Evaluating the Automated Alignment of 3D Human Body Scans

David A. Hirshberg, Matthew Loper, Eric Rachlin, Aggeliki Tsoli, Alexander Weiss, Brian Corner, Michael J. Black

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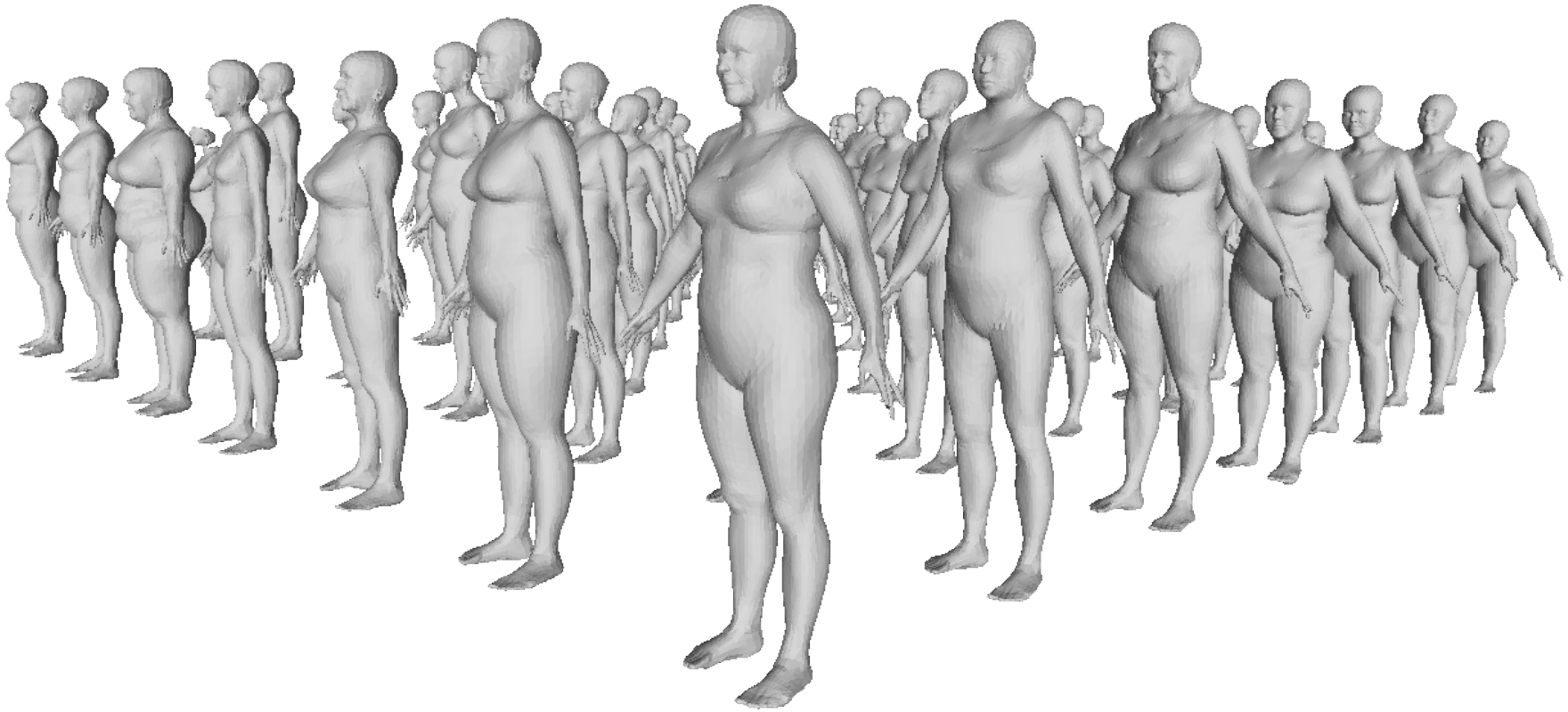
10,000+ laser scans

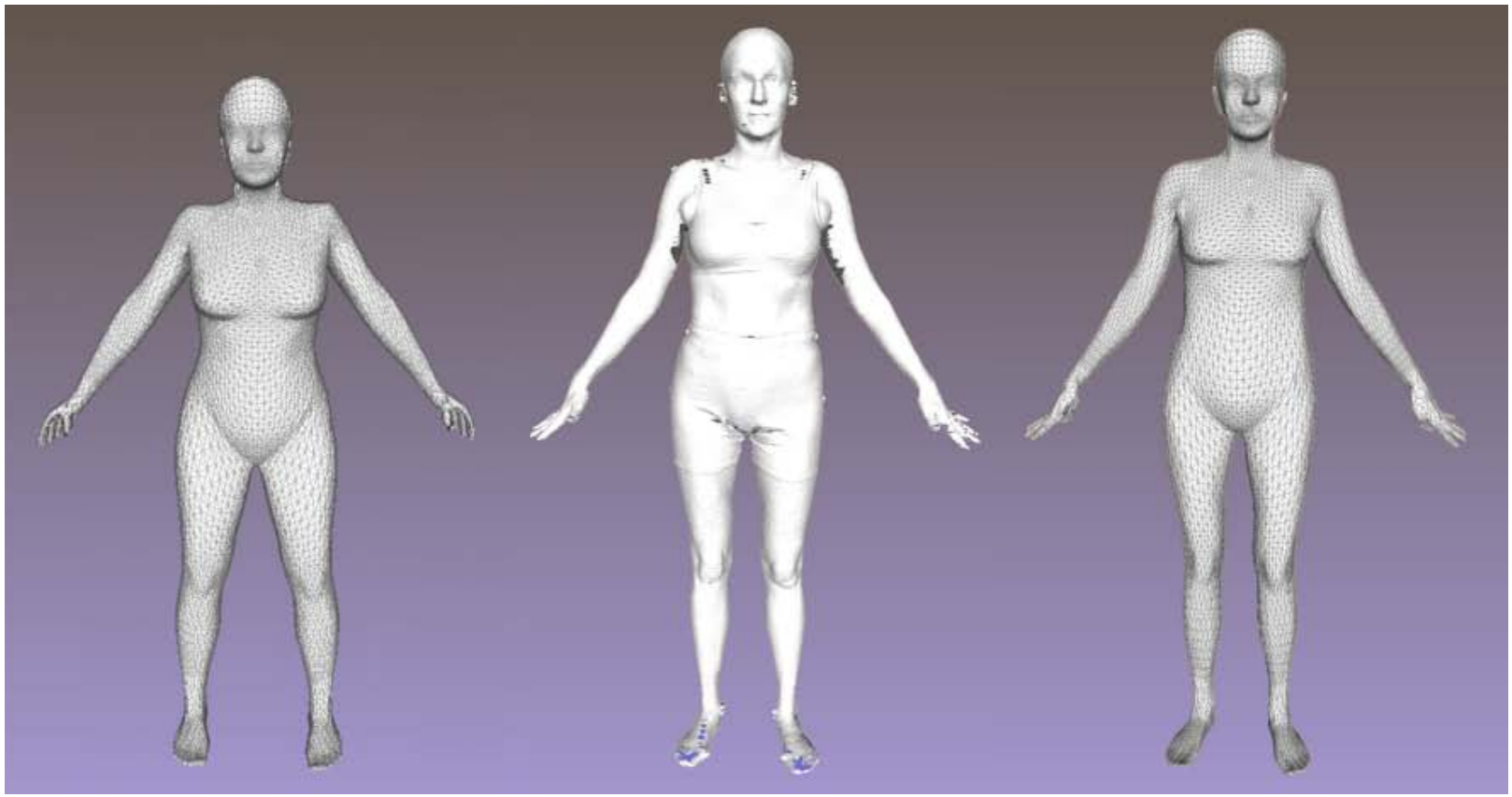
Enable the detailed analysis of human shape

