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Analysis and Construction of Engaging Facial Forms and Expressions: Interdisciplinary Approaches from Art, Anatomy, Engineering, Cultural Studies, and Psychology

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Analysis and Construction of Engaging Facial Forms and Expressions:

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Cultural Studies, and Psychology.

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Virginia Commonwealth University.

by

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LIST OF ABBREVIATIONS

ACRONYMS DEFINITIONS

BCFC …………………………………. Bezier curve-based 3D facial customization

MFAM ………………………………………………. Multi-layered Facial Action Model

ICT ……………………………..………………………….. Institute for Creative Technology

EEG ………………………………………………………… ElectroEncephaloGraphy

PLoF ……………………………………………………… Principle Lines of Force

FFL ……………………………………………………………………. Facial Feature Lines

FL …………………………………………………………………… Fat/wrinkle Lines

FMC …………………………………………………………. Fat-Muscle Controller

SMU …………………………………………………………. Skeleton Motion Units

MMU …………………………………………………………. Muscle Motion Units

PMU …………………………………………………………. Passive Moation Units

RF ……………………………………………………………… Right Forehead area

LF ……………………………………………………………………. Left Forehead area

CRF ……………………………………………………… Center-Right Forehead area

CLF ……………………………………………………… Center-Left Forehead area

CCF ……………………………………………………… Center-Center Forehead area

VRLF ……………………. Vertical maximum points of the Right/Left Forehead areas

HCRF_L Horizontal maximum point of the Center-Right Forehead toward the Left direction

HCLF_R Horizontal maximum point of the Center-Left Forehead toward the Right direction

VCF ……………………………… Vertical maximum point of the Center Forehaed

UpRE …………………………………………………………. Upper Right Eyelid area

LoRE …………………………………………………………. Lower Right Eyelid area

UpLE …………………………………………………………. Upper Left Eyelid area

LoLE …………………………………………………………. Lower Left Eyelid area

VeUpRN ……………………………………………… Vertex in a Upper Right Nose area

VeLoRN ……………………………………………… Vertex in a Lower Right Nose area

VeUpLN ……………………………………………… Vertex in a Upper Left Nose area

VeLoLN ……………………………………………… Vertex in a Lower Left Nose area

VUpRE ……………………………. Vertical maximum point of the Upper Right Eyelid a r e a

CRE ………………………………………………………. Center point of Right Eyelid areas

VLoRE …………………………. Vertical minimum point of the Lower Right Eyelid area

VUpLE ……………………………… Vertical maximum point of the Left Upper Eyelid area

CLE ……………………………………………… Center point of Left Eyelid areas

VLoLE …………………………… Vertical minimum point of the Lower Left Eyelid area

VRN_Up …… Vertical maximum point of the Right Nose vertex toward the Upper direction

VRN_Lo ……. Vertical maximum point of the Right Nose vertex toward the Lower direction

HRN_R Horizontal maximum point of the Right Nose vertex toward the Right direction

HRN_L Horizontal maximum point of the Right Nose vertex toward the Left direction

VLN_Up ……… Vertical maximum point of the Left Nose vertex toward the Upper direction

VLN_Lo ……… Vertical maximum point of the Left Nose vertex toward the Lower direction

HLN_R Horizontal maximum point of the Left Nose vertex toward the Right direction

HLN_L Horizontal maximum point of the Left Nose vertex toward the Left direction

PJE ………………………………………………………………………… Point on a Jaw End

UpCLi ………………………………………………….……………… Upper Center Lip area

LoCLi …………………………………………….……………… Lower Center Lip area

VeRLi …………………………………………………Vertex on a Right end of the Lip

VeLLi ……………………………………………. ………… Vertex on a Left end of the Lip

HJE_RL …… Horizontal maximum point of the Jaw End toward the Right and Left direction

VJE_Lo …….. Vertical maximum point of the Jaw End toward the Lower direction

VUpCLi_Up ……………………………………………………………………………… Vertical maximum point of the Upper Center Lip area toward the Upper direction

PUpCLi ………………………. Prominent maximum point of the Upper Center Lip area

VLoCLi_Lo ……………………………………………..……………………………… Vertical maximum point of the Lower Center Lip area toward the Lower direction

PLoCLi ………………. Prominent maximum point of the Lower Center Lip area

VVeRLi_Up ……………………………………………………………………………… Vertical maximum point of the Vertex on a Right end of the Lip toward the Upper direction

VVeRLi_Lo ……………………………………………………………. ………… Vertical maximum point of the Vertex on a Right end of the Lip toward the Lower direction

VVeRLi_R ……………………………………………………………………………… Vertical maximum point of the Vertex on a Right end of the Lip toward the Right direction

VVeRLi_L ……………….…………………………………………………….………… Vertical maximum point of the Vertex on a Right end of the Lip toward the Left direction

VVeLLi_Up ……………………………………………………………………………… Vertical maximum point of the Vertex on a Left end of the Lip toward the Upper direction

VVeLLi_Lo ……………………………………………………………………………… Vertical maximum point of the Vertex on a Left end of the Lip toward the Lower direction

VVeLLi_R ……………….…………………………………………………….………… Vertical maximum point of the Vertex on a Left end of the Lip toward the Right direction

VVeLLi_L ……………….…………………………………………………….………… Vertical maximum point of the Vertex on a Left end of the Lip toward the Left direction

SYMBOL DEFINITIONS

θ_{F1} ……………………….....…………………………… Angle of the forehead skeleton

θ_{J2} ……………………….....…………………………… Angle of the protrusion of a mouth

θ_{J3} ……………………………………………………… Angle of the jawbone

θ_{N1} ……………………. Angle between a supraorbital arch and a nasal bone

θ_{N2} ……………………….....…………………………… Angle of the bridge of the nose

l_{E1} ……………………………………………………… Length of the eye area

l_{E2} ………………………………………………………… Width of the eye area

l_{FH} ………………………..……………………………… Length of the overall face

l_{FW1} ………………………..…………………………… Width of the overall face

l_{FW2} ………………………………………………………… Width of the jawbone

l_{N2} …………………………………………………………… Width of the nose

$\mathbf{g}$ ………………………………………… Facial feature vector determining genders

$\mathbf{g}_M$ ………………………………………… Facial feature vector for an average male face

$\mathbf{g}_F$ ………………………………………… Facial feature vector for an average female face

P_M ………………………………………… Probability of the facial muscularity

P_F ………………………………………… Probability of the facial femininity

$\mathbf{r}$ ………………………………………… Facial feature vector determining races

$\mathbf{r}_W$ …………………………… Facial feature vector for an average Western face

$\mathbf{r}_{As}$ …………………………… Facial feature vector for an average Asian face

$\mathbf{r}_{Af}$ …………………………… Facial feature vector for an average African face

P_W …………………………… Probability of the similarity to Western faces

P_{As} …………………………… Probability of the similarity to Asian faces

P_{Af} …………………………… Probability of the similarity to African faces

P_{fat} …………………………………………………………… Probability of fat

P_{age} ………………………………………………………… Probability of age

ABSTRACT

ANALYSIS AND CONSTRUCTION OF ENGAGING FACIAL FORMS AND EXPRESSIONS: INTERDISCIPLINARY APPROACHES FROM ART, ANATOMY, ENGINEERING, CULTURAL STUDIES, AND PSYCHOLOGY

By Leejin Kim, Ph.D.

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Virginia Commonwealth University.

Virginia Commonwealth University, 2013.

Major Director: David Golumbia, Assistant Professor, Department of English

The topic of this dissertation is the anatomical, psychological, and cultural examination of a human face in order to effectively construct an anatomy-driven 3D virtual face customization and action model. In order to gain a broad perspective of all aspects of a face, theories and methodology from the fields of art, engineering, anatomy, psychology, and cultural studies have been analyzed and implemented. The computer generated facial customization and action model were designed based on the collected data. Using this customization system, culturally-specific attractive face in Korean popular culture, “kot-mi-nam (flower-like beautiful guy),” was modeled and analyzed as a case study. The “kot-mi-nam” phenomenon is overviewed in textual, visual, and contextual aspects, which reveals the gender- and sexuality-fluidity of its masculinity. The analysis and the actual development of the model organically co-construct each other requiring an interwoven process.

Chapter 1 introduces anatomical studies of a human face, psychological theories of face recognition and an attractive face, and state-of-the-art face construction projects in the various fields. Chapter 2 and 3 present the Bezier curve-based 3D facial customization (BCFC) and Multi-layered Facial Action Model (MFAF) based on the analysis of human anatomy, to achieve a cost-effective yet realistic quality of facial animation without using 3D scanned data. In the experiments, results for the facial customization for gender, race, fat, and age showed that BCFC achieved enhanced performance of 25.20% compared to existing program Facegen , and 44.12% compared to Facial Studio. The experimental results also proved the realistic quality and effectiveness of MFAM compared with blend shape technique by enhancing 2.87% and 0.03% of facial area for happiness and anger expressions per second, respectively. In Chapter 4, according to the analysis based on BCFC, the 3D face of an average kot-mi-nam is close to gender neutral (male: 50.38%, female: 49.62%), and Caucasian (66.42-66.40%). Culturally-specific images can be misinterpreted in different cultures, due to their different languages, histories, and contexts. This research demonstrates that facial images can be affected by the cultural tastes of the makers and can also be interpreted differently by viewers in different cultures.

INTRODUCTION

The face is a crucial attribute in our communication with others. Using facial expressions, people share their emotions, display empathy, and relay interest with each other. The topic of this dissertation is the anatomical, psychological, and cultural examination of a human face in order to effectively construct an anatomy-driven 3D virtual face customization and action model. In order to gain a broad perspective of all aspects of a face, theories and methodology from the fields of art, engineering, anatomy, psychology, and cultural studies have been analyzed and implemented. The computer generated facial customization and action model were designed based on the collected data. Using this customization system, culturally-specific attractive face in Korean popular culture, "kot-mi-nam (flower-like beautiful guy)," was modeled and analyzed as a case study. The "kot-mi-nam" phenomenon is overviewed in textual, visual, and contextual aspects, which reveals the gender- and sexuality-fluidity of its masculinity. The analysis and the actual development of the model organically co-construct each other requiring an interwoven process.

