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An assessment of the application of the robotics theory of the Uncanny Valley (Bukimi no Tani) by Masahiro Mori to the study of realistic human facial animation in computer-generated 3D characters

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2015-05

http://hdl.handle.net/10539/18444

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Preface

Since Charles Darwin's 1872 study of *The Expression of Emotions in Man and Animals* there have been extensive studies of emotion, non-verbal communication and facial expressions (Ekman 5). What these studies show is that humans, except those suffering from genetic or acquired conditions (such as prosopagnosia which may be caused by brain injuries or through congenital disorders), have the ability to discern emotions communicated by facial expressions (Humphreys, Avidan and Behrmann 1). "We have developed an unbelievably fine set of sense for seemingly unimportant details. It may even be assumed that there is no realm in which we are capable of making finer distinctions than in the perception of the human form and in particular the human face" (Flueckiger 3).

The importance placed on emotions and how these are portrayed through facial expressions in animation was a crucial factor that resulted in the rise of Disney Animation in the late 1920's and early 1930's. As Ollie Johnston and Frank Thomas point out in *The Illusion of life*, their inside look into Disney Animation, "until the viewer feels the emotions too he is not impressed with the words…Anyone who merely states his feelings is not acting, and if a cartoon character is not acting, he is not living" (Johnston and Thomas 371).

3D human facial animation has progressed dramatically in the field of computer-generated imagery (CGI) since the technology was first developed at the University of Utah in the 1960s. Responses from audiences to this type of animation have become more complex in recent years as technology has facilitated ever more detailed and convincing computer-generated human faces.

As animation of human faces becomes more complex, the creation and study of this animation draws more on the tools used to understand facial expressions and emotion in fields such as psychology, anthropology, robotics and even neuropsychology. As a result various conceptual tools have been applied to the field to understand the complex issues around representation, imitation and the articulation of human facial expressions.

One of these theoretical tools, which has been borrowed from the field of robotics, is the

theory of *The Uncanny Valley* or *Bukimi No Tani* by Dr Masohiro Mori. Mori, in his 1970 paper, observes a negative or uncanny reaction to realistic human-like robots. “I have noticed that, as robots appear more humanlike, our sense of their familiarity increases until we come to a valley. I call this relation the “uncanny valley” (Mori 33). This observation and his subsequent hypothesis of “*The Uncanny Valley*” have been studied by various roboticists and other academics and scientists since that time.

Much of the research that has been completed on the theory utilises both robots and video clips of 3D computer animated human faces and the transfer of the theory from robotics to computer animation can be understood to be a result of these studies. Furthermore, the technology to create realistic 3D or computer-generated human characters preceded the development of realistic human looking androids by some time.

During the mid-1990s to the early 2000s several 3D computer animated films were made in which similar negative or uncanny responses[1] were observed by critics of realistic human facial animation. Perhaps because of the similarity in the observed responses, or perhaps because of the above-mentioned method used in attempts to verify Mori’s hypothesis, the theory was soon applied extensively to computer animation.

Examples of how Mori’s theory of *The Uncanny Valley* have crossed over into not only the theoretical study of realistic 3D animation but also into popular culture include reviews of films. ‘*Tintin*’ *and the Curious Case of the Dead Eyes* published in Dec 2011 in *The Atlantic* comments “many critics have found Tintin himself to be just a little bit ’creepy’" (Pinkerton) or "unsettling"(Rom). Here at *The Atlantic*, Noah Berlatsky called the film's character's "disturbingly plastic” (Snyder). The expressions “dead eyes”, “creepy” and “lifeless” (Snyder) are often repeated in reviews that focus on the expressiveness, or lack thereof, in the eyes and are of important significance to this study of *The Uncanny Valley*.

This paper will evaluate the research conducted on Mori’s *Uncanny Valley* theory in both robotics and CGI. While the fields overlap, there is a clear distinction between the two. When CGI aims for a standard of realism it is only concerned with photorealism while

[1] The first of these was Pixar’s *Tin Toy* (1988) featuring a human baby. The technology at the time made it difficult to create non-rigid surfaces such as human skin which came out looking angular instead of smooth (Price 104). Reviews of the film include IMDB’s *Great Film, Ugly Baby* (IMDB). The film went on to win an Academy Award.

realism in robotics may deal with a host of other areas. The paper attempts to understand the application of the theory to realistic 3D computer-generated facial animation and evaluate its applicability to CGI.

Chapter 1: An Outline of Mori's Theory and Subsequent research

1.1 An Outline of *Bukimi No Tani* -The Uncanny Valley in Robotics and CGI Based on Mori's Original Theory

Masahiro Mori was a professor of engineering at Tokyo University in 1970 when he was invited to submit an article to the journal *Energy* as part of a round-table discussion on robotics and thought.

The article that Mori authored was *Bukimi no Tani* and was published in *Energy.* It was subsequently translated from Japanese into English by Karl MacDorman and Takashi Minato and published under the title *The Uncanny Valley* in 1970. In this article Mori presented a compelling argument for a phenomenon of uncanny reactions to human-like robots based on the familiarity of robots on a scale ranging from robots with no resemblance to humans to robots with a very close resemblance.

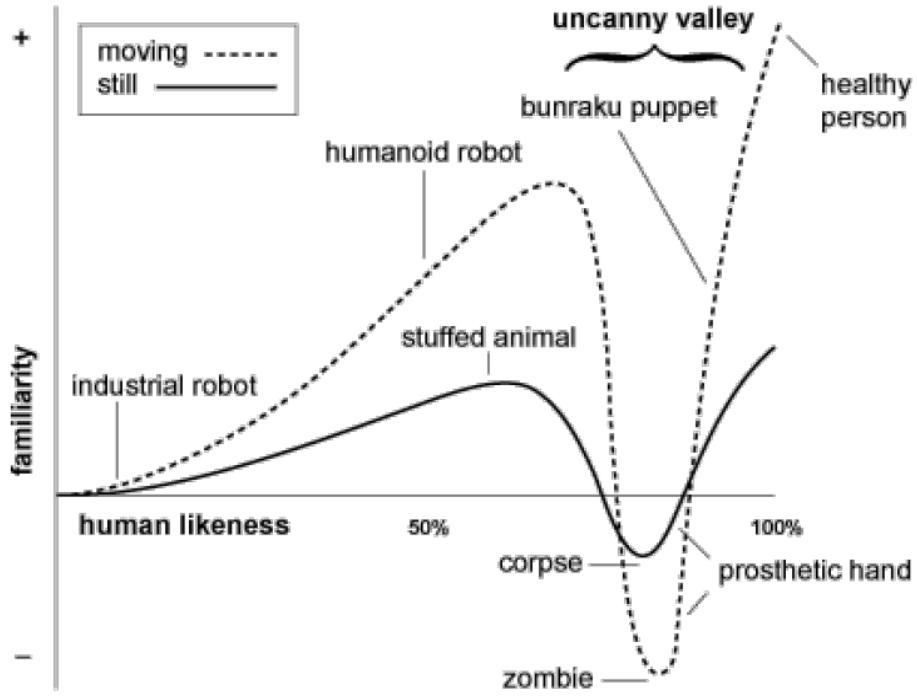

Figure 1: Mori's Graph of Familiarity and Human Likeness simplified from Mori's *Energy* article in 1970, translated by MacDorman and Minato.

In a 2012 interview on the subject he states “Since I was a child, I have never liked looking at wax figures. They looked somewhat creepy to me. At that time, electronic prosthetic hands were being developed, and they triggered in me the same kind of sensation” (qtd in Kageki). Mori states: “as robots appear more human-like, our sense of their familiarity increases until we come to a valley. I call this relation the 'uncanny valley'” (Mori 33).

Mori’s theory asserts that humans find appeal in robots that resemble them only up to a point. They then find them uncanny (words such as ‘creepy’ are often used to describe them) (Snyder). When their similarity to humans is indistinguishable, there is once more great appeal.

In his 1970 article Mori further argues that this sense of the uncanny is amplified by movement. The first argument he makes in this regard refers to a human-like robot that can simulate laughter, which its designer postulates is made up of twenty-six different movements. Slowing these movements down to half speed creates a sense of uncanniness. According to Mori, the peaks and troughs of the graph are amplified by movement. This is crucially important when considered in relation to CGI. It is much easier to make a photo-realistic 3D CGI character as a still image than as a piece of moving footage.

Mori proposes that, when watching a Bunraku puppet show, the viewer crosses over the uncanny valley and into the realm of the familiar once again. Bunraku is the original puppet theatre of Japan, named for the theatre in which it was first performed (What is Bunraku)[2]. He claims that although upon close observation the puppets are not similar to humans “but we enjoy a puppet show when we are seated far from the puppets” (Mori 34).

I disagree with where he places these stylised puppets on his graph. His argument that we have crossed over the uncanny valley and are now appreciating a lifelike

[1]. Originally known as *ningyō jōruri* or puppet narrative drama. Jōruri is a type of shamisen music and, as the name indicates the plays were, and often still are, performed to a Jōruri accompaniment (What is Bunraku?).

performance with great appeal, postulated in 1970, could not have foreseen the extent to which the modern puppet shows of our time, CGI, have come to imitate the human form. Bunraku is described as “probably the most developed form of puppetry in the world” (What is Bunraku). CGI however, has developed in recent years to a point where very subtle and seamlessly integrated representations of human characters are created in films (Seymour). We may thus regard these iconic metaphoric forms contained in puppet shows as having great appeal but being placed well before the last peak before the valley. In other words, they have maximum appeal before beginning to simulate human form closely enough to give us a sense of the uncanny. (*See Figure 1*).

I would suggest that what Mori is touching on here is a notion common in film studies and scriptwriting and analysis, the theory of “the suspension of disbelief” (Coleridge 97), which concerns what the poet Samuel Taylor Coleridge called “poetic faith” (Coleridge 97). He elaborates that this “consist[s] in the interesting of the affections by the dramatic truth of such emotions, as would naturally accompany such situations, supposing them real” (Coleridge 97). I agree with the principle that Mori applies in that an audience could regard the actions of puppets as plausible and that this creates an empathetic response to the characters within the narrative which is necessary for the audience to enjoy the story. It is even possible that being far from the performance may remove some of the detail that a technically critical audience could focus on. I would argue though that it is implausible that an audience would regard the puppets in *Bunraku* puppet shows as either real humans or very similar to humans as the graph implies.

Mori goes on to argue that a solution to *The Uncanny Valley* is, what he calls, “escape by design” (Mori 35). He explains that if designers (as the theory pertains to robotics) aim for the first peak of the graph, their creations can have great appeal without falling into the trap of the uncanny reaction. While he concedes that “the second peak is higher, there is a far greater risk of falling into the valley” (Mori 35). This approach seems to call for a permanent restriction on types of design that approach human likeness, which is highly restrictive and does not allow for advances in technology.

Although the theory has garnered significant attention in both robotics and CGI there was originally no empirical research done to validate or disprove it. Since then

several studies, which will be reviewed in this report, have been conducted to prove or disprove the theory.

While the initial research was conducted within the field of robotics (MacDorman, 2006), the techniques engaged in the studies, such as playing clips from CGI films or animated CG characters created for the studies, overlap with the field of CGI animation and film.

It is not known whether Mori's theory is based on definitions created by Sigmund Freud in his 1919 paper *The Uncanny*. Freud explores the many definitions of the notion and draws on an article by his contemporary, the psychologist Karl Jentsch: "Jentsch has taken as a very good instance 'doubts whether an apparently animate being is really alive; or conversely, whether a lifeless object might not be in fact animate' and he refers in this connection to the impression made by wax-work figures, ingeniously constructed dolls and automata" (Freud 226). Mori did however use the example of wax figures which he finds "creepy" as an instance of his motivation for creating *The Uncanny Valley* theory.

It is however worth considering this first attempt to formulate a definition of the term 'uncanny' in other academic writing. In particular Jentsch's definition of uncanny with reference to the Hoffman short story *The Sandman* in which he explicitly refers to the ambiguous state of automatons, in particular the character Olympia (Hoffman 11) whom the protagonist, Nathaniel, confuses with a real girl with whom he falls in love (Freud 228).

Hoffman's original story, which forms the basis of both Jentsch's and Freud's analysis, is about a character, Nathaniel, who as a child is frightened by his nanny's tales of 'The Sandman' who pours sand in the eyes of children who will not go to bed, and steals their eyes in a bag. Nathaniel, terrified by the tale, hears someone visiting his father and suspecting that it is The Sandman, gets up to investigate. He observes some kind of industrial process and is discovered by a lawyer associate of his father who is named Coppelius. Coppelius threatens to blind the boy (Nathaniel) with hot coals from the brazier at which he and Nathaniel's father are at work. Nathaniel's father begs him not to, saving him from being blinded. The ordeal causes a long childhood illness for Nathaniel during which his father dies in an industrial accident and Coppelius disappears.

Later in the story, Nathaniel, now an adult student, is betrothed to marry a sensible girl. Nathaniel thinks he recognises his childhood persecutor Coppelius but this turns out to be a travelling optician named Coppola. He thinks the man is selling eyes but in reality he is selling eye glasses and binoculars. He purchases a set of binoculars from the optician. He uses the binoculars to observe Olympia, whom he perceives to be the daughter of Professor Spalanzani who lives opposite him. He soon falls in love with Olympia. Olympia is revealed to be an automaton created by Professor Spalanzani, with eyes created by the optician Coppola. Nathaniel's childhood ordeal and the confusion he experiences in his adult state drive him mad and he throws himself from a parapet after which the optician Coppola disappears from the watching throng.

Freud and Jentsch have differing views on the uncanny. Where Jentsch's focus is on the ambiguity of whether an automaton is alive or dead, Freud focuses on the repression of the childhood fear of castration as represented by the terror of having one's eyes taken (Freud 228).

The usefulness of these definitions of the uncanny by Freud and Jentsch with regard to CG characters, echoes the criticism of lifelessness in the eyes of the characters. Freud and Jentsch also both base their definitions of the uncanny on the Hoffman short story featuring Olympia, a realistic human like automaton. In the field of robotics, Jentsch's definition of the uncanny is thus relevant to any discussion of realistic robots and potential uncanny reactions to them, particularly in relation to Mori's hypothesis. Mori identifies wax figures as being associated with his personal uncanny reaction while Jentch uses both wax figures and lifelike automatons as examples of objects that create a sense of the uncanny.

For CGI it is particularly Jentsch's definition of "doubts whether an apparently animate being is really alive; or conversely, whether a lifeless object might not be in fact animate" (qtd Freud 233) which is particularly relevant. Ollie Johnston and Frank Thomas point to the importance of this ambiguity in the title of their animation handbook *The Illusion of Life* (Johnston and Thomas 1). For these authors, since our predecessors drew on cave walls, our species has created images that "have an inner life combined with the

suggestion of movement" (1). This ambiguous state of not knowing whether something is dead or alive leaves us with a sense of the uncanny which will inform our further discussion of *The Uncanny Valley* theory, with reference to both the field of robotics and to CGI.

1.2 Subsequent Research on the Uncanny Valley:

1.2.1 Karl MacDorman et al.

Mori's original paper was a two page sketch of an observation he had made in his work in robotics. It outlined his hypothesis on *The Uncanny Valley* but contained no empirical research on the subject.

Since Mori's original paper, Karl MacDorman, one of the translators of the paper and himself an expert in robotics, has conducted rigorous empirical research to try to validate the hypothesis. In many cases though, Mori's hypotheses were not supported. In a 2006 paper MacDorman attempts to plot a graph of strange versus familiar reactions to morphing figures, from the robot Qrio (created by the Sony Corporation) to the Phillip K. Dick android (created by robotocist David Hanson) to a photograph of Phillip K. Dick himself. MacDorman hoped to emulate the path of *The Uncanny Valley* graph with this study (MacDorman 2006).

While this experiment did initially generate some data that seemed to validate the curve of the uncanny valley in people's reactions, as did the study mentioned above with morphing video footage (MacDorman 2006), in his final findings he concludes that "The results indicate that the perceived human likeness of a robot is not the only factor determining the perceived familiarity" (MacDorman 2006).

In the third experiment, MacDorman (2006) featured fourteen video clips of different robots and androids. The uncanny valley hypothesis was not supported and the reactions of the participants followed an average which indicated appeal and eeriness or uncanniness at levels which seemed unrelated to human-likeness (MacDorman 2006). The conclusion that MacDorman reached from this study was that other factors besides

human-likeness may make a greater contribution to appeal or familiarity versus eeriness or uncanniness.

He elaborates further on this study: “In particular, the combination of a 50% increase in eye size and human texture and proportions resulted in much greater perceived eeriness than the same proportions with a doll’s texture” (MacDorman 4). The identification of a relationship between the proportion of facial features and the level of detail and realism in texturing and subsequent uncanny reactions to realistic human CG characters or robots is of critical importance. In animation and in CGI it is possible to create distorted or exaggerated features to increase the appeal of a character but MacDorman identifies negative reactions to these disproportionate features in more realistic characters (MacDorman 4).

