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Active Nonrigid ICP Algorithm

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i·bug intelligent behaviour understanding group
learning · imaging · interfaces

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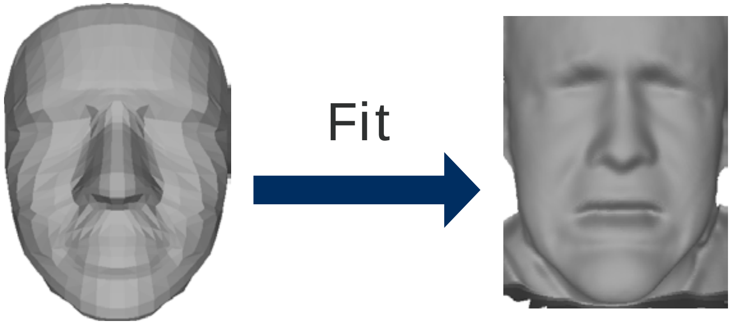
The Problem

Our goal:

- Accurately fit a 3D facial mesh.
- Model facial expression.

Challenges:

- Complex, non-linear and highly deformable facial structure.



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Prior Work

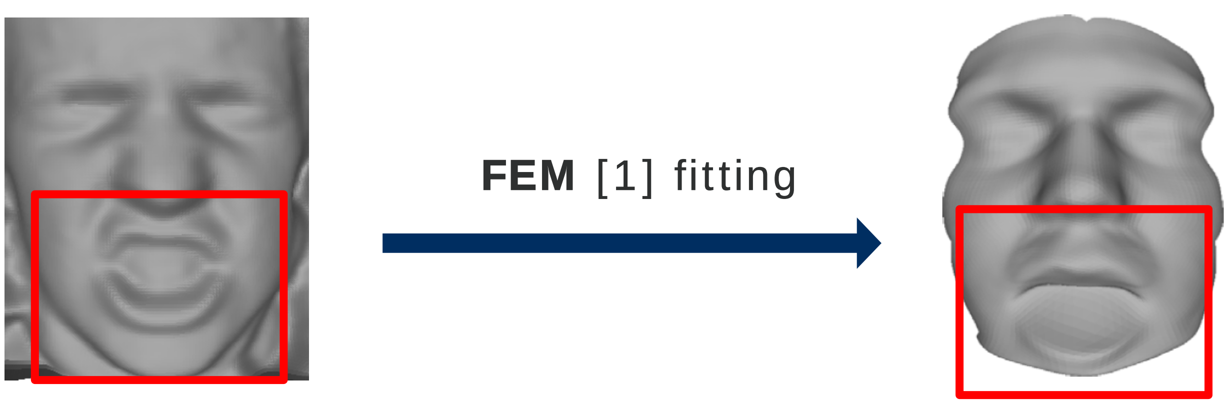
- Deformable fitting using annotated face model (AFM) [1]. We refer it to **FEM** in our paper.
- Non-rigid Iterative Closest Point (NICP) [2].
- 3D Morphable Model Fitting with ICP [3].

[1] G. Passalis et al. Intraclass retrieval of nonrigid 3D objects: application to face recognition. T-PAMI 2007.
[2] B. Amberg et al. Optimal step nonrigid icp algorithms for surface registration. CVPR 2007.
[3] B. Amberg et al. Expression Invariant 3D Face Recognition with a Morphable Model. FG 2008.

