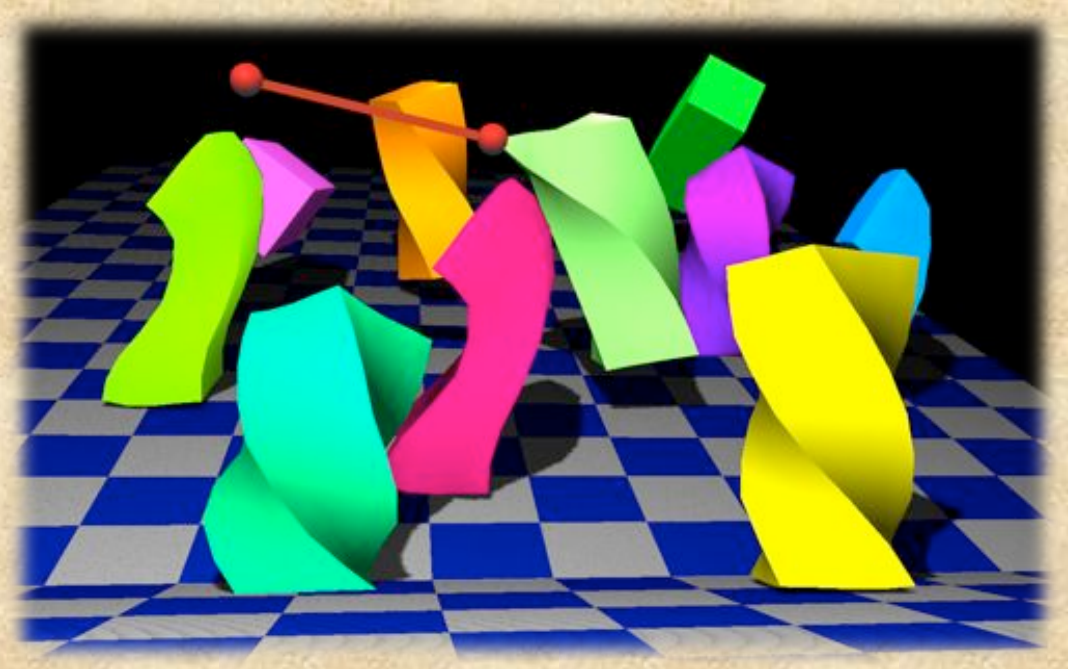
Real-Time Example-Based Elastic Deformation

Y. Koyama[1], K. Takayama[1,2], N. Umetani[1], T. Igarashi[1,3]

[1]The University of Tokyo [2]ETH Zurich [3]JST ERATO



Use

FEM

Example-Based Elastic Materials
[Martin11]

Finite Element Method

Speed up

Use

Our method

Shape Matching
[Müller05]

Use

FEM

Example-Based Elastic Materials
[Martin11]

Finite Element Method

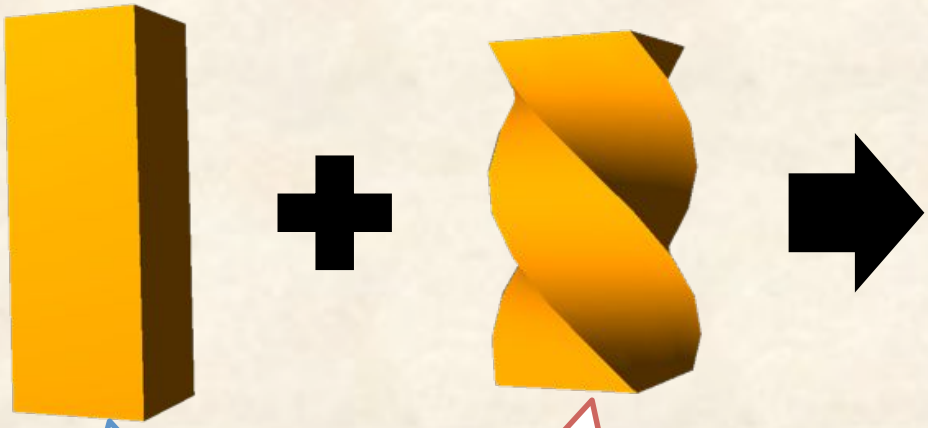
Speed up

Use

Our method

Shape Matching
[Müller05]

Example-Based Elastic Materials [Martin11]



Rest shape

Example pose

Result of simulation

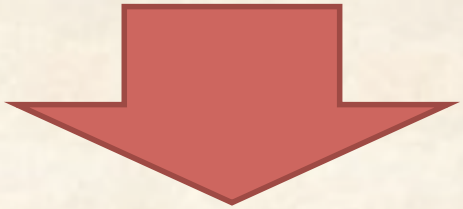
Advantages

1. **Artist-friendly simulation**
   - Direct design of deformations

2. **No pre-defined scenarios**
   - Useful for games...?

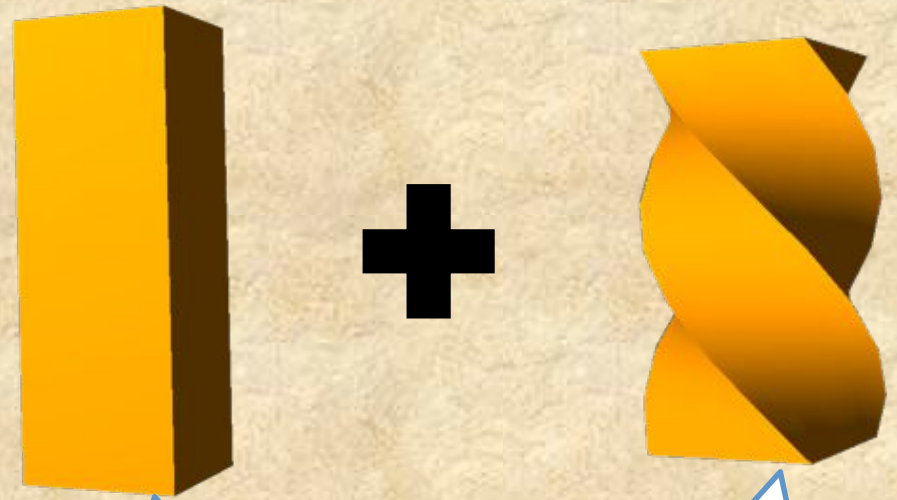
Limitation of [Martin11]

- **Slow**
  - not real-time, not interactive
  - **Finite Element Method (FEM)**
  - **Non-linear** optimizations



Our motivation: real-time, interactive

Real-Time Demo



Rest shape

Example pose

Example-Based Elastic Materials
[Martin11]

Use

FEM

Finite Element Method

Speed up

Our method

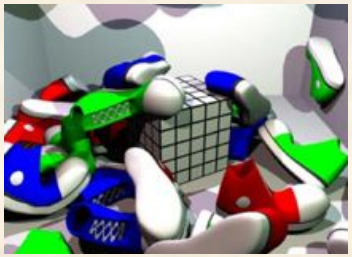
Use

Shape Matching
[Müller05]

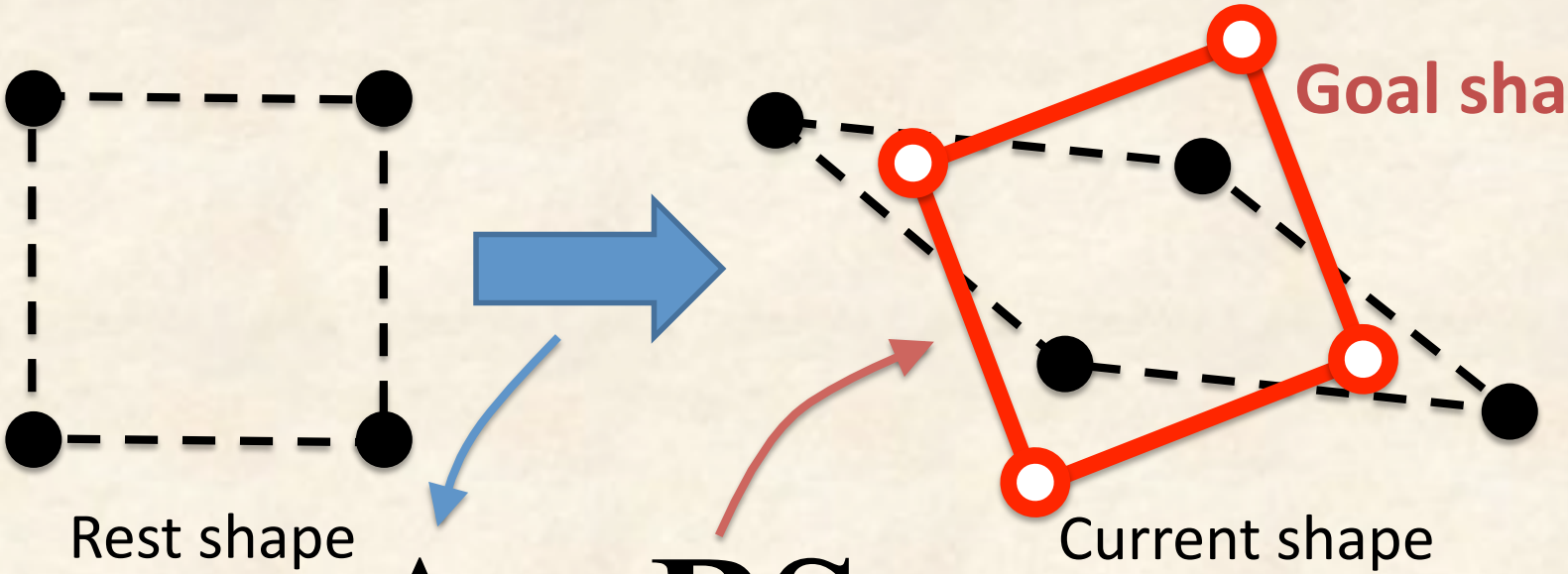
Shape Matching [Müller05]