The dissertation consists of four chapters: (1) a survey of anatomical, psychological, and technological approaches to sympathetic face and its construction; (2) construction of Bezier Curve-based Facial Customization (BCFC); (3) construction of the Multilayered Facial Action Model (MFAM); (4) an overview of a culturally -specific attractive face: kot-mi-nam - male faces in Korean culture.

While Chapter 1 and 4 mainly focus on the analysis and understanding of a human face from different perspectives, Chapter 2 and 3 propose the novel facial customization and action model using the engineering methodology.

The first chapter provides the information from anatomy, psychology, computer graphics, and engineering to design the facial customization and animation model, which are presented in Chapter 2 and 3. Chapter 1 introduces facial anatomy from the fields of art and medical science. An overview is provided regarding psychological theories of facial recognition processesand attractive faces are introduced. Finally, the recent 3D virtual and humanoid face construction projects and their related works are relayed.

In Chapter 2 and 3, the anatomy-driven facial customization and action model are presented. After the model was designed, all mathematical equations are derived and the effectiveness of this model is evaluated. This part of the works are collaborated with Seonyeong Park[1] and Dr. Yuichi Motai.[2] The purpose of this model is to create a cost-effective yet highly realistic and sophisticated 3D facial model for affective human-computer interface (HCI) and facial robots.

Chapter 2 presents an anatomical approach to BCFC. In order to customize a face effectively, BCFC is customized by three types of Bezier curves extracted from the anatomical structures of the human face: First, Principal Lines of Force (PLoF) from the facial skeleton, second, Facial Feature Lines (FFL) from facial features, and third, Fat/Wrinkle Lines (FL) from fat stored area underneath the skin and wrinkle lines. BCFC enables us to customize the base face into a variety of faces for different races, sex, ages, and allows us to manipulate the degree of fat on each part of a face. The experimental results validate that BCFC shows enhanced performance by 25.20% compared to the existing program *Facegen* [1], and by 44.12% compared to the program *Facial Studio* [2].

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Chapter 3 presents the MFAM. For the realistic rendering of facial expressions, a physics-based MFAM is developed rooted in the anatomical principal of facial expressions generated by facial muscles. This enables the rendering of a variety of subtle and complex facial expressions like those of a real human. This multi-layered model expresses facial movement more delicately over 2.87% of the facial area for happiness and 0.03% for anger expressions than Blend Shape techniques.

Chapter 4 provides an overview of a culturally-specific attractive face: Kot-mi-nam - male faces in Korean culture. Since the 2000s, Kot-mi-nam images have formed new masculinity that crosses boundaries of gender images and sexuality in both Korea and the West. This phenomenon is overviewed in textual, visual, contextual aspects. Regarding the textual aspect, kot-mi-nam and its related terms are introduced along with terms denoting certain facial expressions considered attractive. Regarding the visual aspect, a 3D face of average kot-mi-nam is modeled combining three celebrities, and then analyzed using the BCFC model. Pictorial codes of kot-mi-nam images are also analyzed in the context of commercialization and objectification of male sexuality. Finally, the historical and cultural contexts in Korea, and foreign influences, including Japanese male idols, Visual Kie, Western pop culture, and girls' manga culture in Japan are discussed.

I. SURVEY OF ANATOMICAL, PSYCHOLOGICAL, AND TECHNOLOGICAL APPROACHES TO SYMPATHETIC FACE AND FACIAL EXPRESSION CONSTRUCTION

1. Introduction

This chapter introduces research on (1) anatomical information to understand anatomical mechanisms of a face and its expressions; (2) psychological theories and researches of facial recognition processes and attractive faces; and (3) techniques and technology of 3D facial modeling, animation, and android development. Section 2 in this chapter analyzes the anatomical structures of a face including skeleton and facial expression muscles from the anatomical references from the fields of art and medical science. Section 3 introduces psychological facial recognition theories. Section 4 introduces theories of attractive faces in the aspects of the aesthetics of a face and the aesthetics of pictorial codes. Section 5 illustrates the process of the virtual face construction in 3D graphics software which consist of modeling, texture mapping, and coloring & texturing. Section 6 compares the techniques of virtual 3D face and android constructions. Section 7 is a conclusion.

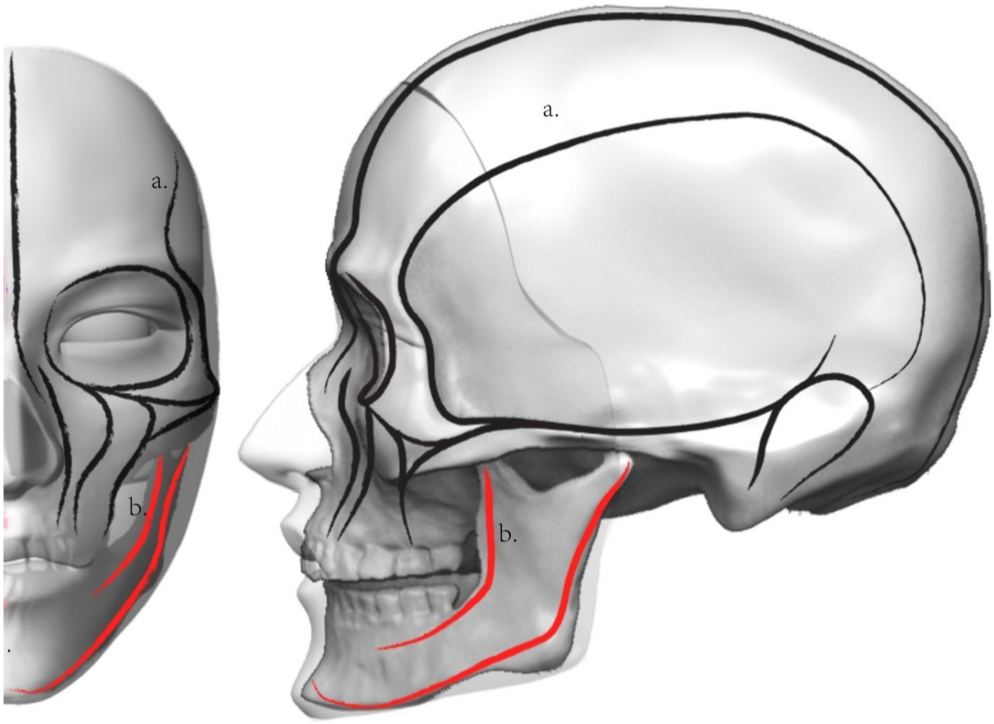
2. Facial Anatomy

In-depth studies of facial anatomy are crucial to create realistic 3D virtual face or humanoid face and its sympathetic facial expressions. While facial expressions of a 3D model has been created by changing its surface, facial expressions of a humanoid face have been created by changing positions of facial features (action units). However, these methodologies only mimic the look of facial expressions, not fundamentally "make" facial expressions. In case of facial expressions using blend shapes, the artists need to animate changing textures and wrinkles for more realistic renderings of them. Anatomical construction of a face and facial expressions can be adapted to vast areas which require realistic facial expressions.

Another benefit of anatomical construction is the creation of customizable facial expressions. Most facial animations so far are based on different categories of emotions, but in fact each person uses different muscles for the same emotion, and many facial expressions cannot be categorized into specific emotions.

Therefore, the fundamental approaches to facial expression creation have great potential to impact many related area aesthetically and practically. Section 2.1 discusses facial skeleton, Section 2.2, facial expressions muscles, and Section 2.3, anatomical references for facial and expression construction.

2.1 Facial Skeleton



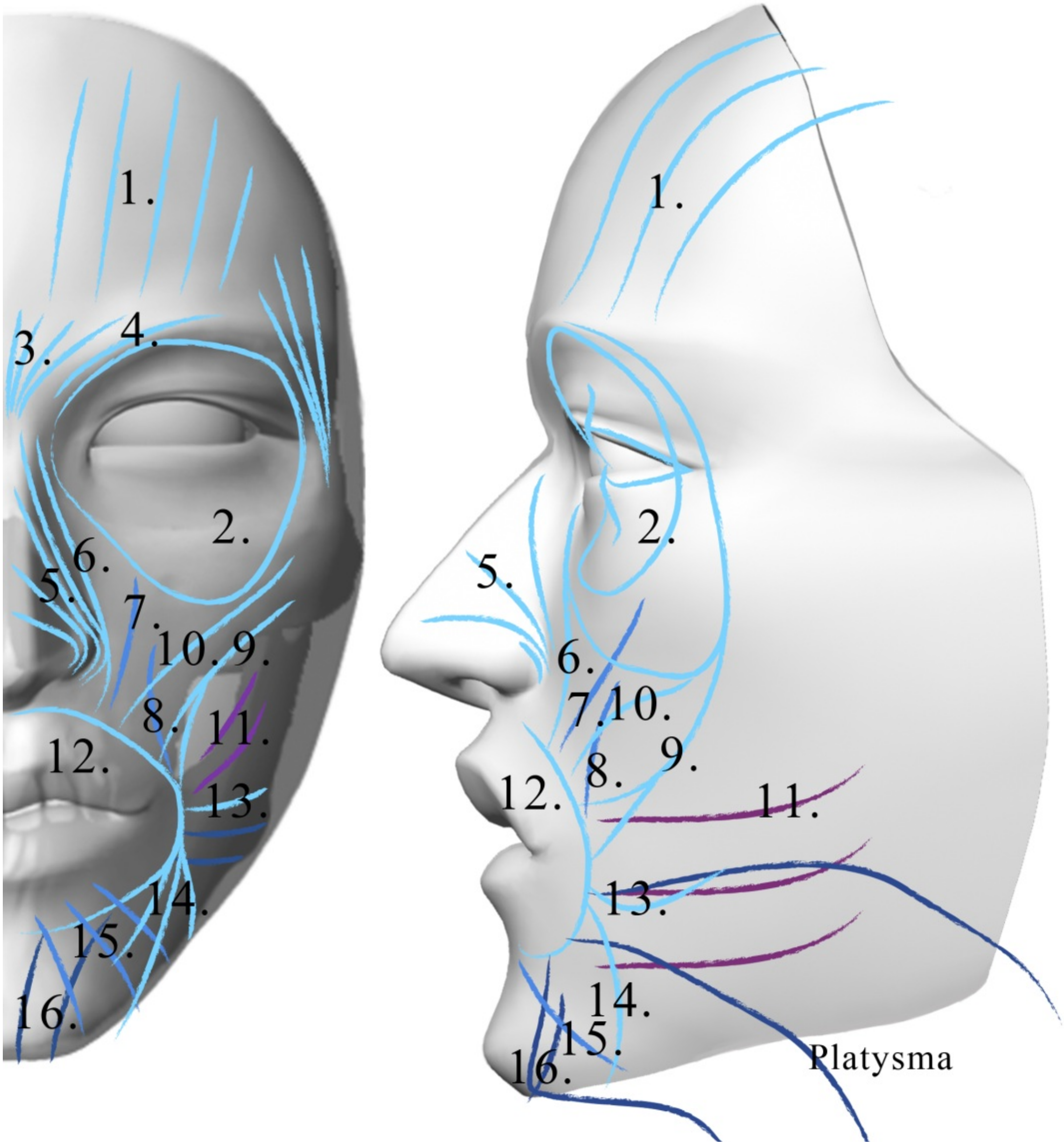
(a) Front view (b) side view

Fig. 1. Principal lines of force in the facial skeleton. (a) Front view. (b) side view. The arrangements, angles, and ratios of these lines define the basic form of a face which will affect face recognition of different sexes and races. a. refers lines on the skull and b. refers lines on the mandible.

