8.2 The Bind Pose & Limitations

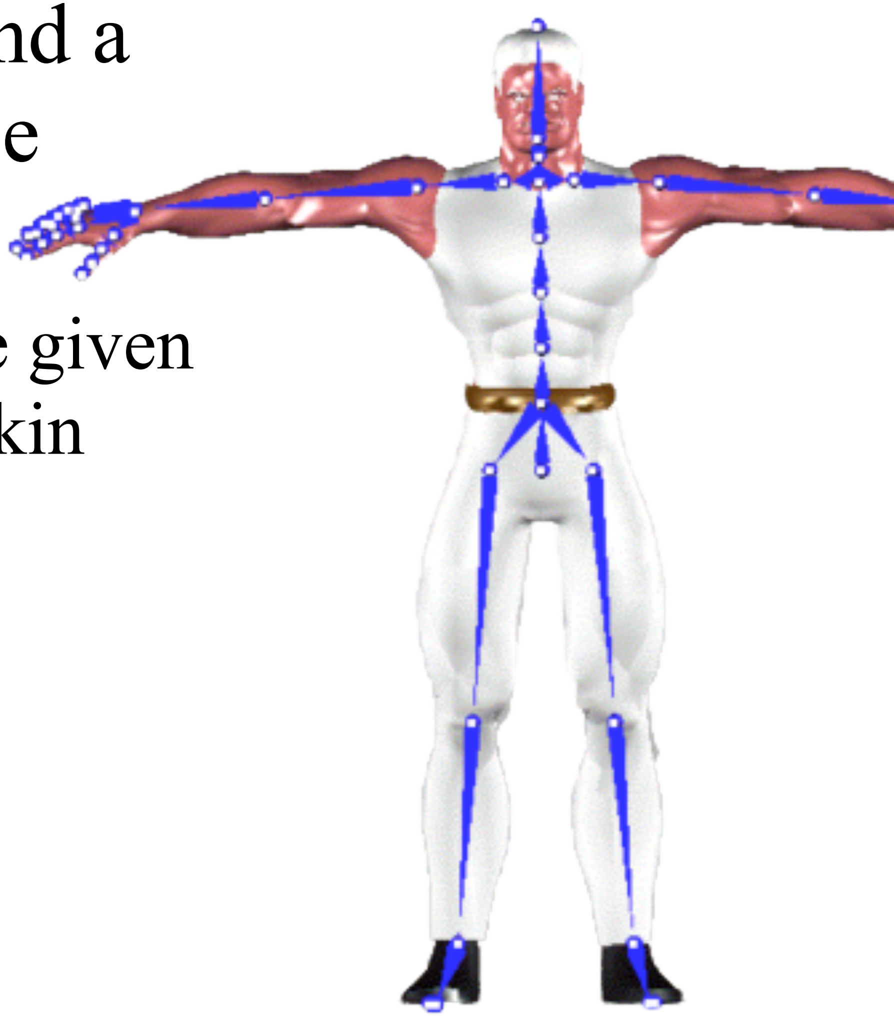
Epic Games / ign.com

In This Video

- The Bind Pose: matching the skeleton to the skin
- Skinning limitations and workarounds

Bind Pose

- We are given a skeleton and a skin mesh in a default pose
  - Called "bind pose"
  - Undeformed vertices $\mathbf{p}_i$ are given in the object space of the skin



