NSF Engineering Research Center
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Iterative Refinement of Point Correspondences for 3D Statistical Shape Models

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Introduction

- Shape atlases : Representation and Modeling
- Bone Atlases for the study of anatomical variation
- Dense Point based representations from registration to a template
- Incorrect point correspondences can influence the statistical modeling

Prior Work

- Active Shape Models

  Cootes et al., 1995
  Active shape models - their training and application.

- Registration to mean shape

  Chui et al., 2004
  Unsupervised learning of an atlas from unlabeled point-sets.

- Iterative Bootstrapping

  Chintalapani et al., 2007
  Statistical Atlases of Bone Anatomy: Construction, Iterative Improvement and Validation

- Optimization of MDL

  Davies et al., 2010
  Building 3-D Statistical Shape Models by Direct Optimization

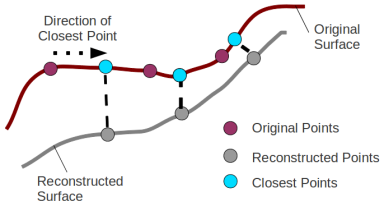
Proposed Method

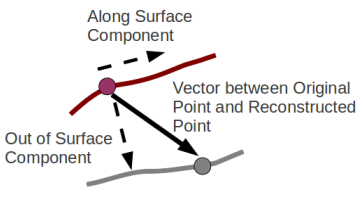
Iterative method with two steps:

- Use current point correspondences to generate model (PCA)

$$V_i^{rec} = \bar{M} + \sum_{i=1}^{n} \lambda_i Y_i$$

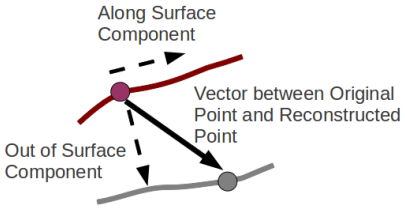
- Use model to re-estimate point correspondences

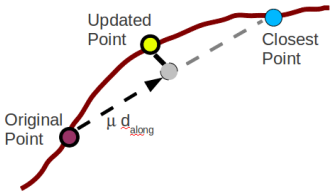




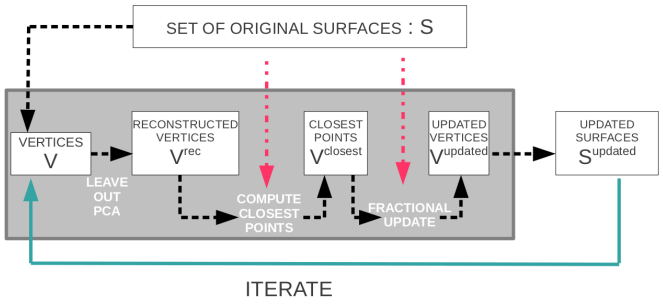
Fractional Update

- Closest Points may cause illegal triangles
- Comparing surface normals to check for “flipping” triangles can identify this
- Fractional update: Select largest m such that no triangles are flipped





Flowchart



S = {V,T} : Original Surfaces (Meshes and Triangles)
V : Original Vertices
V^{rec} : Reconstructed Vertices
$V^{closest}$: Closest Points on Original Surface to Reconstructed Vertices
$V^{updated}$: Vertices after fractional update
$S^{updated}$ = S{$V^{updated}$, T}: Updated Surfaces

Algorithm

Algorithm 1 Point Update Algorithm

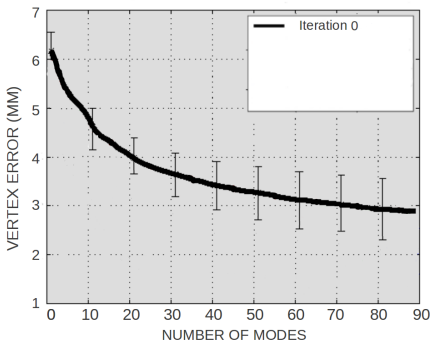
Input: $\mathcal{S} = \{(V_i, T) | i = 1 \dots N\}$, Stepsize s
for all $S_i = (V_i, T) \in \mathcal{S}$ **do**
  Generate ${\mathcal{V}'}_i$ and compute PCA model $\Rightarrow (\bar{M}, Y)$.
  Reconstruct V_i with $\bar{M}$ and $Y \Rightarrow V_i^{rec}$
  Compute closest points to S_i. $\Rightarrow V_i^{closest}$
  Compute direction vector d_{along} for every vertex
  Set $\mu = 1$ and compute fractional update $\Rightarrow V_i^{updated}$
  while $V_i^{updated}$ is not consistent **do**
    $\mu = \mu - s$
    Compute fractional update $V_i^{updated}$
  end while
end for
Output: $\mathcal{S}^{updated} = \{(V_i^{updated}, T) | i = 1 \dots N\}$