- Method for deformable objects
  - **Geometry, not physics**
  - **Fast, robust,** and **stable**

[Müller05]



Key ideas



$$\mathbf{A} = \mathbf{RS}$$

Polar decomposition

$\mathbf{A} \in \mathbb{R}^{3\times3}$

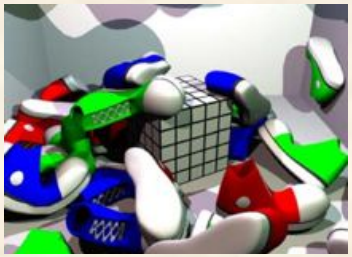
= Linear transformation

$\mathbf{R} \in \mathbb{R}^{3\times3}$

= Rotation

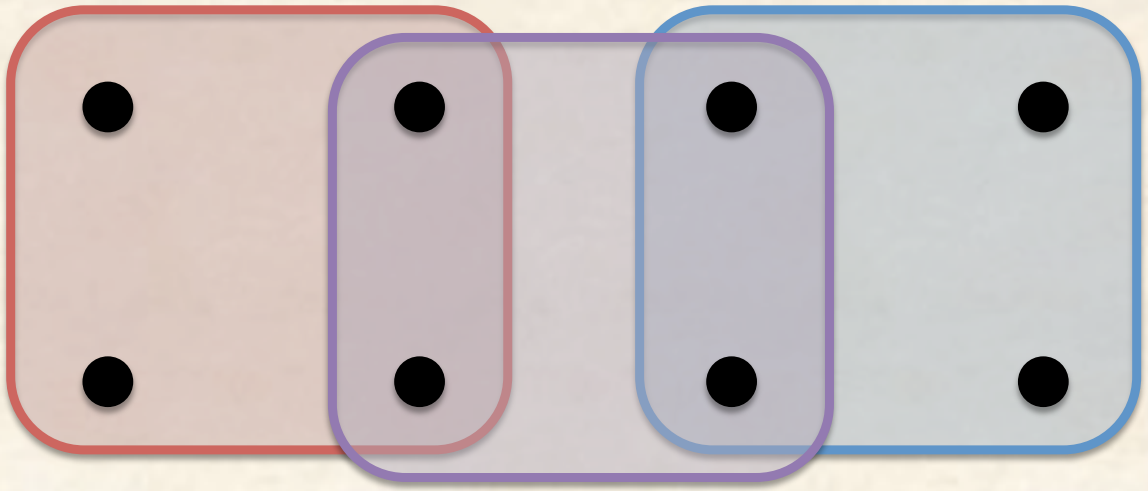
$\mathbf{S} \in \mathbb{R}^{3\times3}$

= Stretch and shear



Extension to multi-region

- Overlapping local regions
  - Increasing the **range of deformation**



Multiple regions

Use

FEM

Example-Based Elastic Materials
[Martin11]

Finite Element Method

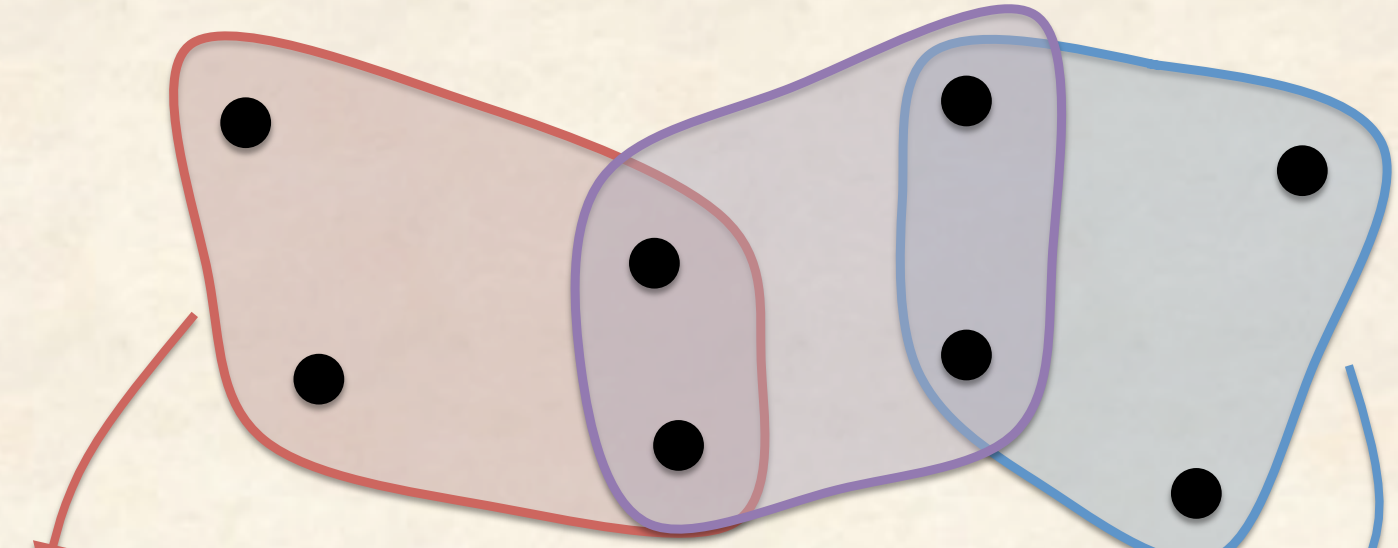
Speed up

Use

Our method

Shape Matching
[Müller05]

Deformation Descriptor



$$\mathbf{A}_1 = \mathbf{R}_1\mathbf{S}_1$$

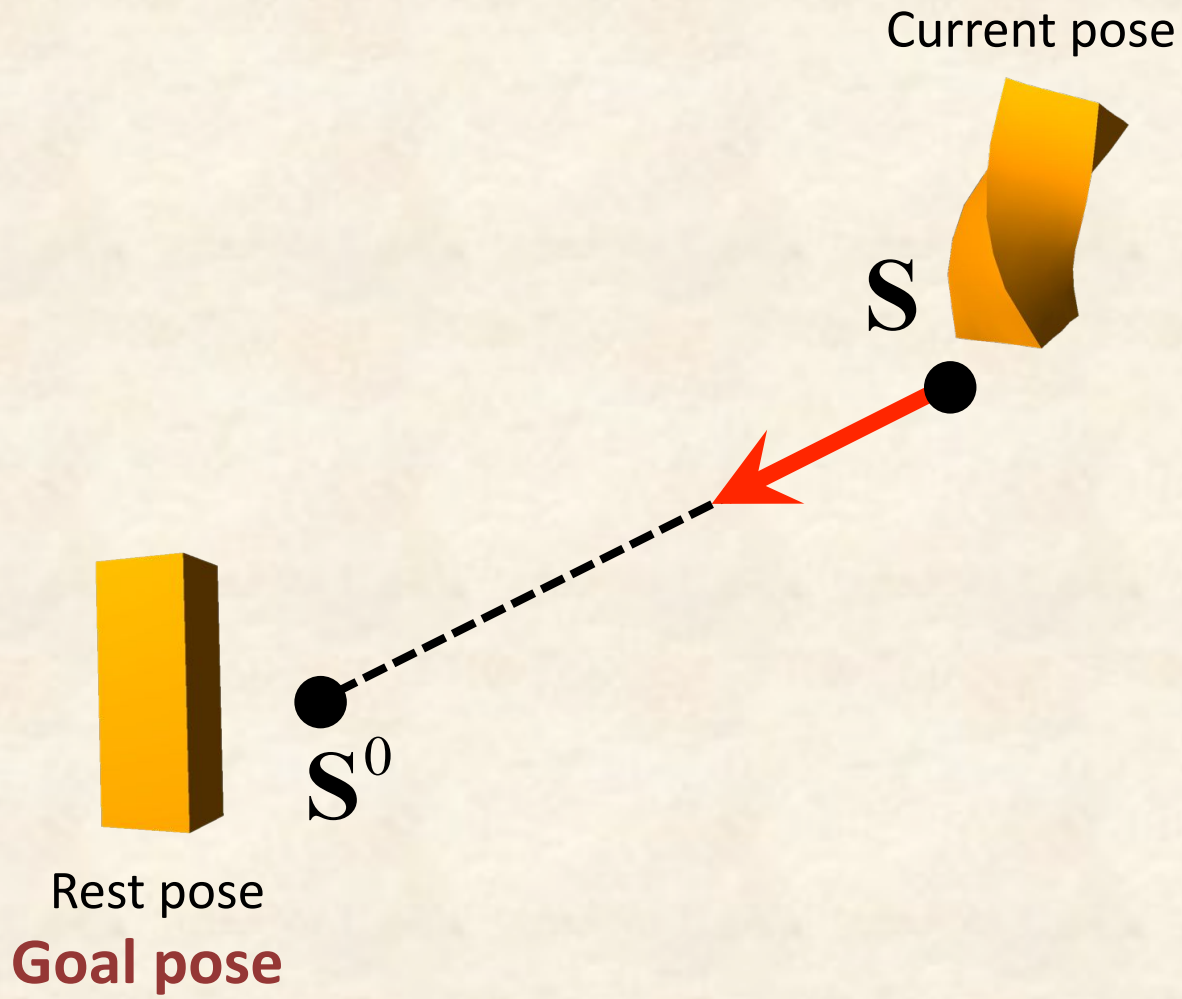
$$\mathbf{A}_2 = \mathbf{R}_2\mathbf{S}_2$$

