Example-based Dynamic Modeling

Zhang wenjing

School of Computer Engineering

Supervisor:

Prof. Zheng Jianmin

Co-Supervisor:

Prof. Nadia magnenat Thalmann

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Outline

- Background & Related work
  - Purely geometrical modeling
  - Physically based modeling
- Our method
- Future work

Our goal

user
desired
deformation
efficient
Good
deformation
physical
realism
dynamic

Background

- Traditional method use general numerical criteria

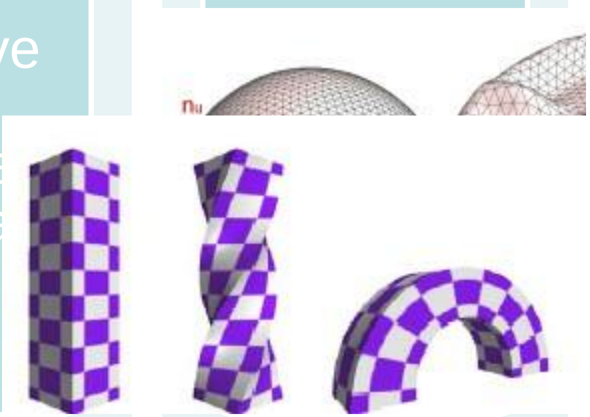
Laplace mesh editing

[sorkine,2004]

Preserve the Laplacia coordina

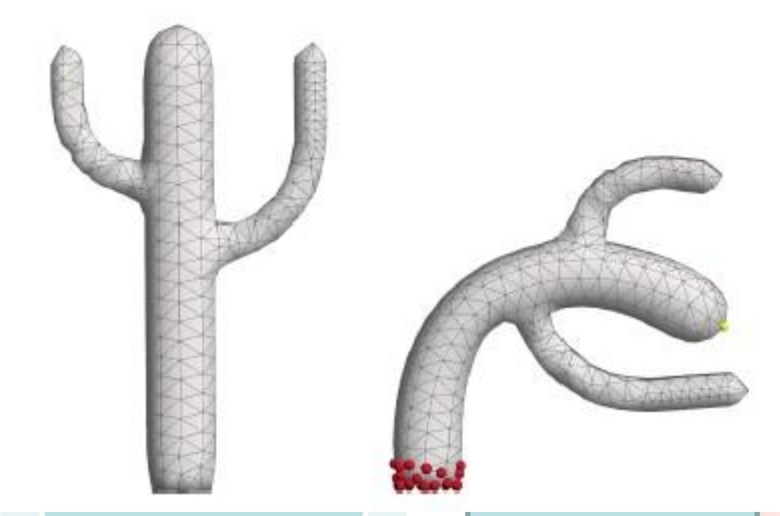
As rigid as possible deformation

[Sorkine, 2007]



Poisson based modeling

[Yu, 2004]



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Background

- Example –based deformation

Mesh-based inverse kinematic

[summer,2005]

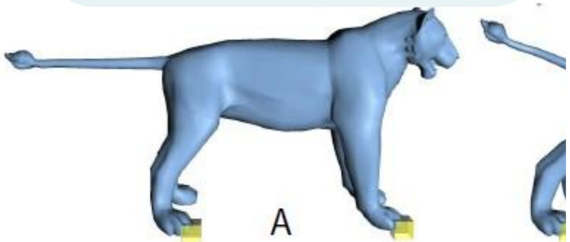
Search the optimal deformation in the example space

Example-based facial rigging

[Li, 2010]

