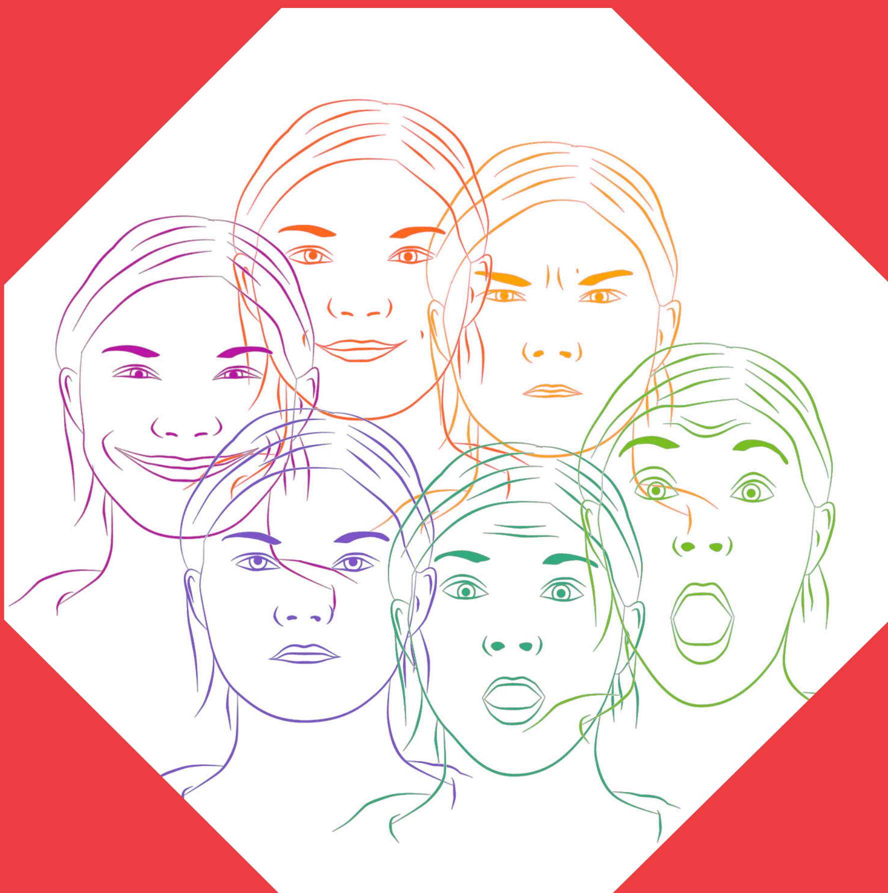
Department of Computer Science

Blending and Exaggeration of Animated Facial Expressions of Emotion

Meeri Mäkäräinen



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Blending and Exaggeration of Animated Facial Expressions of Emotion

Meeri Mäkäräinen

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Aalto University
School of Science
Department of Computer Science

Supervising professor
Professor Tapio Takala, Aalto University, Finland

Thesis advisor
Professor Tapio Takala, Aalto University, Finland

Preliminary examiners
Assistant Professor Zerrin Yumak, Utrecht University, the Netherlands
Associate Professor Zsófia Ruttkay, Moholy-Nagy University of Art and Design, Hungary

Opponent
Professor Emeritus Göte Nyman, University of Helsinki, Finland

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Abstract

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Meeri Mäkäräinen

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Abstract
Facial expressions have a very important role in social communication. As the development of technology enables more and more realistic virtual humans, they may become much more common in our everyday lives, and believable facial behavior is crucial for the success of a virtual character. This thesis states that the facial expressions of virtual characters should be designed so that they would be able to express a rich variety of different emotions and emotional intensities, and that blending and exaggerating facial expressions can be used to bring variety to facial expressions. This thesis also considers the uncanny valley phenomenon, which implies that even though increasing realism increases familiarity and likability of cartoony characters, very realistic characters can appear eerie, disgusting and horrifying instead.

This thesis explores the possibility to express complex emotions by blending the expressions of basic emotions: anger, disgust, fear, joy, sadness and surprise. The thesis introduces a physically-based facial model and a method of producing anatomically correct basic emotion blends. Using a series of questionnaires, it was found that while some of the blends were perceived as pure basic emotions or combinations of two basic emotions, some blends induced perceptions of complex emotions, such as shame or malicious joy.

It is generally believed in the animation community that the expressions and movements of less realistic characters should be exaggerated to convey sufficient emotional intensity, but exaggerating highly realistic characters can lead to a strange appearance. This belief was supported by a study using a questionnaire to measure how people perceive the same facial expressions on different levels of realism and with different levels of exaggeration. Moreover, it was found that the maximum emotional intensity that can be reached without a strange appearance appears to be roughly the same on all levels of realism.

In the uncanny valley literature, it is usually assumed that perceived strangeness is primarily associated with a negative emotional response, such as fear and disgust. This thesis introduces a study where emotional reactions to facial images were studied using facial electromyography and a self-assessment questionnaire. It was found that the primary emotional reaction to strangeness was amusement, instead of negative emotions.

This thesis provides insight into how blending and exaggeration can be used to create believable facial animation with expressions of various emotions on various intensities. Furthermore, this thesis advances the understanding of perception of facial expressions in general, as well as the uncanny valley phenomenon.

Keywords facial animation, virtual characters, facial expressions, uncanny valley

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Tiivistelmä

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Tiivistelmä
Kasvonilmeillä on suuri merkitys sosiaalisessa vuorovaikutuksessa. Teknologian mahdollistaessa yhä realistisempien virtuaalisten ihmishahmojen luomisen niiden läsnäolo arjessamme voi lisääntyä, ja virtuaalisen hahmon onnistumisen kannalta sen kasvonilmeiden uskottavuus on olennaisen tärkeää. Tämä väitöskirja esittää, että virtuaalihahmojen kasvonilmeet pitäisi suunnitella niin, että ne kykenisivät ilmaisemaan laajasti erilaisia tunteita ja tunteiden voimakkuuksia, ja että ilmeiden yhdistelyä ja liioittelua voidaan käyttää ilmaistun tunneskaalan laajentamiseen. Tässä väitöskirjassa käsitellään myös outo laakso -ilmiötä, joka tarkoittaa sitä, että vaikka piirrosmaisilla hahmoilla korkeampi realismin taso lisää hahmon miellyttävyyttä ja tuttuutta, hyvin realistiset ihmishahmot voivat kuitenkin vaikuttaa pikemminkin oudoilta, inhottavilta tai kauhistuttavilta.

Tässä väitöskirjassa tutkitaan mahdollisuutta ilmaista monipuolisempia tunteita yhdistelemällä kasvonilmeitä, joilla ilmaistaan perustunteita ilo, suru, viha, inho, pelko ja yllätys. Väitöskirjassa esitellään fysiikkaperusteinen kasvomalli ja menetelmä anatomisesti oikeaoppisten yhdistelmäilmeiden luomiseksi. Kyselyjen avulla selvitettiin, miten ihmiset havaitsevat näitä ilmeitä. Vaikka osa yhdistelmäilmeistä havaittiin yksittäisenä perustunteena tai kahden perustunteen yhdistelmänä, osa yhdistelmistä tuotti havainnon monipuolisemmasta tunteesta, kuten häpeä tai vahingonilo.

Animaatioyhteisössä uskotaan yleisesti, että vähemmän realististen hahmojen liikkeitä ja ilmeitä tulee liioitella riittävän voimakkaan tunneilmaisun saavuttamiseksi, mutta hyvin realististen hahmojen liioittelu sen sijaan voi johtaa outoon lopputulokseen. Kyselyssä, jossa mitattiin, miten sama kasvonilme havaitaan eri realismin ja liioittelun tasoilla, löydettiin tukea tälle uskomukselle. Lisäksi huomattiin, että korkein tunteen voimakkuus, joka liioittelulla voidaan saavuttaa, on suunnilleen sama kaikilla realismin tasoilla.