Motivation

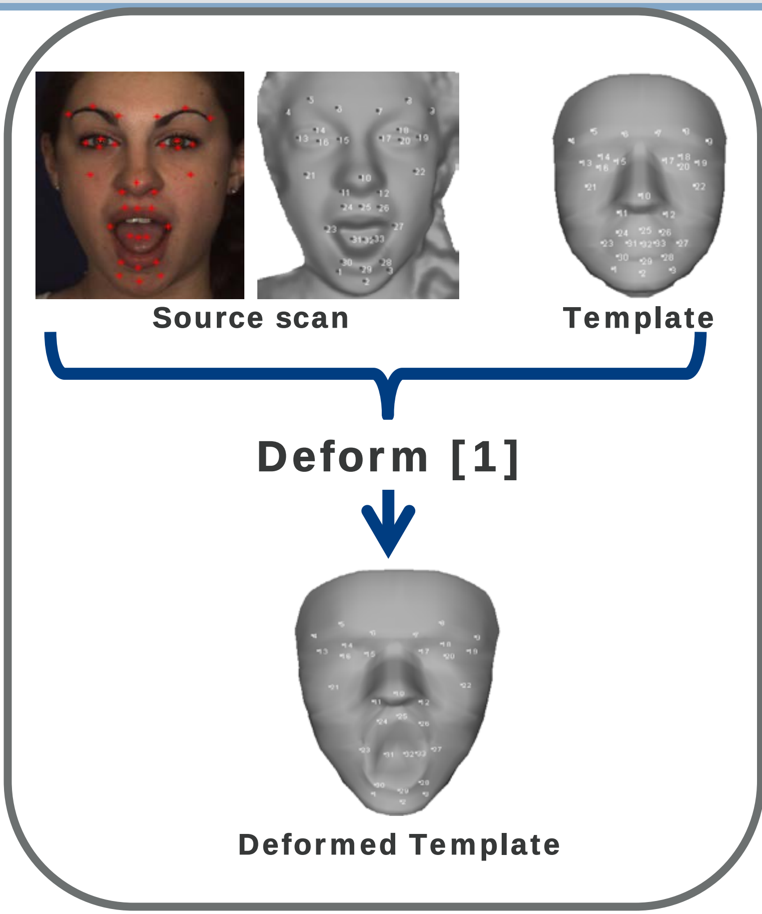
- To better model facial expression

- To better capture the face parts



[1] G. Passalis et al. Intraclass retrieval of nonrigid 3D objects: application to face recognition. T-PAMI 2007.

Our Pipeline



Step 1: Initialization

[1] A. Jacobson et al. Bounded biharmonic weights for real-time deformation. SIGGRAPH 2011.

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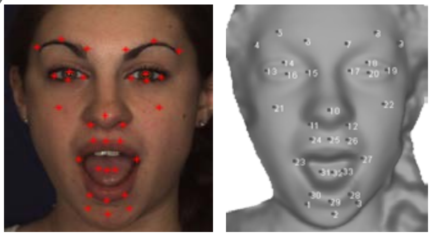
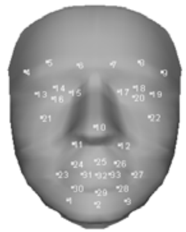
Our Pipeline

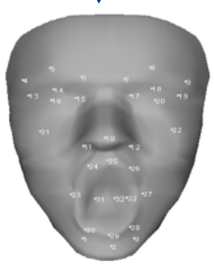


Source scan



Template

Deform [1]



