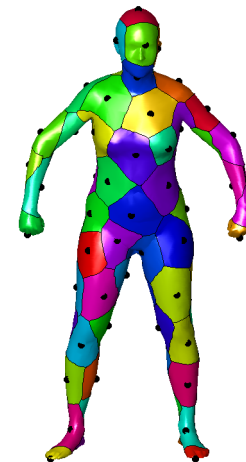
$$T_e = 0.28$$

model mesh



PGSE

data mesh



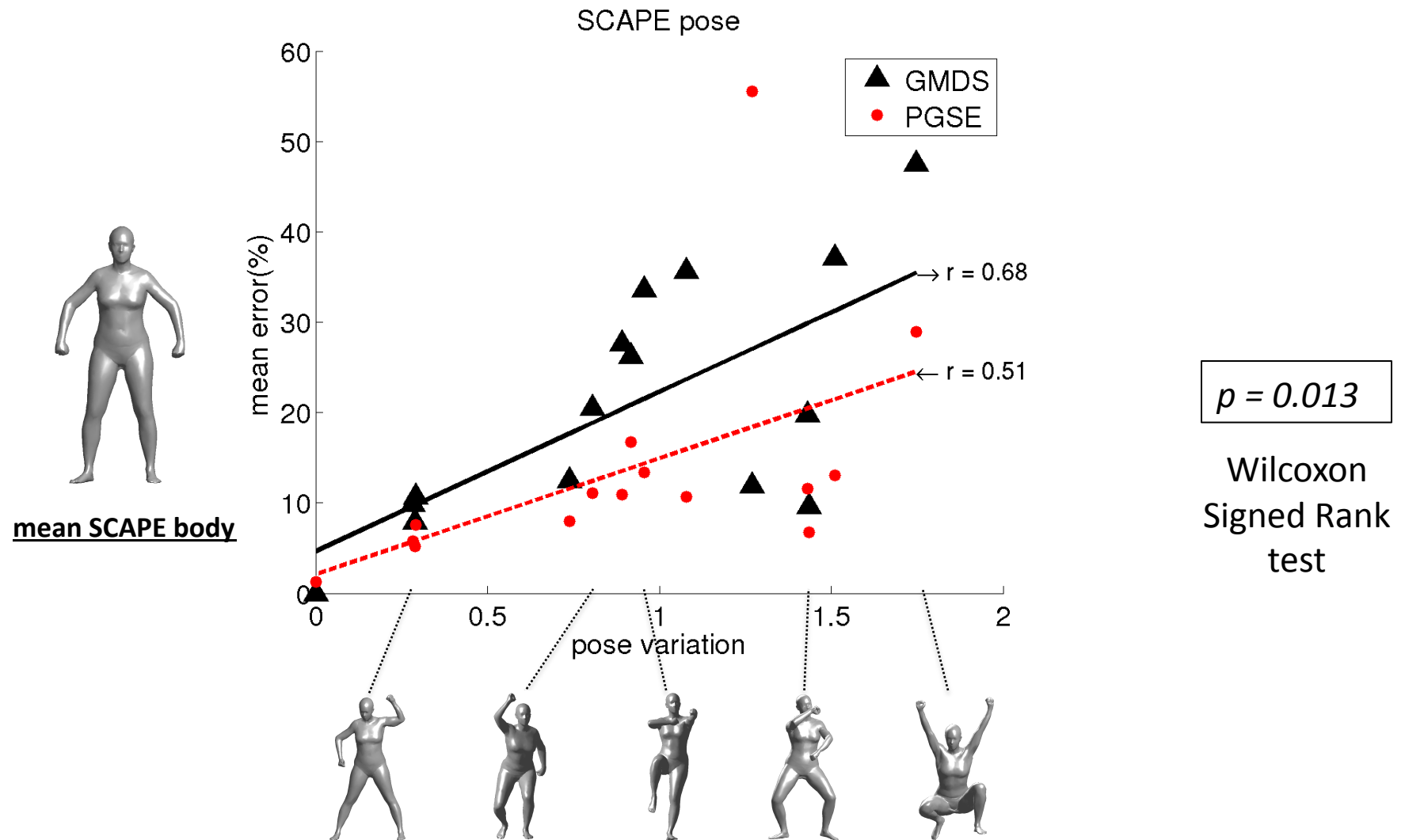
model mesh



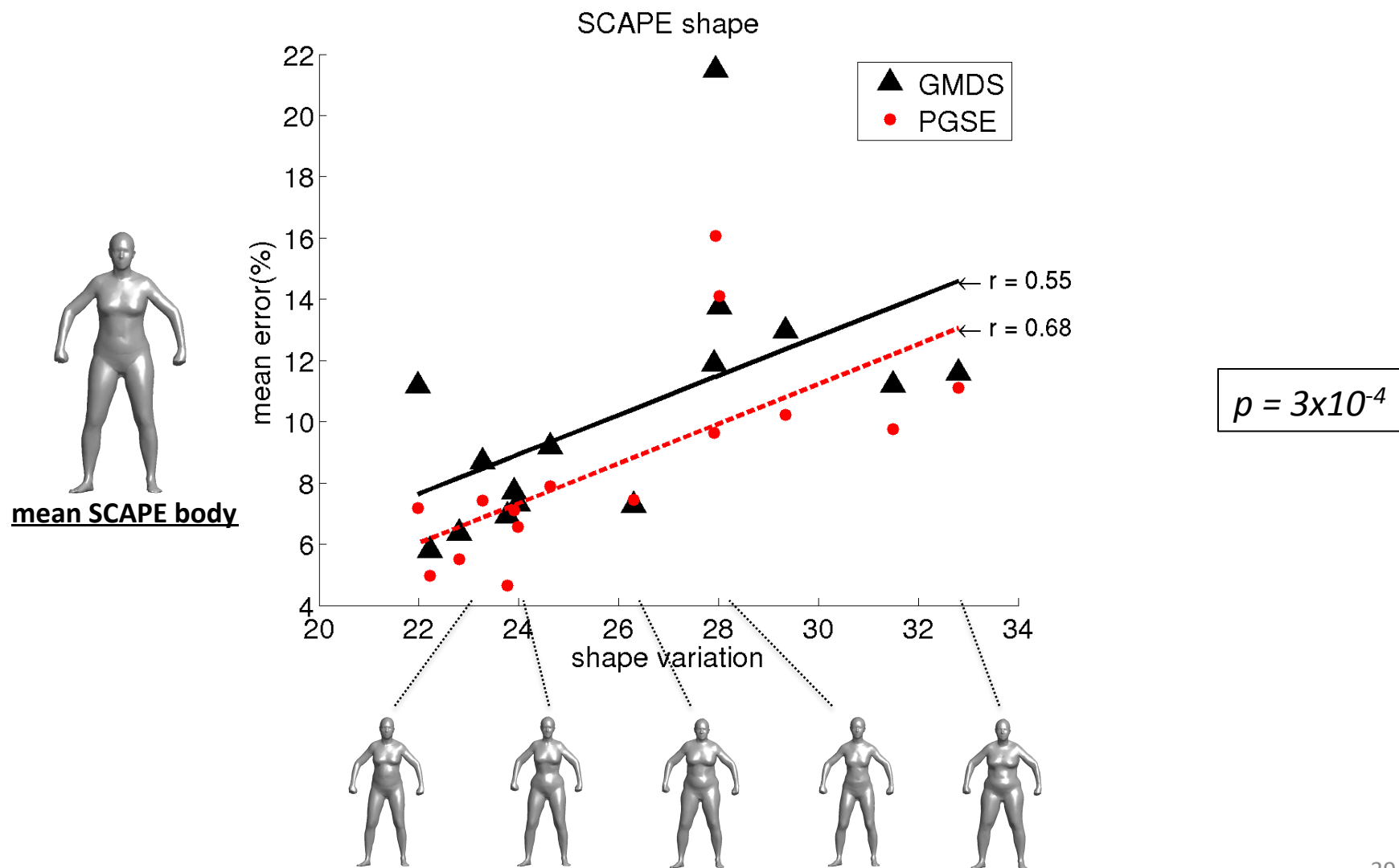
$$T_e = 0.11$$

$$T_e = \text{mean} \left(\begin{array}{c} \text{Voronoi} \\ \text{areas} \\ \text{in data mesh} \end{array} - \begin{array}{c} \text{corresponding} \\ \text{Voronoi} \\ \text{areas} \\ \text{in model mesh} \end{array} \right)$$