A facial form is defined by inner structures: a frontal part of a facial skeleton, muscles, and subcutaneous fat. Contraction and relaxation of muscles create facial expressions and wrinkles. Understanding facial anatomy, especially each muscle's functions and location (including origin and insertion) will enhance more effective construction of a realistic and sympathetic face and facial expressions. The anatomical approach to facial construction can be useful to both virtual face construction and android face construction and especially beneficial when the artificial face is designed to respond to Electroencephalography (EEG), the recording of brain neuro-signals.

The facial skeleton is a structure that supports the paranasal sinuses. Fig. 1 represents the principal lines of force in the facial skeleton which may be compared to the columns of a house [6]. The arrangements, angles, and ratios of these lines define the basic form of a face which will affect face recognition of different sexes and races. (a) refers lines on the skull and (b) refers lines on the mandible. While a. is prominent regardless of different ages and weights, b. may be less prominent due to the development of muscles and fat. Bone structures, especially the ratio of principal lines of force remains consistent in different facial expressions except for jaw bone movements.

2.2 Facial Expression Muscles



(a) front view (b) side view

Fig. 2. Simplified lines of facial expression muscles. The numerical numbers are listed in Table 1. [1]. There are 20 muscles that enable facial expressions. 16 muscles of facial expressions for each side of a face were marked with simplified lines (except for platysma). The unmarked 3 muscles are inside the facial skeleton. The illustration helps the viewer to understand the general idea and direction of facial expression muscles.

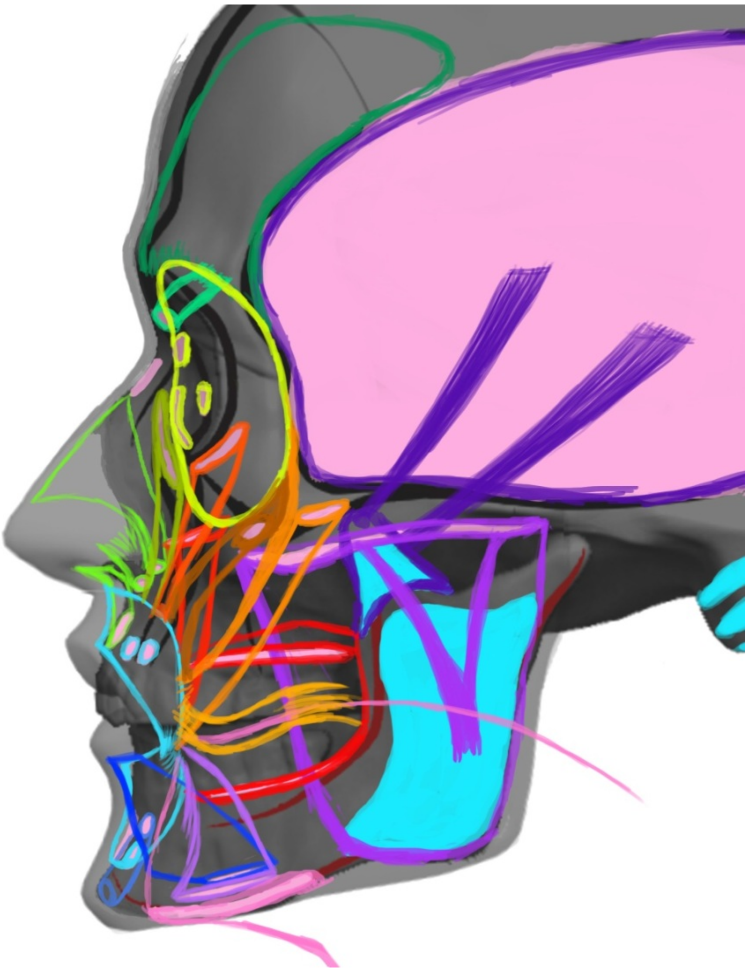


Fig. 3. Origins (pink areas) with outlined shapes of facial expression muscles, side view. One side of each facial expression muscle is attached to the origin, mostly a part of a facial skeleton, and the other side is attached to othe muscles or facial skin.

TABLE 1
FACIAL EXPRESSION MUSCLES [3]

Muscle	Facial Expressions
1. Occipitofrontalis	elelvates eyebrows; wrinkles skin of forehead
2. Orbicularis Oculi	-Orbital part: valuntary closure of eyelids, furrowing of nose and eyebrows during squinting -Palpebral part: voluntary (sleeping), involuntary closure (blinking) of eyelid -Lacrimal part: pulls eyelid medially
3. Procerus	pulls eyebrows medially and inferiorly (frowning)
4. Corrugator Supercilii	acts with orbicularis oculi to pull eyebrows medially and inferiorly (during squinting)
5. Nasalis	-Transverse part: compresses nasal aperture (compressor naris) -Alar part: widens nasal aperture (flares nostril) by drawing ala toward nasal septum

6. Levator labii superioris alaeque nasi	elevates upper lip; flares nostril
7. Levator labii supurioris	elevates upper lip
8. Levator anguli oris	raises angle of mouth; helps form nasoloabial furrow.
9. Zygomaticus major	pulls corner of mouth superiorly and laterally
10. Zygomaticus minor	pulls upper lip superiorly
11. Buccinator	suckling in nursing infant; press cheek against molar teeth, working with tongue to keep food between occulusal surfaces and out of oral vestibule; expels air from oral cavity/resists distention when blowing *Unilateral: draws mouth to one side*
12. Orbicularis oris	Act as oral sphincter; compresses and protrude lip, resists distention (when blowing) resists distention (when blowing)
13. Risorius	reacts corner of mouth as in smiling, laughing, grimacing
14. Depressor anguli oris	Pulls angle of mouth inferiorly and laterally
15. Depressor labii inferioris	pulls lower lip inferiorly and laterally, contributes to eversion (pouting)
16. Mentalis	elevates and protrudes lower lip (drinking)
17. Masseter	elevates mandible; assists in protraction, retraction, and side-to-side motionelevates and protrudes lower lip (drinking)
18. Temporalis	Vertical (anterior) fibers: elevates mandible Horizontal (posterior) fibers: retract mandible Unilateral: lateral movement of mandible (chewing)elevates mandible;
19. Lateral pterygoid	bilateral: protrude mandible (pulls articular disk forward); unilateral: lateral movements of mandible (chewing)
20. Madial pterygoid	elevates (adducts) mandible

By anatomical definition, the muscles of facial expressions are "the superficial layer of muscles that arise either directly from the periosteum or from adjacent muscles and insert onto other facial muscles or directly into the connective tissue of the skin." The muscles terminate in the subcutaneous fat, which enable the movement of facial skin [3].

Fig. 2 is a front and a side view of simplified lines of facial expression muscles. The numbers currespond with Table 1, list of facial expression muscles. There are 20 facial muscles that enable facial expressions. The list is modified from the tables from the anatomy textbook from dental medicine [3]; only muscles that are involved in facial feature movements were included. 1-4 create eye expressions; 5 and 6 create nose expressions; 5-16 create lip expressions; 17-20 move mandible (jaw bone).

Fig. 3 is a side view of a face that illustrates the origins and outlined shapes of facial expression muscles. The origins of muscles are painted pink. Knowing these helps us to understand how they contract to create facial expressions.

2.3 Anatomical References for facial and expression construction.

TABLE 2
COMPARISON OF ANATOMICAL REFERENCE BOOKS.

Target Field	Pros	Cons
3D Figure Modeling [4]	Provide detailed techniques of Zbrush Figure Modeling	Not enough information on the anatomy of facial and expressions.
3D Facial Animation [5]	Provide in-depth discussions on facial 3D modeling and animation.	Lacks anatomical discussions on facial structures and expressions.
Figure Art [6]	Provide anatomical information for figure drawing and modeling	Difficulty of understanding accurate structures from sketches. Not enough information on the anatomy of facial expressions
Figure Art [7]	Provide photo references of various facial expressions of different age and race, from different angles	Lacks systemic categorization of facial expressions Lacks analysis and discussions on facial expressions
Dental Medicine [3]	Provide accurate and detailed information on the anatomy of facial and expressions.	Lack of illustrations with various angles.
Medicine [8]	Accessible online Clear and accurate illustrations of the human anatomy	Not enough information on the anatomy of facial expressions.

General [9]	Accessible online 3-D dynamic navigation of the anatomical structures	Rough-quality, low resolution 3-D Models.

Using anatomical reference books as a source of information about facial construction poses a fundamental problem. Since no single volume contains comprehensive information, the data must be collected from many different source including dental medicine, art, and general science. From the many reference books I consulted with, I selected six sample references from different fields that provide clear illustrations particularly useful for facial model construction. Table 2 lists pros and cons of each reference.

