Novel metaballs-driven approach with dynamic constraints for character articulation

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Overview

- Introduction
- Our Method
- Experiments
- Conclusion

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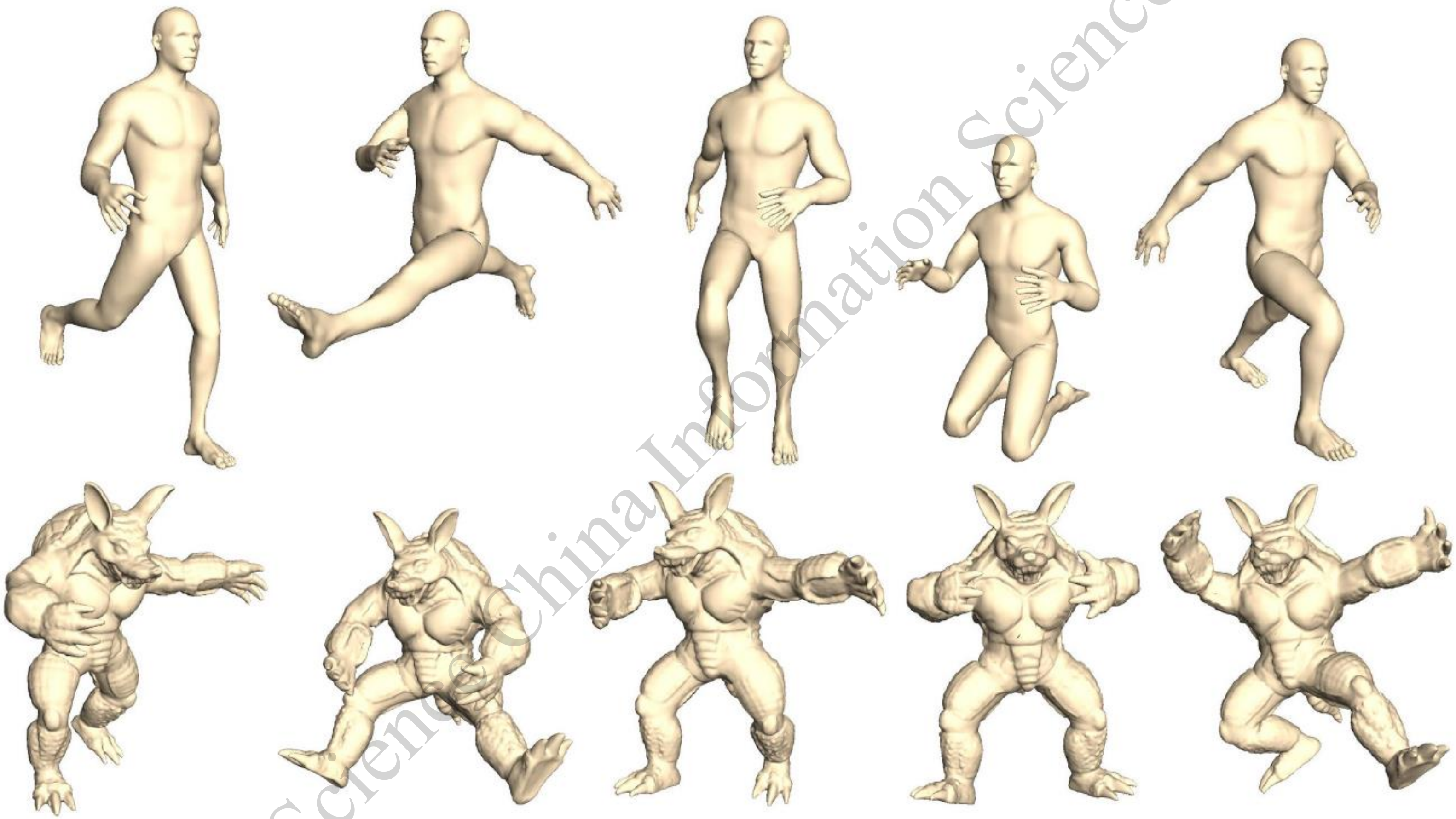
Motivation



Skinning techniques are essential for character articulation in 3D computer animation.

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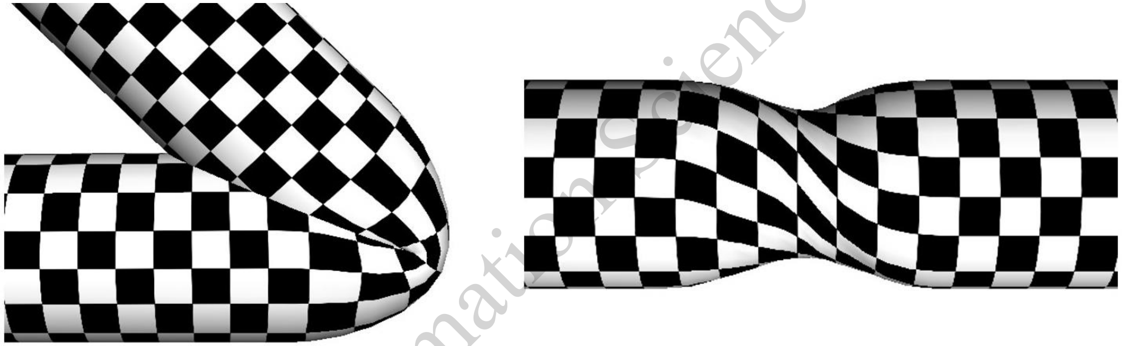
Problem

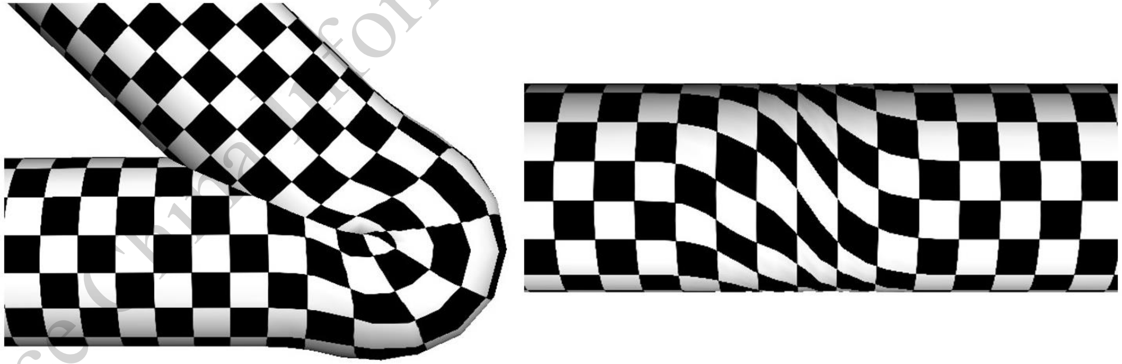
LBS

Magnenat-Thalmann et al [GI88]



DQS

Kavan et al [TOG08]



Skeleton-based methods are widely used in animation industry, especially LBS and DQS. However, due to the lack of the inside volumetric representation, they suffer from joint collapse, candy-wrapper effect and bulging problems.

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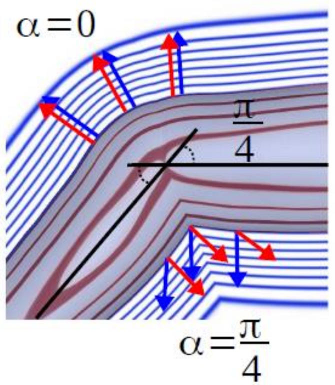
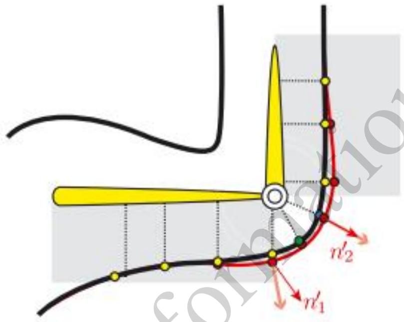
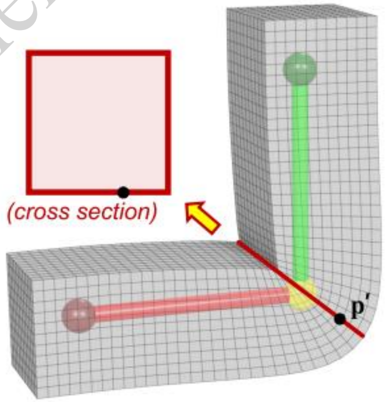
Related works



Vaillant et al [TOG13]
propose a field-based method and deform the character in multiple passes.