$$\mathbf{A}_3 = \mathbf{R}_3\mathbf{S}_3$$

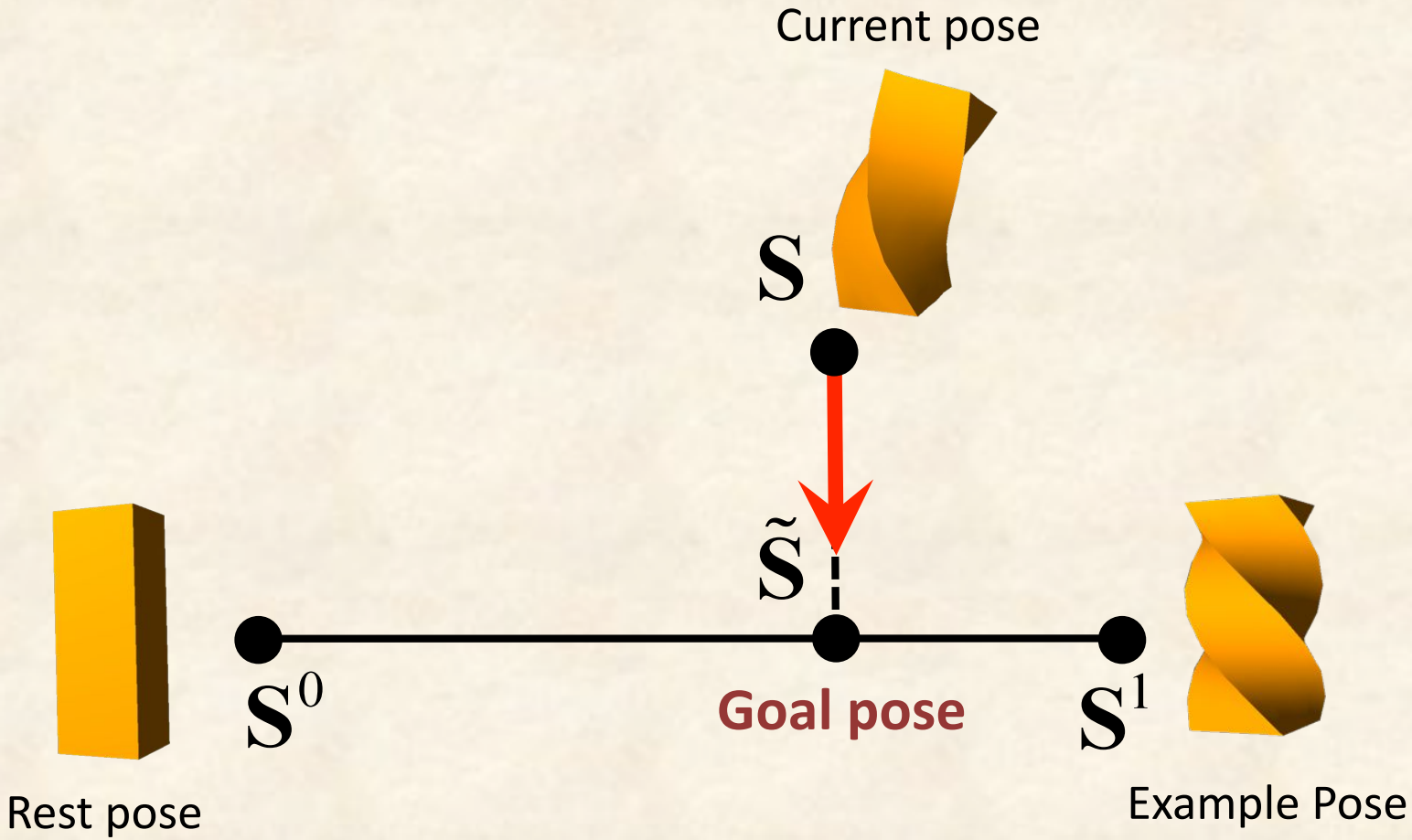
Deformation Descriptor

$$:= \mathbf{S} = \begin{pmatrix} \mathbf{S}_1^T & \mathbf{S}_2^T & \cdots & \mathbf{S}_m^T \end{pmatrix}^T \in \mathbb{R}^{6m}$$

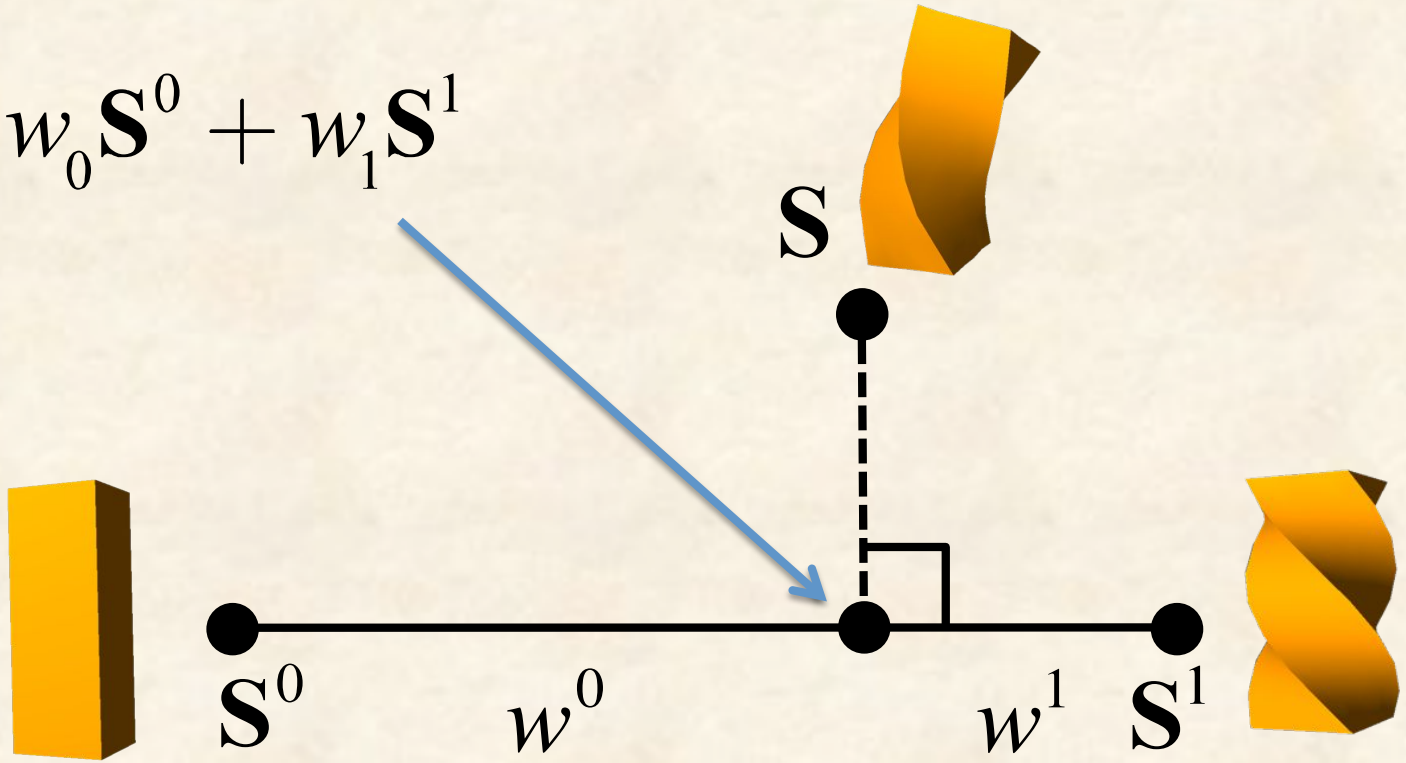
Goal pose
(Standard shape matching)



Goal pose
(Our method)

