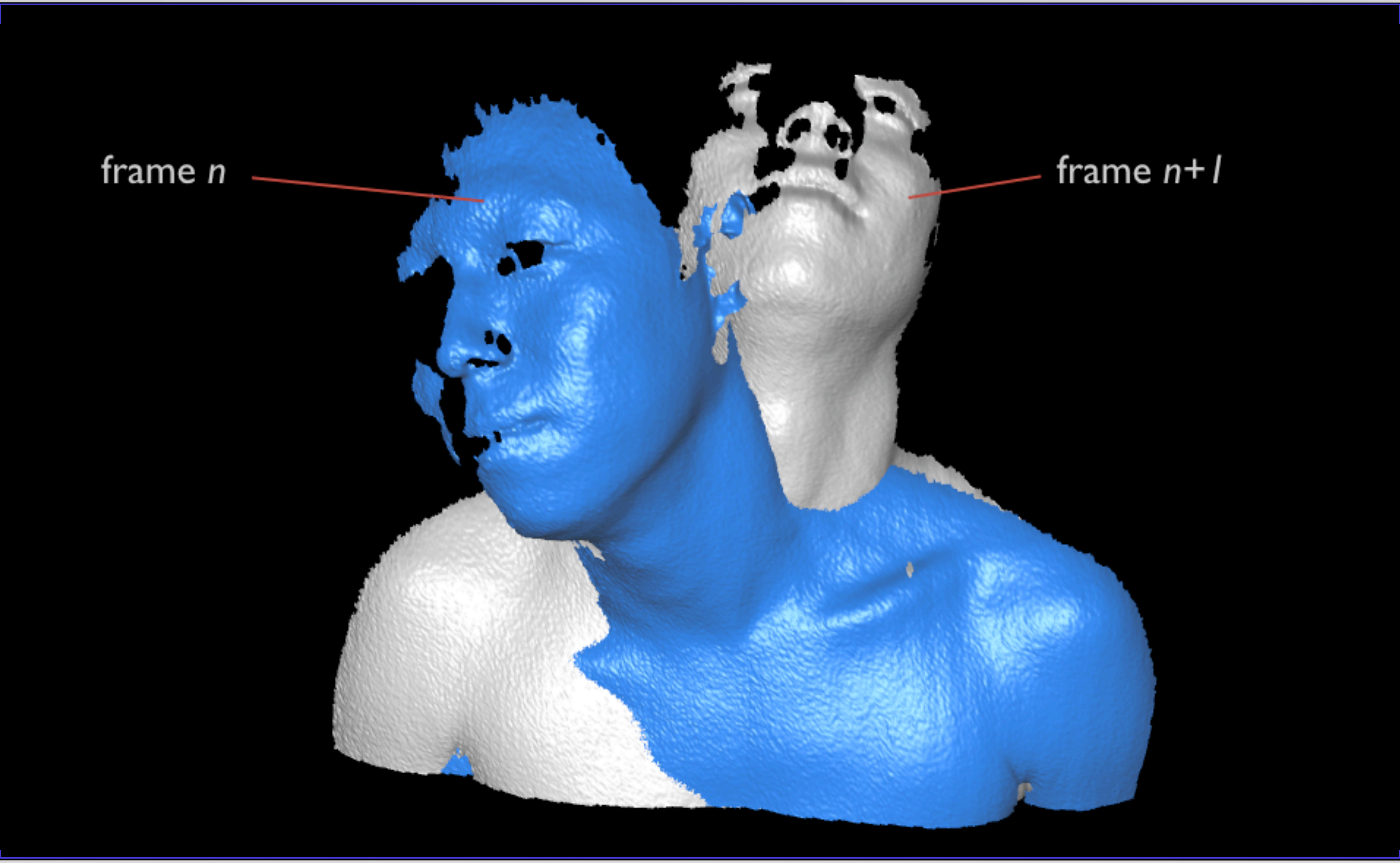
# Geometric Registration for Deformable Shapes

## 2.3 Robust Local Registration

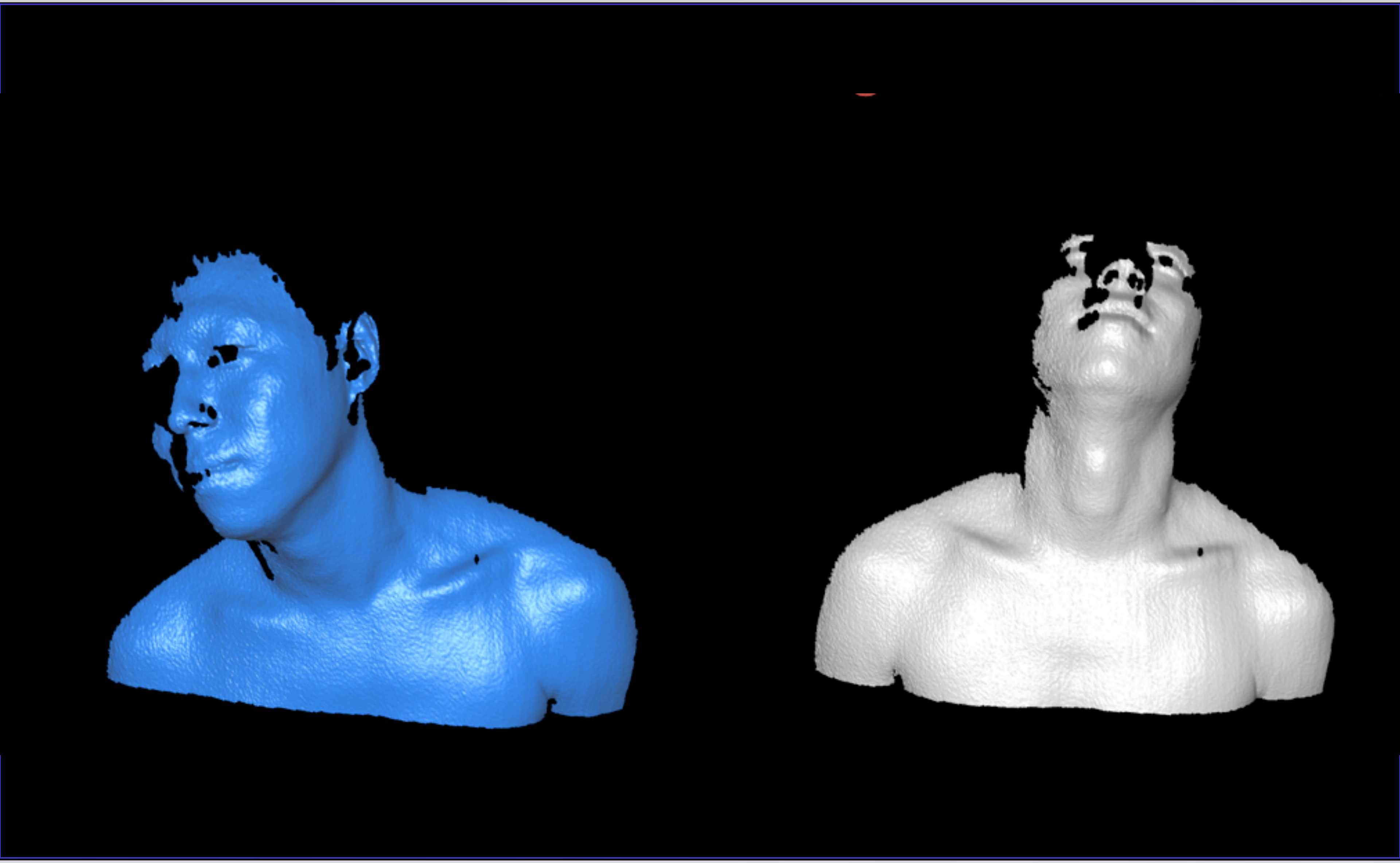
31st Annual Conference of the
European Association for Computer Graphics
eurographics 2010