Kim et al [CAVW14]
propose a correction scheme to remove the bulging artifacts.



Le et al [TOG16]
reduce the artifacts by modifying the centers of rotations.

How to deform a character in real time while reducing the artifacts of traditional methods?
How to introduce enhanced animation effects, such as jiggling, muscle bulging?

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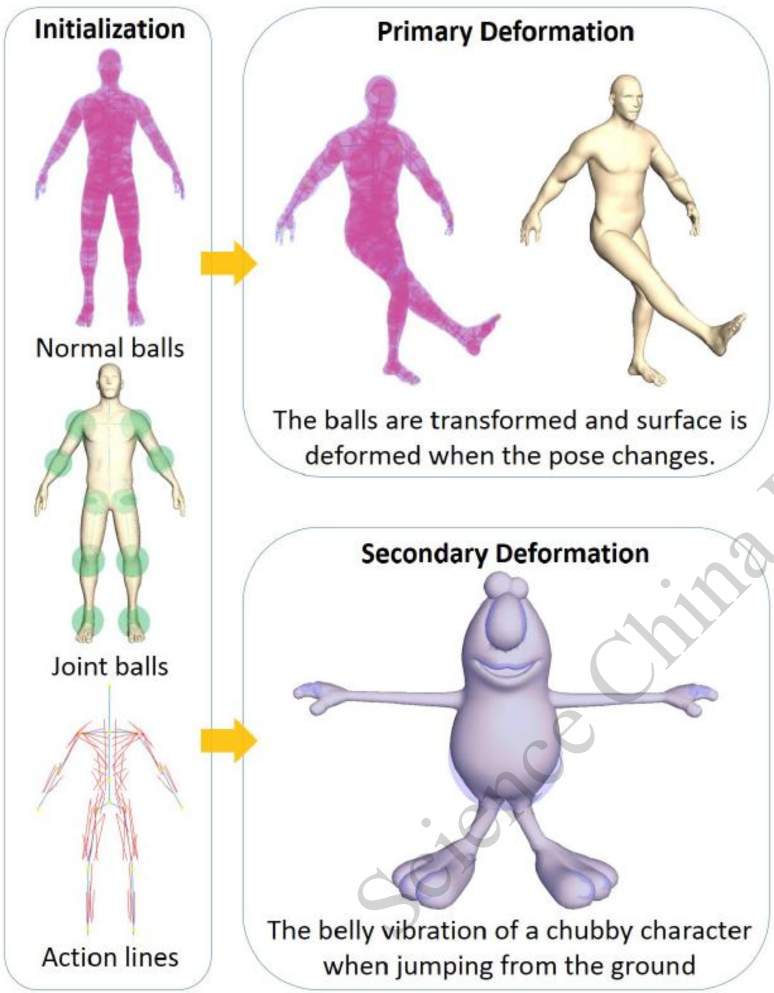
Framework



Our approach places volumetric objects under the surface and designs specific skinning method to represent the character.

We select metaballs as the volumetric objects. We introduce action lines into our model to represent simplified muscles and tendons.

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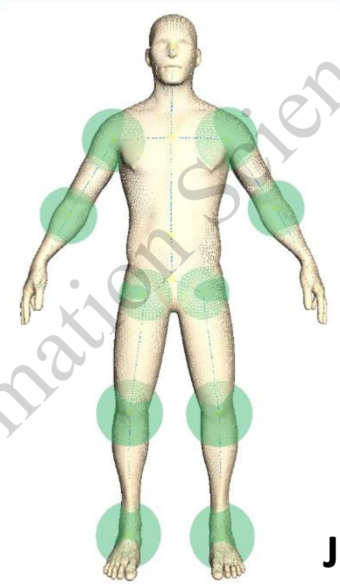
Primary deformation using metaballs

Normal balls



Joint balls

The mesh deformation are composed of two components: deformation by normal balls and deformation by joint balls. Normal balls are generated using sphere-tree construction toolkit (Bradshaw et al [TOG04]). The sizes and positions are modified using the method proposed by Pan et al [VC15]. The joint balls are created at the joints of the skeleton, and the radius is set manually.

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Primary deformation using metaballs

The final position of the vertex is formulated as:

$$\hat{\mathbf{v}}_i = (1 - w_i^{\alpha})\,\underbrace{\mathbf{v}_i^{\lambda}}_{\text{normal ball}} + w_i^{\alpha}\underbrace{\mathbf{v}_i^{\eta}}_{\text{joint ball}}$$

Our skinning method is divided into 3 steps:

(1) Update the skeleton and the metaballs.

(2) Refine the positions of balls under position-based dyanmics (PBD).

(3) Generate the mesh according to the balls.

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Primary deformation using metaballs

Our algorithm is summarized as:

Algorithm 1 Primary Deformation of Our Metaballs Model

```
Update the positions and orientations of the skeleton and action lines.
for all balls do
    Calculate the position using LBS.
    Rotate the individual coordinate.
    (Optional) Compute size for muscle bulging effect.
end for
for all constraints do
    Solve constraints under PBD.
    Refine balls positions.
end for
for all vertices do
    Deform by normal balls.
    Deform by joint balls.
    Blend deformation results.
    Handle surface overlapping.
end for
```

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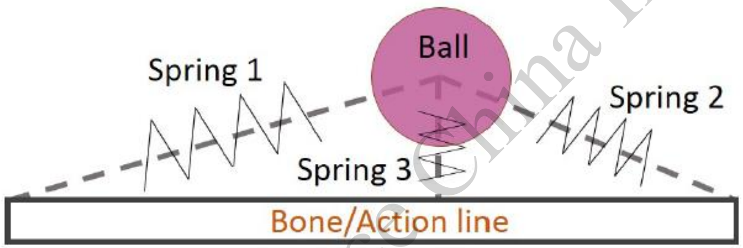
Deformation by normal balls

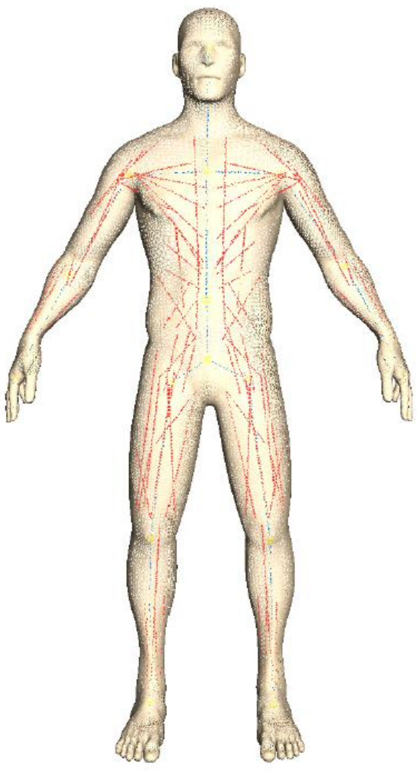
Each ball is transformed by the near bone with a weight:

$$w_{ij}^{\beta} = \left(\frac{1}{d_{ij}^{\beta}}\right)^{k}$$

$$d_{ij}^{\beta} = dist_M\left(\mathbf{c}_i^{\lambda}, B_j\right)$$

Springs are set up to constrain the motion of balls.





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Deformation by normal balls

Mesh vertices are deformed depending on the balls. The position of deformed vertex is a weighted blending of the balls' transformation.

