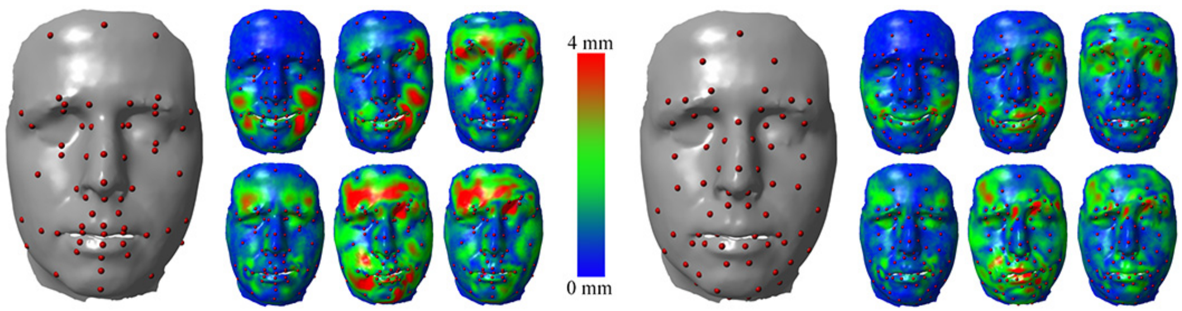
IEEE Transactions on Visualization and Computer Graphics (TVCG) 2013



Marker Optimization for Facial Motion Acquisition and Deformation

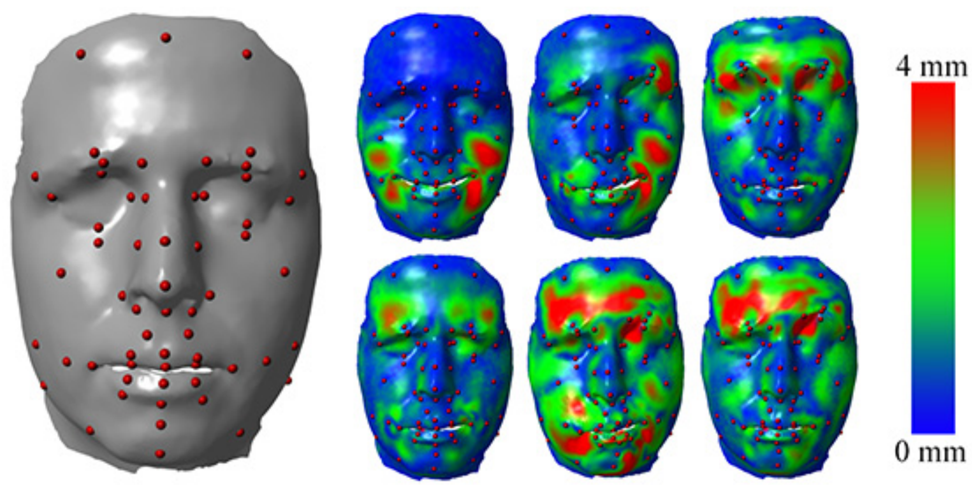
[†]*Binh Huy Le*, [‡]*Mingyang Zhu*, *and* [†]*Zhigang Deng*

[†]UNIVERSITY of HOUSTON

[‡] Nanjing University of Science and Technology

Roadmap

- Motivation
- Problem Formulation
- Algorithm
- Results & Validations
- Discussion
- Q & A



MOTIVATION

Optical Motion Capture

Marker-based

× Low spatial resolution

→ Body capture

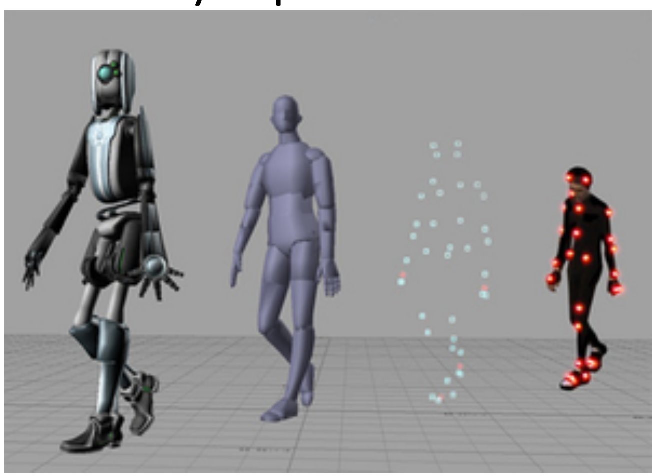


Image Courtesy of Wikipedia

Markerless

✓ High spatial resolution

→ Facial capture

Image Courtesy of Beeler et al.

Optical Motion Capture

Marker-based

- × Low spatial resolution
- ✓ Robust tracking

Markerless

- ✓ High spatial resolution
- × Drifting

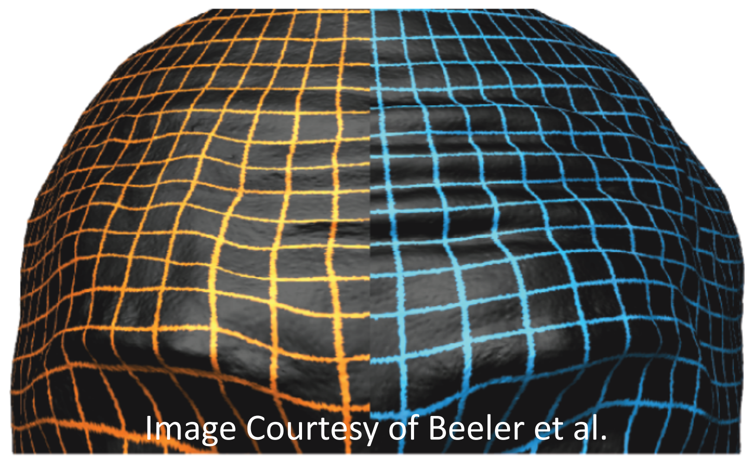


Image Courtesy of Beeler et al.

Optical Motion Capture

Marker-based

- × Low spatial resolution
- ✓ Robust tracking
- ✓ Large working volume
- ✓ Face + body capture


Making of The Polar Express movie

Markerless

- ✓ High spatial resolution
- × Drifting
- × More limited setup
- × Face or body capture only

Optical Motion Capture

Marker-based

- × Low spatial resolution
- ✓ Robust tracking
- ✓ Large working volume
- ✓ Face + body capture
- ✓ You might have one already

Markerless

- ✓ High spatial resolution
- × Drifting
- × More limited setup
- × Face or body capture only

Optical Motion Capture

Marker-based

- × Low spatial resolution
- ✓ Robust tracking
- ✓ Large working volume
- ✓ Face + body capture
- ✓ You might have one already

→ Still good for facial capture

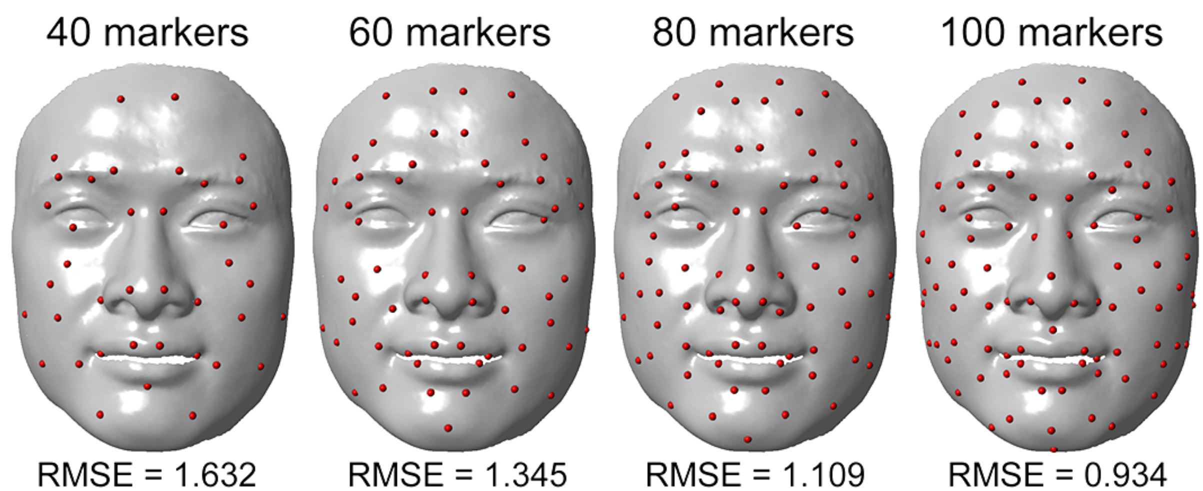
Markerless

- ✓ High spatial resolution
- × Drifting
- × More limited setup
- × Face or body capture only

Marker-based Facial Motion Capture

How many markers should be put on the face?

- Putting more → time consuming
- Putting less → data loss



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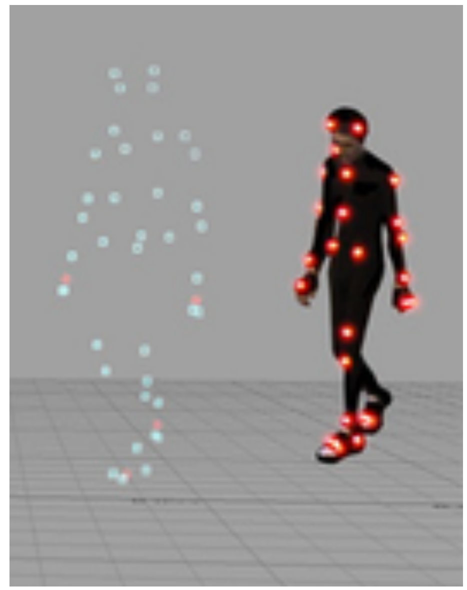
How to put markers?

- Guidance is not as clear as with body capture
- Hard to quantify how good a layout is



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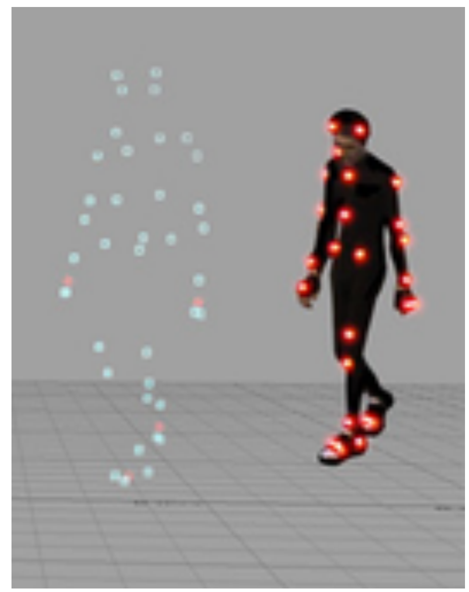

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Can we do something more than acquisition?

