

Animating Virtual Characters

Skin deformation

Skeleton based deformation - Skinning

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Objective: Deform articulated character

Idea: Use skeleton to control limbs

Articulations as rotations

Animation Skeleton

Set of frames T_i : position, orientation

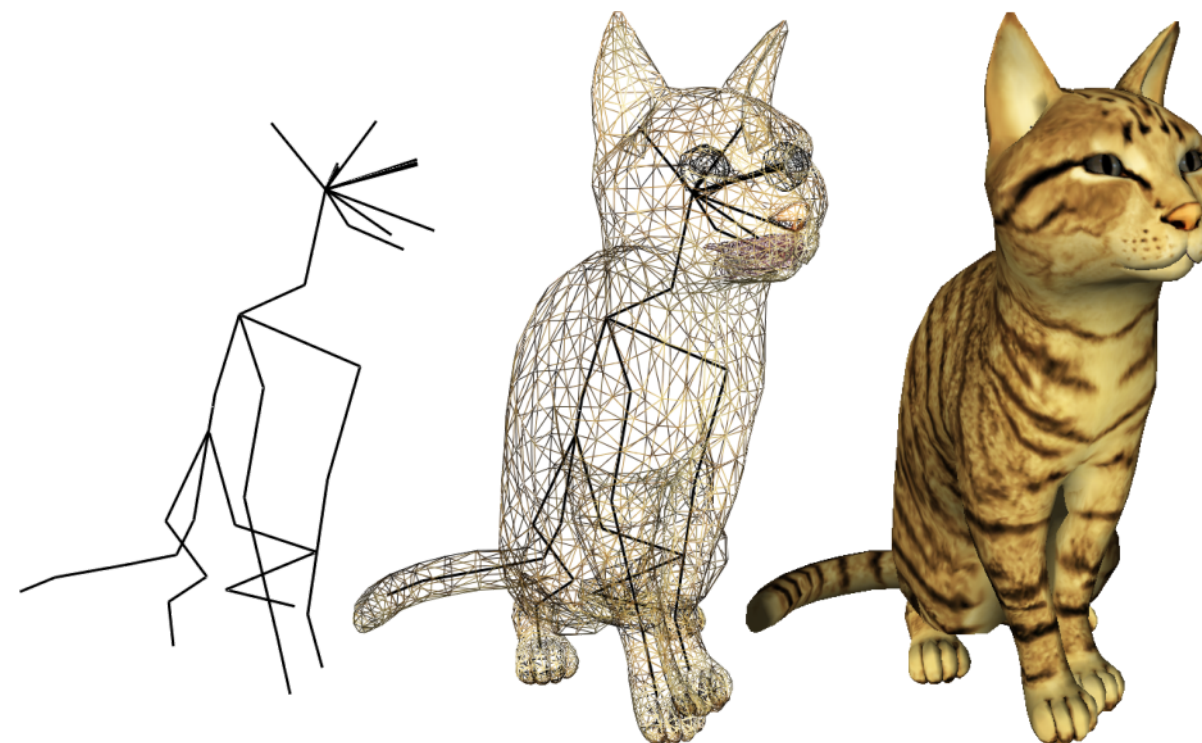
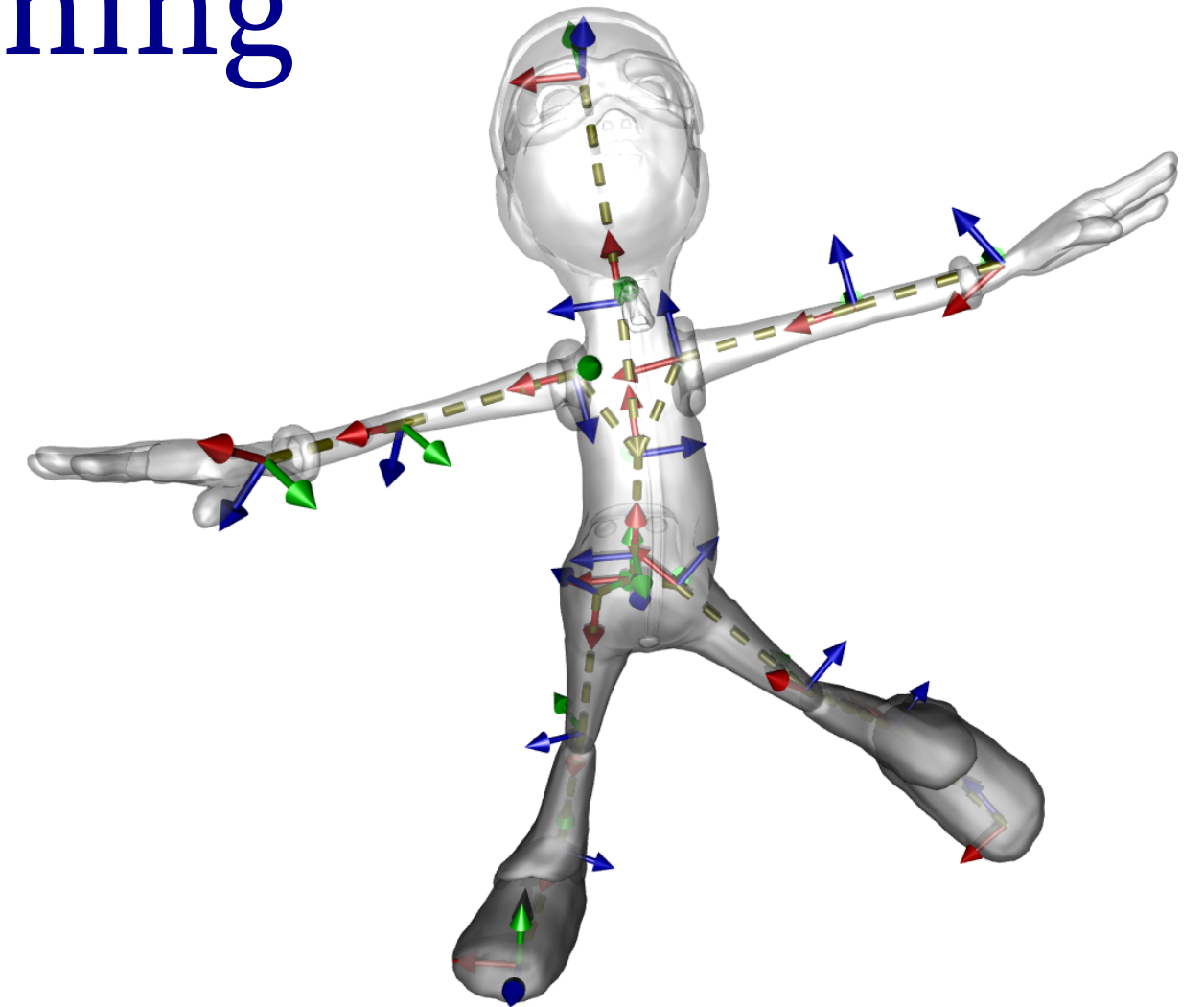
Describe non-rigid parts of the character (dof)

Terminology

Joint = A frame T_i

Bone = Segment between two joints

Note: Animation skeleton $\neq$ Anatomical skeleton



Rigid Skinning

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Attach rigidly subset of vertices to specific bones, described by its root joint/frame.
Vertices are following rigid deformation of their associated frame.

