Deformation Techniques

Exploring the Blending of Free-Form Deformation and Linear Blend Skinning

A research proposal by Stuart Bryson

Project Summary

Animation films involving 3D characters are becoming increasingly popular with both audiences and the studios producing them. Producing believable and expressive animated deformations of these characters is still a time consuming process. We propose a method that combines free-form deformations (FFD) and linear blend skinning (LBS) to help increase the animators efficiency while still giving them the control and flexibility they require to reach their artistic goals. While FFD and LBS are widely used in the industry, our method is unique as it allows both FFD and LBS to affect the deformation of the character in an animator controllable manner.

Aims

Full-feature 3D animation films are becoming increasingly popular with both audiences and the studios producing them. The majority of these 3D animations contain articulated characters that must achieve believable and engaging animation. Production studios and software developers have taken many different approaches to how this animation is achieved and each approach has brought pros and cons.

The role of the animator is to create not just realistic animations, but also expressive and dramatic animations, of these 3D characters. Often an animator will want to step outside the bounds of physical possibility in order to achieve their artist goals. In order to animate these characters, the animator must use a variety of tools to deform the 3D model.

There are many deformation techniques available. Some of these techniques provide outstanding results but offer the animator little room to manipulate the expression and dramatic side of the character. Examples of these usually occur in the physical simulation models of animation. Conversely, other techniques that provide a vast array of controls can often slow the animator down. The aim of these deformation techniques is to increase the efficiency of the animators' workflow. A deformation technique is of little value if it provides so many controls that it actually decreases the efficiency of the animator.

Not only is it important to obtain the balance between control and efficiency with the deformation technique, it is also important to abstract the animator from the implementation of the characters geometry. Common techniques for modelling 3D characters include Polygonal, Non-Uniform Rational B-Splines or NURBS and Sub-Division Polygonal modelling. Providing the animator with a common technique for animation of these modelling techniques will not only mean the animator is not required to understand how the model was modelled, but also liberates the modellers from any constraints the animators may have placed on their modelling techniques. Some deformation techniques already provide this abstraction, where as others are tightly coupled with the modelling.

Currently there is no deformation technique that achieves both these goals. We aim to determine a good balance between animator control and efficiency. The technique we will develop will provide the animator with the appropriate amount of control, enabling them to achieve dramatic and expressive animations, while still maintaining an efficient workflow that does not needlessly slow the animator. Further, the technique we will develop will not be tied to any modelling technique and therefore will free the animator from any required geometric understanding.

Our method will be evaluated based on both the outcome of the method; how believable or engaging the deformation is, and also the usefulness of the tool from the animators' point of view; how useful and efficient the tool is in aiding the animator in achieving their artistic goals. We believe that both of these outcomes are just as important as each other. An effective deformation technique is useless if it cannot be used in an industrial setting. Just as useless is a tool that is really easy to use but produces poor results.

Background

There are many approaches to deformation of animated 3D characters. Deformation ultimately alters the shape and topology of the geometry. Some deformation techniques are specific to the mathematical model of the geometry and cannot be applied to other models, other techniques are flexible enough to be used on different models. Further, different techniques are more appropriate for animation rather than just the single shape model.

Common Techniques

Some of the most common deformation techniques include Free Form Deformation, Linear Blend Skinning, Shape Interpolation and Physical Simulation.

Free Form Deformation

Free Form Deformation or FFD is a deformation technique initially described by Sederberg and Parry (Sederberg and Parry, 1986). Essentially, FFD places a lattice around the geometry and creates a deformable space using a trivariate Bézier volume defined by the points of the lattice. The lattice has an arbitrary number of divisions in 3 axes and will be defined according to the expected deformations.

