Pose to Pose Skinning of Animated Meshes

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Abstract

In computer animation, key-frame compression is essential for efficient storage, processing and reproduction of animation sequences. Previous work has presented efficient techniques for compression using affine or rigid transformations to derive the skin from the initial pose using a relatively small number of control joints. We present a novel pose-to-pose approach to skinning animated meshes by observing that only small deformation variations will normally occur between sequential poses. The transformations are applied so as a new pose is derived by transforming the vertices of the previous pose, thus maintaining temporal coherence in the parameter space, reducing error and enabling a novel forward propagated editing of arbitrary animation frames.

Categories and Subject Descriptors (according to ACM CCS): I.3.5 [Computer Graphics]: Computational Geometry and Object Modeling—Geometric Algorithms I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Animation

1. Introduction

Linear blend skinning (LBS) is a popular mesh deformation technique built around the observation that a quasi-rigid animation can be compactly described by its skeleton. Any vertex position in LBS is expressed as a convex linear combination of the vertex transformed by each influencing joint's coordinate system. In spite of its limitations, LBS is widely used in film animation and video games for animating articulated characters using efficient implementations on the gpu.

[JT05] (SMA - Skinning Mesh Animations) used LBS to approximately reproduce deforming characters as a function of the motion of mean shift bones resulting in reduced storage requirements, gpu-accelerated rendering and additional supported operations. Skinning components were extracted by employing bone data fitting. Extending this work, [KMD*07] (SAD - Skinning Arbitrary Deformations) presented a *dual quaternion skinning* based scheme that can compute approximations for arbitrary animations, without relying on quasi-rigid components by suggesting that uniformly selected vertices on the mesh can act as bones. Moreover, these methods allow limited editing of the mesh animation sequence by either (non-inherited) pose editing modifying the bone transformations or propagating small changes of the rest-pose geometry over the rest of the animation. Recently, [KSO10] (FESAM - Fast and Efficient Skinning of Animated Meshes) introduced a novel algorithm based on iterative coordinate descent optimization supporting both skeletal and highly deformable animations. Despite of its fast and efficient behaviour, only restricted pose editing can be supported since spatial coherency is not preserved in the weight space. Moreover, FESAM does not facilitate rest pose editing since its fitting scheme requires iterative modifications on the rest pose.

We introduce a novel pose-to-pose skinning technique that aims at preserving temporal coherence. This scheme results in reducing the approximation error and further supporting arbitrary propagated pose editing. Editing can then be smoothly propagated at the subsequent frames generating new deforming mesh sequences without altering the skinning representation.

2. Temporal Coherent Fitting

Describing the movement of highly deformable objects requires the use of affine transformation matrices to capture deformations other than rotation and translation. A linear blend skinned vertex position v_i^p for a pose p is computed using B number of weights per vertex $\left[w_{1,i}, w_{2,i}, \ldots, w_{B,i}\right]$ and B transformation matrices $\left[M_1^p, M_2^p, \ldots, M_B^p\right]$: $v_i^p = T_i^p v_i$, where $T_i^p = \Sigma_{b=1}^B w_{b,i} M_b^p$ and v_i is the position of vertex i at the rest pose. The vertex weights determine the bones that influence a vertex and are normally considered to be convex: $\Sigma_{b=1}^{B} w_{b,i} = 1$ and $w_{b,i} \geq 0$. A formulation for the problem of skinning approximation can be stated as minimizing: $\Sigma_{i=1}^{n} \left\| \mathbf{v}_i^p - v_i^p \right\|^2$, where $\mathbf{v}_i^p, i \in \{1,\ldots,n\}, p \in \{1,\ldots,P\}$ correspond to the original n vertex positions of the input animation sequence consisting of P poses.

Previous approaches compute the transformation matrices that describe the transition from the rest-pose to an arbitrary pose of the animation sequence. While these fitting techniques perform well for a variety of deformations, artifacts tend to be the more persistent the farther a deformation deviates from the rest-pose shape. Thus, we exploit temporal coherence by observing that only small deformation variations will normally occur between sequential poses. We reformulate LBS equation to handle a pose-to-pose deformation scheme using the following formula:

$$v_i^p = \sum_{b=1}^{B} w_{b,i} Q_b^p v_i^{p-1}, \tag{1}$$

where Q_b^p are the affine matrices of the proxy joint b that weighted derive a vertex of pose p from pose $p-1$. Note that transformations Q_b^1 are used to derive the skin vertices of pose 1 from the rest pose. The fitting of pose-to-pose transformations can be performed in the same way as with the rest-pose scheme. Although fitting is performed from pose to pose, a reproduction scheme from the rest pose to an arbitrary pose can be produced efficiently by using the following recursive formula for defining the T_i^p matrix: $T_i^p = \left(\Sigma_{b=1}^{B} w_{b,i} Q_b^p\right) T_i^{p-1}$, where T_i^p at the rest-pose corresponds to the 4×4 identity matrix.

3. Animation Editing

Similar to displacement editing presented by SMA, geometry editing defined in the reference pose to be automatically propagated at the subsequent poses is allowed. However, previous methods further optimize skinned approximations using rest-pose displacement corrections [KJP02], limiting users to perform efficient editing on the original reference mesh. On the other hand, our pose-to-pose scheme can handle efficient editing of arbitrary key-frames with the extra cost of recomputing the transformation fitting moving to the newly edited pose from its previous one.

Let p_e be the edited pose and $\widetilde{Q}_b^{p_e}$ the matrix that transforms pose $p_e - 1$ to the edited one. An LBS representation is computed for all poses after the edited one using the following formula:

$$T_i^p = T_i^{p,p_e-1} \left(\sum_{b=1}^{B} w_{b,i} \widetilde{Q}_b^{p_e} \right) T_i^{p_e-1,1}, \tag{2}$$

where $T_i^{t_0,t_1} = \prod_{t=t_0}^{t_1} \left(\Sigma_{b=1}^{B} w_{b,i} Q_b^t\right)$.

4. Discussion

While switching to the pose-to-pose scheme reduces the approximation error (see Figure 1) and can support editing tools with much more capabilities as compared to the rest-pose scheme (see Figure 2), there are some limitations that should be addressed. The proposed scheme cannot be implemented in parallel due to the sequential nature of the fitting process. Also, as opposed to other methods, temporal fitting is non-iterative making it harder to converge to the optimal solution. Moreover, skinning approximation flaws that occur in a single pose may be propagated to all subsequent poses due to the sequential nature of the fitting process. Finally, editing correction techniques should be explored that aim at fitting edited poses to the initial animation sequence (for example global scale editing).

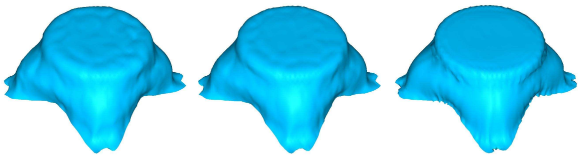

Figure 1: *Illustrating the differences of the uncorrected SAD approximation poses computed with (left) rest-pose and (center) temporal fitting with (right) the original pose.*

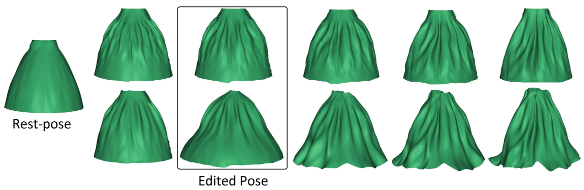

Figure 2: *(top row) The original animation sequence. (bottom row) The result of editing the second pose and subsequently applying the pre-computed pose-to-pose transformations.*

References

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