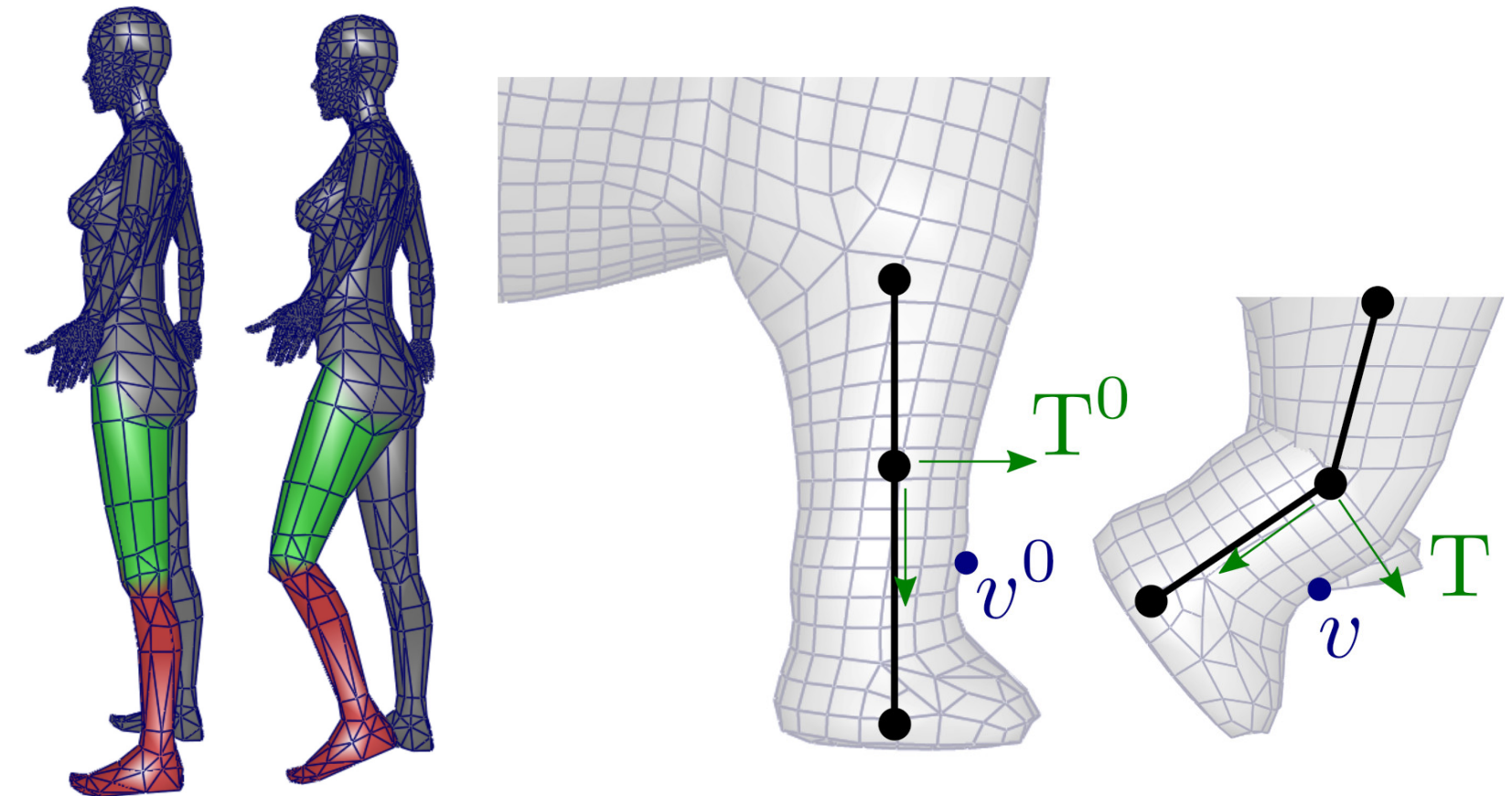
Deformation formulation

Consider, at rest pose/initial state

- A frame T^0
- A vertex v^0 attached to this frame

After deformation

- New frame T
- New vertex position v



Question: What are the new coordinates v w/r T , T^0 , v^0 ?

Rigid Skinning

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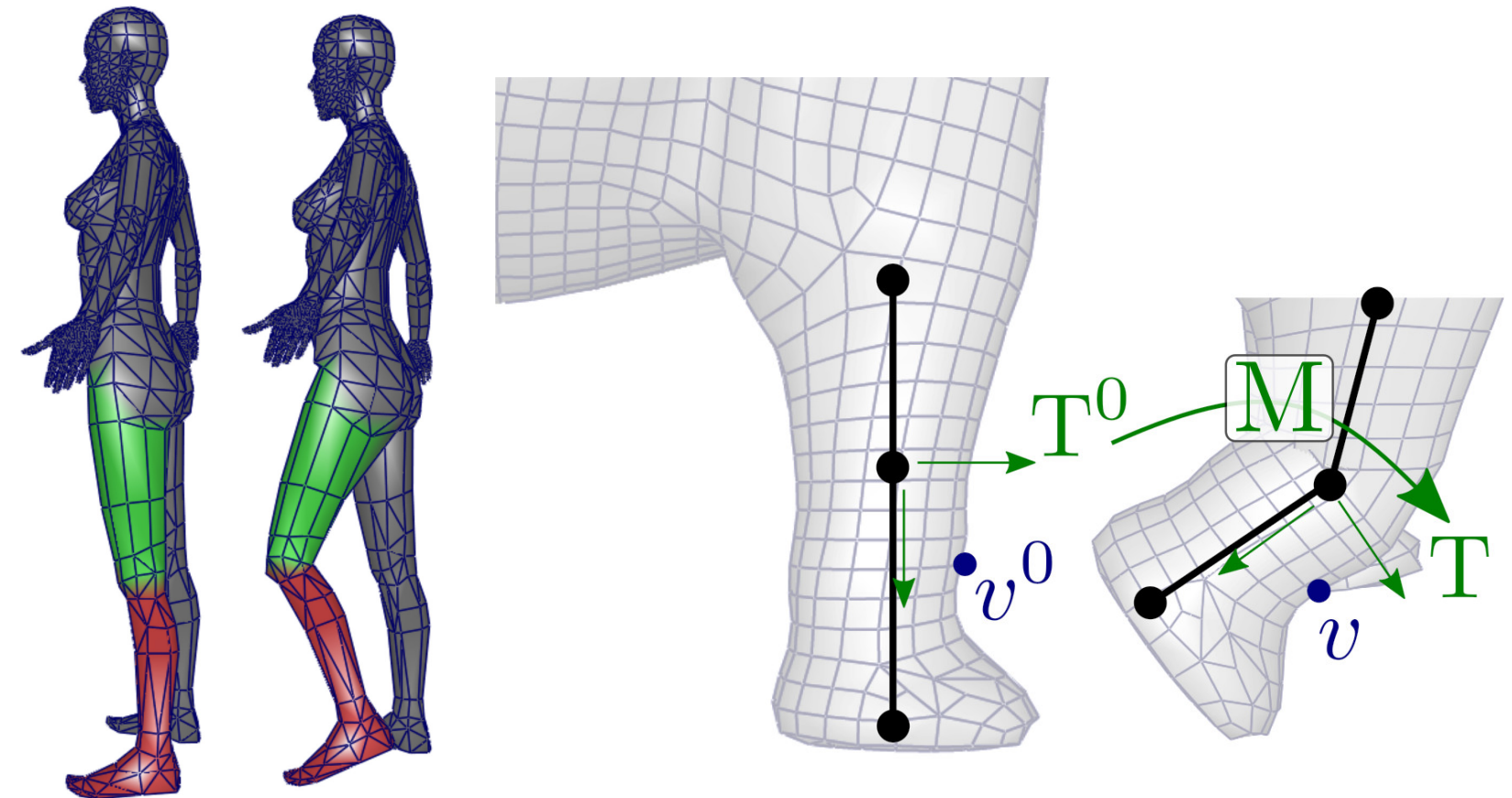
Deformation formulation

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Question: What are the new coordinates v w/r T , T^0 , v^0 ?