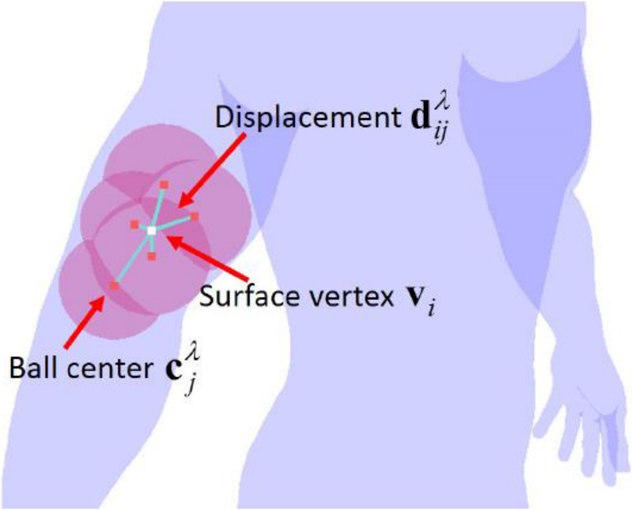
$$w_{ij}^{\gamma} = \left(\frac{1}{d_{ij}^{\gamma}}\right)^{k}$$

$$\begin{aligned} d_{ij}^{\gamma} &= dist_S\left(\mathbf{v}_i, \mathbf{c}_j^{\lambda}\right) \\ &= dist_E\left(\mathbf{v}_i, \mathbf{c}_j^{\lambda}\right) - r_j^{\lambda} \end{aligned}$$

At each frame, the translations and rotations of balls are first computed.

$$\hat{\mathbf{c}}_i^{\lambda} = \sum_{j=1}^{m} w_{ij}^{\beta} \mathbf{T}_j \mathbf{c}_i^{\lambda}$$

The rotation for each ball is handled using spherical linear interpolation (Slerp).



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Deformation by normal balls

The positions of normal balls are refined through the elasticity of springs using PBD. The constraint function is written as:

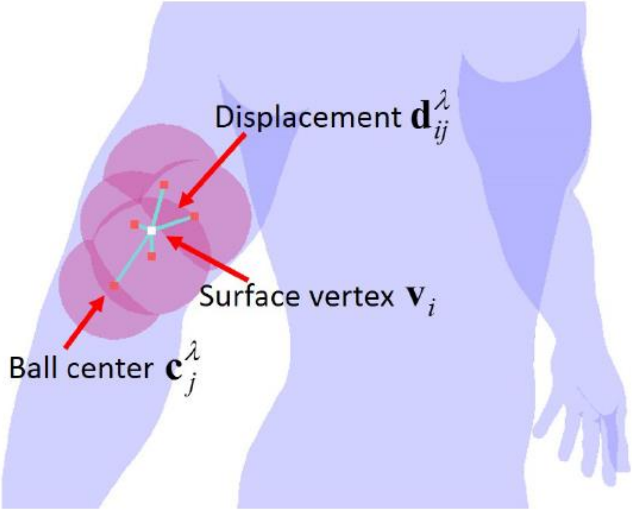
$$C_{stretch}(\hat{\mathbf{c}}_i^\lambda, \hat{\mathbf{c}}_j^\lambda) = \left|\hat{\mathbf{c}}_i^\lambda - \hat{\mathbf{c}}_j^\lambda\right| - d$$

Our skinning method is based on a rotation invariant displacements representation. At beginning, we store the initial displacement for each vertex:

$$\mathbf{d}_{ij}^\lambda = \mathbf{v}_i - \mathbf{c}_j^\lambda$$

After the transformations of balls are computed, the vertex position is computed:

$$\mathbf{v}_i^\lambda = \sum_{j=1}^{n} w_{ij}^\gamma \left(\hat{\mathbf{c}}_j^\lambda + \hat{\mathbf{R}}_j^\lambda \mathbf{d}_{ij}^\lambda\right)$$



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Deformation by joint balls

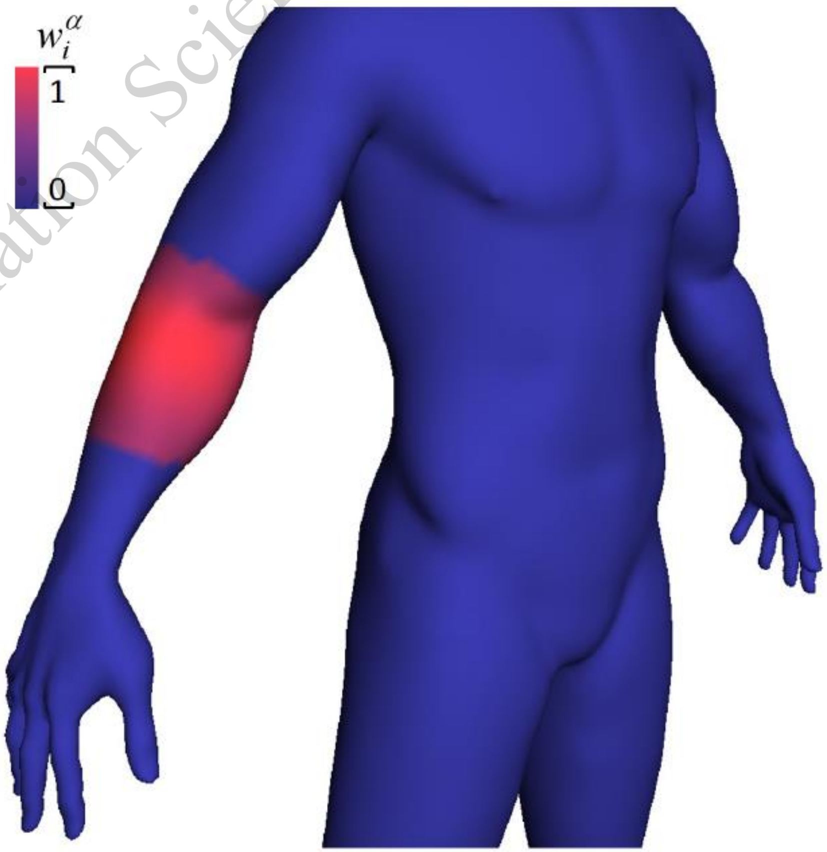
We bring additional joint balls into our metaballs model to add more transitions around the joints. We manually define the size of joint ball. If a vertex is in the range of the joint ball, the influence of the ball is computed using:

$$w_i^\alpha = \left(1 - \frac{d_{ij}^\alpha - r_j^\star}{r_j^\eta - r_j^\star}\right)^k$$

$$d_{ij}^\alpha = dist_E(\mathbf{v}_i, \mathbf{c}_j^\eta)$$

Mesh vertices attached to different bones have different transformations. So we segment the mesh and deform the vertices according to the bone with maximal influence.

$$\mathbf{v}_i^\eta = \hat{\mathbf{c}}_j^\eta + \hat{\mathbf{R}}_j^\eta \mathbf{d}_{ij}^\eta$$



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Blending process

The deformed positions are blended and combined into a new position.

$$\hat{\mathbf{v}}_i = (1 - w_i^{\alpha})\, \mathbf{v}_i^{\lambda} + w_i^{\alpha} \mathbf{v}_i^{\eta}$$

We apply Laplacian smoothing on the boundary of joint regions to improve the deformation quality. To recover the original shape around joints, we also employ a local Laplacian coordinates as a shape-preserving filter. At initialization, we compute the barycenter and the local displacement for each vertex:

$$\mathbf{p}_i^{\mu} = \sum_{j \in S(i)} \frac{1}{N} \mathbf{v}_j \qquad \mathbf{d}_i^{\mu} = \mathbf{v}_i - \mathbf{p}_i^{\mu}$$

A rotation matrix is computed at each frame using Slerp among the influential normal balls, and the final position of vertex is computed as:

$$\tilde{\mathbf{v}}_i = \hat{\mathbf{p}}_i^{\mu} + w_i^{\delta} \hat{\mathbf{R}}_i^{\mu} \mathbf{d}_i^{\mu} + (1 - w_i^{\delta}) \hat{\mathbf{d}}_i^{\mu}$$