# Pairwise
# Non-Rigid Registration

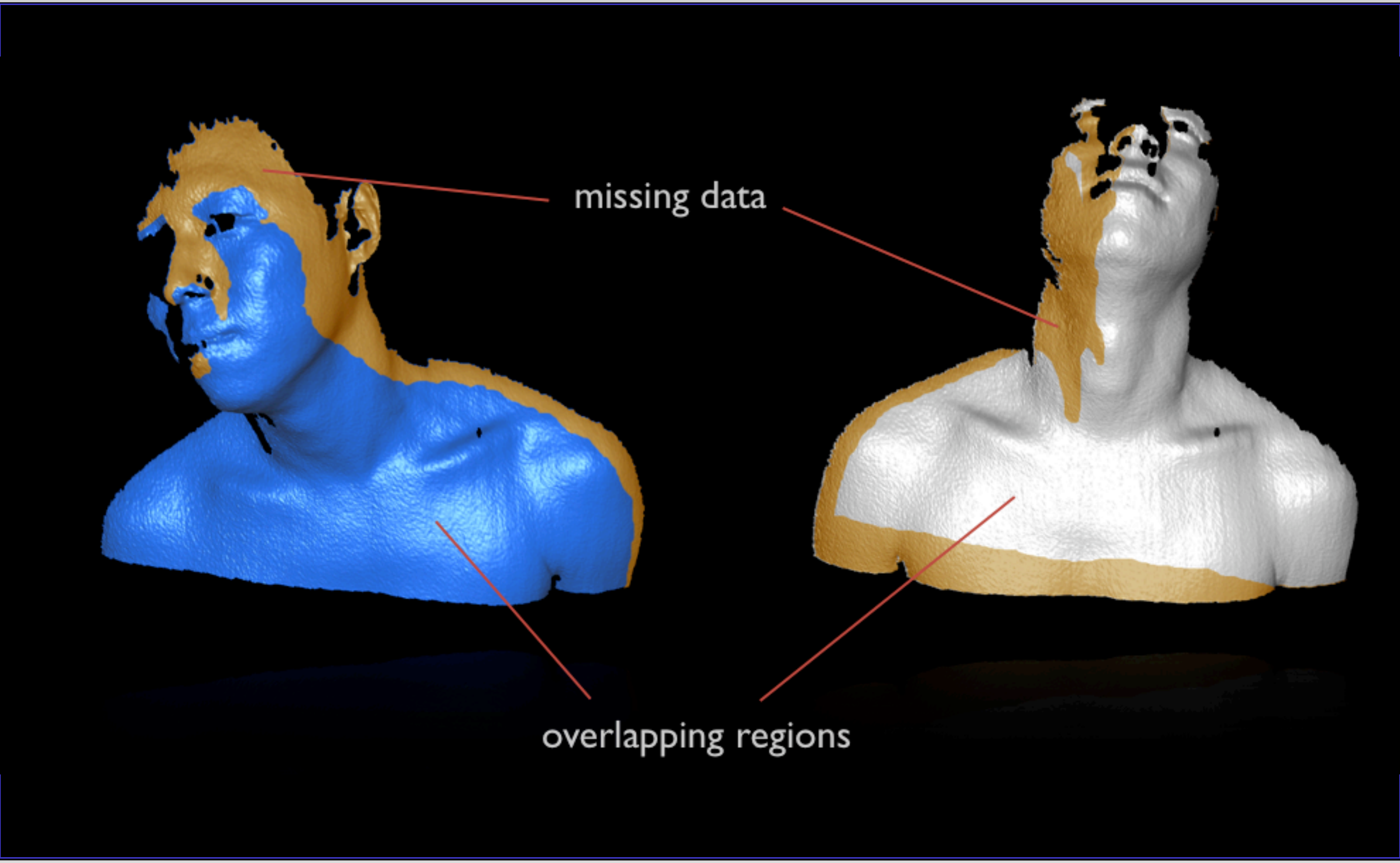
# Initial Alignment



# Source & Target



# Deformation and Occlusion

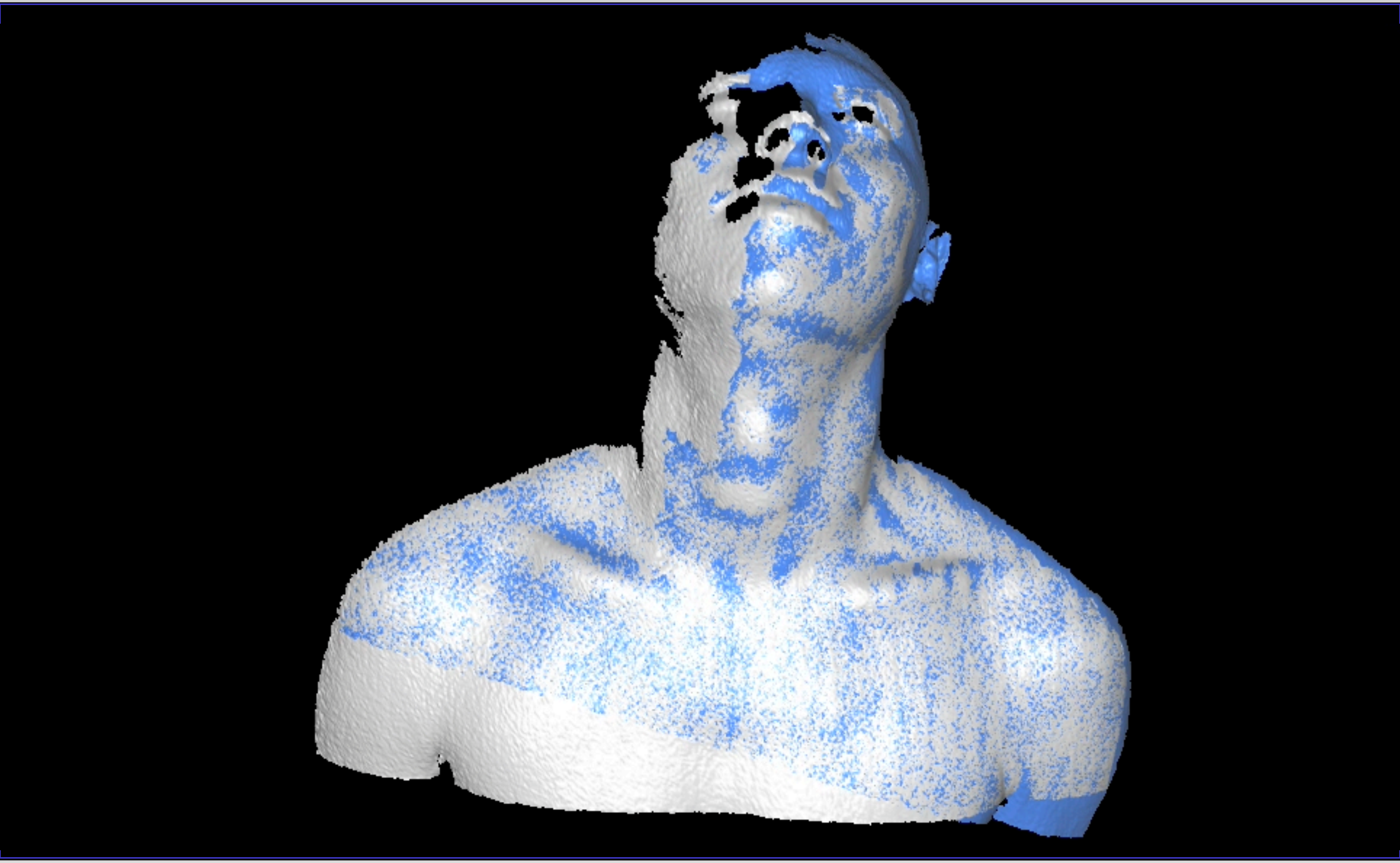


# No Explicit Prior Knowledge

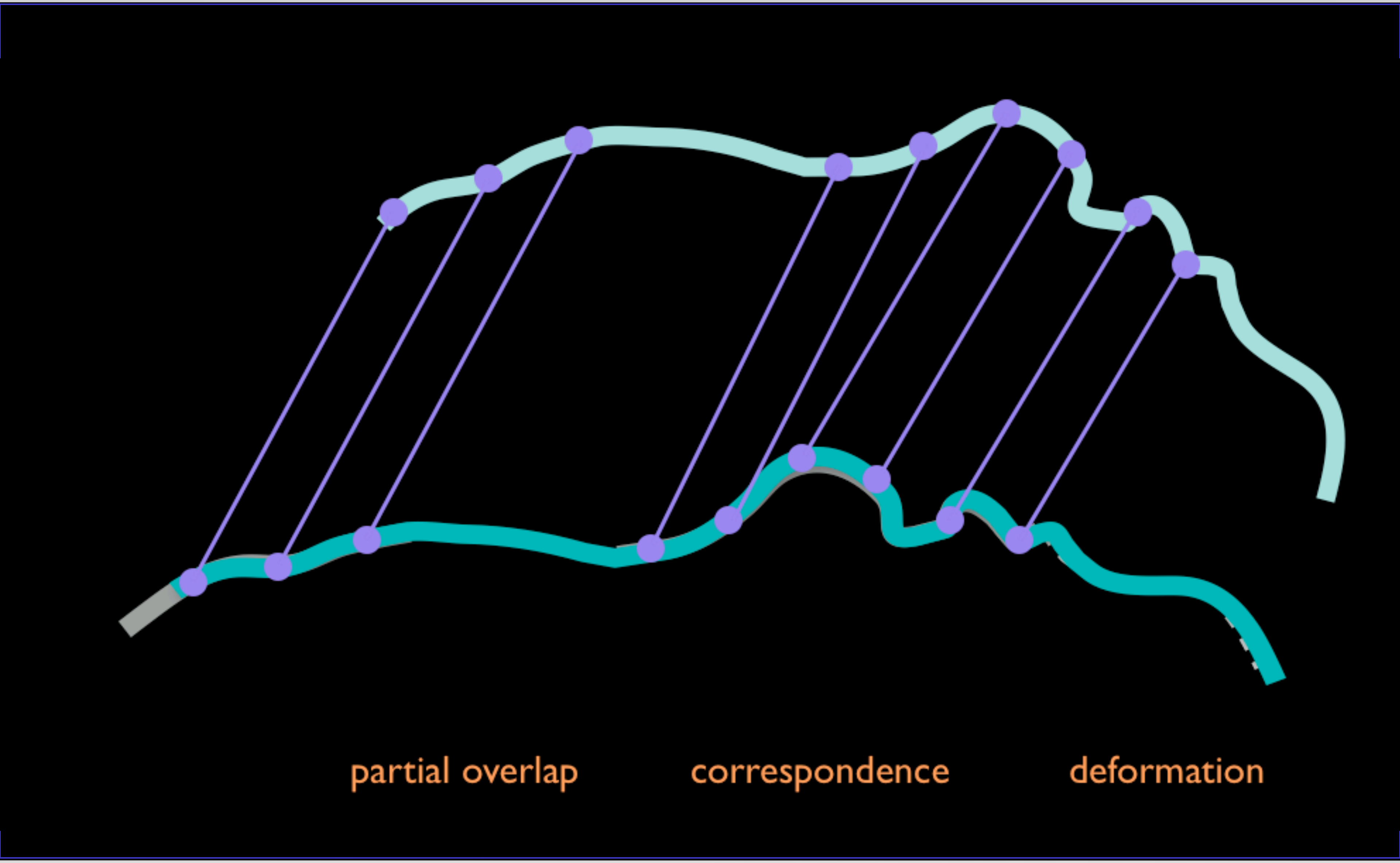
no knowledge about

- full 3-D model
- correspondences
- regions of overlap

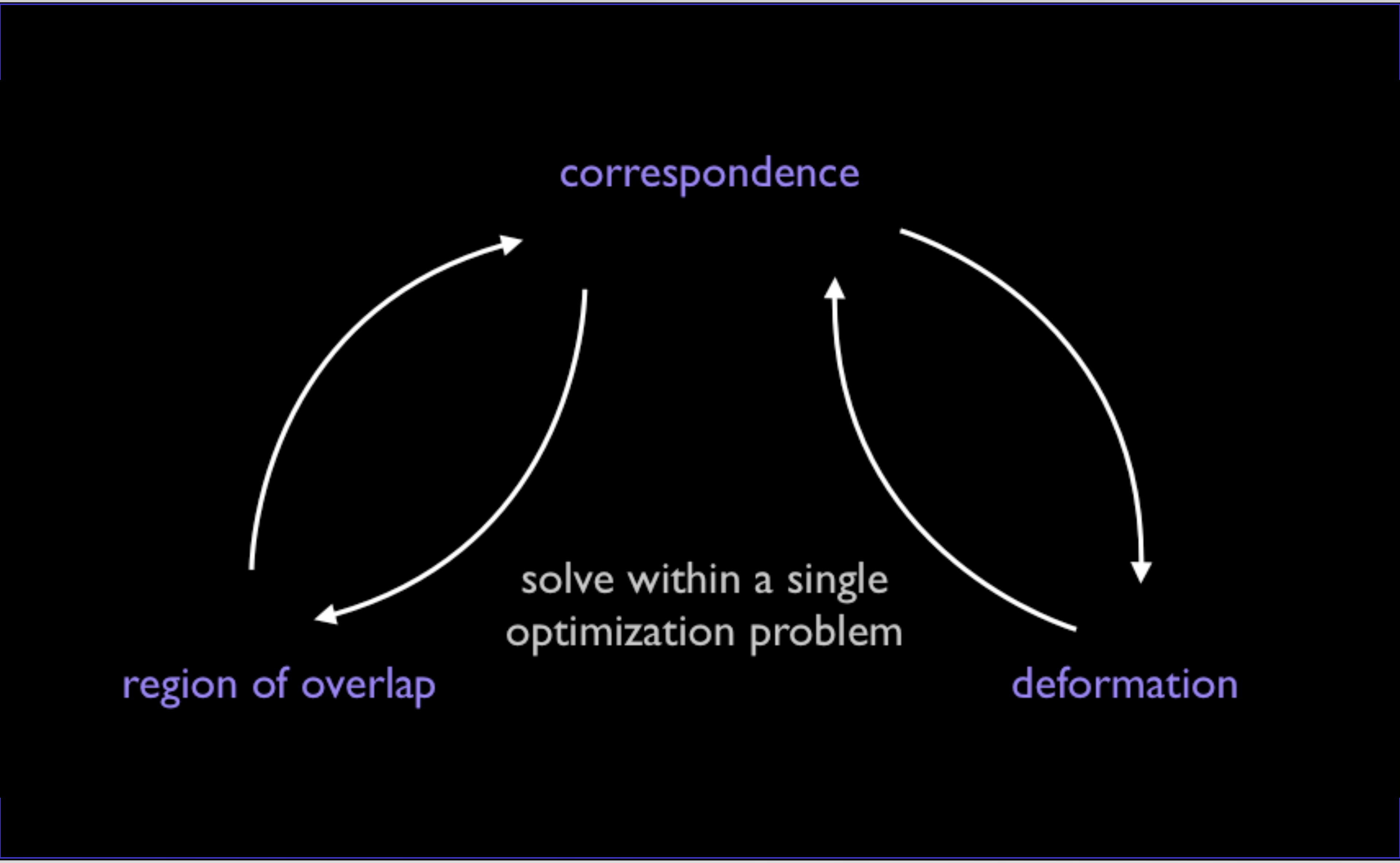
# Goal: Automatic Local Registration



# Ingredients for Non-Rigid Registration



# Chicken & Egg Dilemma



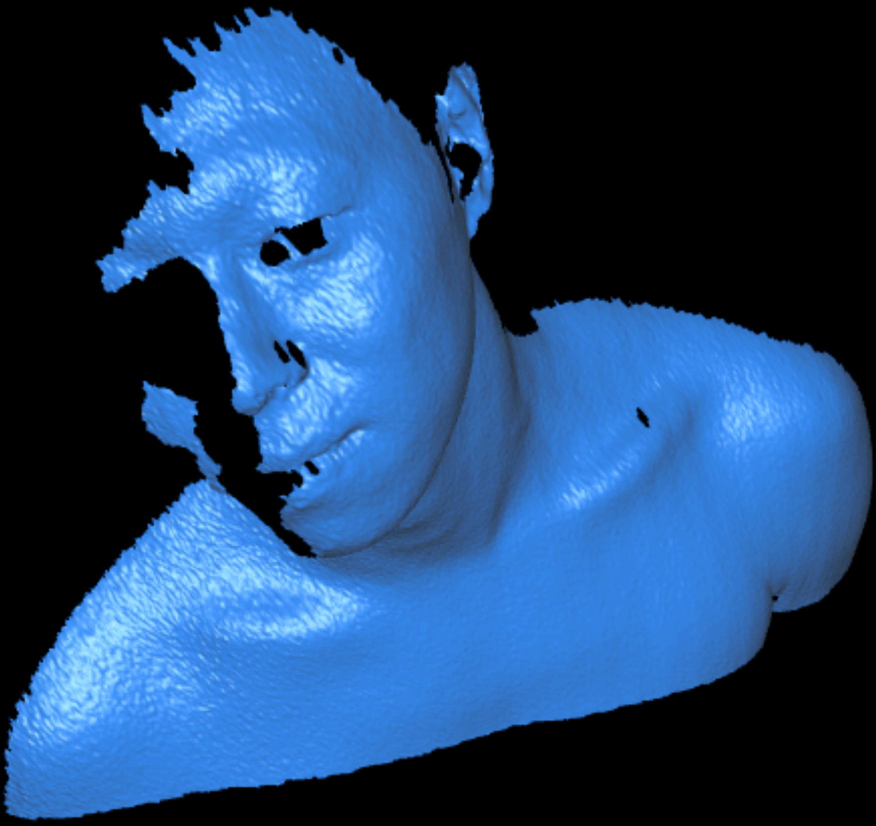
# Embedded Deformation

# Deformation Model

Embedded Deformation

[Sumner et al. ‘07]

- efficiency
- generality

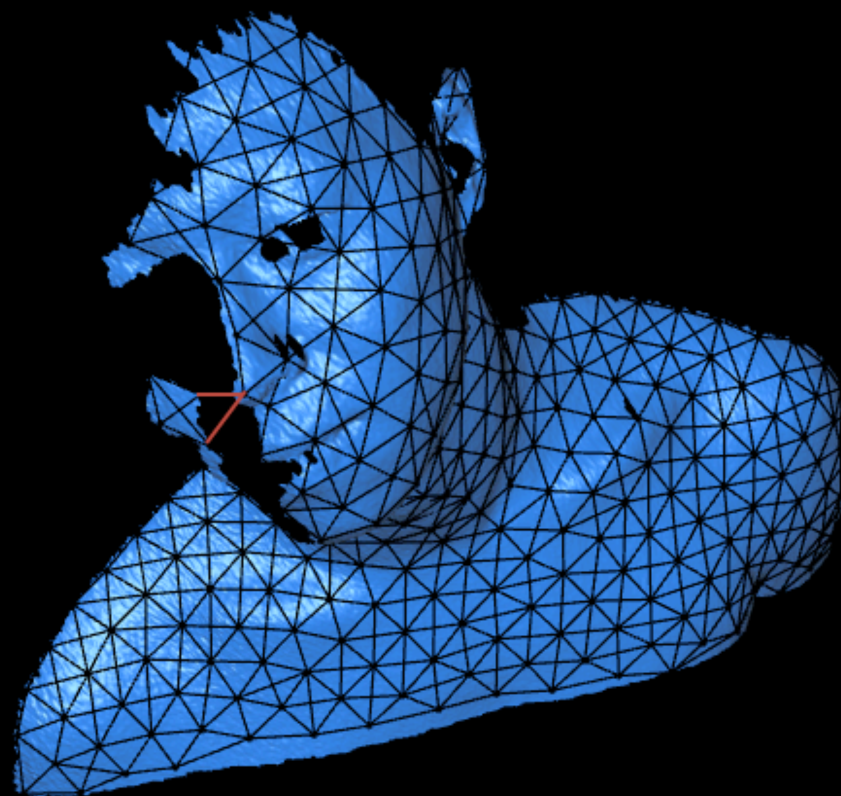


# Deformation Model

Embedded Deformation

[Sumner et al. '07]

- efficiency
- generality
- natural deformation
- detail preservation

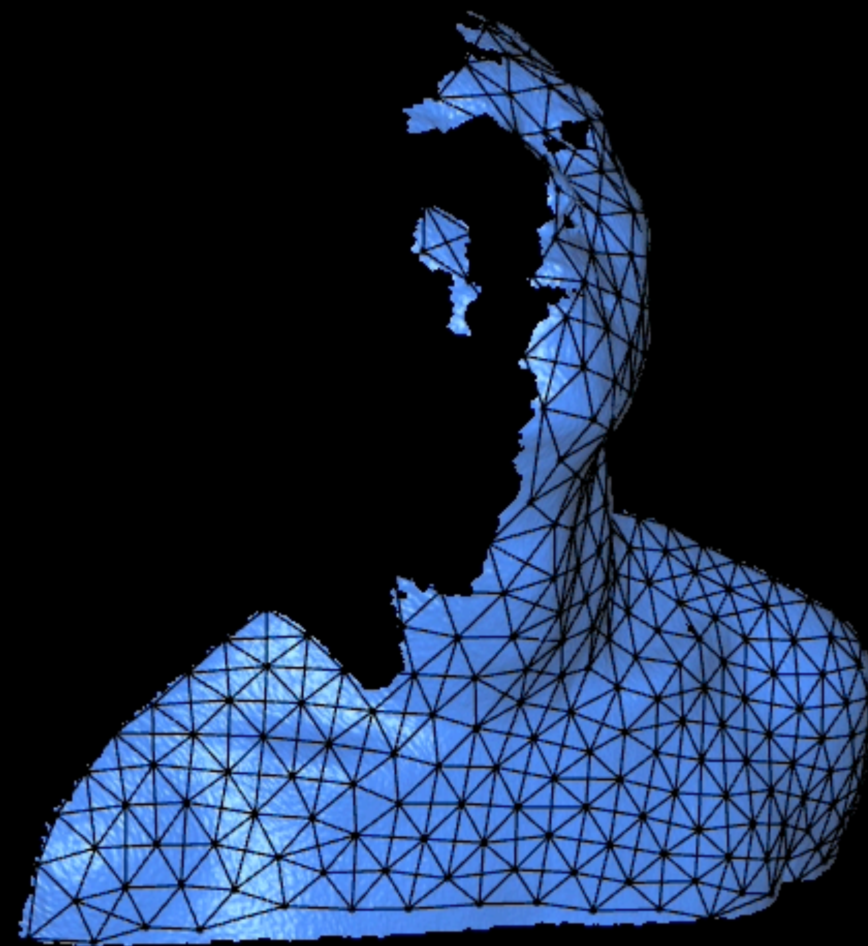


# Deformation Model

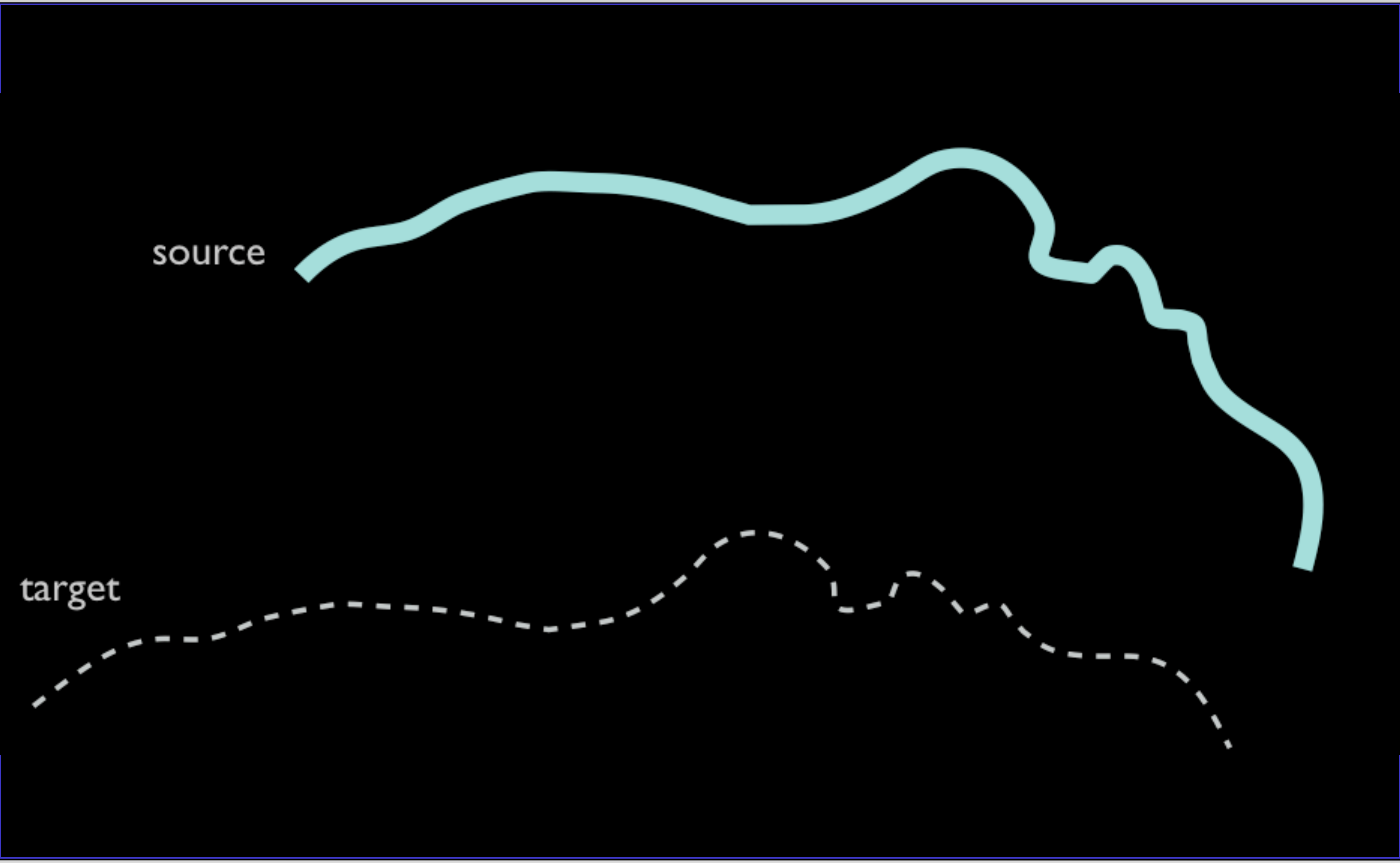
## Embedded Deformation

[Sumner et al. '07]