- Animation?
- Data compression?

PROBLEM FORMULATION

Main Idea

- Use performance capture data to explore optimal layout
  - Different facial poses

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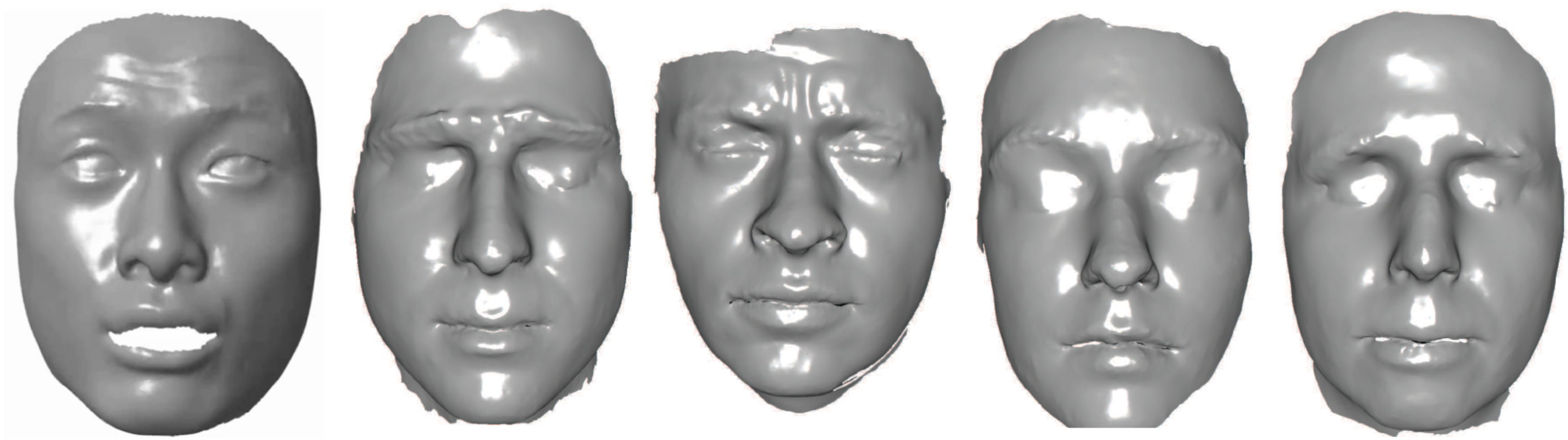
  - Different facial poses
  - Different subjects



Main Idea

- Use performance capture data to explore optimal layout
  - Different facial poses
  - Different subjects
- Marker based capture as discrete sampling of facial surface
  - Given performance capture data (animated 3D mesh sequence)
  - Find **markers' locations** and **deformation model** to estimate input best
  - Some constraints, e.g. markers are on facial surface

Thin-shell Deformation Model

- Minimizing elastic energy: $\underbrace{-k_s \Delta d}_{\text{stretching}} + \underbrace{k_b \Delta^2 d}_{\text{bending}} = 0$

Thin-shell Deformation Model

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- Discretization: $(-k_s \mathcal{L} + k_b \mathcal{L}^2) d = 0$

Laplacian matrix

Thin-shell Deformation Model

- Minimizing elastic energy: $-k_s \Delta d + k_b \Delta^2 d = 0$
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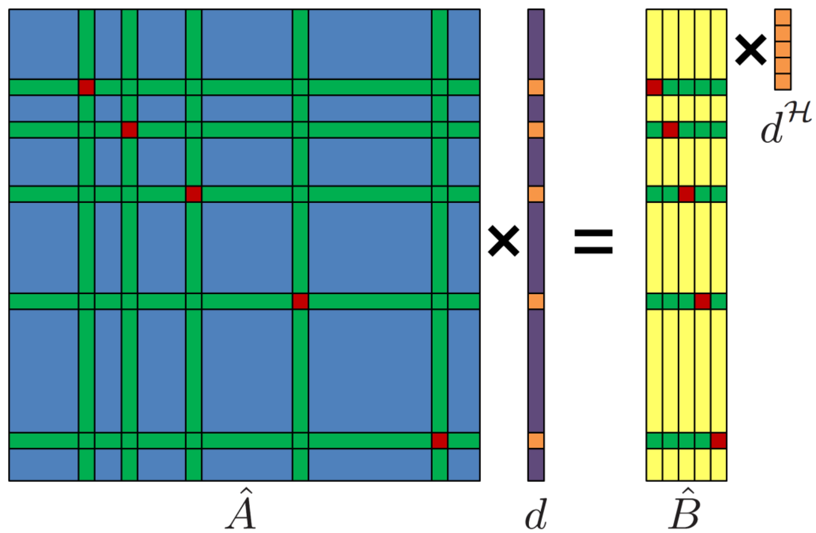
- Constraint some vertices (markers $\mathcal{H}$): $\hat{A} d = \hat{B} d^{\mathcal{H}}$



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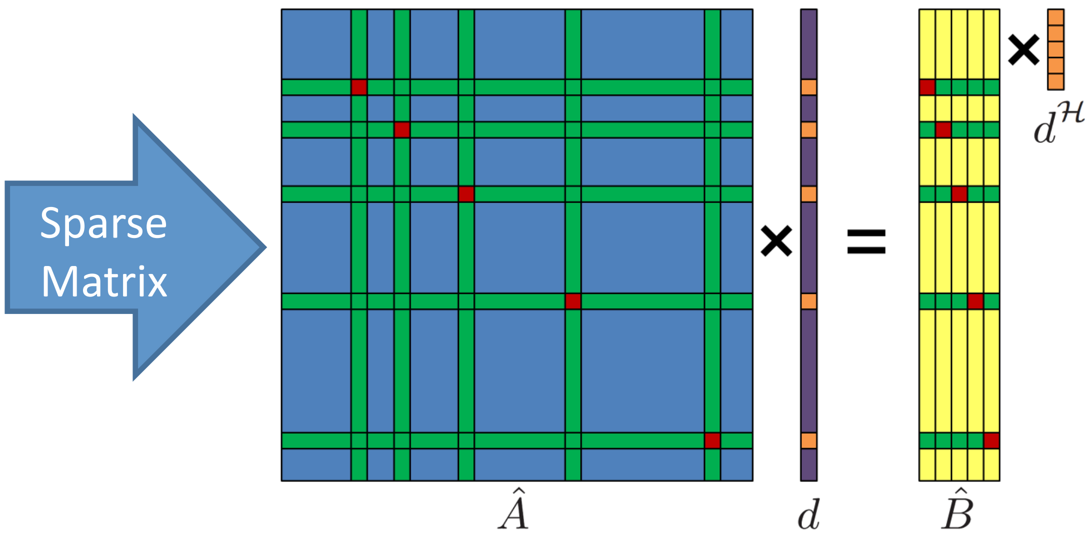

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- Solution: $d = \hat{A}^{-1} \hat{B} d^{\mathcal{H}} = W d^{\mathcal{H}}$
- Solve weights $W = \hat{A}^{-1} \hat{B}$ by Cholesky decomposition $\hat{A} = L^{\mathsf{T}} L$

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$\hat{A}$ computed from rest pose & **markers set** $\mathcal{H}$

$$\mathcal{H} \rightarrow W$$

Objective

- Minimizing reconstruction error

$$\min_{\mathcal{H}=\{h_1,\ldots,h_M\}} E = \min_{\mathcal{H}} \left\| X - HW^{\mathsf{T}} \right\|_2^2$$

Markers Set

Weights

Markers Displacement

Vertices Displacement (from input data)

Objective

- Minimizing reconstruction error

$$\min_{\mathcal{H}=\{h_1,\ldots,h_M\}} E = \min_{\mathcal{H}} \left\| X - HW^{\mathsf{T}} \right\|_2^2$$

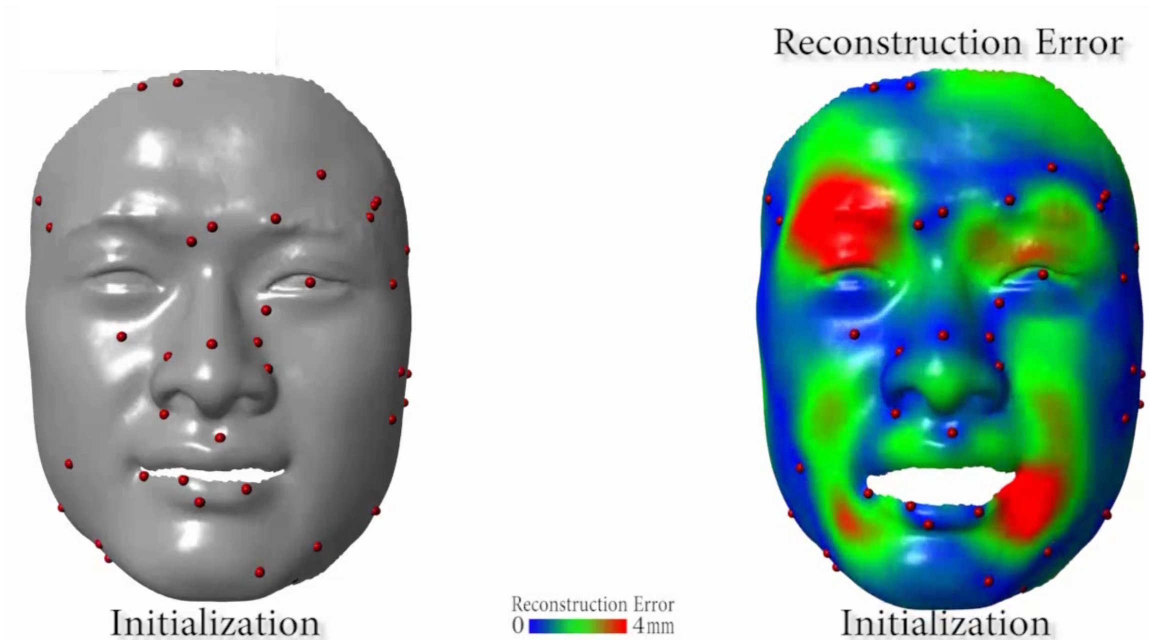
$$\text{s. t.: } H_{i,j} = X_{i,h_j}, \forall i, j$$ → Markers are on the facial surface

$$W = \hat{A}^{-1}\hat{B}$$ → Thin-shell deformation

ALGORITHM

Overview

- Repeated update the markers’ positions one by one to reduce the objective function (reconstruction error)