Deformed Template

Rigid Alignment

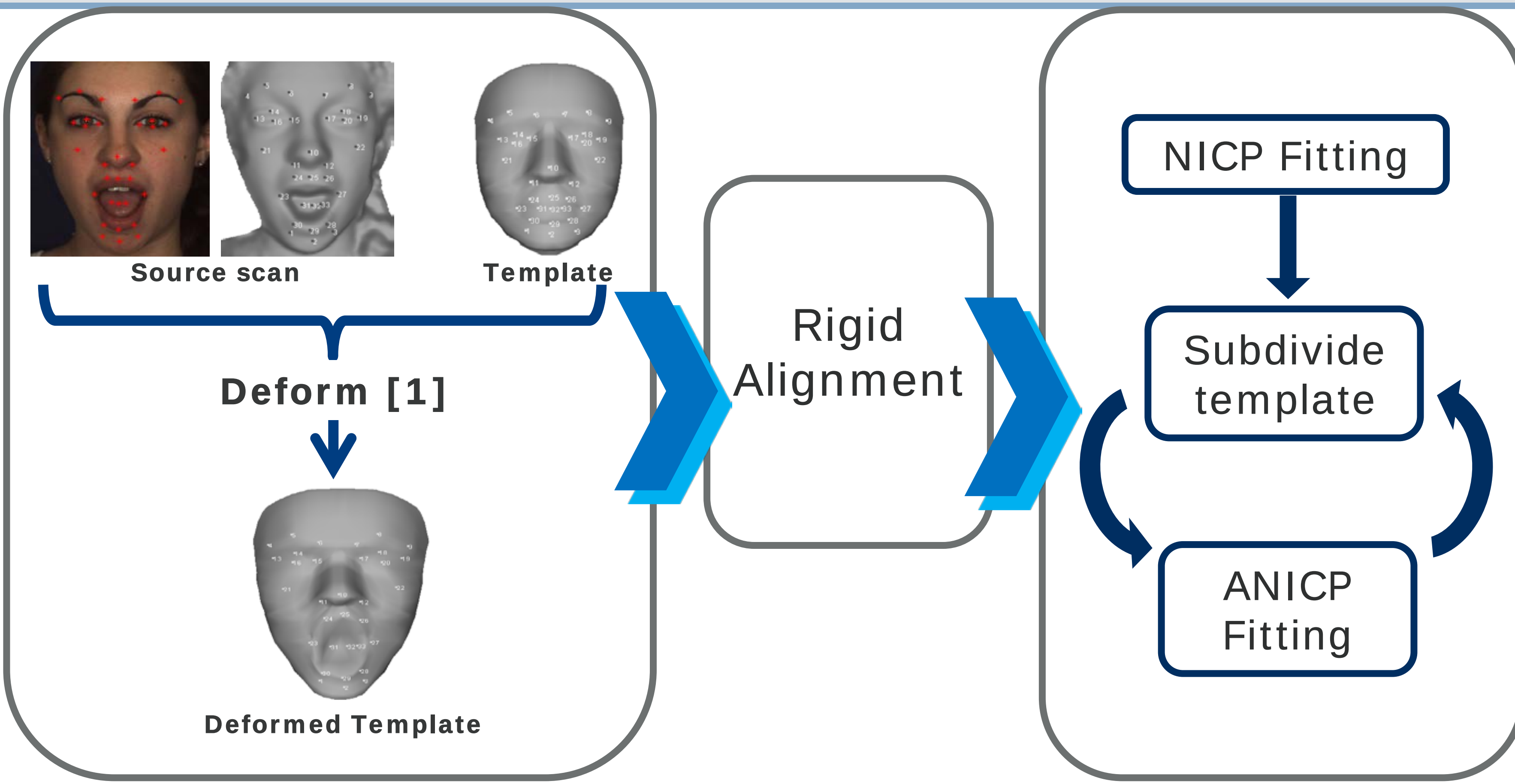
Step 1: Initialization

Step 2: Align Scan [2]

[1] A. Jacobson et al. Bounded biharmonic weights for real-time deformation. SIGGRAPH 2011.

[2] I.A. Kakadiaris et al. Three-dimensional face recognition in the presence of facial expressions: An annotated deformable model approach. T-PAMI 2007.

Our Pipeline

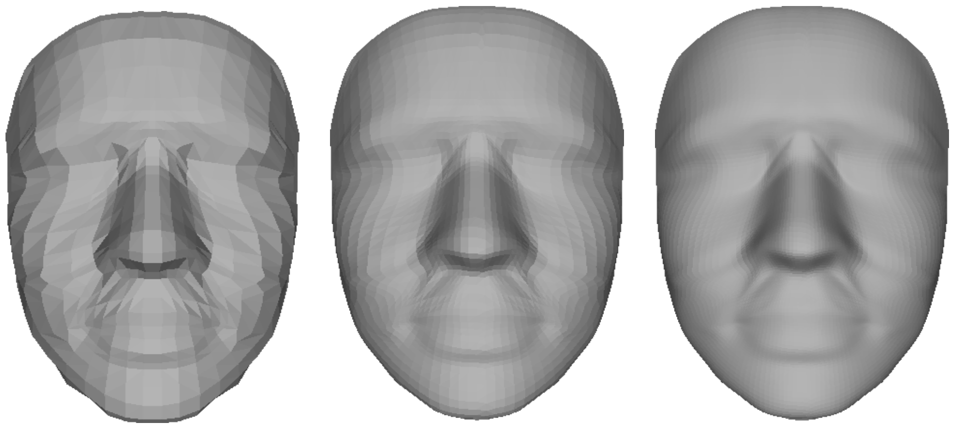


Step 1: Initialization　**Step 2: Align Scan [2]**　**Step 3: Fitting**

[1] A. Jacobson et al. Bounded biharmonic weights for real-time deformation. SIGGRAPH 2011.
[2] I.A. Kakadiaris et al. Three-dimensional face recognition in the presence of facial expressions: An annotated deformable model approach. T-PAMI 2007.