Experimental Setup: Data

- Pelvis Atlas: 110 normal adult male subjects, anonymized
- Each sample is a 512X512X256 CT Volume, manually segmented
- Surface mesh extraction: 11163 points, 23414 triangles
- Each mesh was first registered to a template mesh to establish initial correspondences

Experimental Setup: Validation

- Cross validation: 5 fold
- Training set is used for learning mean shape and modes

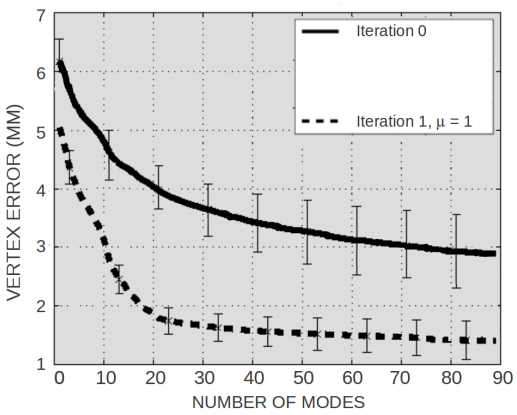


Experimental Setup: Validation

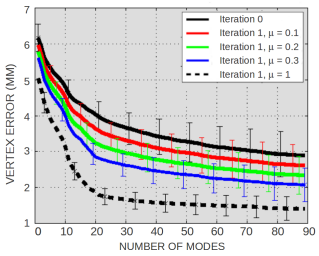
- Cross validation: 5 fold
- Training set is used for learning mean shape and modes
- Reconstruction for all the data is carried out with 30 modes
- Point Update carried out to eliminate out of surface component
- Fractional update carried out to ensure consistency
- Reported Metrics: Vertex Error, Surface Error, Volume Error

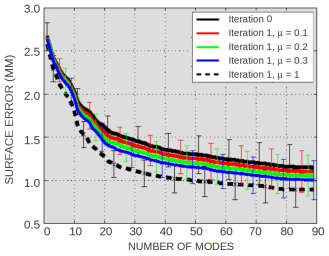
Closest Points

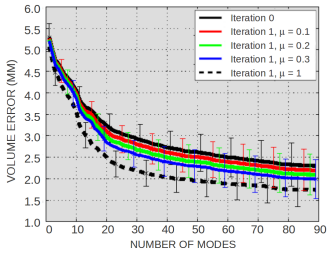
- Leave out Validation with Point Update to the closest points $V^{closest}$



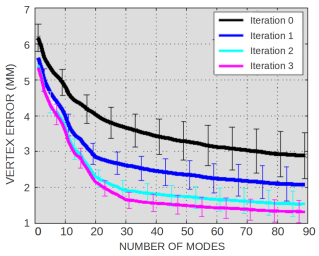
The effect of Fractional Updates

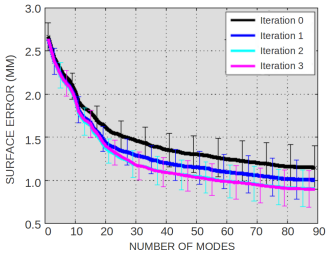


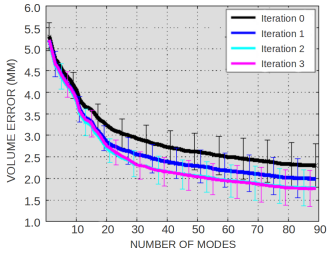




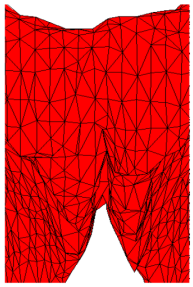
Multiple Iterations



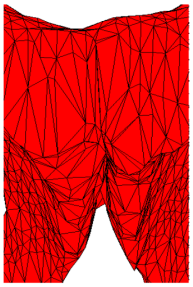




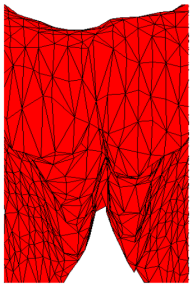
Example of Mesh Update



Target Shape



Iteration 1 – Closest Points



Iteration 3 – Adaptive Fractional Update

Conclusion

- Presented a general iterative method for refinement of 3D point to point correspondences, which does not require any outside information
- Results show reduction in vertex and surface error for leave 20 out validation
- Extensions: Evaluation of consistency using intensity information, application to other types of atlases.

Acknowledgments

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Questions?