v^0 and v have similar local coordinates w/r to T^0 and T

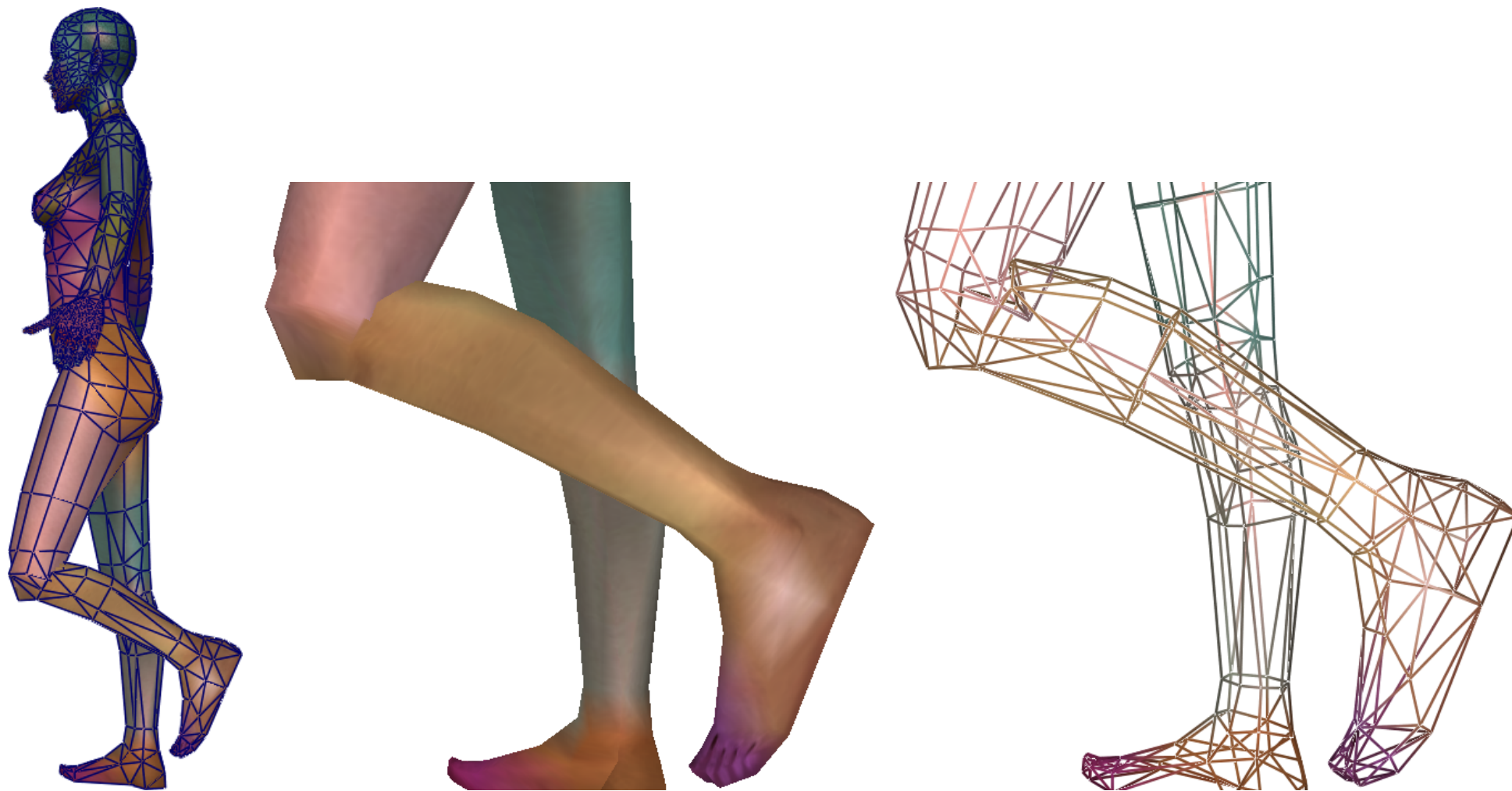
$$\Rightarrow T^{-1}v = (T^0)^{-1}v_0$$

$$\Rightarrow v = T (T^0)^{-1}v_0 = M v_0$$

Rigid Skinning

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- (+) Skeleton is easy to build
- (+) Skeleton interaction is intuitive to model rigid articulation
- (-) Discontinuities/Inter-penetrations



Idea of smooth skinning: Blend discontinuous transformation around articulation

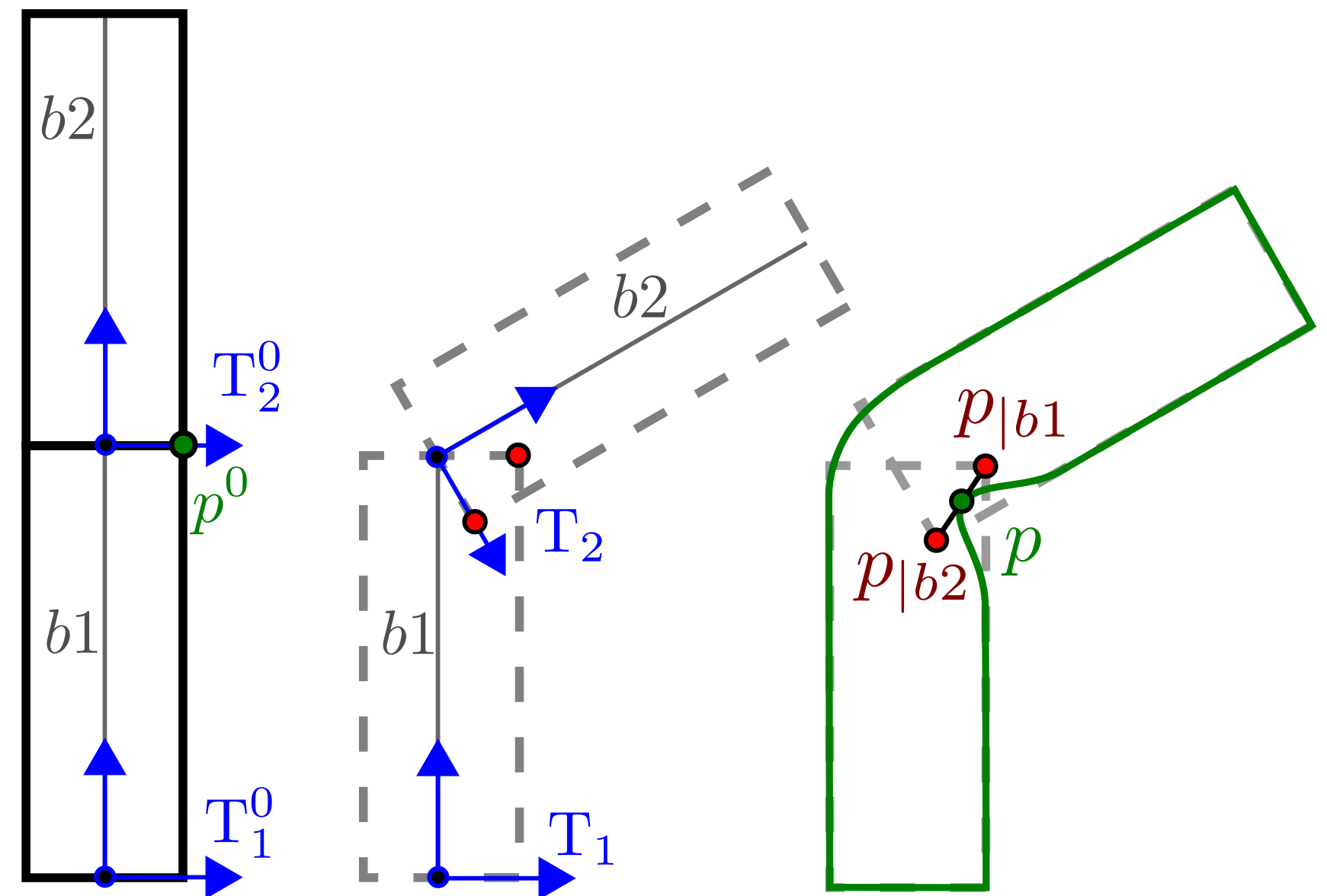
Smooth skinning

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Linear Blend Skinning (LBS): Linear interpolation of positions between associated frames

Example at middle vertex position of a bending cylinder

$$\begin{aligned} p &= 0.5 p_{|b1} + 0.5 p_{|b2} \\ p &= 0.5 \underbrace{T_1 (T_1^0)^{-1}}_{M_1} p^0 + 0.5 \underbrace{T_2 (T_2^0)^{-1}}_{M_2} p^0 \\ p &= (0.5 M_1 + 0.5 M_2) p^0 \end{aligned}$$



Smooth skinning

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Linear Blend Skinning (LBS): Linear interpolation of positions between associated frames

Example at middle vertex position of a bending cylinder

$$p = 0.5 p_{|b1} + 0.5 p_{|b2}$$

$$p = 0.5 \underbrace{T_1 (T_1^0)^{-1}}_{M_1} p^0 + 0.5 \underbrace{T_2 (T_2^0)^{-1}}_{M_2} p^0$$