He further acknowledges in his paper published in 2009, referring to his previous study, that although the methodology of morphing from one figure to another is the basis of his study “the morphing technique introduced visual artefacts that could have increased eeriness ratings” (MacDorman et al. 2009).

1.2.2 Bartneck

MacDorman presents morphing as a neutral process which a computer carries out independently of any human interaction. In reality, in visual effects, the process of morphing is a manual process that uses vectors to align target regions between subjects. Bartneck observes in his study, referring to MacDorman's experiment, “it can be very difficult, if not impossible, for the morphing algorithm to create meaningful blends” (Bartneck et al. "My robotic doppelgänger - a critical look at the Uncanny Valley" 270). I propose that the sense of uncanniness or eeriness in the respondents in MacDorman’s study may be due to the jarring disproportion when the head shape has changed but the eye shape is not proportional, combined with a change to realistic textures of human skin.

Bartneck et al. make an important observation of the application of *The Uncanny Valley* in robotics which is very relevant in CGI: “*The Uncanny Valley* can be used in

attributing the user's negative impressions to the users themselves instead of to the shortcomings of the agent or robot themselves" (275). This is crucial in CGI as there is a broad application of the theory to negative audience responses to 3D human characters which makes an unproven assumption that audiences will always react negatively to realistic human characters. This assumption causally attributes a behaviour to an audience which negates any analysis of factors such as the quality of the animation or the proportion of the characters' facial features and the combination of the levels of detail in texture with the detail in animation. The assumption of a constant negative reaction from audiences to realistic human-like CGI characters by these researchers could be particular to the field of robotics. These researchers (MacDorman et al.) may be unaware of the effects of CGI on their experiments and may not be able to anticipate advances in technology in the field of CGI that could overcome obstacles to realistic human-like CGI characters.

Bartneck makes another important contribution with the "Godspeed Indices" (Bartneck 2009). The Godspeed Indices are a series of semantic differential scale questions with ratings from 1 to 5 with 1 being 'disagree' and 5 being 'agree', which are "Measurement Instruments for the Anthropomorphism, Animacy, Likeability, Perceived Intelligence, and Perceived Safety of Robots". The indices for anthropomorphism include: "Please rate your impression of the robot on these scales:

Fake	1 2 3 4 5	Natural
Machinelike	1 2 3 4 51	Humanlike"

The indices attempt to create a methodology for the assessment of user perceptions of robots. These perceptions can inform design choices to create robots that better suit the needs of the humans interacting with them.

1.2.3 David Hanson

Robotocist David Hanson, from the University of Texas, Dallas, specialises in creating very realistic human-like androids. In a study by Hanson et al. entitled *Upending the Uncanny Valley*, published in 2005, the authors examine responses to realistic androids through an online study of video clips of realistic androids in different ranges of motion.

The study features robots with very realistic faces but where the wiring at the back of the head may be visible or the head is supported on a stick. The respondents reported favourably that the robots were appealing and 85% said the robots were lively with none responding that they found them disturbing, this despite “numerous unrealistic features (head on a stick, no back of head, etc.) (Hanson et al. 29).

This study yields findings which directly contradict the proposition by Mori that humans will find realistic robots uncanny. In interaction with footage of the androids, the research subjects responded positively to the realistic facial features of the androids despite the limitations of the unrealistic features like wiring at the back of the head and the head being supported on a stick

In response to MacDorman’s study, Hanson explored the aesthetic range for humanoid robots (Hanson 2006). He also uses the morph technique to illustrate an uncanny versus a non-uncanny morph. The study uses the exact images used in the MacDorman study, featuring one of his androids but changing the method employed in the morph.

By using “attractively tuned” figures (Hanson 3) in the morph to maintain design principles and keep the figures appealing, Hanson was able to demonstrate that audiences reacted positively and with no uncanniness or eeriness to any of the figures.

Hanson's focus on aesthetics and the importance of appeal in design mirrors the observations of Disney animators in 1937 during the making of *Snow White* (1937) that “all characters in animation, even villains, need to have appeal” (Johnston and Thomas 68).

If one analyses the figures it soon becomes obvious that what they have done to ‘tune’ the morphs is to change the targets and curves of the morph to keep the proportions cartoony and appealing on the robot and then quickly move to human-like proportions, particularly in the upper face and eye region (*See glossary for definition of morphing*).

Hanson uses the same morph technique with the same subjects used by MacDorman (2006) as the basis of his own study and points out how this may be

problematic (Hanson 2006, 3). The danger of a Heisenberg's uncertainty principle paradox, where research yielding the results expected or indeed orchestrated by the researchers, based on the specific parameters of the morphs used, is high because morphs are dependent on human input.

What is useful about Hanson's study is that he shows that morphs can be manipulated to yield different results hence calling into question the overreliance of MacDorman et al. (2009) on this technique.

1.2.4 Angela Tinwell et al.

In addition to Hanson's work in response to MacDorman et al. (2009), a study was carried out by Angela Tinwell et al. ("Facial Expression of Emotion and Perception of The Uncanny Valley in Virtual Characters" 2011) at the University of Bolton to explore the effect of facial expressions in CG characters on perceptions of *The Uncanny Valley*. This study looked at what factors could cause negative responses to CG characters, specifically the mobility or immobility of the upper face region around the eyes.

The model that they used was to record an actor portraying different emotions and then constrain different parts of the face to see how well respondents could identify the emotions and to observe how they reacted to them (Tinwell et al. 2). A CG character was created and similarly constrained to measure the ability of respondents to read various emotions.

The six emotional states used in the study were anger, disgust, fear, happiness, sadness and surprise. Tinwell quotes the psychologist Busso whose research field is emotion and facial expressions: "During speech non-verbal signals are used to interpret the emotional state of a person. Non-verbal signals are largely conveyed by the upper part of the face; the lower region of the face constrained by the articulatory process as described by Busso" (qtd. in Tinwell et al. 8).

The results support the thesis that humans struggle to empathise with or even identify certain ranges of emotion when expression in the upper face is constrained. They

also predictably identify and respond to emotional states most clearly in other humans, and do so least empathetically or accurately on CG faces with the upper face region constrained.

The researchers further note that "perception of the uncanny in virtual characters displaying inadequate facial animation is greatly influenced by the type of emotion the character is portraying" (Tinwell et al. 23). Partially animated virtual characters expressing the emotions of fear, sadness, surprise and disgust were judged significantly more uncanny than fully animated characters expressing the same emotions (Tinwell et al 23).

Tinwell et al. quote Ekman and Darwin who observe that the six basic emotions "anger, disgust, fear, happiness, sadness and surprise", serve "different adaptive (survival or social interaction) functions (Darwin, 1872; Ekman, 1979, 1992a, 1992b qtd in Tinwell et al. 6). For example, detection of fear and sadness in others may foretell potential harm or distress to self and humans react instinctively to such emotions to avoid a possible threat" (Tinwell et al. 6). They also rate the responsiveness to different emotional states with more empathetic and less uncanny responses to the emotions of fear and sadness.

Other emotions lead to more ambiguous data and the researchers themselves point to potential weaknesses in the software in representing certain emotional states accurately. The software used was Face Poser[3] which allows for a sliding scale controller to affect a morph between different poses. What was attempted in this study was to match the human performance and to create expressions in line with Ekman's Facial Action Coding System[4] (Tinwell, Grimshaw and Nabi 13).

[3] Face Poser is an open-source software designed to create different facial expressions for 3D game characters (Valve Developer Community). The technique is used frequently in 3D software such as Maya from Autodesk. Specific facial expressions are created and a slider in the user interface is used to move, or flex from one facial expression to another. See the case study of *The Curious Case of Benjamin Button* for an in depth analysis of how this technique is used in professional 3D animation. The technique used in this experiment was to create six expressions based on Ekman's Facial Action Coding System with a slider to move from one to the other. In *The Curious Case of Benjamin Button* 120 poses were created for primary emotions, but over a thousand expressions were created in total, based on the performance of the actor Brad Pitt and a slider used to morph from one expression to the other (CG Society. Web).

[4] See glossary for a definition of Ekman's Facial Action Coding System. In his early work for his PhD, Ekman travelled to Papua New Guinea to test whether there was a universal set of human emotions. By asking a tribesman who had never been exposed to outside culture how his face would react to a set of hypothetical situations such as "If your child died" he was able to establish a system of facial expressions based on the musculature of human faces which was independent of culture and represented measurable human emotions. These muscles create limitations on exactly what humans can express with facial expressions but also indicate the difference between honest and manufactured emotions or whether we are reacting honestly or lying.



Figure 2: The three conditions Human, Full and Lack expressing the emotion Anger. (Tinwell, Grimshaw and Nabi 8)

Despite the limitations of the experiment (the lack of detail in the CGI character and the restrictiveness of the Face Poser software [Tinwell, Grimshaw and Nabi 13]) there seemed to be consistency in the recognition of emotions although certain emotions were easier to read than others. The authors point out in the abstract that they considered "the limitations of the stimuli and methodology used in previous experiments, with suggestions made for future experiments" (Tinwell, Grimshaw and Nabi 1). In addition they acknowledge in relation to these studies: "However empirical evidence collected as part of this research project suggest that this information is lacking in animated realistic, human-like, virtual characters (1). [5]

This may indicate a potential weakness in the data collected as it is difficult to verify objectively whether these emotions are accurately represented and to what extent disabling certain regions of the face impacts on this, if the software used or the skill of the artists creating the characters have inherent representational limitations. Nevertheless a trend is clearly established in the studies that by disabling the upper face region the perception of uncanniness is increased.

The study points out the importance of the upper facial region and demonstrates the difficulty of representing human subjects realistically, not only in a general way but also that this may require vastly more detail for certain emotions than others: "Emotions with

[5] The problem with these experiments is that creating very realistic human facial animation is incredibly specialised and expensive and requires massive resources. This is explore in more detail in the case studies in chapter 3 of this report.

distinctly different adaptive functions (social vs. survival), were regarded as more tolerable than others with an ambiguity of facial expression …in the lack condition [animation restricted in the upper face region], perception of uncanniness was strongest for the emotions fear, sadness, disgust, and surprise" (Tinwell, Grimshaw and Nabi 1).

In a study entitled *The Uncanny Wall*, Tinwell, Grimshaw and Williams go on to extrapolate, based on the findings of increased uncanniness in CG characters, as follows:

> By implementing unused data from a previous empirical study using videos of virtual characters, we attempt to plot the Uncanny for such characters. Based on the findings from our study, this paper proposes the theory that instead of an *Uncanny Valley*, designers of realistic, human-like characters are faced with an Uncanny Wall, created by the viewers' continually improving discernment of the technical trickery used in the character's creation; this discernment prevents complete believability in the human-likeness of that character. (327)

As part of this study the authors presented 15 video clips to their study group of 100 subjects. The clips included "six photo realistic characters, five zombie characters, three stylised, human-like characters and a human" (Tinwell, Grimshaw and Williams 330).



Figure 3: The 15 characters used in the experiment (Tinwell, Grimshaw and Williams 331).

The authors describe the characters 1 to 6 as photorealistic but even at a glance characters 2 to 6 are clearly a type of 3D which is more figurative or representational than photorealistic. For the purpose of this study at least a cursory definition of the term photorealistic is necessary. Would an audience believe these characters are real and were photographed? Asking this question could provide a useful test for the term. In this case only figure 1 and 15 could fit that description.

The characters 7 to 11 are zombies from different games. While Mori places zombies at the base of the valley in the illustration of his curve (see figure 1), one would need to ask the relevance of the inclusion of these characters in relation to the question of realistic human-like characters and an associated perception of uncanniness. While people may find zombies uncanny and creepy, that uncanniness is almost surely more the result of the design and purpose of the character than an attribute of their level of realism. In many films live actors in make-up acting as zombies create the same uncanny effect as these 3D zombie characters.

The main conclusion that Tinwell, Grimshaw and Williams draw is that while character 1 rates very highly for realism and familiarity, it does not rate as high as character 15, a human. There is a possibility that this specific audience were trained to observe fine detail in CG characters and easily make the distinction between almost real and real. I would argue that to create the term 'uncanny wall' on the basis of this experiment is not convincing. There are instances in which audiences are unable to distinguish between a real live actor and a CGI character and of course, as technology increases there are an increasing number of such instances.

I would argue that, in 2009, two years preceding the publication of the study (Tinwell, Grimshaw and WIlliams) Digital Domain[6] had already created a character that had entertained audiences with very high levels of realism achieved through the seamless integration of the CGI character, Benjamin Button, with live-action actors in *The Curious*

[6] Digital Domain is an American post production facility that specialises in complex visual effects (abbreviated as VFX). They have won multiple Academy Awards for their innovative work in this field. In particular they won an Academy Award for the realistic 3D character of Benjamin Button in the film *The Curious Case of Benjamin Button* (Universal, 2009).

Case of Benjamin Button (2009). Brad Pitt was the actor who was cast to play the lead role in the film. The film follows the character of Benjamin Button as he ages backwards, born old and dying an infant. Ed Ulbrich, executive VFX (Visual Effects) producer from Digital Domain, in an interview on CG Society states that when Brad Pitt observed a shot of the 3D character of Benjamin Button in the film, at the same age as he was at the time of shooting (which was created because of Pitt's unavailability at the time of shooting), he remarked that he did not remember shooting that particular shot (Ulbrich). The 3D character was indistinguishable, not only to a general audience, but also to the person being represented. Given the requirement in Mori's theory of an indistinguishable level of similarity, I would propose that this constitutes an example of such realism, (in terms of the definition in The Uncanny Wall [Tinwell, Grimshaw and Williams 327]) or of photorealism in relation to CGI in that it creates an image indistinguishable from other photographed shots of the same actor.

In addition, the fantasy epics *Avatar* (2009) and *The Lord of the Rings* series of films (2001 – 2014) have created "human-like" characters that raise serious questions about Mori's hypothesis, not by creating characters that cross over *The Uncanny Valley* but rather by creating characters that fall squarely within the valley. I would propose that the characters of the Na'vi in *Avatar* (2009) as well as the character of Gollum in *The Lord of the Rings* series (2001-2014) are approaching realism and are similar to the human form but are clearly not realistic human characters. If one were to place them on Mori's graph they would almost certainly fall within the valley area, yet there is no uncanny reaction to the animation or performance of the characters (except the normal repulsion that we would feel for a villain in Gollum's case, as we would if it was a human actor in make-up). In this case uncanniness stems from the character attributes rather than the degree of realism or familiarity to human observers.

The reason many studios choose not to create realistic 3D characters is because the audiences' perception of uncanniness disrupts the suspension of disbelief (as pointed out in the review of Spielberg's *Tintin* by Snyder). In the case of *Avatar* (2009) and *The Lord of The Rings* (2001-2014) this is clearly not the case. This echoes the proposition of Bartneck et al. that the theory of *The Uncanny Valley* "can be used in attributing the user's negative impressions to the users themselves instead of to the shortcomings of the agent

or robot themselves" (275). By proposing that audiences have an innate reaction against realistic CGI characters, there is a negation of any failings in the animation, texturing or proportion of those CGI characters which may be responsible for that reaction.

The original research by Tinwell et al.(Tinwell et al. 2011 8), which demonstrated the importance of immobility in the upper face region in the communication of non-verbal information, particularly with reference to CGI characters, remains a useful tool in understanding the complexity of realistic facial animation. The research contributes to an understanding of exactly what is lacking in CGI characters which cause uncanny responses such as in *Final Fantasy: The Spirits Within* (2001) (see Zacharek's review on page 20). In particular it identifies an expectation of non-verbal communication during speech. The identification of the different levels of detail needed to represent different emotions is also a critically important observation in understanding this field.

1.2.5 Further Research

In an experiment designed to measure uncanny responses to computer-generated faces published in 2009 and based closely on Mori's uncanny valley theory, MacDorman et al. used computer-generated faces at different levels of realism to try to validate Mori's theory. MacDorman uses a CGI character to which different textures are applied and a wireframe model with a low polygon mesh, a medium polygon mesh and a very dense polygon mesh (MacDorman et al.).

The study carried out by MacDorman et al. notes that the representation of a CG character in high detail with realistic texture, then the representation of a bronze textured model of the same subject and next a line textured model all at differing levels of detail, are highly problematic.

