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Morph targets and bone rigging for 3D facial animation

A comparative case study

Author: Niklas Larsson

Faculty of Arts
Department of Game Design

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Program: Speldesign och grafik

Supervisor(s): Ulf Benjaminsson, Iwona Hrynczenko
Examiner: Steven Bachelder

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Abstract

Facial animation is an integral and increasing part of 3D games. This study investigates how the two most common methods of 3D facial animation compare to each other. The goal of this study is to summarize the situation and to provide animators and software developers with relevant recommendations.

The two most utilized methods of facial animation; morph target animation and bone driven animation are examined with their strong and weak aspects presented. The investigation is based on literature analysis as well as a comparative case study approach which was used for comparing multiple formal and informal sources according to seven parameters such as: performance, production time, technical limitations, details and realism, ease of usability, cross platform compatibility and common combinations of systems.

The strengths and weaknesses of the two methods of 3D facial animation are compared and discussed followed by a conclusion part which present recommendation to which is the preferable method to use under different circumstances. In some cases, the results are inconclusive due to a lack of data. It is concluded that a combination of morph target and bone driven animation will give the most artistic control if time is not limited.

Key words: Computer games, 3D animation, facial animation, morph target, bone driven

Abstrakt

Ansiktsanimering är en integrerad och ökande del av 3D-spel. Denna studie jämför de två vanligaste metoderna för 3D-ansiktsanimering med varandra. Målet med denna studie är att sammanfatta situationen och ge animatörer och programutvecklare relevanta rekommendationer.
De två mest använda metoderna för ansiktsanimering; morph target animation och bone driven animation undersöks och deras starka och svaga aspekter presenteras. Undersökningen är baserad på litteraturanalys samt ett jämförande fallstudie-tillvägagångssätt som användes för att jämföra flera formella och informella källor enligt sju parametrar såsom prestanda, produktionstid, tekniska begränsningar, detaljer och realism, användarvänlighet, korsplattform kompatibilitet och vanliga systemkombinationer.
Styrkorna och svagheterna hos de två metoderna för 3D-ansiktsanimering jämförs och diskuteras följt av en slutsats som presenterar rekommendationer för vilken som är den fördelaktiga metoden att använda under olika omständigheter. I vissa fall är resultaten otillräckliga på grund av brist på data. En slutsats är att en kombination av morph target och bone driven animering kan ge mera artistisk kontroll om tid inte är en begränsande faktor.

Key words: Datorspel, 3D-animering, ansiktsanimering, morph target, bone driven

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Glossary of terms

Clipping
When part of a mesh moves inside the same or a different mesh.

Game engine
A software framework generally among other things containing capacity for graphic rendering, physics, collision detection and scripting.

Facial Action Coding System (FACS)
System of categorizing (sometimes involuntary) human facial expressions brought on by emotions. The most basic are disgust, anger, fear, sadness and enjoyment, five primary emotions recognized to be expressed the same across all human cultures (Ekman, 1977).

Keyframe animation
With keyframe animation, a character is moved or deformed. When executed, the animation program will triangulate a transition from the original pose and shape into the new one (Tai, 2013). Used both as a standalone animation technique, or to compliment, correct and enhance motion capture data.

Mesh
A 3d object made of a collection of vertices, edges and faces.

Pipeline
Sequence of steps required to complete the task.

Rigging
A 3D character can be “rigged” with bones who, after being skinned, can be used to control the 3D character within the boundaries of the rigging and skinning (Lifewire. 2016). The rig can be compared to the strings controlling a puppet during a puppet show (Wallin, 2015).

Skinning
Defining which part of a mech is effected by rig bones.

Topology
Layout of a model. How the vertices and edges are placed to create the mesh surface.

Vertex
A point in 3D space. Vertices are the building blocks of a mesh.

1 Introduction

The human face is something we use to receive and send both voluntary and involuntary information with each day. This familiarity makes humans into experts at noticing flaws and unnatural behavior in human-looking creations like puppets and 3D models, where if the creation is close to resembling a human but not exact it may prompt a feeling of revulsion and disgust in viewers. This feeling of revulsion and disgust is sometimes explained using the "Uncanny Valley" hypothesis, which is further explained in chapter 2.
Standards and expectations for quality and realism from the game industry are continuously increasing, thereby helping to drive advancements in technology (Ping et al., 2013). In 3D games, unlike in movies, there is also a tradeoff between realism and fast computation because of the often-required real-time interactivity with the 3D animation. Creating realistic movement for a 3D face may seem like a simple task, but it requires a deep understanding of the complex system beneath the skin, and will also require very good knowledge of animation principles to create a realistically moving face (Orvalho et al., 2012). For it to appear life-like, animation of a 3D face requires more work than the animation of its body.
There are two primary techniques for 3D facial animation, morph target and bone driven animation. There is no general agreed upon naming convention so in different sources the same techniques may be referred to by various names, however in this study they will only be referred to as morph target animation and bone driven animation.
This study collect and compare literature and expert opinions about these two primary techniques of 3D facial animation and analyze their respective strengths and weaknesses before giving usage recommendations.