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Bind Pose

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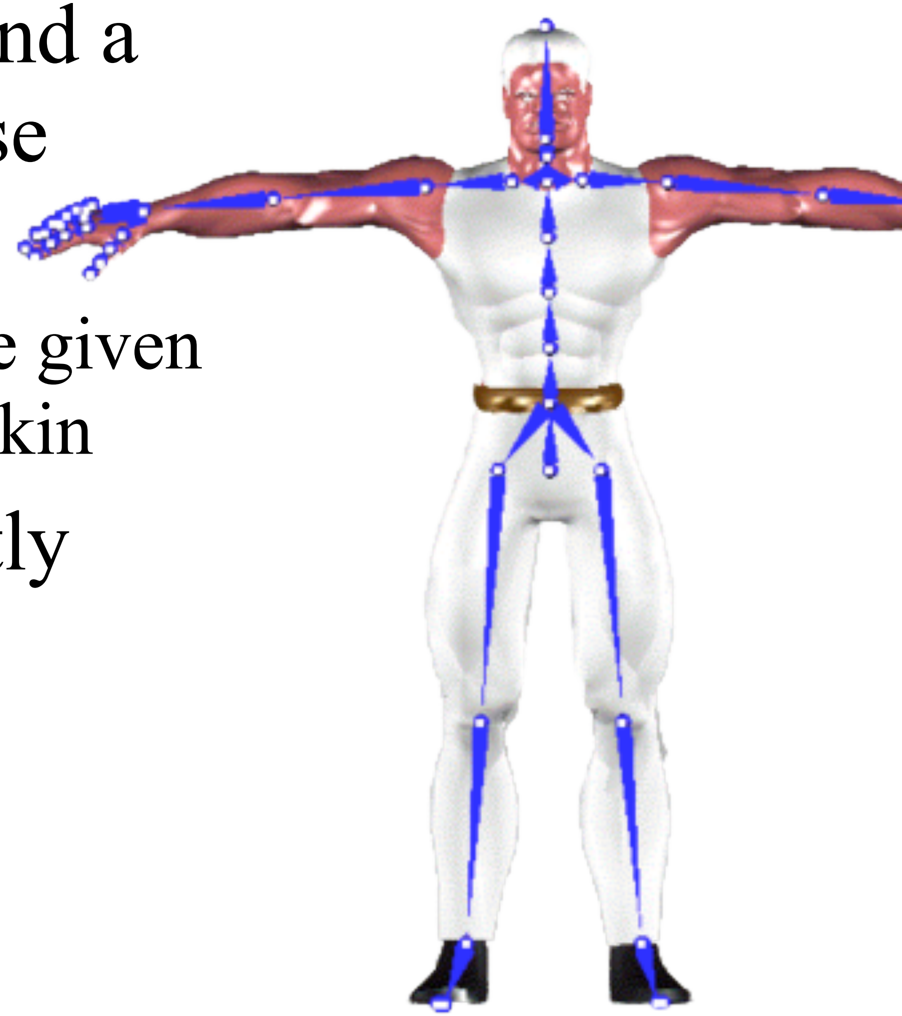
  - Called "bind pose"
  - Undeformed vertices $\mathbf{p}_i$ are given in the object space of the skin
- Previously we conveniently forgot that in order for $\mathbf{p}'_{ij} = \mathbf{T}_j\ \mathbf{p}_i$ to make sense, coordinate systems must match up.