Overview

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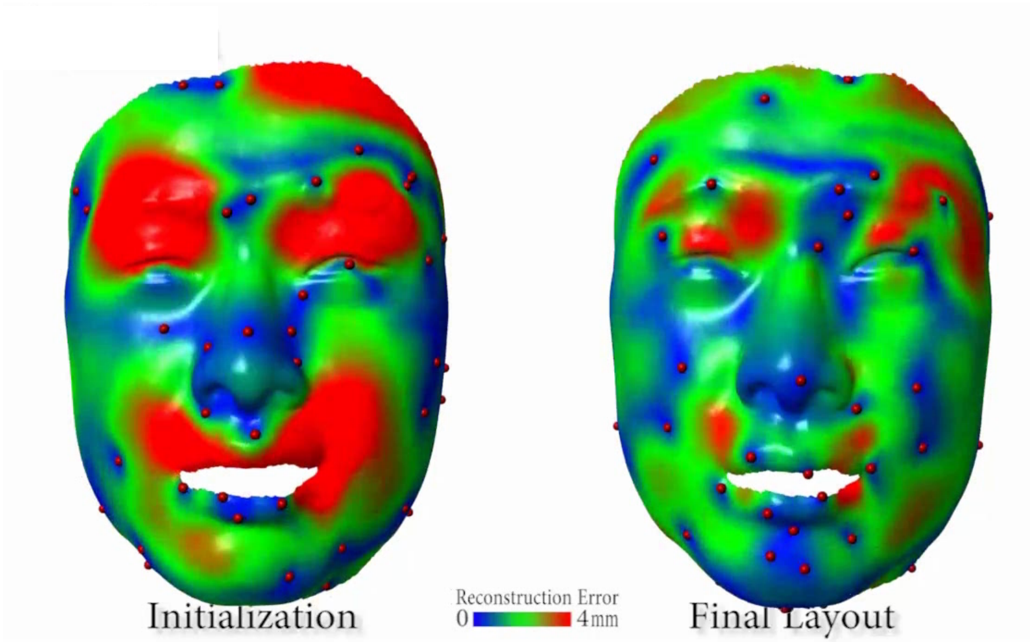
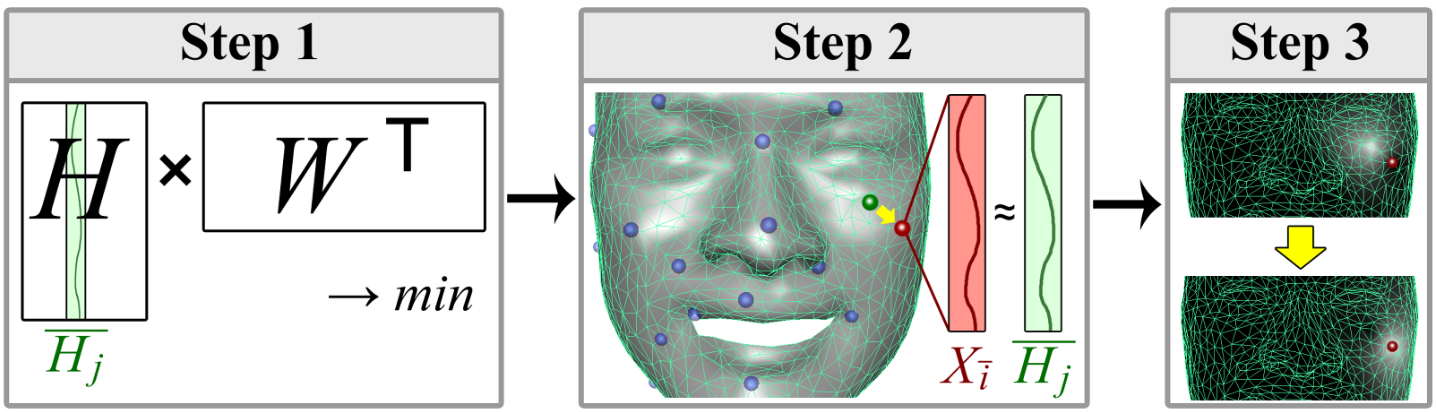


Overview

- Repeated update the markers' positions one by one to reduce the objective function (reconstruction error)
  - Update one marker



Calculating Expected Marker Trajectory

Relocate Marker

Updating Weight Matrix

Step 1: Calculating Expected Marker Trajectory

- Minimizing objective function

$$\left\| H \times W^{\top} - X \right\|_F^2$$

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$$\mathrm{s.t.}\, H_j = X_{h_j}$$

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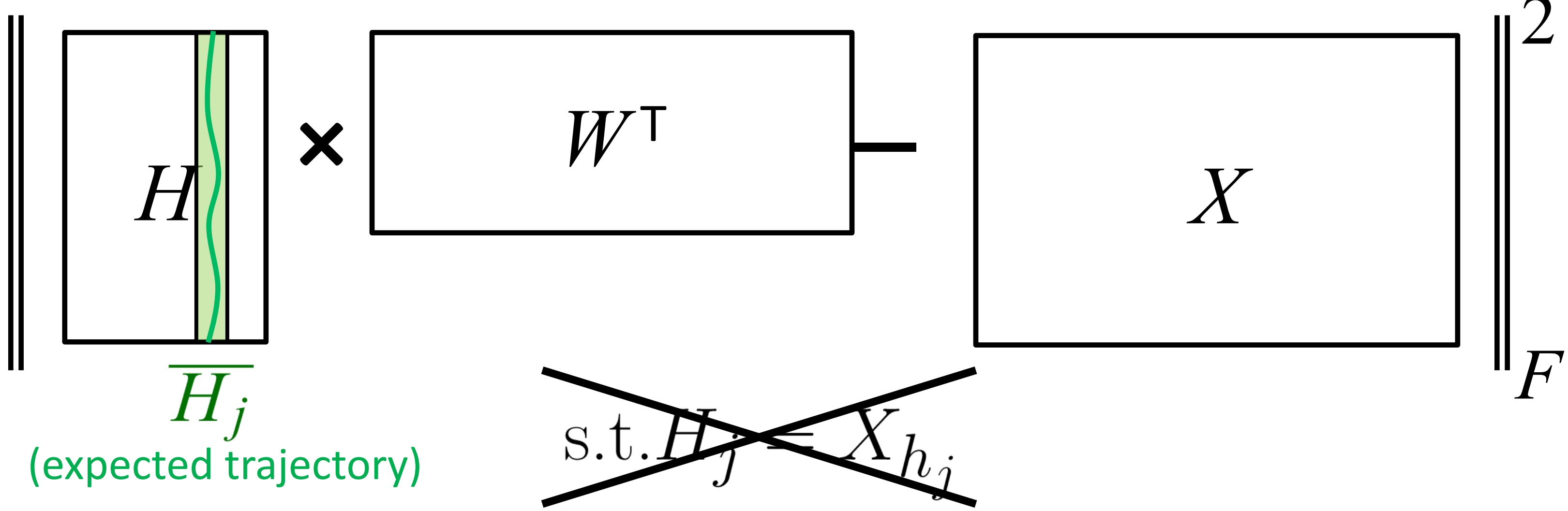
- Minimizing objective function w.r.t. $\overline{H_j}$



Step 1: Calculating Expected Marker Trajectory

- Minimizing objective function w.r.t. $\overline{H_j}$

$$\left\| H \times W^{\top} - X \right\|_F^2$$

$\overline{H_j}$

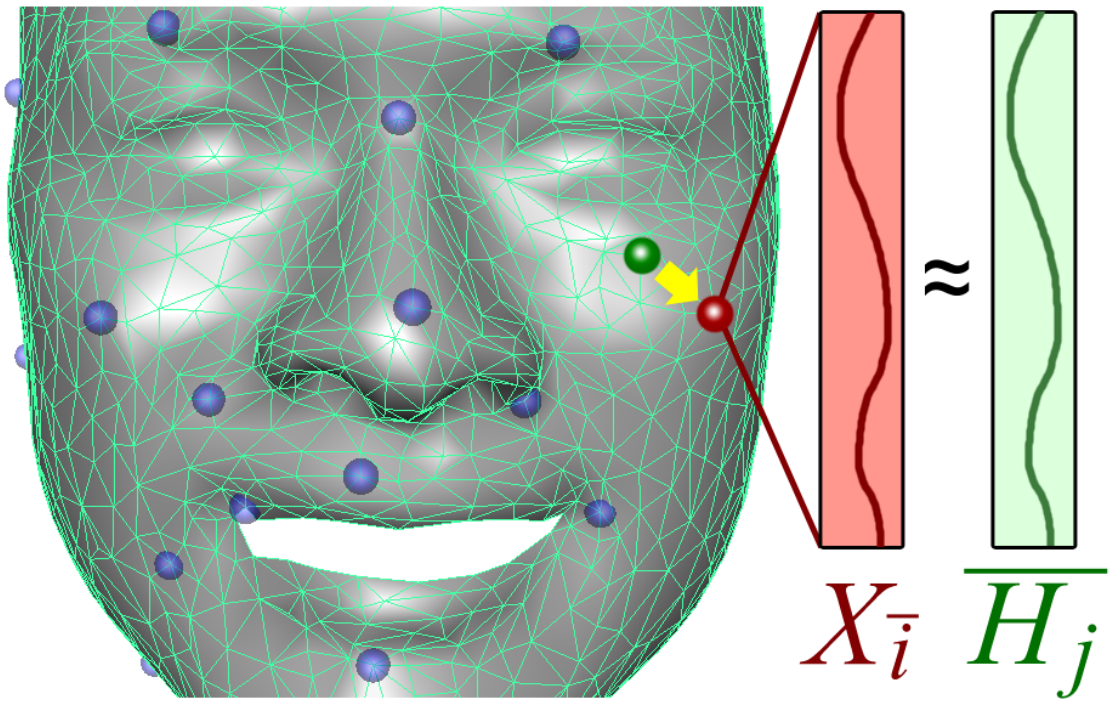
(expected trajectory)