$$\hat{\mathbf{p}}_i^{\mu} = \sum_{j \in S(i)} \frac{1}{N} \hat{\mathbf{v}}_j$$

$$\hat{\mathbf{d}}_i^{\mu} = \hat{\mathbf{v}}_i - \hat{\mathbf{p}}_i^{\mu}$$

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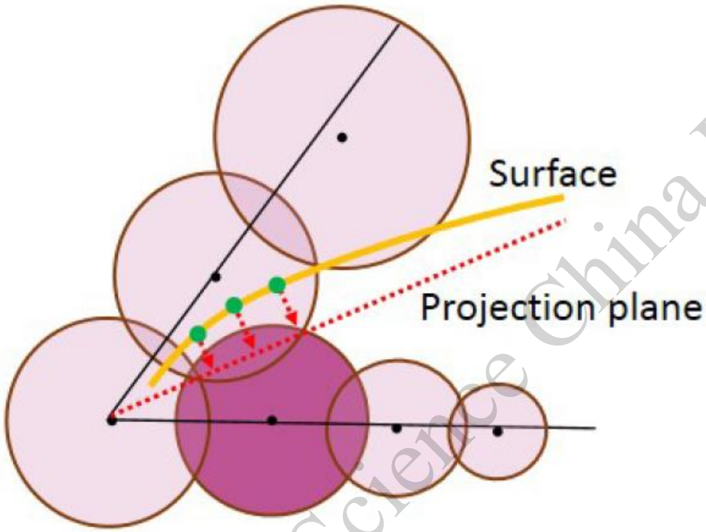
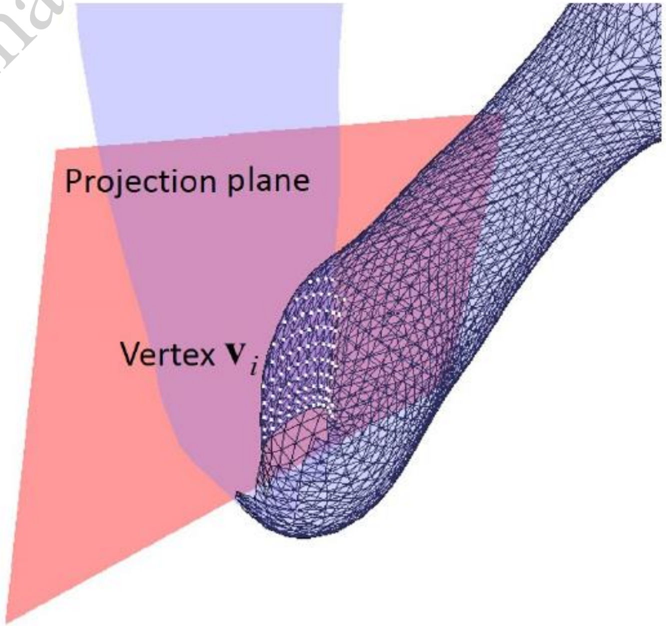
Surface overlapping

We use a hierarchical scheme to handle surface overlapping problem. Each ball is assigned to a bone, and balls on the same bone are combined into a ball set. At each frame, we employ these ball sets to detect collision, then we check if the vertices inside the colliding balls are located on the other bone. If the vertices are located in the range of these balls, they are projected to an interior plane orthogonally.





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Muscle bulging

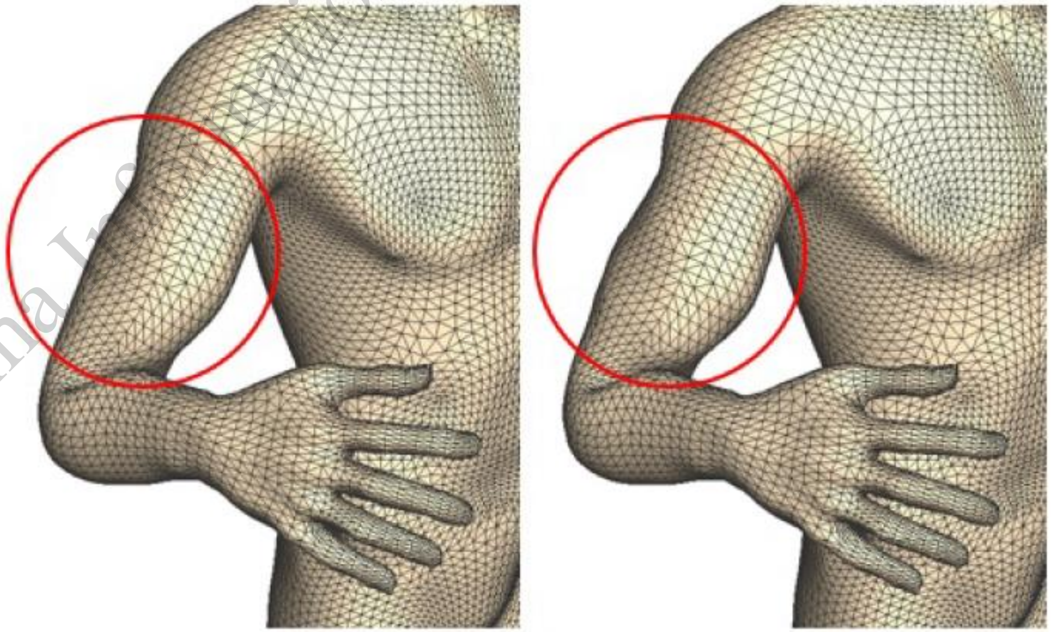
We define the bulging area and select the balls in the area. The size of the selected ball is changed according to the angle between the connected bones:

$$r_i^{\xi} = \left(1 + s \cdot \frac{\theta}{90^\circ}\right) \cdot r_i^{\lambda}$$

The vertex position is computed:

$$\mathbf{v}_i^{\lambda} = \sum_{j=1}^{n} w_{ij}^{\gamma} \hat{\mathbf{c}}_j^{\lambda} + s_i^{\xi} \sum_{j=1}^{n} w_{ij}^{\gamma} \hat{\mathbf{p}}_{ij}^{\lambda}$$

$$s_i^{\xi} = \frac{\sum_{j \in L(i)} r_j^{\xi}}{\sum_{j \in L(i)} r_j^{\lambda}}$$



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Secondary deformation

To achieve this effect, we create the jiggling regions and a time window before animation. Vertices and balls are selected in these regions. At each frame, balls outside the regions are modified when the pose of skeleton changes, then the balls inside the regions are modified through the elasticity of spring using PBD.

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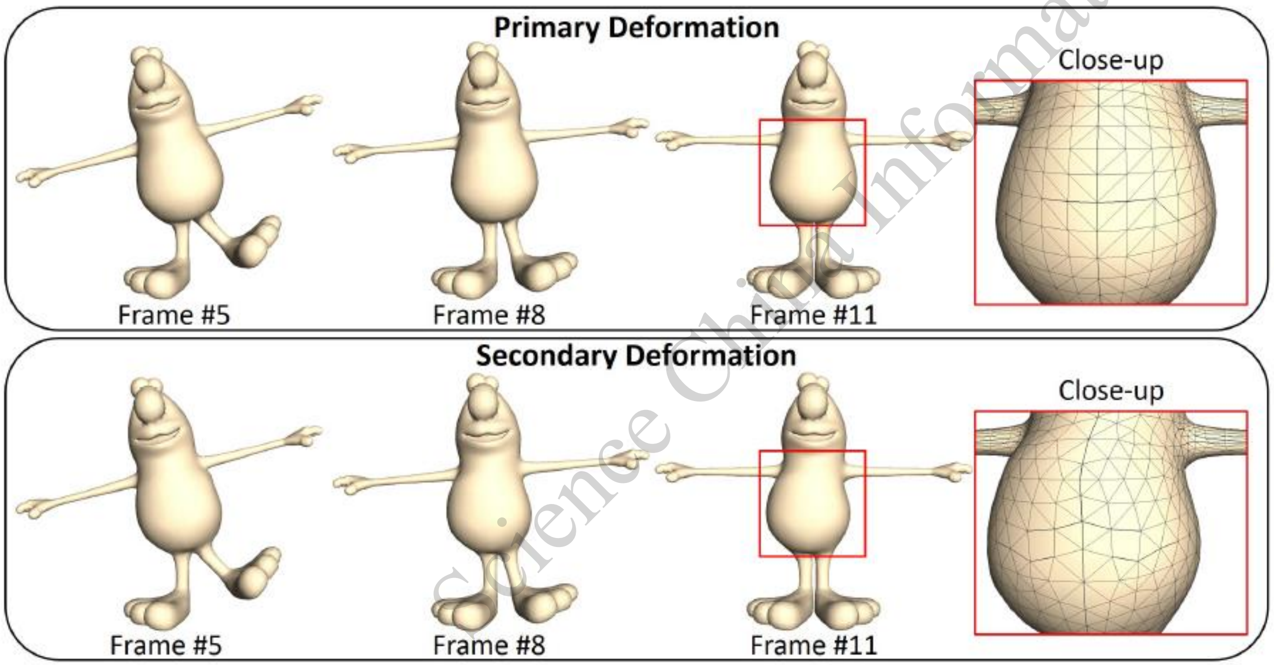