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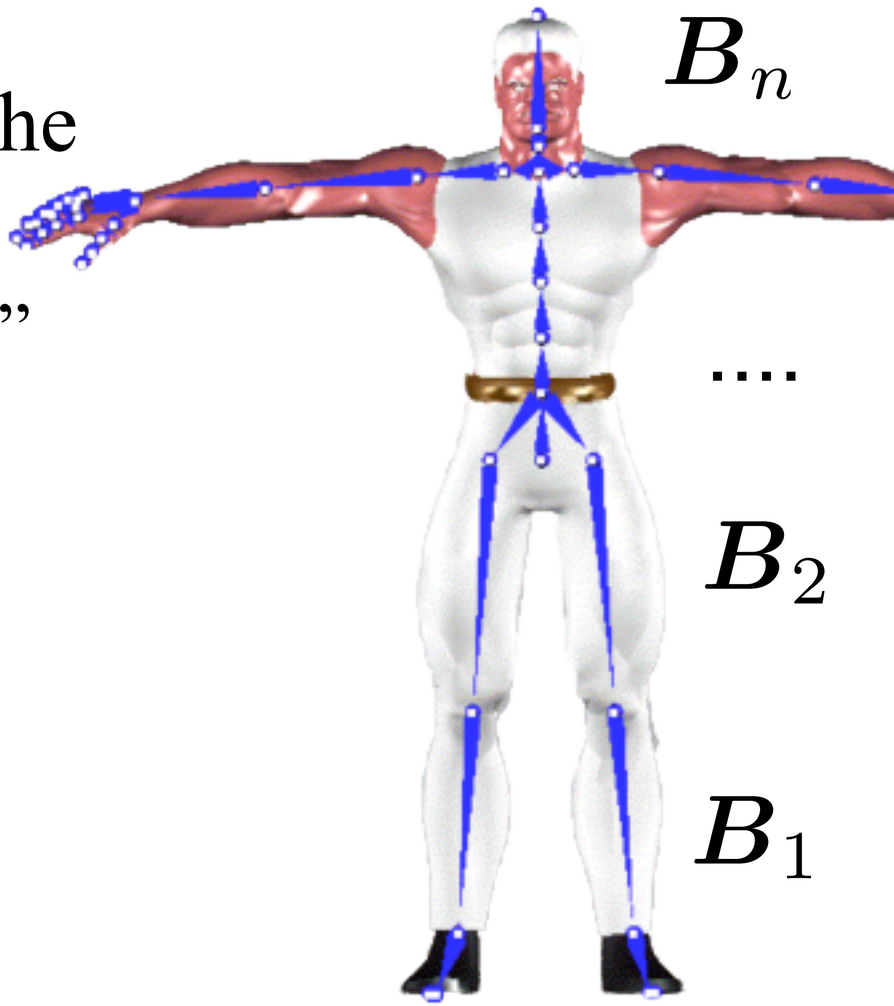
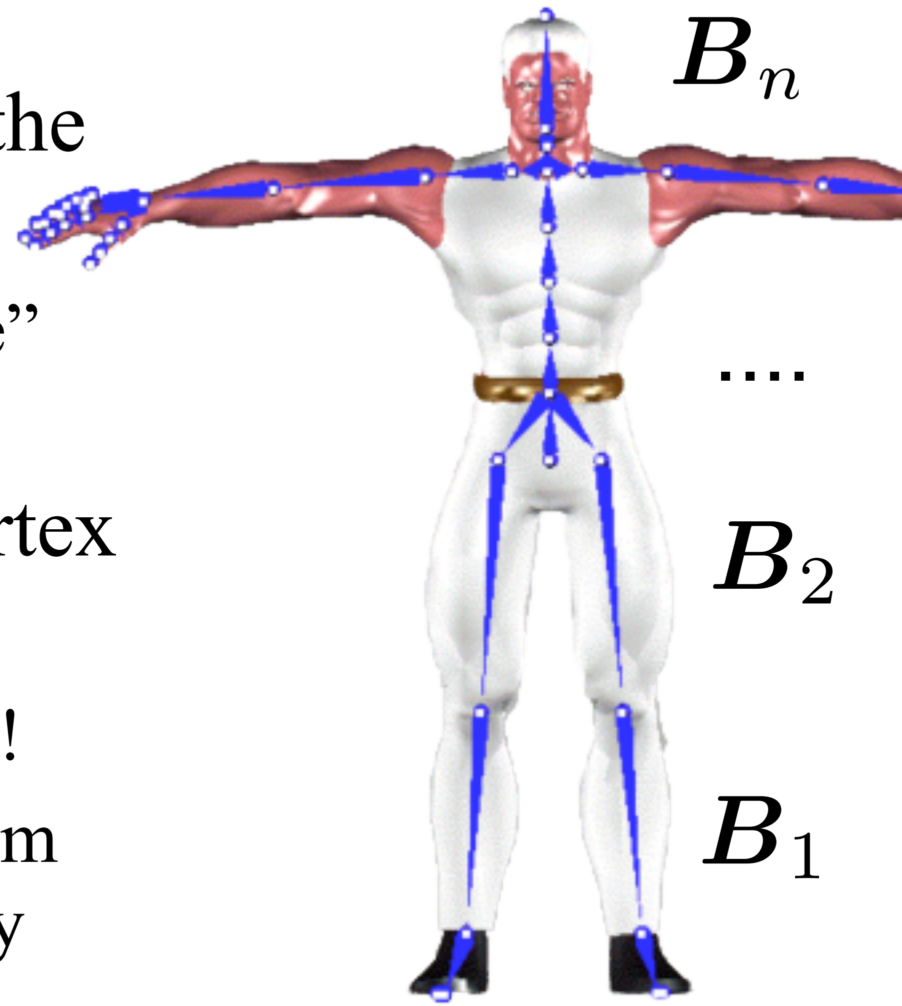
Bind Pose cont'd