$$\cancel{\text{s.t. } \overline{H_j} = X_{h_j}}$$

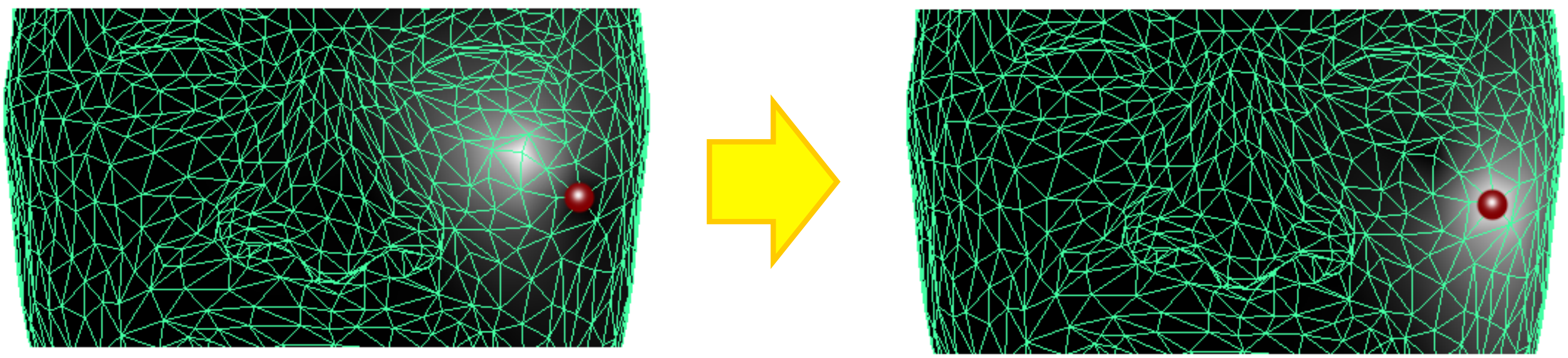
→ Linear least squares

Step 2: Relocate Marker

to vertex with trajectory $X_{\bar{i}}$ closet to the expected $\overline{H_j}$ (L2-norm)



Step 3: Updating Weight Matrix



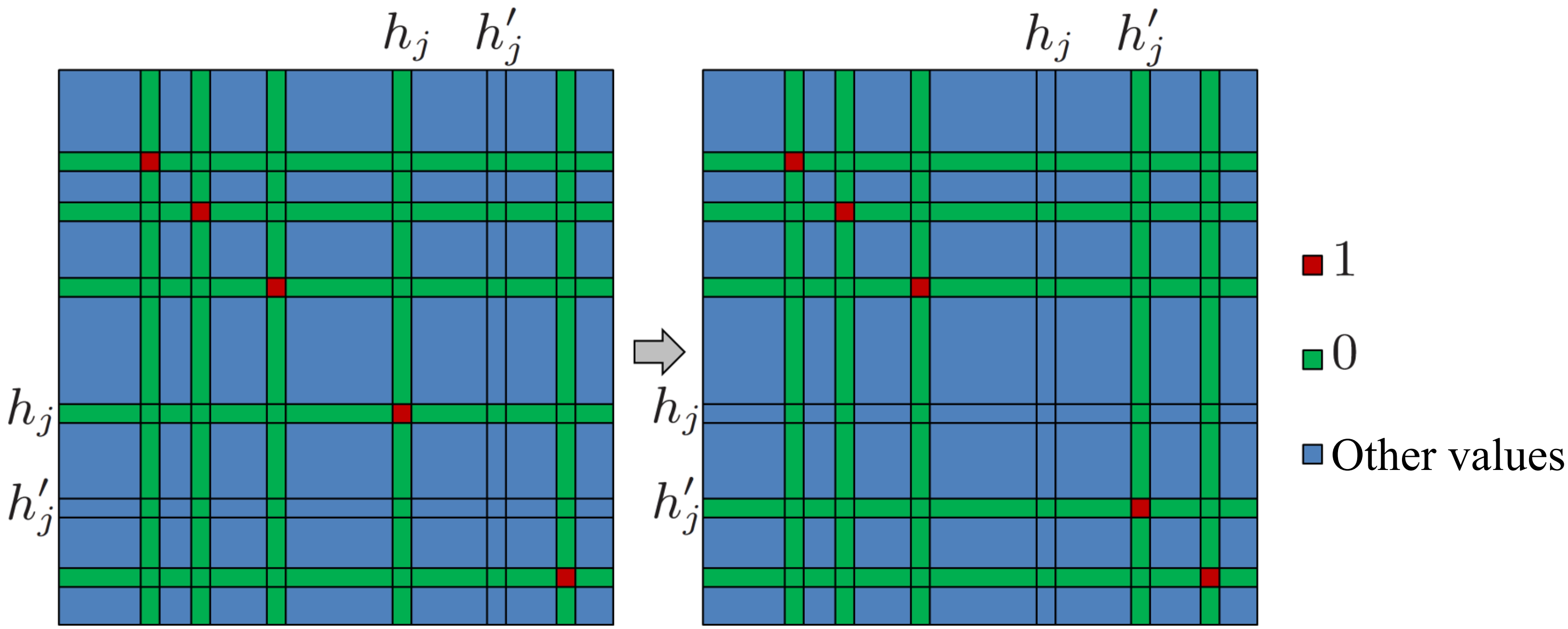
Marker on vertex j move to vertex j'

→ Update $W = \hat{A}^{-1}\hat{B}$

→ Update Cholesky decomposition $\hat{A} = L^{\mathsf{T}}L$

Step 3: Updating Weight Matrix

- Update 2 rows + 2 columns of $\hat{A}$ (use CHOLMOD)



$\hat{A} = L^{\mathsf{T}} L$ $\qquad$ $\hat{A} = L^{\mathsf{T}} L$

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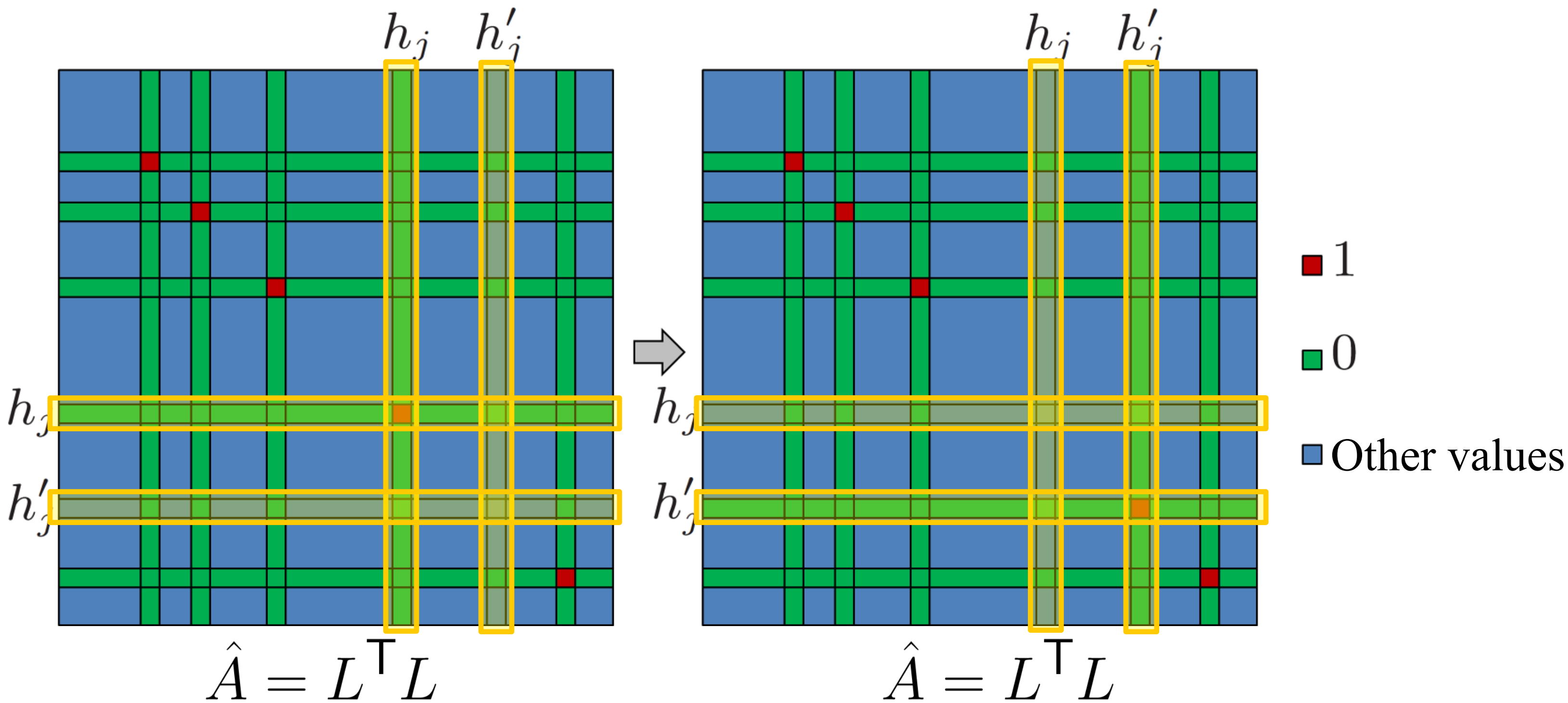
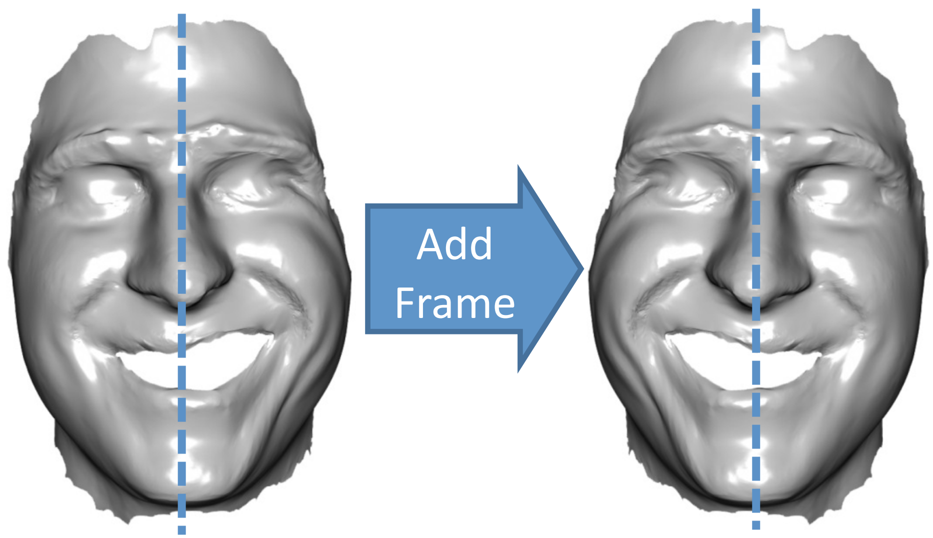


