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

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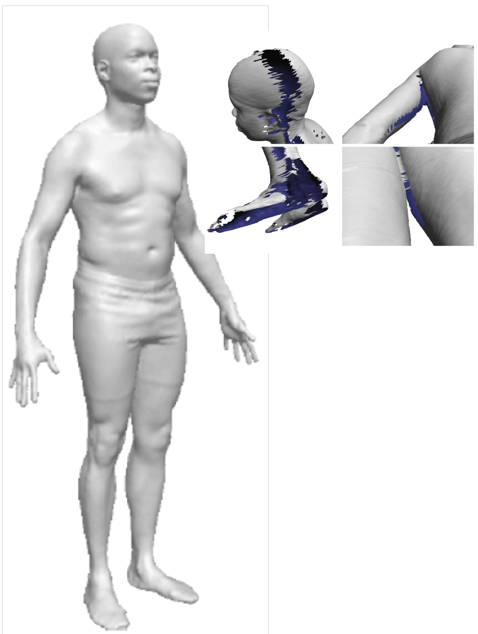
Max Planck Institute for Intelligent Systems

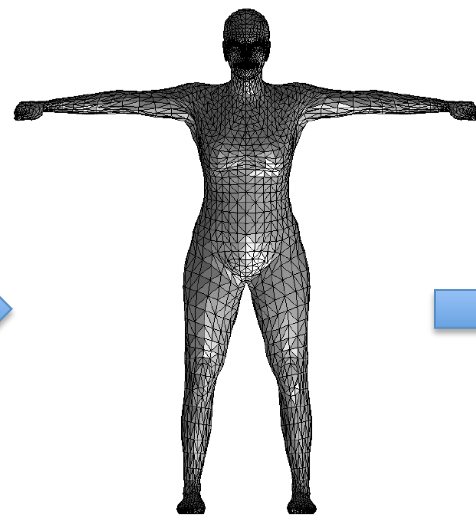
Perceiving Systems Department

Motivation:
Align 3D model to laser scan data

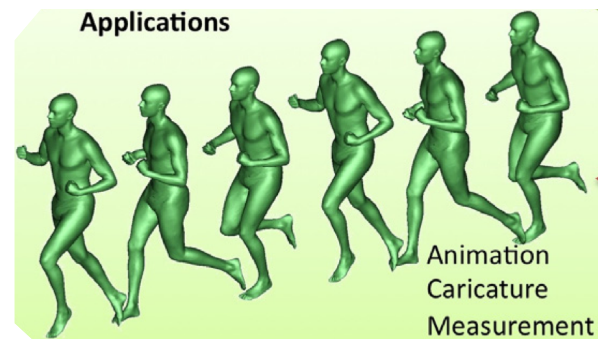


[Allen et al. '03]

high-resolution scan
(~ 80000 points)



low-resolution model
(~ 5000 points)



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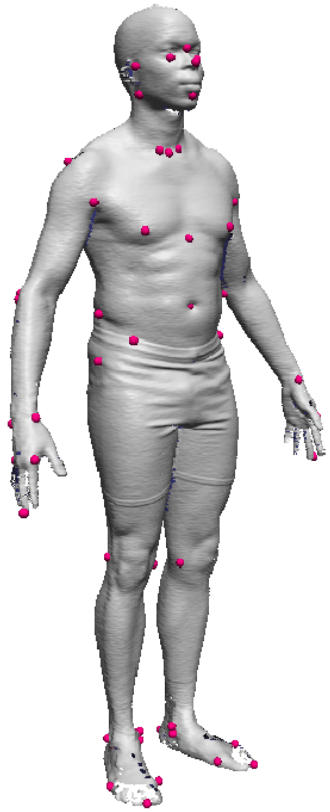

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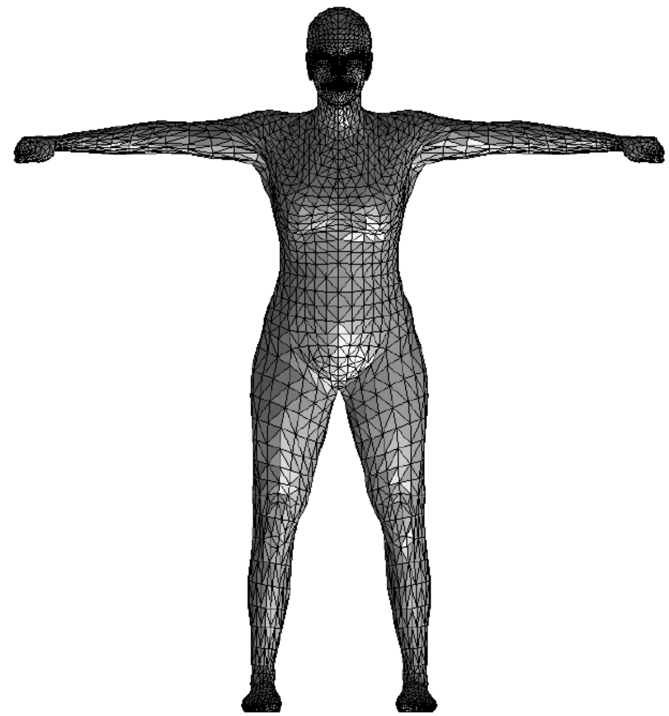

high-resolution 3D scan
(~ 80000 points)

low-resolution model
(~ 5000 points)

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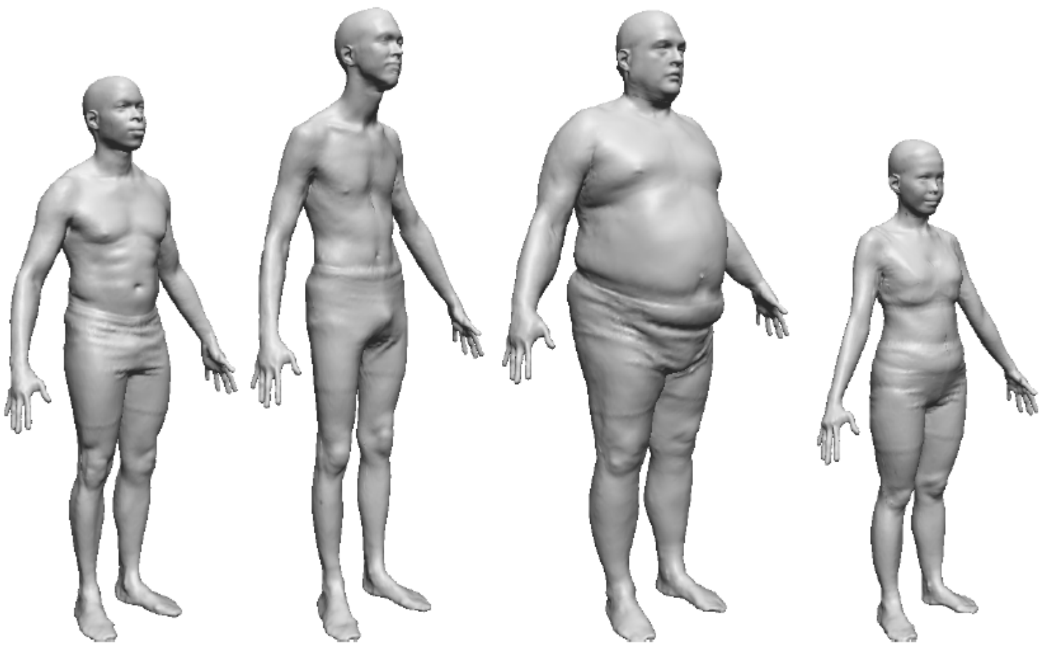
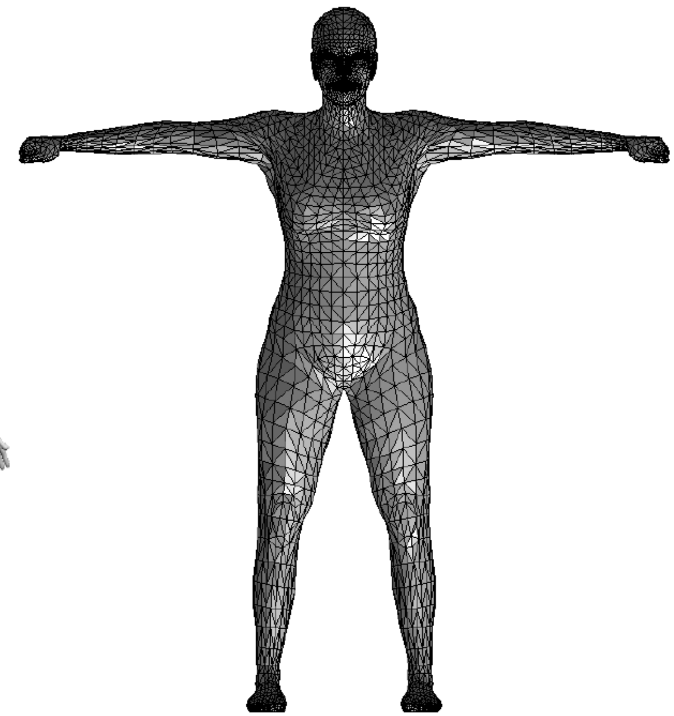
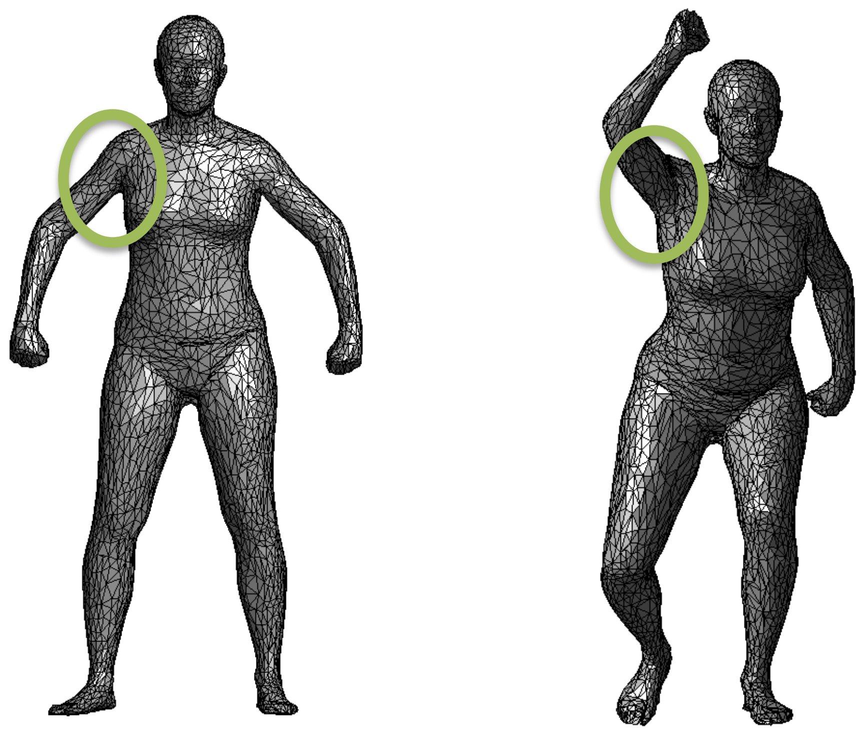