2 Background

2.1 History of 3D facial animation

Human facial expressions have long been documented and analyzed, with Charles Darwin's book "*The expression of the emotions in men and animals"* from 1871 being considered one of the first attempts (Orvalho et al., 2012, p 10). We now know that the human face is capable of a wide range of both conscious and subconscious expressions (Orvalho et al., 2012) and micro expressions (Yan et al., 2013). Faces are so familiar to other humans that when something about it is out of the ordinary, it is generally noticed, and unnatural movement will produce an adverse reaction greater than that against an unnatural look. The human face has been used as a form of communication throughout the entire human evolution, allowing humans to subconsciously receive voluntary and involuntary signals from other humans. Even if the person experiencing it cannot describe what is wrong with the face they are looking at, it can still be perceived as disturbing.

The ability to create increasingly life like characters in our image has driven new scientific studies into human reactions to human-like facial expressions. Once expressions of dolls, androids and 3D models could reach a certain point of similarity to human expressions, it was discovered that humans could have an adverse reaction to them. In 1970, Masahiro Mori published a paper detailing what he called the *uncanny valley*, a hypothesis attempting to describe why and when human looking robots and dolls evoke revulsion in people (Mori, 1970). It states that when robots and dolls look and move increasingly human-like, their appeal increase, until the likeness has risen to the point of the uncanny valley where more likeness instead leads to an increasing reaction of revulsion until this is reversed at the bottom of the uncanny valley from which point more likeness to humans once again leads to increased appeal (see Fig. 1).

Fig. 1. The Uncanny Valley (Mori, 1970).

With expectations on facial animation rising, animators are looking for ways of both making their animations more realistic and to gain higher artistic control, but the uncanny valley phenomena can prohibit the usual gradual progression that one would expect in an area that is both technological and artistic. Instead, if realism is the goal, animators need to aim to produce faces that fall before or after the uncanny valley, or risk evoking revulsion in the audience.

Once the technology started allowing it, methods for simulation of natural facial movement become popular, such as those developed by Hjortsjö (1969) and adopted by Ekman and

Friesen (1978), namely the "*Facial Action Coding System*" (FACS). These methods became very useful for guidance when needing an understanding of each facial muscle in order to craft foundations for emotional expressions in characters during the rigging process for bone driven animation, and when modeling targets for morph target animation (Simantov, 2013). Similarly, the *Phonemes* and *Visemes* mouth shape techniques developed previously by Disney's 2D animators provide support for speech animation for today's 3D animators (Lander, 2000).

Motion Capture, sometimes called performance driven technique in this context, is another way of striving for realistic movement and attempting to satisfy customers while avoiding the uncanny valley. This is done by utilizing actors who provide movement which is then captured and replicated by animation-ready 3D models (Wang, Wang and Wu, 2011; Wallin, 2015).

For a 3D face moving in accordance with these methods to reach its potential for realism, it must be controlled by a system giving it the required movement capabilities.

The techniques for giving a 3D face mesh capability of realistic communication (Wallin, 2015) has come a long way and become more user friendly since the first attempts at computer 3D facial animation (Sturman, 1998), but there is still no industry standard or consensus on what is the best way of achieving a realistically moving face in the cost, time and performance efficient way required for today's 3D games (Orvalho et al., 2012).

Presently, the two primary techniques of achieving 3D facial animation in games are morph target and bone driven animation.

Morph target facial animation is the older and more primitive of the two; technically it is just moving vertexes around and triggering the mesh to shift from one position to another. The ability to place any single vertex anywhere with morph target animation gives great artistic freedom to create subtle details like wrinkles and dilating pupils.

The other technique, bone driven facial animation, is based on a system introduced in 1988 by Nadia Magnenat-Thalmann, Richard Laperrière, and Daniel Thalmann (Magnenat-thalmann, Laperrire and Thalmann, 1988). Bone driven animation equips 3D characters with a skeleton that is in many ways like a simplified human skeleton to control their movement.