$$p = (0.5 M_1 + 0.5 M_2) p^0$$

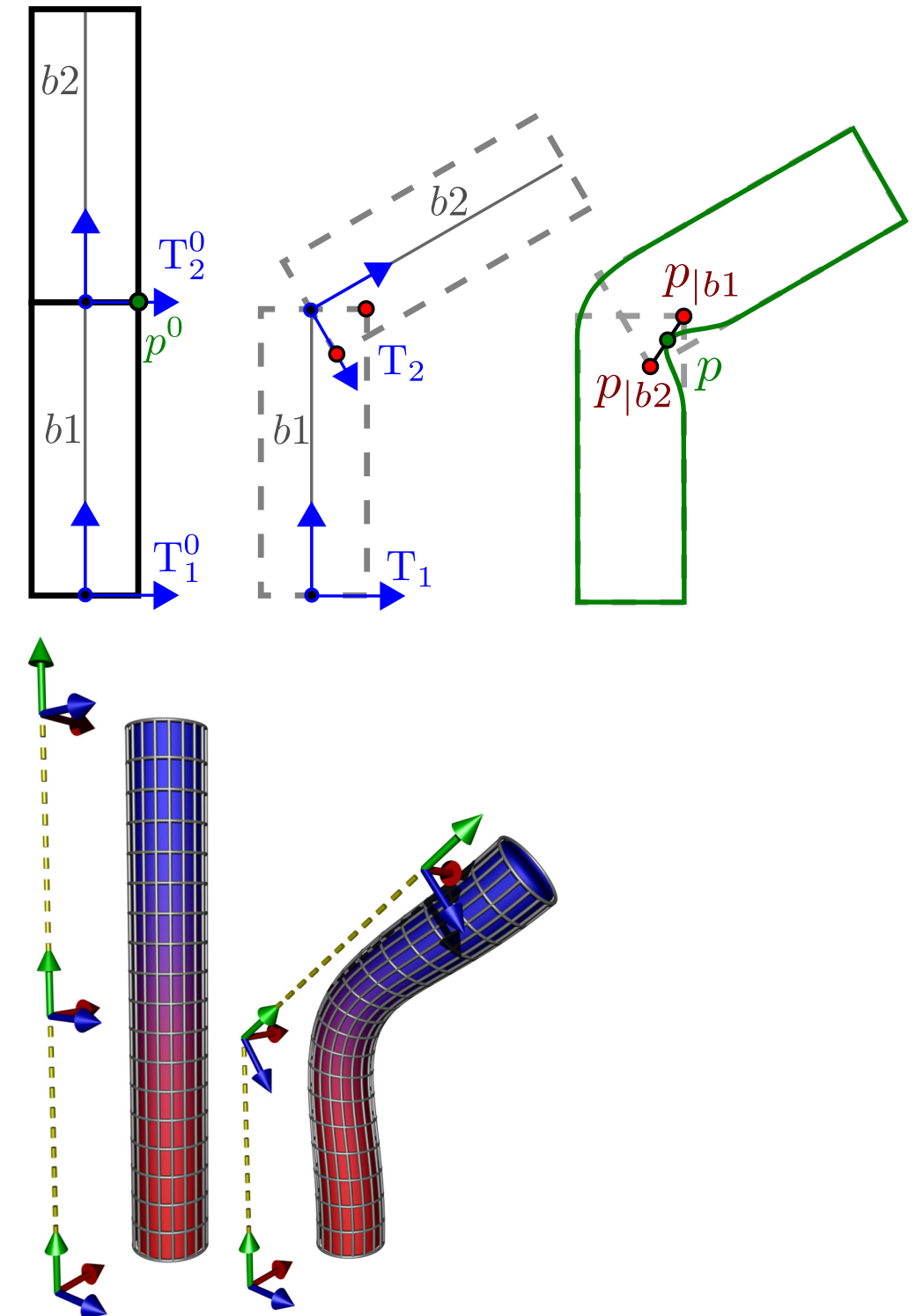
Can be generalized to arbitrary interpolation between two bones

$$p = \alpha p_{|b1} + (1 - \alpha) p_{|b2} = (\alpha M_1 + (1 - \alpha) M_2) p^0$$

α : skinning weights

Can be generalized to any number of bones

$$p = \sum_{k=0}^{N-1} \alpha_k p_{|bk} = \left(\sum_{k=0}^{N-1} \alpha_k M_k \right) p^0, \quad \sum_k \alpha_k = 1$$

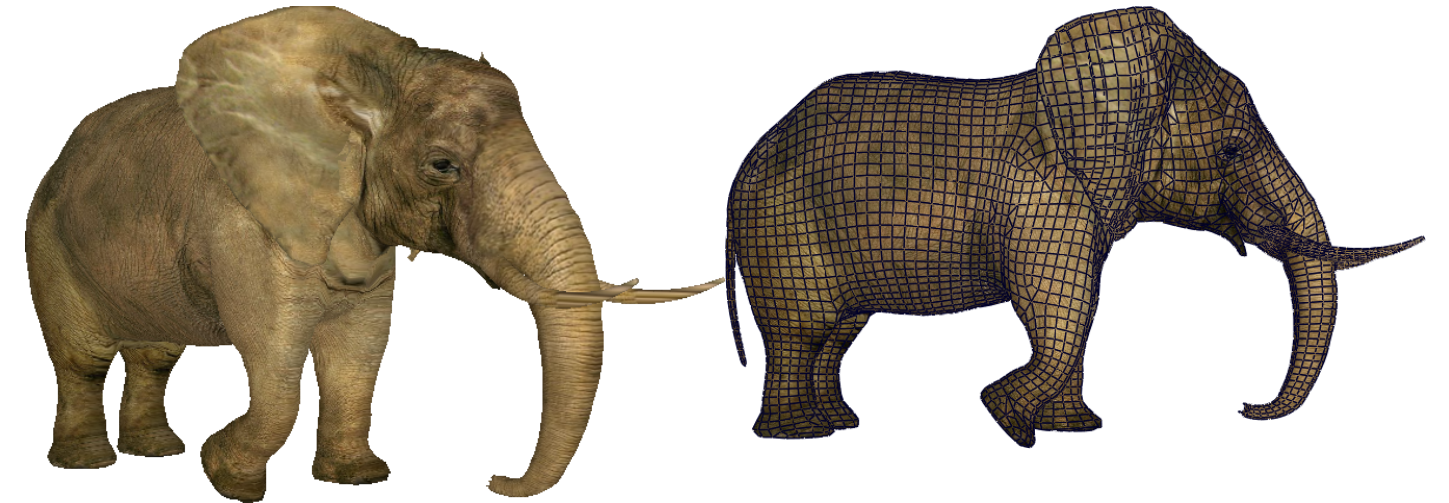


Smooth skinning - Summary

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$$p = \left(\sum_{k=0}^{N-1} \alpha_k M_k \right) p^0 = \left(\sum_{k=0}^{N-1} \alpha_k T_k (T_k^0)^{-1} \right) p^0$$

$\forall k, \alpha_k \in [0, 1], \text{ and } \sum_{k=0}^{N-1} \alpha_k = 1$

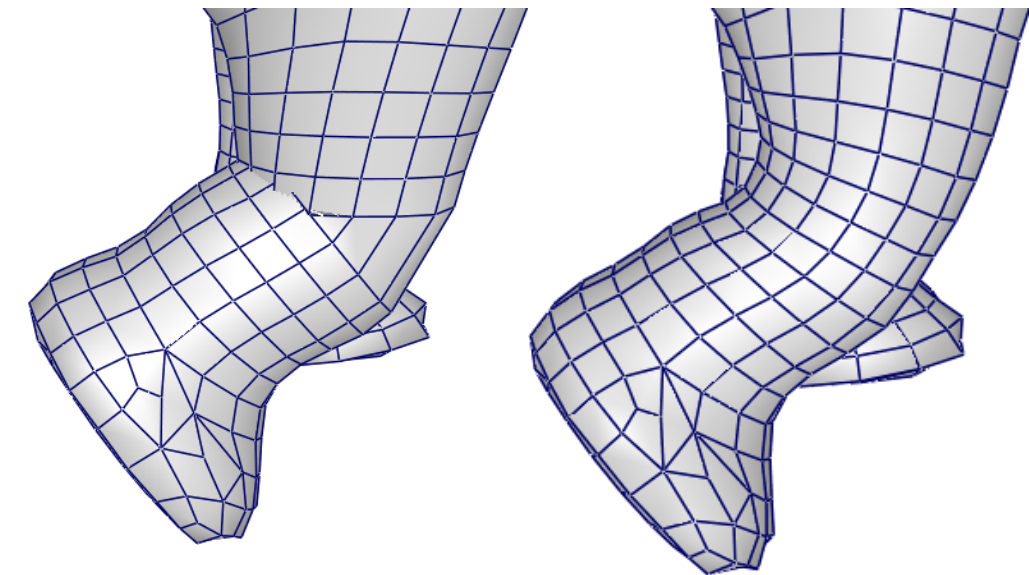


The current **standard** for almost all articulated character deformations

- Intuitive deformation
- Controlable shape (*through weights*)
- Fast to compute (GPU compatible)

matrix average, multiplication matrix-vector

⇒ Heavily used in Animation cinema & Video Game



[*Joint-Dependent Local Deformations for Hand Animation and Object Grasping*. Nadia Magnenat-Thalmann, Rochard Laperière, Daniel Thalmann. *Graphics Interface*, 1988]