10,000+ laser scans
Problem: Analysis requires alignment



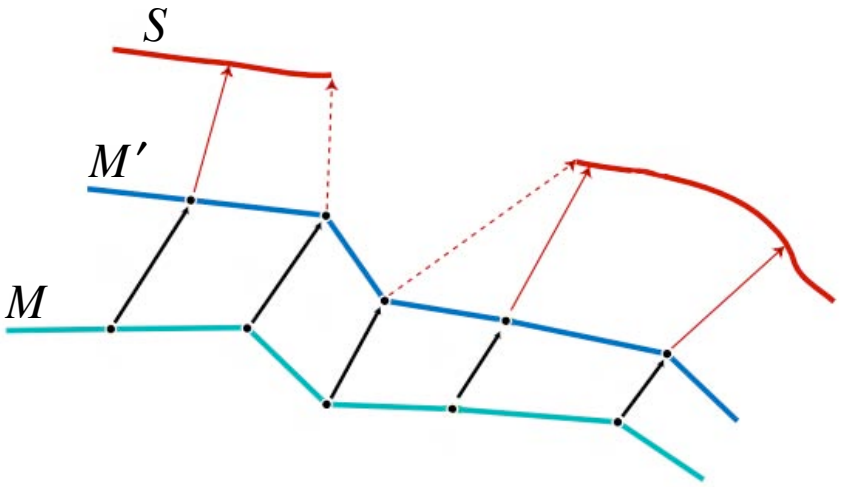
Aligning thousands of meshes is hard.
Must be fully automatic.

Alignment



Template M Scan S Alignment M'

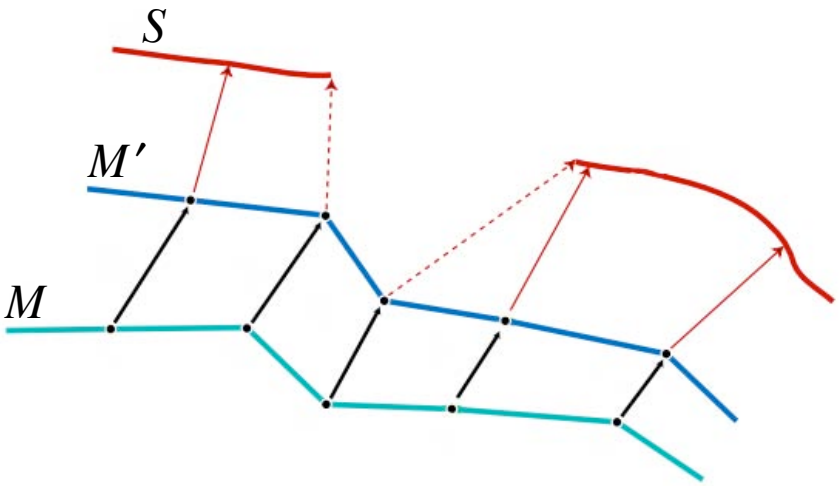
Standard method – a review
Iterative Closest Point (ICP)



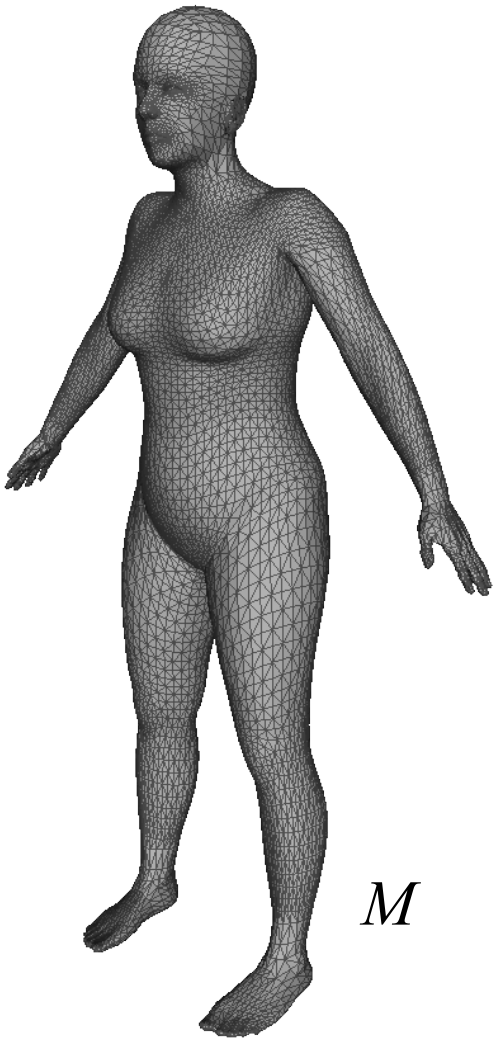
Allen et. al. 2003

To find a set of deformations to transform a template mesh M to a scan S.

Standard method – a review
Template Mesh

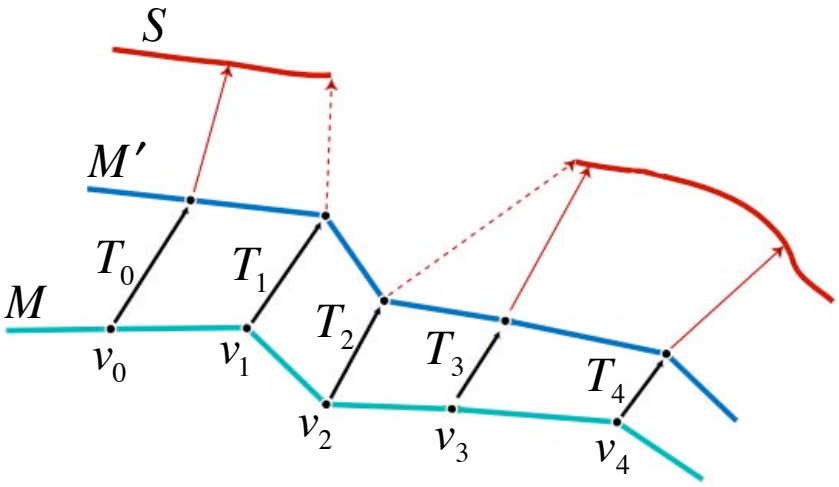


Allen et. al. 2003



Artist Created:
- Symmetric
- Watertight
- Clear banding
- Density varies with curvature

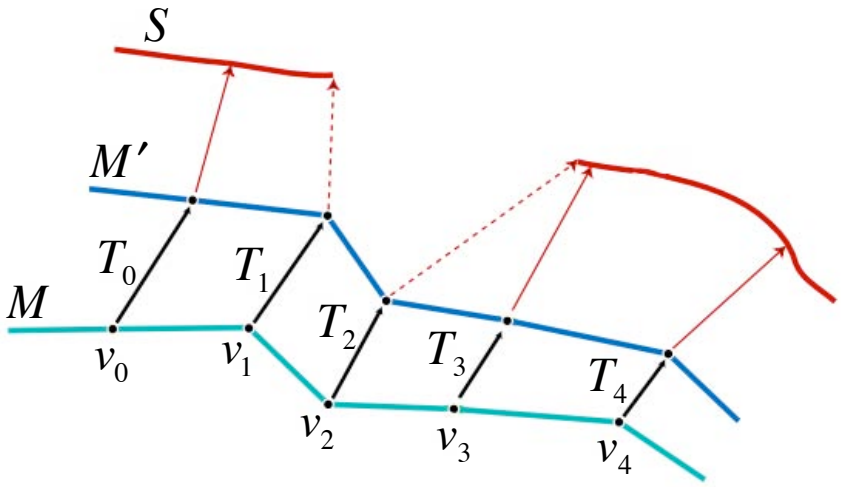
Standard method – a review
ICP Optimization