- In the rigging phase, we line the skeleton up with the undeformed skin.
  - This gives some "rest pose" bone transformations $\mathbf{B}_j$



Bind Pose cont'd

- In the rigging phase, we line the skeleton up with the undeformed skin.
  - This gives some "rest pose" bone transformations $\mathbf{B}_j$
- We then figure out the vertex weights w_{ij}.
  - How? Often paint by hand!
  - Pinocchio was the algorithm that does this automatically



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Bind Pose cont'd

- When we animate the model, the bone transformations $\mathbf{T}_j$ change.

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Bind Pose cont'd

- When we animate the model, the bone transformations $\mathbf{T}_j$ change.
  - What is $\mathbf{T}_j$? It maps from the local coordinate system of bone *j* to object space.
    - Remember hierarchical modeling!

Bind Pose cont'd

- When we animate the model, the bone transformations $\mathbf{T}_j$ change.
  - What is $\mathbf{T}_j$? It maps from the local coordinate system of bone j to object space.
- To be able to deform $\mathbf{p}_i$ according to $\mathbf{T}_j$, we must first express $\mathbf{p}_i$ in the local coordinate system of bone j.
  - This is where the bind pose bone transformations $\mathbf{B}_j$ come in.

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Bind Pose cont'd

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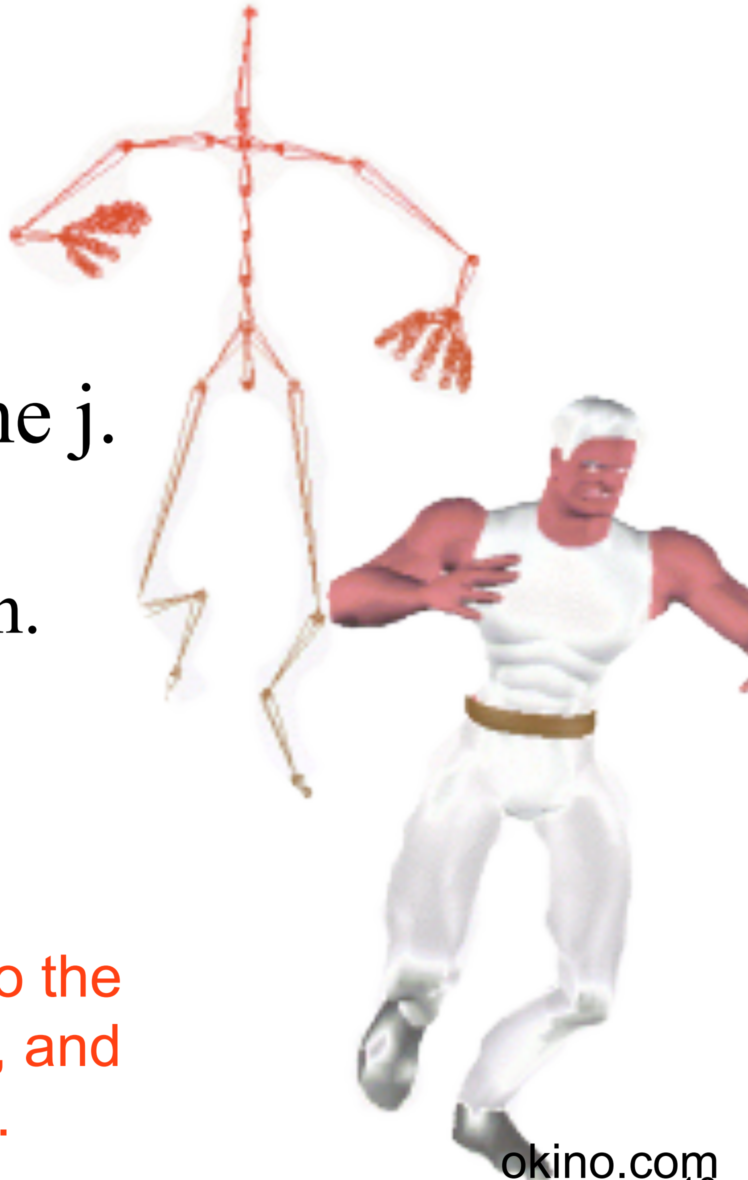
  - This is where the bind pose bone transformations $\mathbf{B}_j$ come in.