Aikaisemmassa kirjallisuudessa on usein oletettu, että outo laakso -ilmiössä havaittuun outouteen liittyvä tunnereaktio sisältää ensisijaisesti kielteisiä tunteita, kuten pelkoa ja vihaa. Tässä väitöskirjassa esitellään tutkimus, jossa kasvokuvien aiheuttamia tunnereaktioita tutkittiin kasvolihasten lihassähkökäyrän ja itsearviointikyselyn avulla. Tutkimuksessa todettiin, että kielteisten tunteiden sijasta ensisijainen tunnereaktio outouden yhteydessä oli huvittuneisuus.

Tämä väitöskirja antaa tietoa siitä, miten ilmeiden yhdistelyä ja liioittelua voi käyttää hyväksi uskottavan kasvoanimaation luomiseksi niin, että tunteita ilmaistaan laajalla skaalalla niin tunteiden määrän kuin tunteiden voimakkuuksienkin suhteen. Lisäksi tämä väitöskirja edistää ymmärrystä kasvonilmeiden havaitsemisesta yleisesti sekä outo laakso -ilmiöstä.

Avainsanat kasvoanimaatio, virtuaalihahmot, kasvonilmeet, outo laakso

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Preface

I am extremely happy for having had the opportunity to study a research topic that combines my passions for computer science, visual arts and psychology. I started this work in the Telecommunications and Multimedia Laboratory in Helsinki University of Technology, which later became the Department of Media Technology in Aalto University. My work was supported by the Graduate School in User Centered Information Technology, the Academy of Finland (projects Interactive Emotional Embodied Experience and Enactive Media), the aivoAALTO research project of Aalto University, and the Finnish Cultural Foundation.

I am deeply grateful to my supervisor, professor Tapio Takala, who has supported and guided me with incredible patience during my on-off relationship with this dissertation. I appreciate him for providing an excellent balance of guidance and freedom that enabled me to find directions for my own research. I also warmly thank my co-authors, especially Dr. Jari Kätsyri, whose expertise was essential to the success of these studies. Special thanks also to professors Mikko Sams, Riitta Hari, Niklas Ravaja and Pia Tikka, each of whom has provided valuable guidance regarding their own field of research.

I sincerely thank the pre-examiners, professors Zsófia Ruttkay and Zerrin Yumak, for their insightful comments and helpful suggestions. I am also grateful to all the people who helped with the individual studies, as well as the participants, who patiently evaluated one facial expression after another. Thanks also to the members of staff in the department for all the assistance.

During these years I have met, and had the opportunity to work with, a number of amazing people. I have really enjoyed the company of Tommi, Ville, Inger, Antti, Raine, Perttu, Markus, Klaus, Roberto, Tuukka, Päivi, Jussi, Jussi, Jaakko, and others.

I am indebted to my family for unwavering support. I especially want to thank my sister, professor Minna Isomursu, whose advice along the way as well as comments on the manuscript were of great help.

Finally, I would like to express my deepest gratitude to my spouse Olli and my children Riitu, Helka and Mandi, for sharing the adventures of life with me.

Helsinki, October 12, 2019,

Meeri Mäkäräinen

I'd also like to thank the Van Allen belts for protecting us from the harmful solar wind, and the earth for being just the right distance from the sun to be conducive to life, and for the ability of water atoms to clump so efficiently, for pretty much the same reason. Finally, I'd like to thank every single one of my forbears for surviving long enough in this hostile world to procreate. Without any one of you, this book would not have been possible.

—Jasper Fforde, *The Woman Who Died a Lot*

Contents

List of Publications

This thesis consists of an overview and of the following publications which are referred to in the text by their Roman numerals.

I Meeri Mäkäräinen and Tapio Takala. An approach for creating and blending synthetic facial expressions of emotion. In *9th International Conference on Intelligent Virtual Agents (IVA2009)*, Amsterdam, The Netherlands, Lecture Notes in Computer Science, Volume 5773 pp. 243–249, September 2009.

II Meeri Mäkäräinen, Jari Kätsyri and Tapio Takala. Perception of basic emotion blends from facial expressions of virtual characters: pure, mixed or complex?. In *26. International Conference in Central Europe on Computer Graphics, Visualization and Computer Vision 2018 (WSCG 2018)*, Plzen, Czech Republic, pp. 135–142, May/June 2018.

III Meeri Mäkäräinen, Jari Kätsyri and Tapio Takala. Exaggerating facial expressions: A way to intensify emotion or a way to the uncanny valley?. *Cognitive Computation*, vol. 6, no. 4, pp. 708–721, December 2014.

IV Meeri Mäkäräinen, Jari Kätsyri, Klaus Förger and Tapio Takala. The funcanny valley: A study of positive emotional reactions to strangeness. In *19th International Academic Mindtrek Conference*, Tampere, Finland, pp. 175–181, September 2015.

Author's Contribution

Publication I: "An approach for creating and blending synthetic facial expressions of emotion"

The initial idea was suggested by Prof. Tapio Takala. The author designed and implemented the facial model, and wrote the manuscript, under the guidance and supervision of Prof. Takala.

Publication II: "Perception of basic emotion blends from facial expressions of virtual characters: pure, mixed or complex?"

The author was the main contributor to study design, data collection and writing. The analyses were performed jointly by the author and Dr. Jari Kätsyri, Dr. Kätsyri being mainly responsible for the analyses of Experiment 1, and the author for the analyses of Experiment 2.

Publication III: "Exaggerating facial expressions: A way to intensify emotion or a way to the uncanny valley?"

The author was the main contributor to study design, stimuli preparation, data collection and writing. The author performed the analyses together with Dr. Kätsyri, so that Dr. Kätsyri conducted most of the statistical tests and the author most of the analyses otherwise.

Publication IV: “The funcanny valley: A study of positive emotional reactions to strangeness”

The author was the main contributor to everything except data collection, in which the assistants did the majority of work.

1. Introduction

1.1 Animated Facial Expressions

Face-to-face communication between humans is arguably the most natural way of communication to us, yet it is immensely rich and nuanced, and hard to understand entirely. Whenever meeting other people, we automatically make several conclusions based on nonverbal signals, such as their posture, movement and facial expressions.

Similarly, when seeing animated characters in movies, games or virtual environments, we interpret their body language and facial expressions in complex ways. Facial expressions especially are thought to affect the emotions which we attribute to a person or a character. A face of an animated human-like character will always send a message about the emotions of the character. Understanding how people perceive synthetic facial expressions is essential to give animators the control over this message.

Progress in the fields of computer graphics and artificial intelligence means that more and more realistic virtual humans can be created, and that communication between a human and a machine can mimic human-to-human communication in much more detail. This increases the possibilities of an animator, but it also increases the need for understanding how people perceive the smaller and smaller details in nonverbal communication of the characters.

Although technological advances allow more and more realistic human-like characters, for many practical applications a less realistic style will continue to be more appropriate. Besides being easier to implement, a less realistic style is also thought to be useful because it allows more artistic freedom. How much this artistic freedom can be used to enhance emotional communication on different levels of realism is not yet fully known.

1.2 Objectives and Scope

The purpose of this thesis is to find out how facial expressions of virtual characters should be created so that they would be able to express a rich variety of different emotions and emotional intensities. Specifically, the focus is on blended facial expressions of basic emotions and exaggerated facial expressions. The thesis answers to the following research questions:

1. How can synthetic blends of facial expressions of basic emotions be created without reducing the magnitude of the basic expressions? (Publication I)

2. How do people perceive synthetic basic emotion blends: are they perceived as basic emotions, mixed emotions or complex emotions? (Publication II)

3. How can exaggeration be used for images of facial expressions with varying levels of realism to produce optimal emotional expressivity? (Publication III)

4. When exaggerated facial expressions are perceived as strange, is the emotional response positive or negative? (Publication IV)

Figure 1.1 shows how the four publications in this thesis relate to each other and the wider context. Publications I and II study creating and perceiving blended expressions of basic emotions. Publications III and IV study perception of, and reaction to, exaggerated facial expressions.