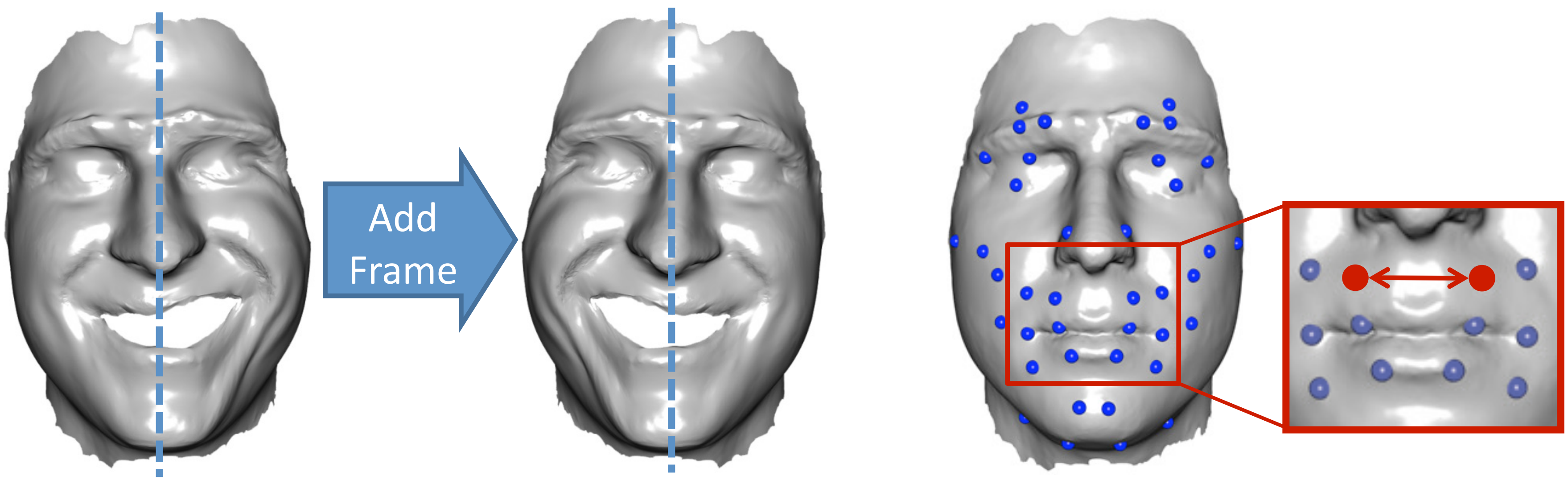
Handling Constraints

- Symmetry
  - Mirror input data



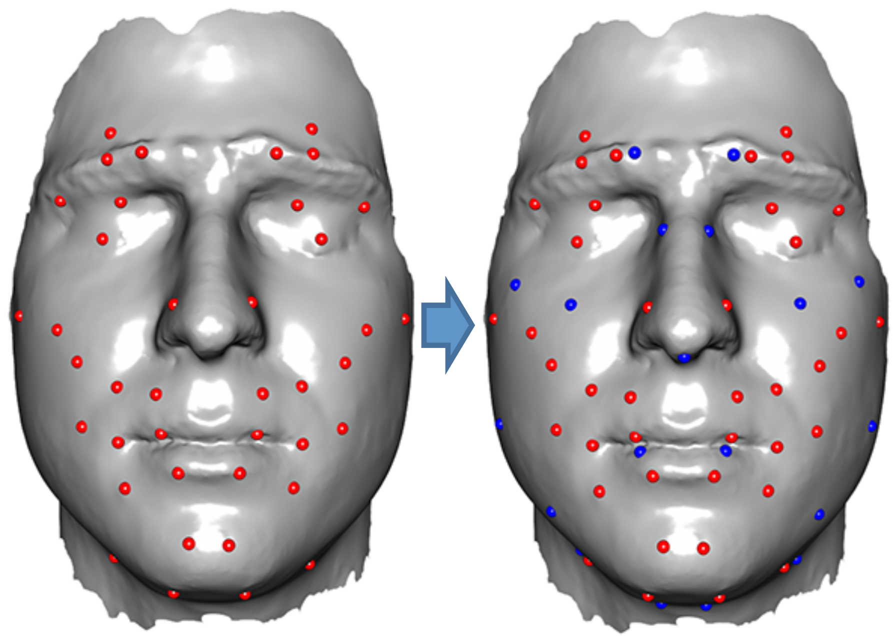
Handling Constraints

- Symmetry
  - Mirror input data
  - Enforce makers’ positions



Handling Constraints

- Symmetry
  - Mirror input data
  - Enforce makers’ positions
- Multi-resolution
  - Fix a subset of markers



Handling Constraints

- Symmetry
  - Mirror input data
  - Enforce makers' positions
- Multi-resolution
  - Fix a subset of markers
- Boundary
  - Add fixed virtual markers on boundary

With Boundary Constraint

Handling Constraints

- Symmetry
  - Mirror input data
  - Enforce makers' positions
- Multi-resolution
  - Fix a subset of markers
- Boundary
  - Add fixed virtual markers on boundary
- Prohibited regions, e.g. eyes, lips
  - Remove vertices from input meshes

Handling Constraints

- Symmetry
  - Mirror input data
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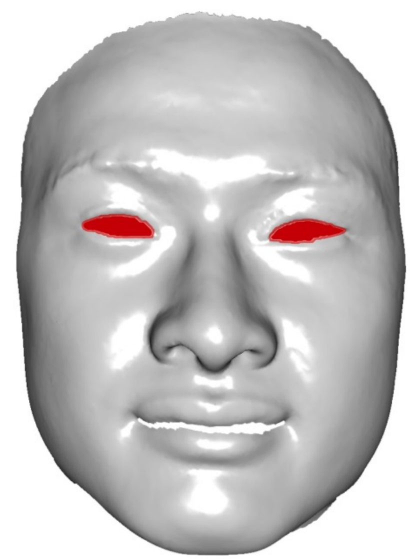

Combining Data from Multiple Subjects

- One dataset as reference
- Map other datasets to the reference
  - Non rigid registration on rest poses
    Constructing dense correspondences for the analysis of 3d facial morphology [Mao et al. 2006]
  - Vertex to vertex correspondence across datasets found by nearest point search on registered rest pose

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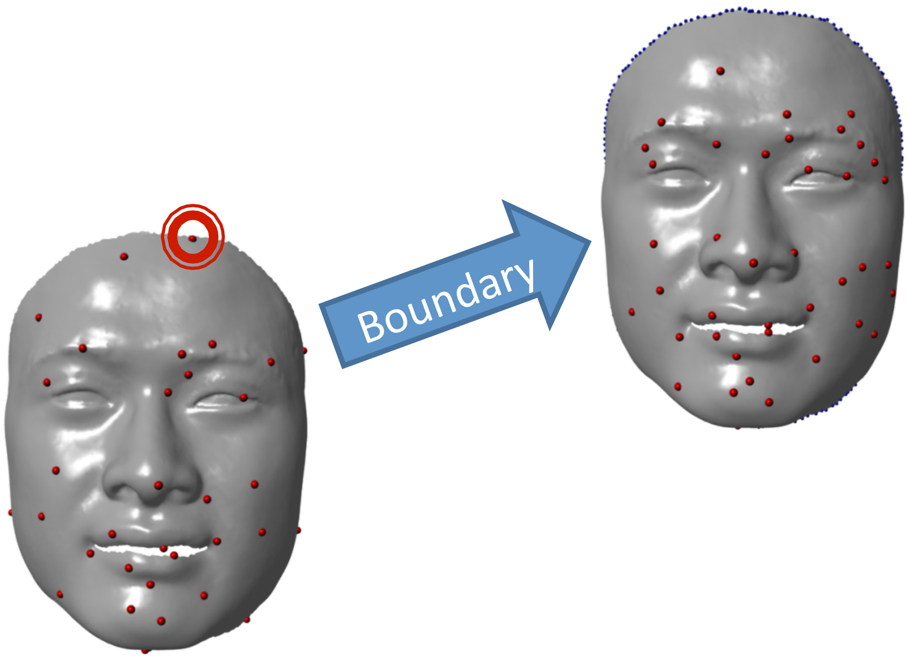
  - Non rigid registration on rest poses
    Constructing dense correspondences for the analysis of 3d facial morphology [Mao et al. 2006]
  - Vertex to vertex correspondence across datasets found by nearest point search on registered rest pose
- Optimization
  - Update only one marker layout on reference dataset then map to others
  - Different weights matrix for each dataset

RESULTS & VALIDATIONS

With Different Constraints



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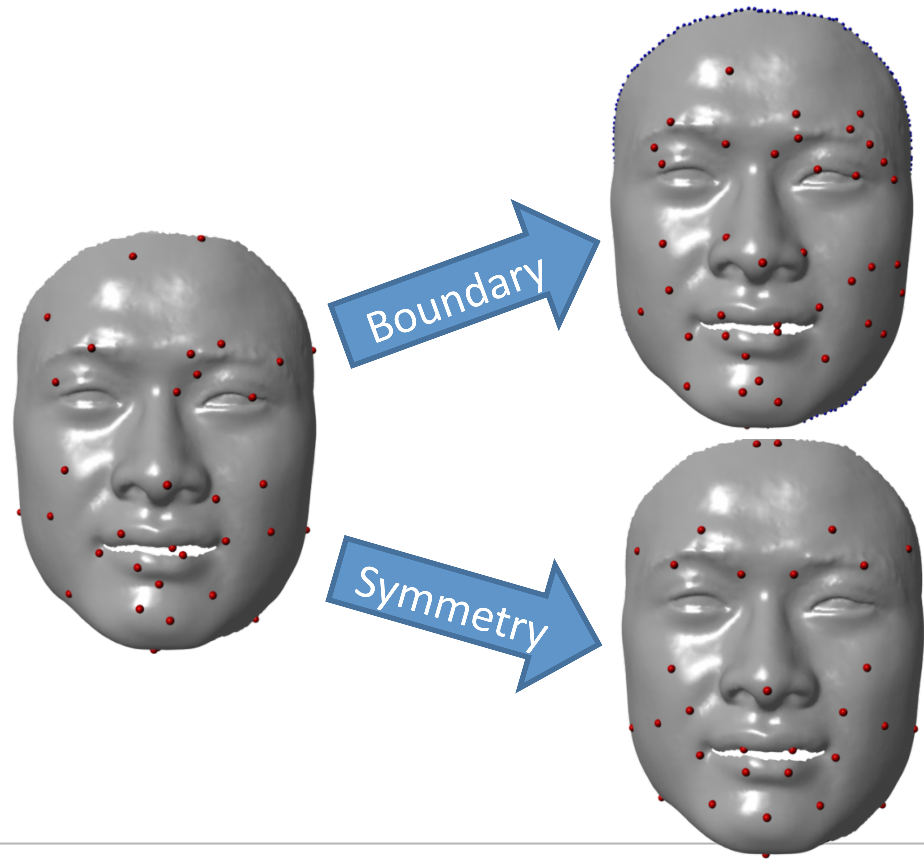