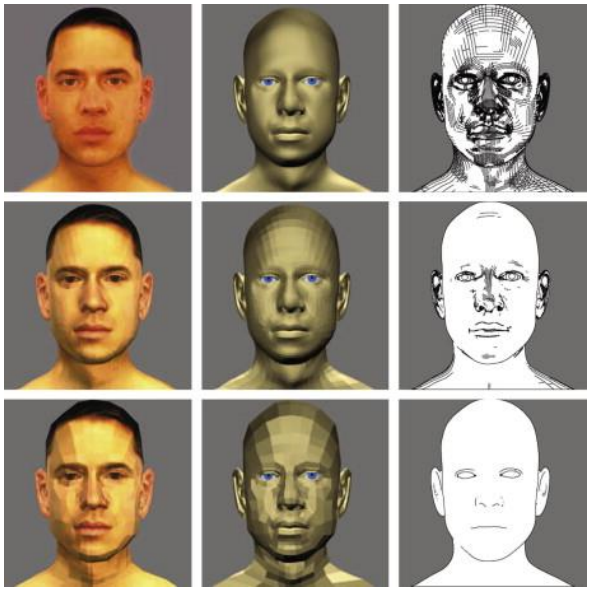

Figure 4: Photorealistic, bronze, and line texture models at varying levels of detail (MacDorman et al.).

Hanson, in section 1.2.3 above, makes an argument for the importance of design and aesthetics, and how this can affect research on robotic design. His emphasis on "attractively tuned" morphs greatly impacts the results of a repeat of MacDorman's morph studies (Hanson 3). In relation to the issue of the design of their CGI test character, MacDorman et al. concede in their conclusion, that the higher numbers of lines in a wire mesh model do not necessarily translate into greater detail, or as Mori might phrase it, higher levels of familiarity (MacDorman et al.).

MacDorman et al. thus again premise this claim on the belief that a computer will objectively produce different neat categories of levels of detail, which neatly fit their model of low detail or high detail and, unfortunately, do not make any allowance for human or artistic input in this process. As a result the images and the results of this part of the study are confusing and inconclusive.

Using the same CGI character for a further test within their 2009 study they take a realistically textured model of a human face and distort the features, bringing the eyes closer together or further apart, distorting the length of the forehead and middle region of the face and compare responses to more accurate proportions. The results of this study verify MacDorman's early findings about the relationship between the proportion of facial features and the perception of uncanniness.



Figure 4: Facial extremes: +/- 10% eye separation and face height (MacDorman et al.).

This study begins to clarify what it is that people find strange about these CGI characters. When the proportions are incorrect or exaggerated on realistically textured figures there is a clash of levels of realism that viewers find uncanny. This is of vital importance to CGI where it is relatively easy to distort the proportions of the facial features of characters. MacDorman identifies this as a possible cause for uncanny reactions to realistic human-like CGI characters (MacDorman et al.).

While MacDorman et al. do observe interesting relationships between realistic skin textures and accurate or realistic proportions in the eyes, their reliance on the bronze and wireframe textures created for the study are less conclusive than a cartoon shader and natural realistic skin texture[7] on a CG model might have been. This is because of their emphasis on creating an objective test for the study, where a computer adds levels of detail in an automated way. A computer in visual effects and animation is merely a tool for artists to create characters. The conclusions of this study are confusing because they overlook this and ignore established conventions that artists use to create specific looks. The researchers attempt to create parameters that will contribute to the objectivity of the study. Unfortunately, relying on wireframe meshes with a higher or lower number of polygons does not make CGI characters more or less detailed. In this case, more polygons

[7] A cartoon shader would be something like what was used in *The Incredibles* to create the pleasing skin tones of the characters. A realistic skin texture is generally created from high resolution photographs of human skin that are projected onto a CGI character and move with the geometry of that character to create the illusion of a real person.

actually give the impression of less detail in a wireframe CGI character.

MacDorman et al's view seems to be that by removing any artistic input the computer will somehow produce examples which are objective for their study but it is clear that the computer yields very little meaningful information without a strong human hand guiding it. It is hard to treat the study as objective without it having some kind of context in the world of computer-generated images, particularly when it seeks to draw such sweeping conclusions about the field.

In an attempt to create more uniform tools to assess user perceptions of robots, Ho and MacDorman revisit the Godspeed Indices[8] in a 2010 study. They use the questionnaire by Bartneck et al. (2009) to plot anthropomorphism and likeability which MacDorman interprets as a potential *x*- and *y*-axis for Mori's graph (Ho and MacDorman p1517)[9]. The intention of the study was to use an assessment of user perceptions of robots to aid in their design process.

The early studies of MacDorman et al. relied too heavily on wireframe meshes in an attempt to create a sense of objectivity seemingly driven by the parameters of computer-generated design. In an advance on the attempts at objectiveness in earlier studies by MacDorman (2006, 2009) Ho and MacDorman's 2010 study evaluates artificial CG characters with five video clips of CG characters at various degrees of realism used in conjunction with five video clips of robots and androids.



Fig. 5: The five frame grabs from the video clips in the top row contain computer-animated human characters from the films (1) *Final Fantasy: The Spirits Within*, (2) *The Incredibles*,

[8] See earlier discussion of Bartneck for a definition of the Godspeed Indices.

[9] The Godspeed Surveys are named as such because they "are intended to help creators of robots on their development journey by measuring "the user's perception of robots" (Bartneck et al. 2009).

and (3) *The Polar Express*, (4) an Orville Redenbacher popcorn advertisement, and (5) a technology demonstration of the *Heavy Rain* video game. The remaining five video clips contain (6) iRobot's Roomba 570, (7) JSK Laboratory's Kotaro, (8) Hanson Robotics' Elvis and (9) Eva, and (10) Le Trung's Aiko. (Ho and MacDorman 1510)

In this study parameters such as 'humanness', 'warmth', 'eeriness' and 'attractiveness' were used to evaluate the different video clips. Hanson's studies described in paragraph 1.2.3 of this thesis, outlining the importance of aesthetics and design are reminiscent in these categories. In relation to human-like characters being "attractively tuned" (Hanson 3) he demonstrates the importance of appealing design principles. An additional category of perceived safety is included in the study and a correlation is observed between "anthropomorphism, animacy, likeability and perceived intelligence" (Ho and MacDorman 1509). The researchers conclude: "This correlation indicates that they may be measuring the same concept, not separate concepts". I would suggest in this instance, based on the images used in the study, that interviewees made the distinction between the categories but that there is in fact a strong correlation between the categories for these characters as outlined by Hanson.

In the case studies chosen for this paper I will examine scenes from the film *Final Fantasy* which formed part of the Ho and MacDorman study.

There have been varied critical responses to these films. Butler and Joschko in a study of the films *Final Fantasy: The Spirits Within* (2001) and *The Incredibles* (2004), argue that *Final Fantasy* is an example of a validation of Mori's theory (Butler and Joschko) and cite critical responses to the film referring to it as being 'creepily artificial' (Zacharek).

Ho and MacDorman's study contradicts these findings as respondents to the particular clip of the character of Dr Aki Ross from the film *Final Fantasy: The Spirits Within (*2001) do not register her in this comparative study as significantly "eerie". They point out that "There is also considerable individual variation in emotional responses to humanoid robots and animated human characters" (Ho and MacDorman 1516). Butler and Joschko's study lacks recourse to any empirical data for its findings and is premised on the reviews

of critics and box office earnings. In this respect it is difficult to analyse the motivations or rationale as to why audiences may have responded positively or negatively to the two films.

The study by Ho and MacDorman seems to broaden the scope of MacDorman's earlier research from merely looking at uncanny responses in a mechanistic way to an analysis of a broader range of emotional responses to both robotics and CGI with regard to realistic human-likeness.

In terms of understanding the complexity of realistic representations of humans in the precise and expensive world of CGI, these broader terms such as “animacy, likeability and perceived intelligence” (Ho and MacDorman 1509) would allow for a more accurate assessment of audience responses. This may allow for an understanding of the reasons for the success or failure of certain films compared to others.

The limitation of the development of the four indices that the Ho and MacDorman study outlines is that it seems still to rely on the empirical studies of his earlier work to validate Mori's theory and seeks to present the indices (humanness, warmth, eeriness and attractiveness) as the parameters for successful robotic design in the future. (Ho and MacDorman p1517). These parameters are conceptualised, again without contending with the reasons for responses to differently designed robots or CG characters. What the indices do provide, is a framework within which to measure user perceptions of robots based on empirical data.

1.2.6 Barbara Flueckiger - The Model of Distance

Ho and MacDorman’s observation of “considerable individual variation” in responses to realistic robots and CGI supports *The Model of Distance* posited by Barbara Flueckiger. She maintains in her criticism of *The Uncanny Valley* hypothesis that the model is highly subjective (Flueckiger 7).

Barbara Flueckiger is professor of New Media in the Department of Film Studies at the University of Zurich. Flueckinger makes a case for an alternative model in the field of

CGI to the *Uncanny Valley* hypothesis. In her 2011 paper *Computer Generated Characters in Avatar and Benjamin Button* she proposes an alternative to the uncanny valley which she calls *The Model of Distance*. “Aspects of appearance and behaviour should be at similar distance from a photorealistic image defined as a standard. If a character is very stylized, for example, it should be animated in a correspondingly stylized way” (Flueckiger 6 - 7).

MacDorman’s research makes an important contribution in the observation of the link between uncanny responses and the proportion of facial features in realistic CGI characters and androids. He notes that research subjects rate realistically textured and rendered human characters as more uncanny if their proportions do not similarly match human proportions (MacDorman et al. 700).

Tinwell et al.’s (*Facial Expression of Emotion and Perception of The Uncanny Valley in Virtual Characters* 8) observation of the relationship between detail and animation in different regions of the face (particularly in the upper face region above the lower eyelid) with regard to conveying emotion, create a more sophisticated paradigm with which to evaluate audiences’ responses to different types of CGI films.

- There would therefore appear to be a strong correspondence between the level of detail of modelling and texturing in CGI characters and the amount of articulation or detail required in animation, which corresponds with Flueckiger’s *Model of Distance* (Flueckiger 6).
- For more iconic figures, less detailed and more exaggerated animation is acceptable, but for greater levels of realism in the design of CGI characters there needs to be a linear progression of detail in the animation, particularly in the upper face and around the eyes to match the level of realism in the design of the characters.
- The proportion of facial features should also follow the same linear progression as shown by Hanson and MacDorman; where large eyes or varying proportions are appealing for cartoon characters, they are uncanny in realistically modelled, textured and rendered characters.

Flueckiger's criticism of *The Uncanny Valley* model stems from a lack of empirical data to substantiate it: "The theory has to be empirically tested for each individual case, because the presence or absence of the effect can be a matter of debate and may vary intersubjectively" (Flueckiger 6). This echoes Ho and McDorman's research where audience perception of a clip from *Final Fantasy: The Spirits Within* (2001) do not rate the footage as significantly "eerie" (Ho and MacDorman).

With regard to the character of Gollum (in *The Lord of the Rings* series of films [2001-2014]), she notes that "his behaviour and appearance both seem mainly photorealistic and organic, with a few deviations that can be categorized as fantastical or at least unusual, like the large ears and eyes, or his way of moving. I hypothesize that these deviations do not disrupt the balance of representation, because they appear equally in the domain of behaviour and form" (Flueckiger 7).

With regard to James Cameron's assertion that he had crossed over *The Uncanny Valley* with his characters in *Avatar* (2010) she makes the important observation that "an empirical review is surely necessary. The differences in physiognomy are very pronounced, however, and there are many deviations from a completely human face, suggesting the conclusion that the characters are not altogether anthropomorphic" (Flueckiger 25). I would make the argument that this difference in physiognomy places the characters firmly within the valley area of Mori's curve rather than in a region where they are very realistic.

The model of distance proposes therefore that more realistic 3D characters require high levels of detail in their animation (both case studies she analyses in the paper make use of facial motion capture to achieve this result), whereas more stylised characters should be animated in a more exaggerated or less realistic way. She proposes that this is in keeping with Disney's principles of animation, specifically the tenth principle of exaggeration (Flueckiger 6).

The contributions of Tinwell et al. in observing the importance of non-verbal communication particularly during speech, as well as the importance of the expressiveness of the upper face region, provide more complex tools for assessing

realistic human-like CGI characters. So too does the observation by MacDorman of the importance of proportion in facial features in relation to the level of detail of modelling and texturing in CGI characters. Bartneck also creates a useful focus on the assessment of techniques used in creating CGI characters (whether there are mistakes in the animation) rather than ascribing behaviour to audiences that have not been empirically substantiated (that audiences have an innate aversion to realistic CGI characters). These tools all provide us with a sophisticated method for the analysis of realistic human-like CGI characters and a means to assess the application of Mori's theory in the field.

Chapter 2: A Brief Outline of Modern Visual Effects and 3D Computer-Generated Characters

The previous section outlines the importance that has been placed on realism in representing or imitating human faces in both robotics and CGI. In order to evaluate realistic computer-generated facial animation it is necessary to frame the discussion within an exploration of the term 'realism'.

2.1 Realism in Facial Animation in 3D Computer-Generated Animation, Visual Effects and Computer-Generated Images.

"Any definition of 'realism' as it operates within any image-making practise is open to interpretation. Certain traditions of film-making practice, however, have provided models by which it is possible to move towards some consensus of what is recognisably an authentic representation of reality" (Wells 24).

Professor Paul Wells is director of the research group *The Animation Academy* and author of several books on animation including *Understanding Animation*. Wells looks at the development of realism in animation by means of an analysis of Disney's animated films. "Even though Disney dealt with what was a predominantly abstract, non-realist form he insisted on verisimilitude in his characters, contexts and narratives. He wanted animated figures to move like real figures and be informed by a plausible motivation" (Wells 25).

The effect that this striving for verisimilitude had on the quality of the animation in *Snow White* (1937) is regarded as a major advance in both the style and narrative content of animation. Disney's goal was of course not photorealism but to improve on the techniques of animation to create plausible motion that would allow audiences to immerse themselves in the stories of the studio's films. While this was a step toward a type of realism, the Disney technique outlined in *The Illusion of Life* (Johnston and Thomas 68), also required animators to adhere to the principles of animation that the studio had developed. These included stretch and squash, exaggeration and anticipation which are not strictly speaking realistic yet they clearly enhance the believability of the animation.

This is a type of realism in animation that is not in a more general sense, realistic as we experience the world around us. It does however, contribute to a plausible motion for more iconic, cartoonish images in animation. For the purpose of the discussion of the uncanny valley, our definition of realism is not based on hand drawn or cartoonish, iconic figures but rather on photographed source material or images which more closely resemble the way we see the world around us rather than through a metaphoric representation. Early animation was all hand drawn frame by frame or sculpted from materials and photographed one frame at a time but in general consisted of cartoonish, iconic or metaphoric images rather than images that we would associate with photography of a highly detailed and realistic nature.

With advances in technology it was only a question of time before the hand-drawn art form of animation would be transferred to the newly invented field of computer-generated imagery. For the purpose of the debate on *The Uncanny Valley*, computer animation can be split into two types: 1) stylised characters that originate primarily from hand-drawn 2D animation, and 2) very realistic animation which uses photographed sources as its frame of reference. Both types of animation serve a purpose and have great value and appeal to their different audiences.

An example of more stylised characters that have the iconic form of hand-drawn 2D animation, can be seen in the design of the characters and environments in *The Incredibles* (2004). The characters' proportions are exaggerated, there is a pastel quality to the texture of their skin tones and their motion is exaggerated and often physically impossible. An example of a realistic character that exists in a photographed environment is the character of Benjamin Button in the film *The Curious Case of Benjamin Button (2009)*.

I argue that the concept of realism germane to this debate refers to photorealism as outlined by Darley who acknowledges that:

> There are, of course, a host of differing and often contradictory conceptions of what constitutes representational realism... The one that came to

> discursive prominence within computer image research and practice is perhaps the one with which we are all most familiar. The proximate or accurate image: the 'realisticness' or resemblance of an image to the phenomenal everyday world that we perceive and experience (partially) through sight. For the majority of those involved with digital imaging at the time, the yardstick of such verisimilitude was photographic and cinematographic imagery. (17)

As opposed to the art movement of photorealism which uses a technique of creating painted images which are realistic to the point that they may be confused with photographs and are often created using photographs as their source, I refer here to photorealism as it pertains to film and cinematography. In 3D Animation and CGI this definition refers to computer-generated images which are created in such a way that they are indistinguishable from images that have been shot using a film or digital live-action camera. Photorealism thus refers to an image plane which has been created in such a way that the elements of it are indistinguishable from an image shot with a film or digital camera. A character in a film that could exist in reality, or may in fact be a double for a real actor that could have been shot with a real camera but has been created in CGI, is an example of photorealism in this context.

In relation to film and visual effects photorealism therefore refers to how closely CGI or 3D images match specific images or shots photographed with a real camera. The test outlined in the discussion on Tinwell in section 1.2.4 of this thesis remains useful in this definition. Could an audience believe that a character or object created in 3D or CGI is a real object that was photographed with a real camera? This may apply to CGI objects or characters that are integrated into live-action shots or images as well as to entirely computer-generated shots or images where an attempt is made to create the illusion of characters, objects or an environment that was recorded or photographed with a real camera.