$$\boxed{\boldsymbol{p}'_{ij} = \boldsymbol{T}_j \boldsymbol{B}_j^{-1} \boldsymbol{p}_i}$$

This maps $\mathbf{p}_i$ from bind pose object space to the local coordinate system of bone j using $\mathbf{B}^{-1}_j$, and then to deformed object space using $\mathbf{T}_j$.



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What is $\mathbf{T}_j\ \mathbf{B}^{-1}_j$? It is the relative change between the bone transformations between the current and the bind pose.

Bind Pose cont'd

What is the transformation when the model is still in bind pose?

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Bind Pose cont'd

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The identity!

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What is $\mathbf{T}_j\ \mathbf{B}^{-1}_j$? It is the relative change between the bone transformations between the current and the bind pose.

Skinning Pseudocode

- Do the usual forward kinematics
  - maybe quaternion interpolation for rotations
  - get a matrix $\mathbf{T}_j(t)$ per bone
- For each skin vertex $\mathbf{p}_i$

$$\boldsymbol{p}'_i = \sum_j w_{ij} \boldsymbol{T}_j(t) \boldsymbol{B}_j^{-1} \boldsymbol{p}_i$$

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Remember from Lecture 2:
Normals must be treated differently!

Skinning Pseudocode

- Do the usual forward kinematics
  - maybe quaternion interpolation for rotations
  - get a matrix $\mathbf{T}_j(t)$ per bone
- For each skin vertex $\mathbf{p}_i$

$$\boldsymbol{p}_i' = \sum_j w_{ij} \boldsymbol{T}_j(t) \boldsymbol{B}_j^{-1} \boldsymbol{p}_i$$

- Inverse transpose for normals!

$$\boldsymbol{n}_i' = \left(\sum_j w_{ij} \boldsymbol{T}_j(t) \boldsymbol{B}_j^{-1} \right)^{-\mathrm{T}} \boldsymbol{n}_i$$

Skinning Pseudocode

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- For each skin vertex $\mathbf{p}_i$

$$\boldsymbol{p}'_i = \sum_j w_{ij} \boldsymbol{T}_j(t) \boldsymbol{B}_j^{-1} \boldsymbol{p}_i$$

- Note that the weights are constant over time
  - Only a small number of matrices change
  - This enables implementation on GPU "vertex shaders" (little information to update for each frame)

Hmmh...

- This is what we do to get deformed positions

$$\boldsymbol{p}'_i = \sum_j w_{ij} \boldsymbol{T}_j(t) \boldsymbol{B}_j^{-1} \boldsymbol{p}_i$$

Hmmh...