ZBrush Digital Sculpting: Human Anatomy [4] focuses specifically on the anatomical modeling in ZBrush. Even though it provides in-depth guidelines to model in Zbrush, it does not provide enough information on the facial anatomy itself. *Stop Staring: Facial Modeling and Animation Done Right* [5] provides an in-depth discussion on 3D facial modeling and animation, specifically regarding speech animation. In this book, visual phonemes or visemes, which are the significant shapes or visuals made by the lips, are the basis of the speech animation. The book discusses each facial feature and wrinkle that creates facial expressions, but it lacks anatomical discussions on how facial skeletons and muscles affect these facial features and wrinkles.

Atlas of Human Anatomy for the Artist [6] illustrates information required for traditional figure drawing and modeling. However, since many drawings were drawn by the artist by hand, drawing styles sometimes hinder the understanding of accurate and detailed information of anatomical forms. Descriptions of facial expressions are relatively brief since the book covers the anatomy of the whole body.

In *Facial Expressions; a visual reference for artists* [7], M. Simon provides photographs of facial expressions of 50 faces in different ages, genders, and races. Each model features 12-14 different facial expressions mostly from front, side, and tilt views. However, photographs are not systemically categorized by consistent facial expressions. Analysis and discussions on facial expressions are not provided.

In-depth information on the facial anatomy can be found in references from medical anatomy and dental medical anatomy. The dental medicine textbook, *Head and neck anatomy for dental medicine* [3] provides very detailed and accurate illustrations and information of the facial skeleton and muscles. However, most illustrations are limited to orthographic drawings that do not provide enough information of three-dimensional shapes. *Anatomy of the Human Body* [8] provides anatomical illustrations of the human body accessible online. Even if the illustrations were drawn in 1917, they successfully describe detailed anatomical structures, especially the area in the skeleton which each muscle is attached to. However, in particular, it does not provide enough anatomical illustrations of facial and expressions.

The understanding attachment of each muscle is extremely hard without looking at the real 3D structure. Illustrations of origins and insertions of muscles, and orthographic views provide reasonable information, but not complete information regarding forms for 3D modeling. *Zygote Body* [9] is online software that enables navigation of 3D anatomical models including skeleton, organs, muscles, nerves, arteries, and venal systems by rotating and zooming in and out. This helps viewers figure out an accurate form and locate each organ or muscle. Nevertheless, the company ZYGOTE only provides the low-polygon 3D model for free online access. The company provides high-resolution quality of the 3D models and illustrations for the fields of medical science.

In conclusion, while references from art disciplines [4], [5], [6], [7] focus on proportion and configural structures of skeletons and outer muscles, references from medical science [3], [8] provide more in-depth information on the human anatomy. The references from art fields mainly focus on the forms and structures of the human body in order to help artists illustrate them intuitively. However, they do not provide in-depth information for the 3D modeling and animation that require more accurate and detailed information. While medical textbooks provide detailed information, they do not provide illustrations from dynamic angles that pose challenges to artists.

3. Psychological Face Recognition

This section briefly introduces psychological theories of face recognition. Psychologists use these theories to explain people's perception and preference of an attractive face. The creation of an attractive face will cause the viewer to be more engaged and sympathetic to the face. By observing form, features, color, texture of a face, people figure out the persons' identity and emotional status, and judge if the person is attractive or not. There have been many studies in the field of psychology and neuropsychology to understand the process of face recognition, many of which are based on empirical studies and/or evolutionary theory.

Face recognition theories can be adapted to the character development and customization. The multidimensional face space model, and theories of own and other racial groups can be adapted for the customization of a virtual character. For instance, through the computer processing of a viewer's face, the race, age, configural/featural information, and skin texture information of the viewer's face may be recognized. In addition, with connection to the data information of social networks, the viewer's preference of a face and facial information of his/her close friends and family members may be gathered. Based on the collected information, the character will be customized automatically.

This section introduces A. Bruce and Young Model (1986), B. The Multidimensional Face Space Model (MDFS), C. configural and featural face processing, and discusses on D. face recognition of visual representation of a face.

3.1 Bruce and Young Model

Bruce and Young Model (1986) of Face Processing postulated a number of stages that has greatly influenced other researches. A representation of a face goes through the Face Recognition Unit(FRU), the Person Identity Nodes(PINs), the Semantic Information Unit (SIU), and the Name Unit [10]. The linear face recognition process of this model was later challenged by researchers such as Ganel and Goshen-Gottstein who suggested that identity, gender, and emotions are handled independently of each other, even if there is some degree of interaction between each process [11].

V. Bruce and A. Young suggested that a face includes seven different types of information (or codes) including pictorial, structural, identity-specific semantic, visually derived semantic, name, expression and facial speech codes. Differences between pictorial codes and structural codes will be further discussed in Section 3.4.

3.2 The Multidimensional Face Space Model (MDFS)

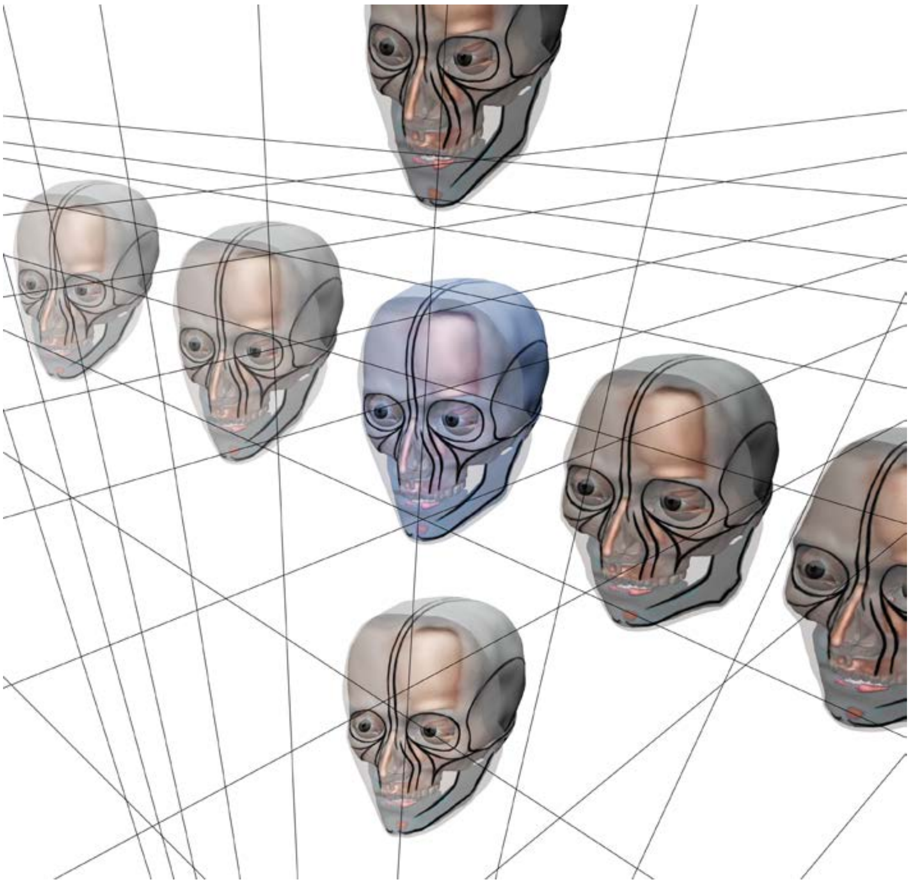


Fig. 4. The character customization system based on the Multidimensional Face Space Model and principal lines of force in the facial skeleton. A blue face in the center is the norm face. To the right, lines become wider and prominent, and to the left, lines become narrower and less prominent. To the top, lines from eyes to jaw become longer, and to the bottom, lines from eyes to the jaw become shorter.

T. Valentine designed the MDFS model to explain how we represent faces in memory. A face is stored based on the values on the facial dimensions. In multi dimensions of MDFS, the average face called norm-based model is the reference point, and the viewer poses the example face in the specific multi-dimensional coordinates in MDFS based on the length and ratio of facial forms and features [12], [13].

When a face is closer to the average face, people recognize it as a face, and when it is further, they tend to recognize it as a distinctive face but also as an 'anti-face (face with opposite features) [14].' The study also showed that when different features are dramatized in the face such as in a caricature, people tend to recognize the person more easily [13].

MDFS model has limits in terms of accuracy of the facial forms and features since it is based on the ratio of facial features such as the length of a nose or the distance between eyes, rather than anatomical structures and facial features. The combination of the MDFS model and anatomical information can create a more sophisticated character customization system. In the project, “Bezier Curve-based Facial Customization” proposed in Chapter II, the principal lines of force in the facial skeleton was adapted to the MDFS model. In Fig. 4, a blue face in the center is the norm face. To the right, lines become wider and prominent, and to the left, lines become narrower and less prominent. To the top, lines from eyes to jaw become longer, and to the bottom, lines from eyes to the jaw become shorter.

The major problem of the MDFS models and other psychological studies is that they mostly focus on the limited perspective of the face, such as a front view or side view. Faces also differ due to the different angles of principle lines of force from profile view and facial feature differences of eyes, eye brows, and lips suggested, which will be explained in Chapter II.

The MDFS model has been popularly adapted to explain one’s own and other group bias including race, gender, age, and species bias. Especially, studies of own-race bias have been actively proliferated. The studies have shown that people tend to distinguish faces and facial expressions of their own-race better than other-race’s faces [15], [16]. The ability to distinguish faces are developed by their experience rather than their original races. [17], [18],

[19]. Even in the case of different races living in the same culture, the degree of paying attention to the other race affect the ability to recognize the other race [20], [21]. Our character customization system based on MDFS and principal lines of force will benefit the creation of an accurate 3D face in different races.

3.3 Configural and featural face processing

Many psychological researchers have suggested that there are two different routes to face recognition: configural processing and featural processing [12], [22]. The concept of configural processing is somewhat ambiguous, whereas featural processing refers the processing of facial features. Maurer et al. [23] suggest three types of processing: 1) first-order relational processing involving processing of basic configuration common to all faces [24], 2) J. Tanaka and M. Farah's [25] holistic processing that stresses the importance of interdependent processing of the configural and featural information of a face as indissoluble wholes, 3) a form of processing that is used to process the second-order relational properties (spatial arrangement of the facial features).