Ron Brinkman in *The Art and Science of Digital Compositing* describes the process of compositing photorealistic images:

> In particular, we are usually attempting to produce [sequences of] images that could have been believably photographed without the use of any post-processing. Colloquially, they should look "real". Even if the elements in the scene are obviously not real (huge talking insects standing atop a giant peach, for example), one must be able to believe that everything in the scene was photographed at the same time, by the same camera. (Brinkman 3)

Modern visual effects and animation are increasingly capable of creating characters that may or may not appear to be real but that exist in a photographed environment and interact with real actors. Completely realistic animated characters may be necessary where the danger of certain tasks is excessive to the human actors (where explosions or other action sequences are involved) (Christophers 23); the physiological appearance of a character may be beyond the physiology of human actors; or they may be required in their performance to do something which is physically impossible. Film-makers constantly explore the boundaries of what is possible in the characters they create and the aesthetic choices that they convey in their narratives and these situations occur with increasing regularity.

As we explore the case studies it will become apparent that we have already entered the age of these very realistic (in terms of the definitions above) CGI characters. The character of Gollum in *The Lord of the Rings* (2001-2014) films exists in a magical domain but the film was shot with a live-action camera. Actor Andy Serkis performed the part of Gollum while dressed in a motion capture suit and interacted with other actors in front of the camera. Multiple motion capture cameras also recorded Serkis' actions. His performance was later replaced with the CGI Gollum (Serkis 11). The character is human-like but not human.

The techniques used in realising the character of Gollum in *The Lord of The Rings* (2001-2014) involved complex motion capture[10] of actor Andy Serkis. Motion capture of the movements of a body was state of the art technology at the time but the technique did not

[10] The process typically involves an actor being dressed in a suit with small reflective balls attached to it. These balls act as markers and are recorded or tracked by an array of specialised cameras. After the performance has been recorded this data is mapped to a CGI character and a wrist marker's keyframes from the suited actor become the keyframes of the CGI character's wrist and so on for the other parts of the body.

(at least in the initial two films in the series) include facial motion capture.[11] In a sense, the type of animation used for Gollum's face is reminiscent of the rotoscoping of the Fleisher Brothers and can be referred to as Rotomation[12]. Rotomation is the process of filming a reference and then copying the performance with a CGI character, often on a frame by frame basis (Flueckiger 33). It is distinguishable from motion capture which uses dots (typically reflective balls or painted dots) on an actor's costume or face which are assigned to the vertices of a CGI character in 3D space (Ulbrich). A dot for a wrist marker is assigned to a CGI character's wrist and the performance of an actor is thus assigned to a CGI character (Cook qtd in Amidi). The animation that took place on top of this rotomation of actor Andy Serkis enhanced and exaggerated the actor's performance to collaboratively realise the character of Gollum in *The Lord of the Rings* films (2001-2014) (Cook qtd in Amidi).

In Kelly Christophers' research report *Realism in CGI Character Performance*, which uses the Gollum character from the first three films in *The Lord of the Rings series* (2001-2014) as a case study, she contends that motion capture was responsible for achieving the realism of this character within the context of the film. With reference to director Peter Jackson's choice of this method she comments: "Originally, Jackson planned Gollum to be a traditionally key-framed CG character, although it soon became apparent that in order to capture the subtlety needed for a realistic performance, he would have to rely on motion capture technology" (Christophers 51). She also outlines, amongst the technology used, the application of the Facial Action Coding System of Paul Ekman. The analysis of this system is brief but the emphasis of the paper is on motion capture.

While Christophers accurately observes the massive impact that motion capture had for the animation of the body of Gollum taken from the performance of Andy Serkis,

[11] The technique in the first film did not include facial motion capture using dots painted onto the face at specific points to register the contraction of different muscles for different expressions. It used a technique of filming the face, and sometimes having the facial performance repeated and shot separately from the body for additional reference and then hand animating. In subsequent films, as the technology evolved, facial motion capture was used for parts of the performance but as Cook points out, not all (Cartoon Brew Web).

[12] "…a hybrid technique was used, referred to by technicians as rotomation (cinefex 96: 69). Here, a proxy is first detached from the background, and secondly, based on the proxy's performance, the digital character is inserted into the image. Its movements were reproduced using motion capture combined with keyframe animation derived from the proxy's movement" (Flueckiger 33). The performance of an actor is used to create a spine and limbs for a 3D character. These are then used to drive the animation of the 3D character by copying their movements but not necessarily through the use of motion capture markers.

she also correctly points out that the facial and hand animation were not motion captured (Christophers 53). The complexity of achieving this type of motion capture of faces at the time was particularly difficult as facial motion capture was only introduced later in the Robert Zemekis film *Polar Express* (2004) (Bredow et al. 35). Bredow et al. outline some of the difficulties they faced with the technique of recording relatively smaller facial tracking markers in their 2005 SIGGRAPH presentation. As a result rotomation was the technique followed for the facial animation in *The Fellowship of the Ring* (2001), using footage of Serkis, where available, as a strong reference for creating the keyframed animation and then enhancing the performance where necessary.

The degree of realism achieved in the character was considered by many critics[13] to be convincing and in their view, set a new standard of realism. Elvis Mitchell of the *New York Times* comments: "Gollum is a frighteningly believable realisation of computer imagery as performer" (Mitchell). That realism was largely dependent on the facial animation and the rich emotional performance of the character of Gollum which was achieved through this rotomation (a process of imitating and enhancing footage of Serkis' performance as opposed to motion capture) and enhanced facial animation from the reference of the filmed actor applied to the CGI character.

Christophers' 2011 paper is an analysis of the existing technology at the time. There were concurrent advances in facial motion capture using ultra-violet paint instead of tracking points and the specialised cameras which make the technology viable. This methodology, which allows for the capture of the surfaces of facial features rather than just points and is tracked retrospectively, instead of requiring individual points to be assigned to vertices, can yield very good results as in the case of *The Curious Case of Benjamin Button* (2009) (Ulbrich). This system was not used in any of *The Lord of the Rings* films (2001-2014). Very good results were achieved using motion capture, or in many cases, animating from recorded reference with no facial motion capture, on the CGI characters of Gollum and others, which is a testament to the skill of the artists who worked on these films. The different methods employed are an indication of the rapid pace of change in facial motion capture technology. The impact that anatomically correct facial muscles have

[13] Todd McCarthy, *Variety*; David Hunter, *The Hollywood Reporter*; Jack Mathews, *New York Daily News*; Elvis Mitchell, *The New York Times*; Steve Rhodes, *Internet Reviews*; Nev Pierce, *BBC*; Bruce Westbrook, *The Houston Chronicle*; Michael Wilmington, *The Chicago Tribune* (Serkis Web)

in rigs[14] which drive the expressions of the character was a milestone technological advance based on Ekman's FACS system, which in turn contributed significantly to the realism of the character (Amidi).

There was some conflict between Serkis and the animators after the various *The Lord of the Rings* (2001–2014) films because of statements that Serkis made about motion capture and the role of 3D animators being responsible for digital make-up (Amidi) or merely transforming his performance onto the CGI Gollum character. In response to these interviews Randall William Cook, Weta[15] animation supervisor for *The Lord of the Rings* (2001–2014) commented: "Let me state that Andy really should be considered the principal author of Gollum's performance, but there's a hell of a difference between principal author and sole author. The Animators who helped shape Gollum's performance are actors of a very special type, working at a high level of achievement… they were doing the same things Andy did, in concert with him, and significantly contributing to the realization of a memorable performance" (Amidi). He pointed out various shots of Gollum in the films which were created without any involvement from Serkis at all, as well as the numerous shots that were enhanced through keyframe animation, rather than using motion capture, as well as various motion capture shots where Serkis was not available and animators were used instead in the motion capture suit. He further noted in this interview the importance of the complex facial rig and muscle system (based on the Facial Action Coding System) that allowed for the subtlety in the performance.

While Christophers' study was an investigation of the strong relationship between body motion capture, facial motion capture and the role of skilled animators and technicians, the pace of development in the field makes it difficult to assert definite rules for the exclusive use of one technique over another. Motion capture is a powerful tool but there is undeniably a strong additional input from animators to add to these performances. The importance of having a muscle system to articulate the expressions required for emotionally complex characters, as outlined by Tinwell, Grimshaw and Nabi (9) and by Cook (Cook qtd in. Amidi), is also crucial.

[14] Rigs are the bone and muscle systems which animators use to drive their animation. They are invisible in the final rendered image but are an essential tool for creating keyframe animation.
[15] Weta is a New Zealand based post production company that specialises in high-end visual effects and animation. They have won numerous awards, including Academy Awards for visual effects.

Previous distinctions that called for the exclusive iconic representation of characters such as in *The Incredibles* (Butler and Joschko), may be put in question by these steps forward in technology. The recommendation by the authors of this paper that all animated films should only use iconic cartoonish characters seems to contradict the technology displayed in films such as *Avatar (2010)* and *The Lord of the Rings* (2001-2014) series of films. There will always be a place for the beautiful stylized character design and animation of *The Incredibles* (2004) but there are types of animation that have been made possible by improvements in technology with regard to human facial animation that are making more varied types of animation possible all the time. It was a stated goal at Pixar while working on *The Incredibles*, (2004) to design the characters in a way where they had maximum appeal without being too close to human. This was an aesthetic choice made by director Brad Bird and executive producer John Lasseter based on a host of creative decisions as well as the technology of the time: "Our goal on *The Incredibles* was to create very stylized human beings who could never pass as real humans but have hair, skin and clothing so true-to-life that their reactions have a stronger, more dramatic impact (Lassetter qtd *The Incredibles* Production Notes).

2.2 General Developments in CGI

Photorealism in animation is associated mostly with computer-generated or 3D animation as opposed to hand drawn or 2D animation. This section will outline a history of relevant developments in computer generated images and 3D computer-generated animation that pertain to realistic facial animation.

While this account follows a chronological order, many of the techniques discussed were developed during the production or post production of specific films and the technology is often associated not only with a specific time but with the film in which it was first introduced. The case studies in this paper are a comparative analysis of two films which display particular attributes with regard to uncanny responses to computer-generated characters. As a result it is useful to see developments in the progression of realistic facial animation not only in terms of the time at which technology was developed

but also whether it was successfully implemented in a particular film as compared to another film.

2.2.1 Early Computer-Generated Animation

Cartesian co-ordinates were developed by the French philosopher and mathematician Rene Descartes (1596-1650) in the 1600s and created a system by means of which the co-ordinates of a point could be plotted in space on an *x*- and a *y*-axis. By adding a *z*-axis any vertex or point could be plotted by a computer. By adding thousands of vertices and joining them, objects can be mapped out in 3D space (Rickitt 154).

The first 3D animation was created in 1972 (Price 13) when Ed Catmul and Fred Parke at the University of Utah sculpted a physical model of a human hand, painted polygons onto the physical model of the hand, and then painstakingly digitized these and converted that point information into digital co-ordinates on a computer. A wireframe mesh was created from this and the first shading system was developed so that the computer could represent the surface area as having properties such as texture and shading. The hand partially closed and then re-opened. The technique was rather cumbersome but it showed the potential of the technology. The animated clip was included in the film *Westworld* (1973) as the first ever piece of computer-generated 3D animation and the first CGI to be used in a full-length motion picture (Price 13).

In 1974 Fred Parke went on to animate a three minute film of a human face. This may be considered to be the very first attempt at facial animation in computer-generated 3D animation (Price 14). The results are surprisingly impressive for the time. The character changes through a number of facial expressions and then articulates two versions of a 30 second piece of lip-synced animation. The surface of the face has both shading and independent movement and textures for the eyes and the surface of the skin[16]. Although one of the expressions features bulging eyes that may be reminiscent of Chuck Jones or Tex Avery's[17] characters, the proportions and the actions are relatively close to human anatomy.

[16] See glossary of terms for definitions of shading and texturing.
[17] Chuck Jones and Tex Avery were Warner Brothers animators who worked on the Looney Tunes series and are often associated with a technique of exaggerating or bulging features, such as eyes, for humorous or narrative purposes.

The eyes in this animation use a separate shader which already makes use of specular light[18]. From the beginnings of computer animation there was an emphasis on achieving a type of verisimilitude close to the human sensory perception of human faces in reality. While the lip-syncing is not effectively achieved, the test shows further potential for the technique even at this early stage. It begs the question as to what might have been achieved had it been supervised, or had there been collaboration with a skilled animator.

About ten years after Catmul and Parke's ground breaking animations at the University of Utah and their inclusion in the film *Westworld,* the first attempt at a large scale creation of digitally created animation and computer graphics for a Hollywood film was attempted. *Tron* (1982) attempted to benefit from the games arcade trend of the 1980s. With a plot involving a character becoming trapped in a computer game, it featured fifteen full minutes of CGI. This film is also the first example of computer-generated facial animation in a Hollywood film. The character of Master Control is represented as a wireframe face with no texture on it or as a rough face with broad nose and eyes far apart projected onto a cylinder. The sequences involve lip-sync animation and the character's dialogue contributes to the plot. It went on to be a cult favourite in the decades that followed and gained enough support to justify a sequel in *Tron Legacy (*2010) (Prince 24).

In the year that *Tron* (1982) was released Steven Spielberg's *E.T. the Extra-Terrestrial* (1982) was also released and broke several box office records (Rickitt 37). The film was produced using entirely optical effects. "The early blockbusters had made significant use of effects but for the most part these involved skilful variations of traditional methods" (Rickitt 37). While the computer-generated effects in *Tron* (1982) were impressive for the time they had a 'primitive' look about them and were competing with spectacular practical and optical effects in blockbuster films that relied on a long history of development (Rickitt 37).

Ten years later Steven Spielberg's film *Jurassic Park* (1993) created realistic

[18] Shaders are attributes of 3D objects which create surface detail. Different types of shaders react differently to light creating more or less reflective or refractive properties when the light from a light source interacts with the object within 3D space (see glossary of terms). In this instance a distinction is made between a shader for a skin texture and one for an eye. The eye is more reflective and has a higher specular quality when hit by light.

organic[19] CGI dinosaurs which interacted with live-action actors. The film was a success with both audiences and critics and demonstrates the advances made in the technology of 3D animation. Although most audiences and many critics regarded the dinosaurs in the film as being entirely computer-generated effects, only 50 shots of the film were created with 3D dinosaurs with all the other shots featuring in-camera puppets (Prince 26). The film was a success because of the seamless integration of digital and in-camera physical effects (Prince 26).

2.2.2 Pixar and the Development of 3D Animated Films

The first 3D character animated short film, *The Adventures of Andre and Wally B,* was released in 1984. The film featured, for the first time in computer animation, motion blur and stretch and squash (Price 58). The film was produced by the Graphics Group, formed in 1979 as part of the Lucasfilm group (Price 58). When Steve Jobs bought them out as an independent company in 1986, the studio was renamed Pixar.

The director, John Lasseter, was a Disney trained animator, whose careful attention to the animation as well as to a clever and compelling narrative brought greater craft and complexity to Pixar's films. He had left Disney, who were in a relative slump during that period and was hired by Ed Catmul at Pixar who realized the value that a trained animation director could bring to his team (Price 54). He joined The Graphics Group (later Pixar) in December of 1983 and was a major contributor to their success (Price 53).

The short animated film *Luxo Junior* (Pixar 1986) was the first time that the aesthetic of 3D computer animation was truly shown off. A simple clear piece of animation featuring two lamps and a bouncing ball, it was brought to life by Lasseter with all his expertise and utilising the principles that Disney had first brought to animation (Price 91-92). The film was nominated for an Academy Award and featured Pixar's Renderman software which allowed for reflections, realistic lighting and shadows and gave the film the unique and appealing look that we have come to associate with 3D animation and with Pixar (Price 92).

[19] Prior to Jurassic Park CGI had most successfully been used to create plastic or artificial objects or characters. The texturing, lighting and rendering required to create organic surfaces, such as the skin of dinosaurs, only became possible with the advances in technology made in this film (Prince 25-27).

Their choice of plastic texturing (non-organic surfaces) for their characters and the objects in the world they inhabited was intentional and when they attempted to portray a human baby two years later in *Tin Toy* (1988), the difficulty of creating organic surfaces such as human skin became apparent (Price 105). Despite criticism of the look of the baby in *Tin Toy* (1988) the film was lauded for its appealing animation and for the clever story which served as a vehicle for all of the toy characters in the narrative. It received the first ever Academy Award for a computer generated animation in 1988 in the category of Best Animated Short Film (Price 93).

Despite *Tin Toy* (1988) director John Lasseter studying hundreds of hours of footage of babies and attempting 'realistic' animation, audiences and critics responded negatively to the human baby character. Following the difficulty of *Tin Toy* (1988), Lasseter chose to move away from realistic depictions of humans (Price 107).