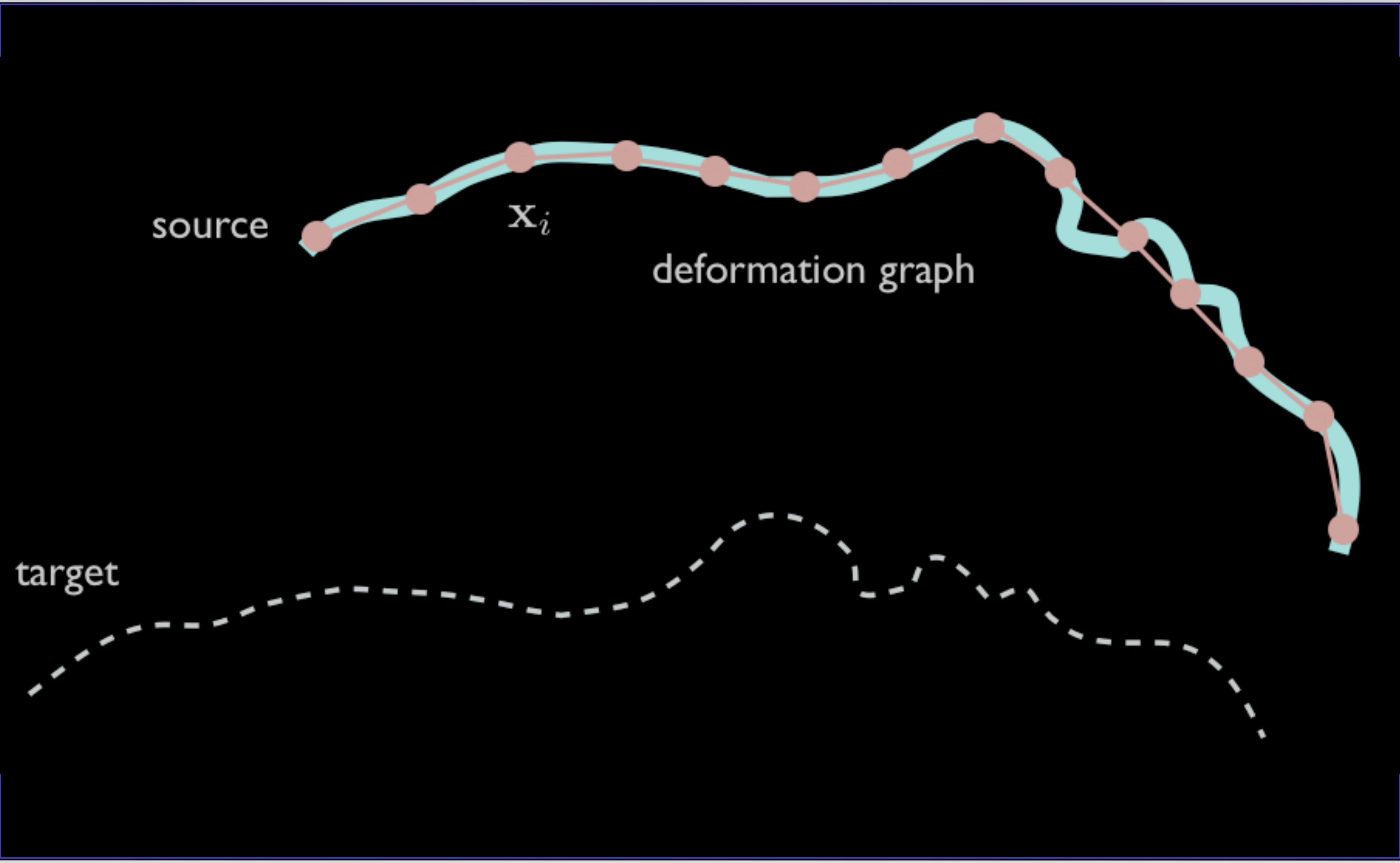
- efficiency
- generality
- natural deformation
- detail preservation