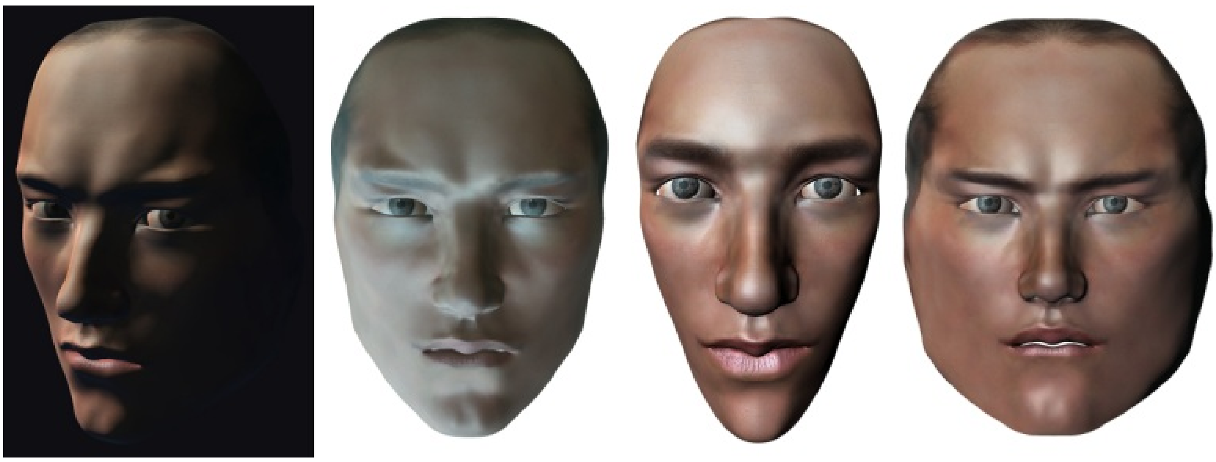
Psychological definitions of configural processing are still ambiguous since their approaches are only explained in terms of the "outer image" of a face, mostly from a front view. The configural processing may involve the processing of the ratio of a face skeleton, a basic form of a head, and the ratio of facial features.

Meanwhile, featural processing is essential especially when differentiating faces in different sexes, ages, and races. Features of the face model may include shapes and colors of eyes, lips, skin tone, wrinkles, and sagging of skin.

3.4 Pictorial Codes and structural codes in face processing

V. Bruce [26] argued that both pictorial codes and structural codes are used to process a face. While pictorial codes are from a particular image of the face seen, structural codes contain information on a face itself, such as facial forms and features [12]. V. Bruce and A. Young [10] introduced Marr's three representational stages beyond the retinal image: the primal sketch, viewer-centered representation (the 2 1/2 sketch), and object-centered representation (3D model).

Inspired by Marr's representational stages, I suggest using pictorial codes and structural codes based on computer generated-face model recognition in order to produce the most accurate imaging. According to this assumption, pictorial codes may refer the information of 2-D, 3-D, or 4-D representations of a face. In the case of 2-D images, it may refer fixed compositions, colors, lines, shading, and textures. In the case of dynamic images such as 3-D or 4-D, multiple images may help participants define a 3-D structure and features of a depicted face more clearly. A real-time rendering of an autonomous 3-D face will increase the accuracy of structural code recognition since it provides dynamic perspectives of it. Studies have shown that people are better at recognizing top-lit 3D faces with shading than a 3D face lit from below or a line drawing of a face since they are familiar with those settings [27], [28], [29], [30], [31]. Based on the theory of pictorial codes and the structural codes, the facial renderings can be more sophisticatedly customized based on the viewers' preferences.



(a) (b) (c)
(d)

Fig. 5. Various renderings of a 3-D male face model: (a) tilt view with dramatic light from left, (b) front view with light from bottom, (c) perspective projection of a 3-D face with focal length 10, (d) orthographic projection of a 3-D face. (c), (d): The shape of a 3-D face is distorted by the camera's focal length and angle of view.

A problematic aspect of psychological empirical research is that they often use facial representations such as schematic drawings and composited photographs, instead of real faces. Images and photographs of a face provide limited information of the face due to limited perspective, lighting, texture, and color [10], [32]. Furthermore, the shape of a face is distorted by different focal lengths. Fig. 5. shows various renderings of a 3-D male face model: (a) tilt view with dramatic light from left, (b) front view with light from bottom, (c) perspective projection of a 3-D face with focal length 10, (d) orthographic projection of a 3-D face. In Figure (c) and (d), the same face look dramatically different from each other due to the different camera setting of focal length and angle of view.

4. Attractive Face

Empirical and theoretical studies on an attractive face can be adapted to the character development; the factors of averageness, bilateral symmetry, sexual dimorphism, neotony, and skin condition may be adapted to enhance the attractiveness of the character. Especially neotenous features such as an oval face with large eyes, a small nose, and a small chin have been already actively adapted in character design and animation industries in Japan and the United States.

However, regarding bilateral symmetry, character’s faces are often portrayed from a slightly tilted view to one side such as Mickey Mouse or Candy in the anime series Candy Candy; or some have ornaments around their faces that skew their overallsymmetry,such as Hello Kitty's ribbon on one ear, Lelouch Lamperouge's left eye glowing in red in the anime series Code Geass, Alex, a main character of a movie *A Clockwork Orange* who attached long eye lashes only to his right eye, and even Michael Jackson's forelock slipped down onto his face.

For the realistic real-time rendering of a virtual face, auto-adjustment technologies of lighting, contrast, and background may need to be developed. Even though there have not enough studies on makeup and hair styling, these factors will be very important for the character customization to add personality and tastes to it.

There are three key aspects regarding a visual representation of an attractive face: A. aesthetics of a face, B. aesthetics of pictorial systems and media, and C. aesthetics of styles and self-adornment. Differences between approaches A and B are closely linked to Bruce's codes for face processing discussed in Section 3: A. aesthetics of a face links to structural codes, and B. aesthetics of pictorial systems and media relates to pictorial codes [10], [26]. When the viewer processes a representation of a face, s/he processes facial information and the information on the medium itself.

4.1 Aesthetics of a face

Aesthetics of a face may relate to the areas of cosmetics, celebrity, and beauty industries, as well as everyday social communications of people. There has been active psychological research on factors that affect people's judgments of a beautiful face: a) averageness, b) bilateral symmetry, c) sexual dimorphism, d) neotony (youthful face), e) skin condition.

a. Averageness

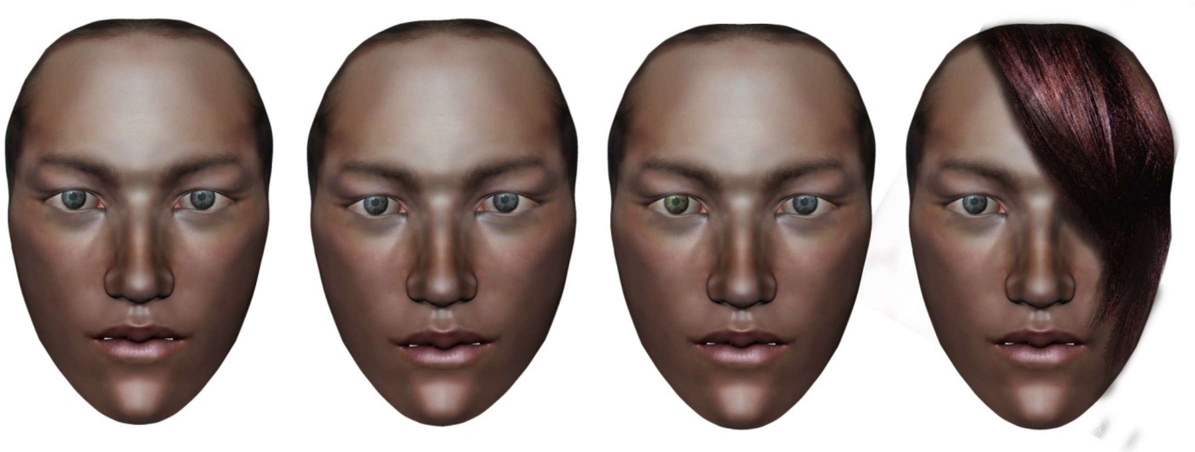
Many empirical studies including J. H. Langlois & L. A. Roggman [33] and A. C. Little & P. J. B. Hancock [34] have displayed that a composite of more faces was considered more attractive than a composite of fewer faces. T. R. Alley and M. R. Cunningham [35] raised a question regarding J. H. Langlois and L. A. Roggman’s [33] use of digitally generated average faces. Specifically they questioned the digital averaging process and found that it may have enhanced attractiveness since a digitally enhanced face is more symmetrical and has smoother and more even skin texture. A technical failure to align accurate feature outlines of composite faces may also have affected the result.

The definition of 'averageness' is also questionable since the result may vary according to the range of a research subject group, especially when it comes to faces of different races. C. L. Apicella et al. [36] conducted a research on judgments of opposite-sex attractiveness in British faces and faces of the Hadza, a tribe in northern Tanzania who did not have many contacts with Westerners. Participants from both cultures considered 20-face composites more attractive than 5-face composites of their own race, but participants from both cultures did not perceive faces of the other race as attractive. The result suggests that the facial norm of each culture is an important determinant to judge attractive faces.

In addition, an 'ideal' face considered as most attractive may be similar to the average face, but not the same; the contour and features of the ideal face are more enhanced than those of the average face of the general group. Perrett et al. [37] compared three composites: (a) average of 60 female faces, (b) average of the 15 most attractive faces, and (c) a caricatured face. (c) A caricatured face exaggerates the differences between (a) and (b) by 50%. (c) was highest rated, (b) was second, and (c) was third.