Dynamic Fitting Procedure

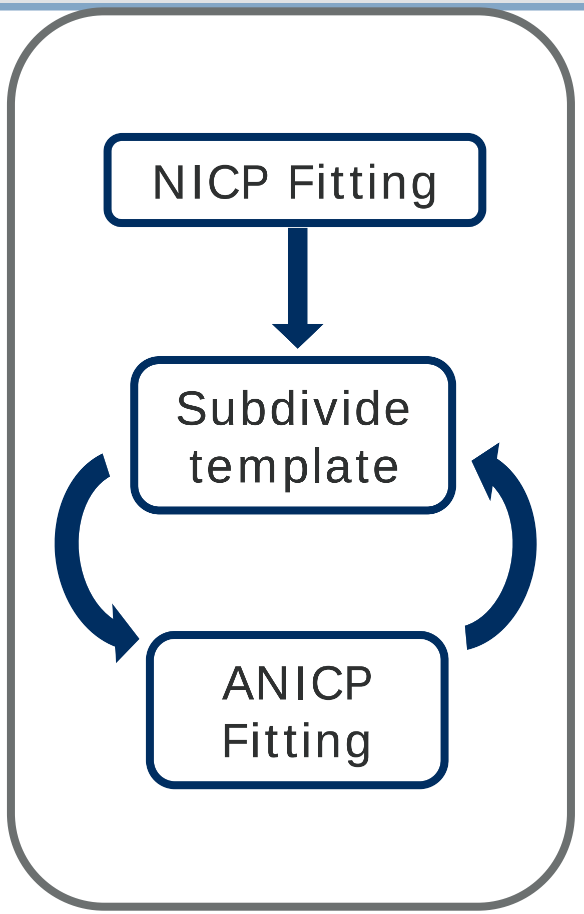
- Coarse-to-fine fitting approach
- Mesh subdivision
  - Loop subdivision.
  - Subdivided mesh captures more facial details.



Template

1st Subdivision

2nd Subdivision



Step 3: Fitting

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Nonrigid Iterative Closest Point

- **v** is the vertex in template, **u** is the vertex from scan, retrieved by closest point matching.
- **X** contains local affine transforms for each vertex.

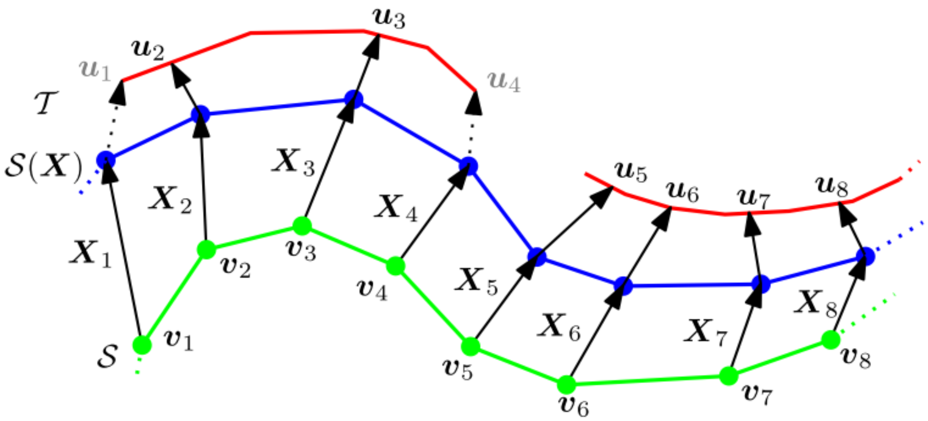

Figure from [1]

[1] B. Amberg et al. Optimal step nonrigid icp algorithms for surface registration. CVPR 2007.

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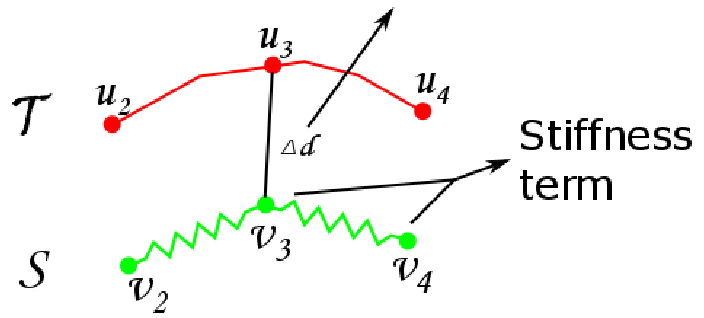
Nonrigid ICP

Distance and stiffness terms:

$$E_d(\mathbf{X}) := \sum_{i=1}^{n} \|\mathbf{X}_i \mathbf{v}_i - \mathbf{u}_i\|^2$$

$$E_s(\mathbf{X}) = \|(\mathbf{M} \otimes \mathbf{G})\mathbf{X}\|_F^2$$



Cost function :

$$E_X(\mathbf{X}) := \alpha E_s + E_d = \left\| \begin{bmatrix} \alpha \mathbf{M} \otimes \mathbf{G} \\ \mathbf{D} \end{bmatrix} \mathbf{X} - \begin{bmatrix} \mathbf{0} \\ \mathbf{U} \end{bmatrix} \right\|_F^2 = \left\| \mathbf{A}\mathbf{X} - \widetilde{\mathbf{U}} \right\|_F^2$$

Fitting objective:

$$\arg\min_{\mathbf{X}} E_X(\mathbf{X}) = \arg\min_{\mathbf{X}} \left\| \mathbf{A}\mathbf{X} - \widetilde{\mathbf{U}} \right\|_F^2$$