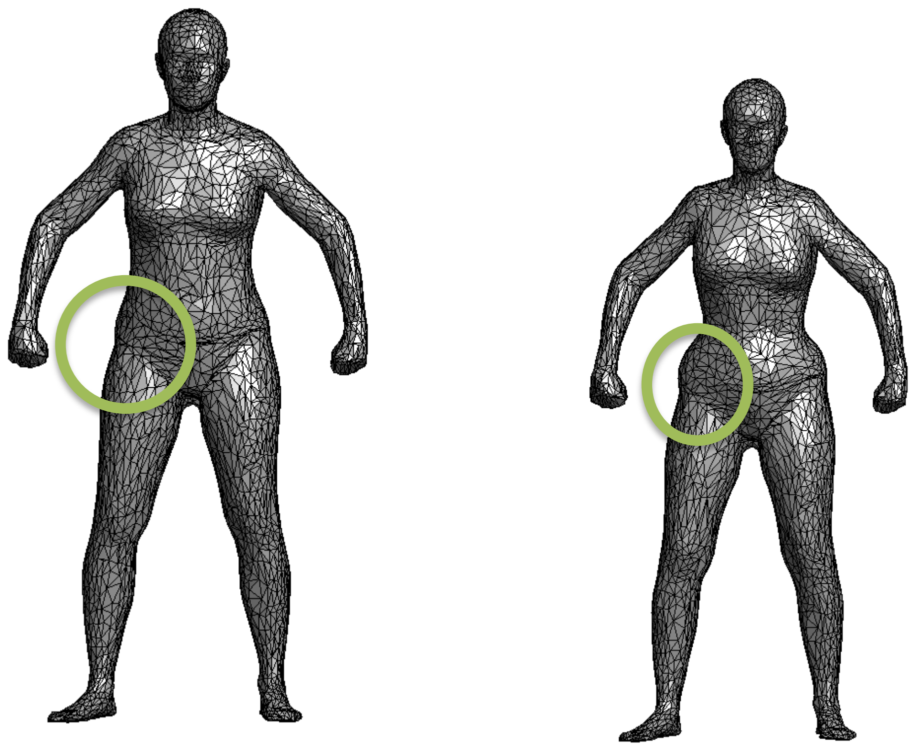
low-resolution model
(~ 5000 points)

Challenge 1: Local geometry changes with pose



pose variation

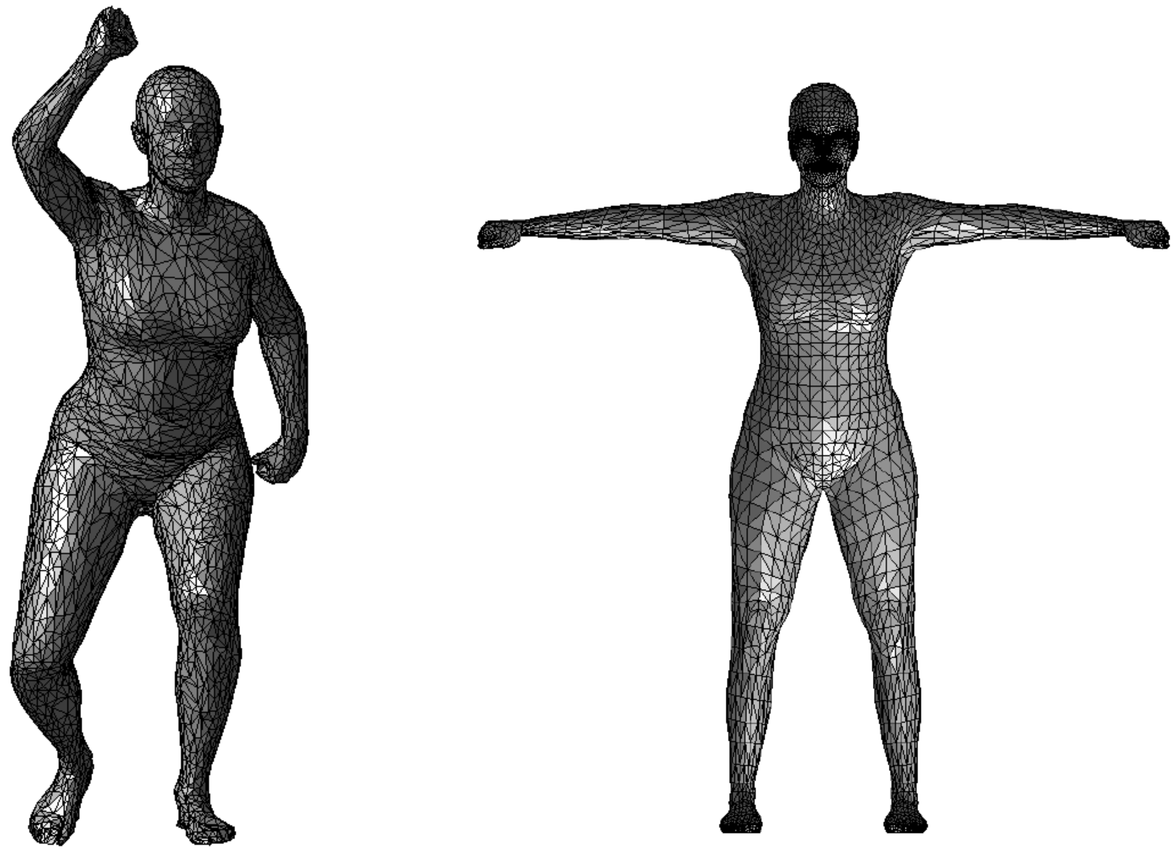
Challenge 2:
Local geometry changes with shape



shape variation

Challenge 3:

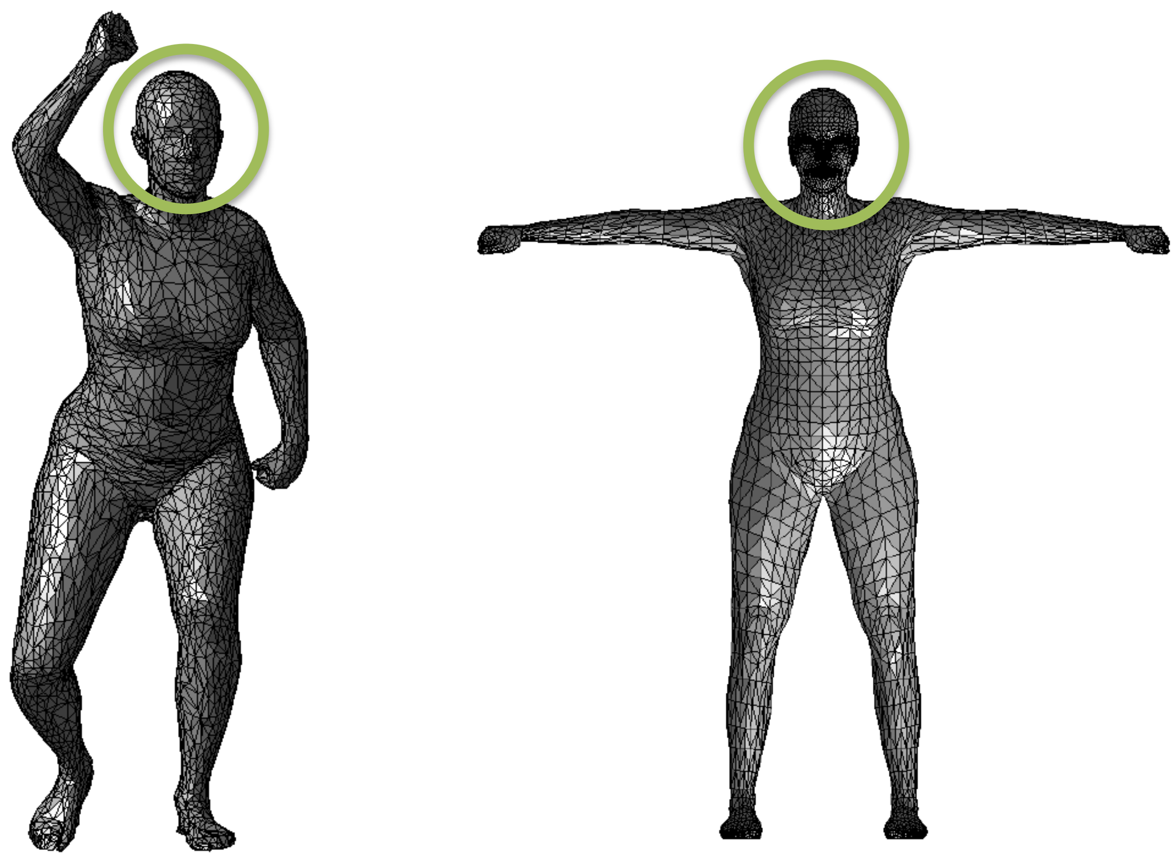
Correspondence between meshes with different resolution



Challenge 3:

Correspondence between meshes with different resolution

almost uniform resolution

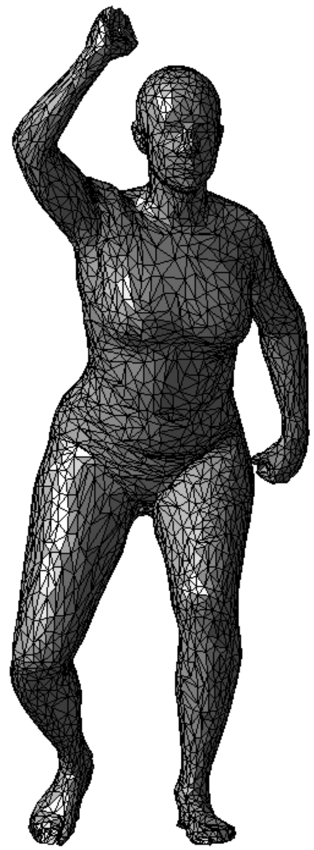


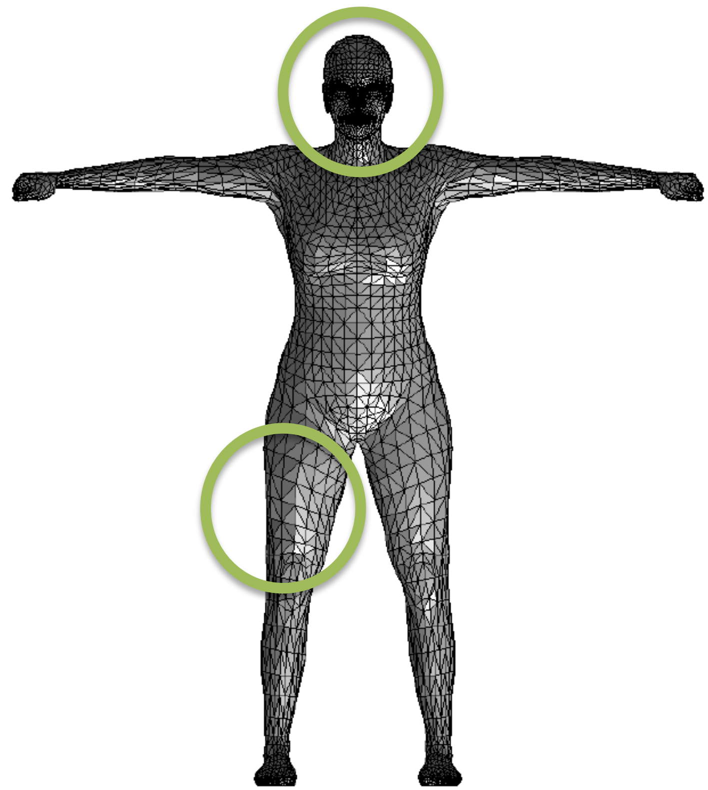
Different resolution between scan and model

Challenge 3:

Correspondence between meshes with different resolution

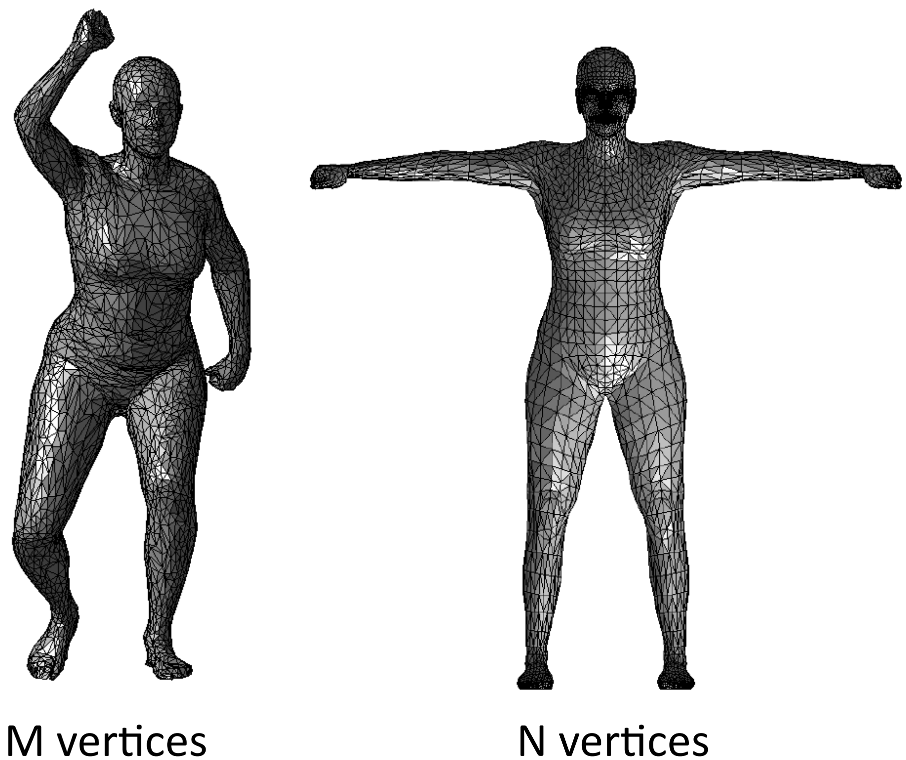
almost uniform resolution





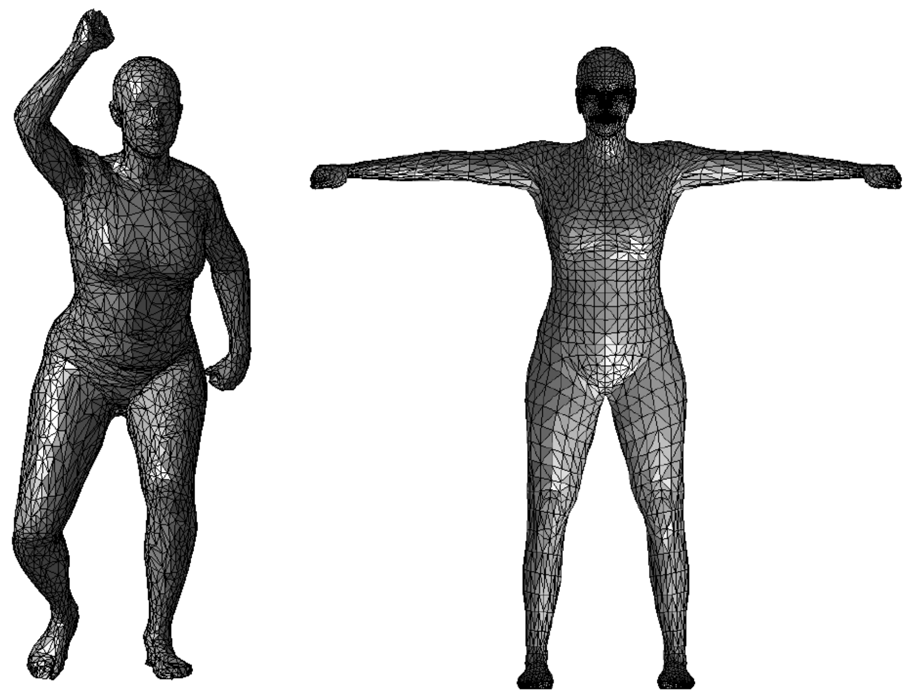
Different resolution within model

Challenge 4: Exponential space of correspondences



- approximately N^M possible correspondences

Challenge 4: Exponential space of correspondences



4000 vertices 2000 vertices

- approximately 3000^{4000} possible correspondences!