Use examples as training data

Intuitive and efficient



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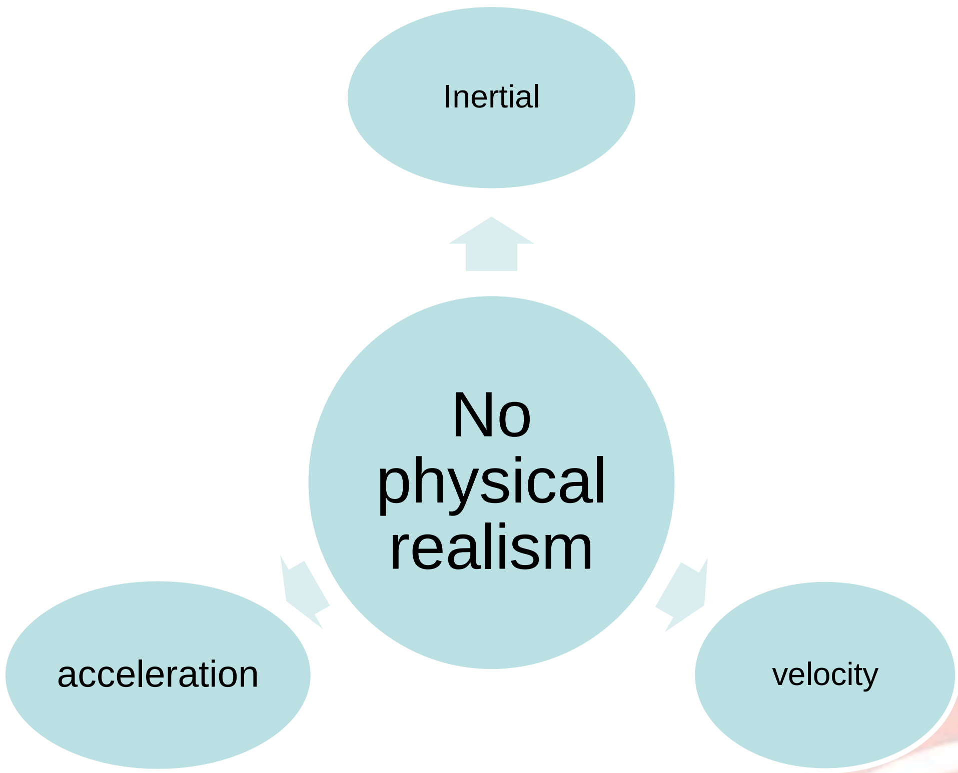
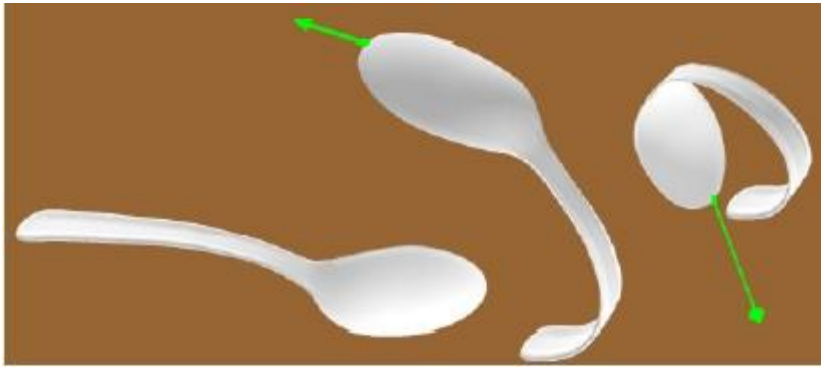
Background

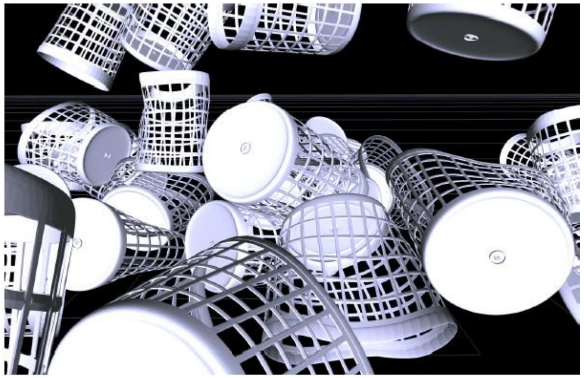
All these are purely geometrical



Physically based modeling

- Use physical mechanics law to guide the deformation
  - Realistic
  - Natural choice for dynamic modeling





Physically based modeling

- Equations of motion [**Euler, Lagrange]**

$$\mathbf{M}\ddot{\mathbf{x}}(t)+\mathbf{R}(\mathbf{x}(t))=\mathbf{f}(t)$$

- *x* = position of vertices

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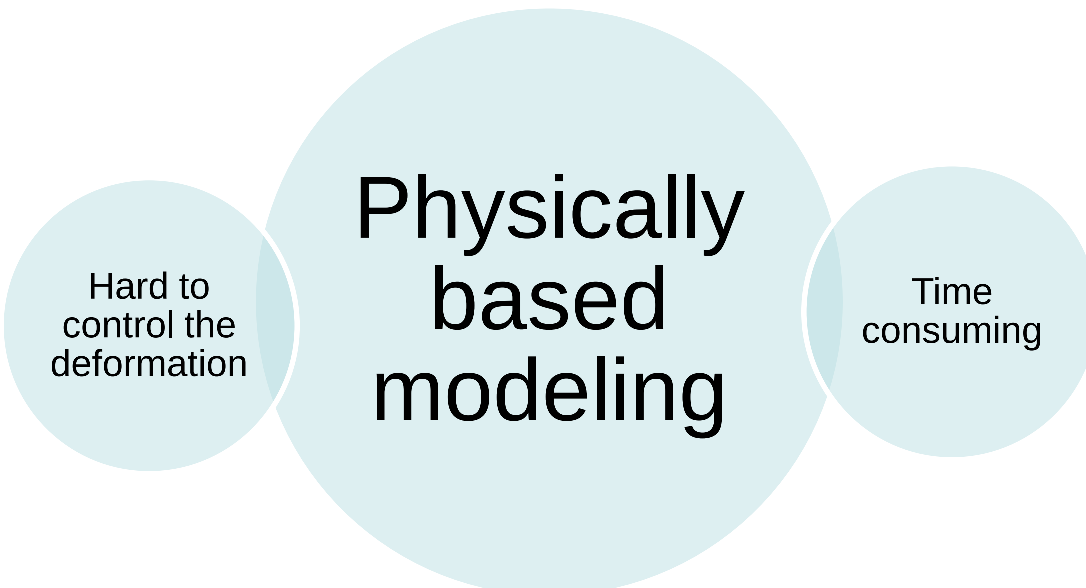
Problems with physically based modeling