Pixar had turned a corner and began to pursue iconic characters (in the short-term made of inorganic surfaces) that occupied stylised worlds[20]. These characters could plausibly exist within their narrative constructs rather than any 'realistic' portrayals, particularly of human characters, in representations of the 'real world' as presented in photorealistic cinema. Given the state of the technology that they were dealing with, these choices have served them well over the course of the last twenty years

The first fully 3D animated feature-length film was the straight-to-video religious release *Veggie Tales* (1994) but it was *Toy Story* (1995) that transformed 3D animation and succeeded with vast audiences. *Toy Story* (1995) created a new aesthetic of lighting and shading which was highly appropriate for the plastic toy characters of the narrative. Over the ten years and several short films they had produced leading up to *Toy Story,* Pixar had developed the techniques and software they would need to produce the film.

Some of the technologies developed and utilized in Pixar's in-house render engine,

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[20] See footnote 19. Initially the technology for rendering 3D and computer-generated images was better suited to representing plastic surfaces like toys or cars, than organic surfaces such as skin or fur.

Renderman, were Ray-Tracing and Global Illumination[21] which account for the accurate reflection and refraction of light against objects and their materials. This created a sense of all objects and characters within a scene being lit by the same lights, casting realistic shadows that were 'photographed' by the same camera. The plausibility of these virtual cameras behaving in a similar fashion to live-action cameras and obeying the physical laws of their virtual environments is what creates the ever increasing sense of verisimilitude in these films. It may not be what we would consider 'real' but it is plausible for the world it exists in and obeys the rules of that environment in a consistent and aesthetically pleasing manner.

In *The Incredibles* (2001), Pixar animation director Brad Bird's aesthetic choice was one of moulded iconic superheroes and a full 'human' cast whose stylised iconic representation had great appeal with audiences. There is a careful avoidance of realistic human characters lest they are judged not by the standards which are set for the performances of cartoons but by those set for humans.

2.2.3 Realism in 3D Animated Films

The Incredibles (2001) had studiously avoided overly realistic 3D human characters but at the same time as it was made and released a much more photorealistic 3D film was also distributed in cinemas. The release of *Final Fantasy* (2001) was the first major attempt at the aesthetics of realism with human characters in a 3D film. The film did not recover its budget at the box office (Sahota) and received very few favourable critical reviews. A review in London's *Time Out* for instance criticizes "the marionette-like impression created by cold eyes and oddly unconvincing body movements" (Timeout Web). I will explore the techniques used in the film and the possible reasons for its failure in the case study analysis. While this was the first time this degree of realism was attempted in a fully 3D film, there was much progress being made with CGI characters in live-action films.

2.2.4 Realism in CGI Characters in Live-action Films

[21] See glossary of terms, these two innovations greatly enhanced the quality of Pixar's films.

With the first two *The Lord of the Rings* films, *The Fellowship of the Ring* (2001) and *The Twin Towers* (2002), an entirely new standard was set for realistic visual effects in cinema and for animated characters interacting with live-action characters. Extensive use was made of motion capture technology and the shooting of reference for facial animation. The recorded and motion captured performance of character actor Andy Serkis created a very good foundation to effect the spectacular CGI Gollum character. The motion capture technique used many tracking points on a black suit which were then assigned to 3D vertices. Although it was based on existing technology, its implementation and the management of the data were significantly improved in these films.

Another technique used was the introduction of sub-surface scattering to create realistic skin textures (realistic here would infer plausible for the character in the cinematic environment). The technique is a rendering tool which allows for the accurate refraction, absorption and scattering of light when it encounters semi-transparent surfaces such as human, or in the case of Gollum, human-like skin. It is computationally complex and relies on advanced software as well as high powered processing machines to render. “We identified the key component to making skin look correct as subsurface scattering, where light diffuses through the skin and makes it look translucent. We did this for the first time on Gollum for The Two Towers” (Letteri, J qtd in. Connelly). It was a turning point in the representation of realistic human and human-like characters.

While the use of rotomation[22] and then enhanced keyframed facial animation based on extensive shot footage of the actor contributed to the level of verisimilitude achieved by the character, there is still a factor of difference from human characters. Gollum is important to this discussion as in presenting a CG character to an audience, the subtlety of performance and the audience’s ability to read the emotional nuances of that performance were much more complex and rich than they had been with any CG character in a film before. “The subtlety of Gollum's movements and expressions is so astonishing that it's difficult to believe this isn't a real creature” (Berardinelli qtd in Serkis). We feel his emotions like a living actor through the entire film.

Of course the character creates some aversion: “A sneaky, clammy, amphibious

[22] See glossary of terms for a definition of rotomation.

creature" as J Hoberman of *The Village Voice* observes (Hoberman qtd in Serkis) and, it could be argued, benefits from any notions of discomfort that we might associate with imperfect representations of human facial animation. There is however, clearly no doubt as to whether he is alive or dead, and the theory of the uncanny valley, as it pertains to realistic CGI, is that it disrupts the suspension of disbelief as in the criticisms of "the marionette like performance" (Timeout) of *Final Fantasy* discussed previously. As Gollum performs with the other characters the audience is never left with the sense of a puppet in which the puppeteer has let go of the controls. Preceding criticism of CG characters as being "dead eyed" and "zombie like" or "puppet corpses" (Snyder) are challenged by this collaborative performance, as Gollum engages the audience and interacts seamlessly with the live-action characters of the film. Gollum's performance and appearance do not draw one out of the story by disrupting the suspension of disbelief, but rather greatly contribute to the audience's immersion in the narrative.

The Matrix Reloaded (2003), the sequel to the box office hit *The Matrix* (1999), created "a startlingly real form of human facial animation" (Rickitt 212), where live-action actors were required to engage in a physically impossible fight scene. The level of expression achieved with the CGI characters in this scene, which was relatively ambitious for the time, was eclipsed by the realism achieved in subsequent human facial animation in films such as *The Curious Case of Benjamin Button* (2009).

Both *The Matrix Reloaded* (2003) and *The Curious Case of Benjamin Button* (2009) relied heavily on facial motion capture and high resolution images of the actors' faces. *Benjamin Button* however, made use of the Facial Action Coding System (FACS) for facial animation rigging first used in *The Lord of the Rings* (2001-2004) films, in order to achieve the detail in the animation and texturing of the faces of the titular character (Dunlop).

FACS was developed in the field of psychology by Dr Paul Ekman and Wallace V. Friesen for the study of human behaviour but has since been adopted in the field of 3D computer animation (Ekman and Friesen 20). The system involves identifying a group of expressions and the muscles of the face that are responsible for them. A coding system is then used to apply the combination of muscles that are responsible for different

expressions. This coding system describes expressions in terms of action units (AUs) and lists descriptive emotions (happy, sad etc) with their relevant AU codes, along with the muscles that are responsible for making the related expression (Ekman and Friesen 20).

3D rigging[23] supervisor Judd Simantov[24] of Naughty Dog, described the rigging process, outlining how the main character rig for the game *The Last of Us* (2014) utilized this technology and how it took five months to perfect the rig for a single character (Symantov).

The FACS system is constantly being revised as Joe Letterri, VFX supervisor on *The Lord of The Rings* series (2001-2014) films points out:

> *The Two Towers* was, as far as I'm aware, the first time anybody coded the expressions of a character based on the FACS system…in *The Hobbit*, there's a skeleton inside them. And it's a real skeleton, and all of the bones are the proper shape. All of the muscles are attached to the bones and represented physically with all the correct lengths, attachments, ligaments and so forth. Surrounding the muscles is a fascia layer that holds them altogether, but then there's a layer of dense tissue on top of it, which represents organs or fat and fills out the rest of the form of the body. And then there's skin that goes on top. (Letterri qtd in. Connelly)

The facial motion capture which was used in *The Curious Case of Benjamin Button* (2009) represents a vast improvement on earlier technology. The system that was first implemented in *Polar Express (2004*) involved tracking multiple points on the face of actor Tom Hanks, which was transferred to the 3D character (Clinton). This point tracking system was later used for James Cameron's *Avatar* (2009). Cameron enhanced the technique by adding head camera rigs to record the actors' facial performances while

[23] Rigs in 3D are the bone and muscle system under the surface of the skin or fur or textures of characters and objects which animators use to drive their keyframed animation. They are not visible in the final rendered images but are a tool that is used to effectively move characters and objects for the purpose of animation.

[24] Judd Symantov is a rigging technical director at the game production company Naughty Dog Inc. Naughty Dog has created some of the most successful and widely sold games in the world, such as *Far Cry* (2003) and *The Last of Us* (2013)

separate cameras recorded their bodies ("From Gollum to “Avatar”).

The Polar Express (2004) and *Beowulf* (2007) are both often cited examples of films critiqued in referencing the uncanny valley hypothesis, as in CNN’s “*Polar Express a Creepy Ride”* (Clinton) and in an article in *The New Yorker* by Margaret Talbot who commented in relation to both *The Polar Express* and *Beowulf.* “Their digital characters have struck most viewers as dead-eyed and stiff” (Talbot). Both films have human characters and both films utilised motion capture to capture animation data for the bodies as well as the faces of their characters.

The Polar Express (2004) is also one of the films cited in the research conducted in an attempt to create an empirical validation of Mori's *Uncanny Valley* theory (Ho and MacDorman). While there would appear to be a lack of conclusive evidence in support of the theory from the empirical studies conducted, critical reviews of both frequently refer to the lack of expression in the eyes of the characters combined with realistic skin textures, as highly unsettling or uncanny (Talbot).

The system used instead of tracking dots in *The Curious Case of Benjamin Button* (2009) was to paint the actor's face with ultra violet paint with a rough sponge that created a mottled texture. Specialized software and cameras were used to record the entire surface of the face and transfer this back to the geometry of the 3D character. The technique will be covered in more detail in the case study, but these variations in the application of the technology contributed to achieving the photorealistic look required by director David Fincher (Dunlop).

Avatar (2009) relied heavily on facial motion capture for the animation of its human-like characters ("From Gollum to “Avatar”). James Cameron claimed the innovations on the film had allowed him to cross over the *Uncanny Valley*:

> We needed to get to the far side of that dip of the response curve which is called the Uncanny Valley and we needed to get to the opposite side where we believed, we don’t have to necessarily believe that it’s a hundred percent photo-real and we don’t have to necessarily believe that they actually exist.

> But we have to believe in them as emotional creatures. I think we've absolutely accomplished that. (Cameron qtd in Christophers 61)

One could argue however, that the epic scale of the film was achieved with very little innovation in the technology of facial animation. Helmet camera rigs had been introduced on *The Polar Express* (2004) ("From Gollum to "Avatar"), motion capture had existed for some time and stereoscopic (3D) film projection in cinemas had also existed for many years, although advances to this technology accompanied the release of *Avatar* (2010).

The film's alien characters are also different enough from humans to be in the valley region of Mori's proposed curve. Flueckiger in her case study of the film analyses the "considerable differences between Na'vi faces, with their broad noses and feline eyes, and human faces" (19). She returns to further analyses of these physiological differences between humans and the characters of the Na'vi noting that they are twice the height of humans, their eyes further apart and their skin is blue (Flueckiger 20). It is possible to read the emotions of the characters perfectly, though yet again, there is no ambiguity as to whether the characters are alive or dead. This can largely be attributed to Cameron's desire to get actor driven performances (Newsweek). Flueckiger comments on the methodology used as follows:

> It should be noted, however, that the images produced by the helmet camera…did not provide reliable movement data. There are two reasons for this. First, a very high-resolution image quality is required for pixel [sic, -optical] flow analysis to function, because without a high resolution filtering problems arise similar to those created with markers. Second, a helmet camera only makes available one frontal perspective, distorted by a fish-eye lens, instead of multiple recording angles. (Flueckiger 18)

There is undoubtedly some fidelity in the performance of the CGI characters which is driven by the actors as Cameron notes: "This is a highly actor-driven process" (Newsweek). Cameron however, implied in this and other interviews that the process in *Avatar* (2010) was merely the capturing of a performance from actors whom he himself

directed on set and which was then transferred to CGI characters. However, the technical processes outlined above indicate that the process was far from a mere recording.

In fact, animators were required to study the footage of actors provided from the helmet cameras, from only a frontal perspective (3D objects and characters are created using several camera perspectives to accurately deal with volume and proportion) and with some lens distortion, and then to animate the CGI character based on this reference footage. This process must allow for some interpretation from the animators responsible, although the primary source of reference for the performance would of course be based on the performance of the actors.

These successful CGI performances, *Avatar* (2010)*, The Lord of the Rings* (2001 – 2014) films and *The Curious Case of Benjamin Button* (2009), are in strong contrast to other attempts at realistic 3D or CGI characters such as in *Final Fantasy: The Spirits Within* (2001). In the case studies that follow I explore possible reasons for the success and failure of these very different films.

Chapter 3: Case Studies

The case studies in this section serve as an analysis of two types of films: realistic 3D animation and photo-realistic CGI characters in a live-action environment. The purpose of the analysis is to consider and analyse some of the factors that may have contributed to the relative success or failure of the films discussed in the context of the debates about *The Uncanny Valley*.

3.1 An Analysis of *Final Fantasy: The Spirits Within* (2001).

Final Fantasy: The Spirits Within (2001) was directed by Hironobu Sakaguchi who also directed the successful series of *Final Fantasy* games. The plot follows the protagonist scientist, Dr. Aki Ross, as she tries to defeat an alien invasion by collecting eight spirits which occur in different living things such as a plant and a dying child (Zacharek).

3.1.1 Production Methodology

One of the criticisms of the film was the convoluted script and slow dialogue that one reviewer compared to watching a dubbed Japanese film (Mitchell). Producer Chris Lee, with regard to the realistic aesthetic states: "Final Fantasy brings this goal to life as the first film with an entire cast of hyper-realistic computer-generated human characters, the ultimate integration of real-world images, human characters and fantasies into a complex 3-D space on the screen" ("*Final Fantasy: The Spirits Within* : Production Notes"). The film still has a particularly stylised aesthetic but there was an entirely new level of detail in the human-looking characters which "were unlike anything anyone had seen in the industry up until this point (Seigh). Sakaguchi maintained at the time "I think it's OK to look at Aki and be convinced that she's human" (Sakaguchi qtd in Kennedy).

The character of Dr Aki Ross famously had 60,000 hairs that needed to be animated and rendered (French). Each individual frame of the film took between fifteen minutes and seven hours to render. The total production time for the film was four years (Park).

Given the intensive workload that the film required, the process of motion capture

was the only feasible choice to complete the 1327 shots of the film. The alternative process of keyframe animation for the entire film would have been ruinously labour intensive. No facial motion capture was used, only motion capture of the bodies of human characters and this was not performed by the voice actors but by lesser known performers ("*Final Fantasy: The Spirits Within*: Production Notes"). All facial and hand animation was done using keyframe or manual animation rather than motion capture (Robertson). Full body motion capture was certainly useful in creating a basis for the animation on *Final Fantasy* (2001) but the process of point tracking and retargeting to vertices in 3D was manual[25], requiring many hours to painstakingly implement corrections. Half of the crew were American and half Japanese and to accommodate all these workers in one place a new studio was built in Hawaii at a cost of $40 million (Park). The film lost a total of $53 million at the box office (Sahota).

Final Fantasy was released in the same year as the first of *The Lord of the Rings* films, *The Fellowship of the Ring* (2001). The method used for the motion capture of Gollum in these films, being driven very much by the performance of Andy Serkis, was relatively complex and received favourable critical reviews such as Elvis Mitchell's review of *The Return of The King* (2003) in *The New York Times:* "Gollum is a frighteningly believable realization of computer imagery as performer" (qtd in Serkis) In contrast *Final Fantasy: The Spirits Within* (2001) received mostly negative reviews, such as Stephanie Zacharek's scathing review in *Salon* "but there's also something creepily artificial about them" (Zacharek).

Although the film was entirely CGI there was still a substantial amount of compositing required (see glossary for a definition of compositing), in which individual layers were rendered out of 3D and then imported into a compositing package to be assembled and finessed, thus reducing the time required for rendering[26]. It allowed the dense geometry of the different characters to be rendered independently and then re-

[25] Motion capture works by tracking individual markers and assigning them to the vertices of 3D geometry (for instance a tracking marker on an actor's hand is assigned to a 3D character's hand). The process was fairly rudimentary at that time and has been refined dramatically in the course of the last 15 years.

[26] See glossary of terms for definition of rendering. Rendering is a calculation of how every object visible to a virtual camera interacts with direct or reflected light or is occluded from the view of that camera and how reflective, transparent or refractive those objects are. Rendering takes all this information and creates an image sequence similar to the processed frames of a traditional movie camera which can then be played back and viewed by an audience.

assembled afterwards. It also allowed for a 'look' to be refined in a final finishing process rather than being defined by what was rendered out of 3D. Compositing supervisor Balcells notes "a shot would be built with anywhere from nine to 498 composite layers!" (Balcells qtd in Park).