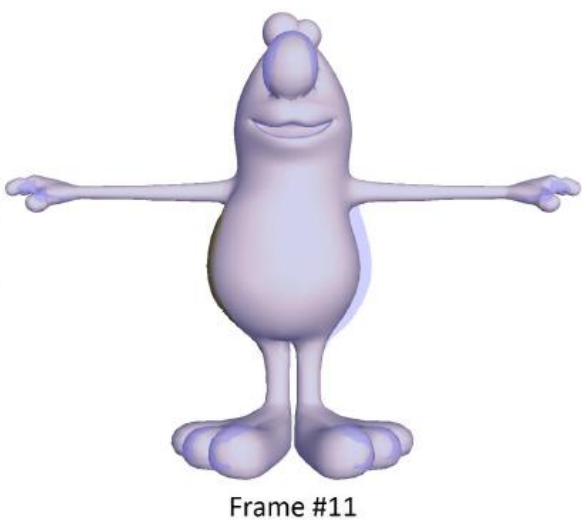

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Experiments

System: Intel(R) Core(TM) i5-6400 CPU (2.71 GHz), 8GB RAM, NVIDIA GeForce GT 720

Data size:

Model	**#V**	**#F**	**#B**	**#S**
Armadillo	34594	69184	564	2269
Chubby model	8620	17236	467	577
Human	24461	48918	512	2268

Time comparison (in millisecond):

Model	LBS	DQS	Our method
Armadillo	19.13	14.75	22.43
Chubby model	3.07	3.37	3.01
Human	6.71	8.08	11.87

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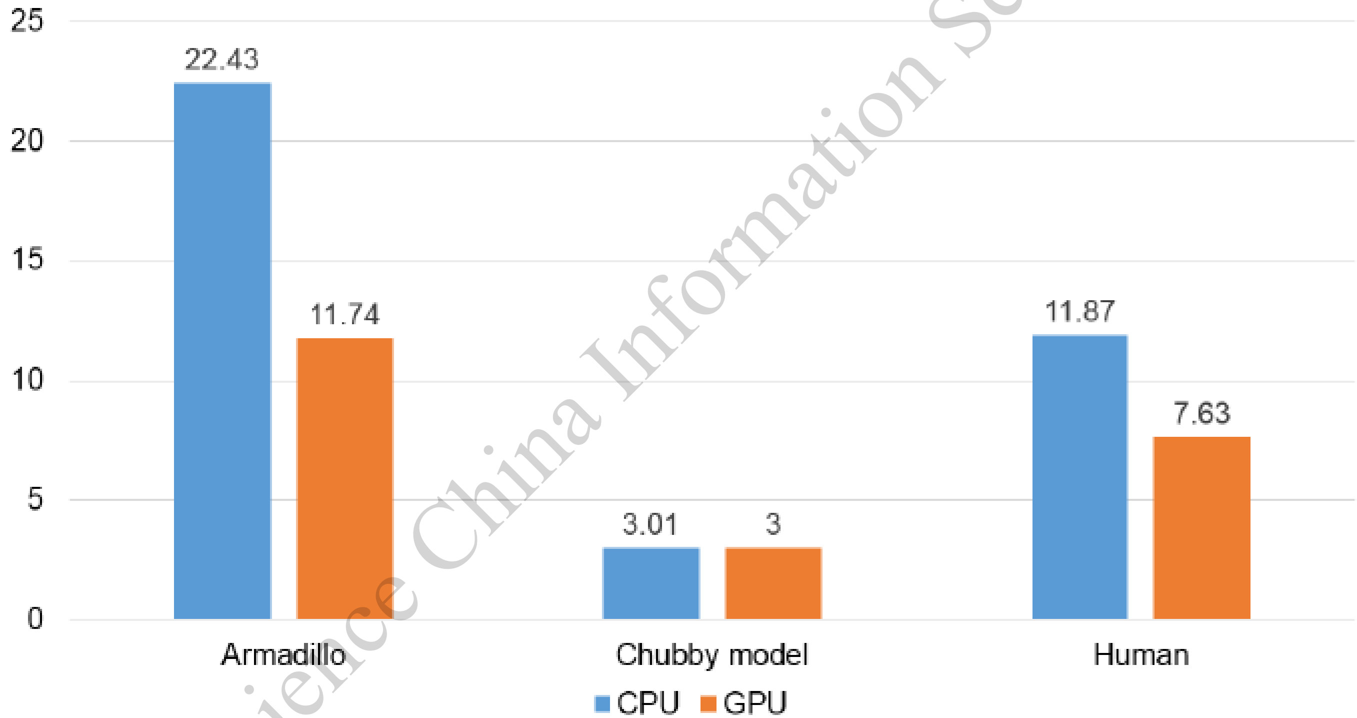
Note: some comparisons can be found in the demo video.

Experiments

GPU acceleration (in millisecond):



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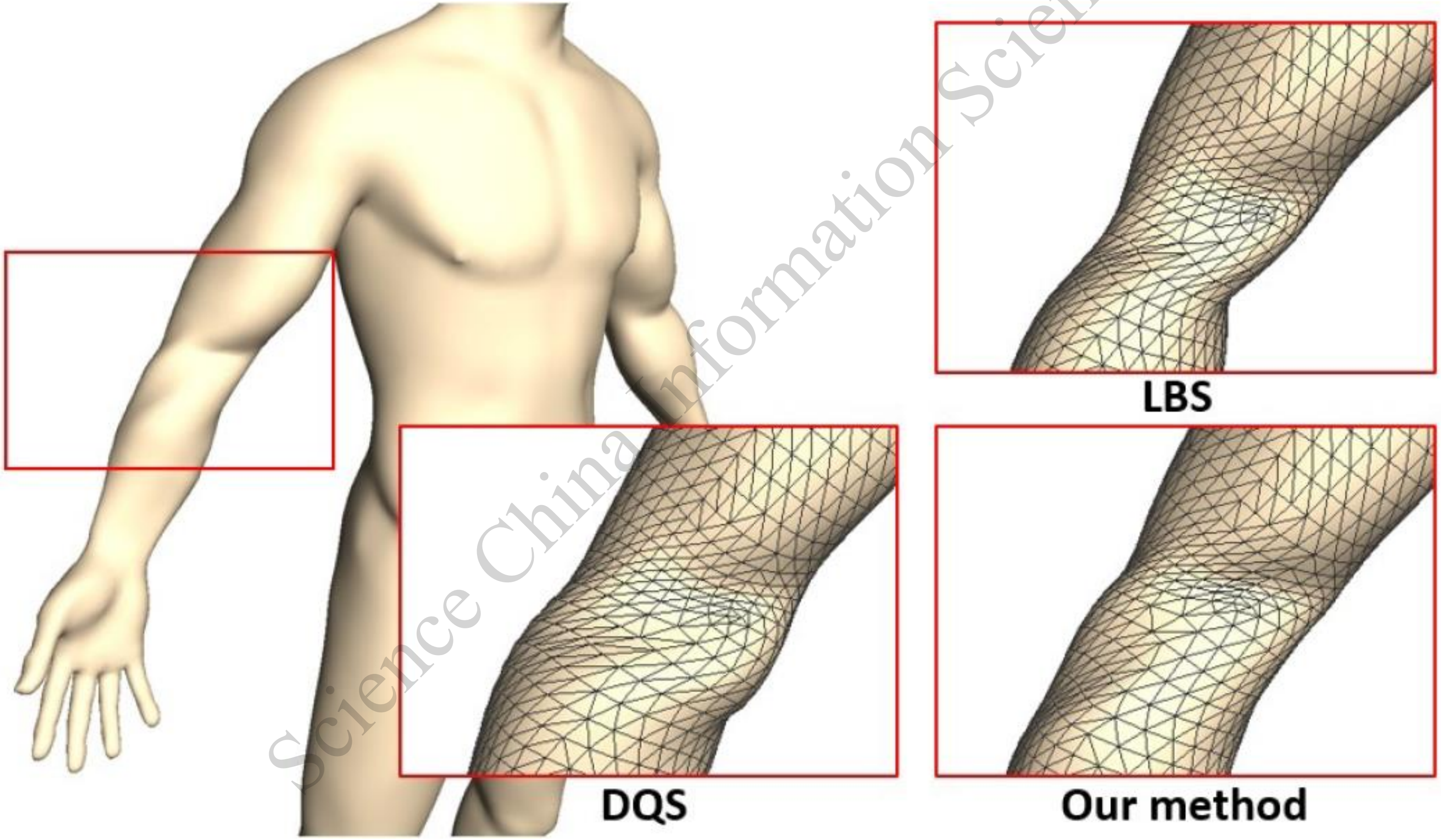
Experiments