Time consuming

$$\mathbf{M}\ddot{\mathbf{x}}(t) + \mathbf{R}(\mathbf{x}(t)) = \mathbf{f}(t)$$

- High-dimensional of the ODEs
  - x is of dimension 3n (n is number of vertices)
- Not real-time for large models
  - around1K DOFs at most for real-time

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Hard to control the deformation

Material parameters → Deformation result

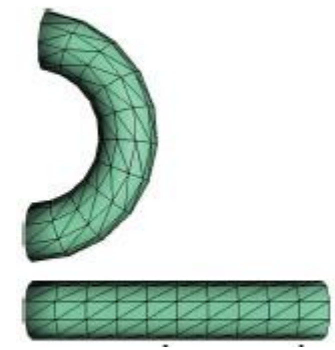
Tedious to tune

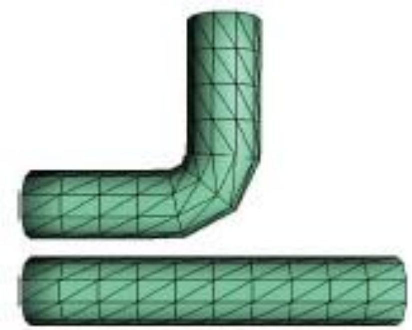
Non-intuitive relationship

User desired deformation

Numerical problem

Contradiction with physical law





Combination

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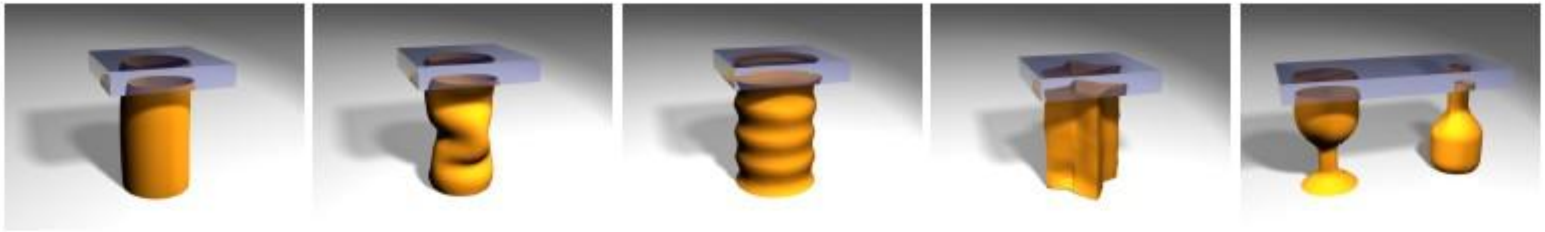
Related work

- Example-based Elastic Material[Sebastian Martin, 2011]
  1. At every time step, projecting the pose onto the example space
  2. use the projection as a rest post to generated additional force
  3. Add the additional force as external force
- First try to combine example based and physically based modeling
- Drawback

  --time consuming



Sebastian M., et al. 2011. Example-Based Elastic Materials. In Proc. of ACM SIGGRAPH’11, 72:1-72:8.