2.2 Current state of 3D game facial animation

Morph target animation, also known as blend shape and shape interpolation, is a method of 3D computer animation where a copy of a mesh, created in a 3D modeling program such as *ZBrush* (Pixologic - Home of ZBrush, 2017), is deformed into a new pose. This new pose is a morph target. The original mesh can then be partially or completely transformed into the shape of the new pose (Wallin, 2015). The morphing movement from start to finish occurs during a pre-determined time frame. It is also possible to reverse the direction of a morph target and thereby create a frown from a target modeled to smile. Morph targets are almost exclusively used for facial animation and is the one most widely used for facial animation (Liu, 2009). Some finer details like changing of wrinkles and pupil dilation is easily achieved with morph targets while opening and closing the jaw and eyelids correctly tend to be difficult to achieve because of the straight triangulation morph targets use (Hjelm, 2010). Depending on how much the eyeball is protruding, the eyeball may be seen through the lid as the vertexes are moving straight from the original pose to the new pose, passing through the eyeball. Figure 2 show the natural movement of the eyelid opening and closing by following the red line between A and B, and the movement of a morph targets eyelid animation, following the black line between A and B. The green line shows the possible movement of a morph target eyelid if a mid-pose is used to avoid clipping of the eyeball. A mid-pose is an extra morph target, which is sometimes needed to avoid clipping during animation.

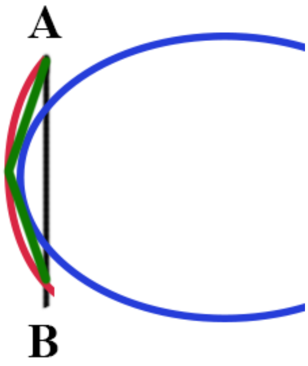

Fig. 2. Eye blink illustration. /Morph targets and bone rigging for 3D facial animation (N. Larsson, 2017).

Since its introduction in 1988, bone driven animation has become the most generic form of 3D animation, and generally what is used for movement in 3D games as well as not being uncommon for 3D facial animation (Magnenat-thalmann, Laperrire and Thalmann, 1988; Tai, 2013).
Bones (the rig) are placed in strategic positions inside the mesh where they can best control the various movements the face is intended to perform. A rig can be transferable between similar meshes but anatomic diversity in humans and the frequent featuring of non-human species makes rigging more difficult when there can be less routine when constructing rigs (Orvalho, Zacur and Susin, 2008).
With bone driven animation, eyelids and jaws can move in a natural way by having the bone controlling the eyelid or jaw move in an arch.
To create animated wrinkles and especially pupil dilation with a bone driven rig is considered very difficult and time consuming because of the many bones it would require and because of the systems limitations (Hjelm, 2010).
Because of the missing 3D facial animation standard, the focus of this study is on these two facial animation techniques. Already 7 years ago Chen Liu pointed out the need for a unifying technology framework in a study of current and future 3D facial animation (Liu, 2009, p.73, p.122). A standardized system for 3D facial animation is still absent (Orvalho et al., 2012, p.7). One of the reasons for the continuing lack of a standard for 3D facial animation in games is game developers creating their own variety of in-house method for facial animation catered to their specific needs (Orvalho et al., 2012; Claeson 2012). Knowing one system should certainly help when learning another, but they are vastly different, potentially leading to decreased mobility in the work force.

2.3 Morph target facial animation preparation pipeline

Starting with the face mesh meant to be animated, a 3D modeling program such as ZBrush (2017) is used to form a copy of the original face mesh into the form of each of the desired facial expressions. Vertexes cannot be added or removed; they can only have their position changed. When moving the eyelids, clipping of the eyeball is common, so a mid-pose can be created to adjust for this. The mid-pose is an additional morph target in the transitioning stage, and can be seen in the center face in figure 3 below. With a mid-pose, the eyelid can move around the eyeball in a V formation and thereby avoid clipping. The possible movement with a mid-pose can also be seen represented by the green line in figure 2 contained in the previous subchapter.

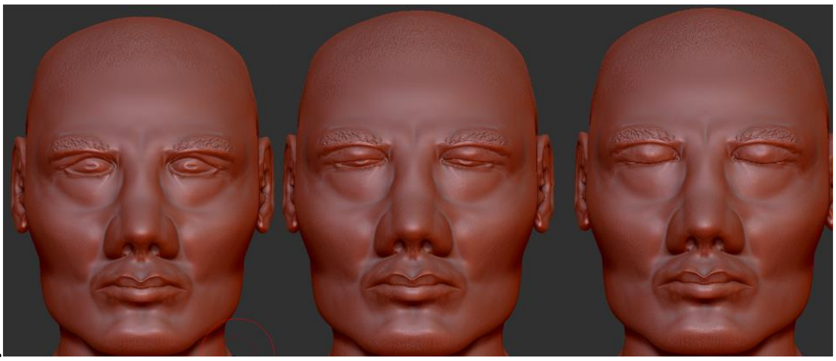
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Fig. 3. Face with morph targets. /Morph targets and bone rigging for 3D facial animation (N. Larsson, 2017).

In figure 3 a face mesh can be seen to the left, and a morph target for it, with closed eyes, to the right. With the morph targets finished, blinking and other movements can be controlled with a slider, and some form of control center will usually be created to more efficiently control and combine facial expressions when animating.