Using this lattice, the artist can sculpt the geometry using the lattice control points. The lattice can be applied to virtually any mathematical model. Before techniques such as FFDs that provide an abstraction layer, artists have had to consider the mathematical model of the surface they are modelling and use specific techniques to modify the model. Each surface type would have different parameters that could be modified by the artist (MacCracken and Joy, 1996, p. 181). Using FFDs, the artist is able to sculpt each model in the same manner. As noted by Sederberg and Parry, FFDs are particularly useful for the artist due to its sculpting metaphor.

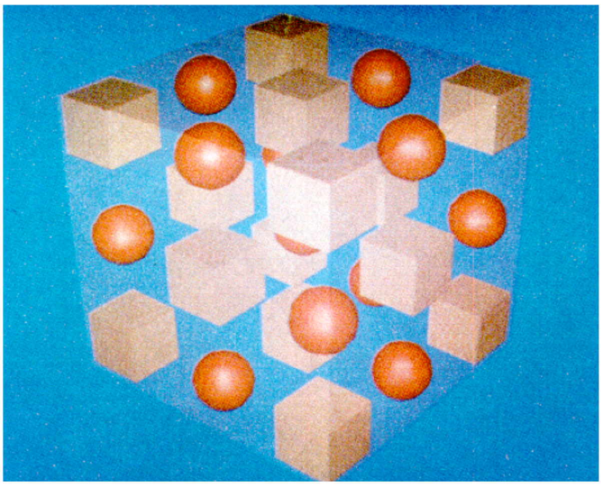

Fig 1. Undeformed Plastic (Sederberg and Parry, 1986, p. 152)

FFD can be used with many modelling techniques including Constructive Solid Geometry or CSG, "as well as those using Euler operators" (Sederberg and Parry, 1986, p. 152) and is not limited to solid geometry but can be used to deform surfaces. Indeed the most common use of FFD nowadays is the deformation of surfaces. Further, FFD can deform models defined by any analytical surface including "planes, quadrics, parametric surfaces patches, or implicit surfaces" (Sederberg and Parry, 1986, p. 152).

Sederberg and Parry give the analogy for FFD in which a clear plastic cube with other embedded geometry is deformed using a FFD lattice. See figure 1.

They defined the mathematics of the deformation as a trivariate Bernstein polynomial in which any point in the lattice can be defined in local co-ordinates and, using a set of control points, can be substituted into the polynomial to find its new position.

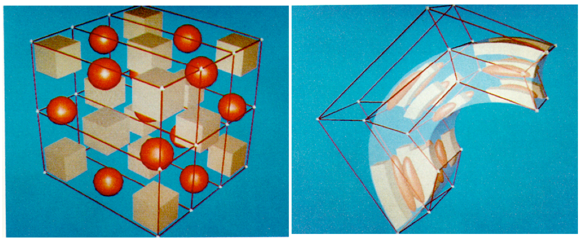

Fig 2. Non-deformed (left) and deformed (right) Control Points (Sederberg and Parry, 1986, p. 153)

Figure 2 shows the lattice and how the control points have been modified. Figure 3 shows the resulting deformation.

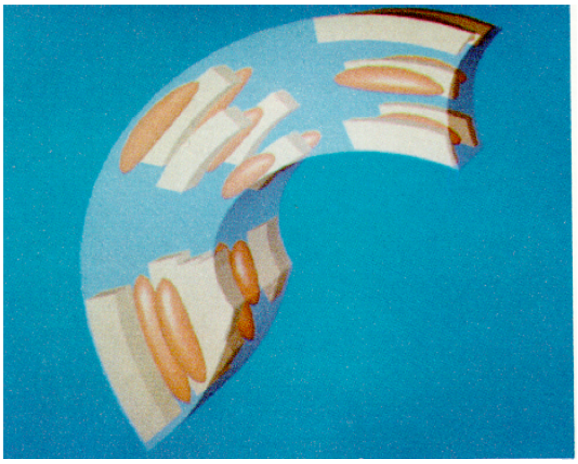

Fig 3. Deformed plastic (Sederberg and parry, 1986, p.153)

Hirota et al. extended FFDs by imposing a physical constraint on the deformation. They added the constraint of volume preservation. Indeed they claim “manipulation … of geometric models should … be compliant with the laws of physics” (Hirota et a., 1999, p. 234). This method allows artists to retain the relative proportions of a model. In fact, the authors claim this is well suited to implementing the standard squash and stretch principles of animation.