Allen et. al. 2003

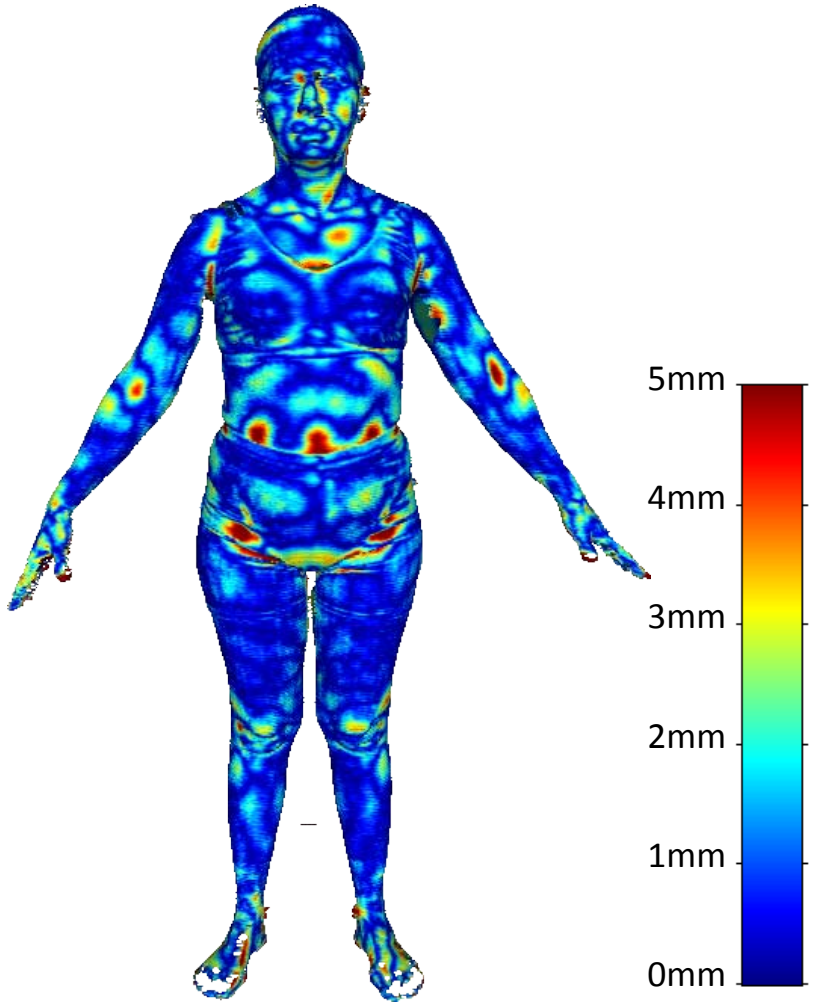
$$E_{accuracy}(T) + E_{consistency}(T)$$

Standard method – a review
Alignment to Scan Distance

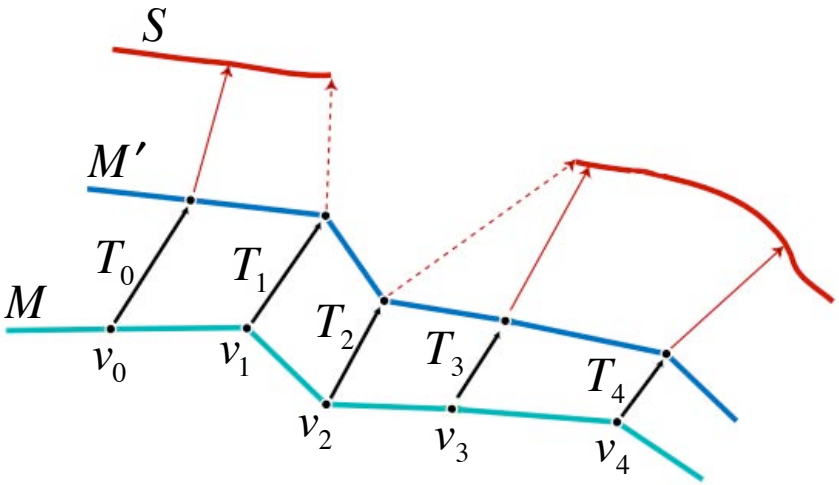


Allen et. al. 2003

$$\sum_{i \in M} \left| T_i v_i - \arg\min_{p \in S} \left(\left| T_i v_i - p \right| \right) \right|$$