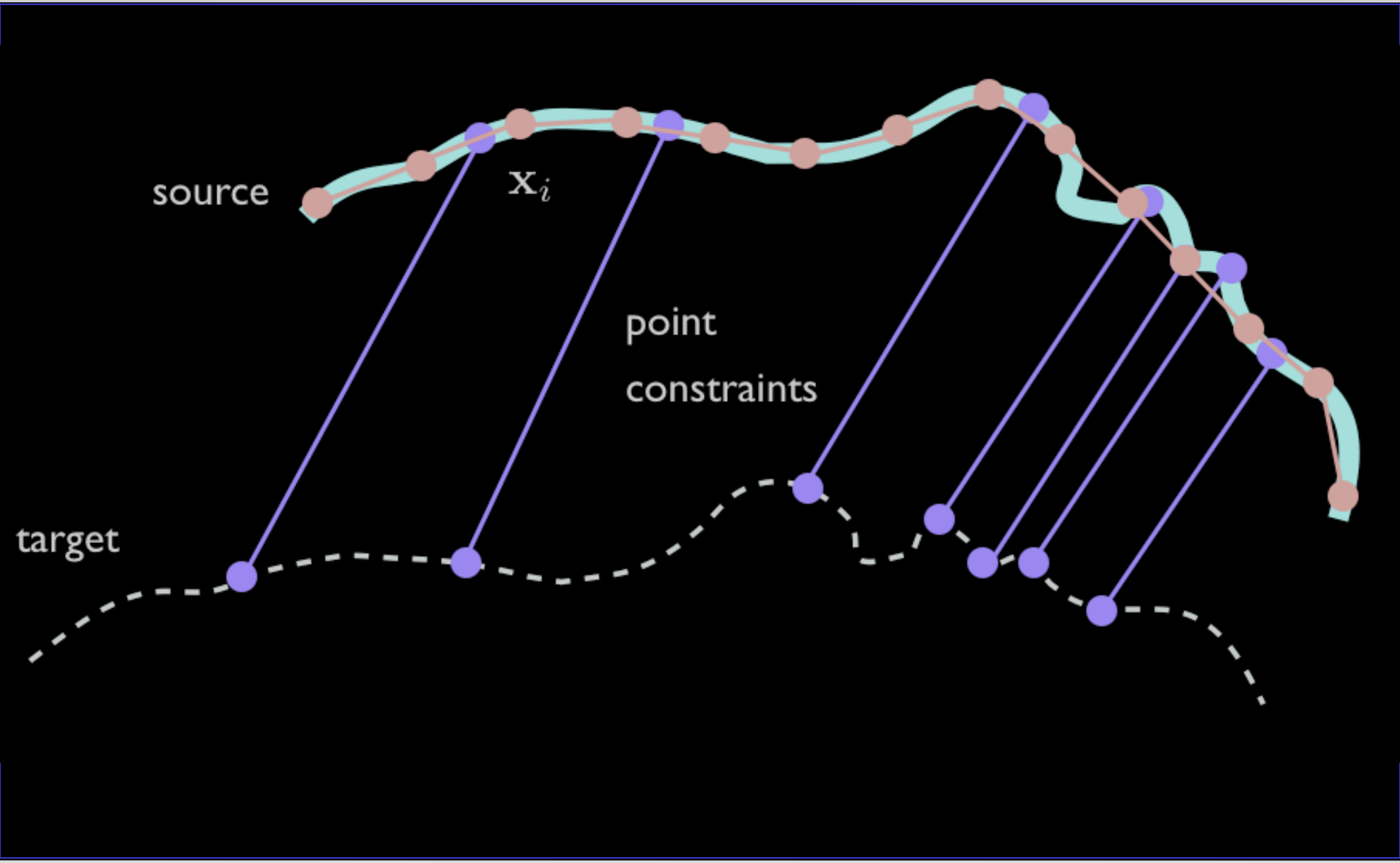
# Deformation Model



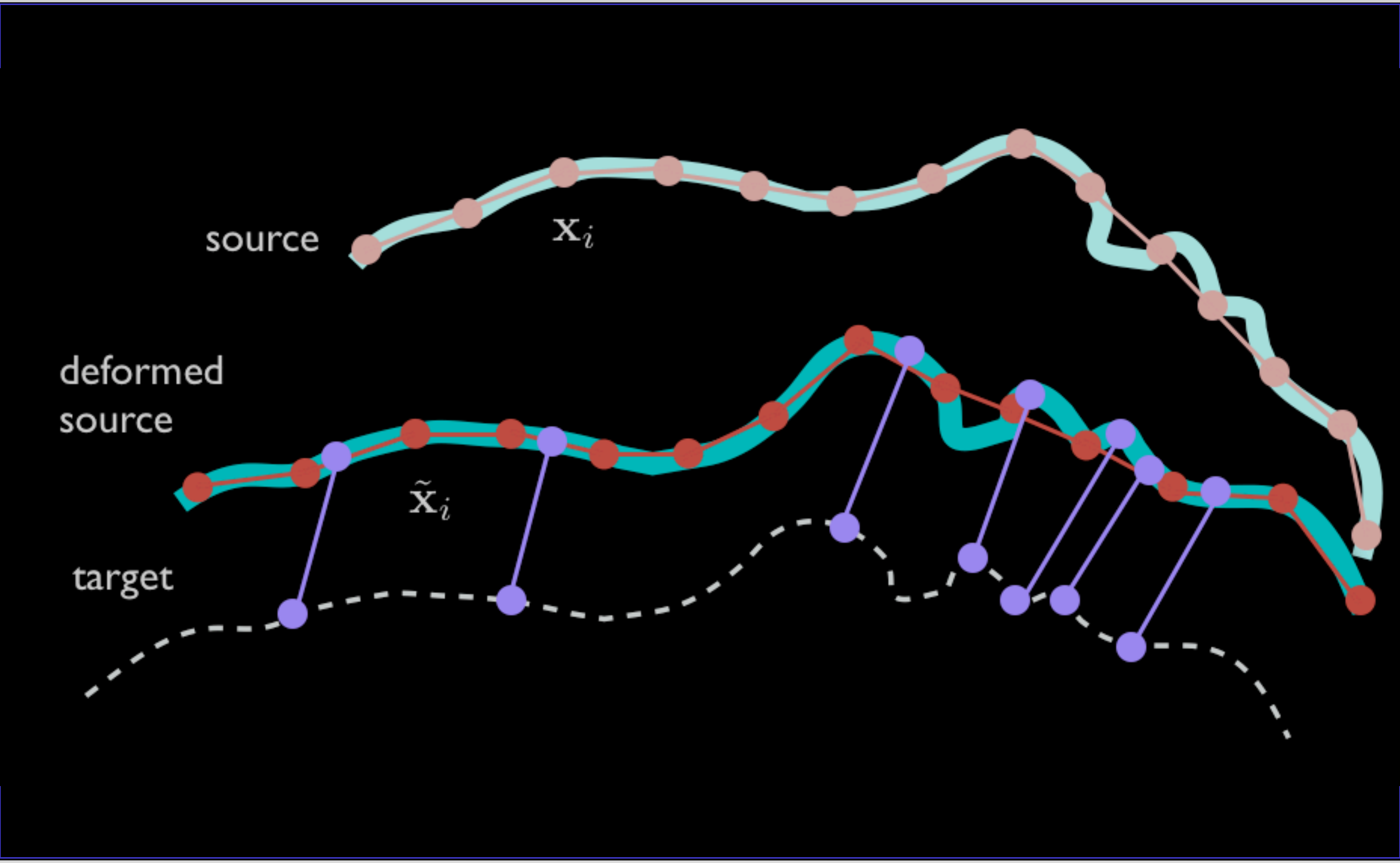
# Embedded Deformation



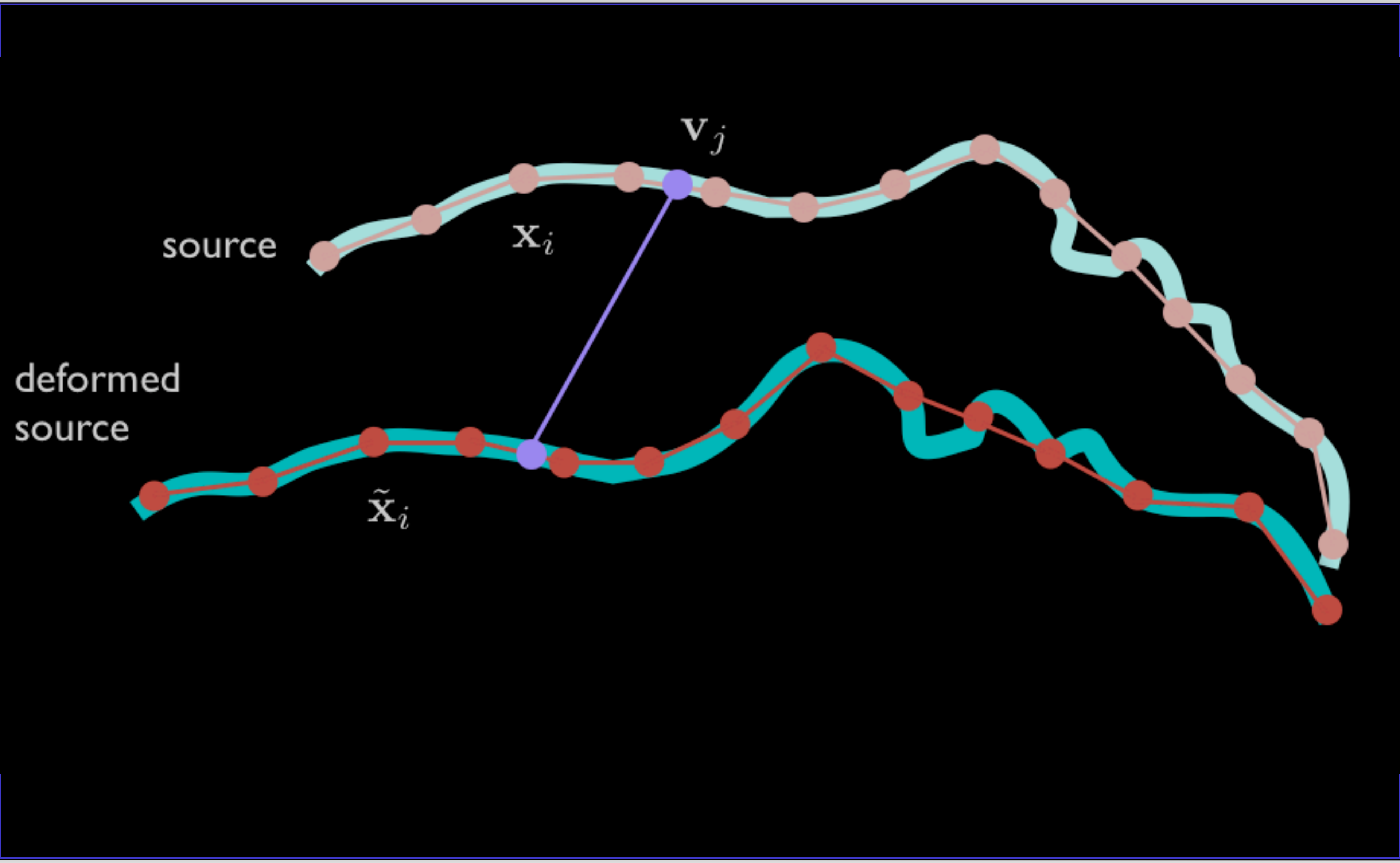
# Embedded Deformation



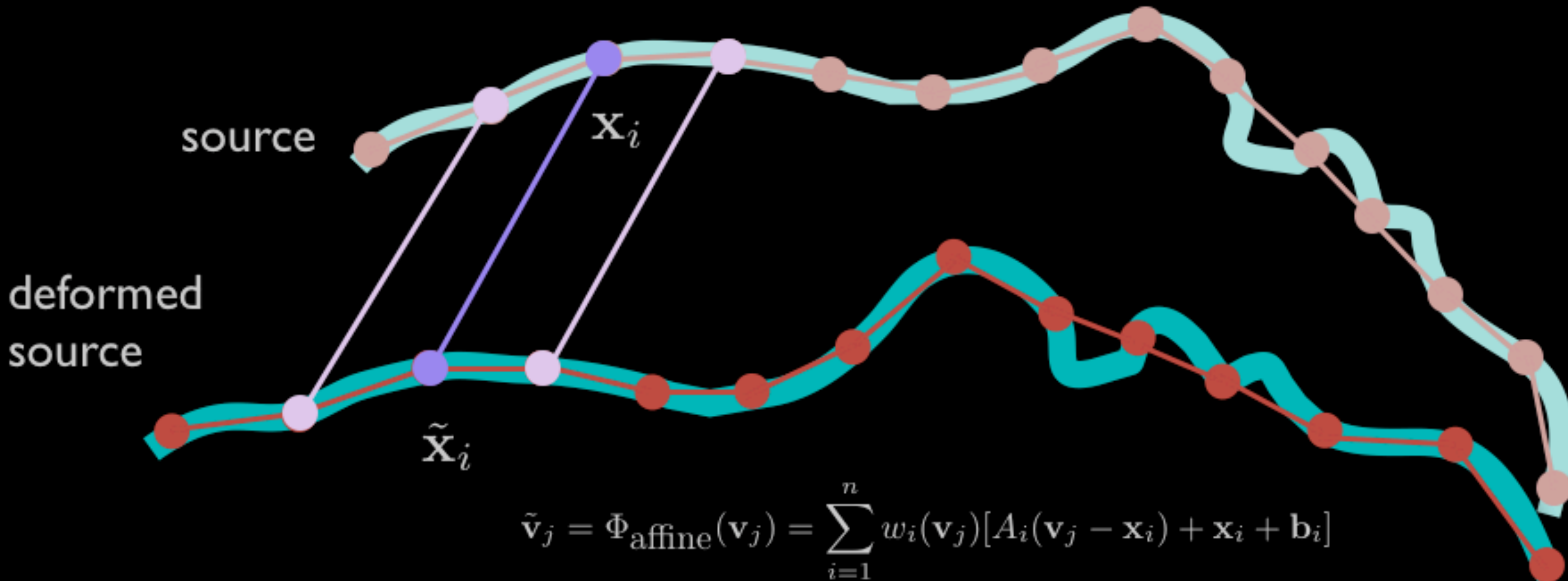
# Embedded Deformation



# Embedded Deformation



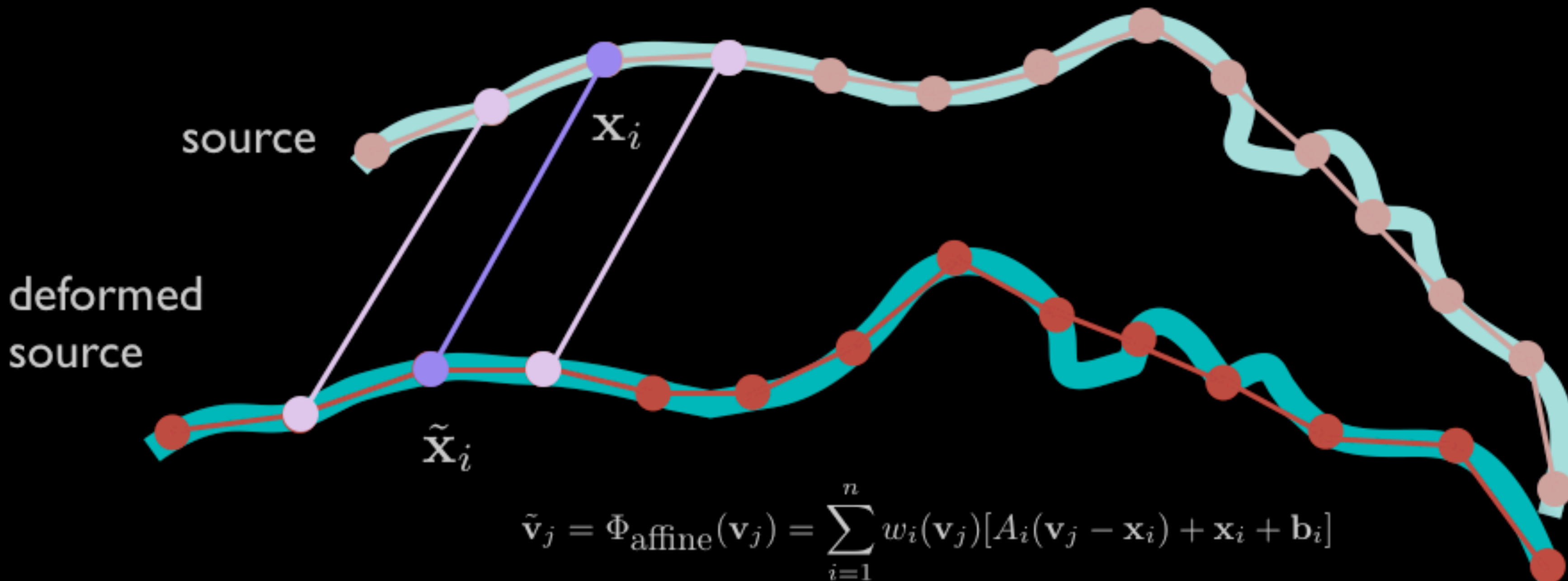
# Embedded Deformation




$$\tilde{\mathbf{v}}_j = \Phi_{\text{affine}}(\mathbf{v}_j) = \sum_{i=1}^{n} w_i(\mathbf{v}_j)[A_i(\mathbf{v}_j - \mathbf{x}_i) + \mathbf{x}_i + \mathbf{b}_i]$$

$$E_{\text{rigid}} = \sum_{\mathbf{x}_i} \left( (\mathbf{a}_1^\top \mathbf{a}_2)^2 + (\mathbf{a}_1^\top \mathbf{a}_3)^2 + (\mathbf{a}_2^\top \mathbf{a}_3)^2 \right.$$
$$\left. + (1 - \mathbf{a}_1^\top \mathbf{a}_1)^2 + (1 - \mathbf{a}_2^\top \mathbf{a}_2)^2 + (1 - \mathbf{a}_3^\top \mathbf{a}_3)^2 \right)$$

# Embedded Deformation



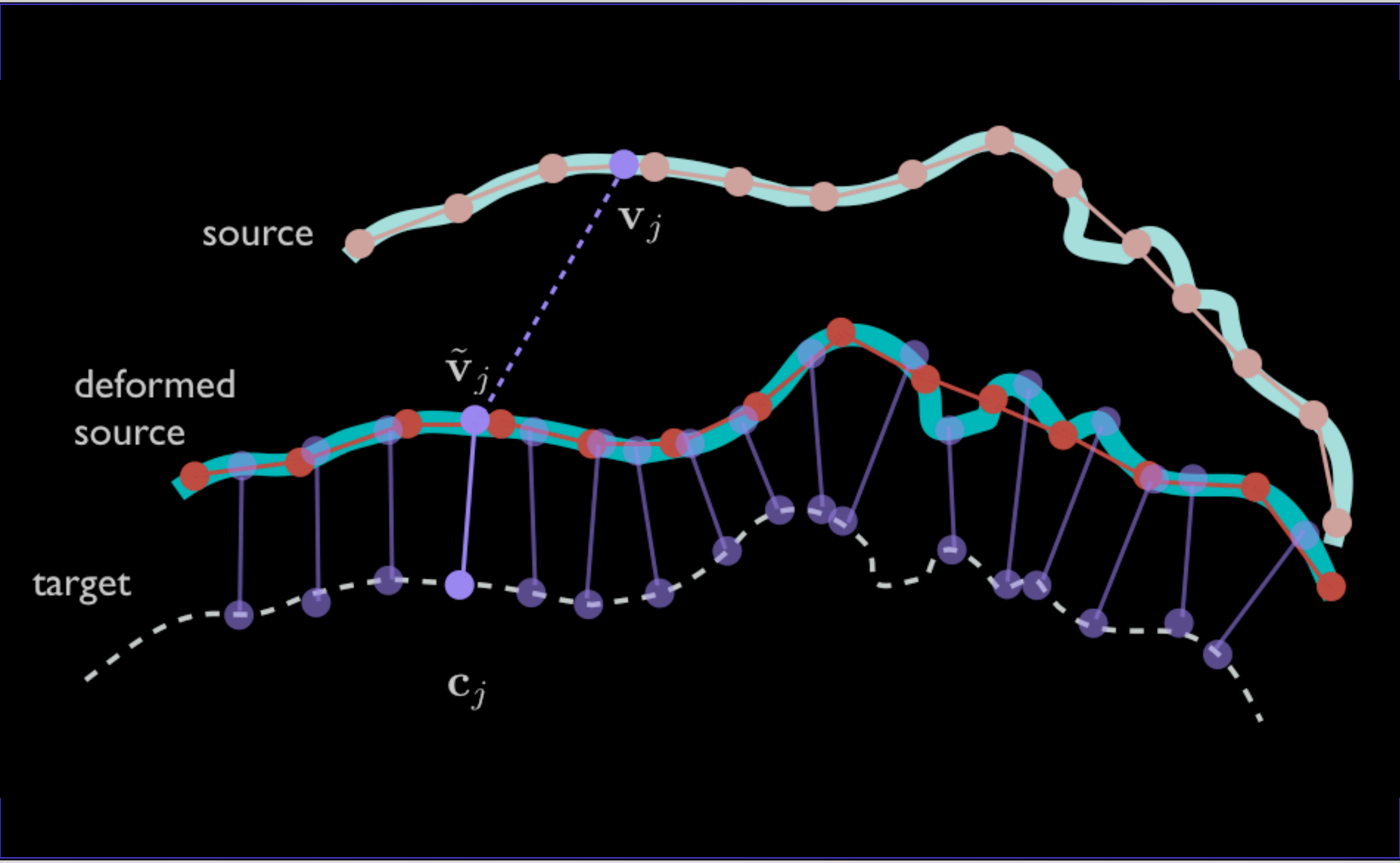

$$\tilde{\mathbf{v}}_j = \Phi_{\text{affine}}(\mathbf{v}_j) = \sum_{i=1}^{n} w_i(\mathbf{v}_j)[A_i(\mathbf{v}_j - \mathbf{x}_i) + \mathbf{x}_i + \mathbf{b}_i]$$

$$E_{\text{rigid}} = \sum_{\mathbf{x}_i} ((\mathbf{a}_1^\top \mathbf{a}_2)^2 + (\mathbf{a}_1^\top \mathbf{a}_3)^2 + (\mathbf{a}_2^\top \mathbf{a}_3)^2$$

$$+(1 - \mathbf{a}_1^\top \mathbf{a}_1)^2 + (1 - \mathbf{a}_2^\top \mathbf{a}_2)^2 + (1 - \mathbf{a}_3^\top \mathbf{a}_3)^2)$$

# Global Optimal Correspondence Optimization

# Minimize Alignment Error

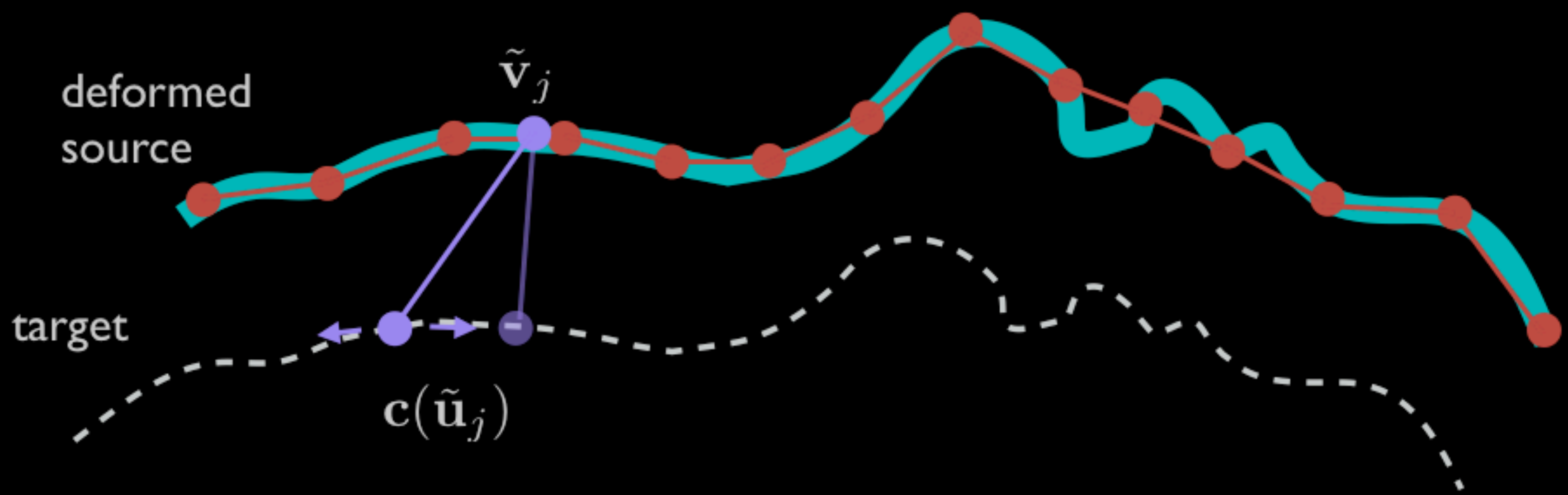


# Correspondences as Unknowns

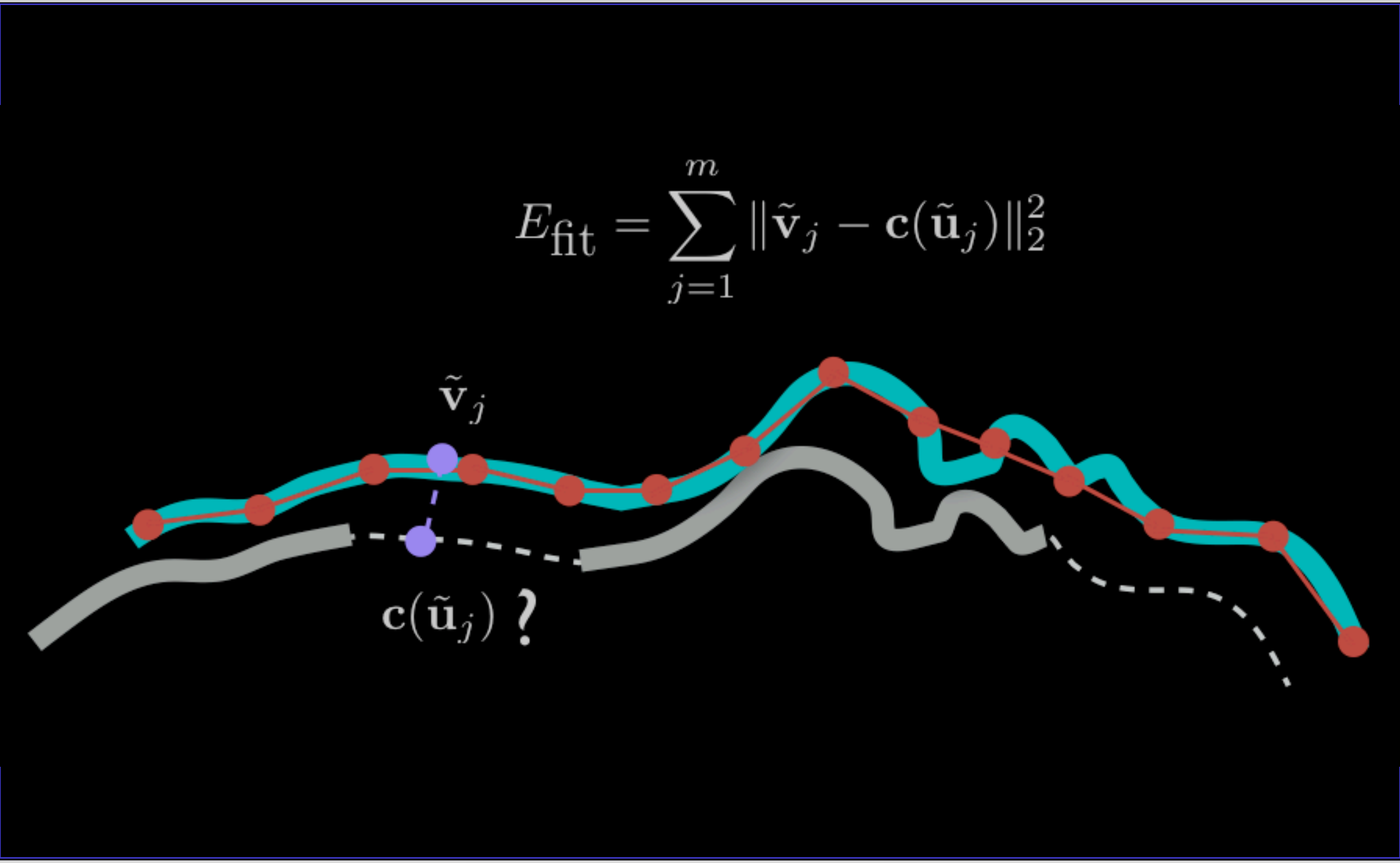
$$\mathbf{c}(\tilde{\mathbf{u}}_j)$$

$$\tilde{\mathbf{u}}_j = (\tilde{u}_j, \tilde{v}_j)$$ optimization variable

$$E_{\text{fit}} = \sum_{j=1}^{m} \|\tilde{\mathbf{v}}_j - \mathbf{c}(\tilde{\mathbf{u}}_j)\|_2^2$$