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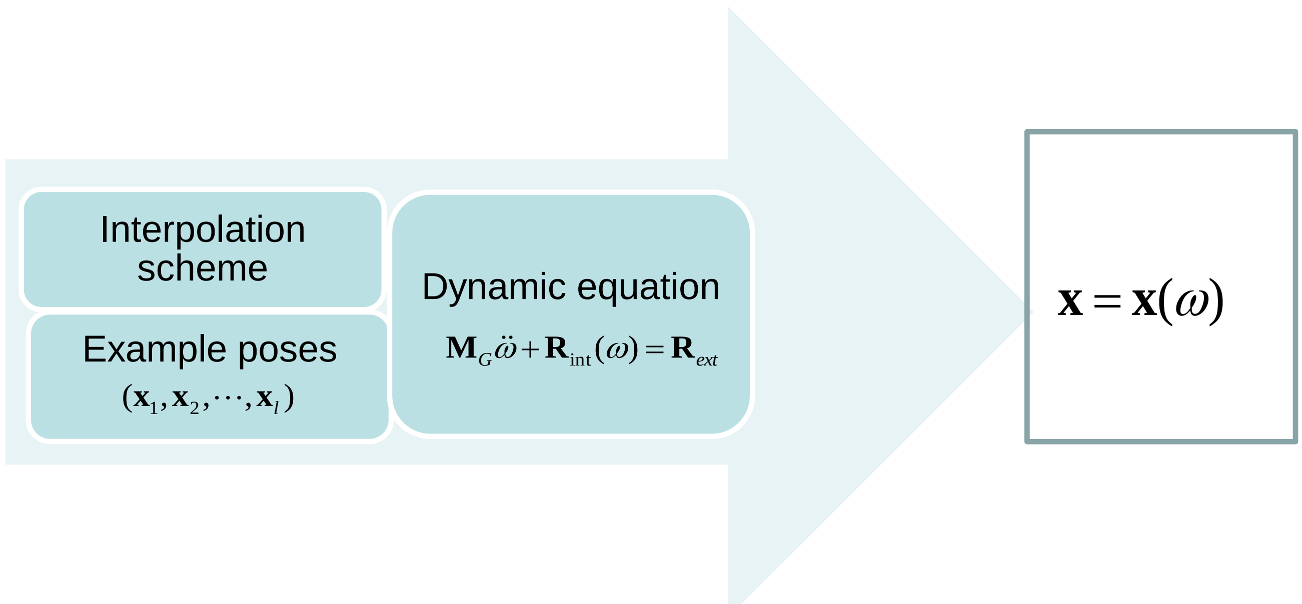
Our method

- Build an example space
- Build the dynamic equation in the example space



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Our method

- Given a based tetrahedron mesh $\mathbf{x}_0$ and l example poses $\mathbf{x}_1, \mathbf{x}_2 \cdots, \mathbf{x}_l$.

$\mathbf{x}_0$ $\mathbf{x}_1$ $\mathbf{x}_2$ $\mathbf{x}_3$ $\mathbf{x}_4$

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Our Method

- We first convert the example pose into feature vector:

$$\hat{\mathbf{x}}_i = \tau(\mathbf{x}_i)$$

- A lot of kinds of feature vector can be used

- We use the feature vector proposed in MeshIk
  - the polar decomposition of the deformation gradient
  - It well preserve the meaningful information in mesh
  - The computation of its derivative is easy

Our Method

- Then we build an example space by linearly interpolating these feature vectors:

$$\{\mathbf{x}, \mathbf{w}\} : \mathbf{x}(\mathbf{w}) = \tau^{-1}\left(\sum_i w_i \hat{\mathbf{x}}_i\right)$$

- $\mathbf{w}$ is the interpolation weight, which acts as coordinates in example space

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Our method

- Build the motion equation using the interpolation weight:

$$\mathbf{M}_G \ddot{\mathbf{w}} + \mathbf{R}_{\text{int}}(\mathbf{w}) = \mathbf{R}_{ext}$$

- $\mathbf{M}_G$ ~ generalized mass matrix

- $\mathbf{R}_{\text{int}}$ ~ generalized internal force

- $\mathbf{R}_{ext}$ ~ generalized external force
- ODE dimension is the number of examples (typically small, around 10)

Our method

- For some application , extrapolation is poor:
- Add constraint to the generalized coordinate.
- E.g. one typical constraint is:

$$\begin{cases} w_i \leq 1 \\ w_i \geq 0 \\ \sum_i w_i \leq 1 \end{cases}$$

Time complexity

$$\mathbf{M}_G \ddot{\omega} + \mathbf{R}_{\text{int}}(\omega) = \mathbf{R}_{ext}$$

- $\mathbf{M}_G$ ~ constant
- $\mathbf{R}_{\text{int}}$ ~ $O(l^3)$
- $\mathbf{R}_{ext}$ ~ $O(nl)$

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Fairness evaluation

Good Deformation			
User desired deformation	Physical realism	Dynamic	Efficiency
Interpolation of examples	based on continuum mechanics	Motion equation	Low dimension of the ODE

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Preliminary result

- CPU time

Demo 1

Demo 2

~3K vertex	~20fps
~6K tetrahedron	
4 examples	

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Future work

- Collision detection and response
  - easy for original system on vertices
  - however, nontrivial for generalized coordinates

    -- especially for nonlinear interpolation

- Extension to surface mesh
  - Designer work on surface mesh more often
  - Conversion from surface mesh to tetrahedron mesh is hard

- GPU implementation

Thank you !