In the field of producing computer animation (the first column in Fig. 1.1), the scope of this thesis is limited to how facial expressions of basic emo-

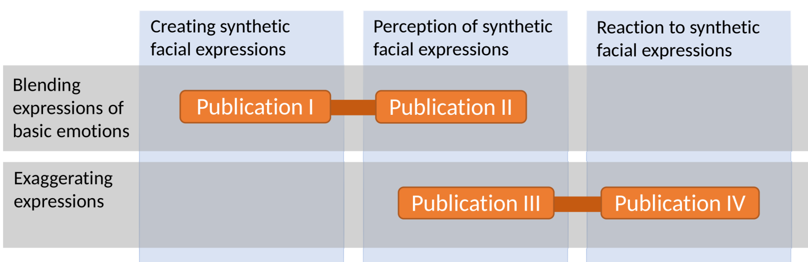

Figure 1.1. The context of the publications in this thesis

tion blends can be animated. The thesis does not consider different animation or rendering methods, animation of other body parts except the face, animation of speech, or transitions between different facial expressions. The methods of producing exaggeration in computer animation are also beyond the scope of this thesis.

In the field of perceiving facial expressions (the second column in Fig. 1.1), this thesis focuses on which emotions people attribute to virtual characters whose facial expressions are blends of basic emotion expressions, and on the other hand, how exaggeration affects the intensity and strangeness of perceived facial expressions.

The viewers' reactions to facial expressions (the third column in Fig. 1.1) are considered only in relation to exaggerated expressions. The focus is on finding out the relationship between the perceived strangeness of a facial expression and the emotional reaction of the viewer. The thesis does not cover the emotional reaction to blended expressions, or the emotional reaction to facial expressions in a natural context.

Also beyond the scope of this thesis are gestures, speech and speech-related facial movements, cognitive models and artificial intelligence, and temporal characteristics of facial movements.

1.3 Thesis Structure

This thesis introduces the research reported in Publications I–IV. Chapter 2 focuses on how blends of facial expressions of basic emotions can be created, and how they are perceived. This research was published in Publications I and II. Chapter 3 is about exaggeration in facial animation, strangeness as a possible outcome of exaggeration, and emotional reactions to strangeness, which were studied in Publications III and IV. Finally, implications and limitations of the thesis are discussed in Chapter 4.

2. Blending Facial Expressions

2.1 Facial Expressions of Emotions

When animated characters are used in games, movies or virtual applications, expression of emotions is a very important feature that can make the character believable and lifelike [9, 109]. Arguably, a character will appear more lifelike and engaging if it can mimic the expression of a wide range of human emotions. To create effective animation of facial expressions, we need understanding of how emotions are perceived from human faces and virtual faces.

2.2 Emotion Models

When facial animation is used for the purpose of expressing scripted emotions, a useful conceptualization of emotion is needed. The most common emotion models used in emotion research are the basic emotions view [34] and the dimensional view [98].

The basic emotions theory [34] suggests that there are six fundamental facial expressions that are expressed and recognised similarly in all cultures: anger, disgust, fear, joy, sadness and surprise. The corresponding emotions are called basic emotions. Whether these emotions are actually more basic than others has, however, been a subject of an intense debate [84, 5]. Also the idea of six fundamental facial expressions has been criticised in many ways. It has been argued that the six basic expressions are not universal after all [41, 52], or not easily described with a single label [58], and that interpretation of facial expressions depends on context [45]. On the other hand, some studies have found evidence for other potentially universal displays of emotion, such as contempt [32, 75], embarrassment [60, 61], shame [61], and love [43]. A recent study identified 22 different emotional expressions, but also found variability across participants and systematic cultural differences in expressing these emotions [20].

In contrast to the basic emotions view, the dimensional view on emotion states that emotion can be best understood as a point in a coordinate system defined by certain emotional attributes. The most common models use the dimensions of valence (pleasure) and arousal [97] or pleasure, arousal and dominance [77]. A four-dimensional model has also been suggested with the additional dimension of unpredictability [38].

Most facial animation system have traditionally been based on the expression of six basic emotions, but the dimensional approach has also been adopted for some models to create a wider range of emotional displays instead of only six separate expressions. As the dimensional theories do not usually specify how facial expressions should be mapped to different emotions, the dimensional facial animation models often also utilise the basic emotions theory. The expressions of basic emotions are typically mapped on the used dimensions, and intermediate expressions are created by interpolating the closest basic emotions [2, 4, 76, 95, 100, 116], although the mapping between facial actions and emotional dimensions has been studied without the connection to the basic emotions [12] and facial expression dimensions have also been studied without emotion labels [100].

2.3 Facial Expressions of Virtual Characters

2.3.1 Facial Animation Techniques

Physiologically, a facial expression is primarily a deformation of facial skin under the influence of facial muscles. While facial expressions of less realistic characters can be animated using a simple texture-mapping method, usually a three-dimensional deformable facial model is required when there is a need for realistic facial expressions. The first animated three-dimensional facial model was created by Parke in 1974 [87]. Over time, facial animation techniques have developed to a high level, but animating believable facial expressions is still considered a difficult task.

Performance capture methods [118, 117, 17] can produce very natural facial expressions by capturing the motion of a real human face, but editing of the animation is not simple. For interactive applications, controllability is easier to achieve using a parameterised model. Facial Action Coding System (FACS) [33] is a commonly used parameterisation of facial actions that is based on coding the muscle activity of a real face.

As for applying facial animation to a character, the most common technique is blendshape animation, which considers a facial expression as a linear combination of target faces [69]. Weights of the linear combination are varied to produce a desired facial display. This method allows animating different facial expressions with little computation. An alternative approach is physically-based facial modeling, which is computationally heavier, but can produce more realistic facial shapes and motions by modeling real facial structures. The first model with facial muscles and deformable skin was created by Platt and Badler [91], and Terzopoulos and Waters [108] developed a more advanced model with more realistic muscles and a trilayer facial tissue model. This kind of model has been developed further by Zhang, Prakash and Sung [123, 124, 125].

Recent advances in facial animation include techniques such as combining blendshape animation with physically-based animation [6, 62] to produce natural facial movements efficiently, creating real-time dynamic avatar based on images of the user [18] and generating facial expressions from audio input [54].

2.3.2 Creating an Expressive Facial Model

Publication I introduces a physically-based facial model, which is primarily based on the model by Zhang et al. [124]. Parameterisation of facial actions uses Facial Action Coding System [33], which defines the muscle actions of the face and the prototypical expressions of basic emotions. The facial model includes deformable skin tissue and muscles for facial actions.

The deformable skin tissue was modeled as a two-layer cross-strutted cubic lattice that acts as a mass-spring-damper system. The bottom nodes of the lattice are fixed to facial bones, while the other nodes can move under the influence of muscle forces.

Two kinds of muscles were implemented: linear and sphincter muscles. A linear muscle has an insertion point in the skin (in this case the bottom nodes of the top layer of cubical elements) and an attachment point fixed to the skull. A linear muscle contraction was implemented as a force that draws all nodes within a certain distance of the insertion point towards

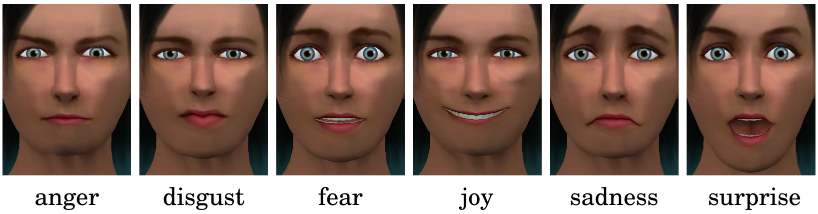

Figure 2.1. Expressions of basic emotions generated using our model

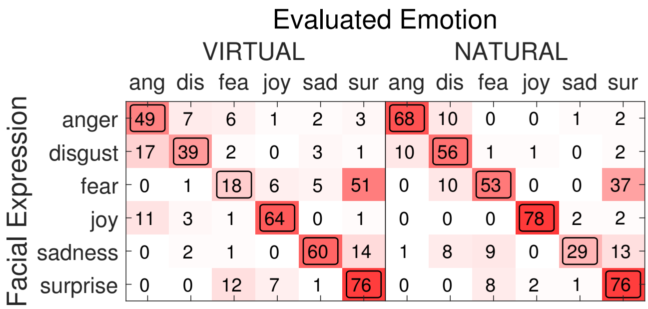

Figure 2.2. Perception of the expressions of basic emotions on our virtual model compared to a natural human face. Numbers indicate how strongly each emotion was perceived in each facial expression on scale from 0 to 100.

the attachment point. Sphincter muscles around the mouth and the eyes were implemented as forces that draw the skin nodes towards the center of an ellipse.