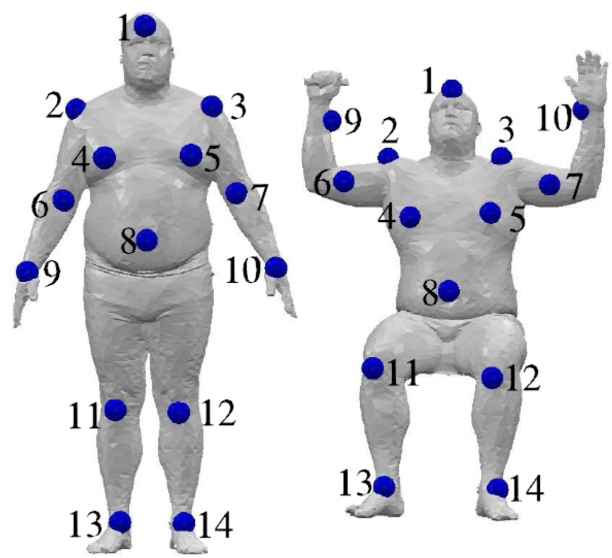
=> Search may end up in local minima

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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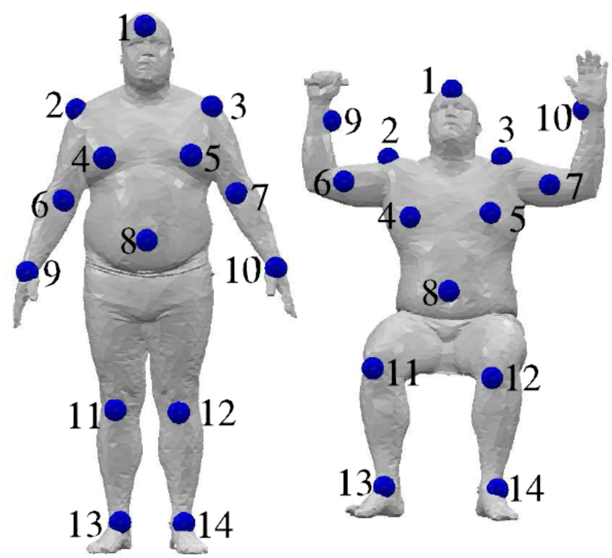
X only for high-res scans



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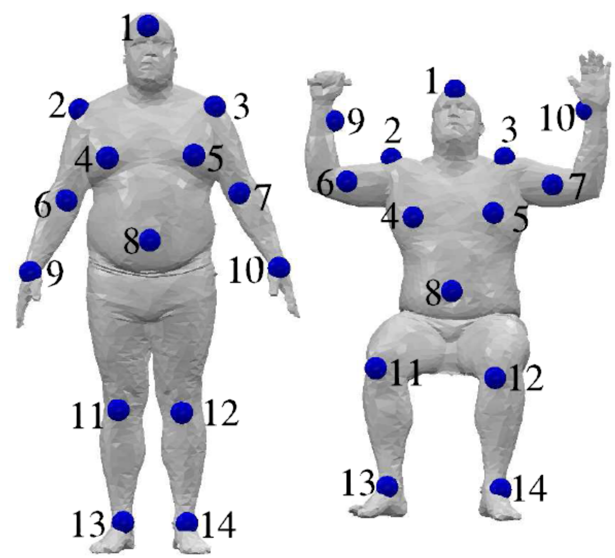
X small shape variation



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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surface Z

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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

Contributions

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

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

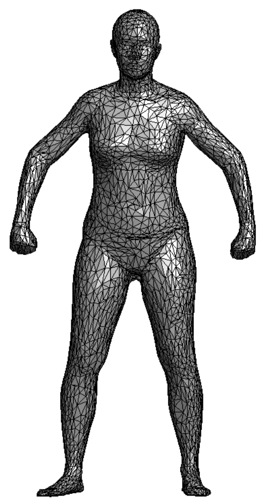
Contributions

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

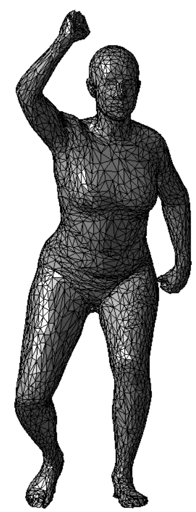
Problem Statement

Input:



Data mesh

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

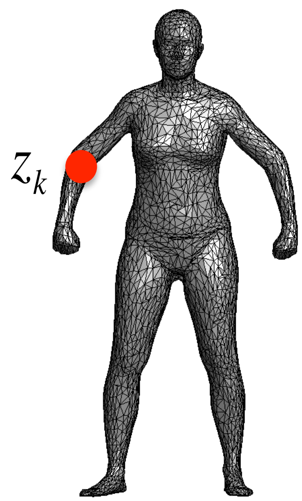


Model mesh

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

Problem Statement

<u>Input</u>:



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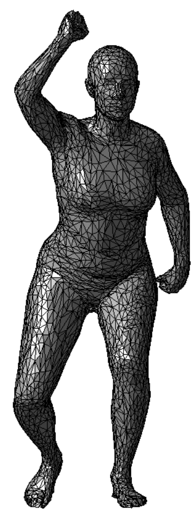

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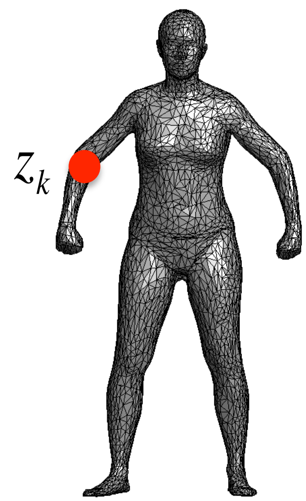

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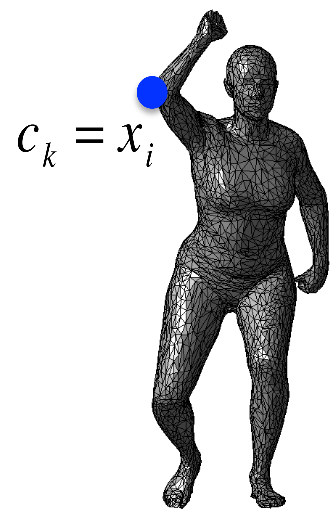