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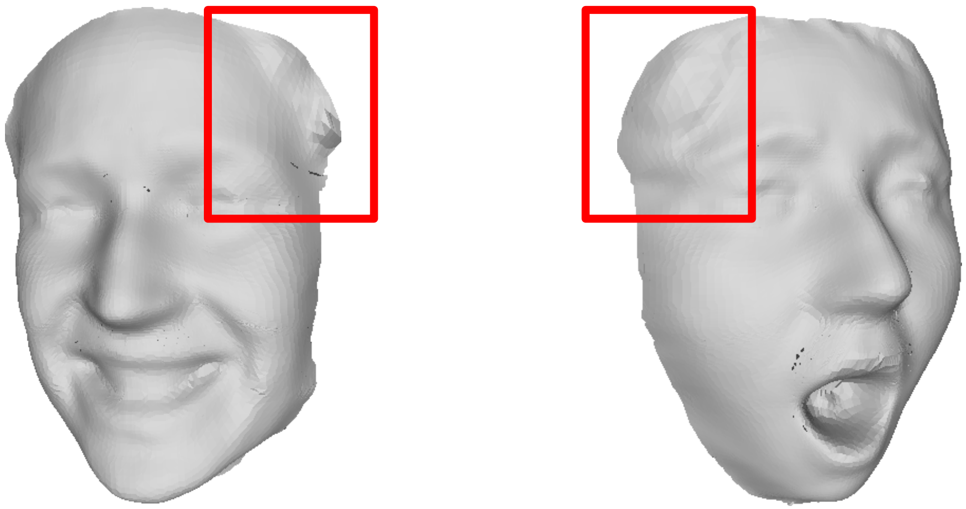
Problem of NICP

- No hard constraint on template vertex **V**: can lead to anthropomorphically inconsistent fittings.



- Face configuration can be modelled via statistical shape model.

Active Nonrigid ICP

Distance term:

$$E_d(\mathbf{X}) := \sum_{i=1}^{n} ||\mathbf{X}_i \mathbf{v}_i - \mathbf{u}_i||^2$$

Replaced by a statistical shape model!

$$\mathbf{v}_i = \mathbf{B}_i \mathbf{c}_i + \mathbf{m}_i$$

Active Nonrigid ICP

New distance and stiffness terms:

$$E_d(\mathbf{X}, \mathbf{c}) := \sum_{i=1}^{n} \|\mathbf{X}_i \underline{\widetilde{\mathbf{v}}_i} - \mathbf{u}_i\|^2 = \sum_{i=1}^{n} \|\mathbf{X}_i \underline{(\mathbf{B}_i \mathbf{c}_i + \mathbf{m}_i)} - \mathbf{u}_i\|^2$$

$$E_s(\mathbf{X}) = \|(\mathbf{M} \otimes \mathbf{G})\mathbf{X}\|_F^2$$

Fitting objective:

$$\arg\min_{\mathbf{X},\mathbf{c}} E(\mathbf{X}, \mathbf{c}) = \arg\min_{\mathbf{X},\mathbf{c}} E_d + \alpha E_s$$

Active Nonrigid ICP

New distance and stiffness terms:

$$E_d(\mathbf{X}, \mathbf{c}) := \sum_{i=1}^{n} \|\mathbf{X}_i \tilde{\mathbf{v}}_i - \mathbf{u}_i\|^2 = \sum_{i=1}^{n} \|\mathbf{X}_i(\mathbf{B}_i \mathbf{c}_i + \mathbf{m}_i) - \mathbf{u}_i\|^2$$

shape parameters ($\mathbf{c}_i$)

local affine parameters ($\mathbf{X}_i$)

$$E_s(\mathbf{X}) = \|(\mathbf{M} \otimes \mathbf{G})\mathbf{X}\|_F^2$$

Fitting objective:

$$\arg\min_{\mathbf{X},\mathbf{c}} E(\mathbf{X}, \mathbf{c}) = \arg\min_{\mathbf{X},\mathbf{c}} E_d + \alpha E_s$$

Active Nonrigid ICP

New distance and stiffness terms:

shape parameters

$$E_d(\mathbf{X}, \mathbf{c}) := \sum_{i=1}^{n} \|\mathbf{X}_i \tilde{\mathbf{v}}_i - \mathbf{u}_i\|^2 = \sum_{i=1}^{n} \|\mathbf{X}_i (\mathbf{B}_i \mathbf{c}_i + \mathbf{m}_i) - \mathbf{u}_i\|^2$$