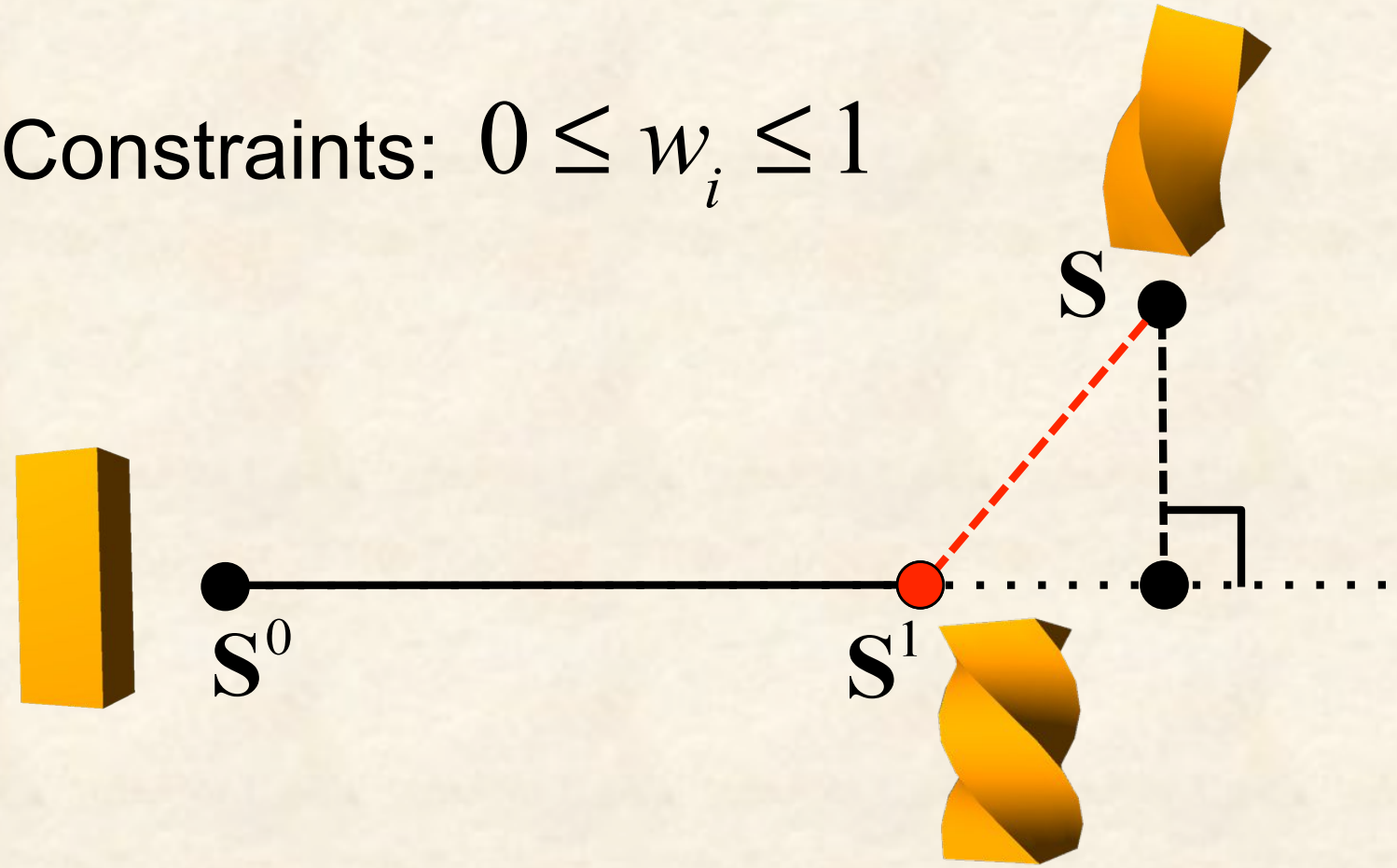


Details of projection
1. Linear projection



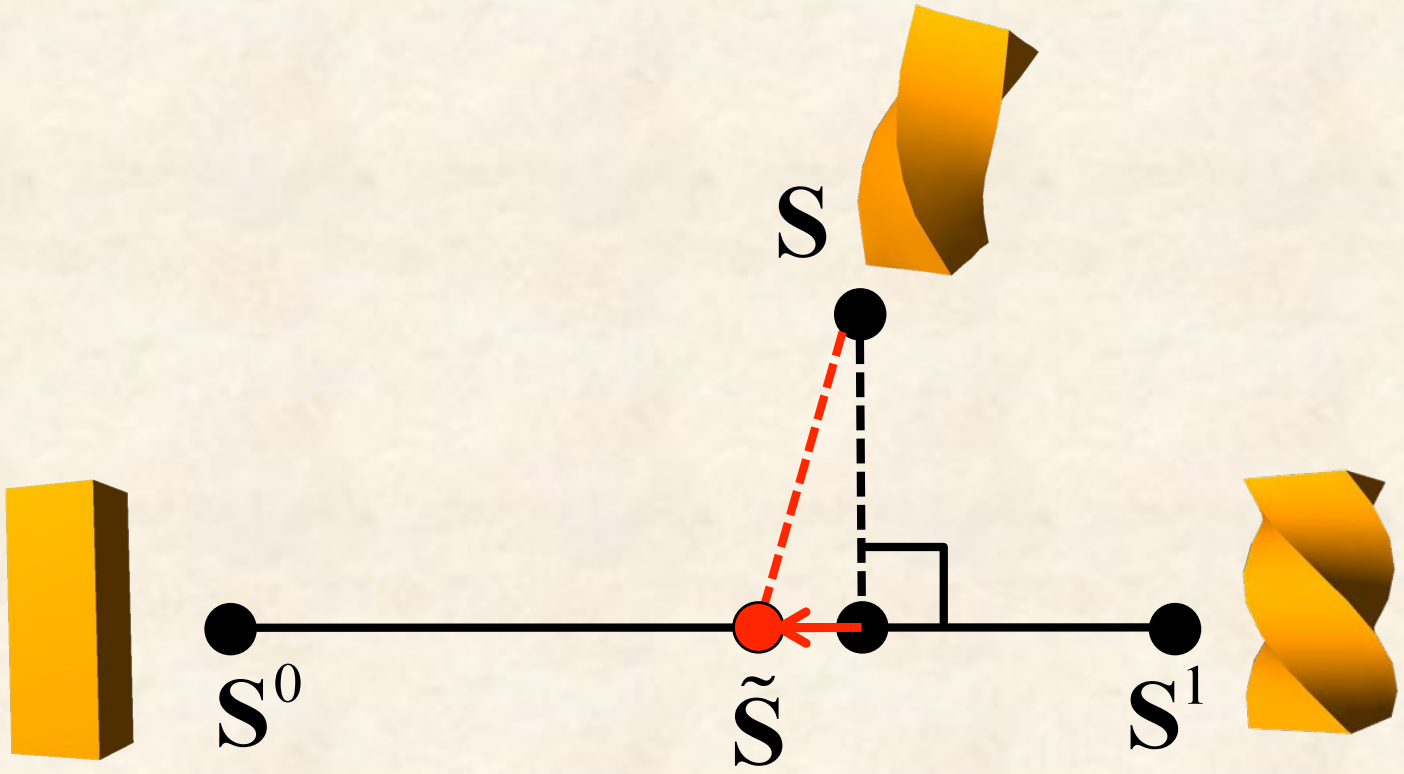
Details of projection
2. Clamping to avoid extrapolation