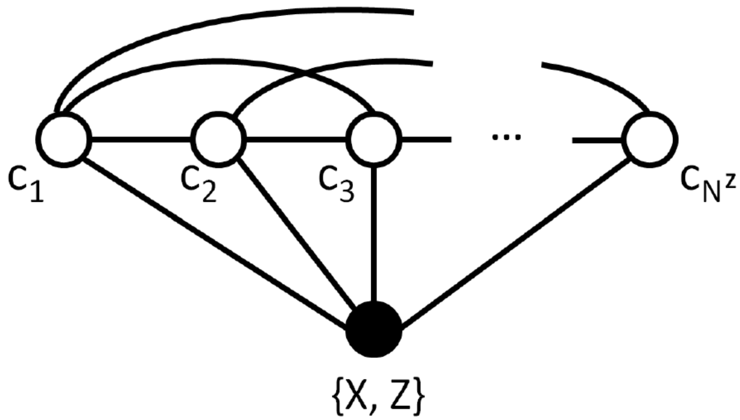
Model mesh

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

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

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

Conditional Random Field (CRF) model

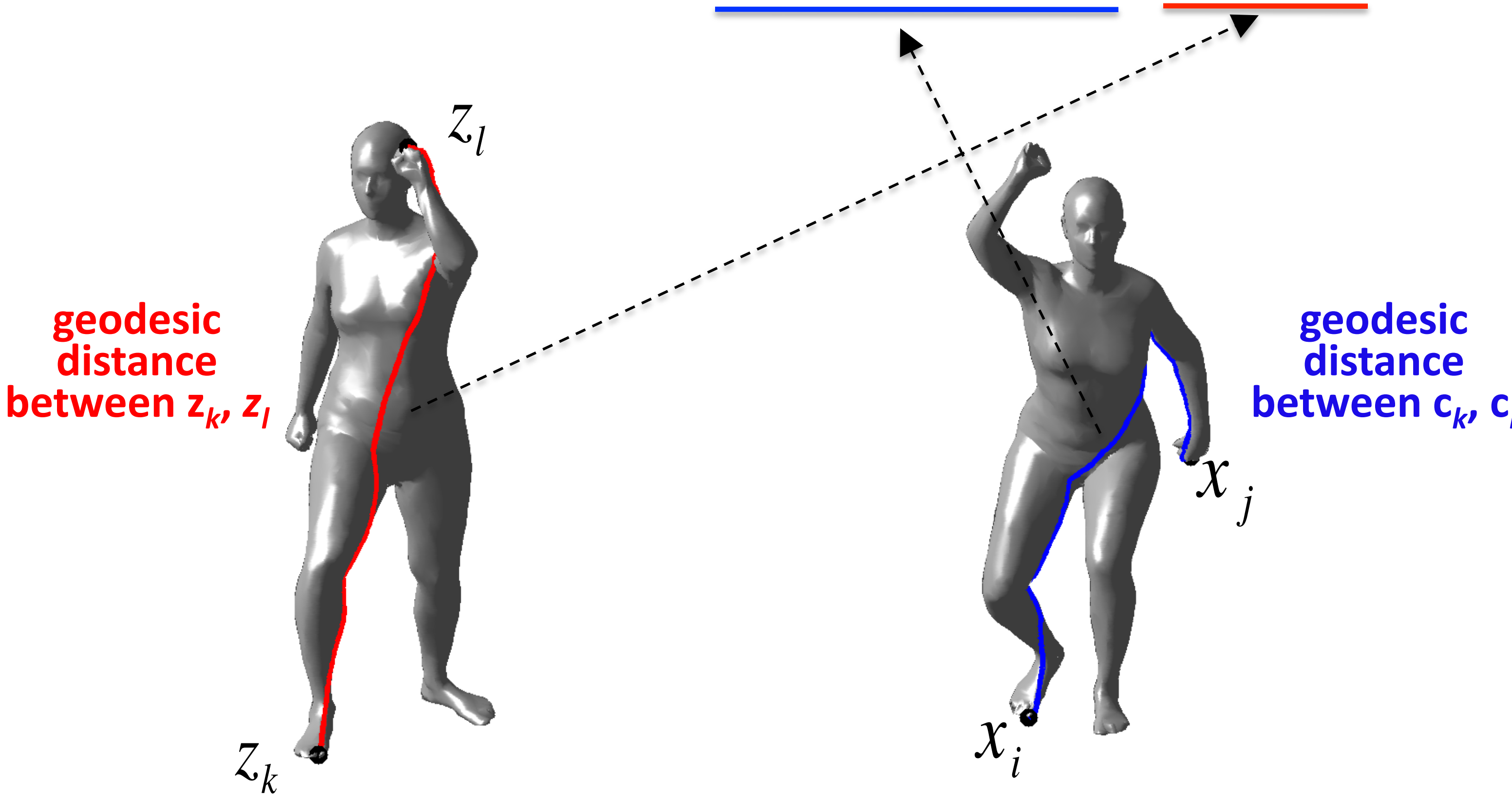


$$\arg\max_{C} p(C \mid X, Z)$$

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

Pairwise geodesic potential

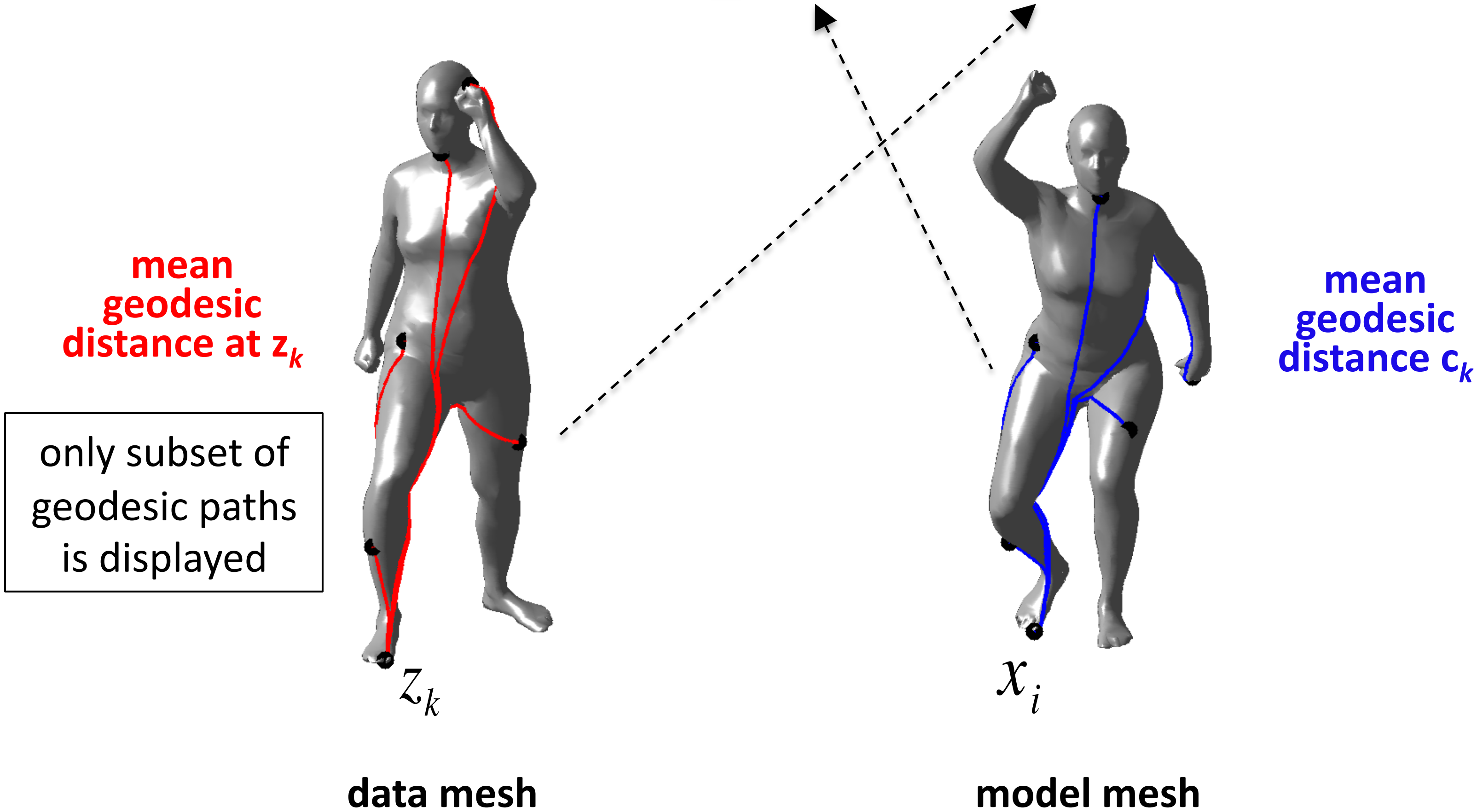
$$\psi(c_k = x_i, c_l = x_j, X, Z) = N(h(c_k = x_i, c_l = x_j; X), h(x_i, x_j; Z), \sigma_{kl}^2)$$