2.4 Bone driven facial animation preparation pipeline

When preparing a 3D face for bone driven animation, a program supporting bone rigging like 3ds Max is used. Bones are placed according to the pivot and rotation that will be required on the face. To prevent the face from unnatural movement during animation, the bones are usually constrained so they can only perform the desired movements. Bones placed in a face mesh for simple animation can be seen in figure 4.

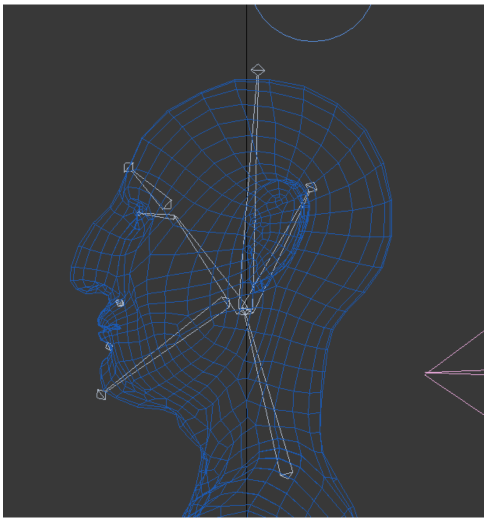
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Fig. 4. Bones. /Morph targets and bone rigging for 3D facial animation (N. Larsson, 2017).

With bones in place, the face can be skinned so each bone controls the corresponding part of the face. In figure 5 the influence of the one such bone is seen, with red signaling much or all influence, and yellow showing areas with less influence from the bone. Uncolored vertexes have no influence from the selected bone.

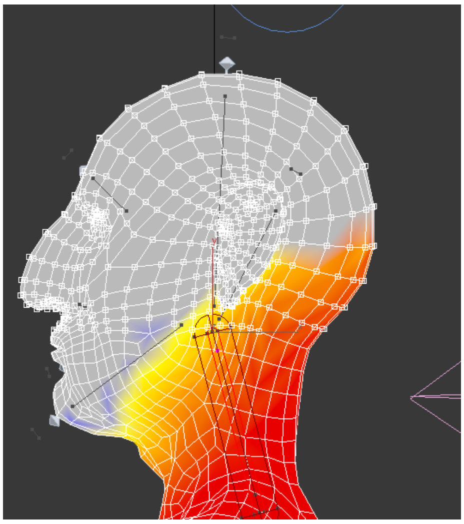

Fig. 5. Skinning. /Morph targets and bone rigging for 3D facial animation (N. Larsson, 2017).

Similar to the preparation for morph target animation, a control center will usually be created for control of the facial animation.

3 Previous work in the subject area

During the composing of this study, no source covering a direct comparison was found. However, several sources concerning 3D facial animation, albeit with a different focus, discuss the properties of bone driven and morph target facial animation. This chapter contains a summary of some previous works in 3D facial animation.

3.1 Current state of 3D game facial animation techniques

In 2009, Chen Liu (2009) released a study where she examined the current and future state of 3D facial animation. The study discusses the properties of morph target and bone driven animation, pointing out that the greatest drawback of morph targets is the inability for animators to create new expressions without going back to model them, making morph targets far less flexible than a bone driven system. The study gives recommendations for all industries doing facial animation to create a unifying system flexible enough to cover all variations of 3D facial animation. A 2012 study by Verónica Orvalho, Pedro Bastos, Frederic Parke, Bruno Oliveira and Xenxo Alvarez also emphasized the need for a unifying system for facial animation, and pointed out the lack of a standard that exist because most of companies producing facial animation in some form preferred to develop their own in-house tools to fit their needs (Orvalho et al., 2012). Orvalho et al also echo the statements of Liu about workflow with morph targets being time consuming, especially if there are changes in the model during production (2012).

In an examination report written by John Hjelm in 2010, he writes about the speed and performance benefits of bone driven facial animation and how it is preferable for low poly models, where finer details like pupil dilation is not needed (Hjelm 2010). Another examination report that was written by Emil Claeson in 2012 is supporting Hjelm's claims about performance and production speed (Claeson 2012). A study of morph targets and FACS's for realistic avatars from 2015 by Mohammed Hazim Alkawaz, Dzulkifli Mohamad, Ahmad Hoirul Basori and Tanzila Sab state the opposite of the performance claims by Hjelm and Claeson by instead writing that a bone driven rig require more computer performance (2010; 2012; Alkawaz et al., 2015).

A journal article published in 2014 by Mohammed Hazim Alkawaz, Dzulkifli Mohamad, Amjad Rehman and Ahmad Hoirul Basori about challenges and the future of facial animation call the animation process challenging and fraught with problems, something they say leads to limited production quality and quantity. The reason given for these problems is that the methods of animation are still immature (Alkawaz et al., 2014).