In general, each muscle in the model corresponds to one Action Unit in Facial Action Coding System. The facial model is controlled by giving Action Unit values for the muscles. Each value defines how strong the force that the muscle exerts on the mass-spring damper system is, and the mass-spring damper system seeks equilibrium under all muscle forces. The facial expressions of basic emotions were modelled by using Action Unit combinations defined by the Facial Action Coding System.

Figure 2.1 shows the expressions of basic emotions created using our model. Validation of our model's expressions of basic emotions was reported in Publication II. Figure 2.2 shows how our virtual expressions were perceived in comparison to the same expressions on a natural face. The natural facial expressions were selected from one actor in Ekman and Friesen's Pictures of Facial Affect collection [31]. The confusion matrix shows that the most common confusion was between fear and surprise. A recognition score analysis (reported in detail in Publication II) indicates that all expressions except fear were recognised correctly from the virtual face, and all expressions except fear and sadness were recognised correctly from the natural face. Thus, while our model's fear expression was not ideal, the overall performance of the model is comparable to a real human. The results of this comparison are congruent with previous research, which has shown that a confusion between fear and surprise is common for synthetic faces [36, 110] but also for natural faces [27, 115], and also that the expression of sadness is often better recognised from a synthetic face [25, 44, 110].

2.4 Emotion Blends

Although an animated character with only six separate facial expressions may be suitable for some purposes, it is still very limited compared to a real human. To increase the emotional believability of a character, it is important to search for ways to increase the richness of emotional expression. Emotional expression can be enriched in several ways, such as adding random variation to facial displays or deliberately designing different variants of basic expressions such as a polite smile and an excited smile. This work attempts to broaden the range of emotional expressions by blending the basic emotions as an attempt to express a mixture of two or more basic emotions. These kinds of expressions of complex emotions have been shown to increase the perceived empathy of a conversational agent [79].

Blending expressions is reasonable, as two emotions can be experienced together, for example happiness and sadness [66], or amusement and disgust [46]. It has even been suggested that many complex emotional states are mixtures of two or more basic emotions, for example smugness could be seen as a mixture of joy and disgust [30, 28]. It has also been shown that many combinations of basic emotions, such as "happily disgusted" and "sadly surprised", have visually distinctive facial expressions that include muscle actions of both basic emotions [24, 23].

The ability of a virtual agent to express simultaneous basic emotions might be useful in many situations. For instance, if a virtual sales assistant has to inform the customer that a product is sold out, it might be appropriate to express a hint of sadness while maintaining a polite smile. Likewise, a virtual tutor's appropriate response to an exceptionally good performance should perhaps include both joy, to give immediate positive feedback, and surprise, to emphasise that the student has exceeded expectations.

2.5 Generating Facial Expression Blends

In previous research, several methods have been used to blend facial expressions of basic emotions. As mentioned in Section 2.2, some facial animation systems consider the basic emotions as points in a two- or three-dimensional coordinate system, and interpolate the intermediate expressions. This method does not produce blends of all basic emotions, and thus for example a mixture of joy and sadness can not be produced.

Another approach for blending is to use different areas of the face to convey different emotions [11, 74, 80, 86, 88]. However, this method can be problematic when either eye or mouth region is essential for conveying both basic emotions, or when both eye and mouth region are essential for one emotion. This is not a problem for asymmetric blends where one emotion is displayed on the right side of the face and another emotion on the left side [1], but that blending method may not suit all combinations of emotions.

Blends have also been produced by averaging the facial features between all pairs of basic emotions [85, 22]. The problem is that averaging makes most facial features milder, and not necessarily anatomically correct. To preserve the intensity of the expressed emotions, additive methods have been suggested [89].

Publication I introduces an additive method for blending expressions of basic emotions. The idea of the method is to sum up all muscle actions in both expressions to create a compound expression. As muscle forces in the model are represented by Action Unit values, each Action Unit value in the blend is the sum of the corresponding values in the two basic emotions. Thus, both basic emotions are still expressed with full intensity in the compound expression, and the resultant expression still looks natural because the facial tissue can only be stretched within natural limits. Figure 2.3 shows the blends produced using our model.

2.6 Perception of Facial Expression Blends

2.6.1 Perception of Blends on Natural Faces

Perception of facial expression blends has been studied mostly using stimuli based on photographs, with varying results. The results of Young et al. [120] indicate that blended facial expressions are perceived categor-

Figure 2.3. All pairwise blends of expressions of basic emotions generated using our model

ically as discrete basic emotions. However, later studies have provided counterevidence for categorical perception [103, 39], and it has even been argued that since blended expressions are more common in real life, they are also more recognizable than pure emotions [65]. When photographs of acted basic emotion blends are presented with a list of alternatives including basic emotions and basic emotion pairs, people can correctly recognise most of the pairwise blends between basic emotions [81, 82, 23].

Using manipulated photographs, de Bonis et al. [21] have shown that sometimes an artificial blend of two expressions of basic emotions can be perceived as a third emotion. For example the combination of fear on the upper part of the face and happiness on the lower part was perceived as admiration, whereas the combination of happiness on the upper part of the face and fear on the lower part produced perceptions of contempt, anger, and distantness.

2.6.2 Perception of Blends on Synthetic Faces

In Publication II, we report a systematic study of how people perceive synthetic blends of basic emotions. As the role of dynamics has been found to be important for identifying facial expressions particularly from synthetic characters [57], we used short video clips depicting the transition from a neutral expression to a peak expression as stimuli. The study was conducted as a series of online questionnaires that were designed to test whether the blends are perceived as pure basic emotions, mixed basic emotions or separate complex emotions.

In the first questionnaire, the participants rated the emotional content of each facial expression using six sliders, one for each basic emotion. They were also asked to list any other emotion words that described their perception of each facial expression. Further questionnaires were then used to explore the relationship between the words and the facial expressions.

Perception as Pure Basic Emotions

First, we tested whether the blends were perceived as pure basic emotions (as predicted by categorical perception hypothesis). A blend was considered to be recognised as a basic emotion if participants consistently gave highest rating for a single basic emotion. Using this criterion, five blends were perceived as pure basic emotions: Anger+disgust was perceived as anger, anger+sadness as sadness, disgust+sadness as sadness, fear+surprise as surprise and sadness+surprise as surprise.

Perception as Mixed Basic Emotions

The second test was whether any of the blends were reliably perceived as combinations of two basic emotions. The criterion here was that the two target emotions consistently receive higher ratings than any of the other emotions. Using this criterion, only the blend of joy and surprise was perceived as a mixture of those two basic emotions.

Perception as Complex Emotions

After listing all the words that were mentioned by participants in the first questionnaire, a series of online questionnaires was used to test how accurately each word describes the corresponding facial expression. First two questionnaires were used to narrow down the list of expression-emotion pairs, and the last stage included two questions that determined the strength of the association between the expression and the emotion word. As this method requires a large number of individual evaluations, a crowdsourcing platform CrowdFlower was used to collect the data. This choice enabled us to collect a large number of evaluations with reasonable effort, although it also meant that the effects of demographic variables could not be controlled for. Figure 2.4 shows the process and the results. The expression-emotion pairs in the final box are those with a strong connection.