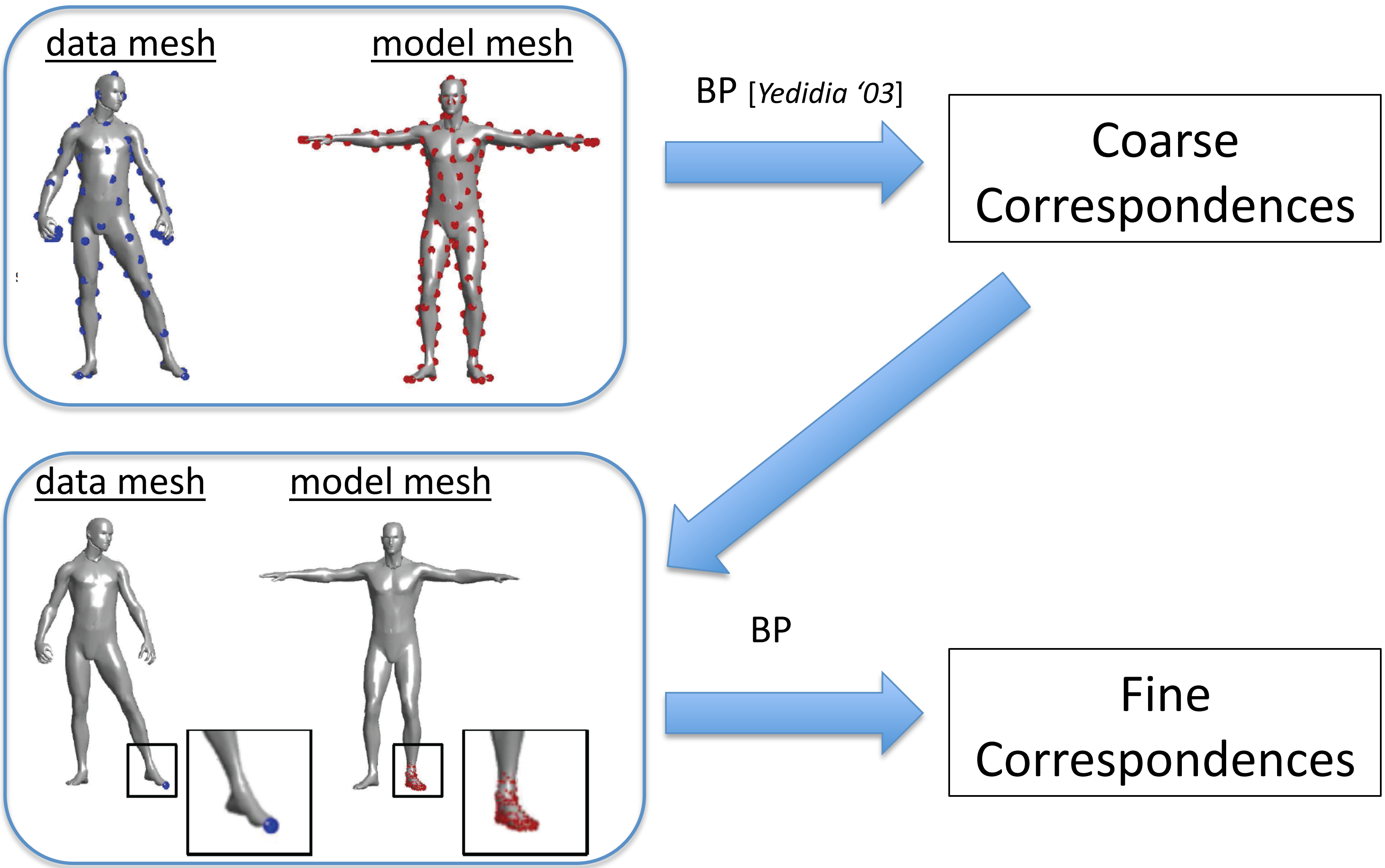
data mesh **model mesh**

Geodesic signature potential

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

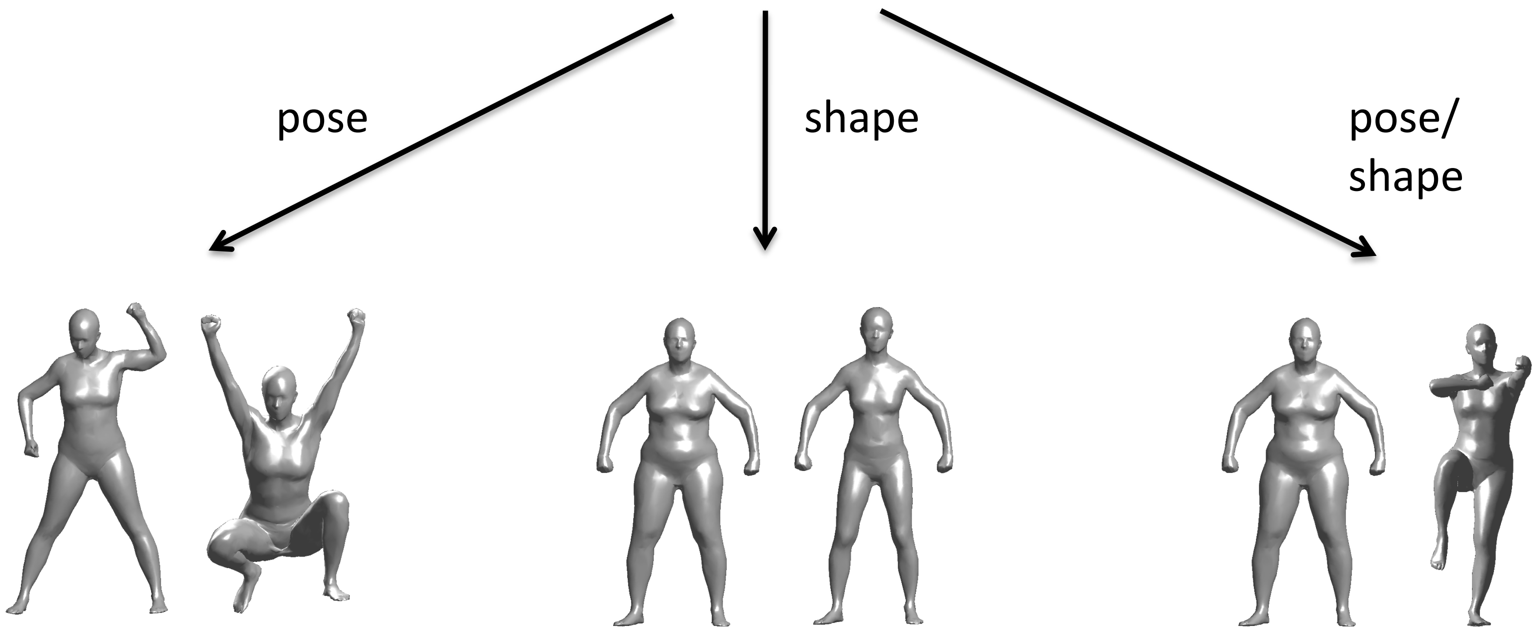


Our algorithm:
Probabilistic Geodesic Surface Embedding (PGSE)



Dataset 1 – SCAPE bodies

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



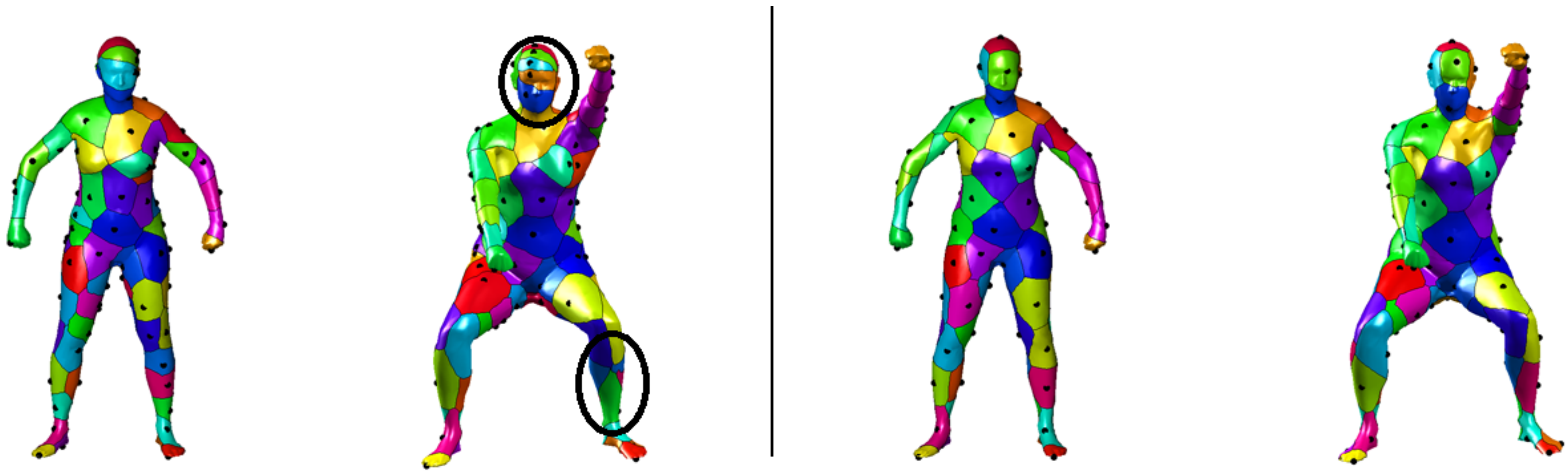
Dataset 2 – TOSCA nonrigid world

- 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 **PGSE**



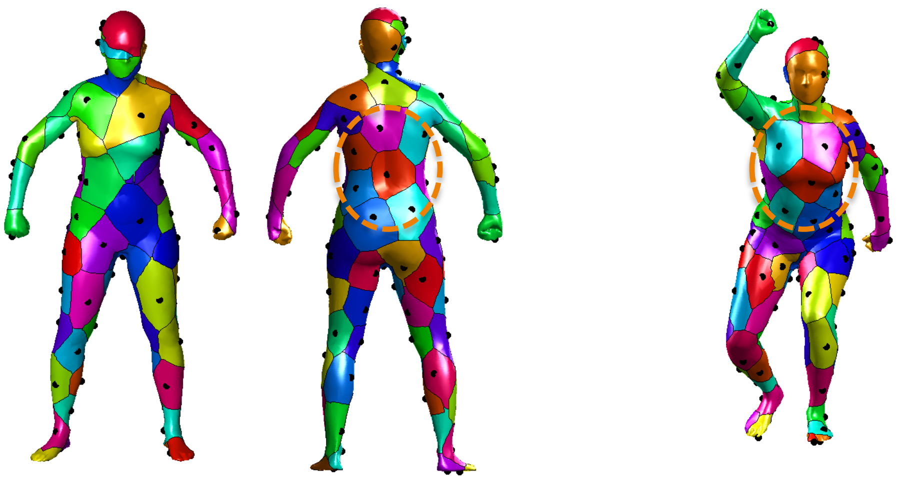
data mesh **model mesh** **data mesh** **model mesh**