Constraints: $0 \leq w_i \leq 1$



Details of projection

3. Ensuring the deformation will return

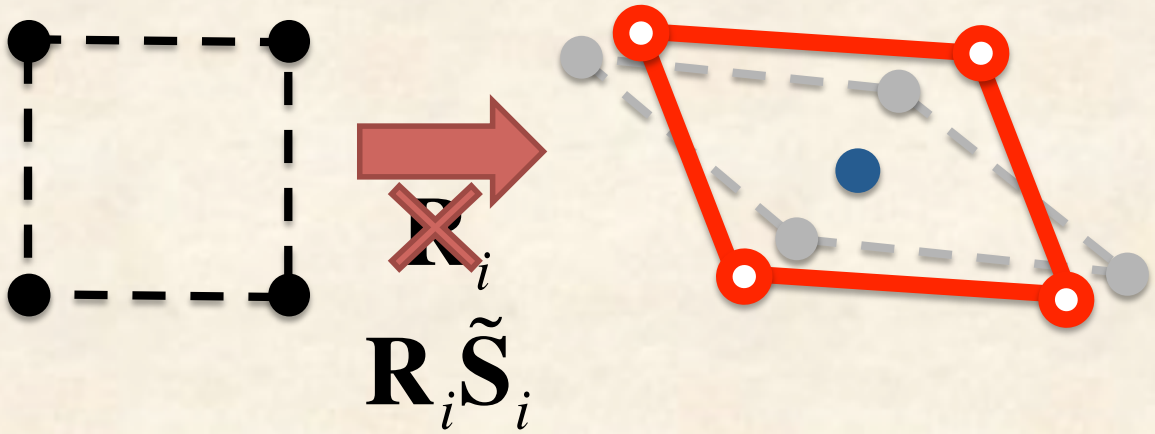


Modifying the Shape Matching

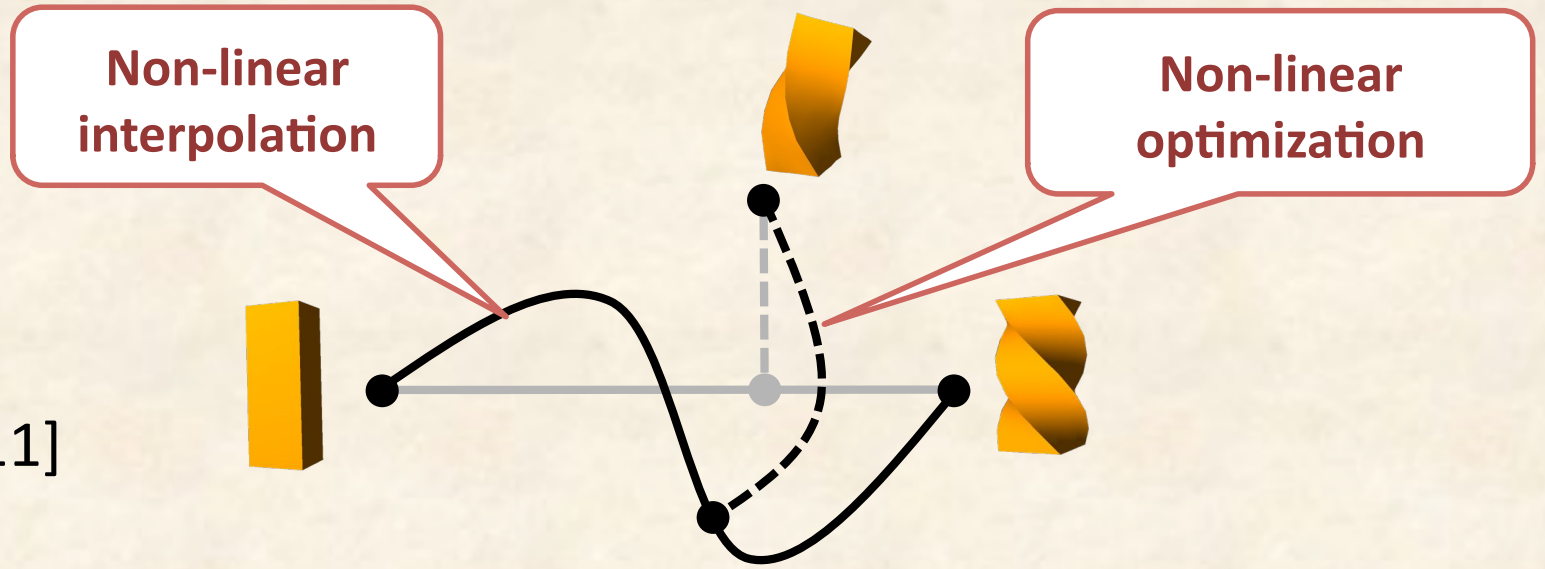
$$\tilde{\mathbf{S}} = \begin{pmatrix} \tilde{\mathbf{S}}_1^T & \tilde{\mathbf{S}}_2^T & \cdots & \tilde{\mathbf{S}}_m^T \end{pmatrix}^T$$

Goal strain of each local region

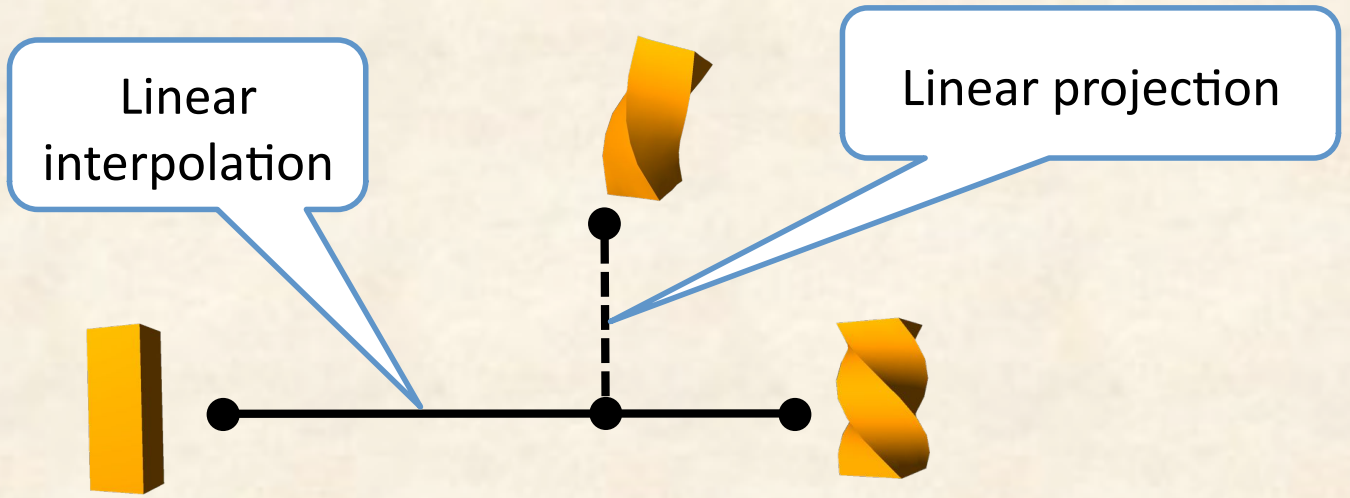
Region i



Non-linear vs Linear

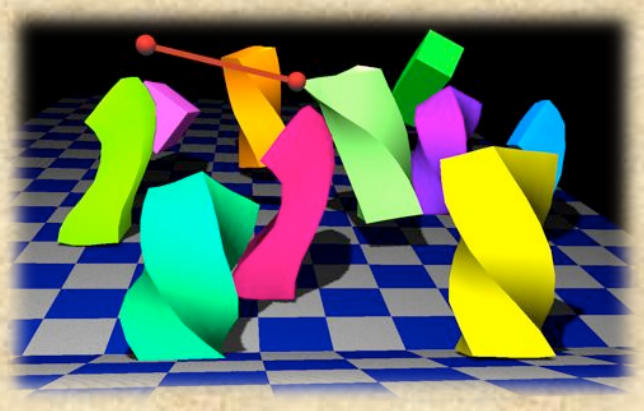


[Martin11]
FEM

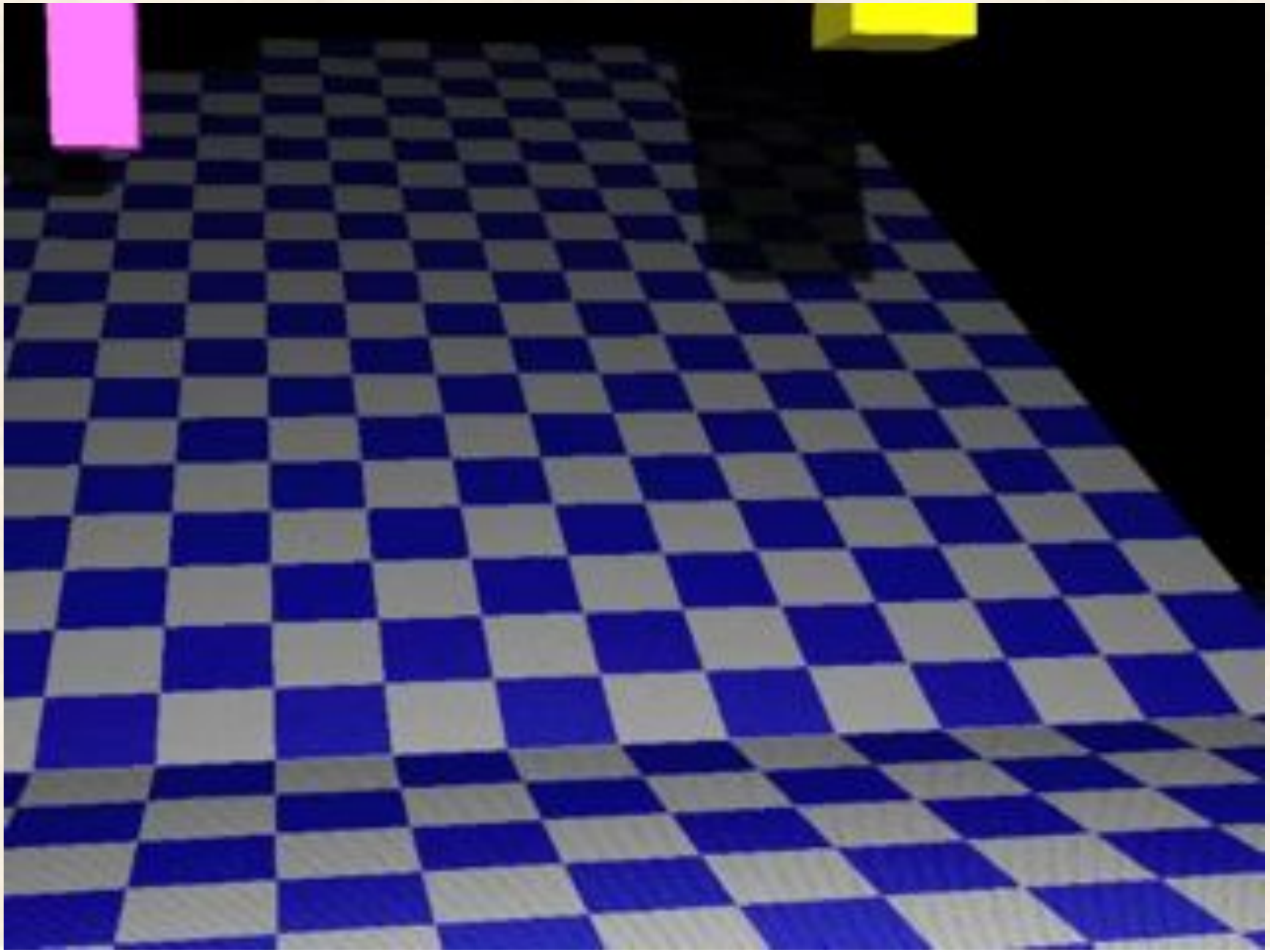


Our Method
Shape Matching

Results and Discussions



Results



Rough comparison
1. Quality

- Very similar effect of example pose

[Martin11]	Our Method
	

Rough comparison
2. Performance

- Two, or three orders magnitude faster

	[Martin11]	Our Method
Vertices	325	225
Time [ms]	528 / 3064 Min / Max	0.33

(twisting cuboid)