- This is what we do to get deformed positions

$$\boldsymbol{p}_i' = \sum_j w_{ij} \boldsymbol{T}_j(t) \boldsymbol{B}_j^{-1} \boldsymbol{p}_i$$

- But wait...

$$\boldsymbol{p}_i' = \left(\sum_j w_{ij} \boldsymbol{T}_j(t) \boldsymbol{B}_j^{-1} \right) \boldsymbol{p}_i$$

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- This is *exactly* what I warned you of earlier: blending matrices entry-by-entry (!!!)

Indeed... Limitations

- Rotations really need to be combined differently (quaternions!)

Figure 2: The 'collapsing elbow' in action, c.f. Figure 1.

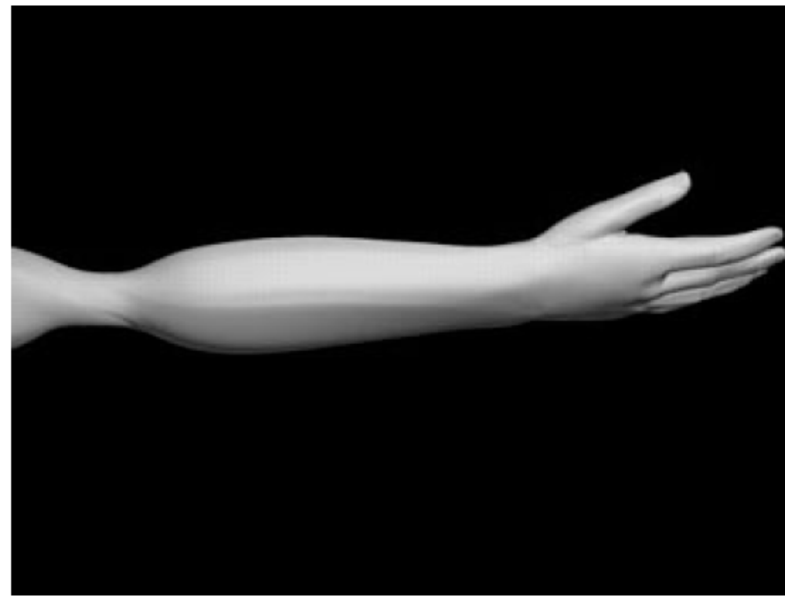


Figure 3: The forearm in the 'twist' pose, as in turning a door handle, computed by SSD. As the twist approaches 180° the arm collapses.

- From: Pose Space Deformation: A Unified Approach to Shape Interpolation and
- Skeleton-Driven Deformation
- J. P. Lewis, Matt Cordner, Nickson Fong

Dual Quaternion Skinning

The common skin deformation technique (linear blend skinning) sometimes produces non-natural results, such as below.

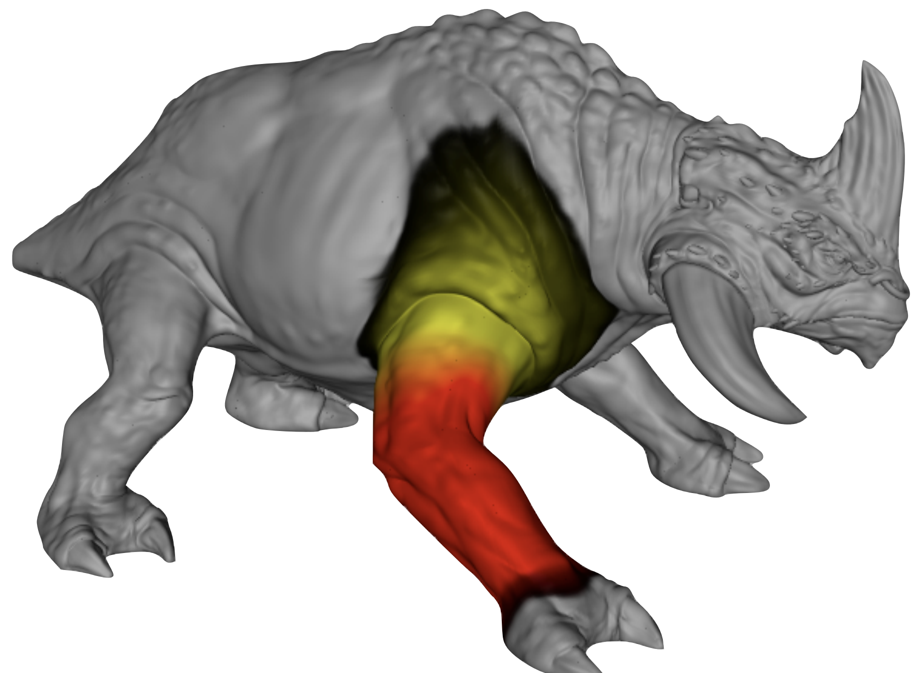
Several more advanced methods exist, but lead to slower run-time performance and require a more expensive character setup. Our approach, based on dual quaternions, removes the skinning artifacts at a small cost in computational efficiency and no cost at all in character setup. The result of our method is pictured below (using the same model files as above).