Geodesic-based error metric

GMDS

data mesh

model mesh

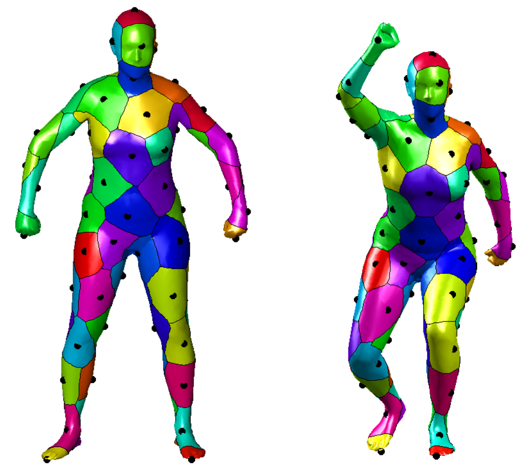


$T_g = 0.043$

PGSE

data mesh

model mesh



$T_g = 0.06$

Low error
Bad fit

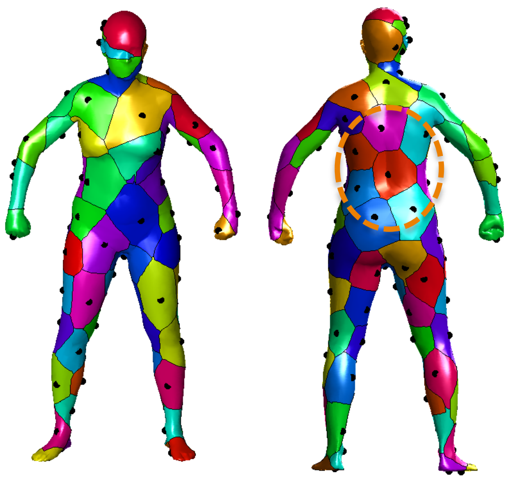
$$T_g = \text{mean}\left(\text{geodesic distances in data mesh} - \text{corresponding geodesic distances in model mesh}\right)$$

Higher error
Better fit

Voronoi-based error metric

GMDS

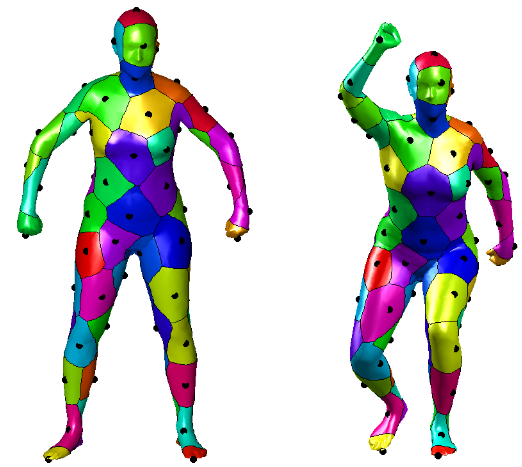
data mesh model mesh



$T_e = 0.28$

PGSE

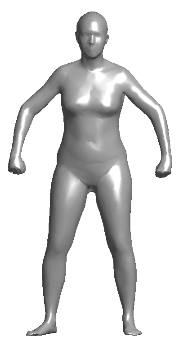
data mesh model mesh



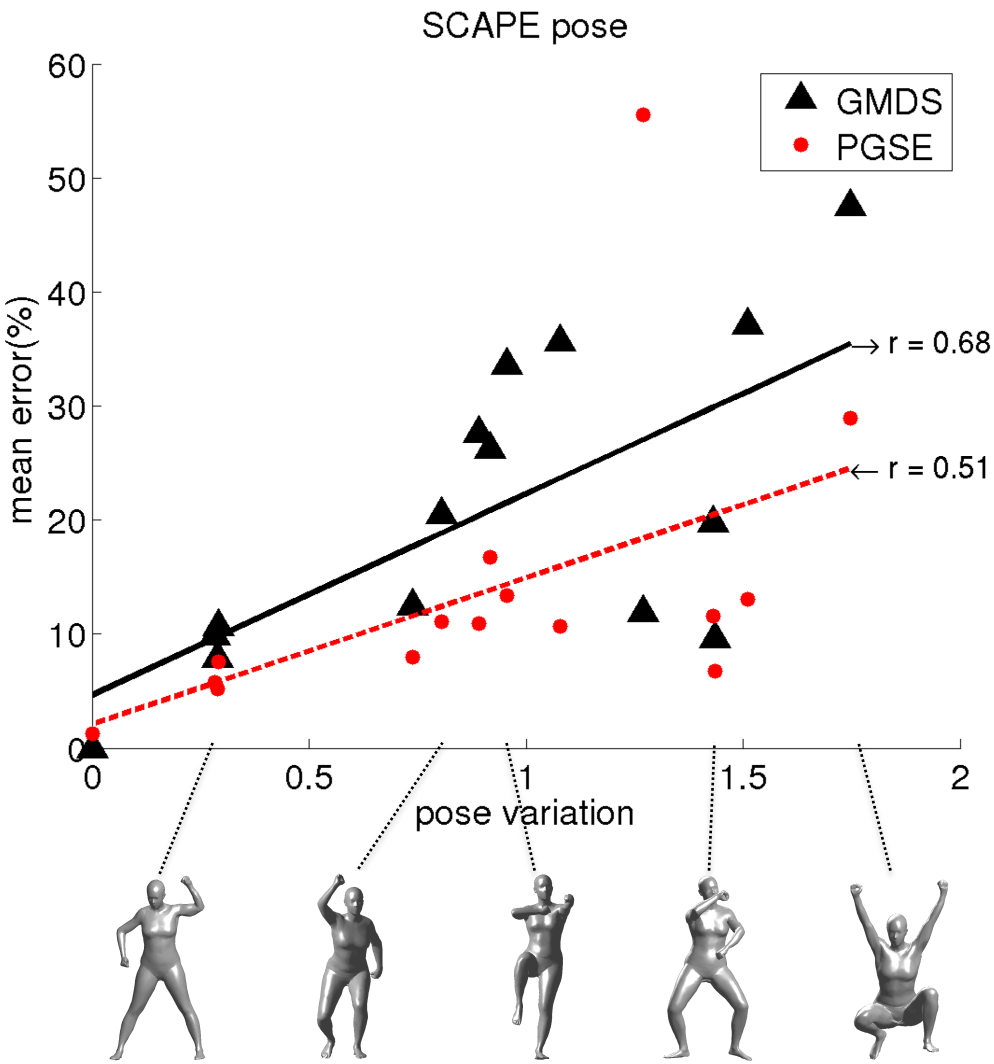
$T_e = 0.11$

T_e = mean(Voronoi areas in data mesh − corresponding Voronoi areas in model mesh)