While Sederberg and Parry and others (Griessmair and Purgathofer) require a parallelepiped lattice, MacCracken and Joy implemented FFDs with lattices of arbitrary topology (MacCracken and Joy, 1996), generalising the original FFD approach. This allows FFDs to be more amenable. Using Catmull-Clark volumes, different lattice shapes can be achieved including a star shaped lattice.

Still others have tried approaches that do not involve parallelepiped lattices at all. Hua and Qin use scalar fields as the embedding spaces (Hua and Qin, 2003). The artist can interact with the system by sketching the scalar field.

There are still many other FFD techniques that are beyond the scope of this paper (Chang and Rockwood, 1994; Coquillart, 1990; Coquillart and Jancéne, 1991; Faloustos et al. 1997).

Some researchers have combined FFD with other deformation techniques. One example is combining physical simulation, skeletons and FFDs (Capell et al., 2002). Another approach of particular note is the research of Chadwick et al. (1989). In their research, FFDs “provide the foundation for [their] deformations” (Chadwick et al., 1989, p. 244). Building upon FFDs, the authors create an animated character using various layers to create the desired animation. A skeletal layer is used for animation, however, unlike Linear Blend Skinning that is discussed below, the skeleton layer does not perform any deformation. One aspect of their method is the ability to “capture the fluid squash and stretch behaviour” (Chadwick et al., 1989, p. 245). This squash and stretch of the muscles is implemented using FFDs.

Linear Blend Skinning

A popular way to animate articulated figures, that is, characters with an underlying skeleton, is to animate a skeleton. This is because the skeleton is the most dominant influence on a figures pose.

While animation of a skeleton is the most convenient way to animate a figure, it leaves the problem of how to deform the actual characters geometry as the skeleton moves. A common technique for doing this is called Linear Blend Skinning.

LBS starts with the basic skeleton defined as a simple joint hierarchy. A piece of geometry or ‘skin’ is then placed around the skeleton. See figure 4.

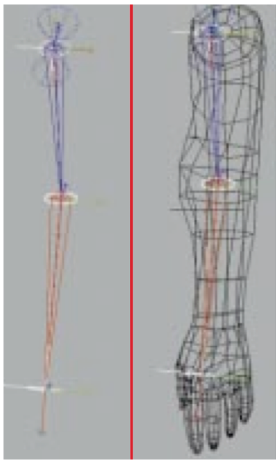

Fig 4. Arm Skeleton (left) with skin applied (right) (Lander, 1998, p. 11)

The geometry must then be skinned to the skeleton. With LBS, this is a straightforward process. Essentially, each vertex has a number of weights that associate it with one or more bones in the skeletal hierarchy. Each vertex position is calculated as the sum of each weight * bone matrix. As the skeleton is modified and each bones matrix changes, the vertex positions move according to their weighting on each bone.

Animation of the character then becomes a simple matter of key-framing each bone in the hierarchy.

Linear Blend Skinning has been used in various software packages and games since the mid 1990s. Lander, however, was the first to publish the basic principles of LBS (Lander, 1998; Lander 1999).

Unfortunately there are many problems with LBS. Webber points out the most common problem with LBS (Webber, 2000, p.9), often known as the collapsing elbow or candy-wrapper effect. This problem arrises when the elbow, or any other geometry section, twists so far that the LBS algorithm causes the vertices in the middle to collapse. See Figure 6.