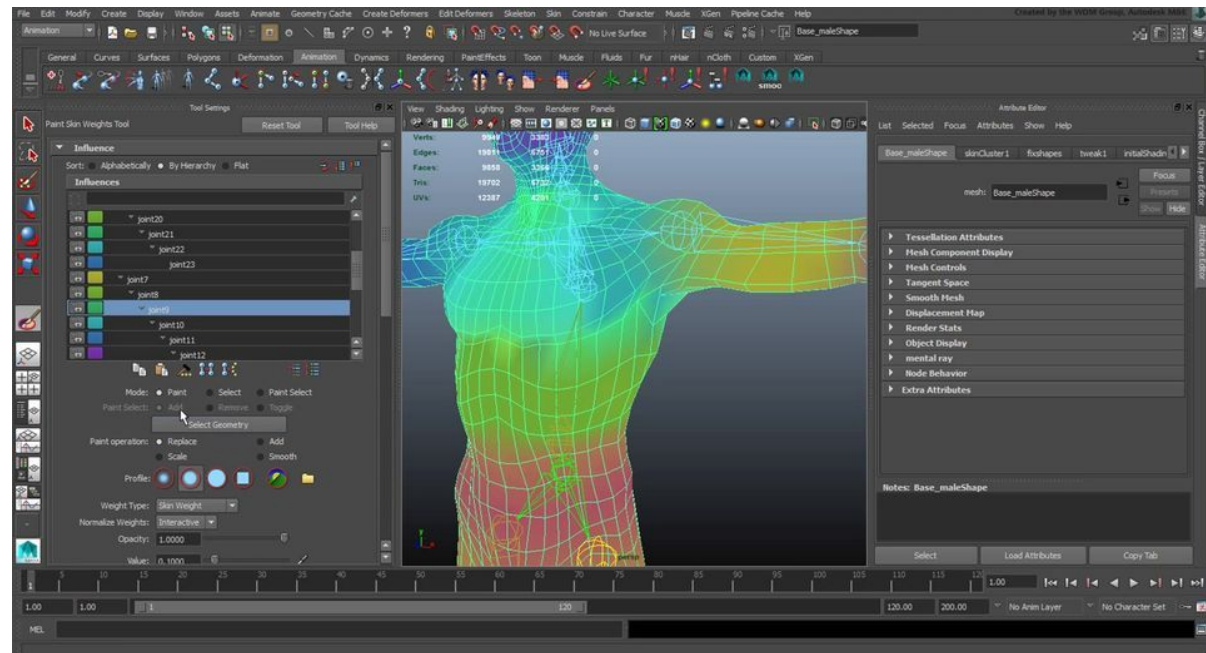
[*Over My Dead, Polygonal Body*. Jeff Lander. *Game Developer Magazine*, 1998]

Skinning weights

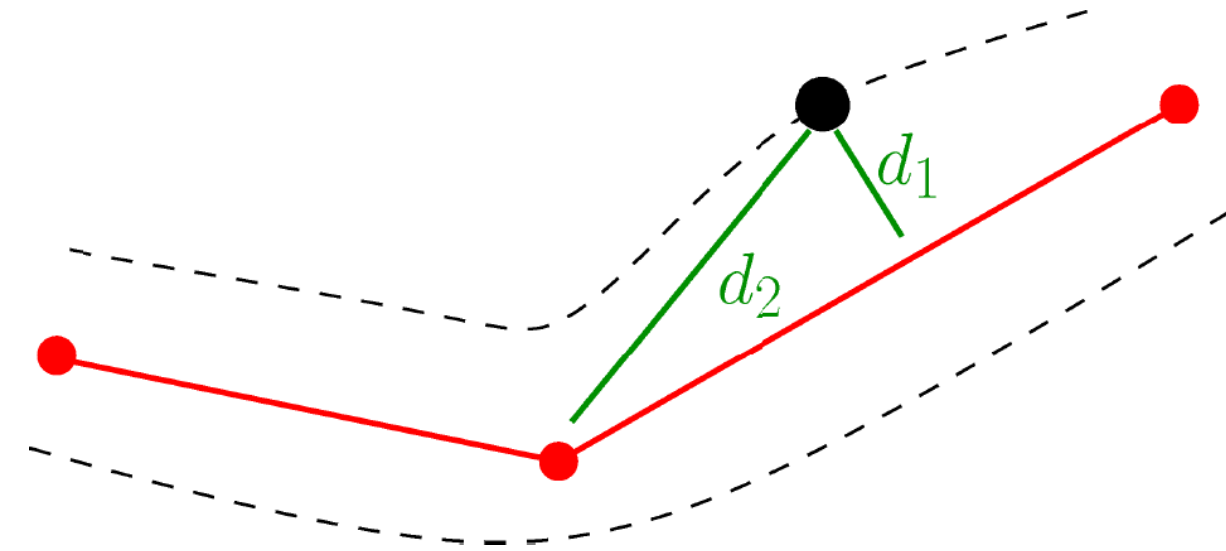
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How to generate skinning weights ?

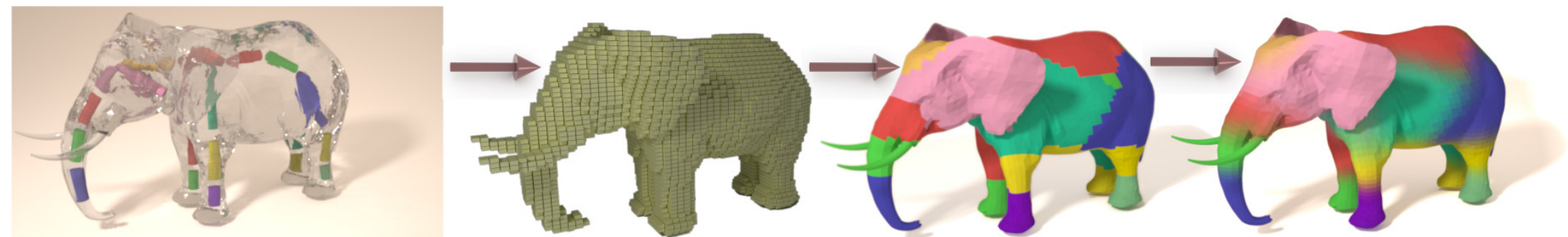
- Paint them manually
- Automatic computation



ex. Using cartesian distances: $\alpha_1 = d_1^{-1} / (d_1^{-1} + d_2^{-1})$



Or using diffusion on the volume/surface



Rigging: Associating bones and skinning weights (or any animation handle) to mesh parts

Skinning: File Format

Unfortunately few standard open format to store skinning animation data

Main open format: Collada (XML), glTF (JSON)