The results in Publication II indicate that synthetic blends of basic emotions are often not unanimously perceived as combinations of two basic emotions, but instead, perceptions of other, complex emotions emerge in many cases. A blend of surprise with any emotion with negative valence is often perceived as shock, and many other complex emotions are perceived in blends of one emotion with positive valence and one with negative valence. These results emphasise the importance of blending also opposite emotional states, not only adjacent ones. The results also indicate that if a virtual human is capable of expressing the six basic emotions, its range of emotional expressions can be expanded by blending the expressions of basic emotions.

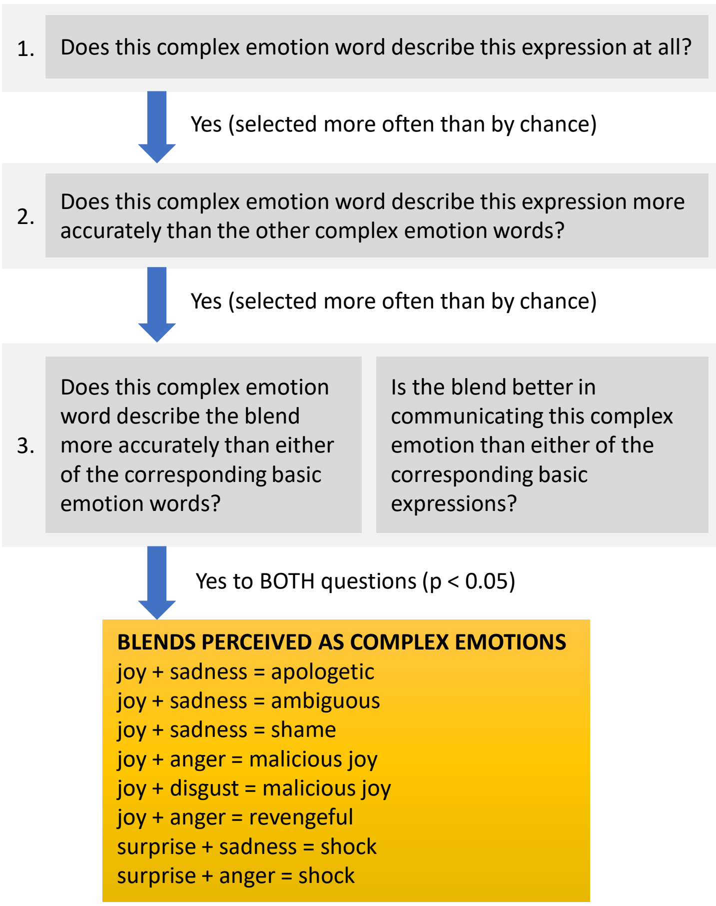

Figure 2.4. Stages of determining whether a complex emotion word describes a facial expression blend.

3. Exaggerating Facial Expressions

3.1 Exaggeration as an Animation Principle

To create a virtual character with lively emotional expressions, we need to consider not only the number of emotions it can express, but also the intensity of emotions conveyed. In traditional animation, animators often follow Disney's 12 basic principles of animation [109] to ensure that characters are lively and engaging. These guidelines are also recognised in 3D computer animation [68] and robotics [96, 42, 106]. As one of these principles, exaggeration is specifically suitable for intensifying emotional expression. Non-realistic animation is thought to allow expanding the range of facial motion to create more extreme versions of same motions, as well as extending motion to face parts or items that would not realistically move, such as a cap flying above the head when the character expresses surprise [99]. Methods of exaggeration include linear extrapolation of facial parameters and using designed samples [100]. Exaggeration has been shown to improve robot facial expressions [96, 121] and increase the felt positive affect and social presence in communication with avatars [83]. Moreover, studies using manipulated photographs [10, 15, 16] and point-light displays [94] have shown that exaggeration increases the perceived intensity of emotion.

3.2 The Uncanny Valley

Modern animation and rendering techniques enable increasingly realistic animated characters. While very simple facial displays are sufficient for emotion recognition [102], increased realism of a human-like agent can increase the perceived quality of social interaction between the agent and

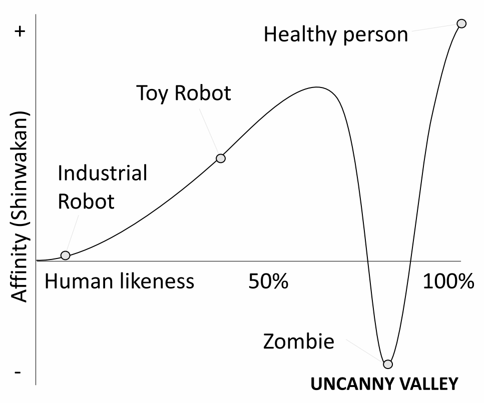

Figure 3.1. The uncanny valley. Adapted from Mori's illustration [78].

a human [119]. However, when creating realistic human animation, the concept of uncanny valley is relevant. The uncanny valley theory [78] predicts that while familiarity and likability generally increase with increasing realism, there is a sudden dip in emotional response when approaching perfect human-likeness, to the extent that an almost-perfect human can appear eerie, frightening and appalling. Figure 3.1 illustrates the relationship between human likeness and emotional response as predicted by the uncanny valley theory.

While originally presented in the context of human-like robots, the uncanny valley theory is currently often discussed in the context of animated characters. For example, films such as The Polar Express, Beowulf, Final Fantasy and Mars Needs Moms have been criticised for uncanny human-like characters [26, 93, 114]. Animators and designers are generally advised to choose a less realistic style if they intend to create pleasant and likable characters [40, 78] and a more realistic style if they pursue a frightening or horrifying effect [112].

It has been suggested that the uncanny valley effect arises when a character's resemblance to a real human evokes our expectations for interacting with a human, but the character fails to fulfil these expectations [73]. The character may appear distorted if the realism of some details does not match the overall realism. For example, abnormally large eyes are considered to be more uncanny on a realistic face than an unrealistic face [104]. On the other hand, reduced emotional expressivity by limiting movement on a part of a face has also been shown to increase uncanniness [110, 114], and it has been suggested that the eeriness of some animated movie characters may be caused by insufficient facial movement that prevents the viewers from relating to the character emotionally [114]. Also real human actors can be perceived as uncanny if their acting is either monotonic and unemotional or unnaturally emotional and theatrical [13]. A cartoon character may appear lifeless and eerie even when it mimics human motion very faithfully and without any exaggeration [109], perhaps because the perceived emotional intensity is reduced when motion is transferred to a less realistic character. Thus, the exaggeration level of facial expressions of emotion has to be chosen carefully, as too little exaggeration may induce a lifeless uncanny appearance, and on the other hand too much exaggeration may give rise to a distorted uncanny appearance.

3.3 Exaggeration and Avoiding the Uncanny Valley

Publication III introduces a study of how exaggeration affects the perception of facial expressions on different levels of realism. It is a common belief in the animation community that less realistic characters can, and should, be exaggerated more than highly realistic characters, but how exaggeration affects the perceived intensity and strangeness on different levels of realism had not been measured experimentally. On the other hand, also contradictory advice exists: It has been suggested that to improve perceptions of intelligence and likability, the facial expressions of realistic characters should be exaggerated and the expressions of cartoon characters should be damped [50].