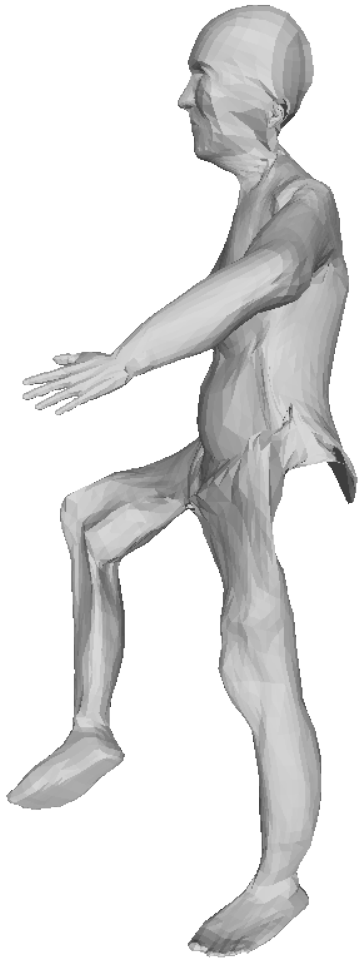


Standard method – a review
Regularization

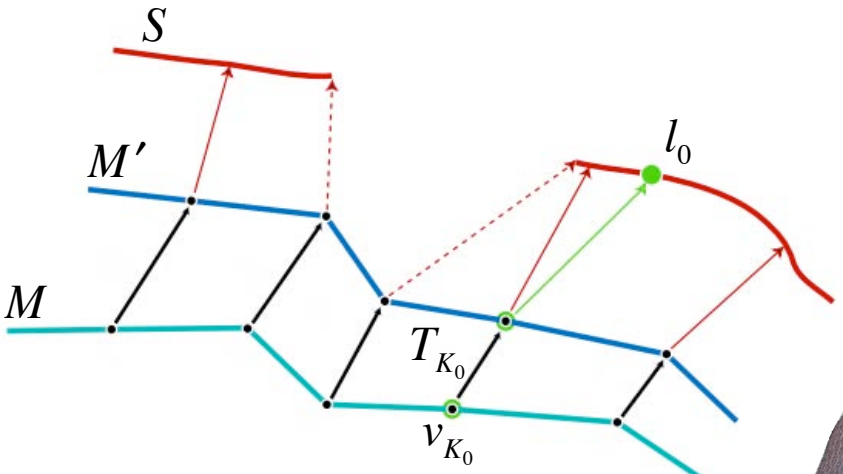


Allen et. al. 2003

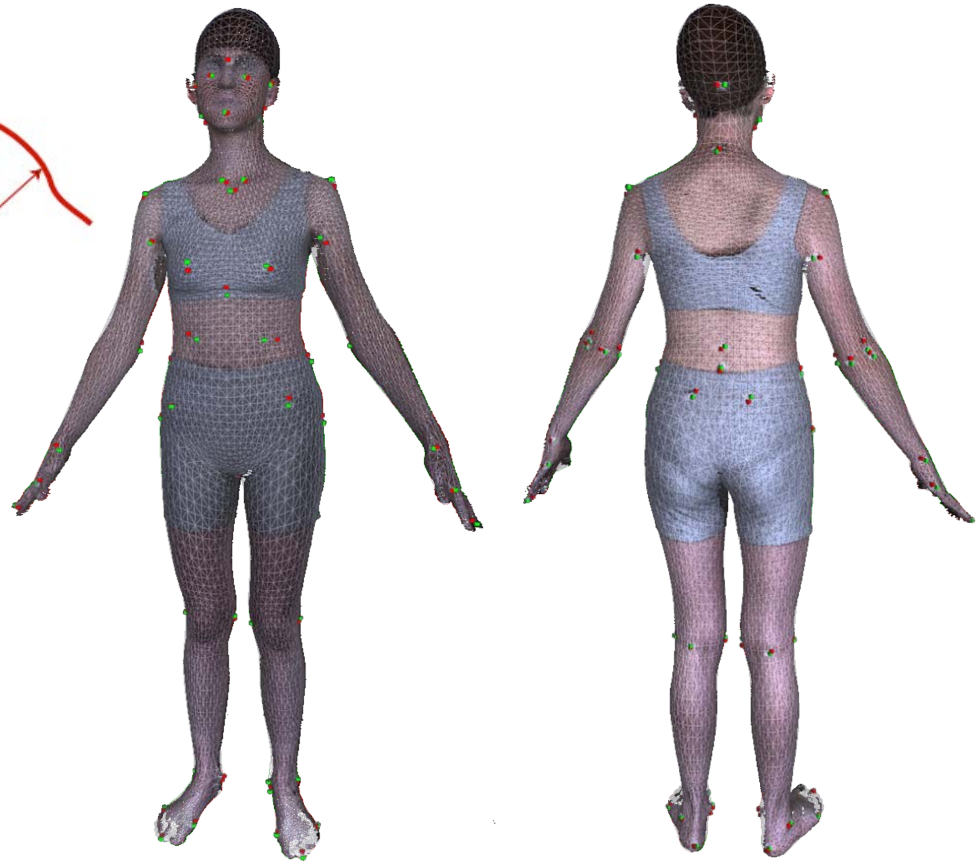
$$\sum_{(i,j)\in edges(M)} \left| T_i - T_j \right|_F^2$$



Standard method – a review
Landmarks

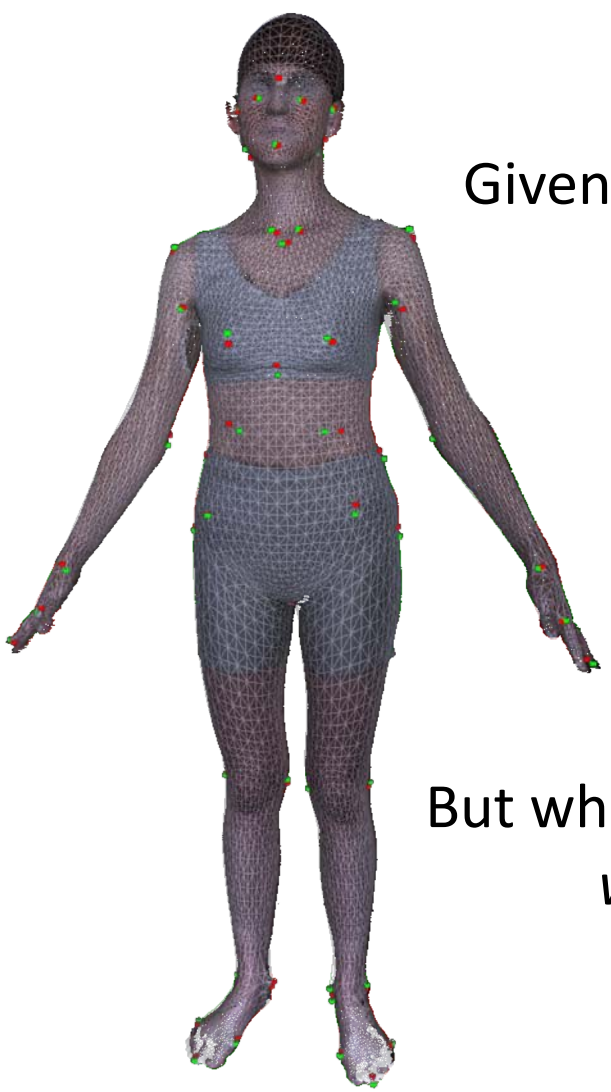


Allen et. al. 2003



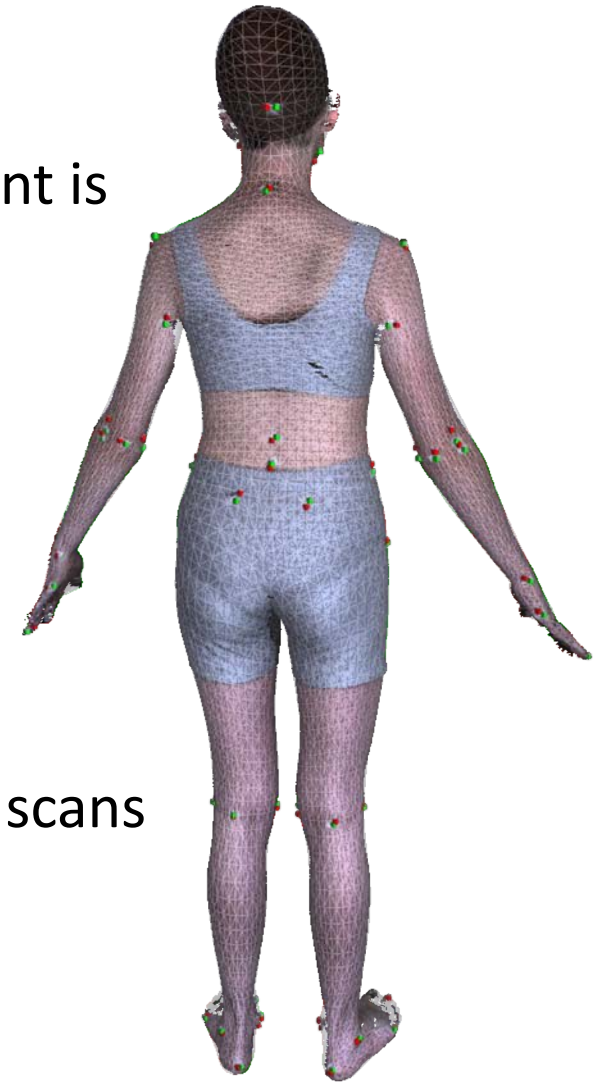
$$\sum_{i \in L} \left| T_{K_i} v_{K_i} - l_i \right|$$