Common software related formats: FBX, Blend, 3DS, ...

```
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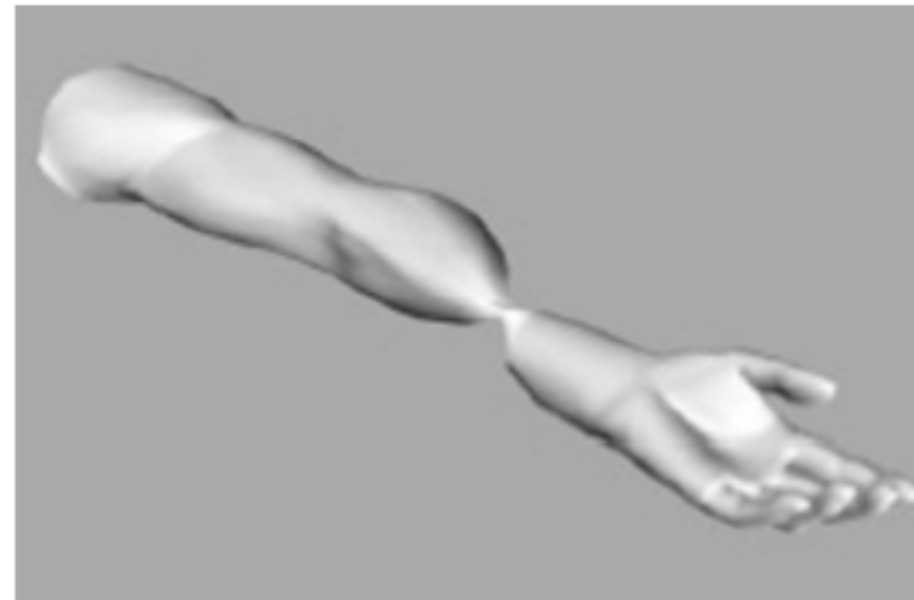
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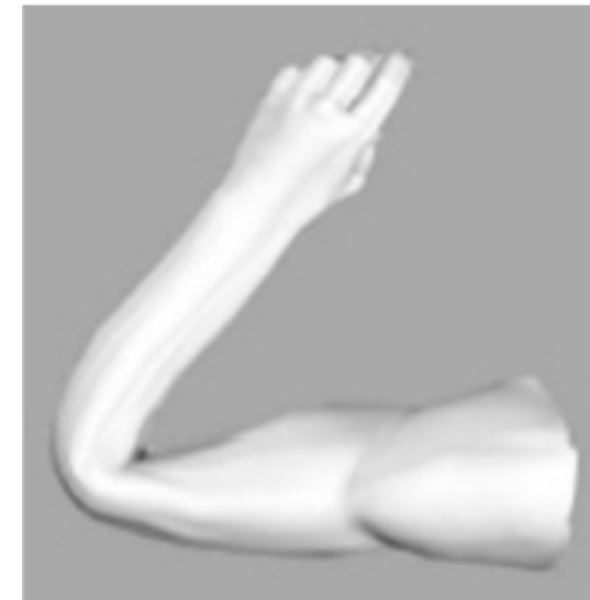
Linear Blend Skinning - Limitations

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- Non-trivial rigging settings
- Artifacts for large rotations: Candy wrapper, Collapsing elbow

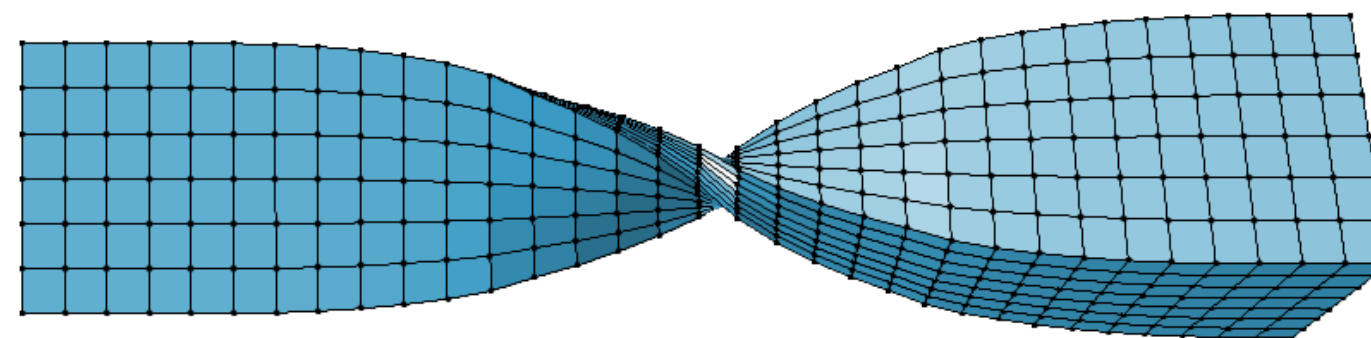


Candy wrapper



Collapsing elbow

Linear blending between rigid transformation matrices



Skinning improvement

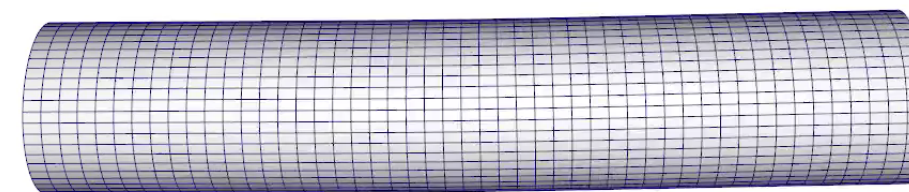
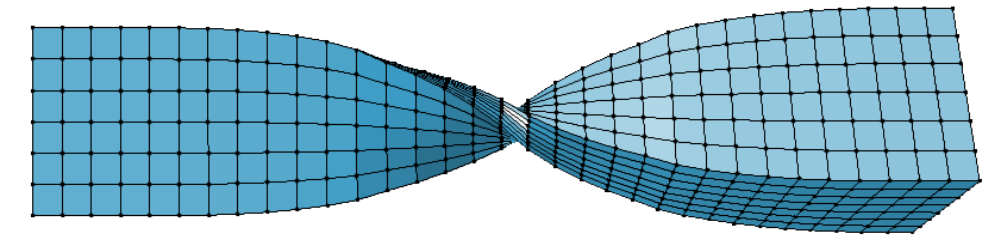
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Avoid linear blending b/w affine transform matrices

First idea: Split rigid transformation matrices in

- rotation part: blend using quaternions (solve candy wrapper)
- translation part: blend linearly

But doesn't work for general deformation: Arbitrary center of rotation
Rotation and translations are treated separately



Possibility to compute an optimal center of rotation at each frame

[Spherical Blend Skinning: A Real-time Deformation of Articulated Models. L. Kavan, J. Zara. I3D 2005.]



Skinning improvement: Dual Quaternion

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Second idea: Use of **dual quaternion**

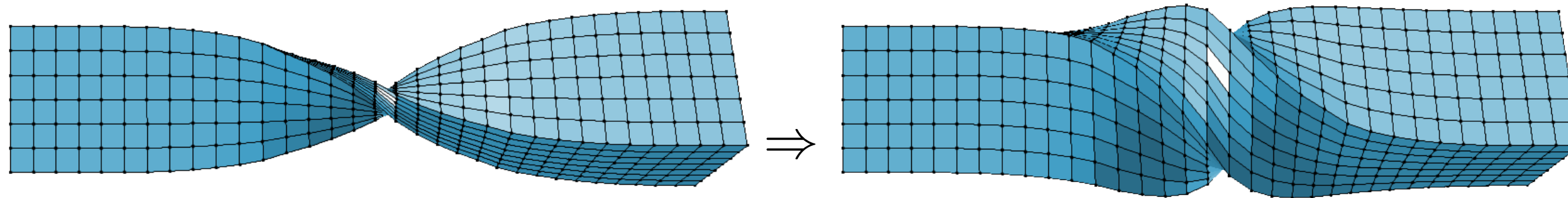
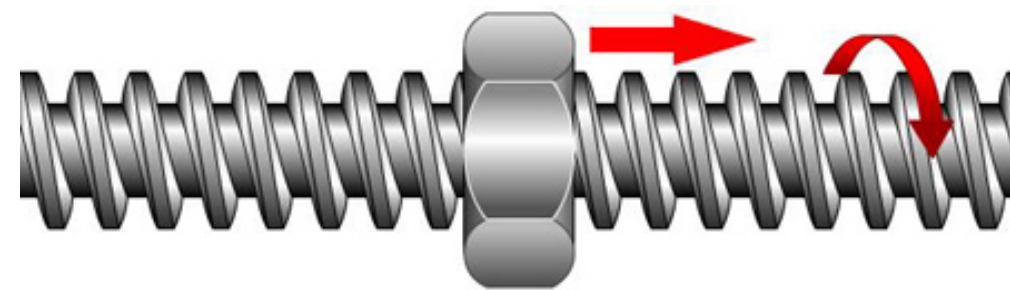
$$\hat{q} = q_0 + \epsilon q_\epsilon, \quad \epsilon \text{ dual element.}$$

Dual quaternion = generalization of quaternion to handle *rigid transformation*

Rotation + translation

Unit dual quaternion models rigid transformation as **screw motions**