4 Purpose

The purpose of this study is to assemble solid, technical, non-anecdotal recommendations and guidelines focused on production pipeline of 3D facial animation that is aimed for the game industry. To document what is the most widespread practice and, if other than what is currently most used, to determine what presently available practice would be most beneficial. Having the preferable practice documented will be valuable for animators when choosing how to approach facial animation, and for software developers when developing software for integrating several animation techniques in a unifying framework. Therefore, the product of this study will be guidelines for animators and developers of animation software.

5 Method

The comparative case study approach was selected for comparing multiple formal and informal sources, with a goal of using these sources to deduce procedure guidelines for 3D facial game animation. A comparative case study is an in-depth exploration of a subject with multiple individuals as sources to gage varying experiences (Goodrick, 2014). The case study parameters are found in subchapter 5.3.
Out of the two most common methods of data gathering, quantitative and qualitative, qualitative was selected as the main method because it is imperative for this study to be based on the opinions of experts in the field and that it is also possible to let these opinions carry different weight depending on academic level, instead of a quantitative study where all opinions are treated equally. Some results are also, in addition to qualitatively, presented quantitatively by table form for easier readability and overview.

5.1 Data gathering

Bibliographic searches were made on Uppsala University Library combined database search engine and on digital science archive DiVA. The target of the searches was peer reviewed studies of the two animation techniques done in the last eight years, with focus on papers dealing with performance, production time, technical limitations, ease of usability, cross platform compatibility and common combinations of systems. Additional searches using the same keywords were made with search engine *Google* for informal records about recent AAA games so that in addition to being compared amongst themselves, academic findings could be compared with industry practice.
The searches were made with key words shown in table 1.

Table 1. Search word combinations.

Key word 1	**Key word 2**
3D facial animation	Morph target
3D facial animation	Blend shape
3D facial animation	Bone driven
3D facial animation	Joint based

Every word in the second column has been searched for together with the word in the first column, as well as searched for independently. Two key words for each animation system were chosen because there is more than one generally accepted naming convention. Results are found in *Appendix A*.

5.2 Scope

The reason for choosing a longer than usual time frame when selecting literature to review is the significant drop in published works on the subject, suggesting either a decline in interest of this subject, or that significant and still relevant work was done at an earlier stage. Following is table 2 showing the decline in number of search results when searching Uppsala University Library database for key words from the latest eight and four years.

Table 2. Number of search results when limiting to last eight and four years.

Key word combinations	**Eight-year scope**	**Four-year scope**
3D facial animation Morph Target	Results: 1 099	131
3D facial animation Blend Shape	Results: 3 401	421
3D facial animation Bone driven	Results: 1 811	383
3D facial animation Joint based	Results: 5 775	766
Total:	**Results: 12 086**	**Results: 1 701**

Comparison searches shown in table 2 were made 17.04.24. Further detail of what does not fall within the scope of this study is found in section 5.4 Limitations.

5.3 Analytical framework

A literary review of the selected papers was conducted, with notes taken on all sections relating to the selected focus areas. Opinions by sources about the focus areas were divided into groups depending on if the expressed opinion could be considered a judgment of better, worse or equal when comparing one to the other of the animation techniques. Following is a list of focus areas and reasons they were selected for this comparative case study.

- Performance:
  In a game, the animations often need to be played out in real time. This makes the memory and processing power requirements of animation techniques important when choosing how to achieve 3D facial animation (Claeson, 2012).
- Production time:
  Time is a cost and major factor to consider when a game studio is choosing production techniques.
- Technical limitations:
  If some movements are only possible to achieve with one of the techniques because of the separate ways they work, it should be established before giving recommendations.
- Details and realism:
  With continuous technological advancements, game studios are expected to deliver increasingly life-like facial animation.
- Ease of usability:
  Easy to use software should contribute to a higher adoption rate, which would help when developing a standard.

- Cross platform compatibility:
  A system working with all game engines for there to be a standard for 3D facial animation in games, the system must work with major game engines.
- Common combinations of systems:
  Knowing what is the most common ways of combining the systems will be needed to compare the finding of this study with practice.

Comparative data was collected from informal sources about techniques used by AAA game studios. Note was taken when a source refers to a technique performing better, equal or worse than the other technique in any of the focus areas. All sources used for this study are found in *Appendix A*.

Statements relating to theory and general practice regarding the focus areas were documented, after which the statements were summarized in chapter 6. Following was a meta study, beginning with a statistical breakdown under chapter 6, a weighing of the merits of statements in chapter 7, a discussion regarding results and analysis in chapter 8 and closing with conclusions and recommendations drawn from results, analysis and discussion in chapter 9.

5.4 Limitations

This study is limited to morph target and bone driven animation in the form they are currently (2017) utilized for 3D facial animation.

Variation in rigging techniques, automated rigging and other methods of detail animation such as animated textures will not be included.

Sources are limited to those produced in the last eight years (2009-2017).