L. M. DeBruine et al. [38] conducted further research that challenges the 'average is attractive' hypothesis by rating a set of 60 gradually differentiated caricatures and anti-caricatures. These sets were based on the differences between an average female face of 60 faces and an average female face of 15 most attractive faces. For an exaggerated face, the differences between the average face and the attractive-average face of 100% was highest rated as an attractive face. The rating gradually decreased as the exaggeration increased both to the right (positive) and to the left (negative) on an attractiveness dimension in face space. The result of their experiments suggests that the judgment of normality and the judgment of attractiveness are in very different patterns, at least in case of a female face; people tend to be more attracted to higher cheek bones, larger eyes, and thinner jaw than the average female face [38]. These characteristics are found in intermediate juvenile faces and in neotonous faces, which will be discussed on Section d.

b. Symmetry



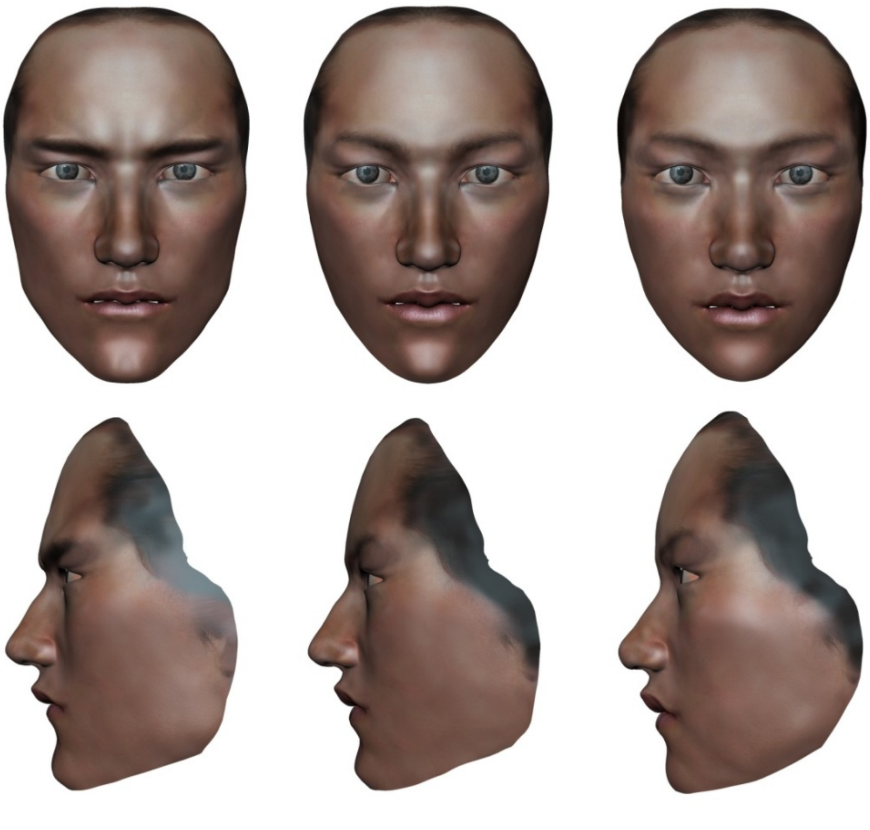
(a) (b) (c) (d)

Fig. 6. Comparison of faces with different symmetrical features: (a) 3-D symmetrical face model, (b) slightly asymmetrical face model, (c) symmetrical face model with asymmetrical eye colors, and (d) symmetrical face model with an asymmetrical hairstyle.

The research shows that symmetry affects the judgment of attractiveness. Early studies suggested that slightly asymmetrical faces were more attractive than perfectly symmetrical faces. However, G. Rhode [39] pointed out that the technical problems with symmetrical facial image creation might have affected the results. In early studies, they used the mirror image of half of the face, and slight errors of an angle and a position of the axis might have caused odd-looking faces. Later studies fixed these technical issues and the symmetrical faces rated as more attracted than the original faces [40], [41]. The changes of these results show potential problems for empirical studies using visual representations.

Nevertheless, it seems to be true that symmetrical or slightly asymmetrical faces are more attractive than visibly asymmetrical faces. While the symmetry of the facial skeleton is crucial for an attractive face, surface conditions, hairstyles, eye features, and decorations sometimes rather tend to cause asymmetry. Fig. 6 is the comparison of (a) 3-D symmetrical face model, (b) slightly asymmetrical face model, (c) symmetrical face model with asymmetrical eye colors, and (d) symmetrical face model with asymmetrical hairstyle. (c) and (d) have asymmetrical features of eye color or hair style, which are often found in celebrities and models' faces.

c. *Sexual Dimorphism*



(a) (b) (c)

Fig. 7. Application of sexual dimorphism to 3-D face models. (a) 3-D model with male facial features: shorter distance between eyes and eyebrows, bigger nose, thinner lips, more developed jar bones, (b) 3-D face model with in-between female and male features, (c) 3-D face model with female features: longer distance between eyes and eyebrows, smaller nose, fuller lips, more oval face. Psychological theories that an increase of sexual features of each sex makes a face more attractive is questionable especially regarding a male face.

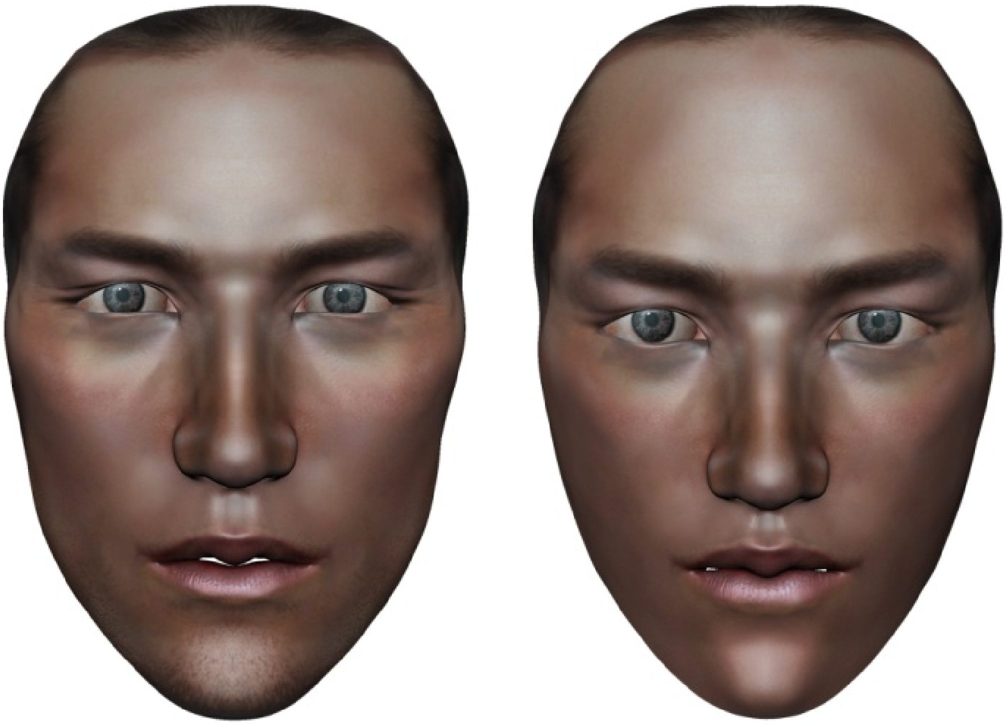
Many psychoanalytical studies [42], [39], [43] confirmed a correlation between an increase of feminine features of a female face and attractiveness. Fig. 7 is an application of sexual dimorphism to 3-D face models. (a) is a 3-D model with male facial features: shorter distance between eyes and eye brows, bigger nose, thinner lips, more developed jaw bones. (b) is a 3-D face model with in-between female and male features. (c) is a 3-D face model with female features: longer distance between eyes and eye brows, smaller nose, fuller lips, more oval face. The comparison of three models raises questions. It is questionable if (a) and (c) are more attractive than (b). (b) may be considered attractive as an 'androgynous' face which has been popular in pop cultures. The result may also depend on whether (b) is a male or female face.

While a majority of recent studies concluded that slightly feminized male faces are rated most attractive [34], [37], [44], regarding a male face, the result of empirical studies have been inconsistent [12, p. 100]. Rhodes et al. [43] collected the ratings of the preferences of male and female faces of Chinese and Caucasians, exaggerated from feminine to masculine in different levels. The most attractive male and female faces of both races are significantly feminized. The result may suggest the possibility of an increasing preference for a feminized asexual face. Social changes of gender roles and evolutionary theory could explain this change of preference.

Sexual dimorphism theory may be true in terms of a configural structure (a bone structure and development of muscles) but regarding facial features and racial differences, it may be questionable. For instance, the distance between the brows and eyes are an important factor to distinguish male and female faces [45]. Asians have a relatively longer distance between the eyes and the brows and they have smaller noses than Caucasians; therefore, for more accurate results, the featural differences of different sexes and races should be considered separately.

Apart from facial information itself, other factors were also shown to be important determinants of male and female faces. Empirical studies showed that women tend to display more frequent facial motions than men, such as blinking, tilting, nodding, and shaking [46]. The hairstyles prove to be an important factor for the determination [47].

d. *Neotony (youthful face)*



(a) (b)

Fig. 8. Application of neotonous features including larger eyes, a smaller nose, fuller lips, less developed bone structures to 3-D male adult face. (a) 3-D adult male face, (b) 3-D neotomous male face.

Neotony refers to retention of traits from early stages in adulthood. A neotenous face has a higher ratio of neurocranium and lower facial features with larger eyes, a smaller nose, and fuller lips than an average face. Fig. 8 is an application of sexual neotonous features to 3-D face models: (a) adult face and (b) neotomous face. D. Jones conducted the experiment on the male preference of female neotenous faces from 5 different cultures including Brazil, the U.S., Russia, Ache, and Hiwi, and all male participants from different cultures rated neotenous female faces as highest attractive even after female age is controlled for. He also studied the female faces on the Cosmopolitan and Glamour magazine covers between 1989 and 1993, and concluded that the model faces are extremely neotenous; predicted ages based on facial proportions are 6.8 years and 7.4 years [48].

D. Jones [48] explained the result using Darwin's evolutionary sexual selection theory. He concluded that the preference of a male neotenous face were not consistent and/or weak. There are differences between female's fecundity / fertility rate changes in different ages and male's rate changes; while the female's curve of natural fecundity and fertility decrease dramatically after their 40s, male's curve declines only gradually. D. Jones [48] suggested that those differences might have affected more preference of the female neotenous face than the male face. However, if there is a correlation between fecundity/ fertility and the preference of the neotenous face, social circumstances of fertility rates may be another important factor; his hypothesis seems only valid in the patriarchal social circumstance that women's physical attractiveness is considered much important factor than men's.