= *rotation about an axis followed by a translation in the direction of this axis*



LBS

DQS

Dual number and dual quaternion

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Dual number $a = a_0 + \epsilon a_\epsilon$

Dual element ϵ is nilpotent : $\epsilon \neq 0, \epsilon^2 = 0$

ϵ commonly used to model infinitesimal quantity (ex. automatic differentiation)

Dual quaternion $\hat{q}$ = Generalization of quaternion to dual numbers

$$\hat{q} = q_0 + \epsilon q_\epsilon$$

- q_0 : pure rotation component
- q_ϵ : encodes translation component (dual part)

Given a unit quaternion q_0 , and a translation $t = (t_x, t_y, t_z)$, the associated unit dual quaternion is

$$\hat{q} = q_0 + \frac{\epsilon}{2} q_t q_0 \quad q_t = (t_x, t_y, t_z, 0)$$

Unit dual quaternion ($\|\hat{q}\| = 1$) describe the set of rigid transformation as screw motion.

Axis-angle representation with dual quaternion

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Similarly to quaternion: "angle/axis" correspondance

- $\hat{q} = \cos(\hat{\theta}/2) + \hat{n} \sin(\hat{\theta}/2)$

- $\hat{\theta} = \theta_0 + \epsilon \theta_\epsilon$

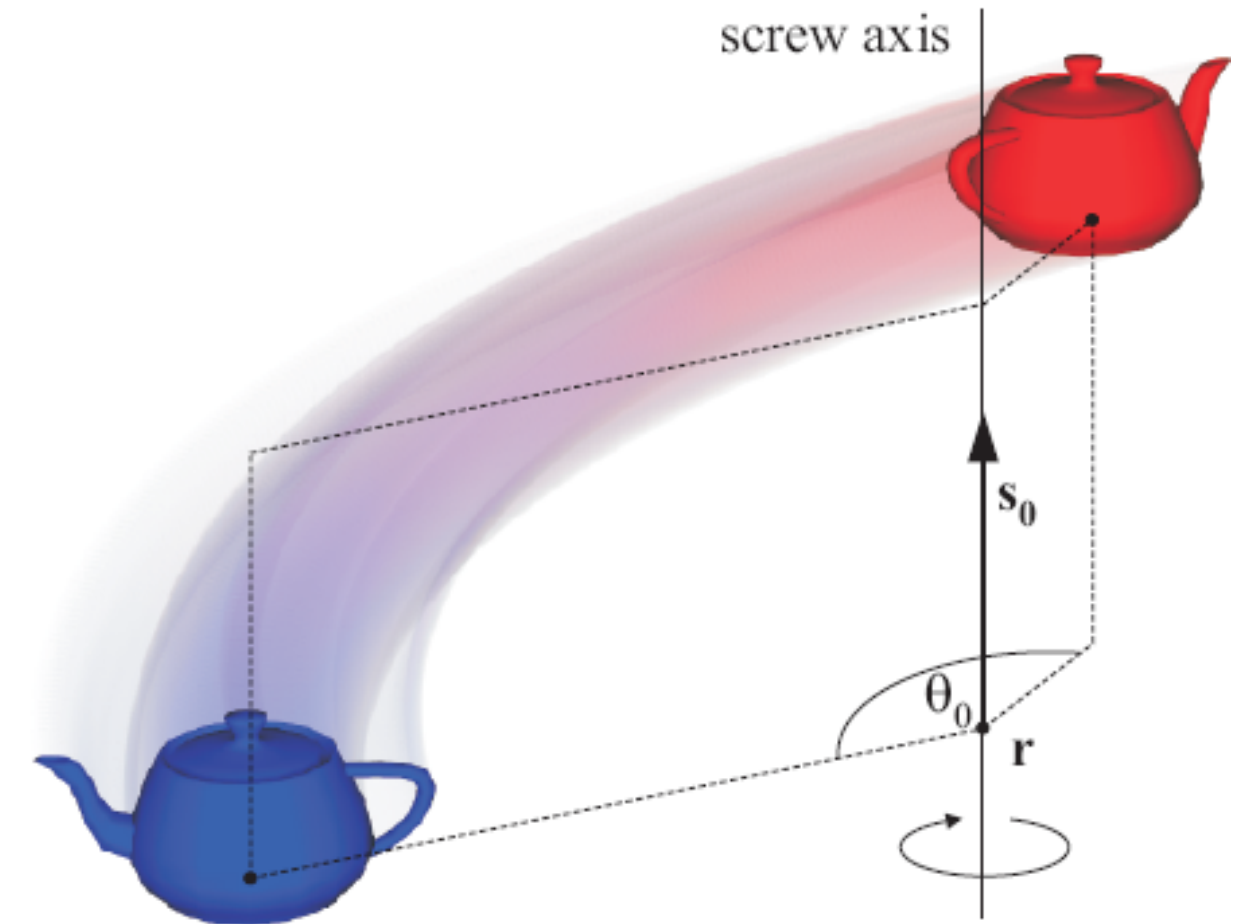
- θ_0 : angle of rotation

- $\theta_\epsilon = t \cdot n_0$: quantity of translation along n_0

- $\hat{n} = n_0 + \epsilon n_\epsilon$

- n_0 : axis of rotation

- $n_\epsilon = \frac{1}{2} ((n_0 \times t) \cotan(\theta_0/2) + t) \times n_0$: called the moment of the rotation axis.



Convert dual quaternion to rotation/translation

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Given a non-unit dual quaternion as input $\hat{q}' = q'_0 + \epsilon q'_\epsilon$