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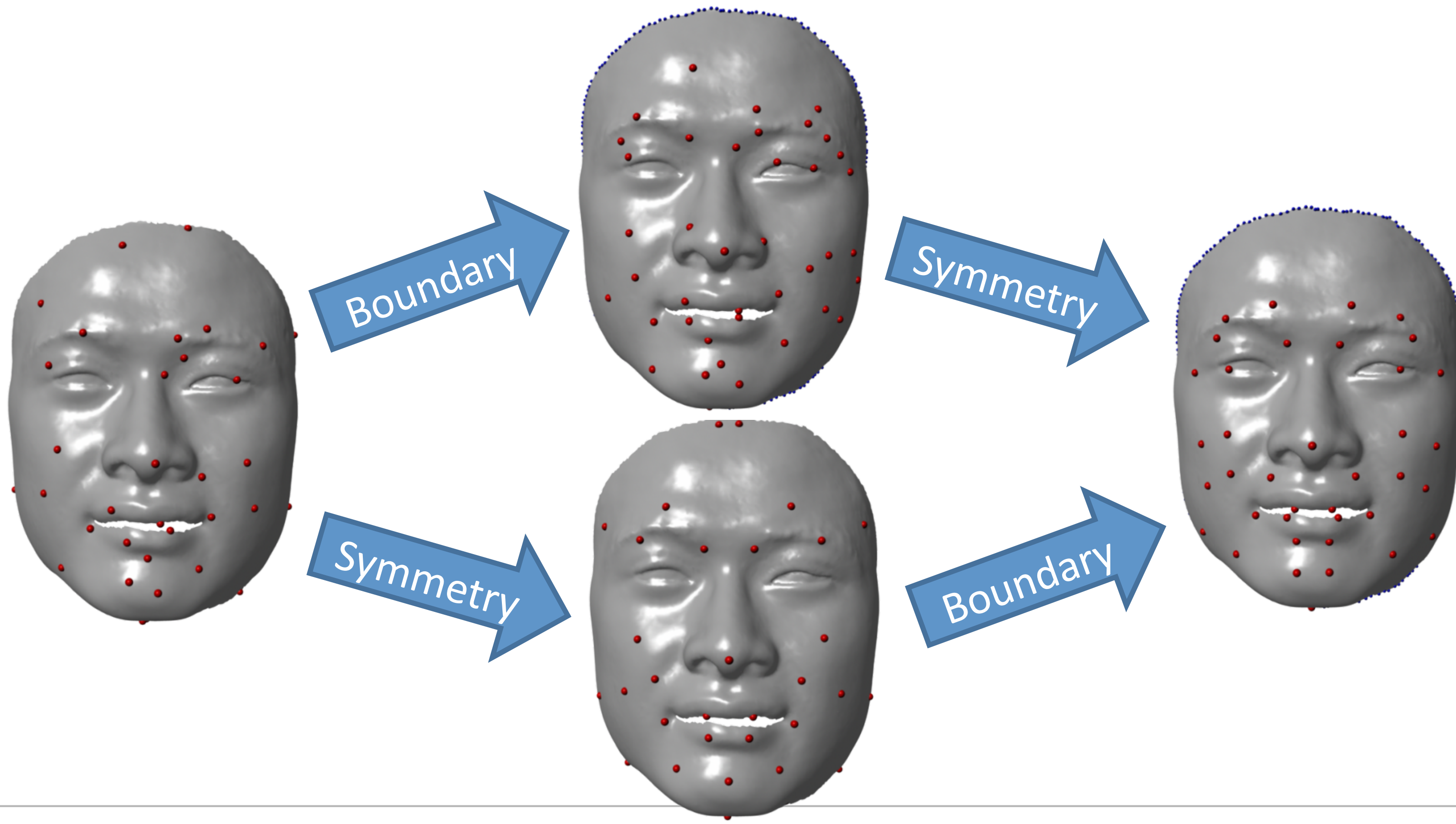
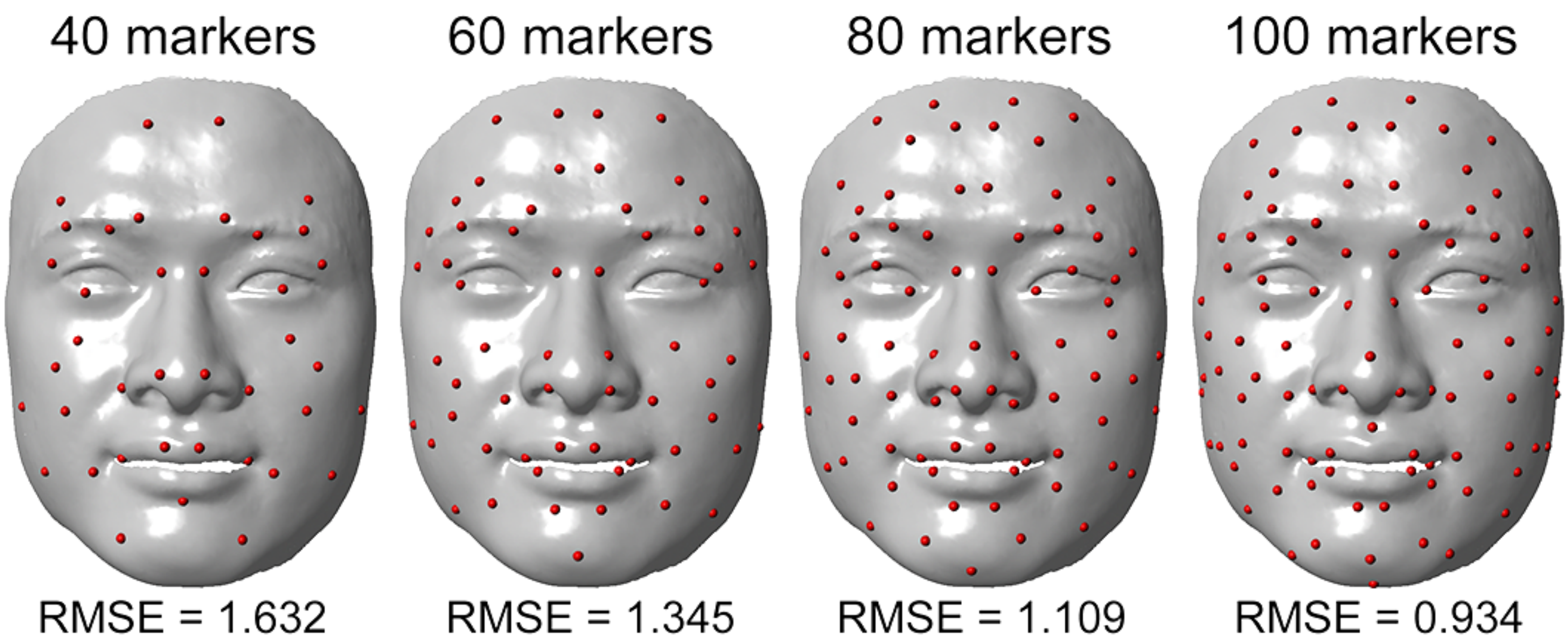
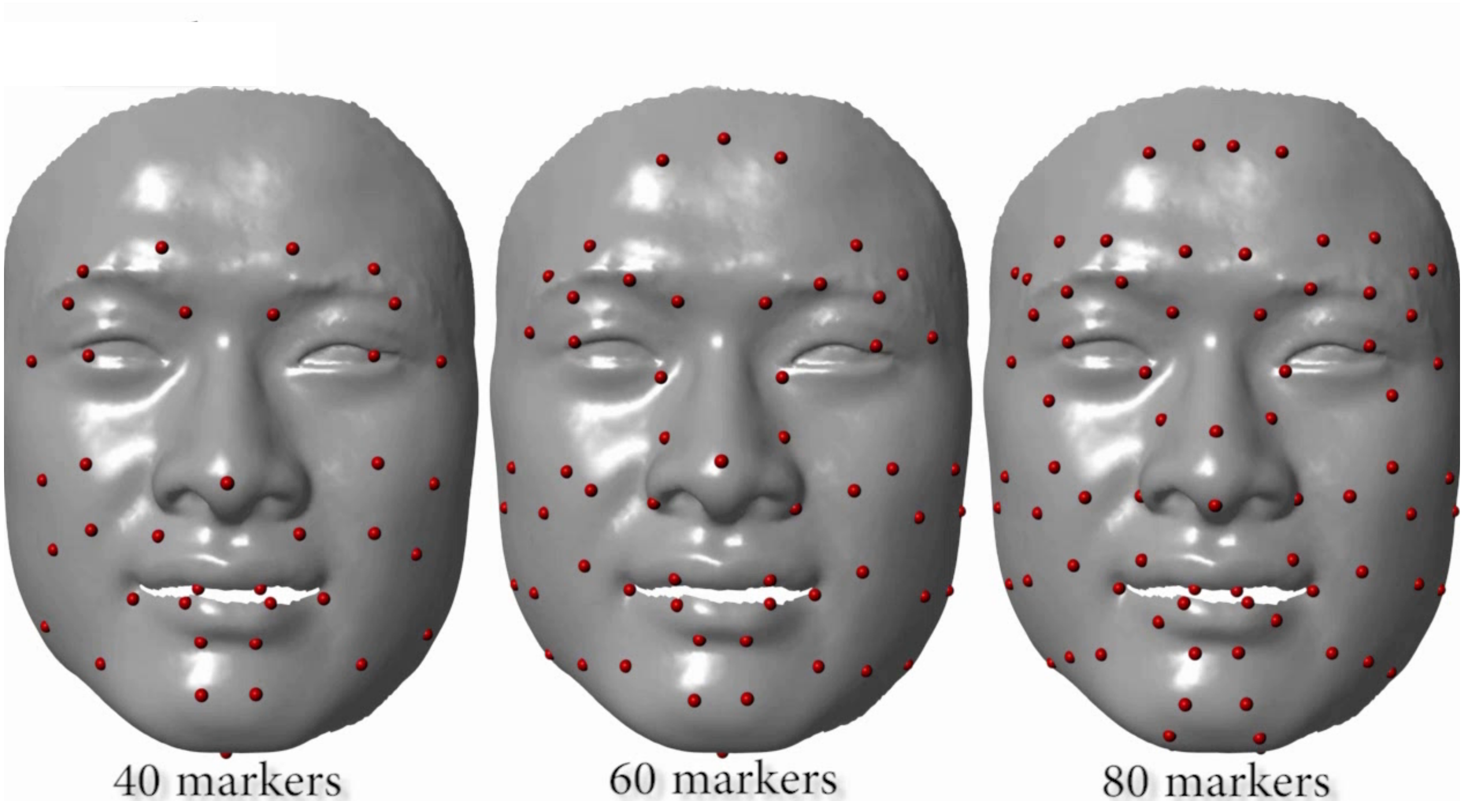