Only relevant public information about recent animation techniques of one game studio was found during the production of this paper, so a comparison between academic and industry practice did not take place.

6 Results

Following results are compiled from the literary review of academic and informal sources. When possible to rate results as better, equal or worse than the other animation system, the results are also presented in table form. Each number in the tables equal a source in the literary review suggesting which method performed better, worse or equal in each respective focus area.
The sources are unvalued in this section. Evaluation of sources is in merited cases found in chapter 7.

6.1 Time and revisions

Because of the separate ways of operating, results will unavoidably be different depending on which method is used, and therefore a visual comparison to determine animation results depending on time is not straightforward. The sources do however all point in the same direction.
Liu (2009) points at the major disadvantage of morph targets being the animator will be locked to pre-made expressions unless going back to the modeling stage, whereas setup for a bone driven system is faster and that once rigged, a bone driven system is both easier to work with and make changes to. Alkawaz et all mirror statements from Liu (2009), and call bone driven rigs both effective and flexible and Ping et all (2013) state the time requirement and labor intensity is restricting the use of morph targets. According to Wallin (2015, p.25) “The problem with morph targets is that artists are forced to make manual manipulation for various vertex points to have different states for the animation.”.
Orvalho et al (2012) discuss the properties of morph targets and state that while the initial setup is simpler, very many targets are required for a morph target animated face. These targets always limit the possibilities of animation. They also bringing up the large amount of time it would take and that considerable skill is also a requirement, and that if topology needs to be changed, all previous targets need to be discarded. Furthermore, Orvalho et al (2012), when referring to bone driven animation they say it will require more preparation because each vertex is only animated by the bones around it but that changes in topology for a bone driven model does not necessarily mean the rig needs to be changed.
Claeson (2012) bring up the potential of saving time by stating that a bone driven facial rig can in some cases be transferred between characters while Ping et all (2013) points out that because of human diversity, creating a bone driven rig that could fit any human model would be impossible.
Orvalho et al (2012) say it is common to during production go back and change the topology of a character face, to enable more movement or to increase resolution. This means that when working with morph targets, it will be common that all targets needs to be modeled again, because of changes to the original face mesh.
In addition, Claeson **(**2012) suggest morph targets are faster for simple animations on models with few details.
Results for time and revisions are presented quantitatively in Table 3 below.

Table 3. Quantitative results for time and revisions.

System of animation	Better	Equal	Worse
Morph Target animation	0	1	6
Bone Driven animation	6	1	0

According to the results shown in table 3, creating facial animation with bones is faster and several sources mention how time-consuming the process of using morph targets is, especially if the model needs to be altered after animation has begun. Claeson (2012) does suggest morph targets are faster for simple animation with a low detail model, but Hjelm (2010) and Orvalho et al (2012) say bone driven animation is faster for simple animation with low detail models. The position of Claeson (2012) about morph targets being faster for low detail models was marked down as a point in the equal category in this table, since he mentions bone driven animation being faster for high detail models.

6.2 Details and realism

Claeson (2012) and Orvalho et al (2012), in similar words, express how morph targets are superior for achieving high quality expressions since all expressions can be entirely hand crafted with each vertex positioned perfectly. Orvalho et al (2012) continues that this perfect positioning is not possible with bones since each vertex is only influenced by the bones it is attached to. Hjelm (2010) also bring up the lack of control with bones and how intricate details like pupil dilation would be very hard to achieve with bones. Moreover, according to Wallin (2015, p.23) “Working with facial expressions or fabrics and models that do not function properly with bone systems, artists often use morph targets.”
Liu et all, in a study exploring non-linear morph target animation, remark that the inability to produce an arch with morph targets lower the realism of morph target animated faces (Liu et all, 2011). The study does not cover bone driven animation.
Judd Simantov, then working for Naughty Dog game studio, says that when making video game “The last of us”, they used morph targets for one of the main characters to keep and create volume and animate pupil dilation, thereby getting 20% more fidelity (Simantov, 2013).
Table 4 contains quantifiable results for source judgments on which system can produce higher quality and more realistic facial animation.

Table 4. Details and quality.

System of animation	Better	Equal	Worse
Morph Target animation	5	0	
Bone Driven animation		0	5

As seen in table 4, all reviewed sources agree morph targets can produce higher quality details and animation. The comment by Liu et all (2011) about lower realism because of no arch possibility with morph targets is not included in the table because the 2011 comment is not in the context of comparing morph targets to bone driven animation and therefore not applicable.

6.3 Performance

Claeson (2012) claim that bone driven animation require less memory and Hjelm (2010) wrote that morph target animation will require more processing power. Alkawaz et all (2015) however, say bone driven animation require more processing power. The results are summarized in table 5.

Table 5. Performance.