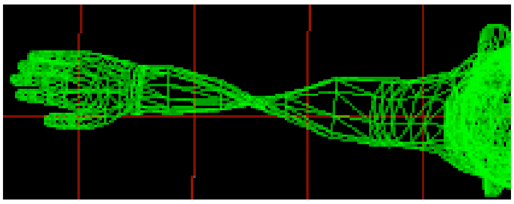

Fig. 6. Twisting Elbow (Webber, 2000, p. 10)

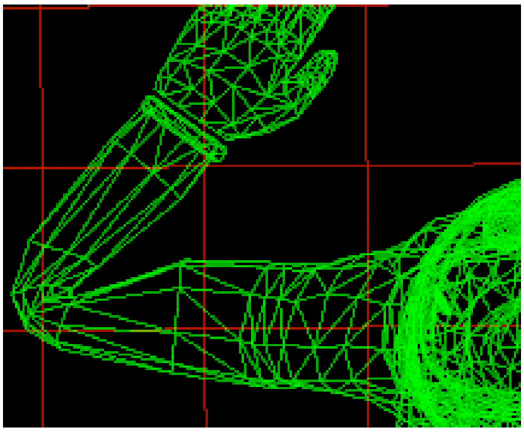

Fig. 7. Bending Elbow (Webber, 2000, p. 10)

This is not just limited to rotation in the twist axis but other axes too. See Figure 7.

Webber showed that adding auxiliary joints improved the results but more set-up is required.

Some authors have generalised LBS by adding more parameters increasing the control the animator has over the deformation (Wang and Phillips, 2002). Its also possible to use auxiliary structures such as the medial to help reduce these artefacts (Bloomenthal, 2002). Different algorithms, such as Spherical Blending, may also alleviate the problems (Kavan and Zára, 2005).

Others have acknowledged the limitations of Linear Blend Skinning. Lewis et al. refer to LBS as Skeleton-Subspace Deformation or SSD (Lewis et al., 2000). They detail the aforementioned problems along with other underlying issues of LBS/SSD. They show that the desired deformations for shoulders and elbows are not achievable regardless of well-tuned vertex weights.

As mentioned, Chadwick et al. use a skeleton layer for their construction of characters, however they do not use LBS. Instead, the skeleton is used to drive a set of FFDs.

Alternative Deformation Techniques

More briefly, two other deformation techniques worth mentioning are shape interpolation and physical simulation. While these techniques are commonly used for animation of 3D characters, we do not believe they are as appropriate for our aims.

Firstly, shape interpolation is an animated deformation technique whereby the artist must model various poses or shapes. The various poses are then interpolated to achieve new poses and also the animations in-between. The blending is achieved by linearly interpolating each control-point or vertex in the mesh. This provides an infinite amount of possible shapes and poses for the animator to choose from.

For this reason, shape interpolation is usually used for facial animation of 3D characters. There are many examples of this (Bergeron and Lachapelle, 1985; Maestri, 1999). Indeed, Lewis et al. make the observation that the entertainment industry usually uses LBS for the deformation of the body and shape interpolation for the facial animation (Lewis et al, 2000, p.165).

A key point with shape interpolation is that it requires the animator to have a mathematical understanding of how the geometry was modelled. In fact, the animator must model each pose and therefore requires an understanding of the geometric implementation.

Secondly, physically simulated animation is a popular area of research as it provides an accurate representation of real world behaviour. Indeed some authors claim “physical simulation is central to the process of creating realistic character animation” (Capell et al., 2002).

Essentially, physical simulations use physical laws to introduce constraints and forces onto the 3D character. The most common method is the use of continuum elasticity first introduced by Terzopoulos et al (Terzopoulos et al., 1988). The main benefit of physical simulations is that much of the realistic secondary motion is automatically given to the animator.

Conversely however, these motions are generated from physical constraints that prevent the animator from modifying these motions and creating their own expression.

Approach

3D character deformation is an active research area and there are many avenues to investigate. Following is a detailed description of the approach that we will take.

We propose a method combining FFD with LBS to allow the animator additional flexibility to help alleviate the visual artefacts often introduced by LBS and also to allow deformation of the geometry from more than just the pose of a skeleton.