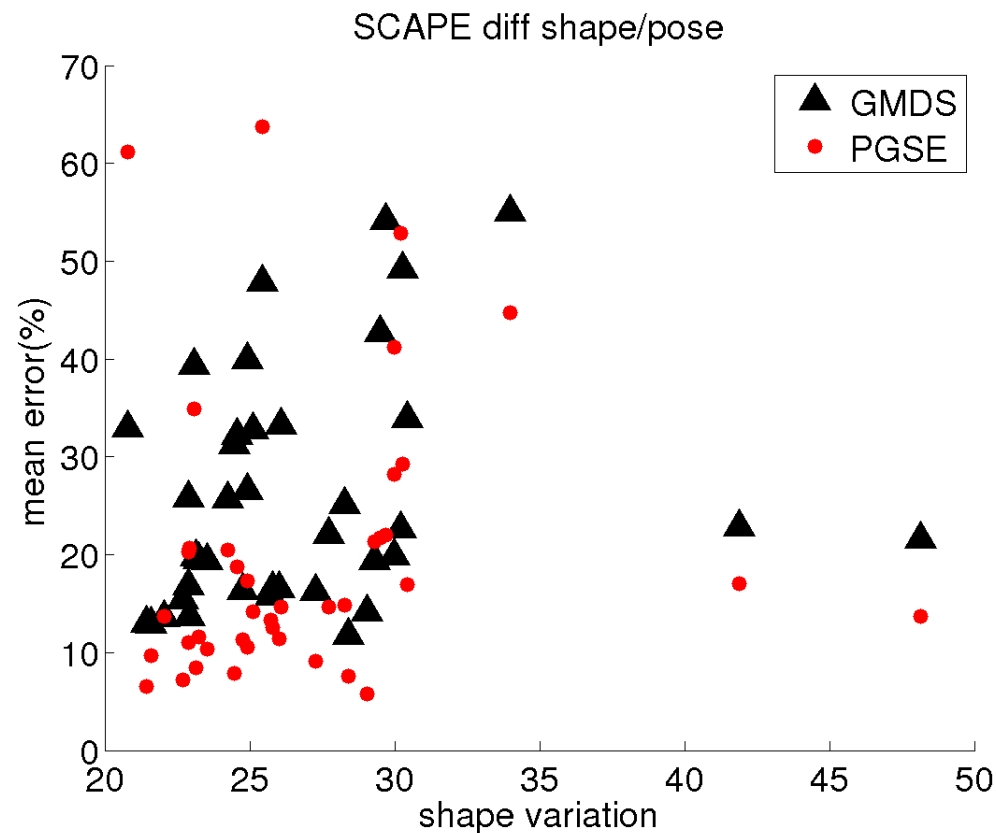
Mean error on pose variation



Mean error on shape variation

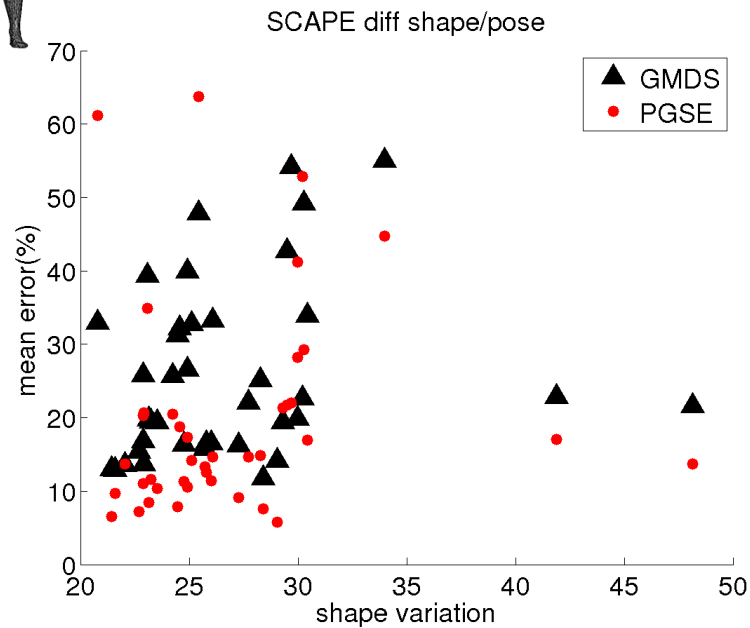
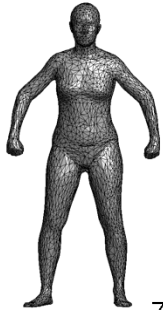


Mean error on pose and shape variation

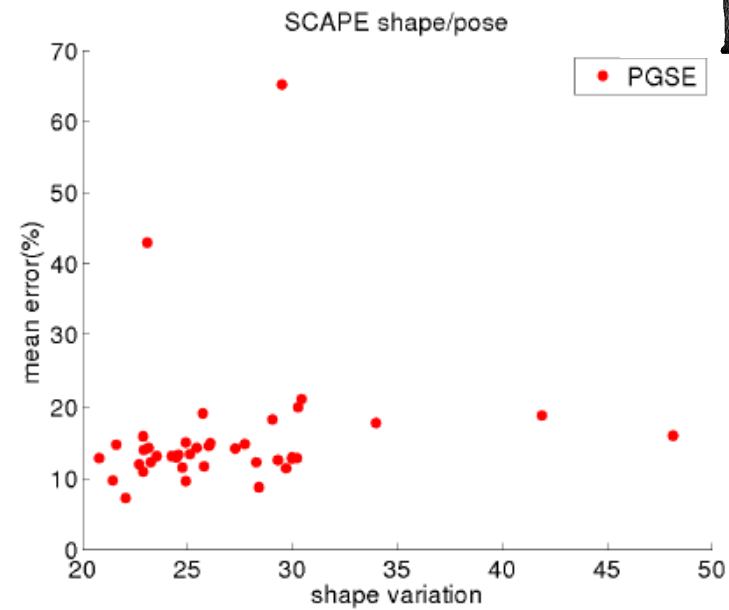
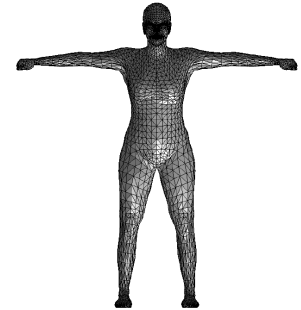


Resolution experiments

mean SCAPE body:



template:



Results – TOSCA nonrigid world

GMDS



data mesh



model mesh

PGSE



data mesh



model mesh

Results – TOSCA nonrigid world

- 146 objects, various poses

	GMDS	PGSE
Mean Voronoi error	0.2799	0.1410
Standard deviation	0.1564	0.1059

Wilcoxon
Signed Rank
test

$$p = 3 \times 10^{-16}$$

Conclusions

- Pose/shape/resolution invariant correspondence
 - geodesic distance preservation
 - local descriptors
- Future work:
 - experiments with 3D laser scans
 - partial matching
 - changes in topology (intersecting parts)
 - evaluation using ground truth correspondences

Acknowledgements

- Computer vision lab @ MPI
- Office of Naval Research (contract W911QY-10-C-0172)

Thank you!