The process of the facial animation was similar to what had been done before on 3D films, which involved shooting reference and animate to the recorded video guide[27]. Disney artists had done this as early as in *Snow White* (1937) where footage of actors and dancers were used as a reference for animators to work from to create the level of verisimilitude required (Johnston and Thomas 320). In *Final Fantasy: The Spirits Within* (2001) the production company Square Picture's artists created a library of poses or emotions, such as "Lower Eyelid Twitch", as well as a phoneme library for the different mouth shapes for lip syncing. The method they employed was to create sliders for these different states which an animator could control for performance (Park).

At the time these processes were considered best practice in animation. In the production of *Final Fantasy: The Spirits Within* (2001) reference material for the performance of the characters was also shot, although it was not taken from the actors (Donald Sutherland, James Woods and others) who were doing the voice performances. The result was a disjuncture between the 'look' of the characters and the voices emitting from them, and weaker performances from the actors doing the body motion capture. The voice cast had been chosen because they were famous and talented actors but critics were quick to point out the unsettling effect of having very recognisable actors' voices emanating from better looking but unrecognisable 3D models. "There's a digital Ben Affleck (with Alec Baldwin's voice), a digital Neve Campbell (with Ming-Na's voice), a digital Jason Priestley (with Steve Buscemi's voice)" (Atkinson). Critics further pointed to the difficulty the actors had in conveying their voiced performances and how they tended to overcompensate in their performances: "The voicing actors are obviously overcompensating for their lack of physical presence, speaking each line as if trying to make a great impression. Even the usually brilliant Steve Buscemi sounds like a first-jobber, determined to get a call back as the not-so-comic relief" (Total Film). These multiple

[27] See the definition of Rotomation for this technique. Animation is done manually over the top of a live action performance. It is still a manual keyframe process as opposed to facial motion capture.

factors that contributed to an unsettling response, erode the simplistic argument of *Final Fantasy: The Spirits Within* (2001) being a textbook example of the *Uncanny Valley* theory based exclusively on an attempt at realism as an aesthetic choice for this 3D film.

Additional factors that affected the failure of the film include a poor script and weak performances and direction in the reference for the animation. Several reviews however, point out an uncanny effect resulting from a lack of articulation or expression of the CGI characters (Zacharek, Caro, and Timeout) which clearly identifies this issue as significant. There is however confusion in these reviews between the realism of the characters and the lack of expressiveness of the CGI characters as a reason for the failure of the film. As was shown with the CGI character of Gollum, audiences can accept realistic CGI characters but only if they have similar levels of animation and the articulation of their facial expressions.

3.1.2 Aesthetic Choices

The aesthetic look of *Final Fantasy: The Spirits Within* (2001), set in a post-apocalyptic earth, circa 2065, with beautifully ethereal, monstrous alien spirits that invade the planet, generally received good reviews. Roger Ebert had given the film a favourable review which essentially told audiences to watch it purely because of the amazing scenes and beautiful characters (Ebert).

Ebert was also dismissive of the script as “basic space opera” but put forward that this was “merely a vehicle for the beautiful images” (Ebert). Unfortunately he was firmly in the minority in his opinion and the poor script and confusing story as well as the weak direction resulted in scathing reviews of the narrative which were echoed by poor audience attendance. The film could be accurately if not kindly described, as a massive failure in terms of its lack of box office earnings (Sahota) as well as in terms of negative critical reviews (Zacharek).

Character designer Roy Sato attempted to make all the characters as realistic as possible but more so for the lead character of Aki Ross (Brockbanck). I maintain that this

realistic type of character design causes an associated risk. Audiences expect a level of non-verbal communication in the animation which matches the level of detail of the modelling, texturing and rendering in line with Flueckiger's *Model of Distance* (7). Flueckiger, in her paper *Computer Generated Characters in Avatar and Benjamin Button* identifies *Final Fantasy: The Spirits Within* (2001) as an example of a film where the detail in the modelling and texturing of a CGI character is not matched by the detail in the facial animation (Flueckiger 7).

As Flueckiger points out in her *Model of Distance* in section 1.2.5 "aspects of appearance and behaviour should be at a similar distance from a photorealistic image defined as a standard" (6). "In *Final Fantasy*, for example, one can observe a clear separation between a photorealistic surface and a behaviour that is stylized, since significantly limited in expressive repertoire" (Flueckiger 7).

The immobility of motion in the characters' faces, particularly in the upper face and in the eye region is often pointed out by reviewers of the film: "They look at each other and their gazes don't quite meet — there's something a little blank, even slightly cross-eyed, about them" (Zacharek). This criticism echoes Tinwell's observation of the correlation between expressiveness in the upper face and the recognition of emotions in non-verbal human communication (Tinwell et al., "The Uncanny Valley in Virtual Characters" 2 2011)

Dialogue scenes, such as the first meeting between the two lead characters, Dr Aki Ross and Captain Grey Edwards, are a good example of this lack of expressiveness. The scene takes place after Grey and his commando team have saved Aki as she retrieves a plant from an abandoned New York, now overrun by phantoms. Grey is wearing a helmet for most of the scene but when he takes it off we hear his dialogue and see his face movements. The dialogue is more convincing with the helmet on because it initially hides his facial expressions, or lack thereof.

The close camera angles on both characters reveal that only the immediate area around the mouth and a small area of the eyes of both characters have any motion. The rest of the face including the cheeks, which Ekman's study on the FACS system points out should contain a number of lateral muscles that are pulled when the mouth changes shape during

speech (Ekman and Friesen 22), are totally static. So too is the forehead and the brows. There is no motion in the nose of either character. The muscles at the back of the jaw which should be driving the movement of the mouth are completely static and no muscles in the neck are stretched as one would expect from movement of the mouth.

I propose, in line with the paper on non-verbal communication by Tinwell, Grimshaw and Nabi (2) that the area that an audience focuses on the most is the eyes, particularly the brows and the crow's feet areas at the sides of the eyes. These should constrict involuntarily in an exchange where both parties are angry. Having just survived a near death experience, they should also exhibit an alert state of pupil dilation which should constrict as the scene progresses and the irritation sets in. The motion of all the characters in the scene is unconvincingly relaxed. None of these involuntary sub-conscious micro-gestures are apparent.

The immobility of the facial expressions in the CGI characters, particularly during dialogue in this scene, but generally throughout the film, leave a viewer with a sense of paralysis or morbidity. I propose that uncanny reactions to the film, or directly to these scenes of dialogue, are a result of this lack of expressiveness, particularly in the upper face which recalls an instinctive reaction from audiences reminiscent of pathogen avoidance or a fear of morbidity (Tinwell, Grimshaw and Nabi 2).

It may have been difficult to predict the overwhelmingly negative response to *Final Fantasy: The Spirits Within* (2001) as there had been very positive feedback from the trailer and additional press material prior to the release of the film (Sahota). Critical reviews of the film were mostly negative (Zacharek) and the box office earnings of the film, in as much as this can be construed as an indication of audience approval, were low (Sahota).

By comparison, Peter Jackson had initially wanted to fully hand animate the character of Gollum in *The Fellowship of the Ring* (2001). However, after some initial tests he realized that Andy Serkis' performance was going to be crucial in getting an emotive performance of the CGI Gollum character with which audiences could empathize (Serkis 9). Once he realized that the actor's facial expression should drive the performance he

insisted on full recordings and re-recordings of Serkis as a complete reference for Gollum's performance (Serkis).

3.1.3 Technological Constraints

While the technology that was used to create *Final Fantasy: The Spirits Within* (2001) was still in early development, the level of detail and the crafted aesthetic that was achieved was a milestone for 3D animation and VFX.

Unfortunately for the production company the facial animation became the focal point of criticism. The level of animation may have been acceptable for a hand-drawn 2D animated film but at this level of detail it appeared lifeless and eerie. Flueckiger applies her *Model of Distance* as a tool to assess the film. According to Flueckiger the film is an example of a highly detailed computer-generated character without a corresponding highly detailed and physiologically accurate level of detail in animation (Flueckiger 7).This is also consistent with Tinwell's observations regarding non-verbal communication in the upper face region (Tinwell , Grimshaw and Nabi 3).

The unfortunate timing choice for the makers of *Final Fantasy: The Spirits Within* (2001) meant that they were on the cusp of a new technology but were still using an outdated production mode. Motion capture was being implemented to great effect but had to be linked to actor driven performances. The performances on which the animation in *Final Fantasy: The Spirits Within (2001)* was based were from stand-in actors or the animators themselves rather than the talented actors of the voice cast and were not directed by Sakaguchi but by the animators themselves. Without strong performances and direction the CGI characters were not as convincing as they could have been. It was fairly common practice prior to *The Fellowship of the Ring* (2001) for animators to base their animation on reference material that they recorded within the animation studio featuring only themselves acting out the role that required animating. The technique that Jackson used on *The Fellowship of the Ring* (2001) was to direct a professional actor for this performance and to base the animation on this performance.

Reviewers point out the beautiful aesthetic of the film (Ebert) which is indicative of

not only the skill of the artists involved but also the advanced technology used, such as Pixar's PR Renderman technology and the Maya software, running on hundreds of Silicon Graphics supercomputers (Pistacchio). The compositing was done in a software package called Shake[28] and was considered cutting-edge technology that was used by the largest and most successful visual effects production companies at that time. The look of the film is still very beautiful even thirteen years after it was made, in contrast to other films which used state of the art technology for special or visual effects of their time, such as the *Superman* (1978 -1983) films starring Christopher Reeves, that have aged comparatively badly, in that the effects used in these films are very obvious and unconvincing to modern audiences.

3.1.4 Analysis of Expression in the Upper Face Region

The methodology of recording live-action reference material and copying this in animation, yielded positive results, and remained the benchmark in 2D or hand-drawn animation for over 50 years.

The problem with trying to utilise this technique for more realistically rendered human faces is that it crosses into an area of primal human cognition. Nelson notes that "The ability to discriminate and to recognize emotion from facial expressions develops in a complex fashion in infancy" (Nelson et al. qtd. in Adolphs 30), pointing to research that this ability in humans may be at least partially innate. It is further claimed that "Newborns already possess an innate ability to mimic some simple facial gestures (such as someone sticking out their tongue) (Meltzoff and Moore qtd in. Adolphs 30). Humans have from birth the ability to interpret a host of non-verbal communication contained in facial expressions. Given the complex dialectic between what is learned and what is innate it is very difficult to break this down in an analytical way. Only humans suffering from some form of congenital or acquired prosopagnosia lack this ability (Humphreys, Avidan and Behrmann 1).

The sheer volume of controls which must be manipulated in order to animate these

[28] "Shake was an image compositing package used in the post-production industry. Shake was widely used in visual effects and digital compositing for film, video and commercials." (Wikipedia, Web). Its powerful node based architecture and the fact that it could run on standard Apple computers instead of proprietary hardware made it very popular for the production of visual effects on films.

voluntary and involuntary expressions (such as a nostril flare or a pupil dilation) make the process extremely difficult to carry out. Manual or keyframed facial animation requires a vast number of controls to effect the micro-gestures that people consciously or sub-consciously decode in non-verbal communication on a constant basis. It is for this reason that a cataloguing system of facial expressions to denote specific emotional states such as Ekman's FACS system can be extremely useful (Ekman and Friesen 20).

The expressions of the characters throughout the film *Final Fantasy: The Spirits Within* (2001) constantly takes one out of the drama of the narrative. Marc Caro, writing for the *Chicago Tribune*, points to the exact moment where this happens, which he observes within the first few scenes of the film, from a full screen close-up of Dr Aki Ross's green eye which pulls back to a wide shot of her "you continue to be thrown by how lifelike she is". Shortly after this though, she is joined by a team of military personnel and "the novelty wears off" (Caro).

Caro astutely observes the exact moment that the dialogue begins in the film, although he does not point this out in his review. We may observe from this that the characters appear realistic and believable up to the point that we expect what Tinwell, Grimshaw and Abdel-Nabi identify as "a perceived lack of emotional expressivity generated in the upper face region during speech" (Tinwell, Grimshaw, Abdel-Nabi 1). This technical 'error' in the animation leads to a host of negative responses from the viewer. This is not simply assessing a bad performance from an actor, but looking at a human face that for some reason is constrained by a paralysis which is preventing it from conveying all the rich meaning that any viewer has come to expect in every single face to face interaction in which we constantly engage.

3.1.5 Findings

The combination of factors that resulted in the failure of the film and which was identified by various reviewers includes a weak script (Zacharek), the mismatch of voice actors with the physical appearance of the cast (Total Film), not using the voice actors to drive the motion capture performance ("*Final Fantasy: The Spirits Within* : Production Notes") and the lack of a complex enough rig or sufficient animation particularly in the

upper face to match the level of detail and complexity of the 3D characters (Flueckiger 6).

The resulting critical reviews were however, not only a rejection of these technical flaws in the film, but a rejection of any animation that attempts to imitate human likeness in a realistic fashion, as claimed by Marc Caro for the *Chicago Tribune* "`*Final Fantasy*' tests limits of animation, but drains characters of humanity*".* There is an inconsistency in these reviews however, as at the very same time, critics and audiences were quite prepared to accept a similar level of realism in the Gollum character because there was sufficient information in the performance to serve the narrative (Serkis).

To extrapolate based on this film (*Final Fantasy: The Spirits Within (2001)*), that realistic animation should be avoided completely and to seek to validate Mori's hypothesis based on this data, does not follow. If one is to make a valid comparison between a human performance and an animated one to test uncanny reactions from audiences or research subjects, then it should be argued that a highly realistic model of the same subject would have to be created where the muscle system and the animation are capable of conveying all this information. A good example of this follows with the analysis of *The Curious Case of Benjamin Button* (2009).

3.2 An Analysis of *The Curious Case of Benjamin Button (2009).*

The Curious Case of Benjamin Button (2009) is a film adaption by screenwriter Eric Roth of a short story by F. Scott Fitzgerald. The lead character, Benjamin, is born old and ages backwards and the narrative follows the pathos of the character's one true love only being a compatible age for a brief period of their romance. It was directed by David Fincher and stars Brad Pitt and Cate Blanchett.

In explaining the casting of Brad Pitt in the lead role and directing the actor's subtle performance, Fincher observed: "I wanted Benjamin as recognisable as Brad – this is a guy who can't walk 50 feet in the civilised world without seeing a photograph of himself – so people are very used to seeing his face. So we wanted the audience to go, "Wow, those are his ears, just bigger and droopier. That is his nose, just a little bit bigger and droopier" (Fincher qtd in. Salisbury).

3.2.1 Production Methodology

Digital Domain was approached to quote on an early script of an adaption of the F. Scott Fitzgerald short story *The Curious Case of Benjamin Button* in 1994. At the time a decision was made by the artists at the company that the technology did not exist that would allow them to be able to achieve a realistic CG character interacting with live-action actors in a believable way (Ulbrich)

They were approached again in 2005 and at that time considered that sufficient advances had been made to explore techniques that could achieve the effects needed to pitch for the contract to create the CG character and the VFX for the film (Ulbrich).

In the process of analysing the existing animation and CG characters at that time, they also evaluated the techniques used to achieve the effects in these films. The main technique that had been successfully developed was the use of facial markers to record the performances of actors using facial motion capture which could be extracted and applied to the geometry of 3D generated characters.

The problem that faced director David Fincher in making aesthetic and casting choices was that the narrative plays out within a realistic environment over multiple generations. The character ages backwards and starts off very old becoming more youthful by the end of the story. This created an obvious physiological impossibility with the use of the forty-four year old Brad Pitt.

In response to this Fincher elected to use multiple actors for the body of Benjamin Button at the different stages of his life but consistently used Brad Pitt as the source of the facial performance for the character. The challenge was to create seamless integrations of a CG head for Benjamin which would be driven by Pitt's performance (Fincher qtd in Salisbury).

Sculptor Rick Baker was commissioned to create, "three different lifelike maquettes, Benjamin at 60, 70, and 80 years of age" (Dunlop). Baker also created life casts from the

shoulders up of the various actors playing Benjamin's body, then grafted on the various heads, resulting in three different busts of Pitt at different ages" (Dunlop). Once the maquettes were approved they were scanned into 3D software and used to create 3D models of Pitt to be used in different stages of the film.

Although there had already been application of facial motion capture technology on films since the 2004 Robert Zemekis film *Polar Express* (2004), Digital Domain sought to advance that technology. The existing method was to place points on an actor's face which were recorded and then retargeted to vertices in 3D software to plot out the actor's performance as useable data in 3D space (CG Society). Ed Ulbrich, in an interview on Ted Talks, proposes that there was just not enough information from this technique as they lost all the data on the surfaces between the points (Ulbrich).