The goal of our study was to systematically explore how exaggeration of emotional facial expressions affects the perceived intensity of emotion on different levels of character realism, and when exaggeration causes uncanniness. The study was conducted as an online questionnaire in which participants evaluated facial expressions on six levels of realism and six levels of expression magnitude. Figure 3.2 shows some of the stimulus images. Figure 3.3 shows how the emotional intensity and strangeness ratings varied with the magnitude of expression and level of realism. The following hypotheses were confirmed:

1. The perceived intensity of an emotion increases when the realism of the face increases.

2. The perceived intensity of an emotion increases when the magnitude of the facial expression increases.

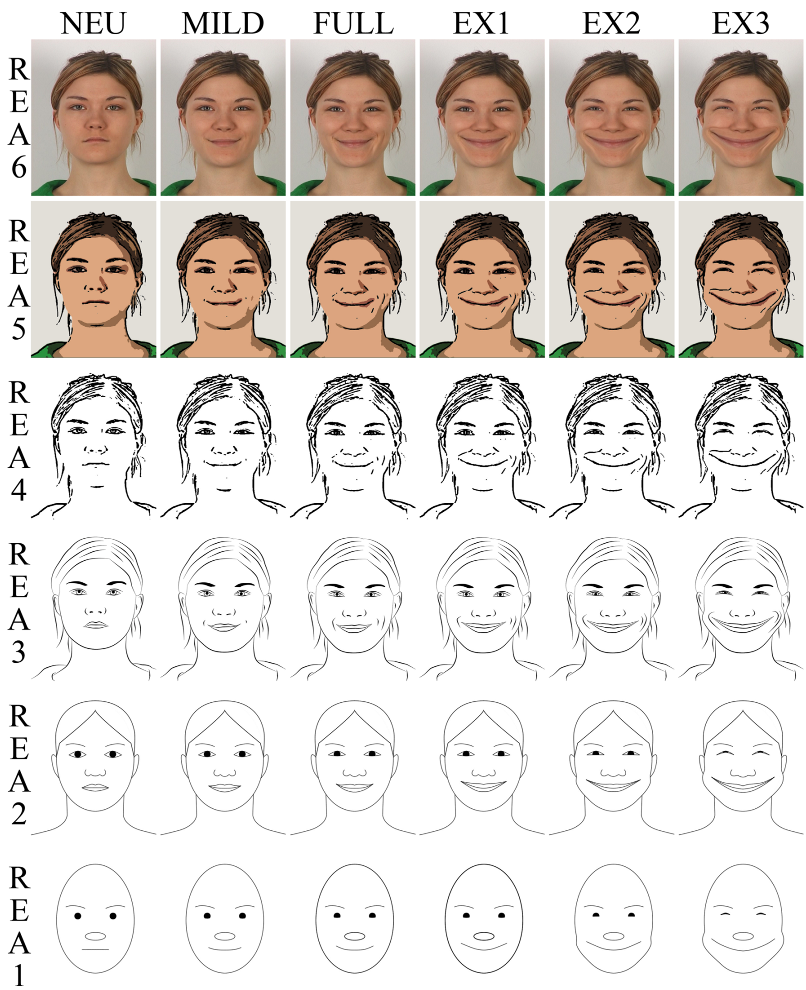

Figure 3.2. Stimulus images of the expression of happiness in Publication 3. The rows show the six levels of realism and the columns show the six levels of the magnitude of the facial expression. Images REA6 NEU, REA6 MILD and REA6 FULL are from the TKK video sequence collection [55], and all other images are based on them.

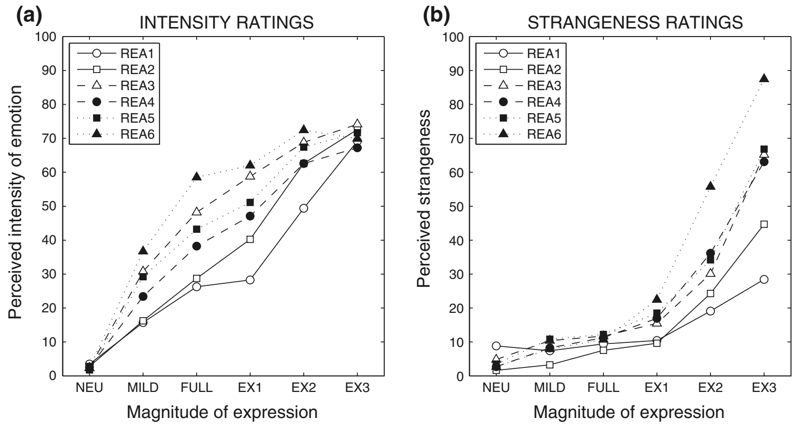

Figure 3.3. Mean ratings of (a) intensity and (b) strangeness by level of realism.

3. The perceived strangeness of a facial expression increases with the magnitude of the facial expression when exaggeration is used.

4. The perceived strangeness of a facial expression increases with the level of realism when exaggeration is used.

The results indicate that while exaggeration effectively increases perceived emotional intensity, it also increases perceived strangeness, especially when a realistic style is used. Thus, too much exaggeration can cause an uncanny, distorted appearance in realistic characters. On the other hand, too little exaggeration for less realistic characters may reduce the perceived emotional intensity of their expressions, which can give them an uncanny, lifeless appearance. These results are partly similar to the results reported by Hyde et al. [51], which showed that exaggeration can decrease the perceived naturalness of a realistic character. In their study, damping decreased the perceived intensity of emotion, but exaggeration did not significantly increase the intensity. Furthermore, the relationship between decreasing emotional intensity and decreasing realism was also found in another, more recent study [122], which, however, did not include exaggeration.

One goal of our study was to determine the optimal level of exaggeration for each level of realism. Figure 3.4 shows perceived strangeness plotted against perceived intensity of emotion. This graph shows that for each level of realism, perceived strangeness remains low as long as the perceived intensity of emotion is on the natural range. After the natural maximum intensity is reached, however, strangeness ratings start to rise.

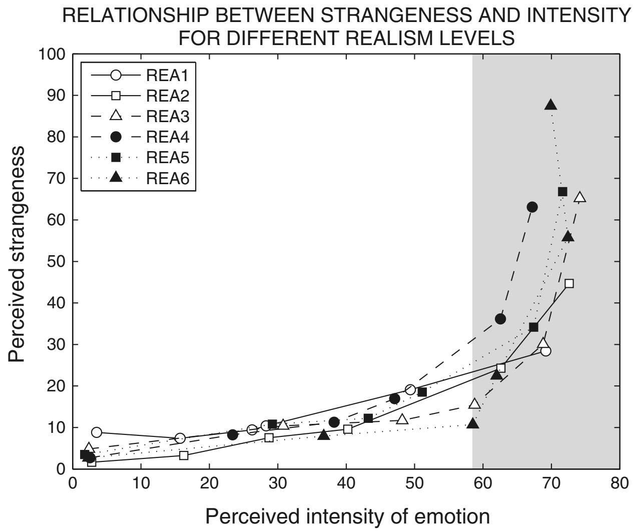

Figure 3.4. Perceived strangeness plotted against perceived intensity of emotion. The white area represents the range of emotional intensities that can be expressed by a natural face without exaggeration. The gray area represents intensities that are beyond the natural range.

Based on this observation, our conclusion is that the optimal expressivity for each level of realism is reached when facial expressions are exaggerated to the level of emotional intensity of real human expressions, but not beyond. Regarding the exaggeration and realism levels used in our experiment, the exaggeration level EX1 would be most suitable for the more realistic characters, and EX2 for the less realistic characters. For the least realistic character REA1, even the level EX3 could be used.

3.4 The Positive Side of The Uncanny Valley

3.4.1 Emotional Reactions to Uncanniness in Previous Research

The uncanny valley, as illustrated in Fig. 3.1, is a theory about the relationship between two traits of a robot or a character: human likeness and affinity. However, even though the uncanny valley has been a subject of a number of studies, it is still not entirely clear how these two dimensions should be understood [56]. The definition of affinity was vague in Mori's original paper [19, 56], and different studies have measured this dimension in different ways. Mori's original Japanese term *shinwakan* (親和感) for the y-axis has been translated to affinity [78], familiarity [70] or likability [7, 8], and Mori's word for the negative y-axis, *bukimi* (不気味), has been translated to eeriness [47], creepiness or strangeness [48].