Usual Solution

- Have the artists deal with it O:-)
- In practice, build a rig that has extra bones near joints that move in sync to counter the artifacts.
  - Tedious, but this is what people often do.
  - Need sophisticated animation controls to drive this.
- Cool paper that does this automatically: Kavan, Collins, O'Sullivan: <u>Automatic Linearization of Nonlinear Skinning, I3D 2009</u>

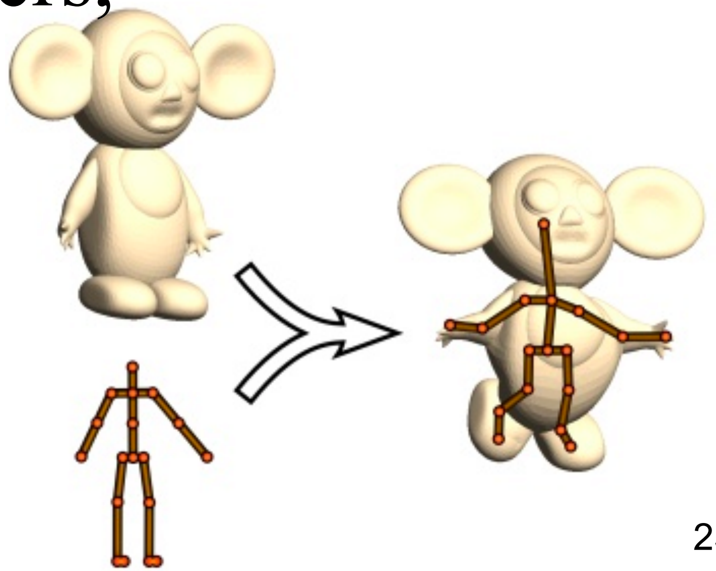
Figuring out the Weights

- Usual approach: Paint them on the skin.
- Can also find them by optimization from example poses and deformed skins.
  - Wang & Phillips, SCA 2002



Super Cool: Automatic Rigging

- When you just have some reference skeleton animation (perhaps from motion capture) and a skin mesh, figure out the bone transformations and vertex weights!
- Ilya Baran, Jovan Popovic: Automatic Rigging and Animation of 3D Characters, SIGGRAPH 2007
  - http://www.mit.edu/~ibaran/autorig/
- You saw this earlier



The Other Direction

- When you have no skeleton, but a source animation for the full mesh (not so common)