Standard method – the lesson

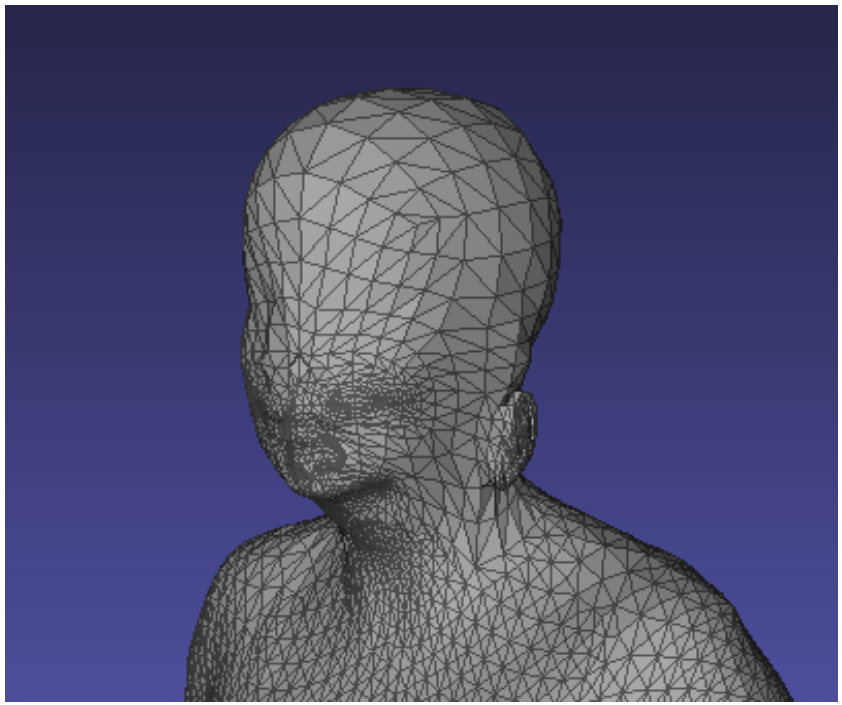


Given landmarks, Alignment is straightforward

But what if we have 10,000 scans *without* landmarks?

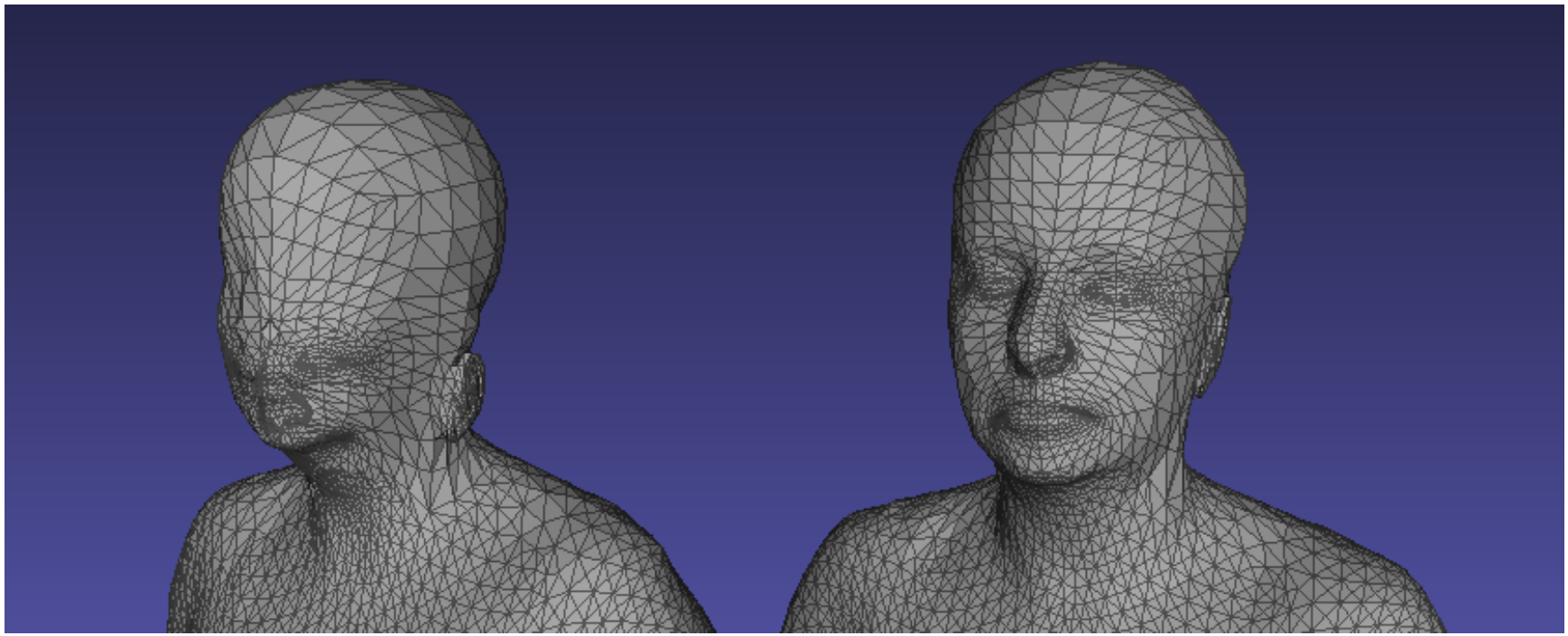


How many landmarks do we need?