Empirical uncanny studies are often based on participants evaluating certain traits of characters, such as strangeness-familiarity [73, 112, 113, 111], eeriness [73, 72, 92], and acceptability [90]. Most studies have not measured the emotional reaction elicited by the stimuli, but it has generally been assumed that eeriness would be associated with negatively valenced emotions, such as fear and disgust. There are empirical results that support this assumption, showing that uncanniness is generally associated with negative emotions, such as fear, shock, disgust and nervousness, and not associated with positive emotions, such as happiness, relaxation, love and amazement [48]. However, amusement was not among the emotions that were studied.

3.4.2 Measuring Emotional Reactions

In Publication IV, we introduce a study that measured the emotional reactions elicited by pictures of facial expressions. The stimuli were the same images that were used in Publication III, and thus their perceived strangeness had already been measured previously. The goal of this study was to determine whether the perceived strangeness is associated with a negative emotional response, as previous literature would predict, or a positive emotional response.

The emotional response elicited by the stimuli was evaluated by measuring the participants' facial muscle activity using electromyography (EMG) and subjective feelings using a self-assessment questionnaire. EMG is useful in differentiating emotional valence [14], and self-assessment with multiple alternative emotions allows to differentiate between specific positive and negative emotions.

We evaluated emotional valence by measuring the activation of the facial muscles *zygomaticus major* and *corrugator supercilii*. Zygomaticus major is the muscle that raises the corners of the mouth to produce a smile, and it is usually associated with positive valence [64, 67, 107]. Corrugation supercilii, in turn, produces a frown by lowering the inner part of eyebrows and bringing them closer to each other. The activation of corrugator supercilii has a negative correlation with emotional valence [64, 67, 107].

As a self-assessment measure we used a multiple-choice questionnaire with the options happy, sad, angry, fearful, disgusted, surprised and amused.

The results of this questionnaire were used to verify the EMG results as well as to gain deeper insight to specific positive or negative emotions that were experienced by the participants.

3.4.3 Strangeness Associated with Positive Emotions

The results presented in Publication IV show that the participants' emotional reactions to strange images were positive rather than negative. Both EMG and self-assessment results support this interpretation.

The results of the EMG measurements are illustrated in Fig. 3.5. There was a significant positive correlation between perceived strangeness and activation of zygomaticus major for all facial expressions, and a significant negative correlation between strangeness and activation of corrugator supercilii for happy expressions. For angry and surprised expressions there was no significant correlation between strangeness and activation of corrugator supercilii. Thus, the EMG measurements failed provide evidence for any association between negative emotions and strangeness, but instead provided quite strong evidence for positive emotions associated with strangeness. Based on our EMG measurements only, we can't differentiate between happiness and amusement, as the Duchenne smile is involved in expressing both emotions [29, 105].

The results of the self-assessment questionnaire, as illustrated in Fig. 3.6, support the interpretation that strangeness was associated with positive emotions more than negative emotions. Relatively strong positive correlation between strangeness and reported amusement reveals that the most likely emotion induced by the strange images was amusement. In line with expectations, fear and disgust were also found to have a significant, although weak, positive correlation with strangeness.

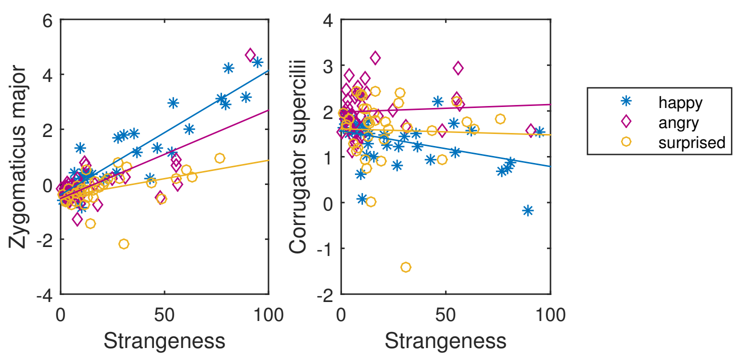

Figure 3.5. Activation of facial muscles plotted against strangeness.

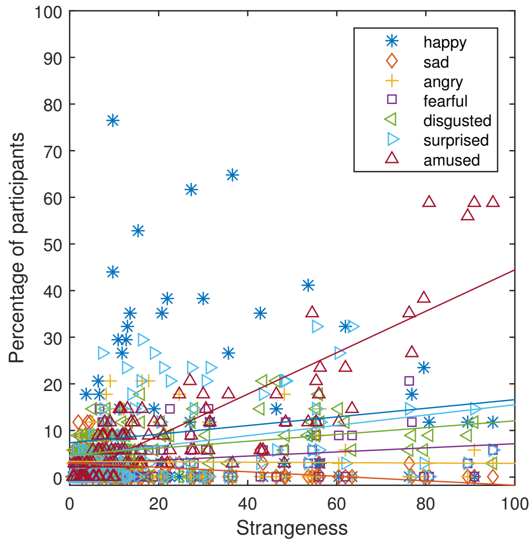

Figure 3.6. Self-assessment results plotted against strangeness.

All in all, the results in Publication IV indicate that contrary to a general assumption made in previous literature, the emotional response to perceived strangeness of a human-like character is not always primarily negative, but instead, the most prominent emotional response can be also positive, such as amusement. A recent study has found a somewhat related result, where a consultation with a computer-animated doctor was found to be more enjoyable and more persuasive than a real consultation, although the computer-animated doctor had been evaluated as more eerie than the real one [71]. The amusing and funny aspects of uncanny characters have been largely overlooked in the uncanny valley literature, but as these studies indicate, sometimes the positive aspects might be even more prominent than negative aspects.

4. Discussion

4.1 Theoretical Implications

This thesis contributes to the research of facial expressions of animated characters in the areas of blending facial expressions, exaggerating facial expressions and the uncanny valley.

In the area of blending facial expressions, this thesis introduces an additive method that produces natural expressions without diluting the original expressions. Our study of facial expression blends was the first one that systematically explored for all pairwise blends of basic emotions whether they are perceived as pure basic emotions, combinations of basic emotions or separate complex emotions. We found that the blends were generally not perceived strictly as combinations of two basic emotions, but instead, some of the blends elicit perceptions of complex emotions. The results can contribute to understanding the perception of facial expressions in general, not only synthetic expressions.

In the area of exaggeration of facial expressions, it has been a general practice that less realistic characters are exaggerated more than more realistic characters. It has also been known that more realistic characters may more easily look strange when exaggerated. However, it has not been previously known how the perceived intensity of emotion changes when the same facial expression is displayed on several levels of realism, and how much the perceived intensity of emotion can be increased by exaggeration. The results in this thesis show that the perceived intensity of a facial expression decreases with the decrease of realism, that the perceived intensity can be increased to the level of a natural full facial expression, and that further exaggeration beyond the maximum natural intensity causes a perception of strangeness.

To uncanny valley research, the contribution of this thesis is that contrary to a common view, perception of strangeness or eeriness is not always primarily associated with negative emotions, such as fear and disgust. We have shown that there are situations in which the most prominent emotion aroused is amusement. Previous research in the field of uncanny valley has not always considered this possibility, but future research should do so in order to avoid incorrect conclusions.

In Publication IV, we concluded that the reaction to strangeness was primarily positive, based on relatively high number of people reporting amusement, and measured smiling for strange faces. However, also fear and disgust correlated positively with strangeness, although they were reported less often than amusement. Sometimes strong negative emotions can also induce a smile—it has been suggested that smiling may serve a positive self-regulatory function in distressing emotional circumstances, such as seeing something intensely disgusting [3]. In this case, frequently reported amusement was likely to be the source of smiles, but a further, interesting question would be whether amusement itself was aroused as a self-regulatory function to relieve the negative emotions caused by strangeness. The reaction to uncanny images may involve a quite complex emotional experience, and further studies on the nature of this experience would perhaps be essential to understanding the uncanny valley phenomenon.