The preference of a neotenous face is not equivalent of the preference of a juvenile face. D. S. Berry and L. Z. Mc Arthur [49] presented a series of outline profile drawings of individuals ranging from juvenile to adult, and collected ratings of different social characteristics of each drawing. While the most juvenile-looking face was rated weakest and least threatening, intermediate-juvenile-looking face was rated sexiest. The result may support that the perceived vulnerability and sexiness do not exactly correspond to each other, but the validity of the experiment is questionable since the perception of an outline drawing of a face and that of a real face, a volume drawing, or a photograph of a faceare quite different from each other.

The features of a neotenous face such as a higher ratio of neurocranium and lower facial features with large eyes, small nose, and full lips result from the ratio of face skeleton, the growth of cartilage, the athrophy of connective tissue, and muscle development. After the age of 25, the eyebrows steadily descend and make eyes look smaller [50]. Cartilage steadily grows throughout adulthood, which may result in larger ears and a longer, wider, and more protrusive nose. The lips get thinner due to the loss of connective tissues [50], [51], [52].

e. Skin Condition

Even if there have been a great deal of research on forms of an attractive face, not many studies have been performed regarding a correlation between an attractive face and its skin condition. As most people would imagine, flawless, younger, and healthier looking skin was rated most attractive in several studies including B. Fink et al. [53] et al. and A. C. Little and P. J. B. Hancock [34].

f. Hair Styles and Self-Adornment

There are many non-Western cultures that the practice of self-adornment is a crucial factor to determine an attractive face, such as maori men who cover their faces in tattoos, or young Ainu women of Japan in the 19th century who had tattoos in between their nose and mouth [12]. Even if we do not have dramatic adornment of a face like these regional tribes, we do have self-adornment of a face: make-up and hair styling.

There are not many academic researches on the effects of makeup or hair styling on an attractive face. Unlike the adornment of regional tribes, the main purpose of makeup in contemporary cultures is mainly to create illusions of bigger eyes, fuller eyelashes, fuller lips, and flawless and healthy looking skin. Hair styling may also affect the estimation of age, personality, configural, and featural information of a face. Different skin textures and hairstyles may be applied to the face model for the character customization.

4.2 Aesthetics of pictorial codes

Various types of renderings of a face such as a drawing, picture, print, video, sculpture, and 3D printing are used to represent a face. The most significant problems of psychological empirical studies on a face is that many of them consider the result based on the visual representations of faces as the same as the result based on real faces. The information of a face is limited or distorted in a visual representation of a face, and the viewer may find the image attractive due to the style and aesthetics of pictorial codes and medium itself.

For example, D. Jones [48] conducted the empirical test of the neotomy hypothesis by comparing two samples of facial photographs of U.S. female and male models with the facial photographs of University of Michigan undergraduates. He extracted ten female model images from Cosmopolitan and Glamour magazine covers between 1980 and 1993. Then he chose five images from the cover; models not facing directly toward the camera, with their mouths open, celebrities, and non-Caucasians were excluded. In fact, composition of the image, facial expressions, angle of the face, direction and intensity of lighting, contrast, color schemes, and even background greatly influence the attractiveness of the face. Many psychological studies tried to extract these pictorial codes of the sample images for reading of structural codes of a face, but it seems almost impossible since the sample images themselves already have pictorial codes in them.

In addition, each media has its specificity that may also affect the preference of the face. While the image captures the moment of a face at a certain moment with a certain pose, expression, and angle, with a certain lighting and background, video captures the time-based linear changes of a setting and circumstance of a face, yet still operating with limited time and perspectives. Meanwhile, a 3D rendering of a face may provide more information on a face itself, which is closer to the information of the real face, or even higher sometime. A 3D rendering can be viewed from different perspectives, zoomed in and out for the texture information, in different lightings. The use of a 3D rendering may enable scrutinization of a face, but it may be a different experience from the examination of a real face due to the additional options of zoom-in and zoom-out views and the free rotation of a face, and easily manipulatable lighting and background. If these options are limited to the seeing of a real face, differences of the viewer experience may be reduced.

5. Realistic 3D Virtual Face Construction Techniques

TABLE 3
TECHNIQUES FOR REALISTIC 3D VIRTUAL FACE CONSTRUCTION

Process	Techniques
Modeling (Section A)	3D scanning [54] Manual modeling 3D sculpting [4]
Texture mapping (Section B)	UV texture mapping [4], [55] Ptex [56] Polypaint [57]
Coloring &Texturing (Section C)	Texture Painting [4] Warp 2D image [58] 3D Surface texture scanning [54] surface scattering [4], [59], [60] Normal Mapping [54], [61]

There have been many projects to create the realistic virtual face and facial expressions, that aim to cross the "uncanny valley[3]," coined by Prof. Mori in 1970 [62]. This terms means computer generated humans or androids look and act "almost" like humans, but not perfectly, which invokes feelings of revulsion. It may be because we are extremely good at recognition of a face and facial expressions compared with recognition of other objects; empirical studies showed that even children aged between 4 and 6 are sensitive to genuine smiles and fake smiles [63], [64].

Recently, state-of-the-art technologies of 3D graphics software, affect recognition, facial expression synthesis, and speech synthesis enable us to create more realistic virtual

[3] There have been many controversies regarding uncanny valley theory. For instance, J. Złotowski et al. [159] proposed that an uncanny valley is rather an uncanny cliff; the likeability of androids and robots increases by the complexity of design but decreases abruptly at some point.

faces that can be animated corresponding with viewers in real-time [65]. Real-time renderings of a face can be used not only as an avatar for the art project, virtual meeting, social networking, mobile device interface, or even shop assistant, it can also be used for academic experiments in the field of psychology or medical science. For instance, S. Boker et al. [66] used a motion-tracked synthesized avatar for their psychological studies to explore the correlation between motion dynamics and the judgment of sex; they synthesized the voice and the look of the avatar by motion-tracking one participant (A)'s face, and let his/her avatar have a conversation with the other participant (B). The experiment had an interesting result that 91.9% of the participants (B) rated the female avatars as female and male avatars as male, even in cases of the original participants (A) with the opposite sex. The result suggests the importance of a face to define its sex and personality.

As shown in Table 3, manual construction of a 3D virtual face consists of three steps: A. modeling, B. texture mapping, and C. texturing, lighting, & rendering. Figure 1 illustrates the process of 3D face construction.

In the field of 3D animation and game industries, artists have utilized 3D graphics software such as Maya, Max, or Blender to render virtual faces and facial expressions.3D modeling, painting, and texturing became more intuitive and instant to artistswith the introduction of digital sculpting and painting software such as Zbrush, Mudbox, and Sculptris

5.1 Modeling

There are two ways to create a 3D mesh: 3D scanning, and modeling. O. Alexander et al. [54] experimented with the hyper-realistic rendering of a face and facial expressions of the actor Emily using the techniques of 3D facial capture, character modeling, animation, and rendering. Emily's face was scanned in USC ICT's Light Stage 5 with 156 white LED lights turned on, for the estimation of diffuse color, specular shine, and surface normals. Even if 3D scanning enables us to obtain accurate coordinate information of points on the surface of a face, the processing and modification of points require considerable time and effort with current technology.

At this point, polygon modeling may be one of the most popular 3D geometry types for face modeling. Polygons are straight-sided shapes (3 or more sides), defined by "vertices" which has the three dimensional coordinate information of x,y,z [67]. The faces of a polygon model may consist of triangles, quadrilaterals, or Ngons, but a consistent quad polygon model is more preferred due to the smoother rendering of the edges; Ngon and triangles may produce a pinch during animation [4]. In the field of engineering, triangle polygon models are frequently used for facial expression synthesis for simpler calculation [68].

5.2 Texture Mapping

Texture mapping is a method to add surface texture. The most common method of texture mapping is UV texture map. By defining the U and V coordinates, the modeler adjusts how the 2D texture is wrapped around the surface of the model [4]. Most modeling software provides UV mapping tools including automatic UV mapping and/or manual UV mapping. There are also stand-alone applications for the creation and editing of a UV texture map such as UVLaygout [55].

In 2008, a new texture mapping method called Ptex was proposed by B. Burly et al. [56] from Walt Disney Animation Studios, for more instant and effective painting process on the 3D surface. Since Ptex stores a separate texture per quad face of the polygon model using a per-face adjancy map, it eliminated the UV mapping setup process that requires a considerable amount of time and effort. Disney Ptex library has been released as an open source under the BSD license [69], and later introduced in Mudbox 2012 [70]. Zbrush also has a similar painting method called Polypaint that allows painting without first assigning a texture map [57]. Unlike Ptex, Polypaint can be tranferred to a texture map later.

5.3 Coloring & Texturing

Multiple 2D texture maps including diffuse (color), specular (shine), transparency, bump, or normal maps can be used to create realistic or stylized color, texture, and reflection. The problem of the real-time computer graphics rendering is that it only processes the surface of an object based on light setting. In reality, light penetrates the surface of a translucent object, absorbed, scattered and re-emitted, which is called "surface scattering (SSS)." Especially, in the case of skin, only about 5-7% of the light incident is reflected back to the environment, and the remaining portion is scattered into internal tissues. Therefore, simulation of reflective-refractive scattering of skin surface and subsurface skin layers will enhance photo-realistic rendering of skin [4], [59], [60].

However, high-quality rendering of skin with SSS effects is still not popularly used in real-time face animations since large data of texture computation slows down computer performance. There has been much recent research to improve the performance of high-quality real-time rendering [59], [60] which will be accessible to general users in the near future.

6. Face and Facial Expression Construction Techniques

Facial expressions are made by the superficial layer of muscles which are connected from the periosteum or adjacent muscles to other facial muscles or connective tissue of the skin. Since they are directly attached to the skin, muscle movements move the facial skin as well [71]. Virtual and mechanical android faces simulate the face and facial expressions using various techniques. In Table 4, 9 project papers were compared to see which different techniques and methods they used in A) face construction, B) facial expression construction, and C) facial expression categorization. In addition, the techniques were analyzed to determine D) whether they enable communications between users and the face and E) the realistic quality of their final output.