Standard method
6 landmarks

Fewer landmarks requires a Smarter alignment algorithm



Standard method
6 landmarks

Our method
6 landmarks

Standard Method

Many high quality landmarks

Simple alignment

Our Method

But: Good landmarks are hard to get

But: Fails without good landmarks

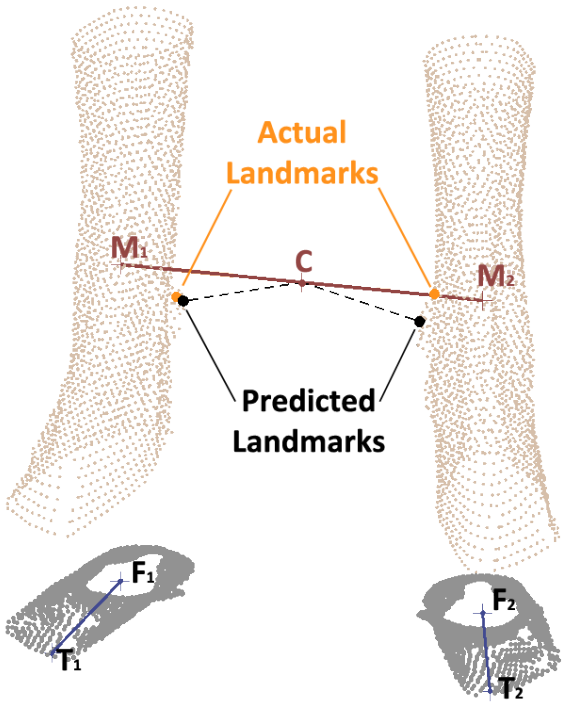
Few quick and dirty landmarks

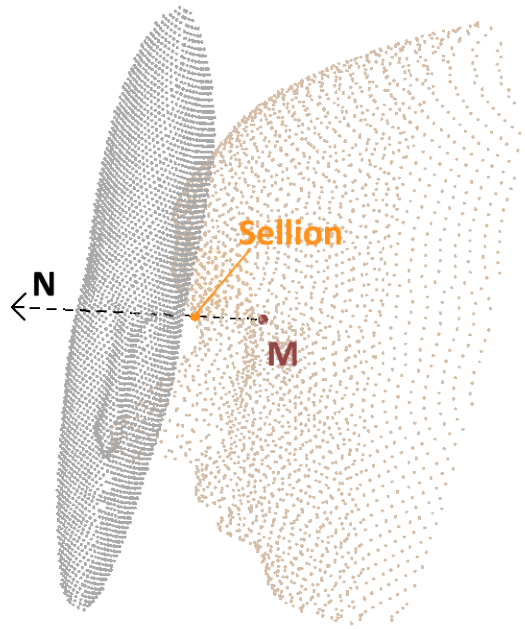
Smart alignment

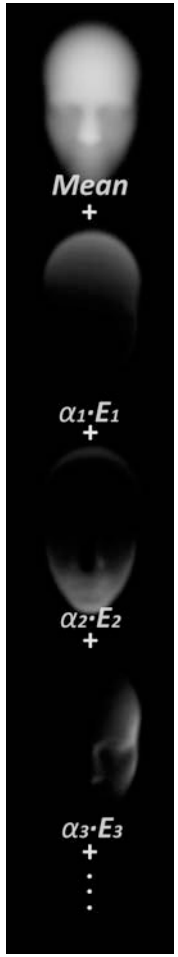
Simple landmark detectors

Sellion: mean error 6.2mm

R/L Medial Malleolus: mean error 8.1mm

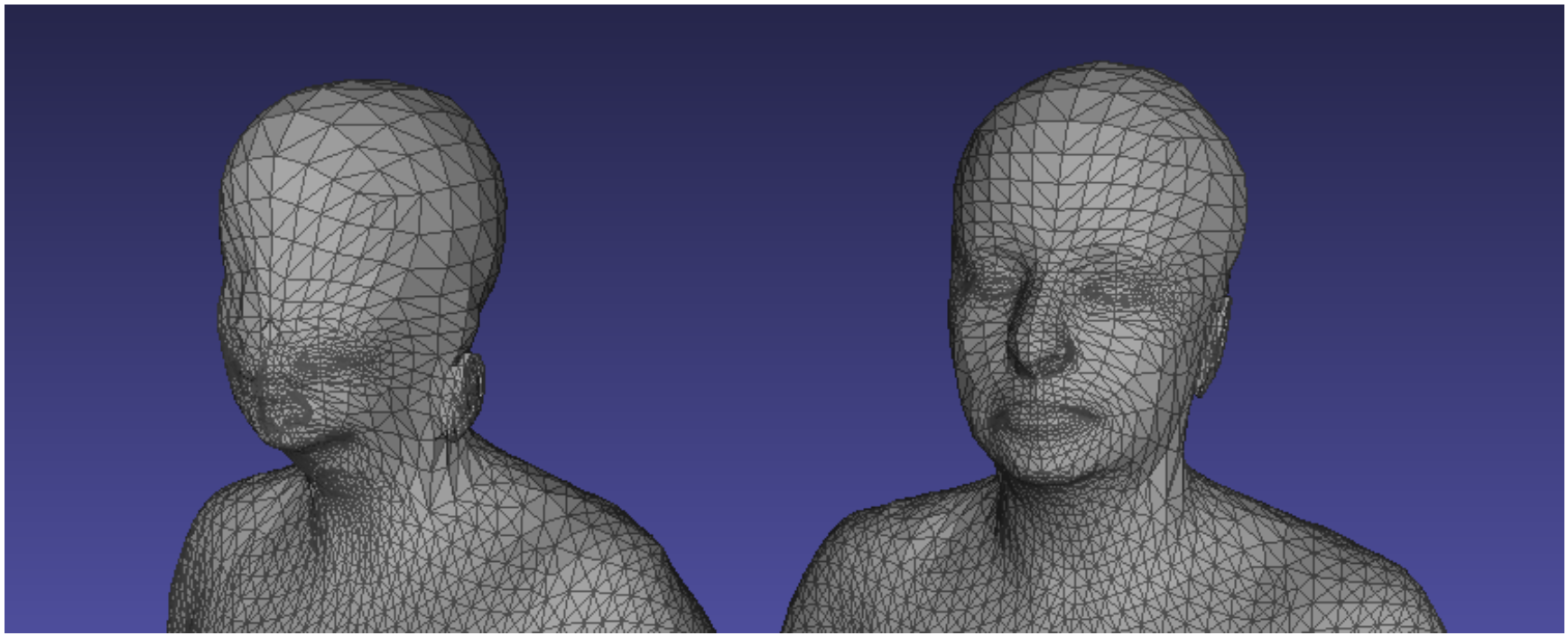






Eigen depth faces

What breaks with few landmarks?



Standard method
6 landmarks

Our method
6 landmarks

Standard Method

Many high quality landmarks

Simple alignment

Regularization: Smoothness

But: Good landmarks are hard to get

But: Fails without good landmarks

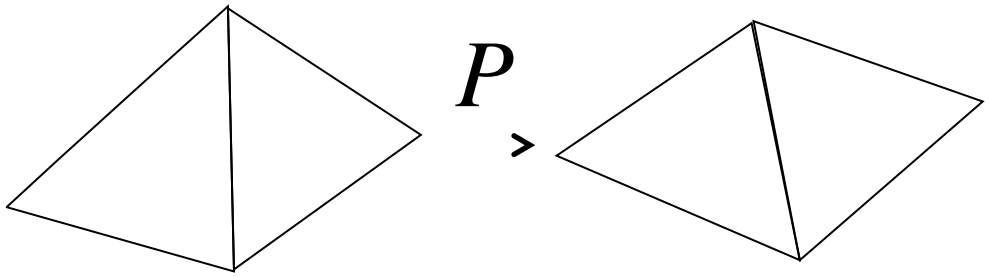
But: “Sliding” problems

Our Method

Few quick and dirty landmarks

Smart alignment

Pick the best regularizations from the graphics and mesh alignment literature



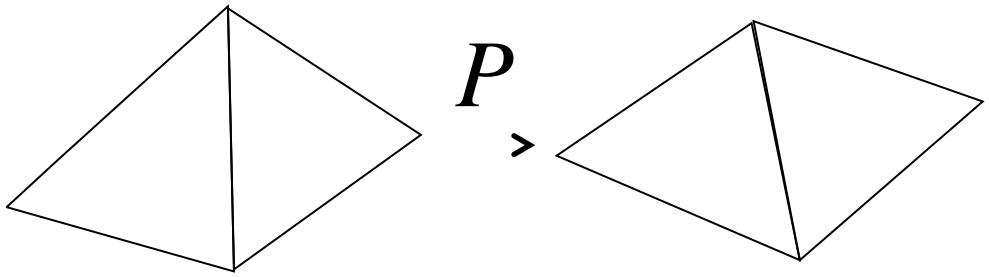
The motion of the mesh vertices defines a linear transformation for every two-triangle patch

Smoothness

$$\sum_{i,j \text{ overlapping}} AreaOfOverlap_{ij} \left\| P_i - P_j \right\|_F^2$$

Penalize dissimilarity of transformations for overlapping patches

Pick the best regularizations from the graphics and mesh alignment literature



The motion of the mesh vertices defines a linear transformation for every two-triangle patch

Local Rigidity

$$\sum_i Area_i \min_{R \in SO(3)} \|P_i - R\|_F^2$$

Penalize dissimilarity of transformations to rotations

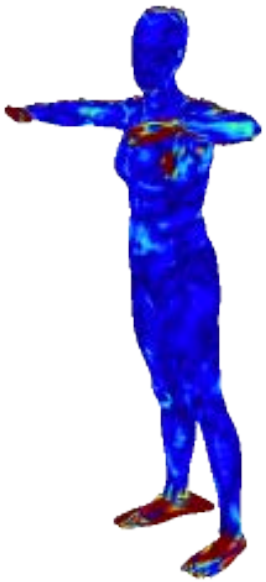
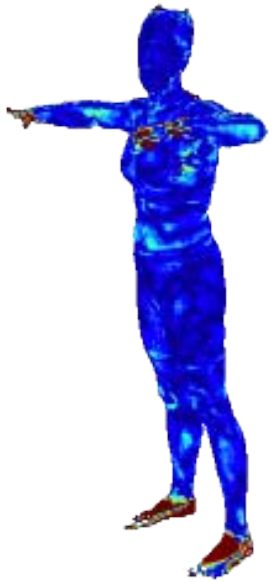
Standard Method		Our Method
Many high quality landmarks	But: Good landmarks are hard to get	Few quick and dirty landmarks
Simple alignment	But: Fails without good landmarks	Smart alignment
Regularization: Smoothness	But: “Sliding” problems	Regularization: Smoothness, Local Rigidity, Coarse to fine

What else breaks?