We do not consider physical constraints such as volume preservation or animation simulations appropriate. These methods place considerable constraints on the animator that restricts the animator from achieving dramatic or expressive animations. While these animations may be outside the realm of physical possibility, ultimately the animator should have the freedom to create these animations if it is their artistic goal.

We also do not consider shape interpolation appropriate. Shape interpolation requires the animator have an intimate knowledge and understanding of the implementation details of the geometry. That is, if it is modelled with polygons or Non-Uniform Rational B-Splines for example.

Combined Method

There are many different ways in which FFDs and LBS could be combined. One way might be to use FFDs to determine the weights of LBS. Once the weights have been determined from a set of well-defined poses, the FFDs could be removed and all deformation would be driven by LBS.

Chadwick et al. used a combined method, however in their method, there was no LBS deformation. Instead, they used a skeleton to drive the FFDs.

Our method will deform the mesh according to both an FFD and an LBS input. The proposed technique works as follows.

The 3D character is comprised of a series of bones that combine to make a skeletal hierarchy.

An FFD is associated with each bone. The world transformation of each FFD will be constrained to that of the corresponding bone. We will call this correlation of bone and FFD a *section*.

The geometrical deformation for each section is then determined by both the LBS deformation and the FFD. The animator determines the amount of influence that each deformation technique has over a particular section.

Figure 8a and 8b illustrate this principle. The yellow grid shows the 2 FFD lattices. The red lines indicate the 2 bones in this hierarchy. The blue lines indicate the cylindrical geometry that is

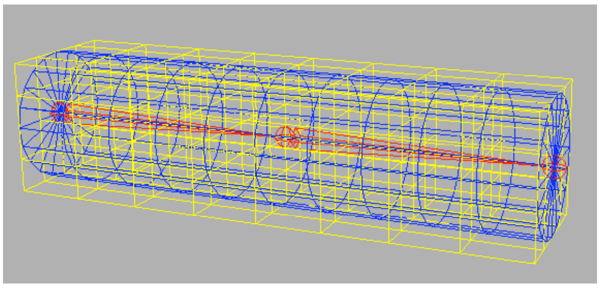

Fig. 8a Undeformed cylindrical mesh skinned to two joints and two FFDs

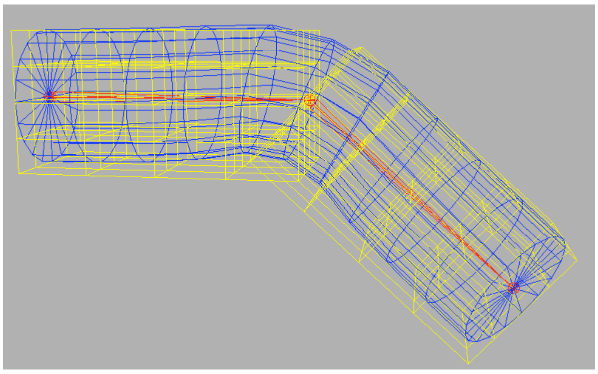

Figure 8b. As a joint rotates, the mesh is deformed by LBS and the transform of the second FFD is rotated to match the joint

to be deformed.

Each section will have a blend value. The animator will control this blending using a value between 0 and 1. 0 indicates the deformation will be calculated using purely LBS. 1 indicates the position will be calculated using only FFD.

The resulting vertex or control-point position of the geometry will be calculated as follows. First, the position will be calculated using LBS, LBSp, then the position will be calculated using the FFD, FFDp. Finally, the blended position of these, p’, will be calculated using the blend factor, b. The equation is as follows:

$$p' = LBSp * (1 - b) + FFDp * b$$

Figure 9a shows a cylindrical mesh being deformed by LBS only. Figure 9b shows the desired effect of blending LBS with FFD.