Limitation

- Physical accuracy

  [**Good**] FEM

  [**Poor**] Shape Matching

Future Work

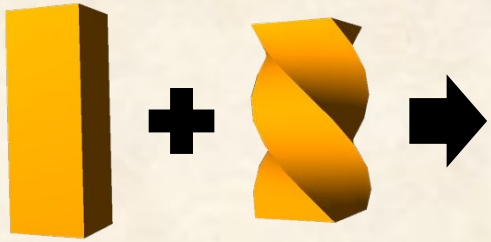
2D structures (e.g. cloth)

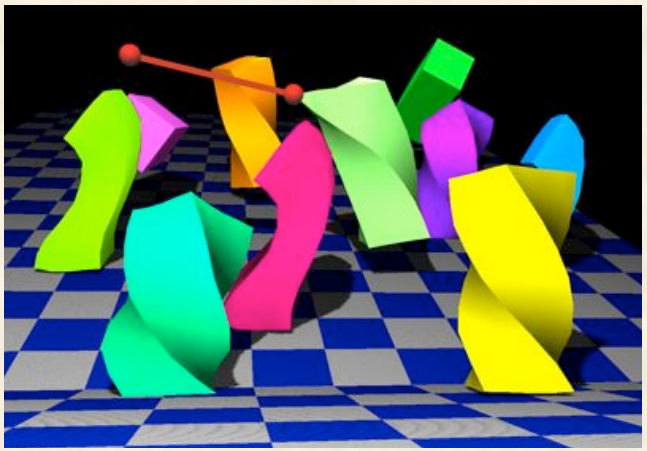
1D structures (e.g. hair)

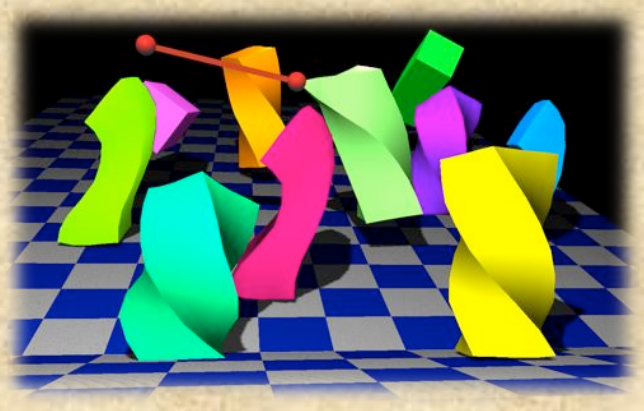
[Müller11]

Summary

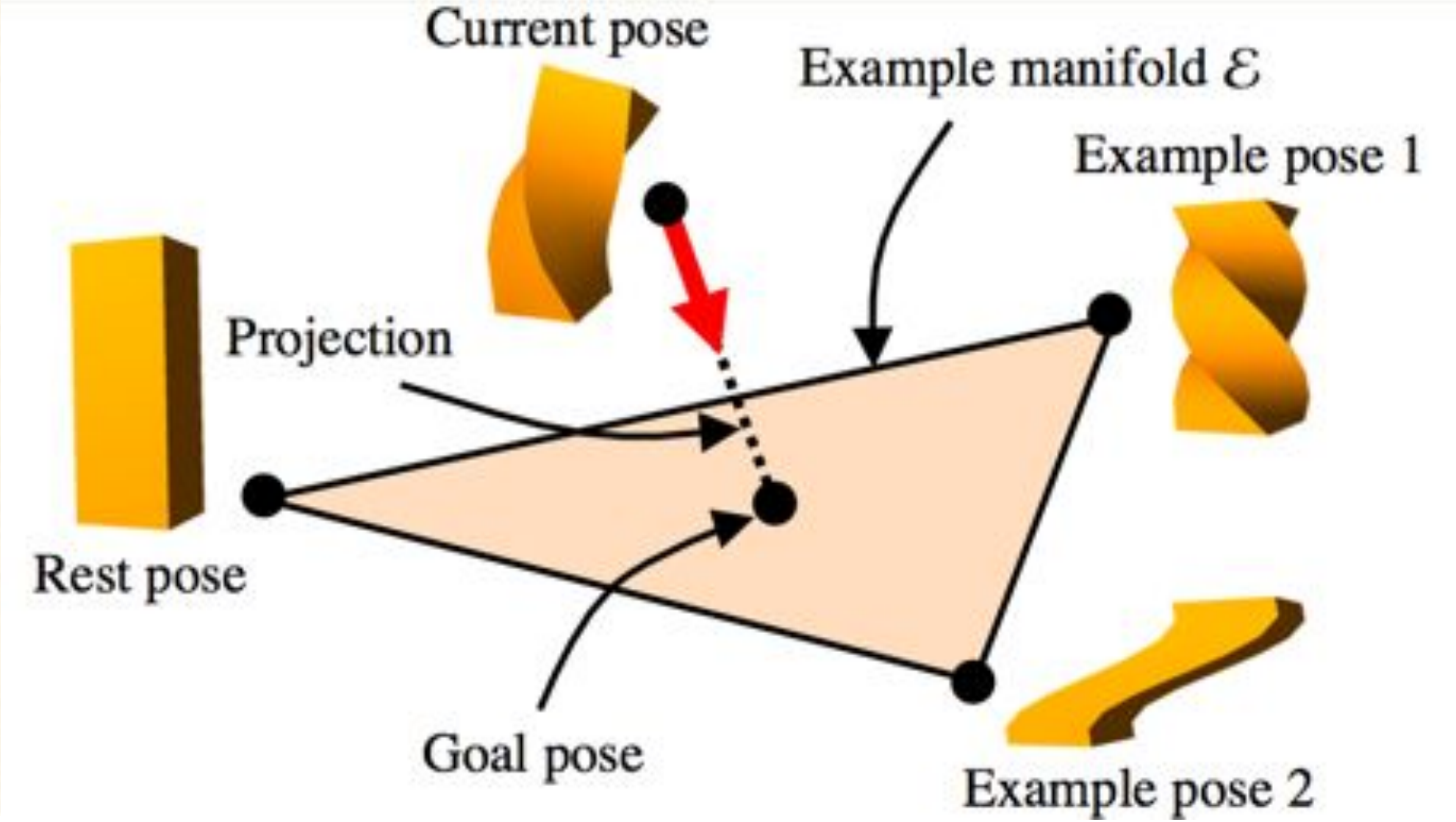
- New method for **example-based materials**
  - Based on **shape matching** technique
  - **Real-time, interactive**
  - **Decreased physical accuracy**





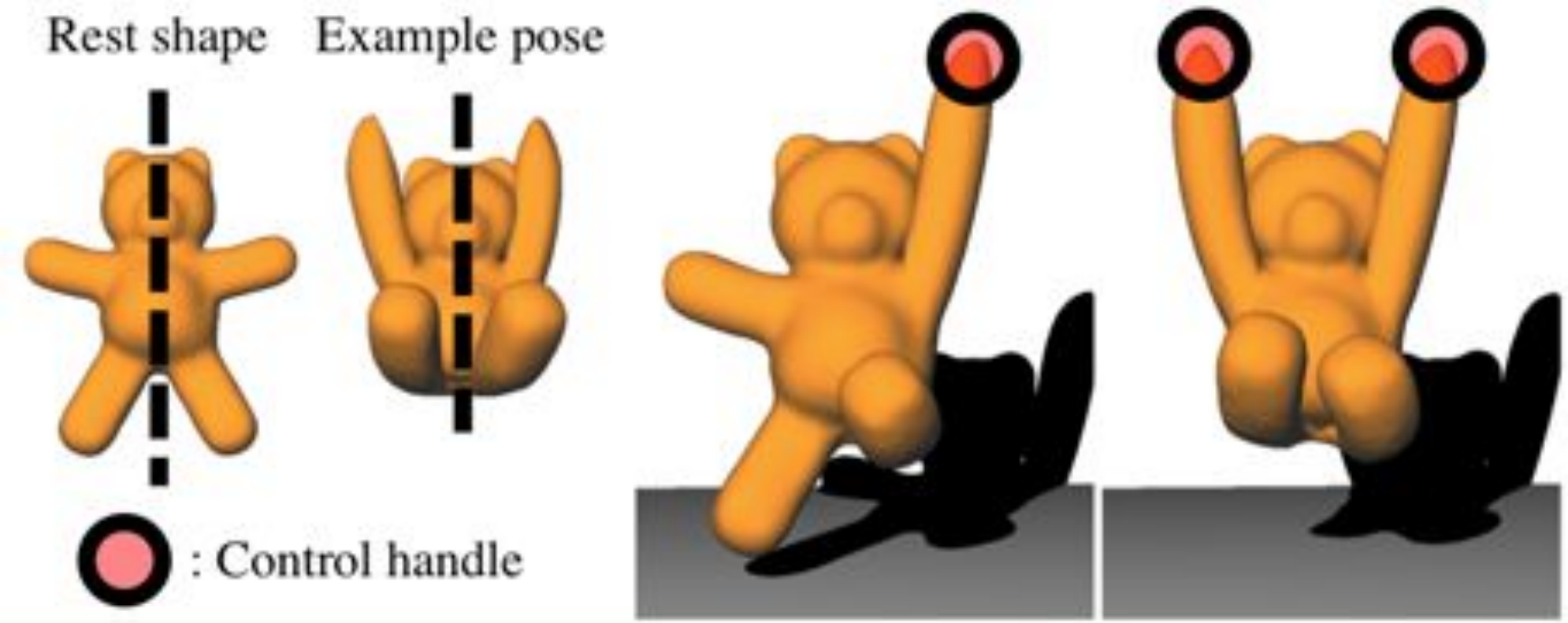


Case of two examples (manifold should be a plane)