System of animation	**Better**	**Equal**	**Worse**
Morph Target animation	2	0	1
Bone Driven animation	1	0	2

Two sources say morph targets require less performance, while Alkawaz et all (2015) present a conflicting view.

6.4 Ease of usability

Only two sources make comments relating to the difficulty level of the two techniques, but they are not contradictory since one method being difficult does not equate the other being easy.
Orvalho et al (2012) say that considerable skill is required to create a realistic 3D facial animation with morph targets and according to Wallin (2015) "For facial rigging the traditional joint/bone structure is inefficient and very difficult to use.".
Results are summarized in table 6 below.

Table 6. Ease of usability.

System of animation	**Better**	**Equal**	**Worse**
Morph Target animation	1	0	1
Bone Driven animation	1	0	1

6.5 Cross platform compatibility

Claeson (2012) says bone driven rigs are easy to import into most game engines, while some do not support morph targets. Hjelm (2010) express an opposing view, which is that morph targets work better across platforms because there are fewer ways of handling them.

Table 7. Cross platform compatibility.

System of animation	Better	Equal	Worse
Morph Target animation	1	0	1
Bone Driven animation	1	0	1

The only sources commenting on compatibility, Claeson (2012) and Hjelm (2010), held opposing views regarding which animation system is supported by more game engines.

6.6 Technical limitations

Wallin (2015) says morph targets are often used to create expressions that will not function with bones. According to Hjelm (2010), pupil dilation is very difficult to achieve with bone driven animation, and animators have less control over a bone driven rig. Orvalho et al (2012) write that exact poses can only be achieved with morph targets since each vertex has been positioned by hand, something that is not possible with a bone driven rig. Judd Simantov said they needed morph targets to achieve the last 20% of fidelity when making "The last of us" (Simantov, 2013). Liu et all (2011) write that morph targets linear way of handling animation hinder the potential for realism since the human face move in a non-linear way. Both morph targets and bone driven animation have limitations for what is possible to achieve. With morph targets it is not possible to create the arch movement of a human jaw, eye or eyelid, and bone driven animation does not give total control when creating expressions. Furthermore, with morph targets, the animator is bound to animate with only the already modeled targets, unless more targets are created. According to Liu (2009) and Orvalho et al (2012), morph targets are limited to the mesh they were crafted for, or a copy with the exact same topology, while bone driven rigs can be moved, (Orvalho et al., 2012). With bones, it is possible to create a rig versatile enough to allow creation of many new and unplanned facial expressions.

Morph target animation can only be reused with a face that share the exact same topology, while with bones it is in some cases possible to reuse the rig and animation with a character with similar topology. That the animator is bound to animating only pre-made expressions unless more targets are modeled is the greatest weakness of morph targets according to Liu (2009) and Wallin (2015).

6.7 Common combinations of systems

Claeson (2012) write about the widespread use of morph targets to correct problem areas in a bone driven rig, areas like corners of the mouth that are difficult to animate realistically with a strictly bone driven rig. Claeson (2012) continues that a face with primarily morph target animation will often use bones where a face naturally use a rotating movement, which occurs with human jaw, eyelid and eye movement. Orvalho et al (2012) state that a combination can provide a 3D face with both the flexibility and smooth movement of bone animation and the expressiveness that can be achieved with morph targets.

When Naughty Dog released "The last of us" in 2013, Simantov (2013) say they used morph targets to enhance the bone driven facial animation on one of the two main characters, while the face of the other main character was animated with bones. When "Uncharted 4" was released by the same studio in 2016, all facial animation of main characters was done with a combination of morph targets and bone driven animation (Uncharted 4 Nathan Drake 3D Model Tech Demo, 2017)

As stated in the previous section, both systems have limitation. However, the strengths of the systems complement each other. When using a combination of both systems, morph targets are used to craft the exact desired expression, and bone driven animation is used for rotating movement.

7 Analysis

Following is an analysis summary of each of the seven case parameters.

7.1 Time and revisions

When examining factors relating to time and revisions, sources appear in agreement about bone driven animation being the faster way of producing animation and when making changes to it. That one source suggests morph targets may be faster for simple, low detail animation and a different source present an opposing view merit further investigation.

7.2 Details and realism

Comparable to the time and revisions category, there is also general agreement among the sources regarding details and quality, namely that morph targets can produce finer details and animation with higher realism.

7.3 Performance

Performance wise, two sources consider morph targets the more efficient option, while one source differ. The conflicting source is both the newest of the three, and the one produced at the higher academic level. This merits caution and further investigation before giving recommendations for better performance.

7.4 Ease of usability

The only two sources commenting on difficulty level of the animation techniques call one or the other "very difficult" or "require considerable skill". Even with only two sources it should at least be safe to assume none of the techniques are easy or user friendly, but a recommendation cannot be based of it.

7.5 Cross platform compatibility

With only two sources commenting on cross platform compatibility, both being examination reports, and both holding conflicting views, the question of which animation system works with the most platforms is no closer to an answer.