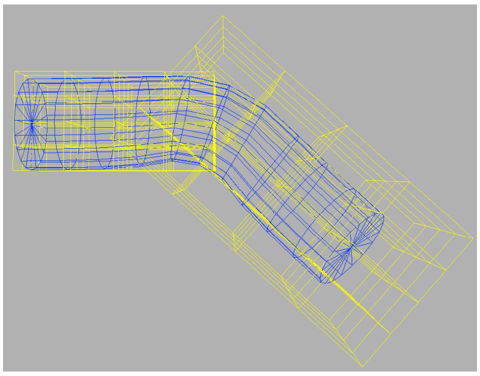

Figure 9a. A cylindrical mesh deformed by LBS only.

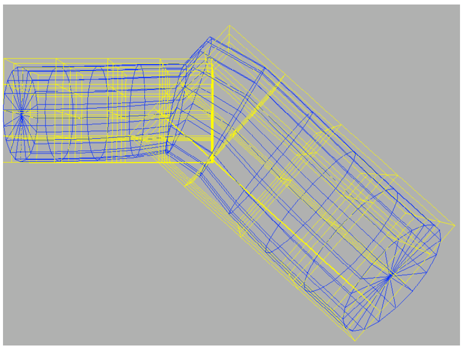

Figure 9b. A cylindrical mesh deformed by LSB and FFD.

The deformed geometry in Figure 9b shows that it is being influenced by both LBS and FFD. If it were purely FFD, the affected section of the cylinder would be more orthogonal.

As the FFD will use the same transform as the bone it is attached to, even when the inputs are fully blended to FFD, the region of mesh affected by the FFD will still be in the correct location.

Hua and Qin claim that using blending functions with FFDs is counter-intuitive but do not elaborate any further (Hua and Qin's, 2003, p. 329). In fact, blending functions have been used throughout many areas of 3D deformation and animation (Kovar et al., 2003; Deng et al., 2006; Mukai and Kuriyama, 2005). Having informally discussed our idea with a number of animators, we believe that blending functions for deformation of animated characters can be readily adapted in practice.

Implementation

AutoDesk Maya® is the industry standard for 3D character animation. It is used throughout the film industry and, with ever-increasing amount, the games industry.

For this reason, we believe Maya is the best platform for development and evaluation. There will be no difficulty in finding animators suitable for the evaluation of our method.

Maya is easy to develop for. It has a strong developer community and a clean, well-defined API. In fact, much of the advanced features of Maya are implemented initially as 3rd party plug-ins that AutoDesk, and previously Alias, have been licensed for use. Further, studios will often develop their own plug-ins for internal use.

The authors also have familiarity with Maya and developing plug-ins for it.

Evaluation

We will use qualitative analysis to evaluate the effectiveness of our approach. Our methodology will be a case study on 5 animators. We will use observation, interviews and surveys to evaluate our approach.

We will not use any quantitative methods for evaluation. The nature of the study, aims and outcomes do not lend themselves to any useful quantitative data.

Our case study will involve 5 different animators who are previously familiar with Maya and 3D character animation. We will provide them with 3 tasks, each used to help identify if an aim was achieved.

We will analyse these tasks in three separate phases. These are observation, survey and results analysis. We will then spend some time integrating the outcomes of these methods.

Tasks

The 3 tasks we will give to the animators are as follows

- The animators will be given a 3D character that has already been 'rigged', that is, set up with both LBS and FFDs. Using this set-up, the animators will be required to animate the character in front of mirror at the gym, flexing their muscles. This task will help identify the flexibility and animator control of the tool.
- The animators will be required to animate an overweight character sitting onto a chair that gives way and the character falls to the ground – their body fat should bounce and jiggle as the overweight character lands on the ground. Once again, helping to identify how much control the animator has.

- Lastly, the animators will be asked to rig their own character using the tools provided. This task will help determine the efficiency of the workflow.