Skinning Mesh Animations

Doug L. James Christopher D. Twigg

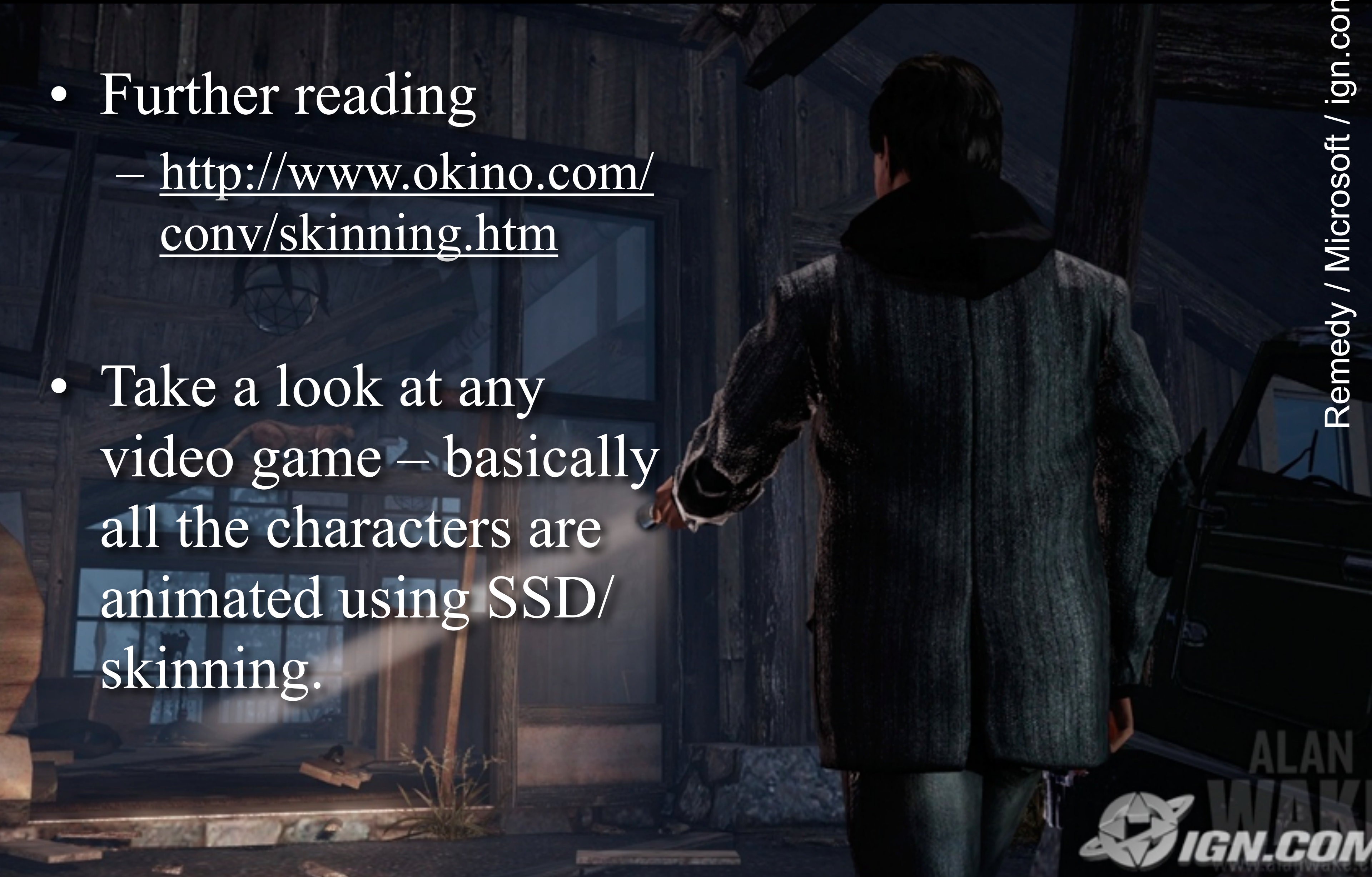
Carnegie Mellon University

igure 1: **Stampede!** *Ten thousand skinned mesh animations (SMAs) synthesized in graphics hardware at interactive rates. All SMAs are eformed using only traditional matrix palette skinning with well-chosen nonrigid bone transforms. Distant SMAs are simplified.*

That's All!

- Further reading
  - http://www.okino.com/conv/skinning.htm

- Take a look at any video game – basically all the characters are animated using SSD/skinning.



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