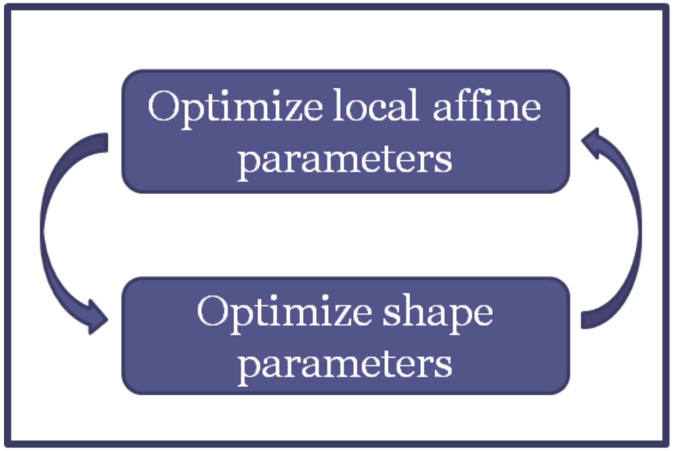
local affine parameters

$$E_s(\mathbf{X}) = \|(\mathbf{M} \otimes \mathbf{G})\mathbf{X}\|_F^2$$

Two objectives:

$$\begin{cases} \arg\min_{\mathbf{X}} E(\mathbf{X}, \mathbf{c}_0) = \arg\min_{\mathbf{X}} E_d + \alpha E_s \\ \arg\min_{\mathbf{c}} E(\mathbf{X}_1, \mathbf{c}) = \arg\min_{\mathbf{c}} E_d \end{cases}$$

Alternating Optimization



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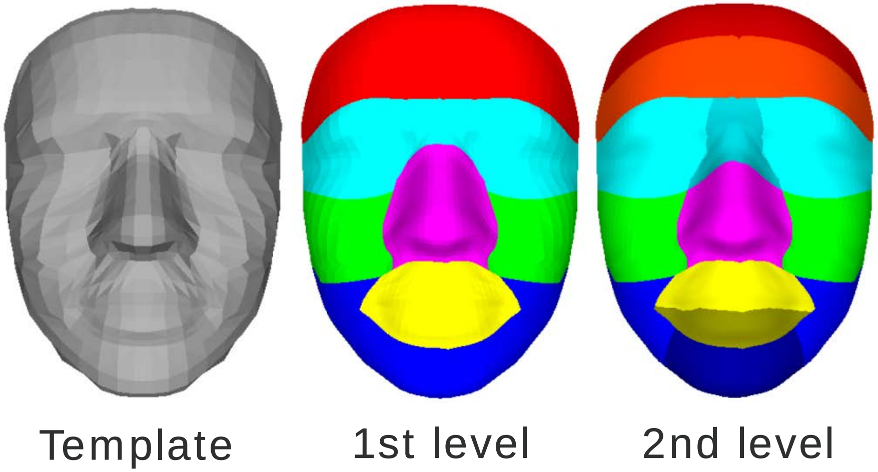
Active Nonrigid ICP

Individual modelling of face parts

- Manual segmentation of face parts.
- The models are built using BU-3DFE [1] database.
- For each part:

$$\mathbf{v}_i = \mathbf{B}_i \mathbf{c}_i + \mathbf{m}_i$$



[1] L. Yin et al. A 3D Facial Expression Database For Facial Behavior Research. FG 2006.

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Experiments – Mouth Coverage

- 100 scans from different subjects in BU-4DFE [1] with exaggerated expressions.
- Manual annotation of mouth region.
- Accuracy calculated as: $S = 1 - \frac{A(D \cap G)}{A(D \cup G)}$

Method	Mean S value
FEM	0.4086
C2F-NICP	0.3841
C2F-ANICP	0.3688
C2F-NICP-PD	**0.2891**
C2F-ANICP-PD	**0.3058**

- **C2F-** : Coarse-to-fine fitting approach.
- **-PD** : Initialization from 2D face alignment.

[1] L. Yin et al. A high-resolution 3d dynamic facial expression database. FG 2008.