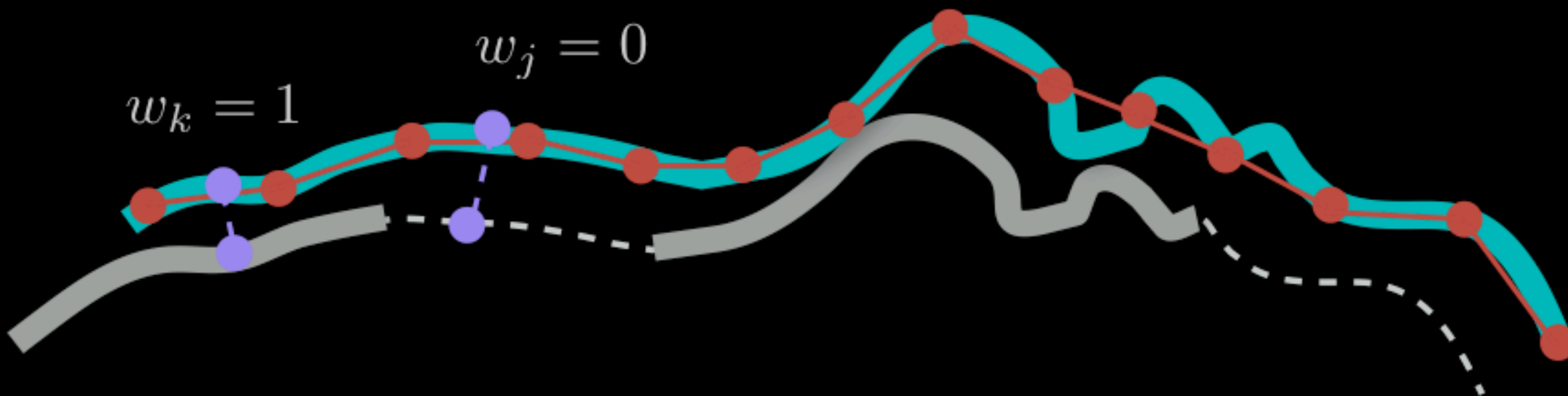


# Partial Data

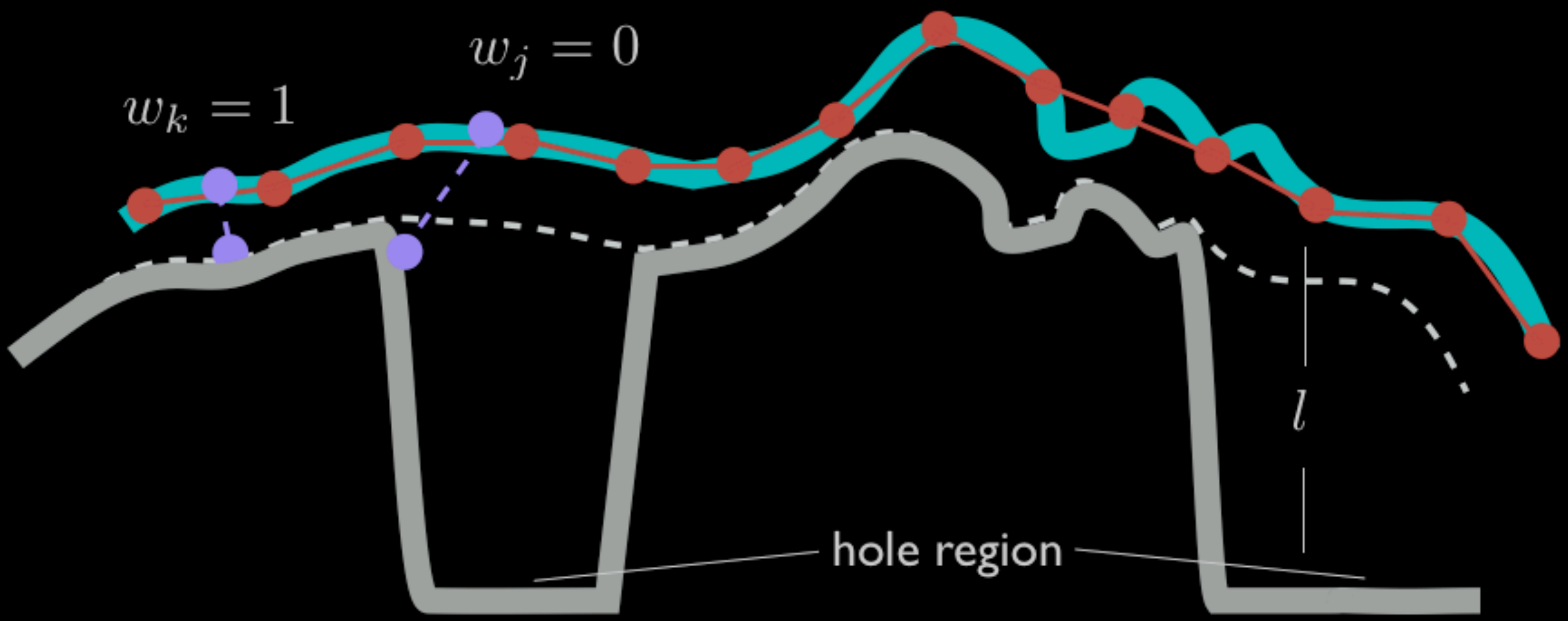


# Confidence Weights

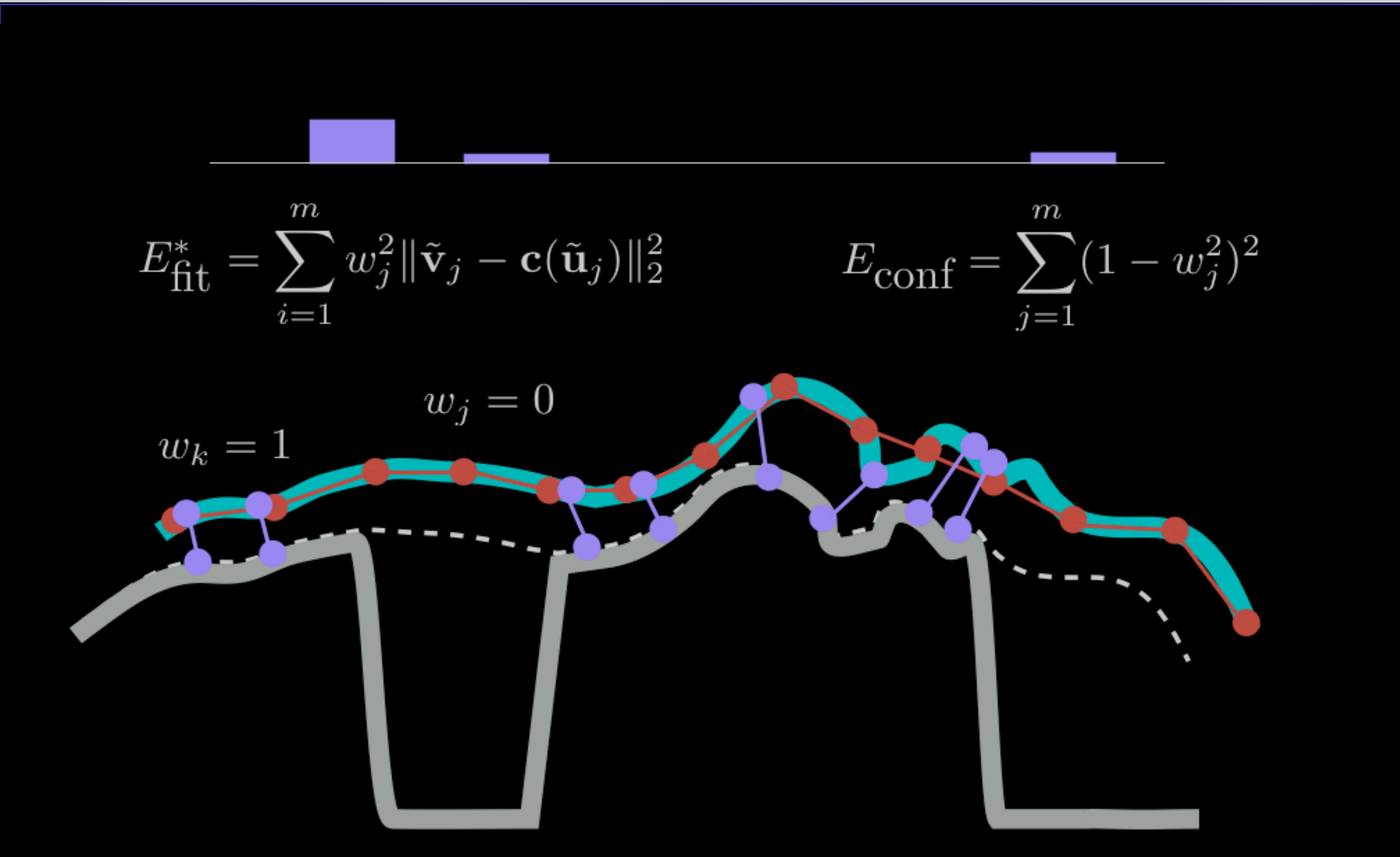
$$E^{*}_{\text{fit}} = \sum_{i=1}^{m} w_j^2 \|\tilde{\mathbf{v}}_j - \mathbf{c}(\tilde{\mathbf{u}}_j)\|_2^2$$



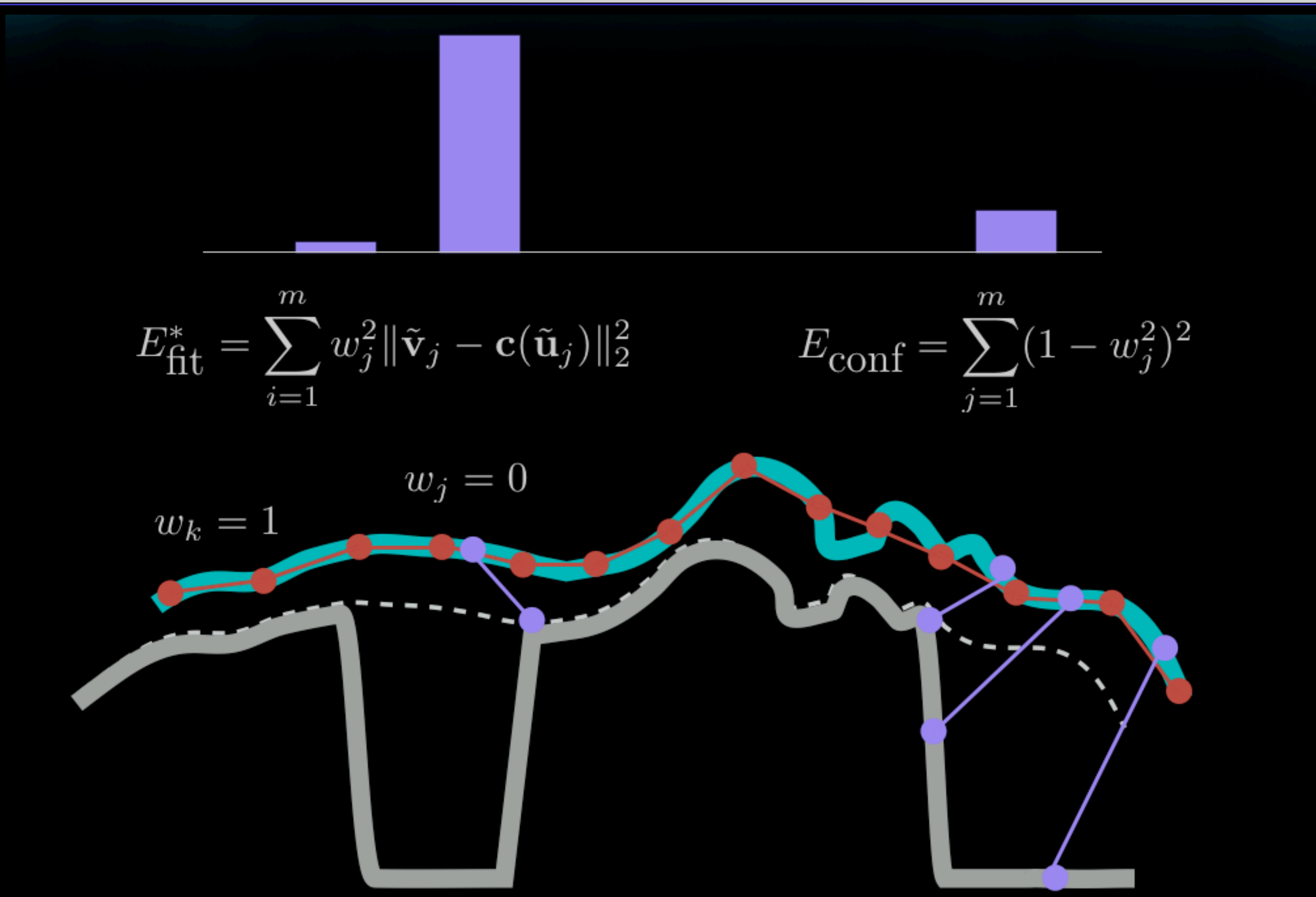
# Continuous Representation



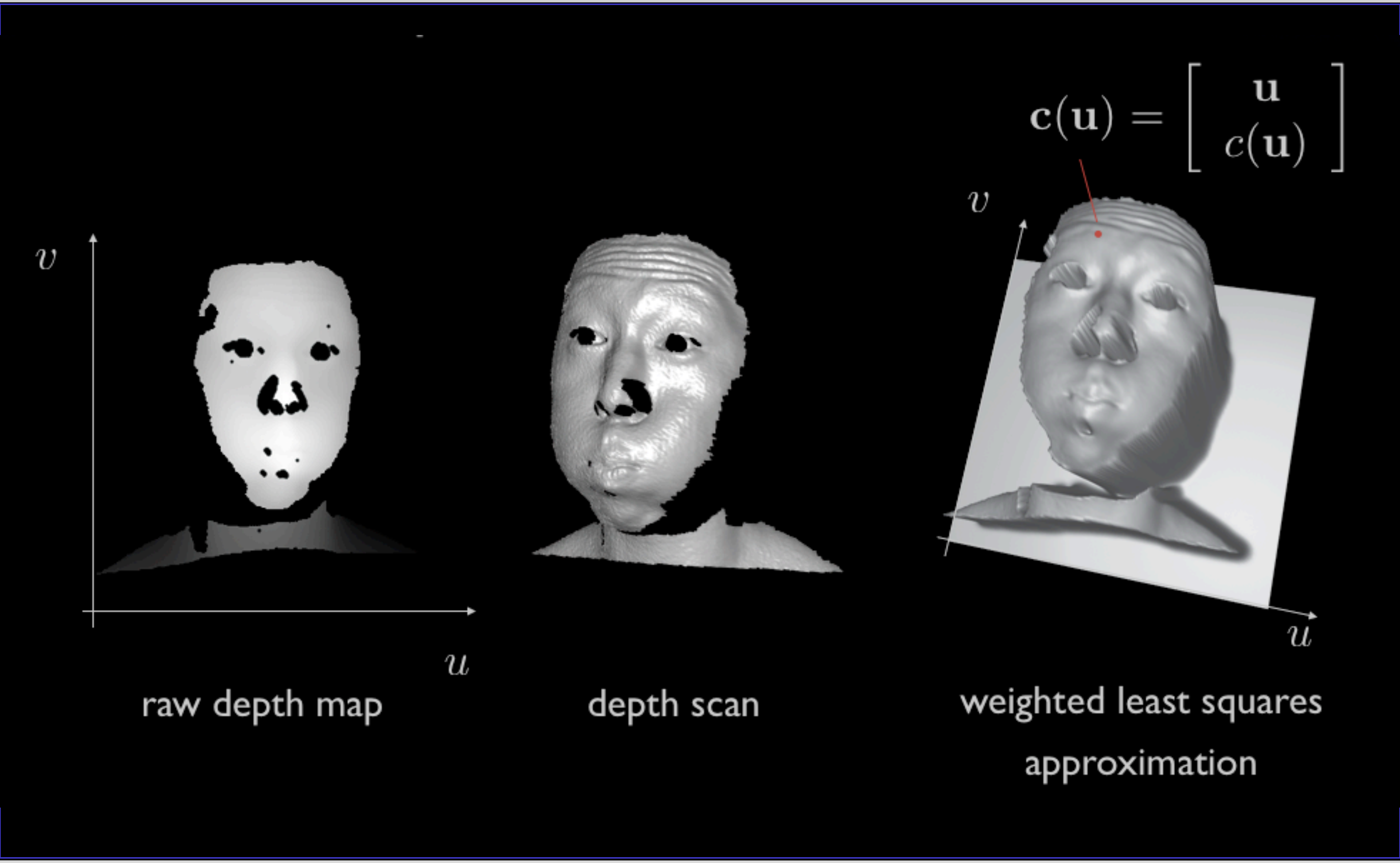
# Continuous Representation



# Continuous Representation



# Depth-Scan Parameterization



# Optimization

$$E_{\text{tot}} = \alpha_{\text{rigid}} E_{\text{rigid}} + \alpha_{\text{smooth}} E_{\text{smooth}} + \alpha_{\text{fit}} E^*_{\text{fit}} + \alpha_{\text{conf}} E_{\text{conf}}$$