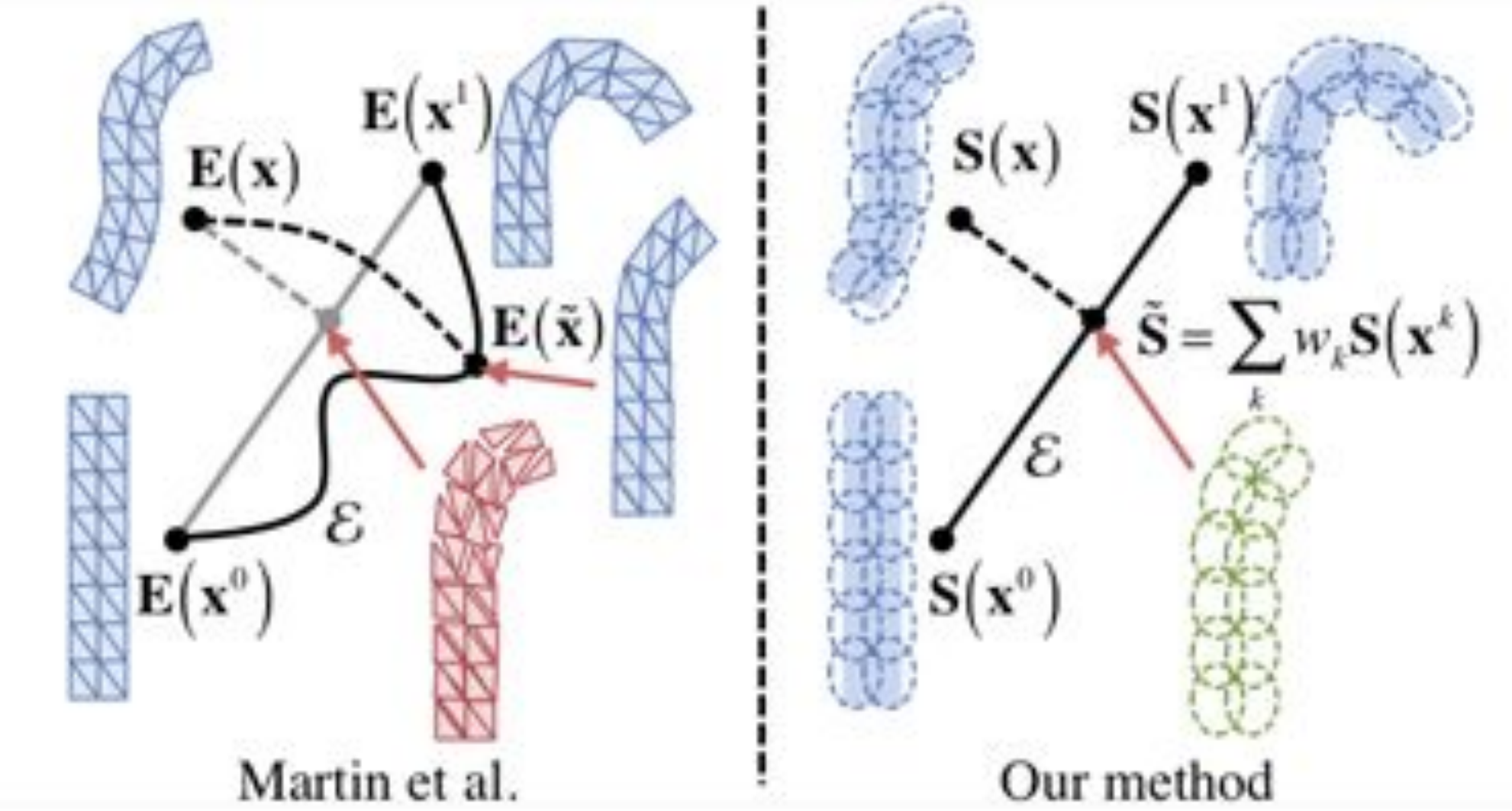


Local Examples

- Separate groups
- Manipulated independently

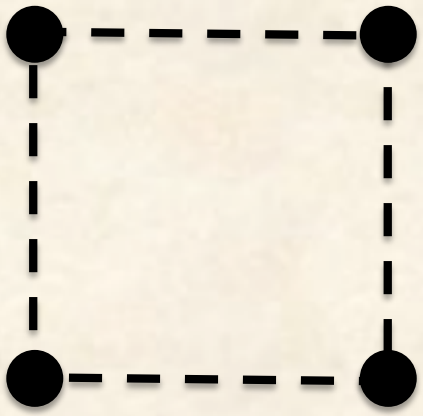


Comparison


$\mathbf{E}(\mathbf{x}^1)$
$\mathbf{E}(\mathbf{x})$
$\mathbf{E}(\tilde{\mathbf{x}})$
$\mathcal{E}$
$\mathbf{E}(\mathbf{x}^0)$
Martin et al.
$\mathbf{S}(\mathbf{x}^1)$
$\mathbf{S}(\mathbf{x})$
$\tilde{\mathbf{S}} = \sum_k w_k \mathbf{S}(\mathbf{x}^k)$
$\mathcal{E}$
$\mathbf{S}(\mathbf{x}^0)$
Our method