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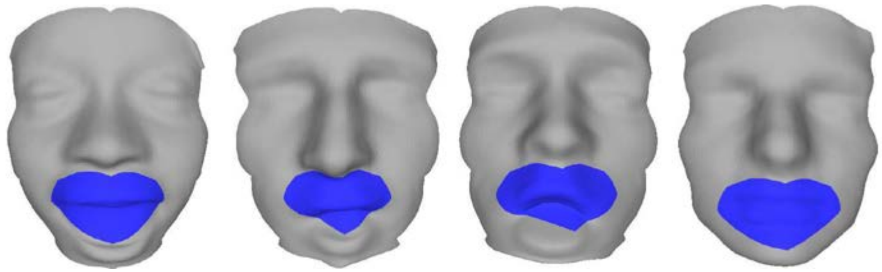
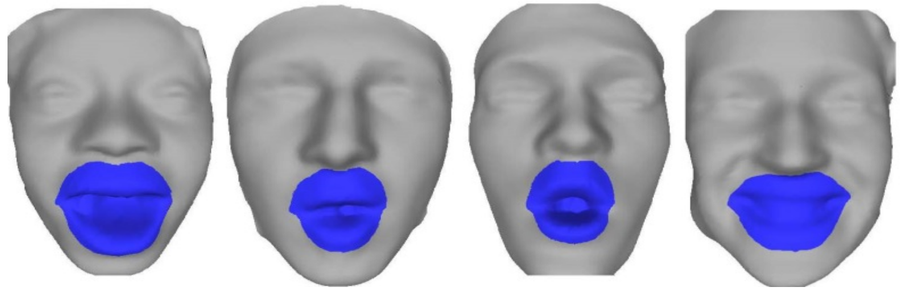
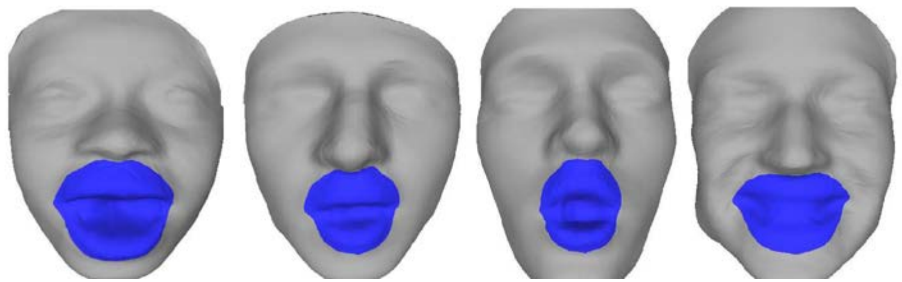
Experiments – Mouth Coverage



FEM



C2F-NICP-PD



C2F-ANICP-PD

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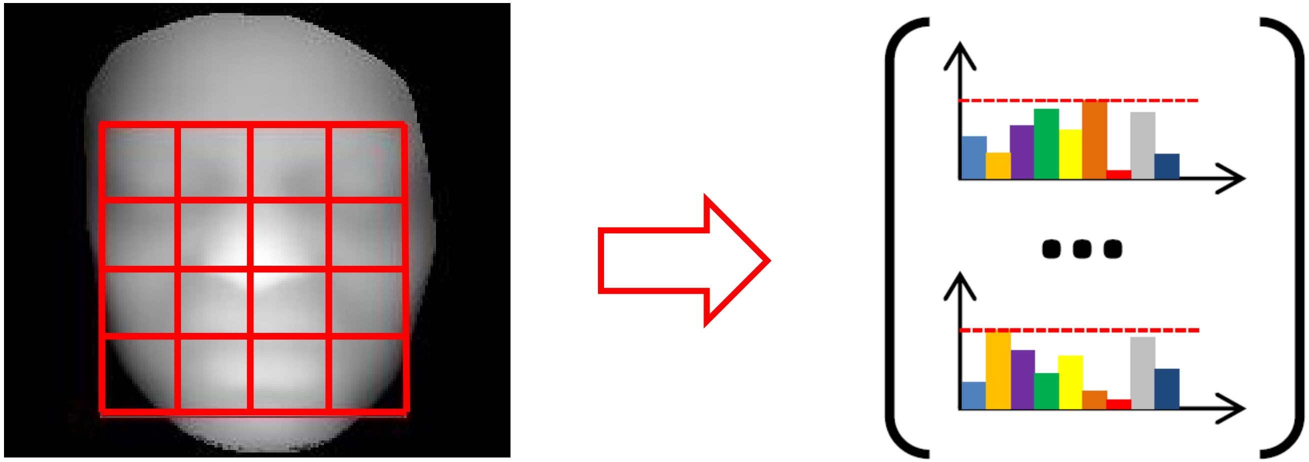
Experiments - FER

- Recognition of six prototypical facial expressions.
- Balanced set consisting of ~6000 instances from BU-4DFE.
- SVM classifier with RBF kernel.
- Histogram of Oriented Normal Vectors (HONV) feature.