How to compute the components of $\hat{q}' / \|\hat{q}'\| = \hat{q} = q_0 + \epsilon q_\epsilon$?

Express the parameterization in rotation-translation:

$$\hat{q} = q_0 + \frac{\epsilon}{2} q_t q_0, \quad q_t = (t_x, t_y, t_z, 0)$$

First, normalize the non dual component: $\hat{q}' / \|q'_0\|$

$$\Rightarrow q_0 = q'_0 / \|q'_0\|$$

Second, enforce the parameterization of the dual component: $\frac{1}{2} q_t q_0 = q'_\epsilon / \|q'_0\|$

$$\Rightarrow q_t = 2 q'_\epsilon q_0^* / \|q'_0\|$$

Dual Quaternion Skinning (DQS)

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- 1- Encode rigid transformation (q^i, t^i) into dual quaternion

$$\hat{q}^i = q_0^i + \frac{\epsilon}{2} q_t^i q_0^i, \quad q_t^i = (t_x^i, t_y^i, t_z^i, 0)$$

- 2- Compute blending in the dual quaternion space (ScLERP)

$$\hat{q}' = \sum_i \omega_i \hat{q}^i = q_0' + \epsilon q_\epsilon'$$

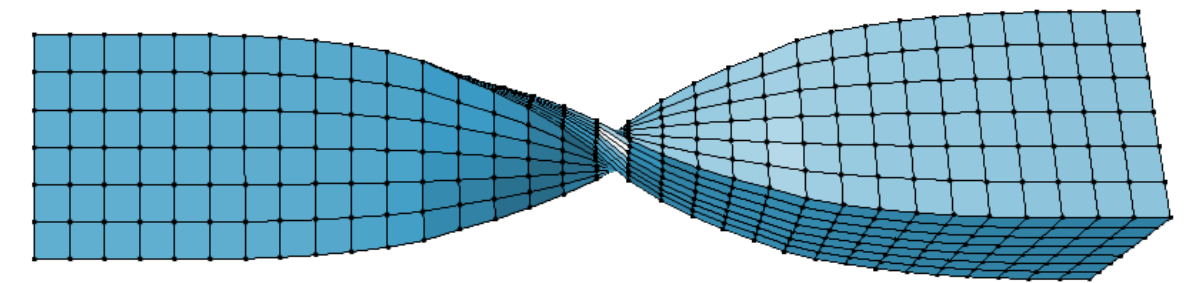
- 3- Extract components (q, t) from $\hat{q}'$

- $q = q_0' / \|q_0'\|$

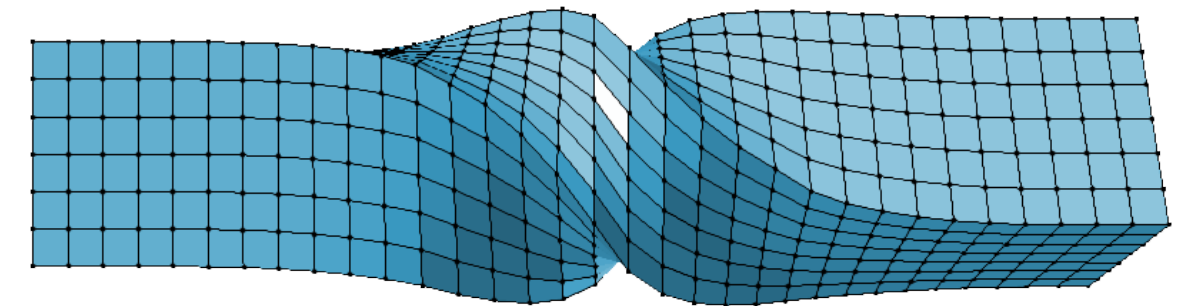
- $(t_x, t_y, t_z, 0) = 2 q_\epsilon' q^\star$
 $q^\star$: conjugate of q .

- 4- Apply finally the transformation (q, t) to position p_0

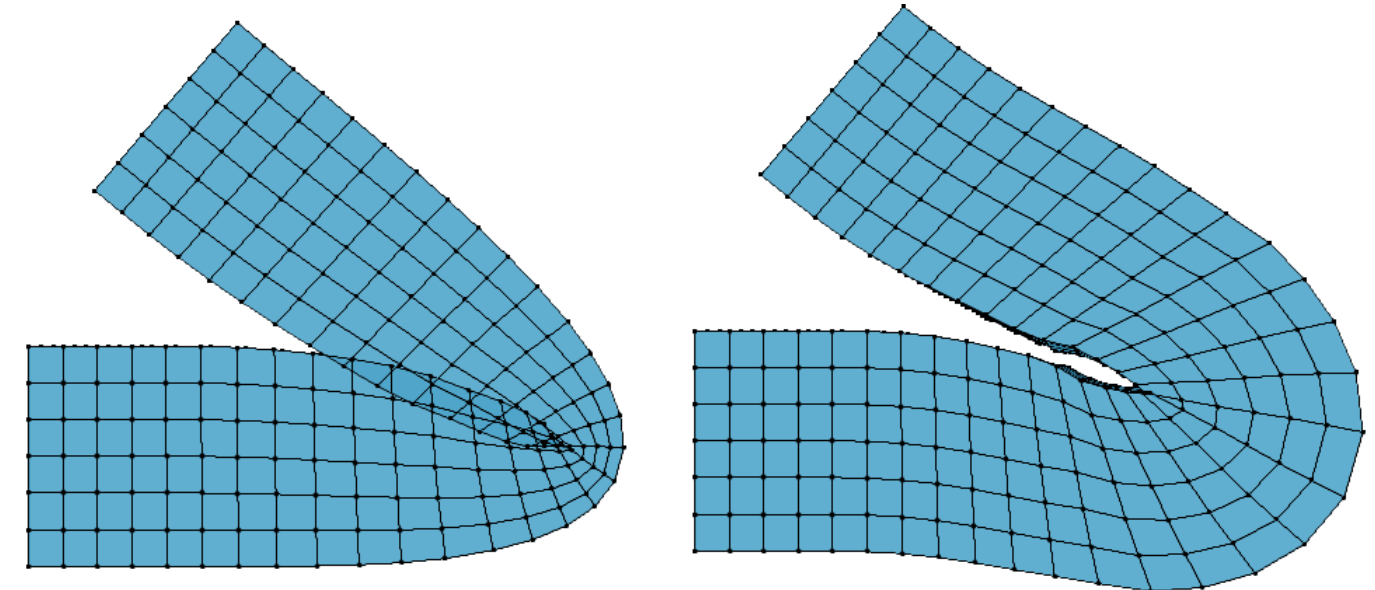
[Skinning with Dual Quaternions. Kavan et al. I3D, 2007]



LBS



DQS



LBS

DQS

Dual Quaternion VS LBS

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Dual quaternion

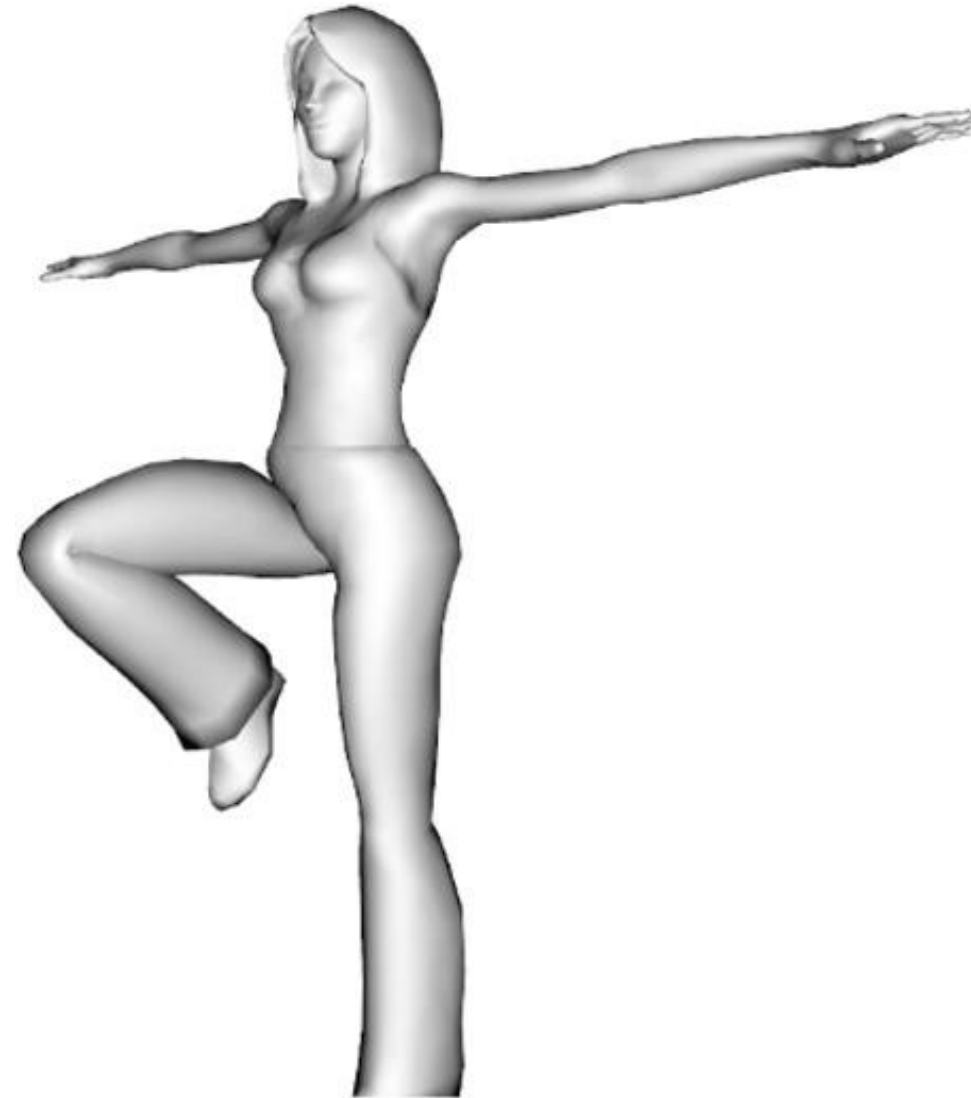
(+) Fully solves *candy wrapper* artifact

(+) Almost as efficient as LBS

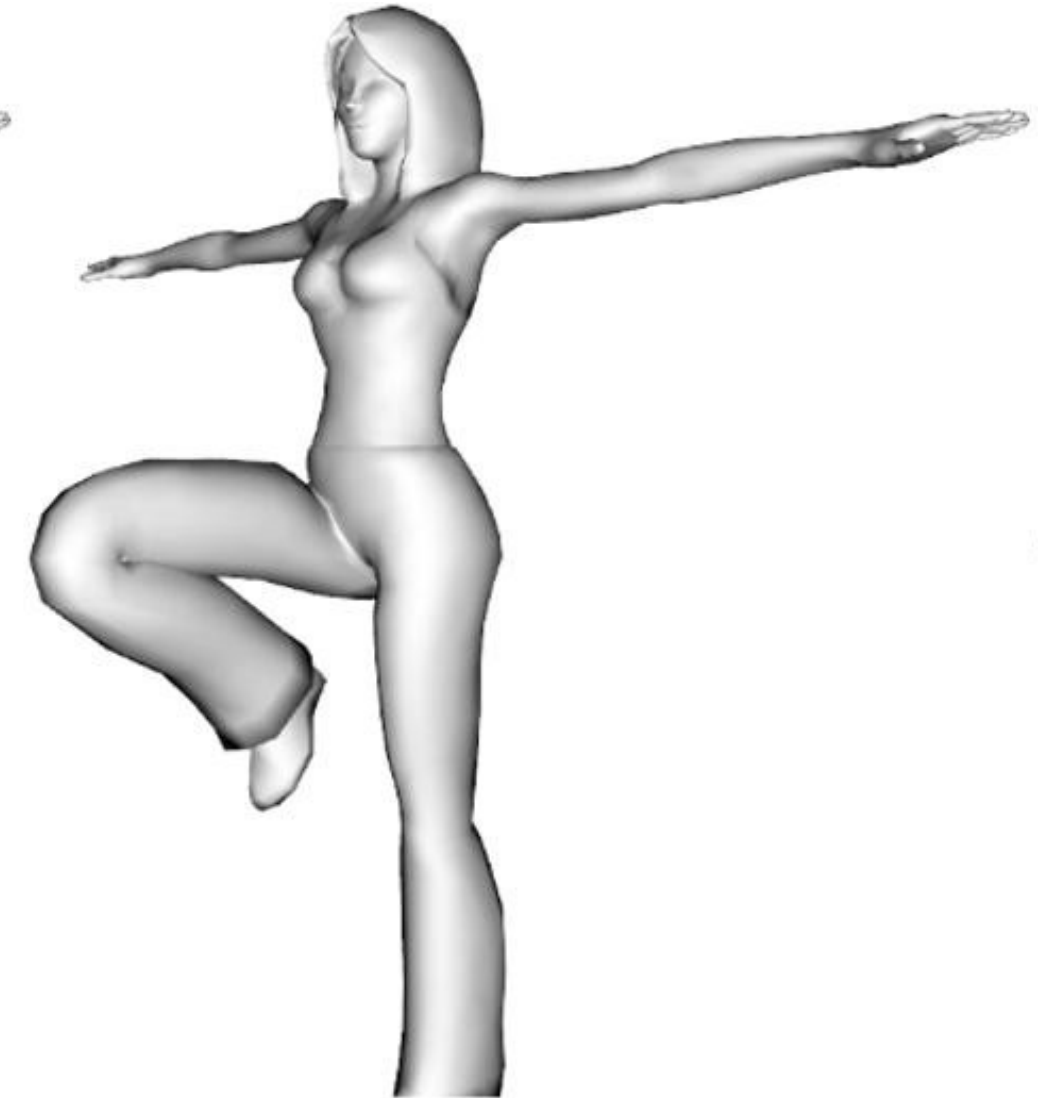
(-) May create artificial/unwanted bulge

Not always preferred to LBS

Both solutions (LBS, DQS) are proposed in standard tools



LBS



DQS