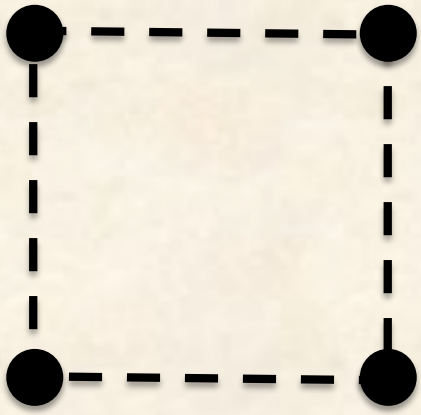
Shape Matching

Model = **A set of particles**



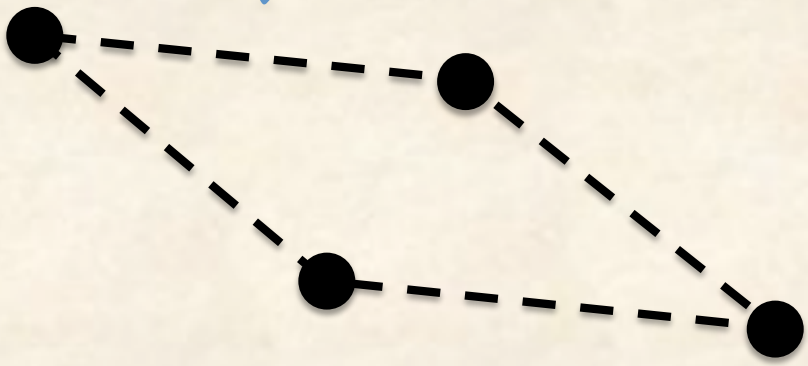
Rest configuration

Shape Matching

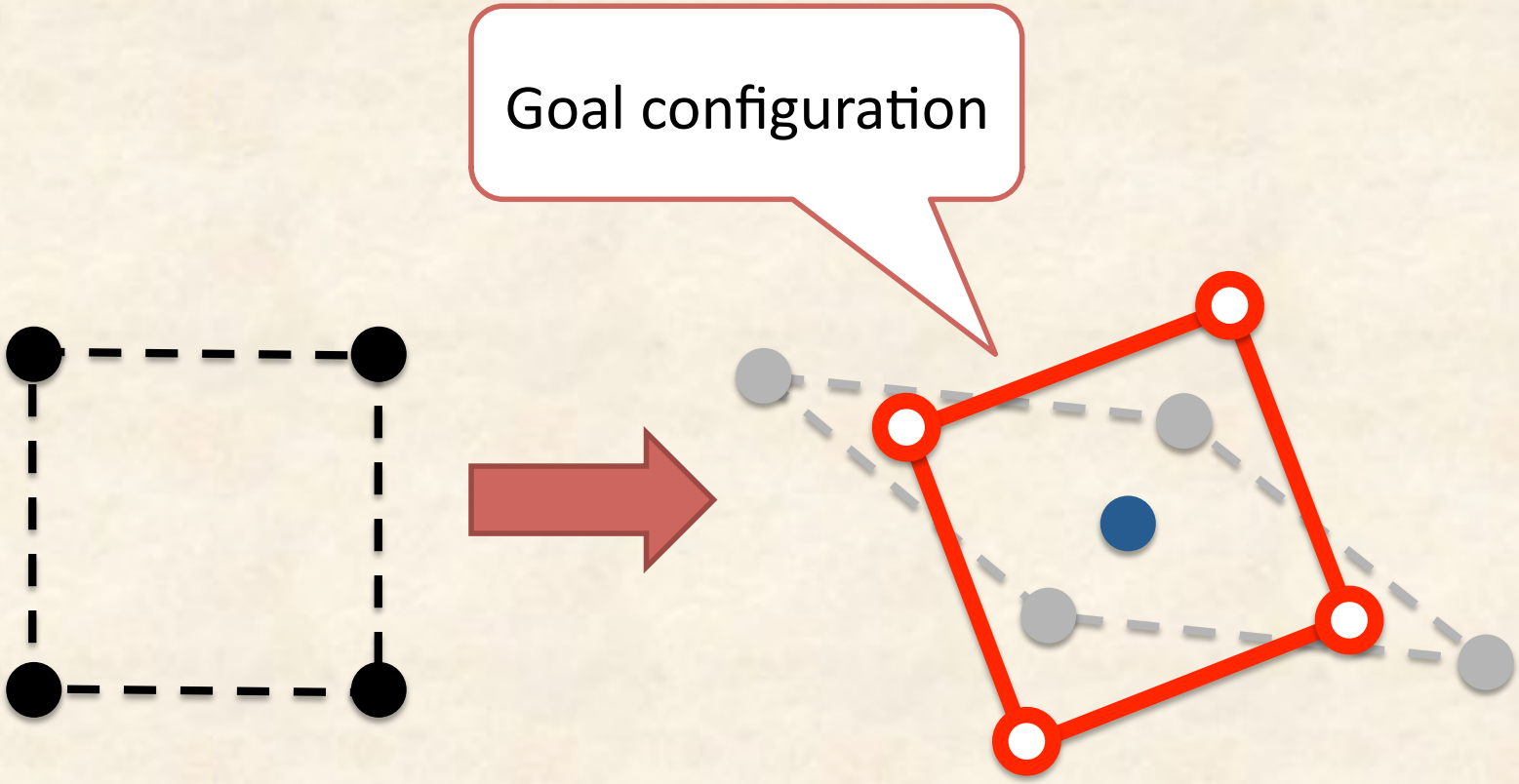


Rest configuration

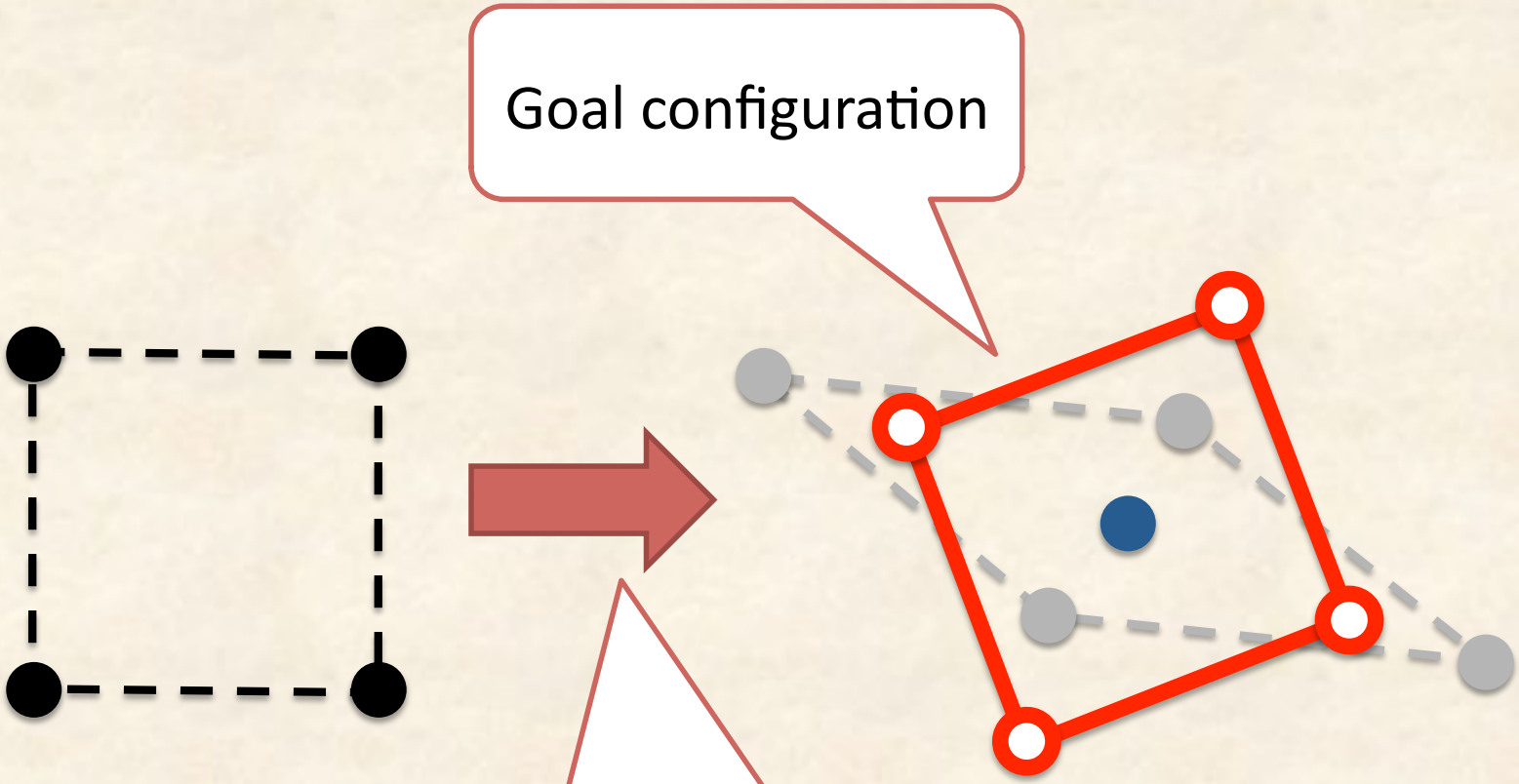
Current configuration



Shape Matching

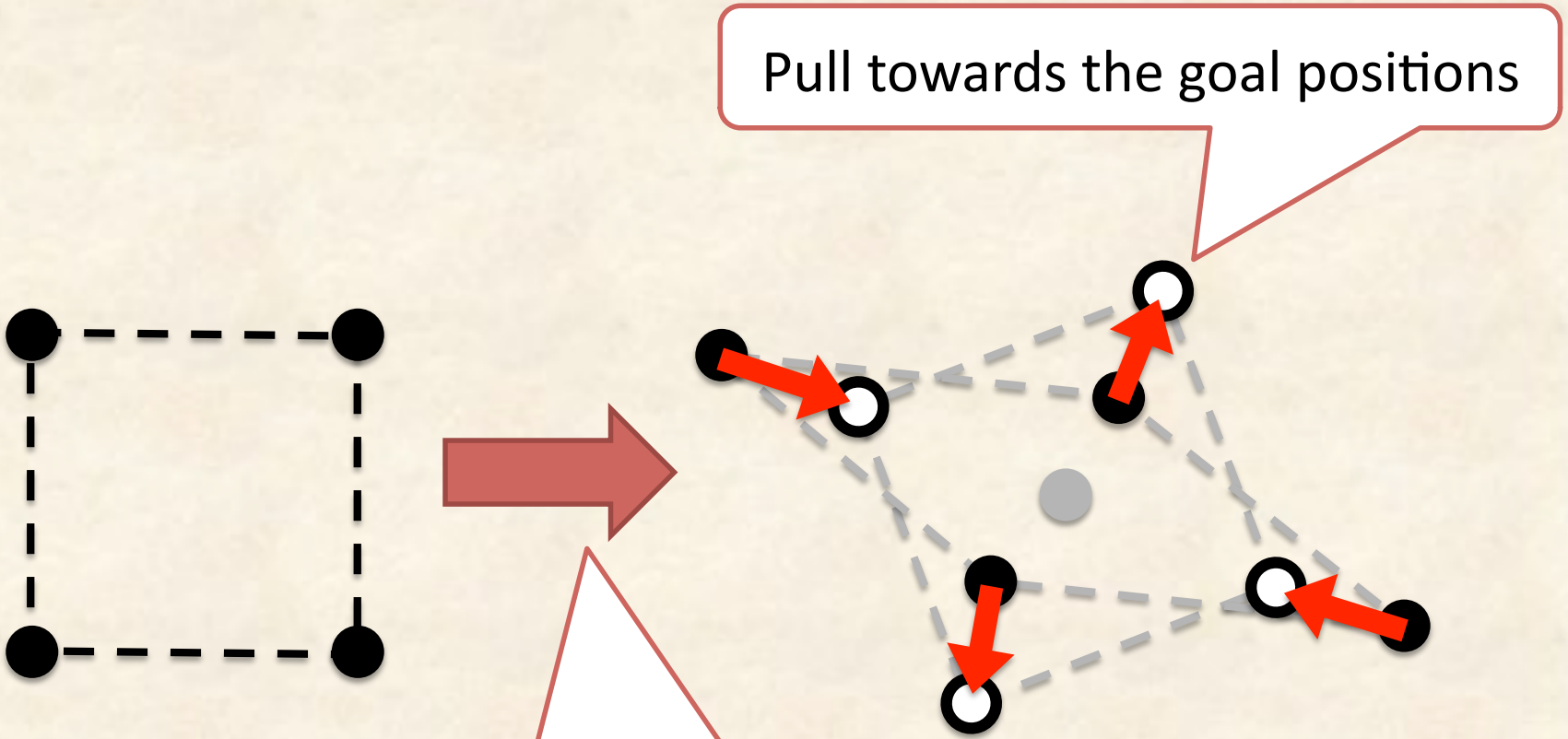


Shape Matching



Rigid transformation
(Translation + Rotation)

Shape Matching



Rigid transformation
(Translation + Rotation)