HONV feature

Experiments - FER

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Method	Main face		Mouth	
	F_1[%]	CR[%]	F_1[%]	CR[%]
FEM	75.65	75.87	73.49	73.38
C2F-NICP	76.50	76.74	74.74	75.05
C2F-ANICP	78.22	78.43	76.15	76.57
C2F-NICP-PD	79.24	79.47	78.18	78.13
C2F-ANICP-PD	**80.94**	**81.16**	**80.44**	**80.41**

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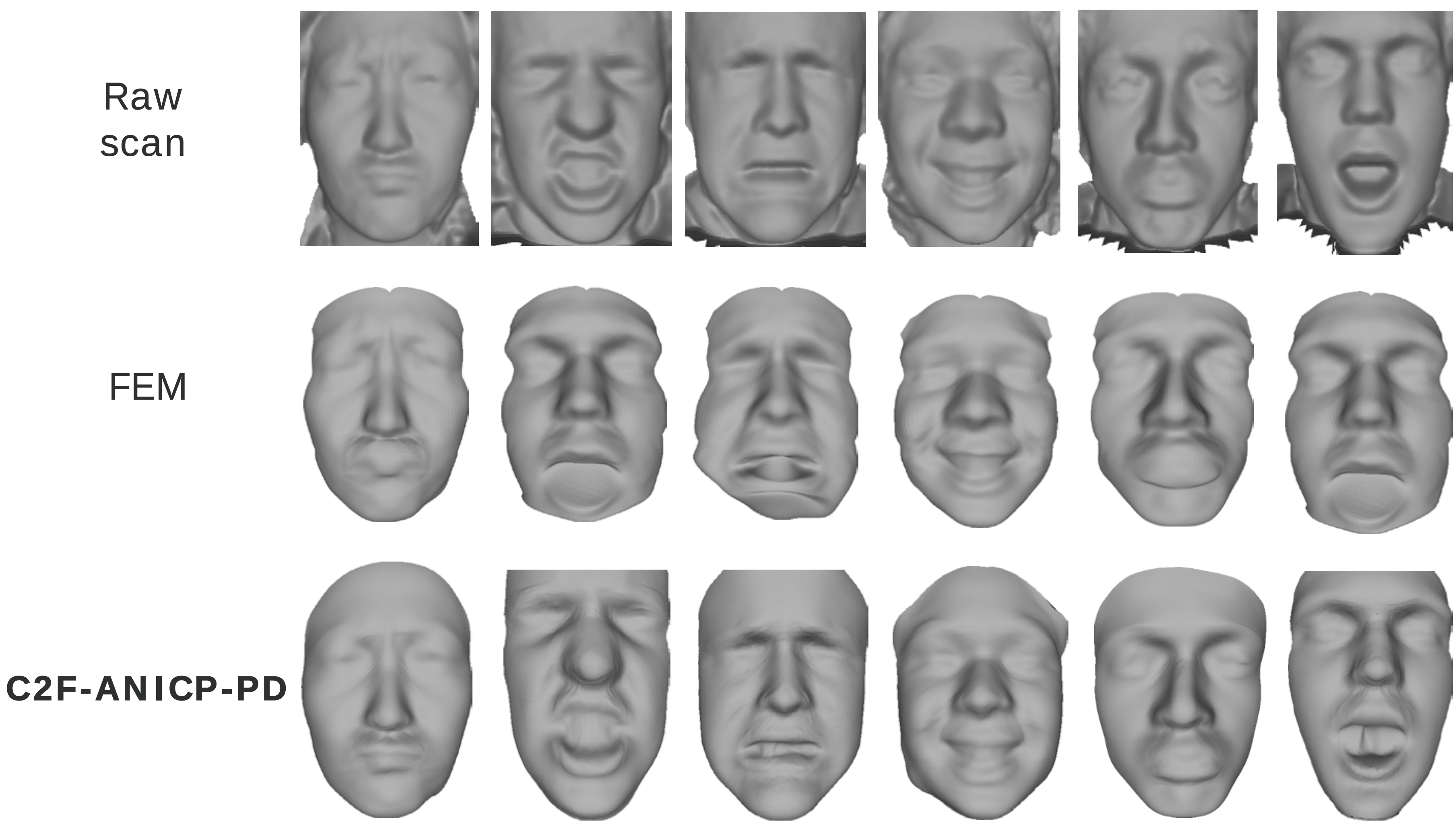
Fitting Examples



Conclusion

- Our coarse-to-fine fitting procedure is shown capable of modelling facial expression.
- The proposed ***Active Nonrigid ICP algorithm*** outperforms state-of-the-art fitting methods, especially in the description and alignment of the mouth region.
- The initialization procedure further increases the performance.

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Thank you !