Observation
As the animators are performing these tasks, we will observe their behaviour. The observation will be performed using the unobtrusive 'observer-as-participant' method. That is, the animators will be aware of our observation but we will not interfere with their activities.

Through these observations we will determine how effective the method is at providing an efficient workflow that does not needlessly slow the animator. We will be specifically taking notes on areas such as:

- How quickly the animator can achieve an outcome
- How effective the animator is in using the tools
- How much time or concentration it takes the animator to achieve certain effects – such as the squash and stretch on the characters muscles
- Can the animator achieve their artistic goals
- Is the animator needlessly slowed or frustrated by the method

Survey
Upon completion of the tasks, we will ask the animators to fill out a survey that will further determine the animators' perception of the tool and its effectiveness according to the original aims.

The survey will be an in-depth qualitative survey that will help determine both the efficiency of the tool but also the effectiveness of the deformations.

The animators will be asked similar questions to both the observation phase and the following results analysis stage. It will provide the animators with ample opportunity to express their opinions on our method.

Results Analysis
While the observation phase of our methodology was focused on determining the usefulness of the method to the animator, this phase is entirely focused on the effectiveness of the deformation itself.

The results of the first two animator tasks will be used to determine how believable and engaging the deformations are. We will be specifically looking for:

- Good continuity between the geometry affected by an FFD and neighbouring geometry that is only affected by LBS
- Good blending between the influences of both FFD and LBS. Particularly when this blend factor is key-framed across many frames
- No unexpected artefacts such as twisting or popping of geometry

Integration
Key to our methodology is the integration of the three phases of our evaluation.

As the data in all three phases is qualitative data, this integration is key to identifying and accepting the trends and also the reluctance or trepidation towards outcomes that are only supported by 1 phase.

The observation and survey phases will help evaluate our first aim: to provide an efficient workflow for animators, while the results analysis and survey stage will help evaluate our second aim: to develop an effective method for 3D character deformation.

Significance, Innovation and Benefits

We propose a unique method that will provide the animator with a good balance between flexibility, control and workflow efficiency.

We believe that our method will provide extensive animator control. The FFD will give the animator the control to create squash and stretch effects that is one of the fundamental principles of animation.

We are not employing any physical simulation that places various physical constraints on the animator. These constraints do not allow the animator the freedom to express themself or the character outside the physical domain. Often 3D characters are quite clearly beyond the realm of physical constraints.

The animator will have the ability to blend the use of FFD and LBS. At any stage during the animation, the animator will be able to key-frame this blend value. For example, this will give the animator the freedom to use LBS as the default and when they desire some muscle bulging, they can key-frame the FFDs influence over the biped region to the desired level. When the bulging is finished, they can then key-frame the FFDs influence back to 0.

One of the main benefits of our research is that it will be developed as a Maya plugin. As mentioned previously, Maya is the industry standard for 3D character animation. Not only does the popularity of this tool facilitate our research, but if successful, our tool will be able to reach a very large audience of animators.

Strategy for Communication of Results

We will publish a technical report to disseminate our results. The report will detail our method, implementation details and evaluation methodology. It will provide the reader with clear benefits of our deformation technique and areas for any future research.

This produced technical report will be submitted to both local and international graphics conferences. Two of the most common conferences include the SIGGRAPH conference and also the Eurographics conference. Most of the references provided in this report come from publications of these conference proceedings.

Personnel

The personnel required for this research will be the author and their supervisor and will take approximately 4 months to complete.

The research will involve the author implementing the given method as a Maya plugin, rigging and testing characters using the plugin, and finally performing the evaluation with the input of professional animators.

The author has an extensive amount of experience in developing plug-ins for Maya. They have a keen understanding of graphics and particularly 3D character rigging, deformation and animation.

This research will be performed as part of the authors Masters of Science in Professional Computing at University of Technology, Sydney.

The authors' supervisor will be required during this time to give guidance and suggestions as the implementation unfolds and upon completion of the implementation, assisting in the research evaluation.

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