4.2 Practical Implications

The results of this thesis can be used to develop animated characters with a great variety of facial expressions expressed in a natural manner. This can increase the likability and usefulness of the characters.

The method for creating and blending facial expressions can be directly utilised in facial animation to produce anatomically correct facial expressions with two or more simultaneous full-intensity facial expressions. The obtained knowledge of the perception of blends can be utilised when there is a need to communicate a certain emotion using a virtual face. For example, to communicate shame, one might want to use a blend of facial expressions of joy and sadness. However, our results also imply that contextual information may be necessary for the blend to be unambiguously recognised as an expression of shame.

Our results regarding the intensity of emotion on different levels of character realism suggest that if an animator does not want diluted emotional intensity or strange appearance, they should use a level of exaggeration that is appropriate for the chosen level of realism. For less realistic characters, more exaggeration is needed for reaching the same emotional intensity, but exaggeration beyond the natural maximum intensity may not be possible without creating a strange appearance. However, this research does not take a stand on whether higher emotional intensities can be communicated using additional cues and/or special effects in combination with exaggerated facial expressions.

Previous literature about the uncanny valley has generally recommended that strangeness and eeriness of animated characters should be avoided when the intent is to induce positive feelings in the viewers [40, 78]. On the other hand, it has been suggested that the uncanny valley can be utilised in applications where negative emotional reactions are desirable, such as horror games [112]. However, this thesis points out that the primary emotional reaction to strangeness may be amusement instead of fear or disgust. This has two practical implications. First, designers who attempt to utilise the uncanny valley to create scary or disgusting characters should make sure that they do not unintentionally create amusing characters. Secondly, the uncanny valley could be utilised in comedy to create more amusing characters.

4.3 Limitations

There are plenty of aspects to emotions, facial expressions, and facial animation, and not all of them are thoroughly considered in this thesis. Moreover, all studies were conducted using a limited set of stimuli, and therefore the results can not be directly generalised to other situations. Similar studies with a wider selection of different virtual characters and different facial expressions would provide more conclusive results.

Our studies on facial expression blends were based on one virtual character, whose accuracy in expressing the basic emotions was not perfect. The recognition rates of the expressions of basic emotions were good compared to the general level of virtual agents, but especially the facial expression of fear was poorly recognised. Therefore, our results are incomplete in regard to the blend of the facial expression of fear with other facial expressions, and how these blends would be perceived.

The dynamic aspects of facial expressions were not thoroughly considered in this thesis. In Publications III and IV we used static images of facial expression, thus ignoring the role of motion. Based on previous literature, we postulated that insufficient amount of motion produces the "lifeless" variety of uncanniness, but this assumption could not be empirically verified using static stimuli.

In Publication II, we used short video clips that depicted the motion from a neutral face to a peak expression of emotion, but the speed of motion was not carefully adjusted for optimal expression of each basic emotion. Several studies have shown that the optimal onset duration for a facial expression depends on the emotion. For example, sadness is more accurately recognised from a slower video clip, while happiness is better recognised from a fast sequence [53], sadness is perceived more natural when it develops slower and surprise is perceived more natural in a fast expression [101], and when people are allowed to adjust the speed of a video clip to produce as realistic facial expression as possible, they choose highest speed for surprise and slowest speed for sadness [49]. Considering these differences in the natural speed of expressing different basic emotions, our blending method can be criticised for displaying both basic emotions with the same speed. It might be more natural to blend them considering the natural timing of each expression, so that for example in the blend of sadness and surprise, the onset of surprise would be faster than the onset of sadness.

Similarly, the synchronous activation of all action units within an expression of a basic emotion might not be optimal. While Paul Ekman has stated that in an expression of a genuine, felt emotion, different action units have ballistic trajectories and an apex overlap (e.g. [35]), other studies have found different, asynchronous temporal patterns for different basic emotions [37, 63].

Our studies were conducted using faces isolated from the body and context. In natural situations, perception of emotion is also affected by head movements, eye movements, gestures and voice as well as information about the environment and context. Using these other cues alongside facial expressions would undoubtedly enable more effective expression of basic emotion blends and complex emotions.

Finally, it is not clear whether our results can be generalised to different cultures. The universality of the basic emotions has been questioned when the recognition rates of basic emotions have been found to be higher for the Western culture and lower for other cultures [52]. Thus, also the perception of blends probably varies across cultures. Our participants represented the Western culture, except for Experiment 2 in Publication II, whose participants represented mixed cultures. The results of Experiment 2 in Publication II may have been affected by the uncontrolled cultural background of the participants, as well as their command of English. On the other hand, in all other experiments the participants were predominantly Finnish, which may also have affected the results as restrained emotional expression is typical for the Finnish culture.

4.4 Further Research

As the nature of this research was exploratory, the most obvious path for further research would be to confirm and refine the findings with carefully designed stimuli and procedures. The stimuli should include facial expressions from several different virtual characters, and the variation in cultural background of the participants should be controlled for. Further studies could also explore the effects of factors such as dynamics, voice, context, gaze, and posture.

Further research on facial expression blends could explore why some of the basic emotion blends seem to produce perceptions of complex emotions and others do not. Our results imply that valence of the emotion is a critical factor determining how a blend is perceived: a blend of two emotions of similar valence (negative) was typically perceived as one basic emotion, while a combination of two different kinds of valence (positive and negative, positive and neutral, or negative and neutral) was typically perceived as either a complex emotion or a combination of two emotions. This might have something to do with how similar or different the visual features of the facial expressions are, or perhaps with the similarities of and differences between the basic emotions themselves.

Regarding exaggeration of facial expressions, our study found that using just exaggeration, the natural maximum intensity of human facial expressions could not be exceeded without producing a perception of strangeness. However, further research could focus on whether higher intensities of emotion can be reached by using exaggeration together with other animation tricks.

Finally, regarding to the uncanny valley, there are two important directions for further research on positive reactions to strangeness. First, it should be examined what determines when an uncanny character appears funny and amusing instead of eerie. Secondly, it would be very interesting to further explore the role of mixed emotions (such as a slight feeling of disgust or fear while generally feeling good) in causing funniness and evoking a feeling of amusement. In theories of humour, the role of ambivalent feelings is recognised [59], but in the context of the uncanny valley, it has not been studied.

5. Conclusion

The main goal of this dissertation was to explore how the facial displays of virtual humans could be designed so that they would be capable of rich emotional expression. This includes both a variety of different emotions and a range of emotional intensities. My work has provided new insights in both aspects.

The question of how to express a variety of different emotions was addressed by building a physically-based virtual face model that allows blending expressions of basic emotions without diluting them, and exploring how these blends are perceived. Our results show that some of the blends can produce perceptions of complex emotions, such as shame, malicious joy or shock, indicating that the range of different emotions expressed can indeed be expanded by blending expressions of basic emotions.

As for emotional intensities, my work focused on the well-known notion that exaggeration is needed for less realistic characters to effectively express emotions, but exaggerating the expressions of more realistic characters would make them look strange. Our study was the first one to systematically explore how the perceived intensity and the perceived strangeness vary with the character's level of realism. We found that choosing the right level of exaggeration for each level of realism, all levels of realism can express roughly the same range of emotional intensity without looking strange.

Finally, my thesis addressed the uncanny valley phenomenon, which is closely related to different levels of realism in animation and the use of exaggeration. Challenging the widespread view of the uncanny valley including a perception of strangeness combined with a negative emotional response, our results showed that a positive emotional reaction, such as amusement, may sometimes be more prominent than negative emotions, such as disgust and fear.

The results of this thesis can be utilised in designing facial animation with believable emotional expressions, which in turn can have a great impact on the believability of the character and the effectiveness of the animation in general. On the other hand, the theoretical contributions of this thesis provide a fruitful ground for further research in the fields of facial expression blends, exaggeration of facial expressions and the uncanny valley.

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