The solution they settled on was Mova Contour which used proprietary hardware and software to capture the surfaces of an actor's face rather than assigning individual points (Dunlop).

The method they employed was to use a sponge to apply UV paint unevenly to the surface of an actor's face (in this case Brad Pitt's). Because of the unevenness in the application of the make-up on the surface, the software could use optical flow (see glossary of terms for definition) to analyse a plane made up of a collection of points and a relationship of shapes rather than individual points and this was then mapped onto 3D geometry. The selection of points was necessary for the tracking data to lock onto. This was then applied to vertices in the 3D geometry. This was done retrospectively and thus required less manual tweaking than point-for-point tracking and mapping (Ulbrich). This contributed to reducing the effort of the much more labour-intensive process of capturing the information in the facial motion capture technique. It did not, however, resolve the problem of how to manage and manipulate the data in 3D afterwards.

The research by Dr Paul Ekman and others relating to the Facial Action Coding System (Ekman and Friesen 20) which had also been utilised for Gollum in *The Lord of the Rings* (2001 – 2014) films, contributed to a solution to this problem (Letterri qtd in Connelly).

Having an understanding of this muscle system was crucial in creating a corresponding muscle system below the surface of the skin of the Benjamin Button character. It was these muscle structures which deformed the skin on the surface of the 3D character. A complex rig was created which drove the thousands of blend shapes which accounted for the recorded performance of Pitt. All these emotive expressions were created by using combinations of action units defined in Ekman's FACS (Dunlop). When this lengthy process of categorisation was completed the animation process itself was one of matching the data across and enhancing or tweaking the captured performance (Dunlop).

A recording was made of Pitt performing with the UV make-up on his face which was then captured and transferred to the 3D model with the FACS rig. This was used by animators to create the base of the performance by targeting the different blend shapes to simulate the various mannerisms and idiosyncrasies of the actor.

Other techniques employed include the use of high dynamic range images (HDRI) to create image based lighting (IBL). This involves taking photographs through different exposures, typically two stops below and two above and one at the appropriate exposure to create a large file that contains all the lighting information on a set. The information is collected by photographing five images of a sphere placed on the lit live-action set or by taking a series of photographs with a spherical 180 degree fish eye lens of all the lights and objects on the set. These photographs are then stitched into an HDR image in software such as Photoshop and then projected onto a sphere within a 3D package to create image based lighting for the CG characters or objects in that shot.
The HDRI technique for IBL results in extremely accurate lighting and, when combined with accurate rendering techniques, can result in 3D characters or objects that very closely resemble live-action shots (Dunlop).

Additional techniques employed included utilising sub-surface scattering (an algorithm which accurately calculates the way light is dispersed in semi-transparent surfaces such as skin (*see glossary of terms*) to match the subtle semi-transparency of aged human skin. Finally high resolution textures were shot of subjects in an old age home

to create the textures of the skin which were wrapped on the 3D model to contribute to the look of Benjamin in his different stages of old age (Sydell).

An array of additional visual effects such as matte paintings and creating youthful versions of the two main actors, Brad Pitt and Cate Blanchett, were created by additional VFX companies for the film. These VFX were achieved with an array of compositing techniques. These techniques involved blending the 3D head of Pitt with the other actors' bodies from shots in the film. It is achieved by creating very finely detailed edges that smooth from the surface of one layer to another by blurring, sharpening or removing elements by cutting them out of the picture as detailed by Sydell and Brinkman (2).

The volume of work on the 3D Benjamin Button character alone took one hundred and fifty artists at Digital Domain two years to complete (Ulbrich). It is worth noting that this time was only for the facial animation and the head replacement and not to create the body of the character which was shot live with two other actors on set.

Of these artists a small team of ten animators worked on the animation of the character. There was still a significant amount of animation required to contribute to the success of the final look of the film but this is a relatively small number of people concentrating solely on facial animation. On such a film many more artists would normally be used but, because of the technique of motion capture, other technical processes replaced the need for manual or keyframed animation which became unnecessary for this production (Ulbrich).

3.2.2 Aesthetic Choices

Director David Fincher wanted to cast Brad Pitt in the role of the backward ageing Benjamin Button. "Initially, in discussions with Brad, he said that he didn't want to play seven or 15 years in somebody's life, that he wasn't interested in organising that kind of a hand-off. But if we wanted him to play the whole of somebody's life, that was something that would interest him" (Fincher qtd in Salisbury). Some of the technical problems associated with one actor ageing through an entire lifetime are the dramatic changes to the scale of the body and how the tissue shrinks as aging takes place so that the skin

sags; a process called “skulling” (Fincher qtd in Salisbury). There was a need for the character of Benjamin to be able to interact with other actors and with objects on set through the different ages. As a result the technique decided on was to cast three different actors for the character at different ages and replace the head with a digital version of Brad Pitt’s head which would be accurate for the physiology of the character at those various ages (Fincher).

As a result it was decided to attempt what had until then been regarded as “the holy grail of visual effects” and to create a CG human character that interacts with live-action characters for about 56 minutes of the total screen time of the film (Ulbrich). The complexity of achieving this result cannot be overstated. CG human characters had been created previously, such as in *The Matrix Reloaded* (2003), but these did not involve close up photography of the face in dialogue and through a range of expressions for as extended a duration of screen time.

3.2.3 Technological Constraints

As stated above, when they were first approached in the mid-1990s Digital Domain initially rejected the work on the understanding that the technology required to successfully achieve the effects was inadequate. It took over ten years before they were asked to quote on the project again and felt comfortable that it was achievable with the technology then in existence.

While there had been great advances in the technology of facial motion capture, particularly on *The Lord of the Rings* films (2001 – 2014) with realistic texturing, lighting and rendering, it was on this film that all these technologies were finally successfully combined to create a realistic human face. The ultraviolet paint technique for tracking planar surfaces was a vast improvement on the quality it had previously been possible to achieve with facial motion capture using only tracking markers.

The additional use of the Facial Action Coding System, which had been designed over 30 years previously, also heavily impacted on their success. Ekman’s FACS system was developed in the 1960s and there are papers on the potential use of the FACS system

and muscular rig systems which predate any of *The Lord of the Rings* films (2001 -2014) by ten years. *The Lord of The Rings, The Fellowship of The Ring* (2001) was however the first application of the model in a feature length film (Amidi). It was the general assimilation of the technique into the animation industry over time though that made the system available to Digital Domain for *Benjamin Button* (2009).

While IBL and HDRI were techniques that had been utilised for some time, the increased speed of computers and improvements in the quality of digital cameras added to the accessibility of these techniques to animation and visual effects. As with many films the innovations implemented on *Benjamin Button* were not necessarily the development of the techniques used, but rather in the expertise of the application of these techniques and the extent to which these methods were implemented in order to achieve the results they did.

An advance on this technology will be a real time version of the ability to capture and map facial performances from actors onto CG characters. The ability of directors to interact on set with performers to achieve these results will greatly enhance the performances and subsequently the quality of the films that can be achieved.

Both Peter Jackson and James Cameron were eager to be able to direct the performance of their CG characters live, on set, interacting with their real actors as much as possible. When this technical difficulty is fully resolved and directors are able to view on a monitor, with their 3D character superimposed in real time over a motion capture actor, the entire focus of directors will be purely on performance as opposed to the vast technological parameters they currently have to manage. Jackson and Cameron both worked very closely with actors, directing their performance on set; in Gollum's case, directing the performance of Serkis with the live-action actors in the same scenes (Christophers 56). Cameron was able to utilise low resolution images of his 3D environment and creatures and used a monitor which overlaid CG elements with the live-action actors.

3.2.4 Analysis of Expressiveness in the Upper Face Region

The artists at Digital Domain went to extraordinary lengths to achieve the level of realism they did in *Benjamin Button*. The expressiveness of the CG character of *Benjamin*

Button, particularly in the upper face and eye region, does not break the illusion necessary for the suspension of disbelief in the film. The film was nominated for thirteen Academy Awards and won three, including make-up and visual effects. Roger Ebert reviewed it as "*The Curious Case of Benjamin Button* is a splendidly made film based on a profoundly mistaken premise" (Ebert). For Ebert the experience of being human is deeply embedded in chronological order. Stories have beginnings and endings but the drama of them is centred on the empathy that we feel for characters which is based (according to Ebert) on our perception of time. "The movie's premise devalues any relationship, makes futile any friendship or romance, and spits, not into the face of destiny, but backward into the maw of time" (Ebert). Other reviews lamented the slow pace of the film but applauded the technical achievement of its CG human character (Starnes, Foundas and Kennedy).

Tinwell et al. argue ("The Uncanny Wall" 2011) that it will always be impossible to achieve seamlessly convincing CG human characters. They maintain that, as effects become more complex, so too will an audience's awareness of these artificial constructs. However, it is justifiable to argue that the CG character in *The Curious Case of Benjamin Button* (2009) constitutes a successful example of a convincing human CG character. Lisa Kennedy of the Denver Post refers to "amazing trickery of technology and makeup to take the actor from a wrinkled, arthritic infant to a man younger than the actor we know today" (Kennedy).

3.2.5 Deductions

Mike Seymour is co-founder of the online magazine and forum FXGuide. He is also co-founder of the respected online training academy FXPHD. He holds a master's in applied mathematics and CGI from the University of Sydney and is currently engaged in his PhD. He writes regularly on issues around VFX and CGI (FMX). In a review for FX Guide Seymour makes the claim that "Audiences are reeling in amazement at the artistry & technical polish of David Fincher's *The Curious Case of Benjamin Button*. But even those with an appreciation of the power of VFX will be stunned to learn that for the first 52 minutes of this epic motion picture, the head of Brad Pitt's character is a CGI creation" (Seymour). This high regard from a professional visual effects stalwart is a response to the amount of work and the level of artistry that was achieved in the production and to the

emotional resonance of the performance that it enabled.

Chapter 4: Conclusion

The focus of this paper, as stated in the abstract at the beginning of the report, is on the applicability of the *Uncanny Valley* theory to realistic facial animation. However, it would be absurd to argue that because it is possible to create realistic animation, that every film should. For instance the stylistic choices of films such as *The Incredibles* (2004) remain hugely appealing. The purpose of the paper has been to analyse the relationship between aesthetic choices made by the creators of films and the general audience/viewership responses that they elicit.

4.1 Anecdotal Evidence Versus Empirical Evidence in Support of the Uncanny Valley Hypothesis.

While psychologist Frank Pollick refers to ”a wealth of anecdotal evidence” (8) to suggest that audiences react badly to realistic CG characters which may support the *Uncanny Valley* hypothesis, there is no empirical evidence in support of this assertion. On the contrary, attempts to provide empirical evidence for the theory have repeatedly failed (Hanson 1). Brenton et al. in their paper *The Uncanny Valley, Does it Exist?* (2005) refer to these anecdotal assertions but in reference to a test subject they observe “a subject was disturbed by the fact that an avatar was graphically realistic but that this realism was not matched by behavioural realism, making the avatar seem “like a zombie” (Brenton et al. 2). This observation was only made by one test subject in their group indicating that the “reaction may be subjective” but it also articulates much more clearly an argument for Flueckiger’s *Model of Distance* in that the respondent indicates that the character would appear less uncanny if behavioural realism matched the graphical realism (Flueckiger 7).

It is also the case that assertions about the existence of an “uncanny wall” (Tinwell, Grimshaw and Nabi 338) are seriously challenged by the achievement of films such as *The Curious Case of Benjamin Button* (2009). In this film audiences accepted a substantial fifty six minutes of the CG facial animated character interacting with live-action characters. Viewers of the film do not appear to have their suspension of disbelief (that allows them to enjoy the narrative) disrupted by an uncanny response to the computer-generated character of Benjamin Button.

4.2 Failures of More Realistic CG Animated Films

These occasional successes do not address the multiple failures of relatively realistic animation in films (*The Polar Express* [2004], *Final Fantasy: The Spirits Within* [2001], *Beowulf* [2007]) when compared with more iconic character designs (*The Incredibles* [2004], *Shrek* [2001], *Wreckit Ralph* [2013]). Why is it that audiences reject these more realistic characters and respond very favourably to 'cartoonish' characters?

There may be a host of factors such as the quality of the script and the likeability of individual characters in these films but there seems to be a trend in these degrees of realism that certainly warrants closer analysis. More iconic or cartoony characters such as Ralph in *Wreckit Ralph (2013)* use more exaggerated motion and require less expressive detail in the animation of the face. More realistic characters such as Gollum in *The Lord of the Rings* films (2001-2014), use less exaggerated animation in the character's motion but detail in facial expression is much more articulated. Films which elicit uncanny reactions to the level of detail in the modelling and texturing of CGI characters such as *Polar Express* (2004), *Final Fantasy: The Spirits Within* (2001) and *Beowulf* (2007), all exhibit less articulation or expressiveness in facial animation, particularly in the upper face region.

A growing body of successful films (all six of *The Lord of the Rings* films [2001-2014], *The Matrix Reloaded* [2003], *The Curious Case of Benjamin Button* [2009] and *Avatar* [2010]) by comparison suggest that as characters approach levels of human likeness or familiarity there is an expectation of an increase in non-verbal communication that is associated with actual humans but which is not expected of iconic forms such as puppets or cartoonish animation (Tinwell, Grimshaw, and Nabi 3). The level of expressiveness of the CGI characters in these films and the richness of the resulting performances of these characters is what makes them successful[29].

I would argue that what viewers are responding to here is a mismatch of detail which is consistent with Flueckiger's *Model of Distance* rather than *The Uncanny Valley* hypothesis (Flueckiger 7). Greater correspondence with realistic facial characteristics such

[29] See the reviews of the characters Gollum and Benjamin Button in the preceding chapter.

as skin texture and detail in 3D modelling demand higher levels of detail in articulation in 3D animation, particularly in the upper face region. If this is missing, audiences have an instinctive reaction of uncanniness, possibly caused by a fight or flight mechanism which recalls pathogen avoidance and other self-preservation modes (Tinwell, Grimshaw, and Nabi 10).[30]

Realistically modelled characters with realistic skin textures that do not have the corresponding muscle rig system to drive the surface animation, nor sufficient articulation in the eye region, may well create uncanny responses. Examples of these responses include the review of *Final Fantasy: The Spirits Within* (2001) (Zacharek) and the review of *The Adventures of Tintin (*2011) (Snyder).

As this study has shown, the expectation that this is an insurmountable obstacle to creating realistic characters, based on Mori's *Uncanny Valley* hypothesis, has been called into question by an increasing amount of empirical research (Hanson et al. 26). The assertion that this is totally insurmountable because of advancing aesthetic sensibilities and that there is an "uncanny wall" or "uncanny cliff" (Tinwell, Grimshaw, and Williams 326) is highly questionable in the context of successful, realistic and partially realistic characters as in *Avatar* (2010), *The Lord of The Rings* films (2001-2014), and *Benjamin Button* (2009). The success of films such as *Benjamin Button* (2009) shows that audiences can accept very realistic CG characters engaged in highly realistic performances and interacting with live-action characters in a believable and emotionally engaged way.

Even before *Benjamin Button* (2009) the character of Gollum in *The Lord of the Rings* series of films (2001-2004) had shown that audiences could accept a high level of realism in CG characters interacting with live-action characters (Christophers 56). Audiences regard the character as alive for the purposes of enjoying the narrative and interacting plausibly with the other characters in the film rather than as a lifeless puppet. In this instance the audience's suspension of disbelief relies on their believing that the CGI

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[30] Tinwell, Grimshaw and Nabi refer to Paul Ekman's research on facial expression which includes an analysis of "survival related emotions considered signals of a threat, harm or distress including anger, fear, sadness and disgust". They propose that aberrance of part of or all of these emotions in virtual characters would be regarded as more uncanny than emotions less related to survival such as happiness or surprise (Tinwell, Grimshaw, and Nabi 7, 10).

character is real for the purposes of the narrative. In this sense the Gollum character is a good example of one which falls squarely inside the valley zone of Mori's graph but without creating any uncanny response. The distinction lies in audiences accepting human-like characters that are not completely human but in which the animation is of a similar level of detail as the texturing and modelling of the character (Flueckiger 7).

This raises major questions about the universal application of Mori's model in instances where characters in films should clearly cause aversion or an uncanny reaction but do not. Examples of these include the Na'vi in *Avatar* (2010), Gollum in *The Lord of the Rings* films (2001 – 2014) and Benjamin in *The Curious Case of Benjamin Button* (2009).

4.3 Sufficient Level of Detail in Non-Verbal Communication

The films mentioned here are examples in which audiences accept realistic CGI characters and relate to their performances. In these examples audiences are not drawn out of the stories by a lack of articulation or expression in the faces of the CGI characters. If this were the case we could describe this lack of expression or articulation as a technical error or a mismatch of detail.