- Minimize **deformation energy**
- Minimize **alignment error**
- Maximize **regions of overlap**

# Regularization Relaxation

$$E_{\text{tot}} = \alpha_{\text{rigid}} E_{\text{rigid}} + \alpha_{\text{smooth}} E_{\text{smooth}} + \alpha_{\text{fit}} E^*_{\text{fit}} + \alpha_{\text{conf}} E_{\text{conf}}$$

$$\alpha_{\text{rigid}} = 1000 \longrightarrow 1 \qquad \alpha_{\text{fit}} = 0.1$$

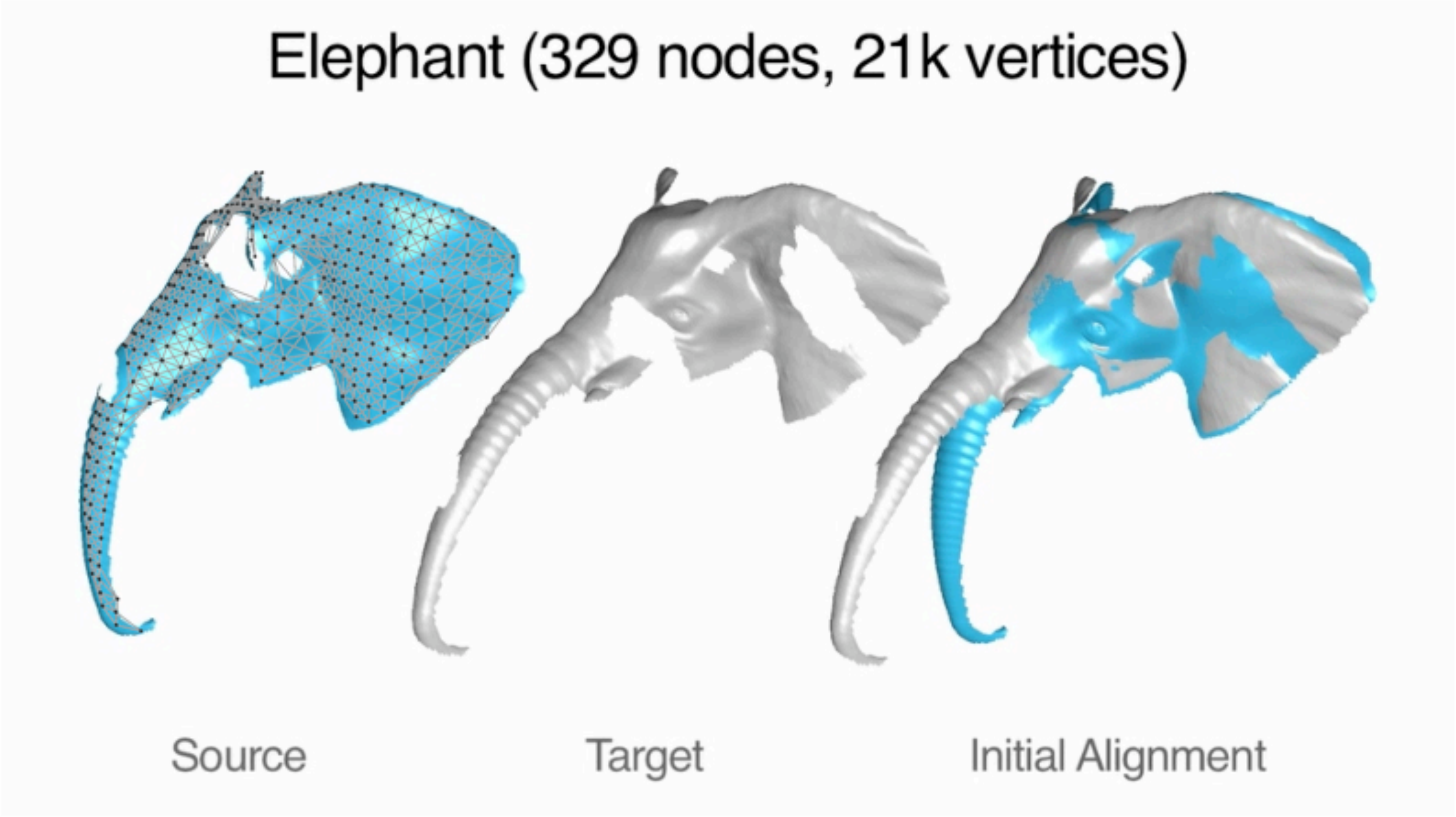
$$\alpha_{\text{smooth}} = 100 \longrightarrow 0.1 \qquad \alpha_{\text{conf}} = 100 \longrightarrow 1$$