Regularization is defined on the template. Unexplained scan data can not be corrected via regularization.

Standard Method		Our Method
Many high quality landmarks	But: Good landmarks are hard to get	Few quick and dirty landmarks
Simple alignment	But: Fails without good landmarks	Smart alignment
Regularization: Smoothness	But: “Sliding” problems	Regularization: Smoothness, Local Rigidity, Coarse to fine
Mesh to scan distance	But: Unexplained scan data	

Bidirectional distance

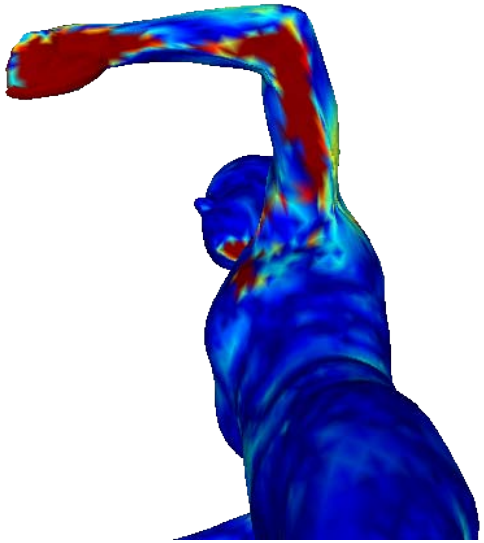
$$\int \rho\left(\text{  }\right) + \int \rho\left(\text{  }\right)$$

Template to Scan

Scan to Template

Standard Method		Our Method
Many high quality landmarks	But: Good landmarks are hard to get	Few quick and dirty landmarks
Simple alignment	But: Fails without good landmarks	Smart alignment
Regularization: Smoothness	But: “Sliding” problems	Regularization: Smoothness, Local Rigidity, Coarse to fine
Mesh to scan distance	But: Unexplained scan data	Bidirectional distance

Are we done yet?

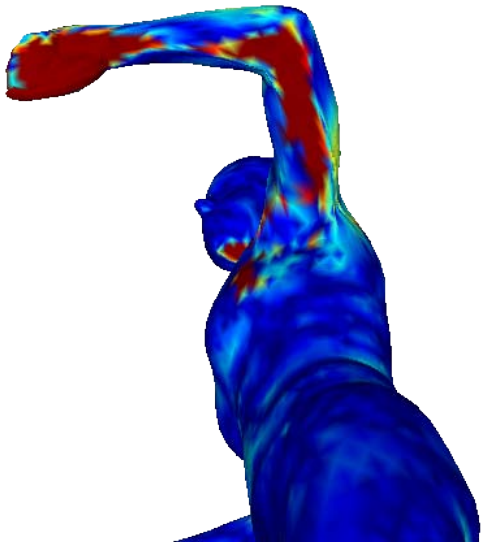


Dealing with holes:
Standard method assumes Cyberware per-vertex confidence data.

Standard Method		Our Method
Many high quality landmarks	But: Good landmarks are hard to get	Few quick and dirty landmarks
Simple alignment	But: Fails without good landmarks	Smart alignment
Regularization: Smoothness	But: “Sliding” problems	Regularization: Smoothness, Local Rigidity, Coarse to fine
Mesh to scan distance	But: Unexplained scan data	Bidirectional distance
Scan holes: Cyberware confidence data	But: confidence data often not available	

Dealing with holes: Robust statistics

Robust statistics on the template mesh to scan distance limits the influence of large distances in holes, increasing the relative weight of regularization towards the template.