With Different Data Sources

- Combine 5 datasets and map to Model #1

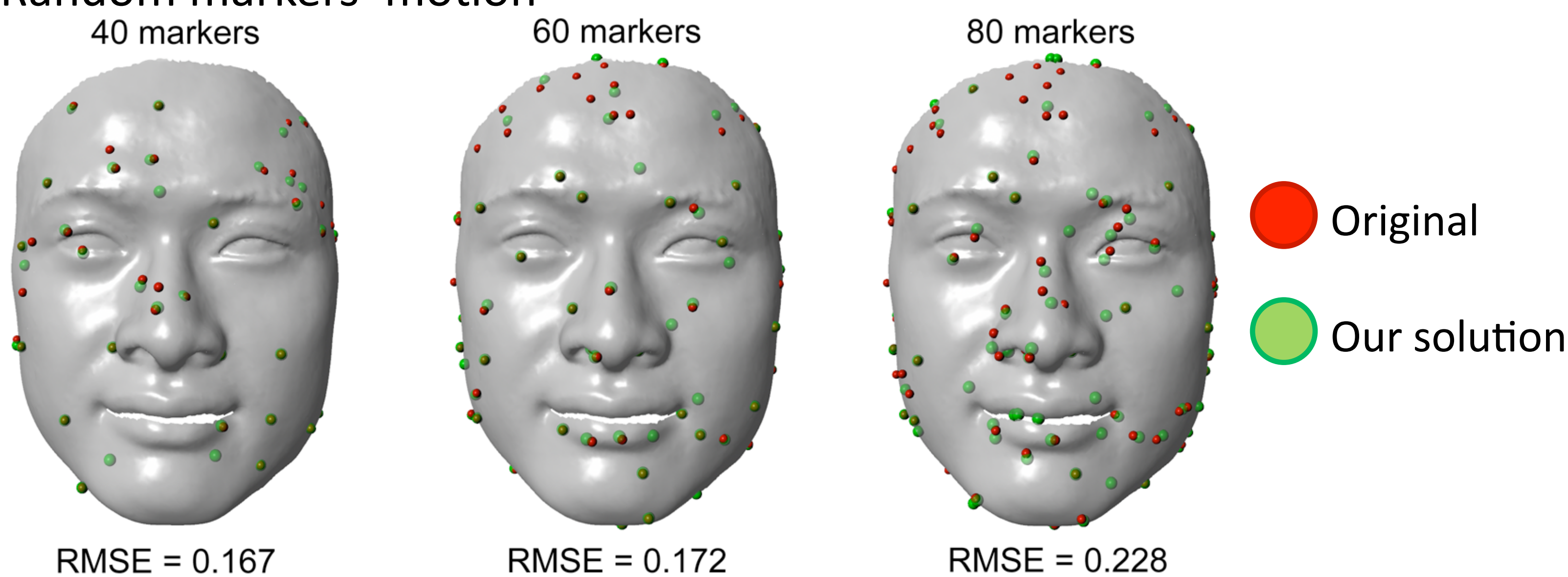


Deformation Error



Validation

- Simulation data
  - Random markers on the rest pose
  - Random markers' motion



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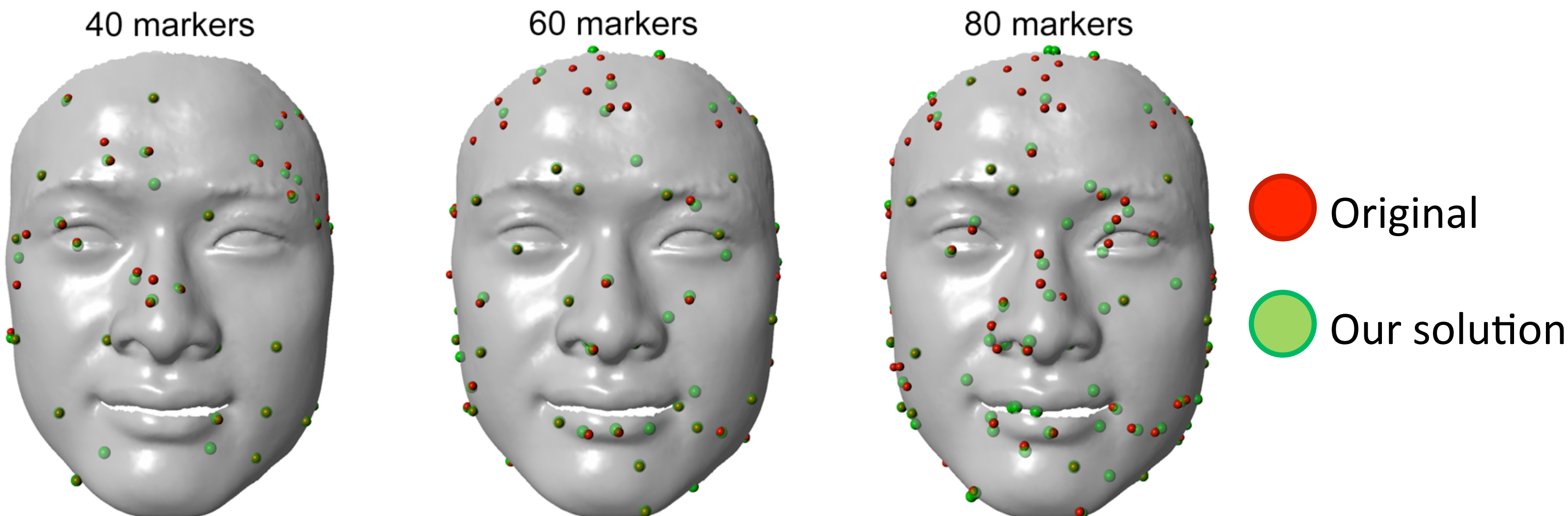
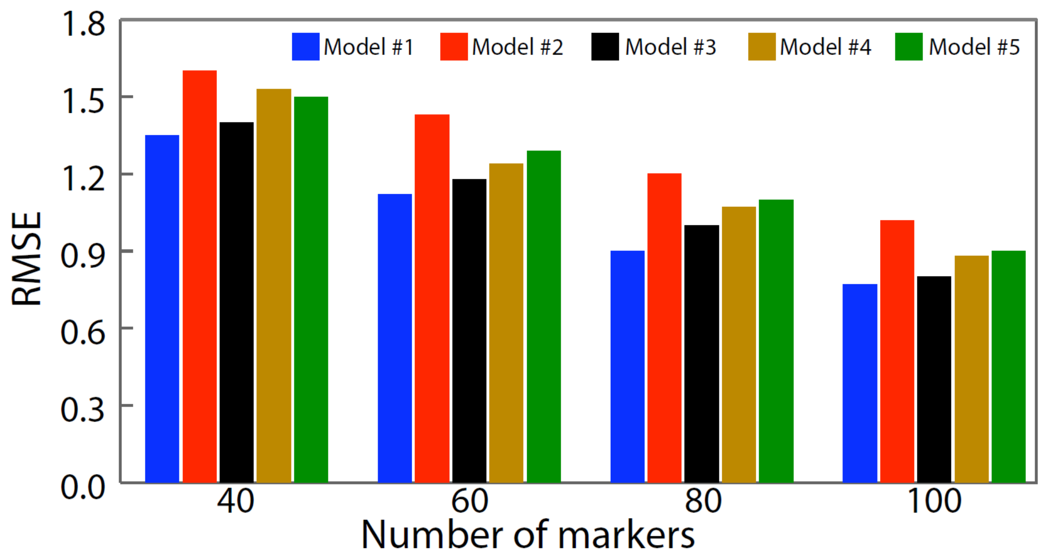


RMSE = 0.167 RMSE = 0.172 RMSE = 0.228

Validation

- Leave one out cross model validation
  - 4 models as training, 1 model as testing