If audiences are not engaged by a performance because they are not convinced by the non-verbal communication of an emotion by these digital actors, they begin to focus heavily on this lack of communication which stirs an instinctive uncanny reaction.

I would argue that a film utilising realistic characters (or compared to the CGI characters of Gollum and Benjamin Button, relatively realistic) such as *Final Fantasy: The Spirits Within* (2001), could have achieved a level of realism in its animation more acceptable to the aesthetic of the film but failed to do so. Because the modelling of the characters brings them closer to the range where we judge humans rather than cartoons, careful attention has to be paid to the detail of performance in animation and the level of non-verbal communication which takes place.

4.4 Challenging Mori's Uncanny Valley Hypothesis

I would propose that Flueckiger's *Model of Distance* has a more robust application

in the assessment of computer-generated human or human-like characters than does Mori's *Uncanny Valley* hypothesis.

In support of this new theory, I would argue that the Gollum character in *The Lord of the Rings* series of films (2001–2014), approaches human likeness without being 'human' while clearly existing in a fantasy environment. Elvis Mitchell of the *New York Times* describes Gollum as "a frighteningly believable realization of computer imagery as performer" (Mitchell). Nor is there any question in the viewer's mind as to whether Gollum is alive or dead. In Freud's original definition of the uncanny, he borrows from fellow psychologist Karl Jentsch to point out that ambiguity forms an important component of the definition of uncanniness. Jentsch proposes as an example of the uncanny "'doubts whether an apparently animate being is really alive; or conversely, whether a lifeless object might not be in fact animate' and he refers in this connection to the impression made by wax-work figures, ingeniously constructed dolls and automata" (qtd Freud 228). The familiar criticism of 3D animated characters as "dead eyed" or "zombies" (Talbot) is thus not appropriate here. In this instance the audience perceives the CGI character of Gollum as being as alive as any of the real actors performing the roles of the other characters for the purpose of the narrative.

Thus we witness the emergence of the CG character that is almost human, but not human, that audiences can accept as real and that contributes to the story without causing the disruption of the suspension of disbelief, which has been identified as problematic in other 3D animated films, as described in Zacharek's review of *Final Fantasy* (Zacharek). Gollum's eyes are much larger and further apart than a normal human, his ears are pointier and larger, his movement would be impossible for a human (Connelly) and yet he remains completely plausible as a fully realised participant in a realistic narrative.

For the purposes of this study we could place the Gollum character anywhere between 90% and 95% on Mori's graph of the *Uncanny Valley* and yet in reviews of the film the character has not been cited as an example of belonging here. We are not repelled by any reference to morbidity or any ambiguity as to whether he is alive or dead. We fully accept him as alive but his personality itself, aided by his appearance (gray skinned, skulking, bulging eyes) places him in opposition to our empathy for the

protagonist.

Flueckiger in her article "*Computer-Generated Characters in Avatar* and *Benjamin Button"* makes the same argument for the film *Avatar* (2010). In response to James Cameron's assertion that he crossed over the *Uncanny Valley*, she points out that the alien characters are human-like, certainly, but they are not similar enough to be completely human (Flueckiger 26). Flueckiger in a thorough analysis of their physiognomy describes the blue skin, the broad feline noses, the distance between their eyes as well as the scale of the characters in particular (Flueckiger 26). They too would find themselves somewhere in the valley zone on Mori's graph. Clearly though, we identify with the characters, we empathize with them and their similarity does not deter us from our enjoyment of the film. Both films enjoyed strongly positive reviews from critics and audiences according to Flueckiger (26) (see also Mitchell).

I would argue further that the application of Mori's unproven hypothesis of *The Uncanny Valley* in films such as *Final Fantasy: The Spirits Within* (2001), *Polar Express* (2004) or *Beowulf* (2007) (French) is in fact a response to reduced articulation in the upper face region. If the films had used a concomitant level of detail in the articulation and animation of muscles around the eyes as they did in the modelling and texturing of the characters, then it is likely that these characters would have exhibited the subtle non-verbal communication required for successful CG human performances. An example from the case study is the 60 000 hairs for the character Dr Aki Ross that needed to be modelled and animated (French). While the hair does move in a realistic way there is very little expression in any area of the face except the mouth and the immediate area of the eyes. In support of this I would offer the specific detail of the terms "dead eyed" "zombie-like" "corpse bride" which repeatedly appear in critical reviews of the films (Talbot) and point to the lack of articulation of the upper face as being synonymous with death, paralysis, morbidity or dangerous illness (Tinwell, Grimshaw and Nabi 10).

4.5 A Way Forward in Realistic Human Facial Animation

The techniques used to achieve the verisimilitude of these characters remain extremely time consuming and expensive for film-makers. The question is whether or not

these extremely complex and expensive techniques can be applied in a more accessible way by other filmmakers, animators, game designers and professionals involved in creating realistic CGI human characters.

The current limitation of using the Facial Action Coding System for rigging 3D characters is that the muscle systems under the skin will differ from one character to another based on the design of the character. The rigs created for Gollum or for the Benjamin Button character were custom built[31] and there is not yet a pre-built or software-integrated solution. As with many new technologies however there are developments by artists and software engineers in this field. At least one plug-in is available for 3D packages that utilizes the FACS principles and takes note of the interconnectedness of facial muscle groups for the expressions of different characters.[32] In addition, stand-alone applications have been developed to simplify the process of capturing facial tracking markers and converting this information to 3D vertices. I would suggest that it is only a matter of time before these tools are integrated into 3D animation software and the rigs that are available to drive facial animation with toolsets which customize the dimensions to suit different character designs.

The advances in facial motion capture using unevenly applied UV paint on the surface of faces of subjects to create sufficient information for surface or planar tracking as outlined in the *Benjamin Button* (2009) case study, rather than point tracking as outlined with reference to *Avatar* (2010), while currently highly specialised, will likely be more accessible and have a broader rollout as has been the case with many other types of technology. The initial research and development of technology tends to be expensive and laborious but when a technology is proven it is generally widely adopted by artists and technicians within the field. In many cases this type of technology will be publicised in papers at conferences such as SIGGRAPH after which they are more widely utilised[33].

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[31] The post production companies that created these CGI characters had to craft unique rigs which were created around the muscle systems of these 3D characters.

[32] A plug-in is a small programme written as an add-on to existing software packages that serves specific specialised purposes. Mathew Dean's FACS Animation Suite for 3DS Max is an example of such a programme (Dean, M. Web). This plug-in creates a rig using the FACS principles which can be adapted to different characters with sliders for the different poses corresponding to Ekman's FACS system.

[33] See the note on the adoption of facial motion capture from Polar Express which was published in a paper presented at SIGGRAPH 2005. SIGGRAPH is the Special Interest Group on Computer Graphics and Interactive Techniques, a yearly conference usually held in Las Vegas.

One may ask whether it will be possible to have higher degrees of articulation in facial animation which includes a rig system based on the FACS without needing to use facial motion capture to drive this. I propose that this is possible (such as for Gollum in *The Fellowship of the Ring* [2001]). As has been stated earlier, Andy Serkis' performance was motion captured for his body but the performance of his facial expressions was recorded and copied and then enhanced by animators, at least in the first two films *The Fellowship of the Ring (2001) and The Twin Towers (2002)* (Cook qtd in Amidi). Facial motion capture was only introduced later in *The Lord of the Rings* films (2001 – 2014).

Since the invention of Rotoscoping by Max Fleischer in the 1920's (Fleischer 35), animators have in fact relied heavily on filmed reference material to create plausible and pleasing animation. The technique of using filmed reference material for animation was heavily employed in *Snow White* in 1937 (Johnston and Thomas 320) and has been widely used since. The success in analysing reference material and applying this to these complex FACS rigs without necessarily using facial motion capture would be dependent on an individual artist's degree of expertise both in animation and in the understanding of anatomy.

As technology and artists' understanding of anatomy (and the rigs and tools to catalogue and articulate this understanding) improve, we can anticipate more films which feature realistic human facial animation. I propose that the theory of the *Uncanny Valley* will come to be associated with the technical difficulty of a particular era in achieving the sought after goal of photorealistic human facial animation in visual effects.

In addition to the application for photorealistic visual effects there is also a range of aesthetic choices that are made apparent by these advances. At the time that *Final Fantasy: The Spirits Within* (2001) was made the combination of these technologies was not in common use (although they were used on *The Fellowship of The Ring)*. One may question the assertion by Square Pixel that the film is photorealistic animation (Park). By today's standards the *Final Fantasy* character Dr Aki Ross would not be considered photorealistic (in that more realistic looking characters such as Benjamin Button have

surpassed that character's level of detail), however it had a great degree of realism for its time. If the level of realism used in the modelling of the 3D characters and their textures had a concurrent level of realism in their animation and particularly the articulation of the muscles around the eyes and the eyes themselves, it would, I propose, have created a much more believable and empathetic performance.

As has been shown in the case study section, *Final Fantasy: The Spirits Within* (2001) was animated without recordings of the voice cast as the primary animation reference for facial animation. While in comparison Andy Serkis' performance in *The Fellowship of the Ring* (2001), although not facially motion captured, was slavishly adhered to by the animators of Gollum. I would argue that this technique combined with the complexity of the FACS rig for Gollum contributed to the success of this character while the lack of the performance reference of the voice cast and the lack of complexity in the rig for the Aki Ross character and others in *Final Fantasy: The Spirits Within* (2001) (such as that given from a FACS rig) contributed to their stiff appearance. The process followed on *The Fellowship of the Ring* is an illustrative example of the effectiveness of this technique.

The significant point is that audiences respond to convincing and inspiring emotional performances from CGI (as well as live-action) characters. These emotive and convincing CGI performances may be increasingly actor driven but are certainly created in concert with talented animators and CGI artists and are undoubtedly now possible from CGI characters.

Glossary of Terms

3D

Abbreviation for three-dimensional (3D). Relating to the ability to view an object in perspective from any viewing angle. The term 3D is generally used to describe geometry containing XYZ coordinates that represent its height, width, and depth (Goulekas 582).

3D animation

Any animation created in 3D space on a computer (Goulekas 582).

3D software

Software used to generate 3D animation and to model objects in 3D Space.

3D space

Any coordinate system in which objects can be created, modified, and displayed as coordinates along the XYZ axes (Goulekas 583).

2D

Shorthand for two-dimensional (2D). It means having only two dimensions, most often, width and height. The term 2D is generally used to describe flat artwork, geometry, or images that contain X and Y coordinates or pixel information, but no Z-depth information. However, even in the absence of true Z information, 2D images can be created to have the illusion of depth (Goulekas 577).

2D animation

Any animation created in 2D space on a computer or by hand-drawn frame by frame on cellophane cels (Goulekas 582).

2D tracking

The process of deriving motion curves from a sequence of images by selecting a

region of interest (ROI) in those images and calculating their movement over time. The data derived by a 2D track is dependent on the number of points tracked. For example, a one-point track will yield only X-translation and Y-translation information, whereas a two-point track can additionally reproduce changes in scale and rotational information that occurs between the two points. It is common practice to place tracking markers on the set during filming to ensure high-contrast points are available to track (Goulekas 578).

Cartesian coordinates

The location of data, represented by coordinates, as defined by the Cartesian coordinate system (Goulekas 68).

Cartesian Coordinate System

A coordinate system in which a point can be located in either 2D or 3D space in terms of its distance from any two or three axes that are at right angles to each other. Since any two axes in a coordinate system can be defined by a plane, the three basic planes used in the Cartesian Coordinate System are the XY plane, XZ plane, and YZ plane (Goulekas 68).

Computer generated imagery (CGI)

Any image created by or manipulated on a computer (Goulekas 96).

Computer animation

Animation created and manipulated on a computer. An Animator sets the keyframes of the objects to be animated, and the computer interpolates the in between frames (Goulekas 96).

Facial Action Coding System

The Facial Action Coding System (FACS) is a method of measuring facial expressions in terms of activity in the underlying facial muscles (Ekman and Friesen). Bartlett et al. defined 46 distinct action units, each of which correspond to activity in a distinct muscle or muscle group, and produce characteristic facial distortions (823). Most approaches to facial expression recognition by computer have focussed on

classifying images into a small set of emotion categories such as happy, sad or surprised (Bartlett et al. 824). Real facial signals, however, consist of thousands of distinct expressions that differ often in only subtle ways. These differences can signify not only which emotion is occurring, but whether two or more emotions have blended together, the intensity of the emotion(s), and if an attempt is being made to control the expression of emotion as noted by Hager and Ekman (qtd. in Bartlett et al. 824).

Global illumination

A rendering method used to produce photorealistic CG images. Global illumination algorithms simulate the way that light energy is exchanged between all objects in a scene by taking into account both direct illumination -light which has taken a path directly from a light source - and indirect illumination - light that has undergone reflection from other surrounding surfaces (Rickitt 372).

High dynamic range images (HDRI)

In photography and computer graphics, high dynamic range (HDR) imaging is a set of techniques that allow a greater dynamic range of exposures or values (i.e. a wide range of values between light and dark areas) than normal digital imaging techniques. The intention is to accurately represent the wide range of intensity levels found in such examples as exterior scenes that include light-coloured items struck by direct sunlight and areas of deep shadow.

Image based lighting

The simulation of light emitted from an infinitely distant (environment) sphere to create photorealistic images. With image-based lighting, an environment texture (an image file, typically a photograph of a real environment) is needed to illuminate the scene and provide the necessary environment reflections (Image Based Lighting Node Attributes).

Material

The visual attributes of an object, such as its colour and texture, that define how the object will look when hit with a light source.

Morph

Generally, any technique in which a minimum of two 3D objects or two digital images are blended together to create a new interpolated result. In most cases, this takes place over a period of time to create a series of frames that animate from point A to point B. However, the term morph is also used to describe any effect used to create motion within a single image or object, either by animating a mesh placed over the image or by animating the object with any variety of deformation tools, such as a lattice box, point groups, or motion dynamics.

Morph targets

The intermediate key shapes used to morph a series of images or objects together when using 2D morphing or 3D morphing techniques.

Motion capture (MOCAP)

An animation technique in which the precise position and movement of an actor is recorded so it can be applied to the skeleton of a 3D character. Markers are applied to a suit that the actor wears and the position of these markers are recorded and converted to 3D vertices. These can then be applied to geometry or meshes of characters in 3D space to create motion keyframes and animate the character. In facial motion capture markers are applied to the face.

Optical flow analysis

A method for procedurally determining the movement of objects in a sequence of images by examining the movement of smaller blocks of pixels within the image.

Planar tracking

The tracking of surfaces or planes within an image to create corner pin data which can be applied to other images to match the motion. Planar trackers use optical flow analysis to track regions in an image instead of points of interest.

Ray tracing

A method of calculating physically accurate lighting in 3D digital scenes by tracing the path of light beams emanating from the camera as they bounce around an

environment before reaching sources of light (Rickitt 374).

Rendering

The process of creating a 2D image based on 3D information, such as the camera, objects, lights, surface attributes, and animation curves contained in a 3D database. The field of view (FOV) created by the position of the camera in the scene relative to the location of the various objects determines what portion of the scene will actually be rendered.

Any geometry falling within the camera's field of view is mathematically projected onto a plane, just as a real camera projects the image within its field of view onto film. The rendering process must also calculate which objects are obscured by other objects closer to camera.

Once the renderer has determined which surfaces will be rendered and where on the plane they will be projected, the last step is to calculate the actual colour of each pixel that is being created in the resulting 2D image.

Rendering software

A software application specifically designed to allow the user to render a scene created in 3D space. Also called a renderer. RenderMan (RMAN) and Mental Ray are popular render software packages.

Shader

The surface attributes that are calculated by the renderer to determine the appearance of the objects in a scene, such as their colour, specularity, and displacement. Shaders come in many different types, including surface shaders, volume shaders, displacement shaders, and light shaders.

Shading

The effect of light across a surface based on the position of the object relative to the light source. The shading of a surface is also dependent on the shading model that has been assigned to the object, such as flat shading, Blinn shading, Gouraud shading, Phong shading, and Cook/Torrence shading.

Surface shader

A shader that calculates the colour of a surface relative to its position in relation to the lights in a 3D scene.

Texture

1. The surface attributes that affect the colour or appearance of a surface.

Texture map

2D images that are applied to a 3D object to define the texture of a surface. Texture maps can be used for colour mapping, bump mapping, displacement mapping, transparency mapping, environment mapping, and projection mapping.

Tracking

The process of extracting a camera move from a series of images based on particular features in the images whose motion can be calculated over time.

Ultraviolet paint (UV Paint)

For the purpose of motion capture, paint applied to the face of an actor which is only visible under an ultraviolet light. Cameras which are sensitive to this bandwidth of light are able to read more detail from the reactive properties of this paint than could be recorded in the bandwidth of light visible to the human eye in which normal cameras function.

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