7.6 Technical limitations

A comparison of technical limitations quickly reveals the techniques have vastly different limitations. Any technique recommendation based on technical limitations will depend entirely on the purpose of the animation. If the face animation is intended to be shared between multiple characters, that can only be done with a bone driven system. On the other hand, if the animation requires a high level of realism with details like cheeks sometimes bulging and possible pupil dilation, it needs to be done at least in part with morph target animation. Strictly linear triangulation is the technical limitation that prevents morph target animation from always being the superior way of producing a detailed and realistic facial animation.

7.7 Common combinations of systems

The common industry practice for combining morph target and bone driven facial animation could not be established for a lack of publicly available information. What information was found showed a bone driven rig with morph targets used to enhance the animation for higher realism. The combination of techniques was used to complement each other's weaknesses to produce the most realistic and detailed result, something than can also be done with animation primary using morph targets, using bones for rotating movement. A combination should be the preferred way if there is sufficient time, budget and skill to allow it.

8 Discussion

The possibility of arch movement for eyelids and jaws is one of the greatest benefits of bone driven facial animation, where it can clearly outperform morph targets. Morph targets on the other hand perform best with creation of subtle details and because it allows the artist to, with great control, shape basically any facial expression and add that extra touch with dilating pupils and wrinkles. Depending on the purpose of the animation, different methods are advisable.

Performance and time wise, it would likely be beneficial to use bone driven animation for smaller game productions that would feature limited face animations. It would be possible to adapt the less extensive rig for reuse on multiple face meshes and the small rig would require less processing power compared to an advanced one.

Ease of entry when trying morph target animation may be encouraging for first time users when it is possible to try individual animations right way once they have been crafted, but it also requires that the animator is proficient in 3D modeling if it is a one-person effort.

Getting started with bone driven animation can be intimidating, but once understanding the basics is overcome, there should be little difficulty in crafting a simple rig that can then be built upon in future projects. Morph targets are not created with any reusability so every new face that needs animating must go through the time-consuming process of being animated (and have new morph targets modeled) from scratch.

With bone driven animation, new unplanned expressions can be created quickly by manipulating the rig in any new way that the rig can support. This is possible to an extent with morph targets by combining or reversing morphs, but most likely a new Morph Target will need to be created.

The ability to move a bone in an arch allows bone driven animation to move an eyelid in a natural way. Doing this with morph targets would require creating several targets along the eyelids trajectory and it still would not completely simulate an arch. Properly moving the jaw without disturbing other active morphs is also difficult to achieve with morph targets.

Results are immediately seen and testable when creating a morph target. When preparing a 3D face for bone driven animation it is first when the rigging and skinning has been done that the animations can be tested, but at that point all supported animations of the face can be tested.

Morph targets allow complete artistic control during the modeling process, but once it reaches the animator she is constrained to the morphs created and to combinations of existing morphs. Similar, the animator of a bone driven animation is constrained to the possibilities created during rigging and skinning of the mesh (and its modeling).

If two meshes have topology similar enough, one face rig can work for both with no or slight modifications. For morph targets no such shortcuts are possible unless the two head meshes share the exact same topology.

9 Conclusion

The most common combinations of the two systems correlate with their strengths and weaknesses, so if the artist or artists are skilled enough, and time is not a factor, 3D facial animation should be produced with a combination of morph targets and bone driven animation to reach the highest level of artistic control. This will allow the techniques to complement each other, with the bone driven animation controlling the rotating movement, and details being created with morph targets.
If there is risk of performance issues because of the platform animations will be played on, no recommendation can be given since sources differed in opinion and therefore no conclusion was reached.
If time is the deciding factor, this study recommends bone driven animation for having a less comprehensive iterative process. It would also be preferable because of the possibility to reusing both rig and animation in some cases, especially if simple facial animation is planned. Simpler animation permit a smaller rig thereby being more likely to support a transfer of both rig and animation to a different face mesh with few or no alterations.
Moving on to which technique is compatible with the most game-engines, sources differ so no conclusion can be drawn other than that it is important to know if the game-engine in use support the selected technique.
No conclusion could be drawn from investigation of ease of usability, also in this case because of sources holding opposing views.
With only one game company as a source, the comparison of academic and industry practice could not take place. It is relevant to note that the game company in question went from only using morph targets for one of the main characters in a game released in 2013, to using it for all main characters in a game released in 2016, showing what they believe is currently the best method for their purpose.
While not all focus areas could be compared to a satisfactory degree, some basic guidelines are offered, and some potentially relevant questions were raised by this study.

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List of Illustrations

Appendix A

Alkawaz, M., Mohamad, D., Basori, A. and Saba, T. (2015). Blend Shape Interpolation and FACS for Realistic Avatar. *3D Research*, 6(1).

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