stiffness reduction

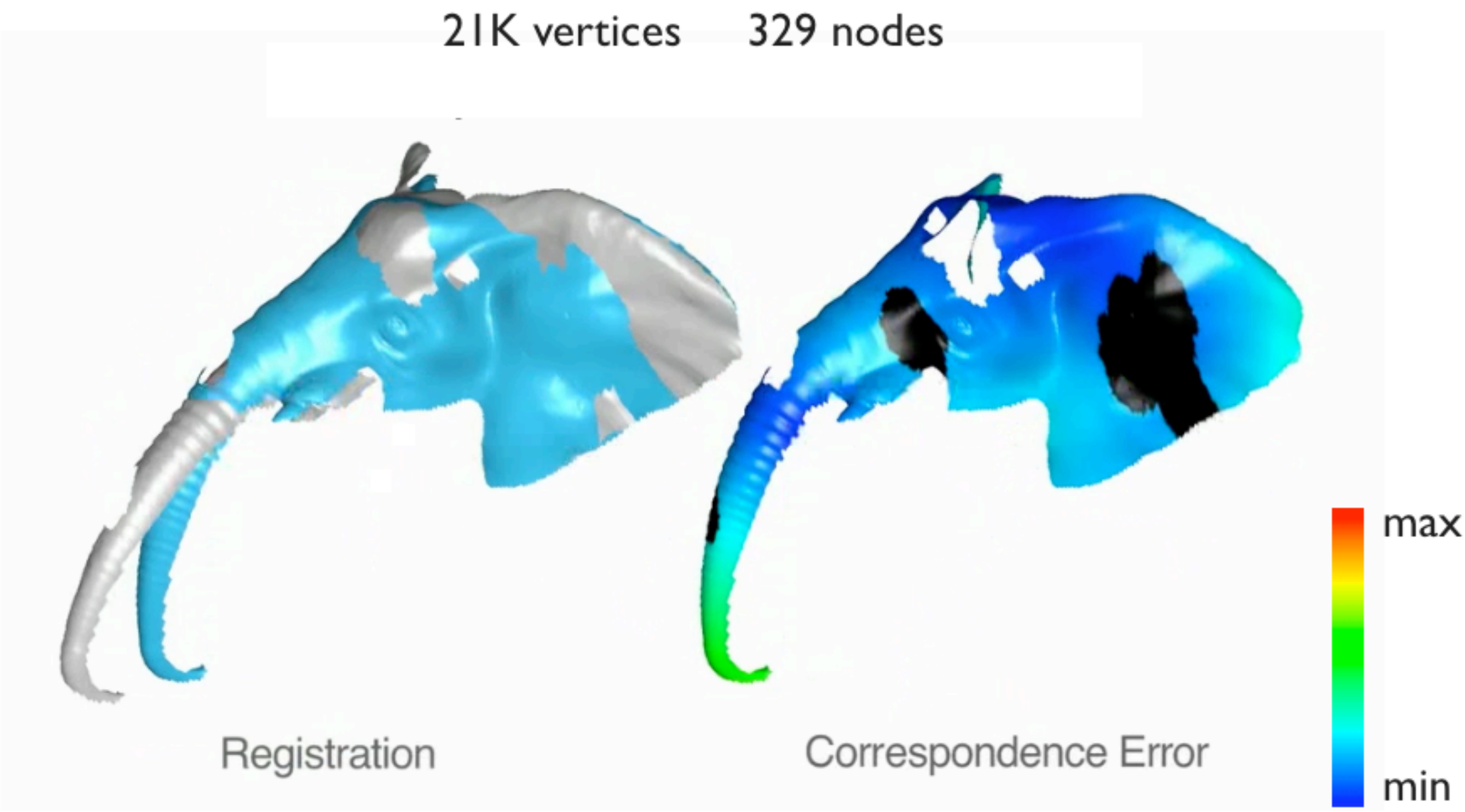
confidence adaptation

# Results

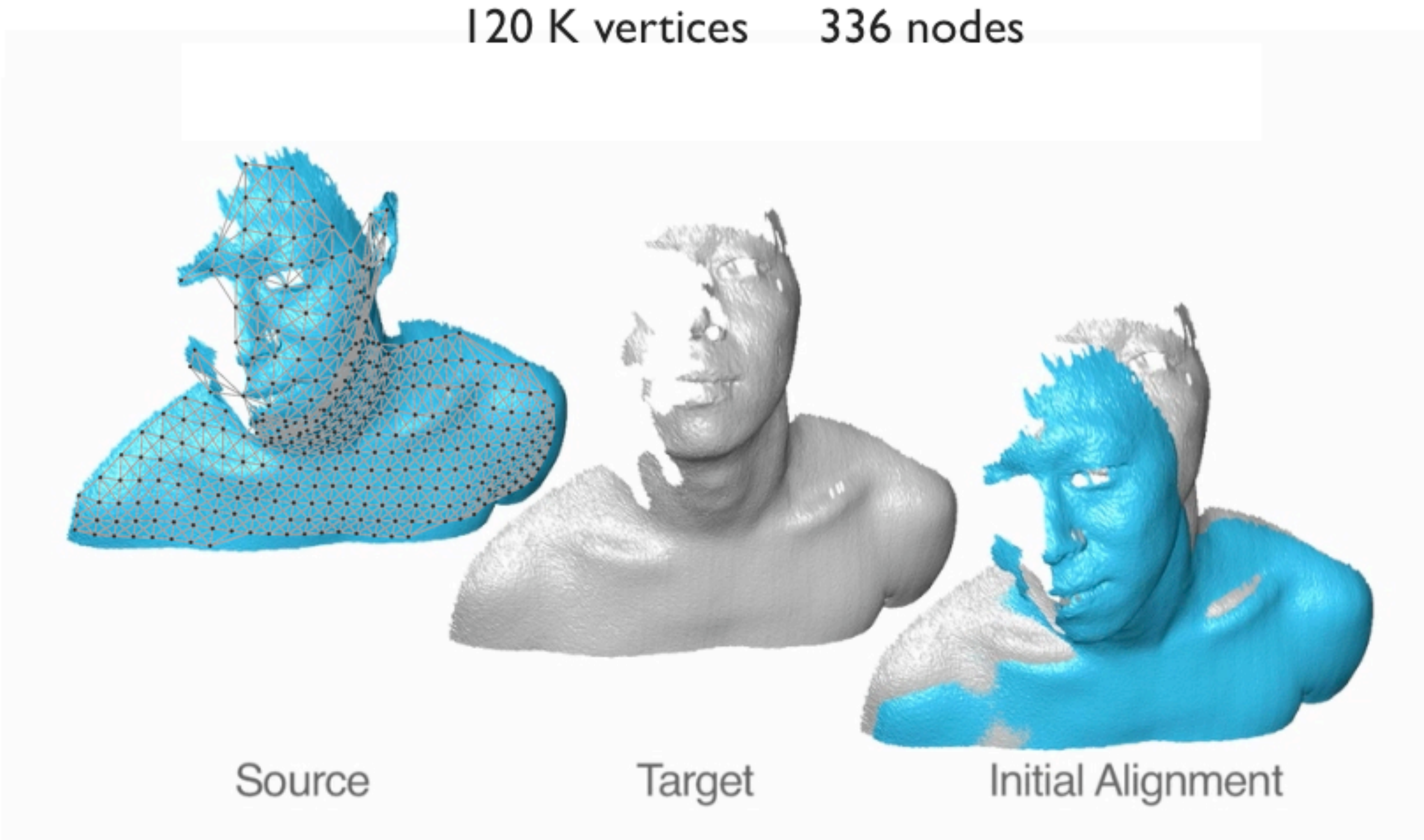
# Synthetic Model



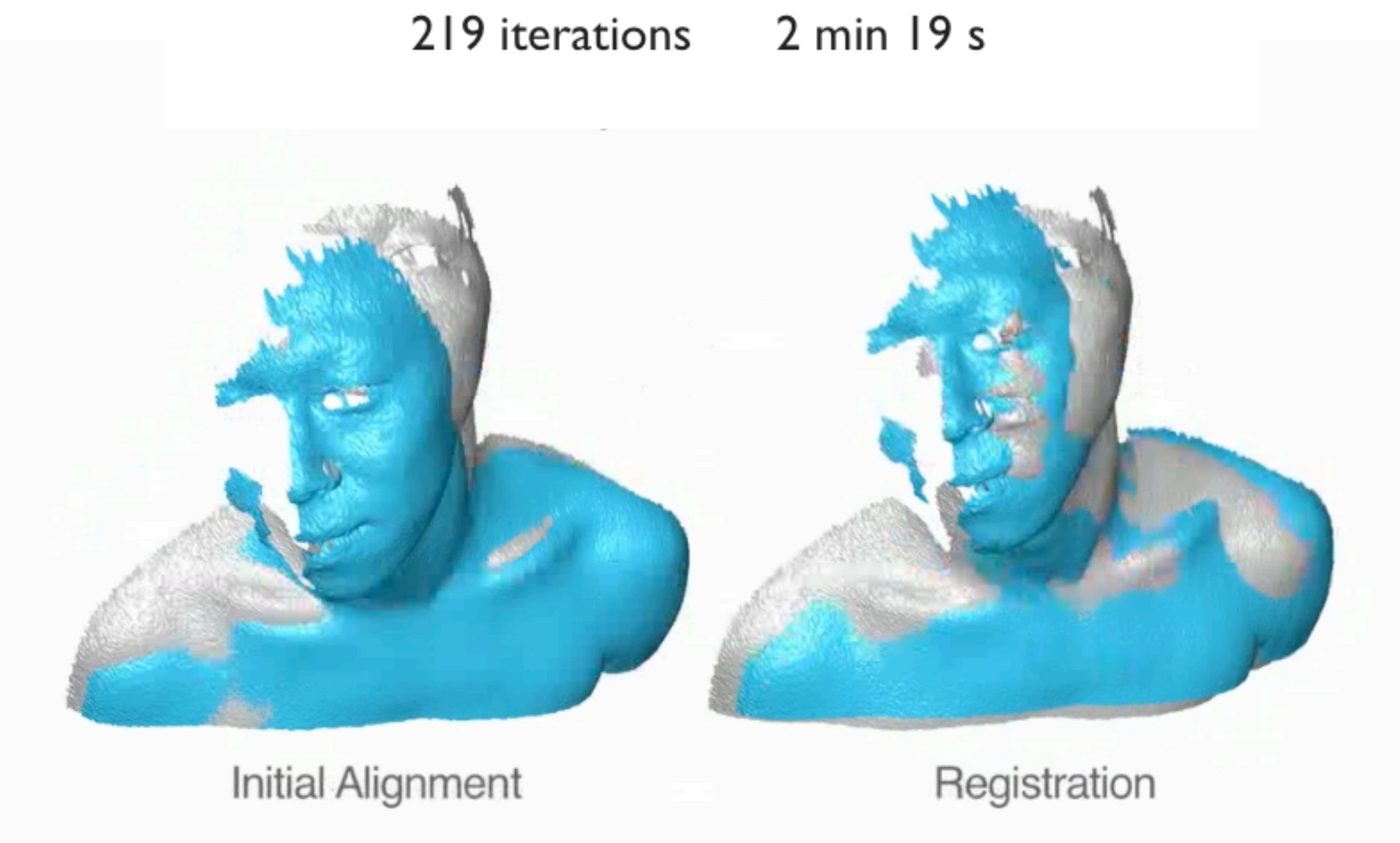
# Comparison to Ground-Truth



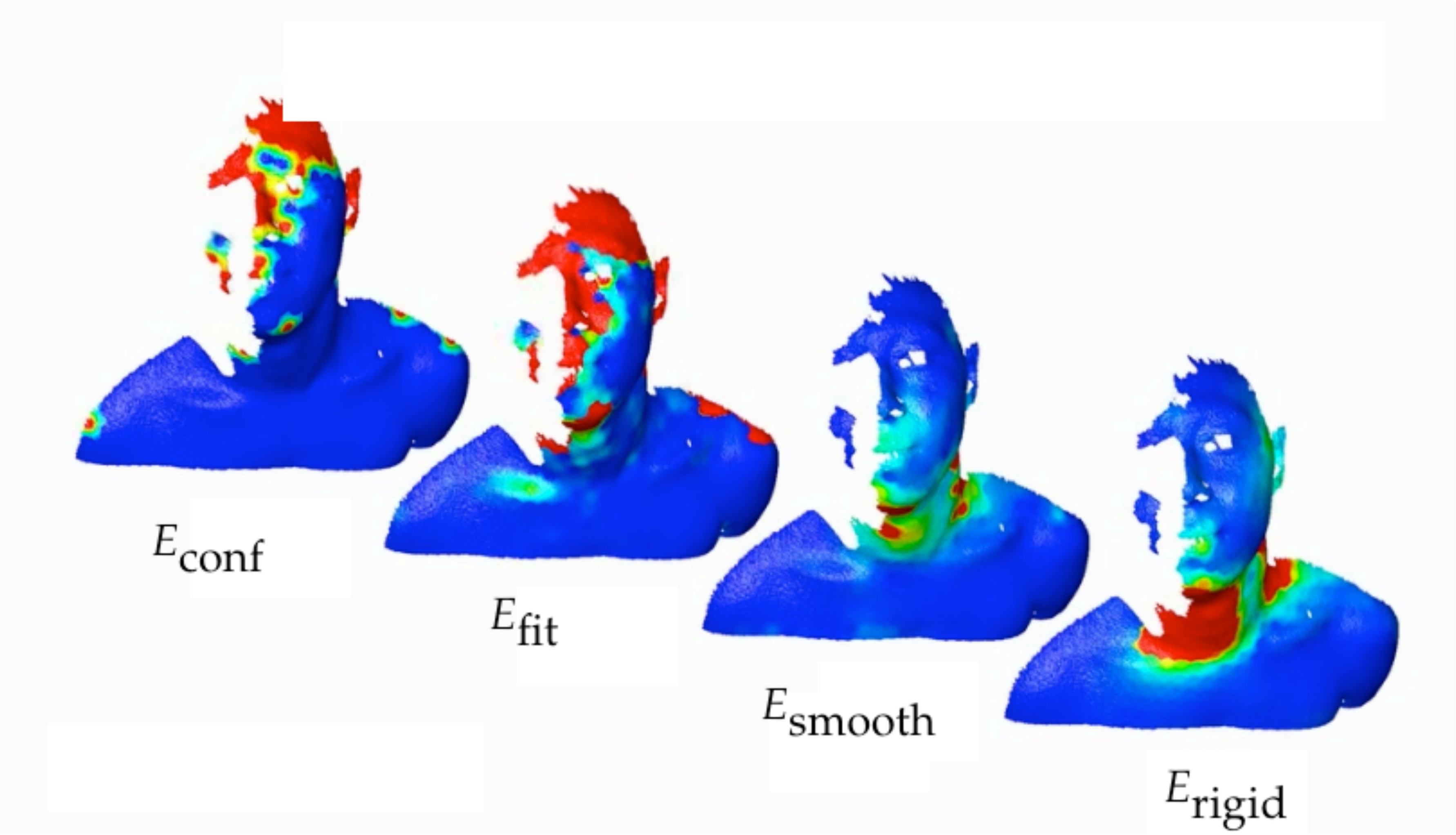
# Real Scans



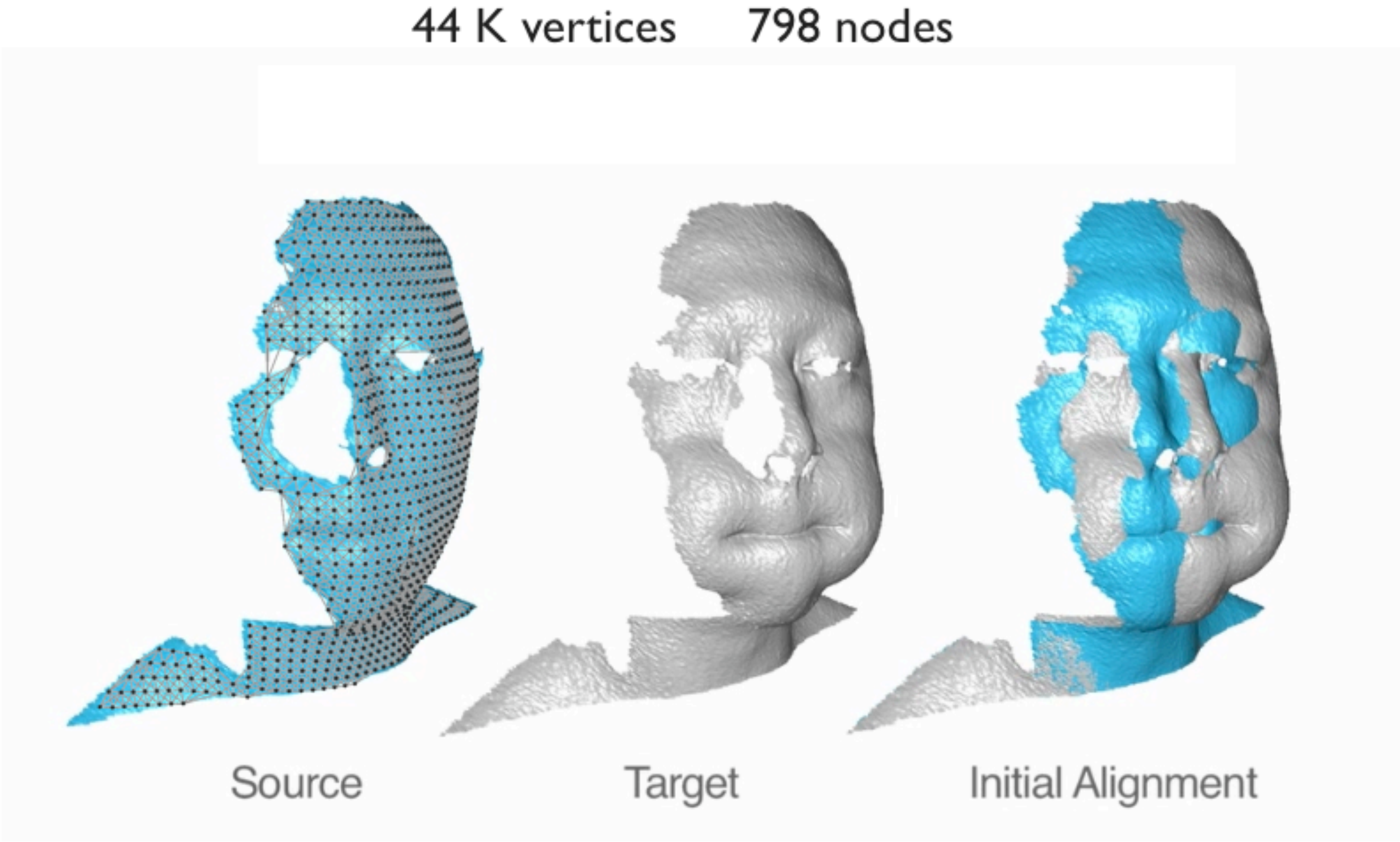
# Optimization



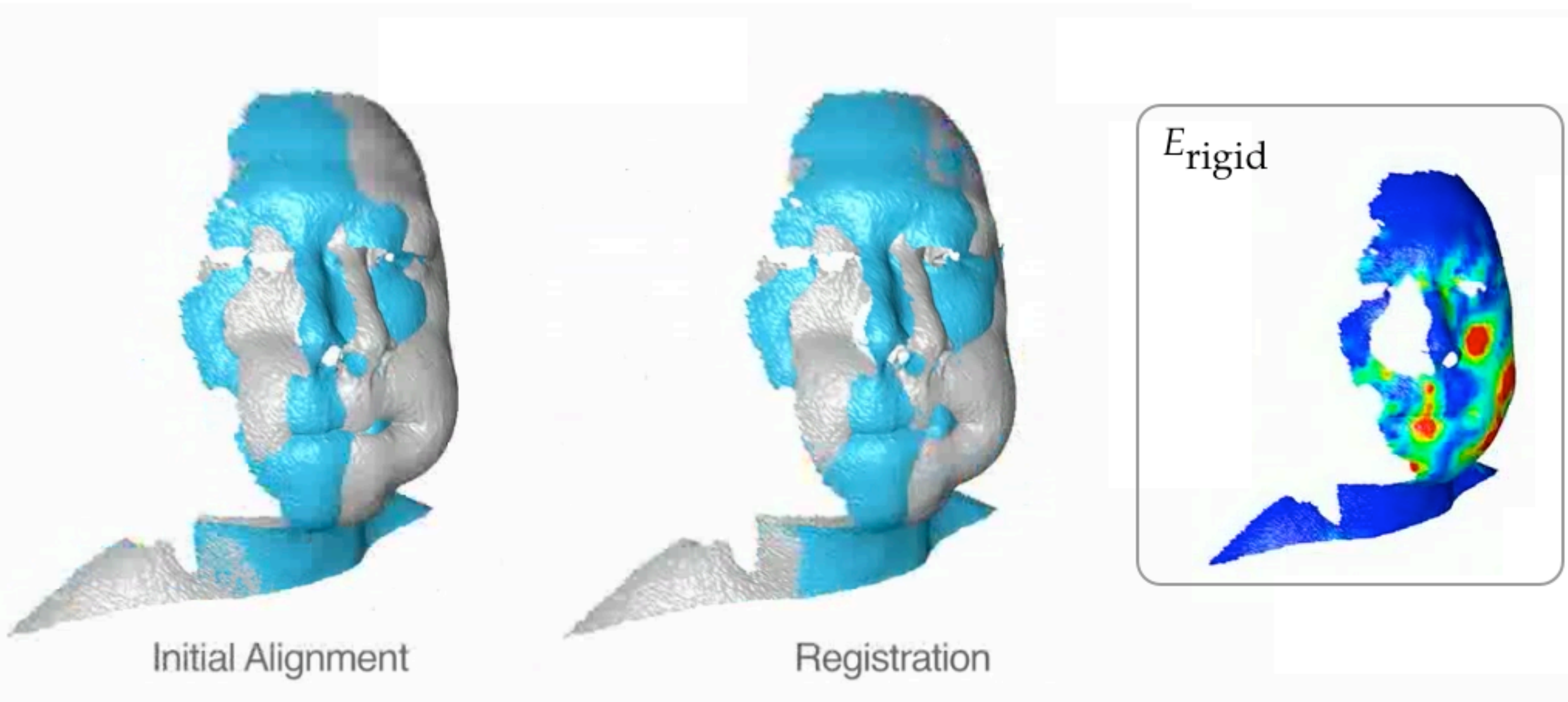
# Energy Term Visualization



# Deformation

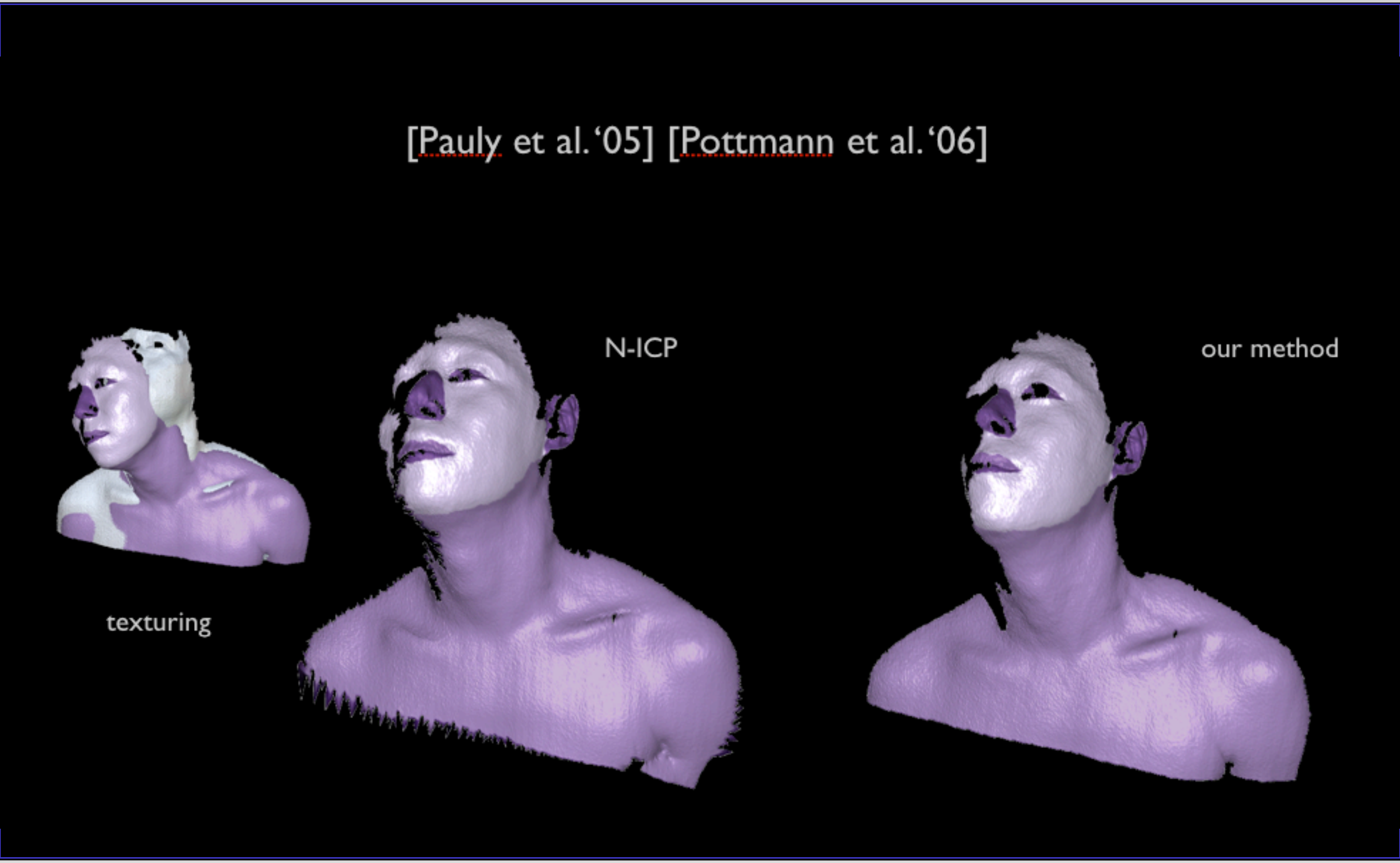


# Optimization

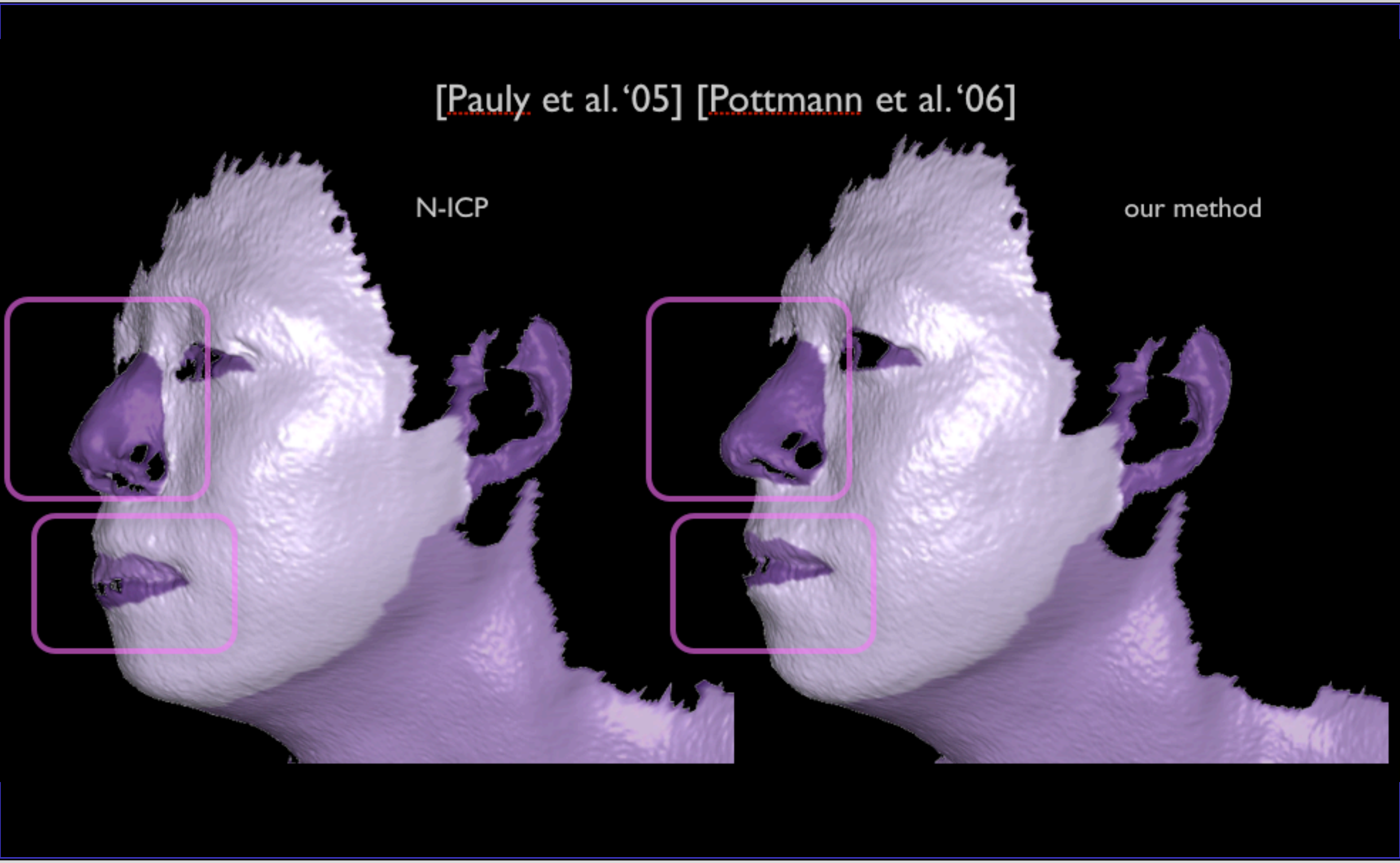


# Comparison to Previous Techniques on Non-Rigid ICP

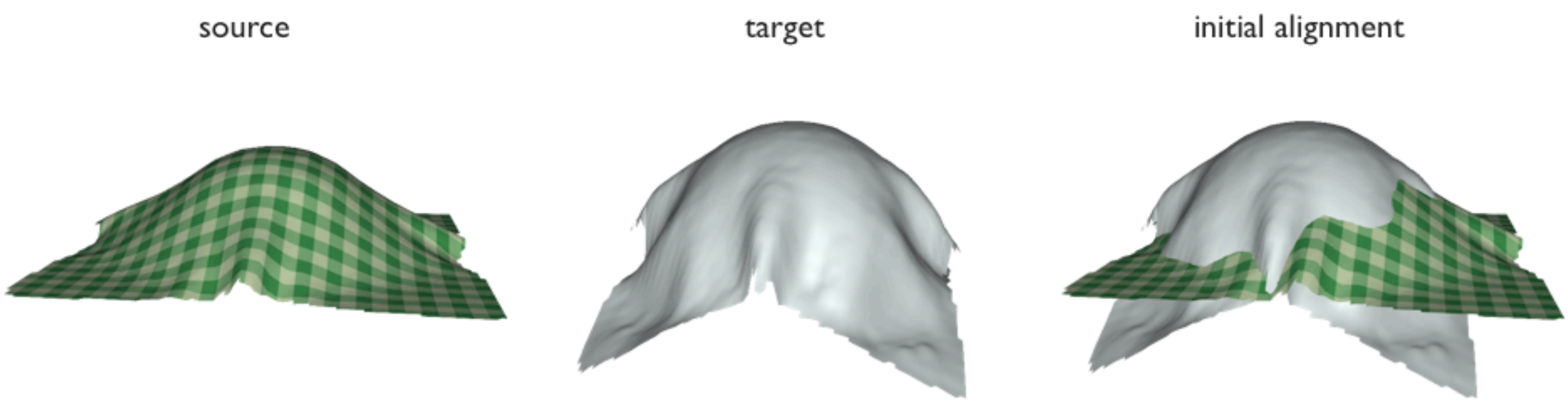
# Comparison with other N-ICP



# Comparison with other N-ICP

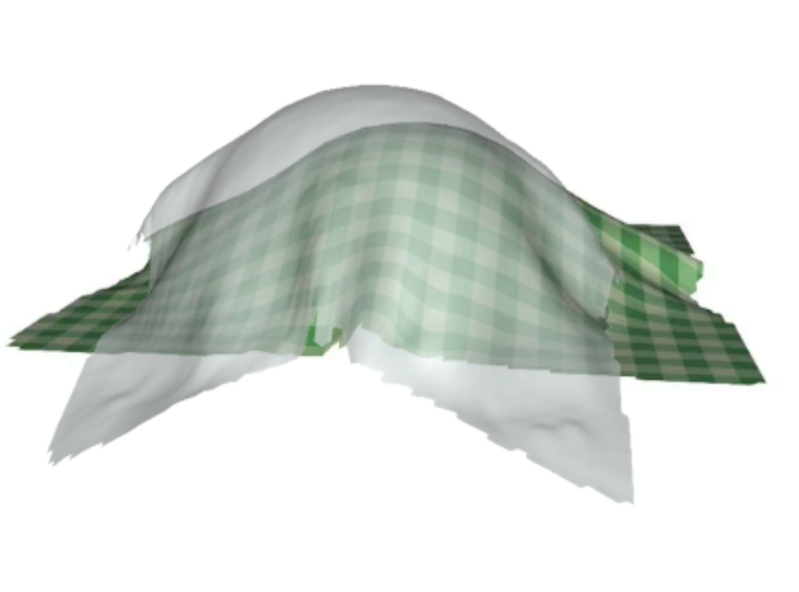


# Depth-Scan of a Draping Table Cloth

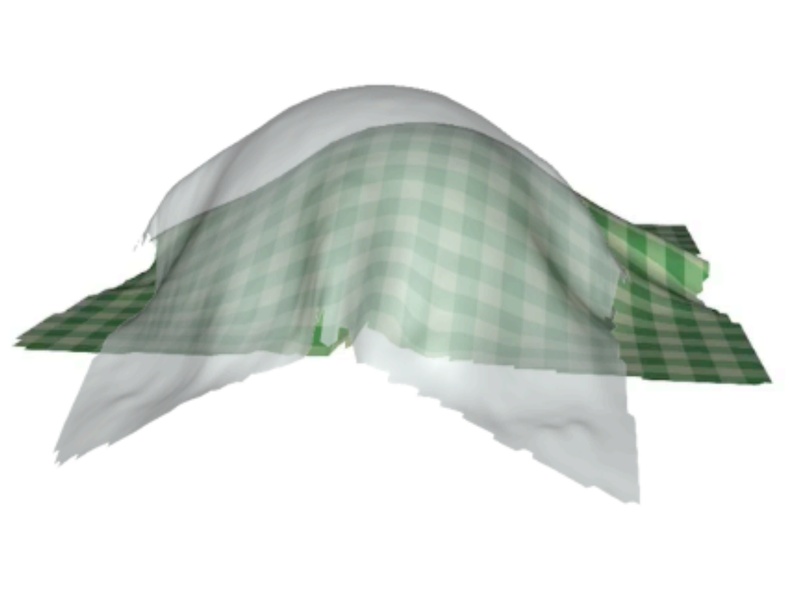