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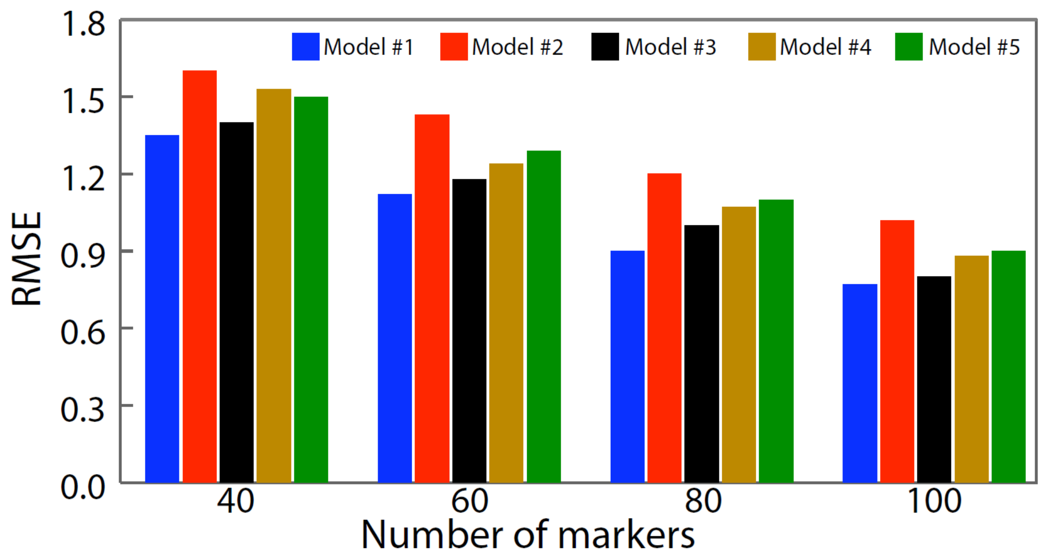
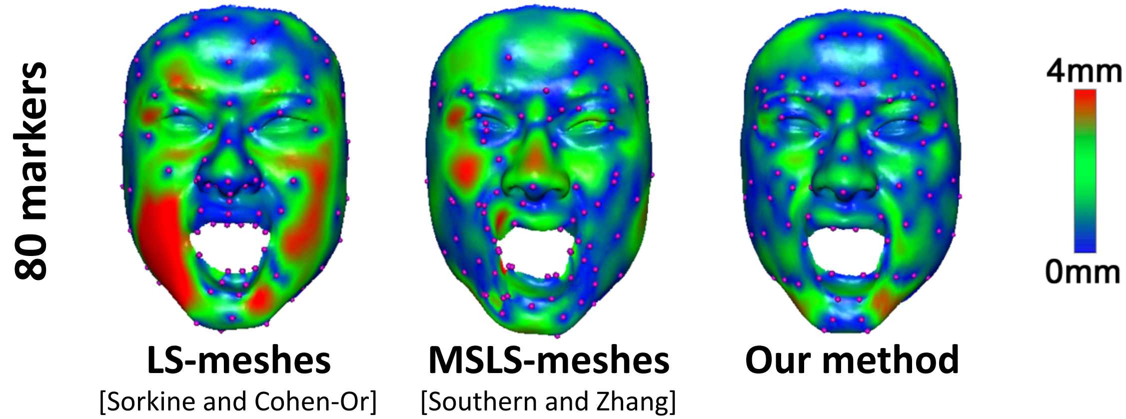


RMSE ≈ 1mm

Comparisons

- Reconstruction error of the input data



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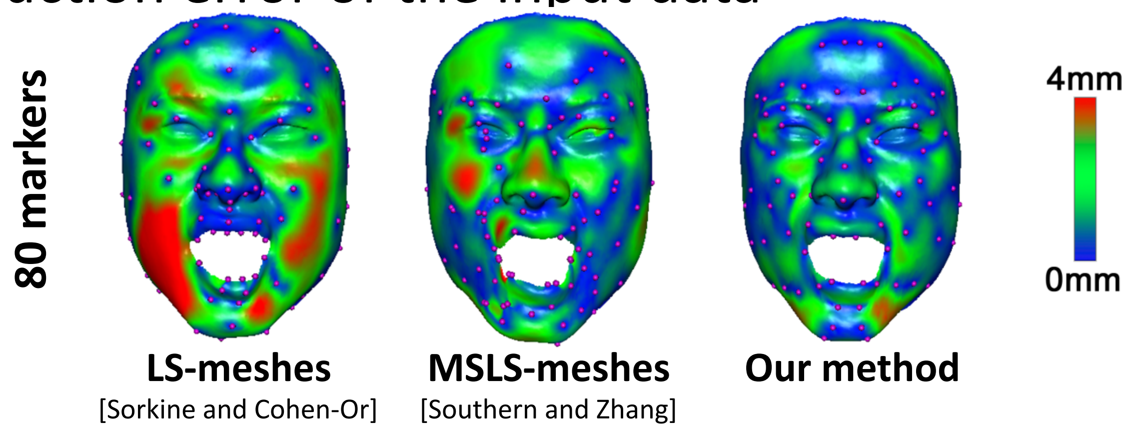

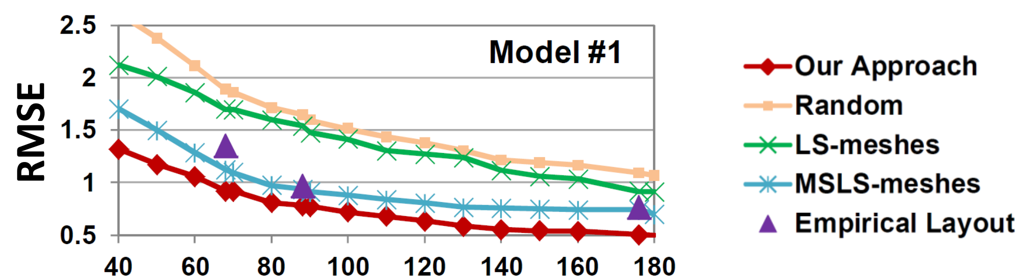

(refer to our paper for more results)

DISCUSSION

Applications

- Select key points $\{h_j\}$ for animated facial mesh sequence X
  - Compression
  - Editing
  - Linear Blend Skinning

$$X = HW^\top$$

Applications

- Select key points $\{h_j\}$ for animated facial mesh sequence X
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  - Compare to matrix factorization: No need to store & transfer W

$$X = HW^{\mathsf{T}}$$

$$\text{s.t.} H_j = X_{h_j}$$

Applications

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  - Compression
  - Editing
  - Linear Blend Skinning
  - Compare to matrix factorization: No need to store & transfer W

$$X = HW^{\top}$$
$$\text{s.t.}\, H_j = X_{h_j}$$

- More precise approximation
  - EigenSkin Correction (EC) [Kry et al.]
  - Key Point Subspace Acceleration (KPSA) [Meyer and Anderson]

Parameters		RMSE (Compression Ratio)		
# Mkrs	Rank	Ours	Ours + EC	KPSA
40	20	$1.598_{(106.8)}$	$0.255_{(16.3)}$	$0.771_{(17.1)}$
60	30	$1.256_{(98.1)}$	$0.157_{(11.3)}$	$0.656_{(11.7)}$
80	40	$1.080_{(90.6)}$	$0.113_{(8.7)}$	$0.626_{(8.9)}$
100	50	$0.865_{(84.2)}$	$0.085_{(7.1)}$	$0.502_{(7.2)}$

(results on model #1 only, refer to our paper for more)

Conclusions

- ✓ Quantitative approach to optimize marker layouts
  - With optional constraints: symmetry, boundary, multi-resolution
- ✓ Applications with better performance than state of the art methods:
  - Animated mesh sequence compression: LS-meshes, MSLS meshes
  - Facial data compression: Key Point Subspace Acceleration

Conclusions

- ✓ Quantitative approach to optimize marker layouts
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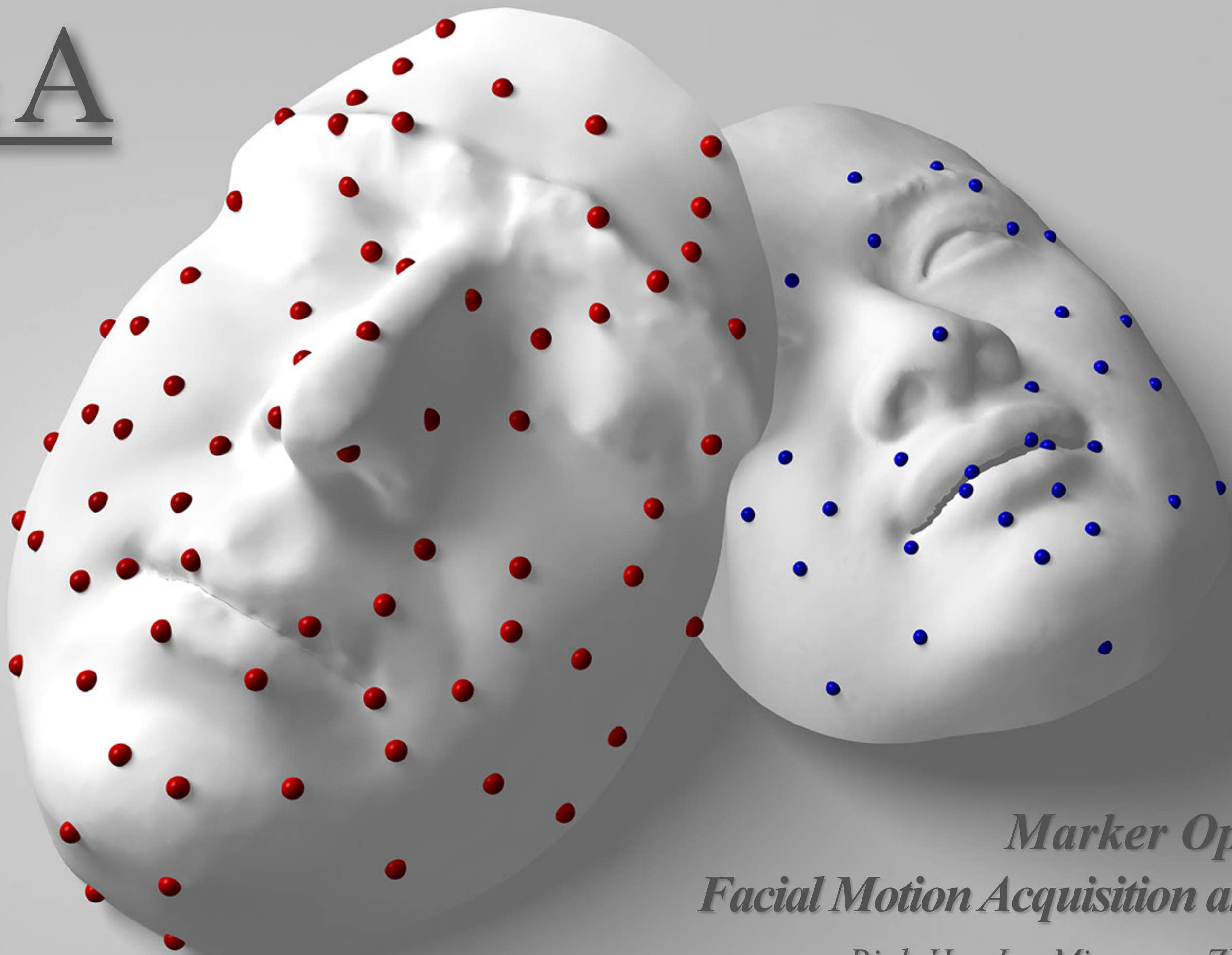
- ✓ Applications with better performance than state of the art methods:
  - Animated mesh sequence compression: LS-meshes, MSLS meshes
  - Facial data compression: Key Point Subspace Acceleration
- × Data dependent (data driven approach)
- × Linear deformation model
- × Local optimum only

Acknowledgements

- Hao (Richard) Zhang for helps and discussion
- Li Zhang, Derek Bradley, and Thabo Beeler for providing datasets
- Anonymous reviewers for giving comments and suggestions

Q & A



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