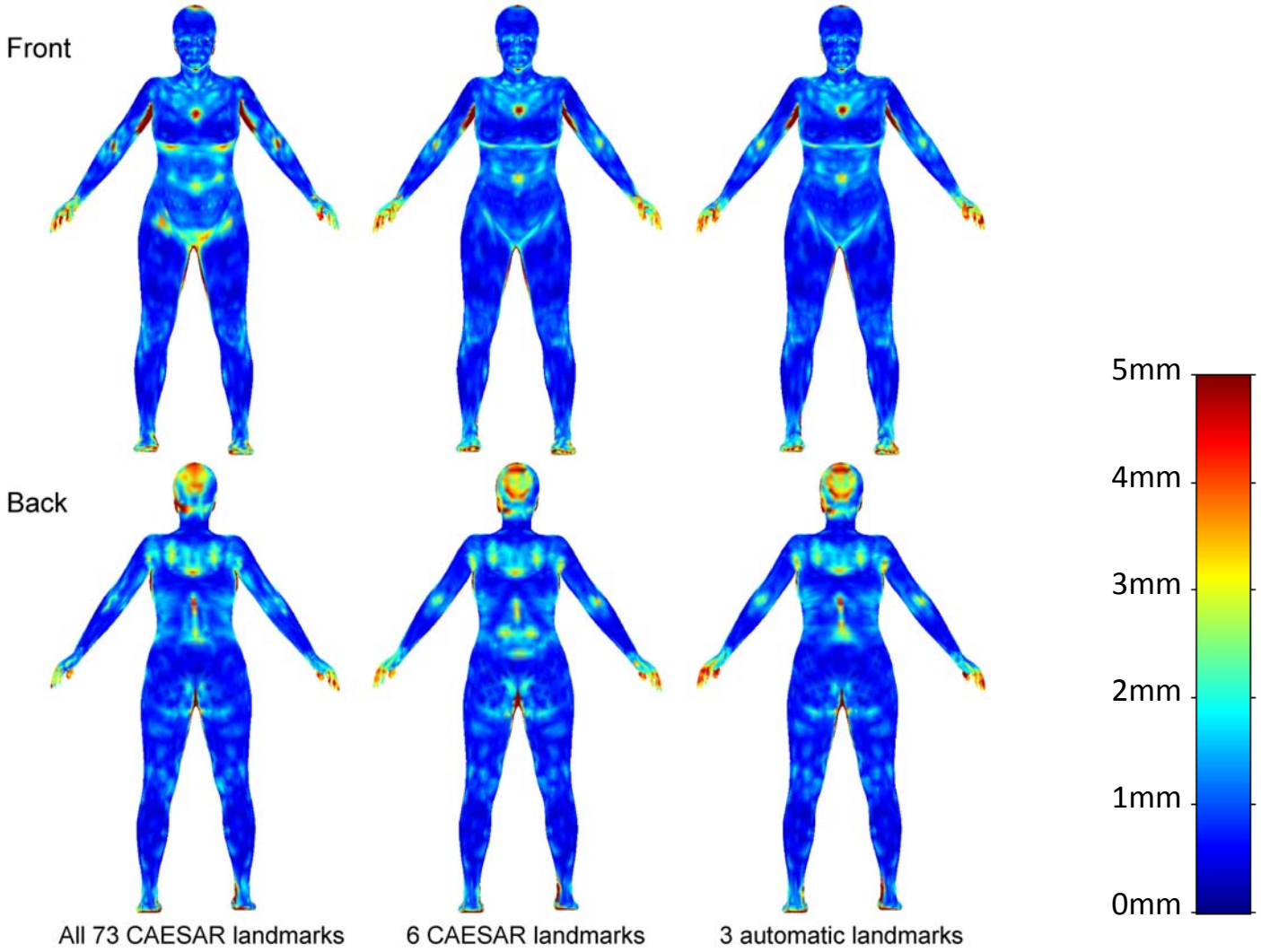


$$\rho(d) = d^2$$

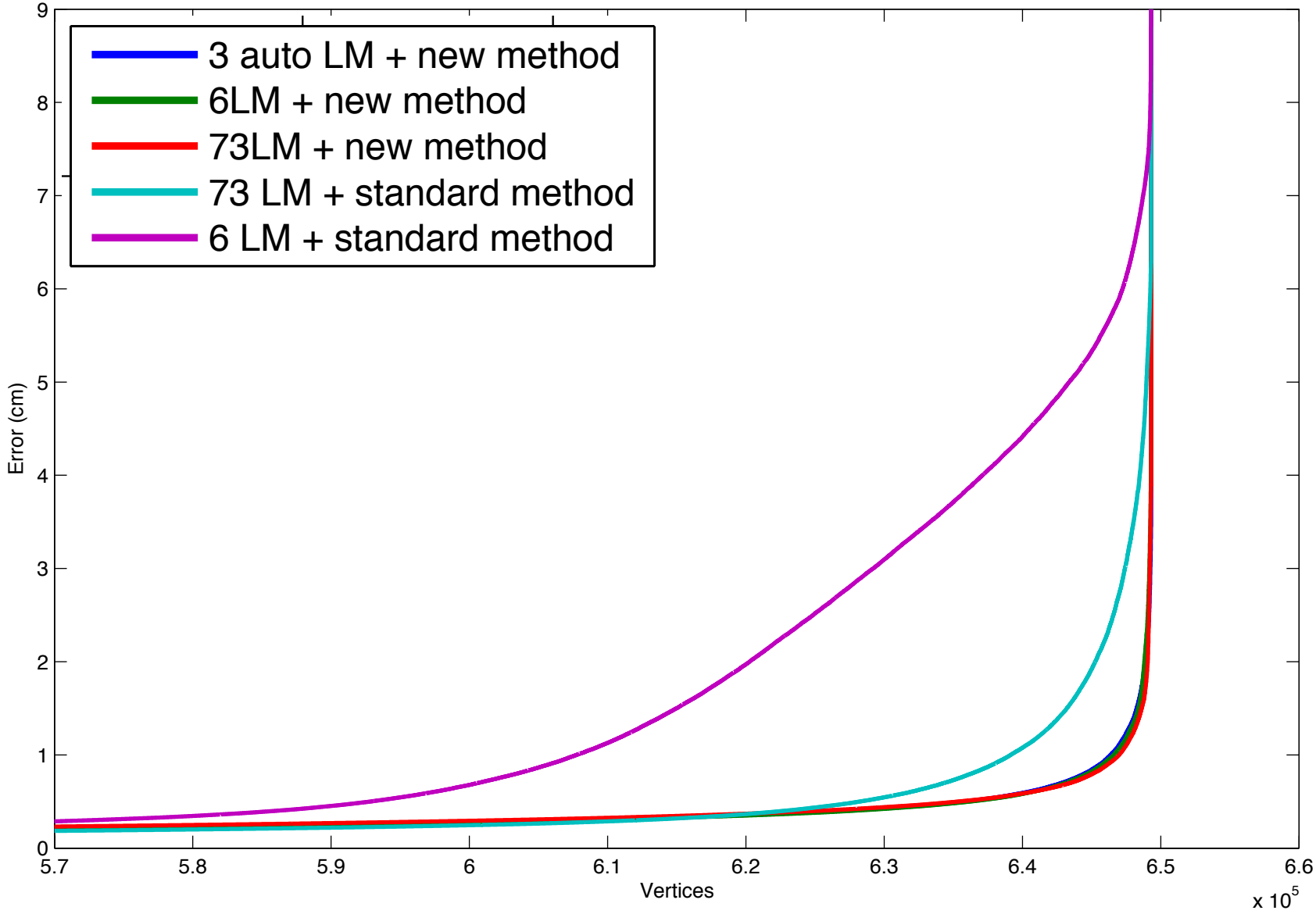
$$\rho(d) = \frac{d^2}{d^2 + \sigma^2}$$

Standard Method		Our Method
Many high quality landmarks	But: Good landmarks are hard to get	Few quick and dirty landmarks
Simple alignment	But: Fails without good landmarks	Smart alignment
Regularization: Smoothness	But: “Sliding” problems	Regularization: Smoothness, Local Rigidity, Coarse to fine
Mesh to scan distance	But: Unexplained scan data	Bidirectional distance
Scan holes: Cyberware confidence data	But: confidence data often not available	Scan Holes: Robust statistics

Evaluation: Mean mesh to scan distance



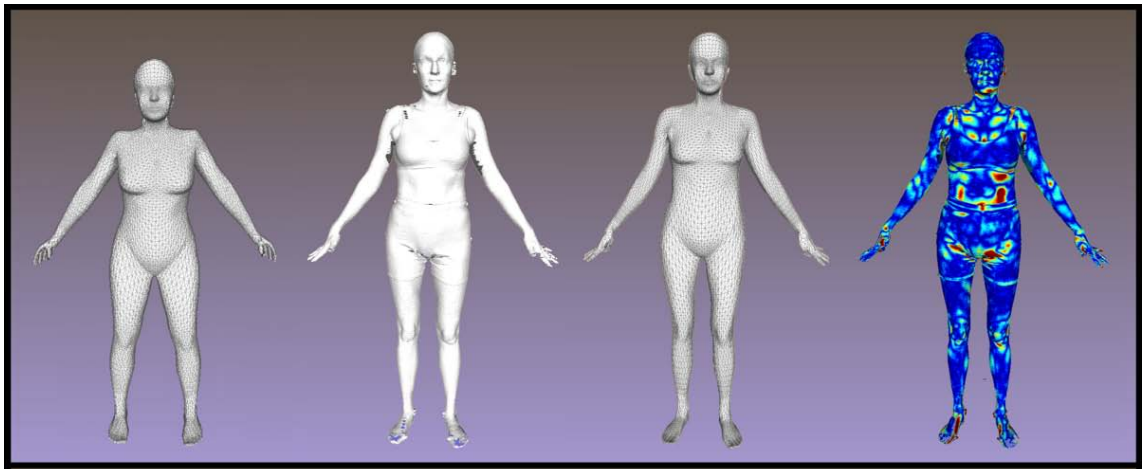
Evaluation: Largest scan to mesh distances



Summary

- Standard: Alignment given landmarks
  - Manual landmarking is tedious, doesn't scale well to huge datasets
  - Standard method fails when given only a few landmarks
- Better: Move the smarts into the alignment algorithm
  - Choose the right regularizations
  - Bidirectional cost function
  - Robust statistics
- Good alignments with 3 automatically detected landmarks
  - Better mesh to scan distances compared to standard method with 73 landmarks
- Fully automatic alignment pipeline, scales well to huge datasets

Questions?



We thank Scott Ettinger for the implementation of the Allen *et al.* alignment method.

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