# Suitable for Isometric Deformations

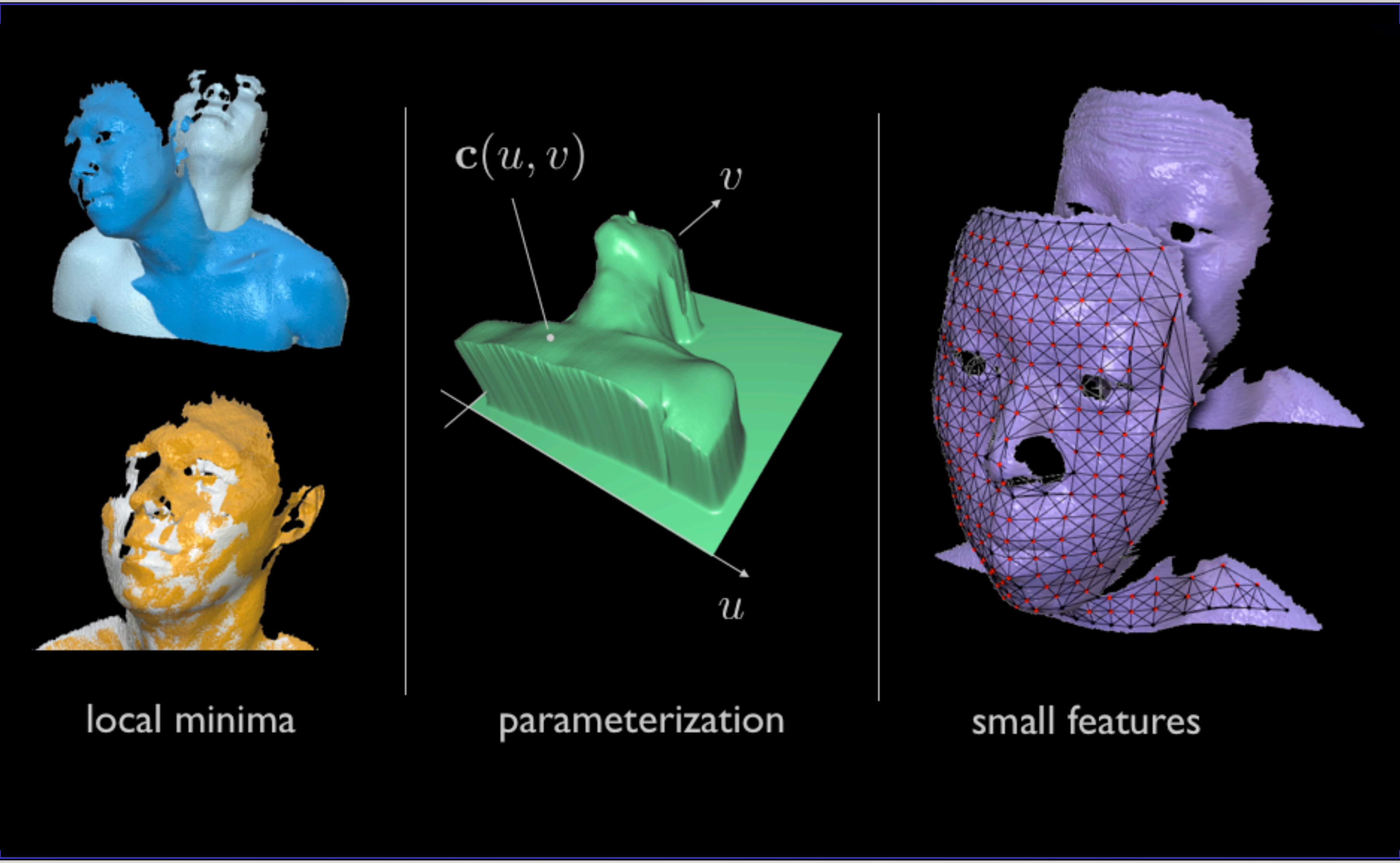
N-ICP



our method

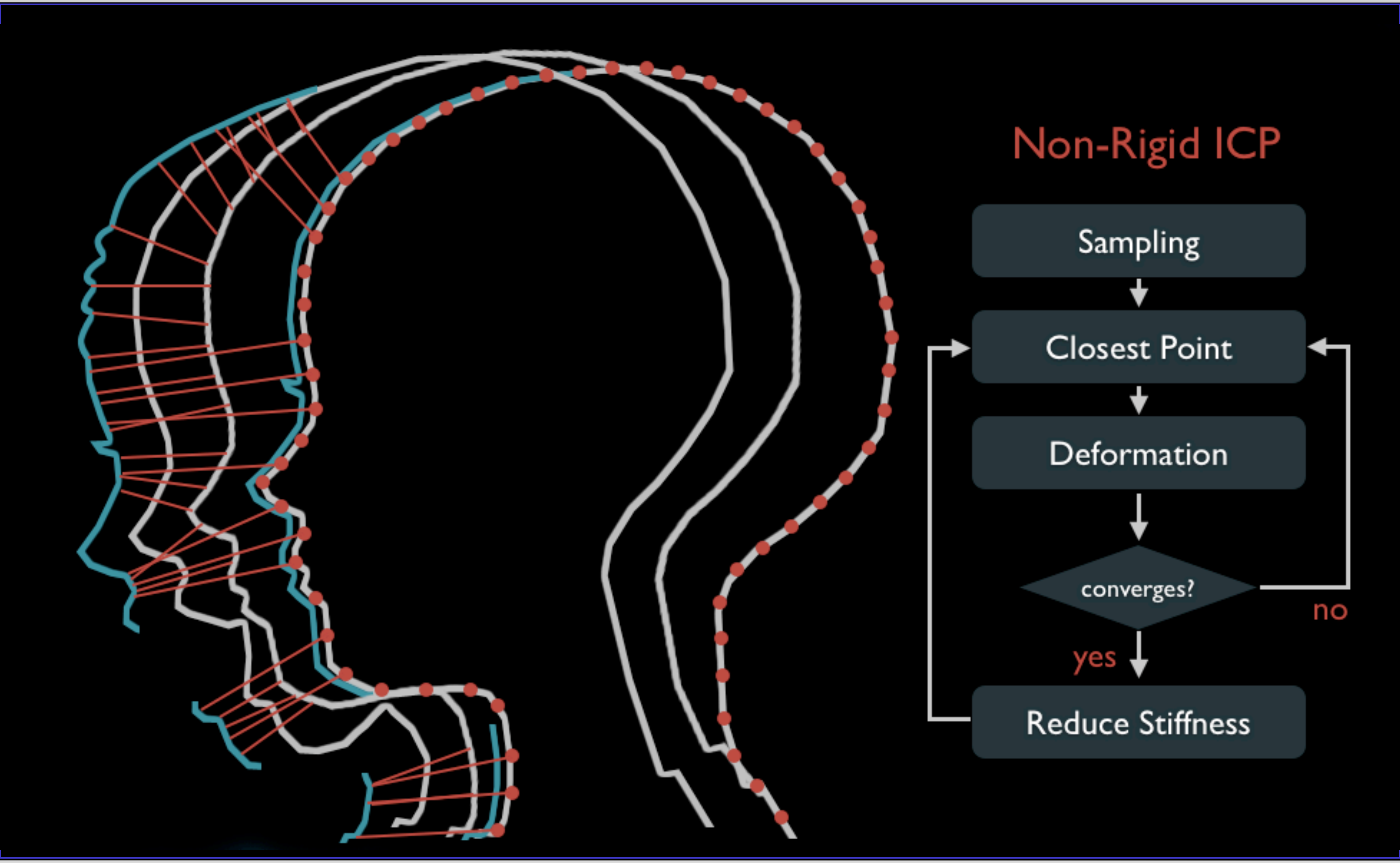


# Limitations

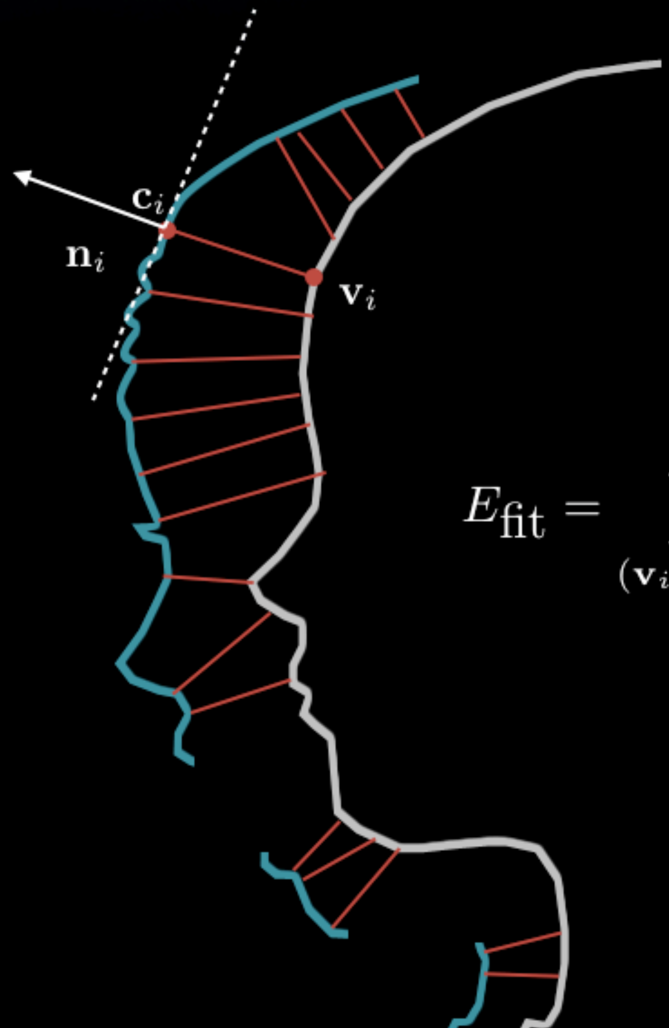


# Robust De-Coupling

# Robust Non-Rigid ICP



# Alignment Error Minimization




Point-to-point Point-to-plane

$$E_{\text{fit}} = \sum_{(\mathbf{v}_i, \mathbf{c}_i) \in \mathcal{C}} \alpha_{\text{point}} \|\mathbf{v}_i - \mathbf{c}_i\|^2 + \alpha_{\text{plane}} |\mathbf{n_i}^\top (\mathbf{v}_i - \mathbf{c}_i)|^2$$

Extension of [Li et al. '08]

# Optimization

## Non-Linear Optimization

$$E_{\text{tot}} = \alpha_{\text{fit}} E_{\text{fit}} + \alpha_{\text{rigid}} E_{\text{rigid}} + \alpha_{\text{smooth}} E_{\text{smooth}}$$

Too few nodes:

- inaccurate

Too many nodes:

- inefficient
- less robust

Extension of [Li et al. '08]

# Talk to you later!