Mean error on pose variation



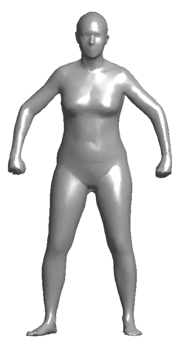
mean SCAPE body



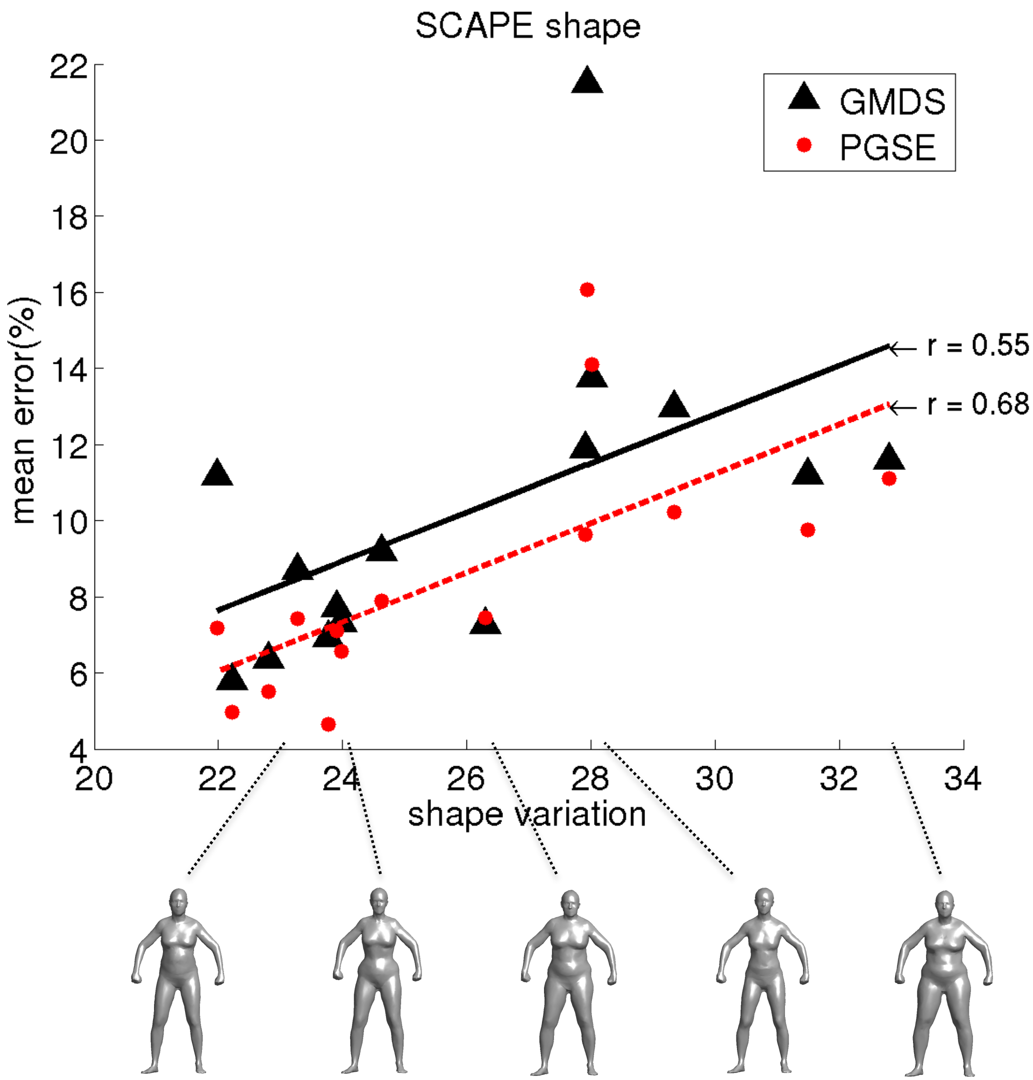
$\boxed{p = 0.013}$

Wilcoxon Signed Rank test

Mean error on shape variation

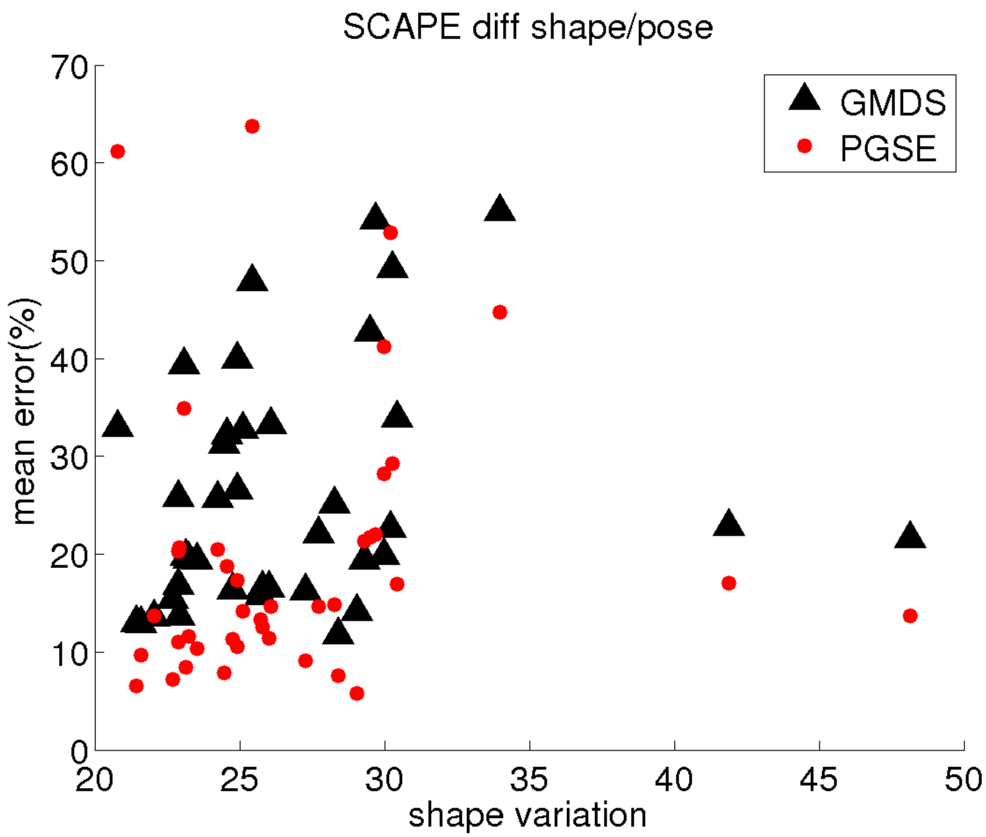


mean SCAPE body



$p = 3x10^{-4}$

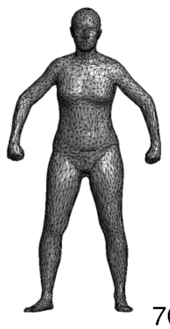
Mean error on pose and shape variation



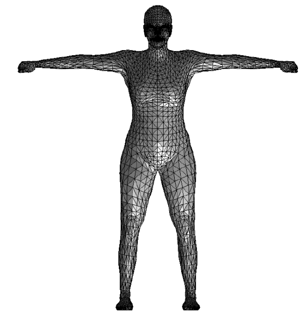
$p = 3.15x10^{-4}$

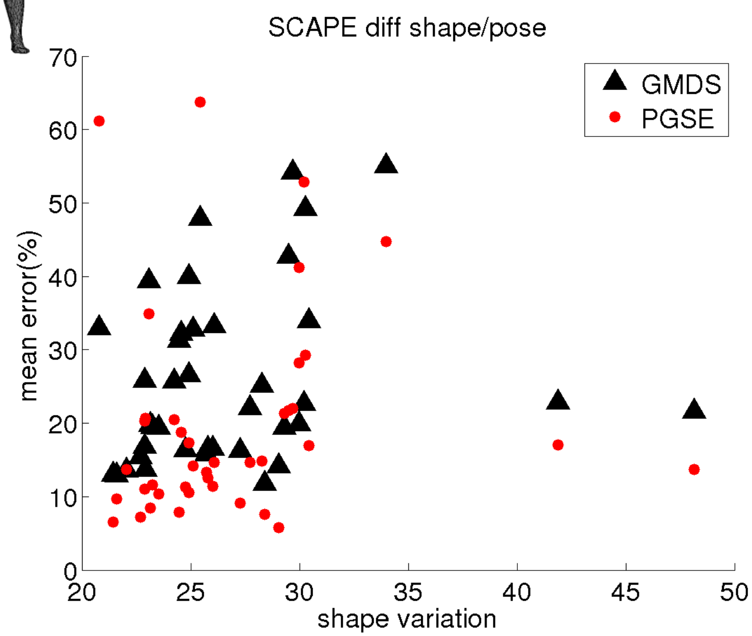
Resolution experiments

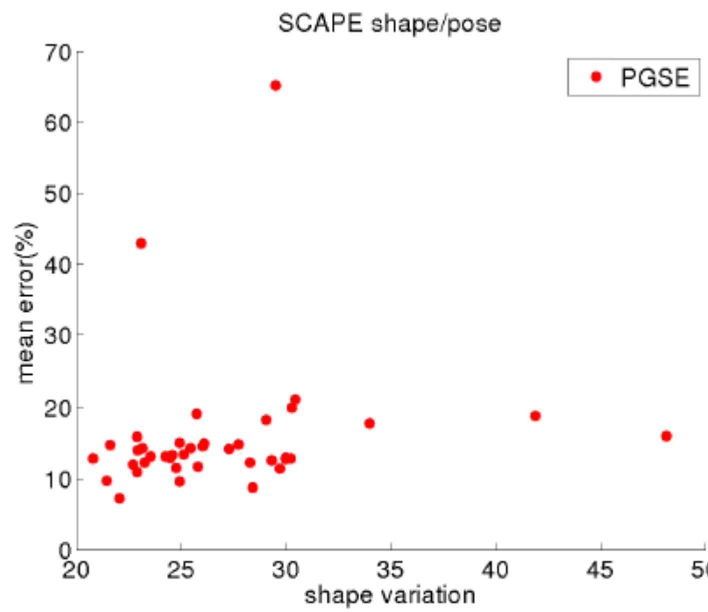
mean SCAPE body:



template:



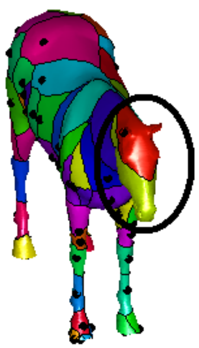




Results – TOSCA nonrigid world

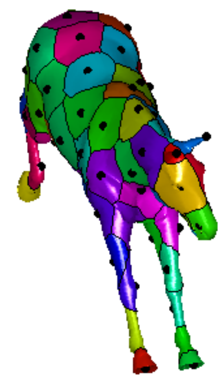
GMDS

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

$p = 3x10^{-16}$

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!