Candy-wrapper effect:



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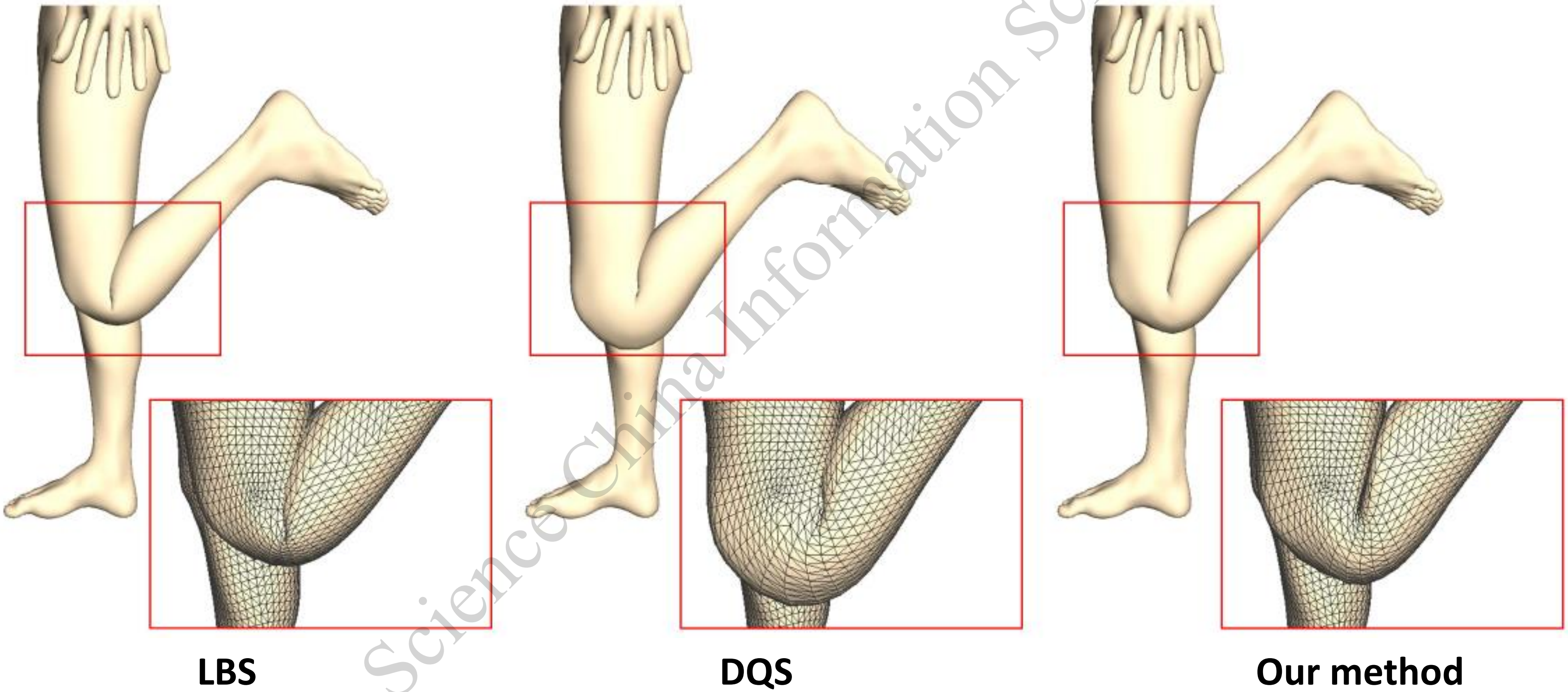
Experiments

Joint collapse & surface overlapping:



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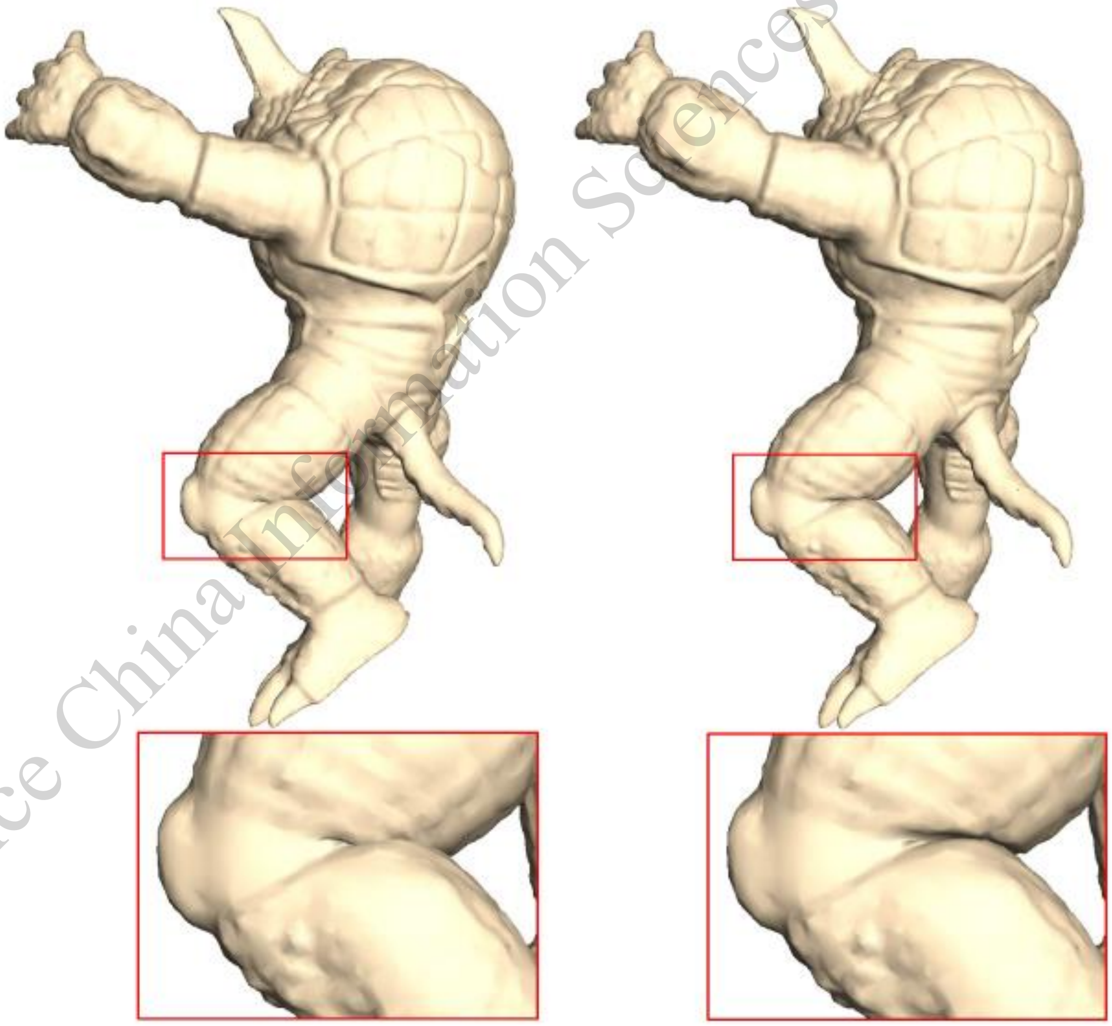
Surface overlapping:



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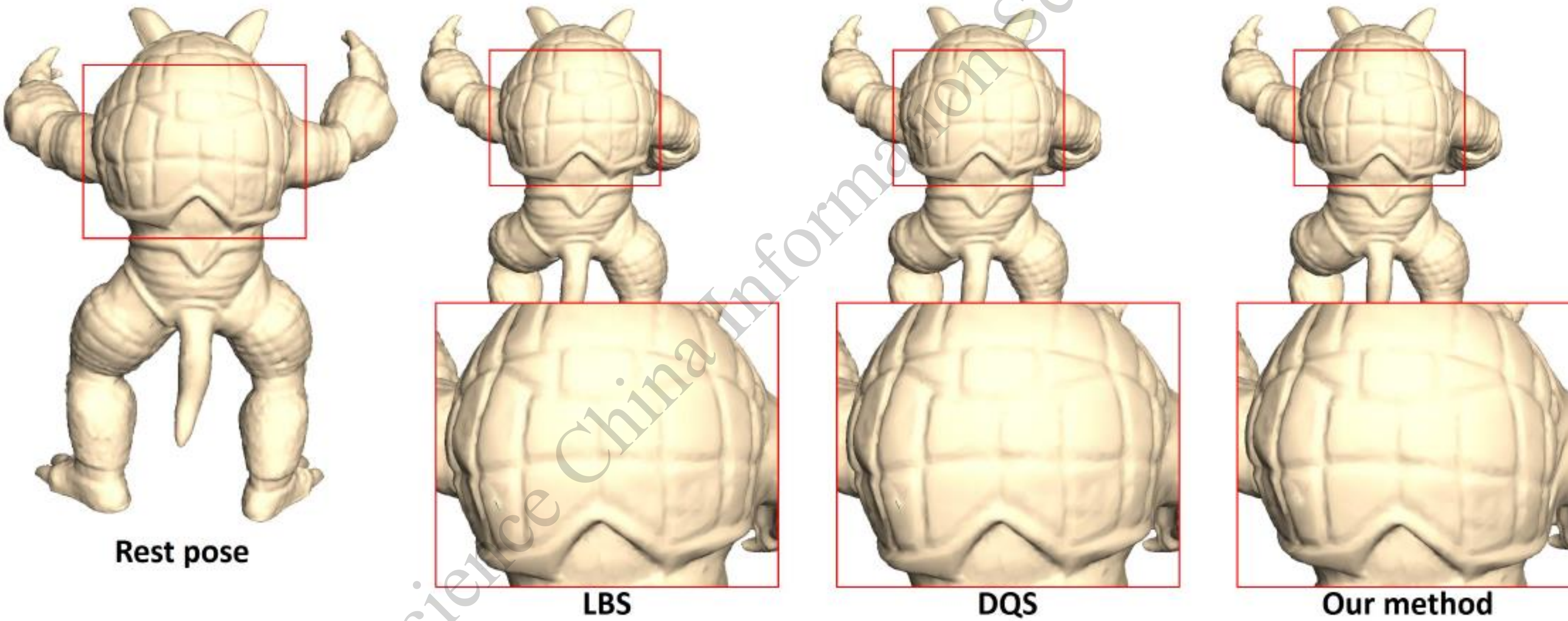
Experiments

Rigidity:



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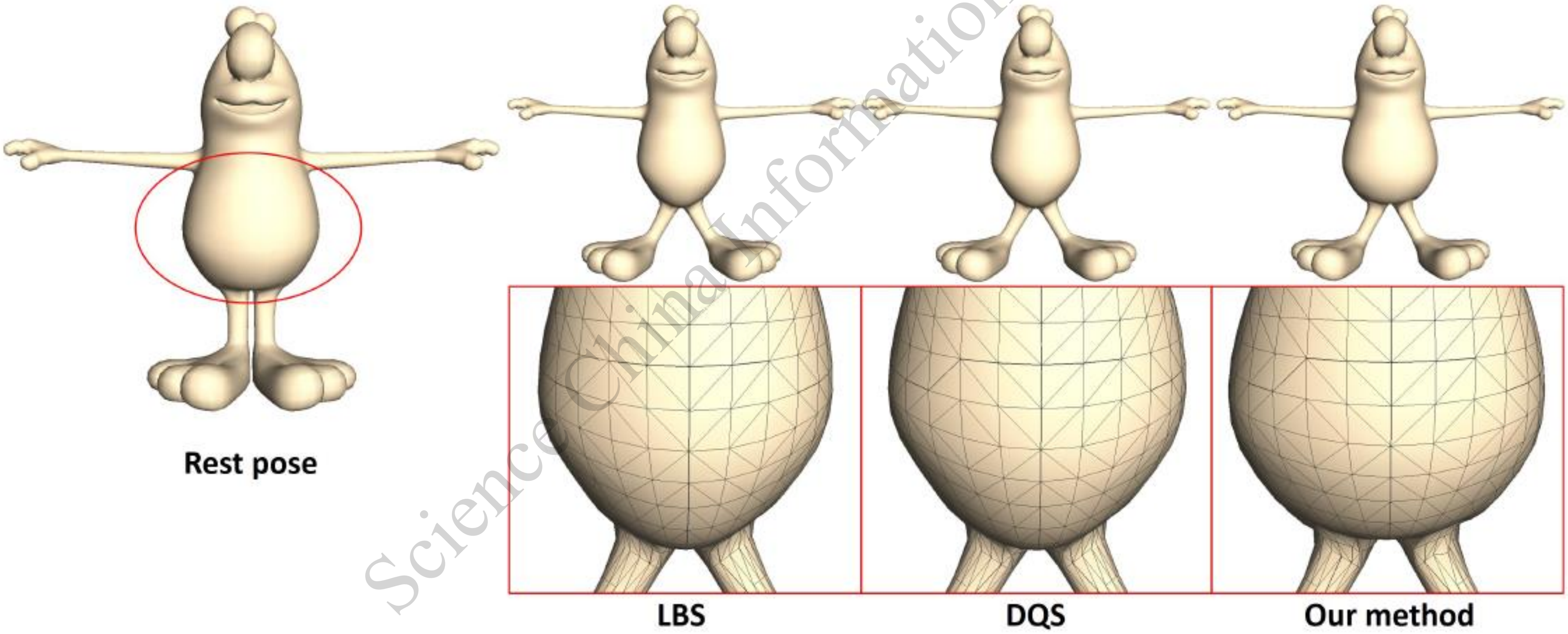
Rigidity:



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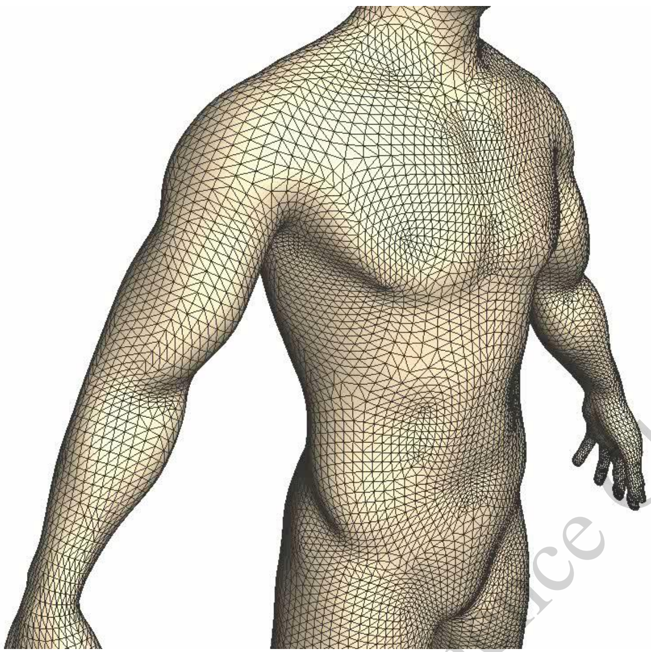
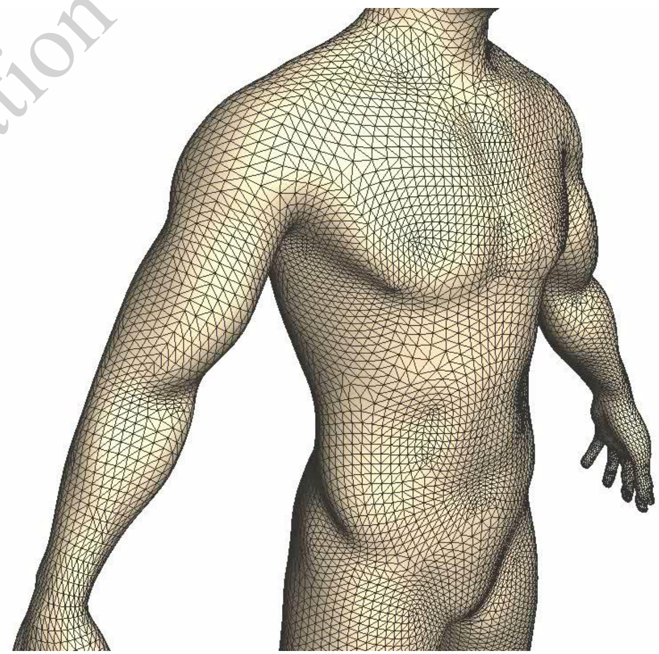
Muscle bulging:





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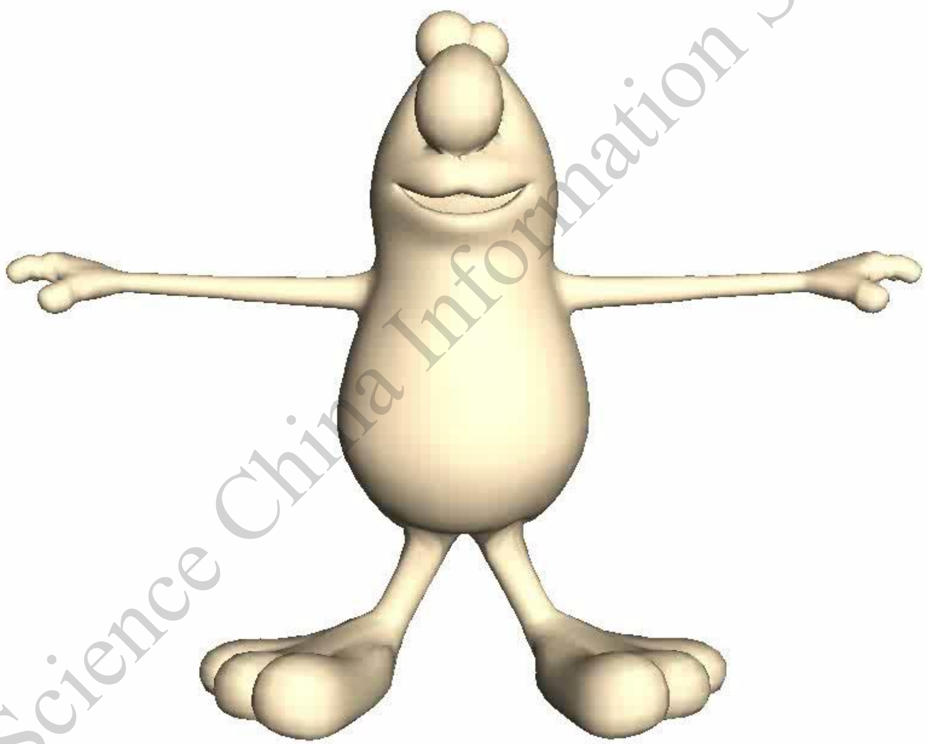
Primary deformation:



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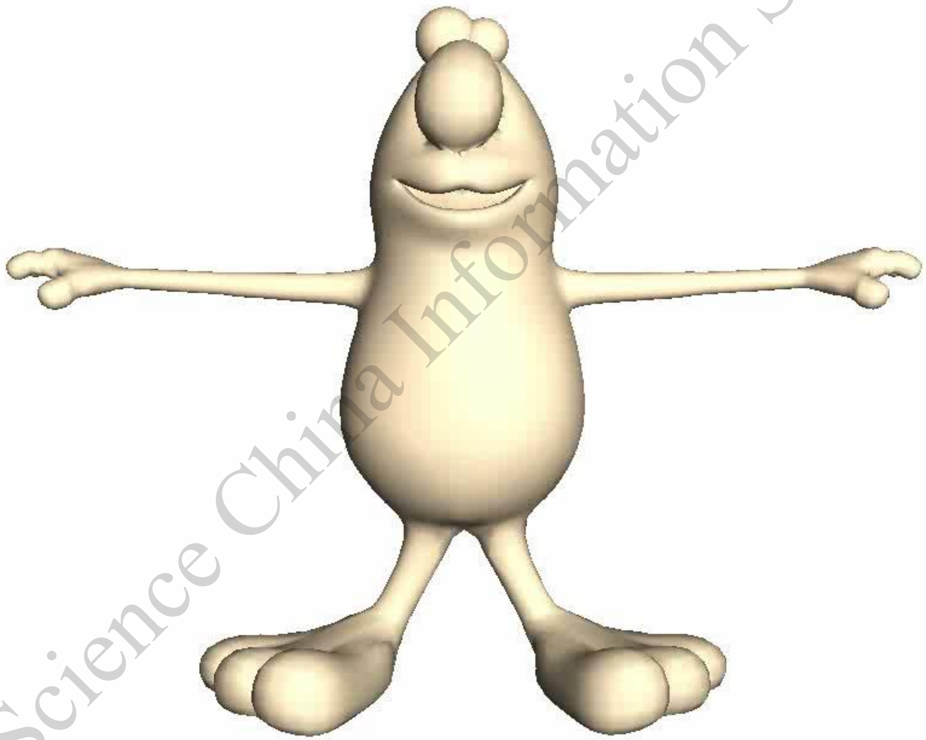
Experiments

Secondary deformation:



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Experiments

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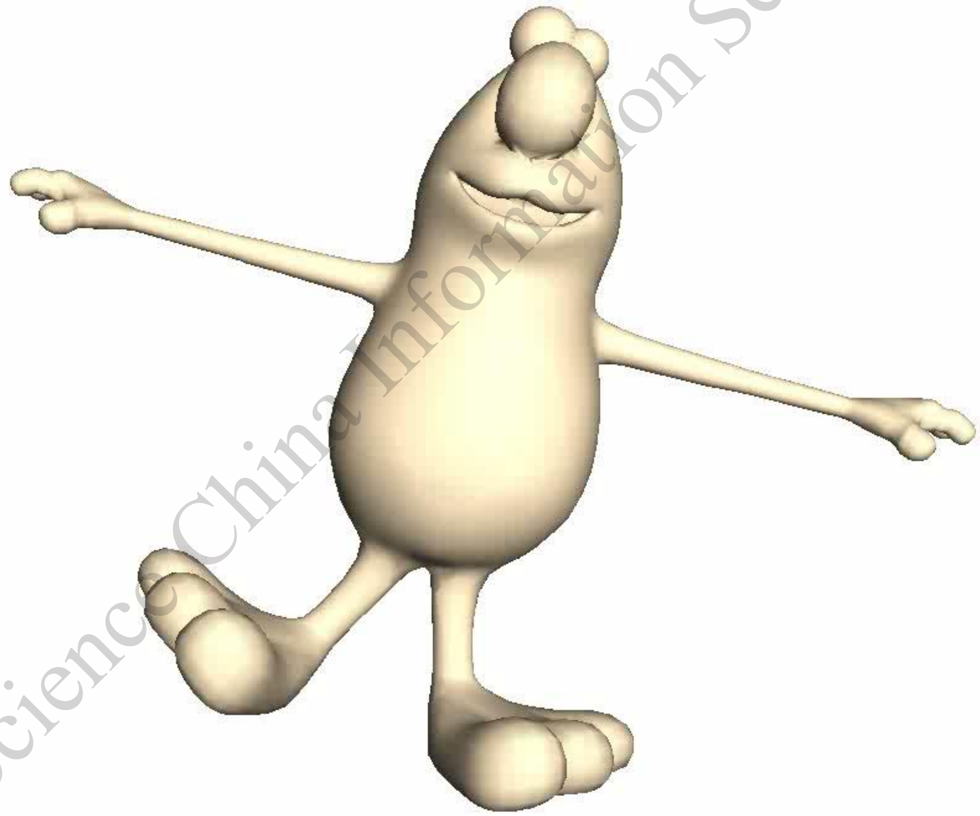

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- Introduction
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Conclusion

Contributions:

(1) Our method comprises dynamic properties, secondary deformation is easy to perform.

(2) After creating additional joint balls, artifacts like joint collapse, candy-wrapper effects are reduced.

(3) We present a method to handle surface overlapping problems and propose a straightforward but effective way to produce muscle bulging effects.

In the future, our work can be improved through three aspects. First, we can use real anatomical joints instead of balls in our model. Second, the action lines can be used to represent the shape of muscle and the mechanical properties. Third, a brush tool to define different regions seems helpful.

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Thank you!

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