Enhanced Dual Quaternion Skinning for Production Use

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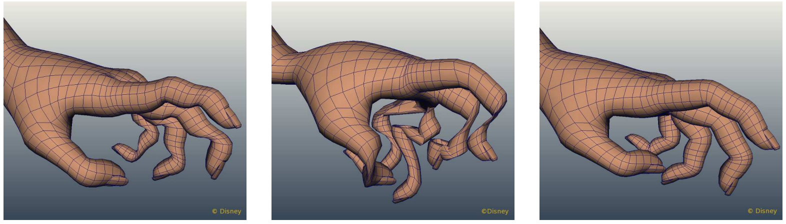
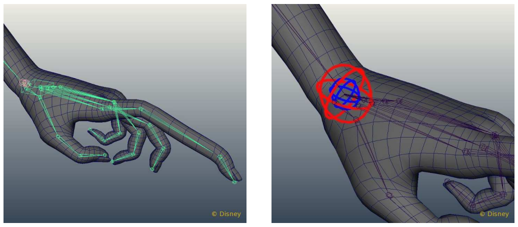


(a) *No scale support* (b) *Partial scale support* (c) *Full scale support*

Figure 1*: DQS and Non-Rigid Transformations*



(a) *Scale Compensation* (b) *Support Joint in Blue*

Figure 2*: DQS Handling Other Joint Types*

1 Introduction

Dual Quaternion Skinning (DQS) is an advanced rigging technique that binds a mesh to skeletal joints. Unlike the popular alternative, Linear Blend Skinning (LBS), DQS avoids the undesirable "candy-wrapper effect" and effectively simulates volume preservation. DQS is a powerful technique, but to get desirable results, it must be extended to meet the needs of production environments, and is therefore not a simple drop-in replacement for LBS.

This paper presents an extension to DQS that successfully met the rigging requirements of Disney's feature *Frozen*. In particular, DQS is configured with LBS to handle non-rigid transformations, hierarchies of differing joints, and arbitrary support joints. This approach made it possible to fully realize the benefits of DQS in practice.

2 Production Requirements

Non-Rigid Transformations "Squash and stretch" is a fundamental animation technique. Unfortunately, the necessary scale and shear operations are not easy to perform with DQS since it inherently handles only rigid transformations, i.e. translation and rotation. Figure 1a shows DQS failing badly when scaling is applied.

Extending DQS to support non-rigid transformations directly is a challenge since it potentially requires the use of high-dimensional algebra. A practical approach is to perform skinning in two phases. In the first phase, the rest-pose mesh is inflated with non-rigid transformations via LBS. In the second phase, DQS uses the rigid parts of these transformations to bend the inflated mesh into shape.

Several ways exist to separate a joint transformation into rigid and non-rigid parts. For DQS, it is insufficient to simply extract the scale and shear elements of each transformation independently. This approach processes rotations incorrectly, and also assumes all joints process scale similarly. What results is an improper handling of scale and shear, as shown in Figure 1b.

A better way, as outlined in [Kavan et al. 2008] and extended here, is to progressively process joints according to the scaling and shearing components of their parents. The first phase is performed without rotations and the second phase operates with purely rigid transformations. This approach requires a large set of matrix concatenations, however it is possible to implement these operations such that runtime performance is nearly equal to that of LBS. The image in Figure 1c shows enhanced DQS handling scale correctly.

Hierarchies of Differing Joints Production rigs commonly intermix two types of joints, compensating and non-compensating. The former negates the scaling influence of its parent, while the latter does not. As shown in Figure 2a, this difference permits joint transformations to apply scale to all descendents or to a single bone.

The two-phase approach presented by Kavan assumes all joints are scale compensating. Extending this approach to handle both types is done by creating M, a temporary matrix for each joint, that varies according to the joint's parent. If the parent is compensating, M scales the translational part of R, the joint's bind pose matrix relative to its parent, by the parent's scale and shear. Rotation is kept intact. If the parent is non-compensating, M scales and shears R completely and then removes non-rigid components. Finally, each joint is separated into non-rigid and rigid matrices, J_n and J_r. The first phase multiplies each M with J_n to perform LBS, while the second phase multiplies each M with J_r to perform DQS. Figures 1c and 2a show DQS handling the intermixing of the two joint types.

Arbitrary Support Joints Production rigs also contain support joints, which are either parts of constraints or functional enhancements. These joints indirectly influence a mesh's shape. They are rarely bound, and, in some instances, are intentionally omitted to avoid duplicate transformations. In Figure 2b, the blue and red joints link the arm to the hand via a constraint. They are linked hierarchically, but only the red joint is actually bound to the mesh.

The two-phase approach, unlike LBS, must bind a mesh with support joints to handle non-rigid transformations. The first phase uses a selection of support joints while the second phase uses none. Support joints are selected if they influence the inflation process. For efficiency and consistency, support joints are best bound separately and selected automatically. This approach encourages the use of conventional joint bindings and ensures the proper selection of support joints.

3 Experience

There are several benefits to this enhancement of DQS. First, it supports easy replacement of conventional LBS with DQS, despite their differing mechanics. Joints can be stretched and squashed in extreme directions, and all bind pose configurations are accepted. Second, it reduces the number of joints found in troublesome areas, such as limbs. Extra joints for resolving the deficiencies of LBS and conventional DQS are now unnecessary. Third, it simplifies cleanup methods that address the same deficiencies, but with a focus on creating aesthetic improvements, not fixing flaws.

References

Kavan, L., Collins, S., Zara, J., and O'Sullivan, C. 2008. Geometric skinning with approximate dual quaternion blending. ACM, New York, vol. 27, 105.

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