[54], [61], [68], [72], [73], [74], [75] are 3D virtual face constructions. The robot face construction projects [76], [77], [78] were added to the list to compare how they differently categorize and create facial expressions.

TABLE 4
FACE AND FACIAL EXPRESSION CONSTRUCTION TECHNIQUE COMPARISONS.

	6.1 Face Construction		6.2 Facial Expression Construction			6.3 Facial Expression Categorization			
Ref.	automatic	manual	performance-driven (motion tracking)	muscle-based	blend shape-based	Emotion - based	Muscle-based	Facial Feature-based	vocal-based
[54]	3D scanning	✔ remeshing	✔		✔ 33			✔ 33 facial expressions	
[61]	3D scanning	remeshing	✔		✔ 22			✔ 22 facial expressions	
[72]	motion capture data + PIEES	Nurbs target face model	✔ 3D Marker -based		✔ 46	✔		✔	✔
[68]	Customization based on 2D	triangle mesh model	✔ 2D, 3D Marker less						
[7	Preset	Preset		✔			✔		

	9]	physics model	physics model				20 muscle contraction simulation	
	[74]	Customization based on 2D, Automatic model rigging	triangle mesh model + training data	✔ 46 points	✔ 23 linear muscles, 46 points	✔ 6 emotions x 16 models	✔ 23 linear muscles	
	[75]	Laser and MRI scans data	Triangle flash mesh, anatomical mesh model	✔ 79 markers	✔		✔ 32 muscles	
	[76]		mechanical frame + soft urethane facial skin.		✔ 19 CPs, 19 DOFs	✔ 6 expressions		✔ 14 Action Units
	[77]		mechanical frame + Sculptured facial skin		✔ 12 DOFs	✔ Smile-based expression		✔ 12 DOFs
Robot	[78]		mechanical frame with facial features		✔ 11 DOFs	✔ 10 emotions		✔ 11 DOFs

6.1 Face Construction

There two methods of face construction: automatic and manual constructions. Even though there have been many projects and research to automate the manual face construction to reduce the time, modeling of a base model and remeshing/adjusting process are still needed in many virtual face development projects [54], [61], [72], [68], [76], [79].

Works reported in [54] and [61] aimed to create realistic facial animation. Both works used 3D scanning technology to obtain high-resolution surface texture data. However, both require manual remeshing of high-resolution surface data to a lower-polygon mesh and normal maps. Both also use normal map blending technique for more realistic rendering of wrinkling in different facial expressions.

Other works [68], [72], [79], [74] predefined single-layer models and they they were then adjusted to the given face data such as facial images or motion captured data. Z. Deng et al. [72] customized nurbs target face model using motion capture data and PIEES system, while D. Sibbing et al. [68] reconstructed a triangle mesh model from different directions and a camera rig.

In works [79] and [75], anatomy-based multi-layered models including facial bones, muscles, and skin were created for physical simulation of facial expressions. L. Beldie et al. [79] made a finite element facial model based on patient specific bone and skin image data, and combined generic muscle data using the Simpleware package, which consists of three modules: +ScanCAD, ScanIP and +ScanFE. The purpose of the project is physical simulation of the maxillofacial surgery and physical simulation of facial expressions before and after the surgery for the purpose of planning and predicting the outcome.

E. Sifakis et al. [75] created their model from the volumetric data from the visible human data set [80], based on the techniques proposed in the work of J. Teran et al. [81]. J. Teran et al. used segmented version of the body data to create the arm muscle, tendon, and skeleton geometry for simulations. However, due to the facial muscles' thin and sophisticated structure, E. Sifakis et al. decided to create a single tetrahedral flesh mesh representing all the soft tissue in the face. Then the 32 muscles activations and bone kinematics were estimated automatically to match 79 motion capture markers.

Meanwhile, robot face constructions are still in their manual stage as prototypes. In [76] and [77] they created mechanical frames and covered soft facial skin, sculpted and casted by artists. In the work of C. Breazeal et al. [78], a frame and movable facial features, such as eyes, mouth, and ears, were used but without facial skin, as a prototype robot. A robot face creation requires good manual and artistic skills to simulate the look and structure of a face.

6.2 Facial expression creation techniques

There are four different techniques to create facial expressions: a) performance driven, b) anatomy-based, c) blend shape based.

a. Performance driven facial animation

Performance driven facial animation focuses on the surface changes of the performer's face. There are two techniques that are used in this approach, namely, 1) 3D scanning and 2) motion tracking.

First, 3D scanning captures the surface coordinates and texture of a performer’s face with different expressions, it can achieve the realistic rendering of facial expressions. The main drawback of this technique is, however, a large amount of data involved, which decreases the processing speed. O. Alexander et al. [54] explored 3D scanning technique for photo-realistic 3D facial animation; 33 different expressions of actor Emily were scanned, remeshed from several million polygon mesh to 4000-polygon mesh, and blandshped. The geometric details lost from the remeshing process were added back later using displacement maps created from high-resolution scans [13]. Regardless of its photo-realistic result, 3D scanning needs a considerable amount of time and effort for manual remeshing and remapping.

Second, the motion capture technique enables real-time rendering of dynamic facial expressions. There is a limit of this technique; it only captures the position changes of markers on the skin surface, not the detailed surface changes such as wrinkles and creases. O. Alexander et al. [54] and K. Y. Liu [61] suggested the technique combining blend shape and maker-based motion capture to enhance thte realistic quality of facial animation. While Z. Deng et al. [72] used the marker-based motion capture technique, D. Sibbing [68] used markerless motion tracking techniques from 2D images to a 3D mesh.

b. Anatomy-based

Anatomy-based facial animations create facial expressions by physically simulating a multi-layered facial model's movements, including skin, muscle, and skeletal structures. Previous works [79], [74], [75] used multi-layered models for facial animations. In 3D computer graphics, blend shapes and performance driven facial animations are more commonly used for facial animations. Physics-based facial animation is still a challenging task due to the complicated structures and physics of facial movements. Many simulation-based facial animations were developed, for the purpose of planning and predicting facial surgery results [79].

Regarding humanoid face construction, in work such as those reported in [76], [77], and [78], action units (AUs) were often used to create a realistic face and facial expressions. AUs were originally reported in [82] as the Facial Action Coding System, and it was customized and modified by other researchers. In work reported by [83], the action unit system was adapted to physically simulate a silicon rubber synthetic skin.

c. Blend shape-based

Blend shapes, the animation technique used to morph more than two meshes, was frequently used in facial animation [67]. Blend shapes require multiple models with different facial expressions, which preserve the same number of vertices. In [54] and [61], blend shapes were used with 3D scanning. Both remeshed the high-polygon scanned data into lower-polygon mesh, and blend shaped meshes and normal maps for the realistic surface wrinkling. O. Alexander et al. [54] blended 33, K. Y. Liu et al. [61] did 22, and Z. Deng et al. [72] did 46 different facial expressions.

6.3 Facial Expression Categorization

C. Landis [82] categorized expressions to social and emotional expressions. Social expressions can be considered as signs such as languages to communicate with each other. Meanwhile, Emotional expressions signify the person's feelings consciously and unconsciously. There is controversy about how to categorize emotions of facial expressions. Facial expressions can be categorized by words denoting emotions such as despair, love, joy, grief, anger, fear, or ecstasy. However, not all facial expressions correspond to these conventional words of emotions. In addition, there is controversy about what words and what language we choose and how these factors would affect the categorizations [32].

Cultural differences in reading facial expressions needs to be also examined to enable in-depth communication between a virtual character and a viewer. Many psychological studies have confirmed that there is a sort of universal reading on basic facial expressions, but subtle differences were found in different cultures. For instance, P. Ekman et al. [83] showed facial photographs of six different facial expressions: anger, disgust, fear, happiness, sadness, and surprise to the participants from five different countries including USA, Japan, Brazil, Chile, and Argentina. The result showed the universality of emotion processing among those countries. Yet the study itself has problematic aspects since 1) the images they used was limited to a specific race, 2) research subjects were limited to developed or modernized countries, and 3) the expressions were limited to six basic emotions; more subtle emotions may not be processed in exact same ways in different cultures.

In virtual and android face development projects, four different categorizations of facial expressions have been used a) emotion-based, b) muscle-based, c) facial feature-based, and d) vocal based. In the field of psychology, neuropsychology, and computer visualization of facial expression animation, 6 basic emotions are popularly used: joy, sadness, anger, fear, disgust, surprise [84]. However, for the rendering of more subtle expressions, muscle-based categorization [85] or the motion-captured data of the surface movement [54], [61] have been explored. While muscle-based categorization focuses on which muscles activate certain facial expressions [79], [74], [75], facial-feature based categorization focuses on the changing shapes of facial features such as eyes, a nose, and lips. Meanwhile, Z. Deng et al. [72] animated a face based on voice.

7. Conclusion

This chapter introduced anatomical studies, psychological theories of face recognition, and state-of-the-art facial construction projects from various fields. As shown in Table 4, since there are not enough anatomical books written specifically for the construction of an anatomical face, references from various fields including medical science and art were overviewed. The principal lines of force of the facial skeletons define overall arrangements, angles, and ratios of a face that varies in different races, genders, and individuals. There are twenty facial expression muscles inserted to the subcutaneous fat or other muscles enabling the movement of different areas of facial skin.

Psychological theories of facial recognition are beneficial when creating more sympathetic facial models and expressions. V. Bruce and A. Young suggested a face includes seven different types of information (or codes) including pictorial, structural, identity-specific semantic, visually derived semantic, name, expression and facial speech codes. T. Valentine suggested that a face is stored in the human's memory based on the values on the facial dimensions, while proposing his multidimensional face space model. Theories such as configural and featural face processing, as well as pictorial codes and structural codes of face processing, are related to the portrait-making process of artists, since it also requires the anatomical, structural, cultural, and pictorial information on a face.

The factors of attractive faces are suggested: averageness, symmetry, sexual dimorphism, neotony, and skin condition. However, the empirical results often differ from each other due to the methodical errors or limits of experiment object models. Furthermore, there are many controversies when defining beauty since the norm of beauty changes over time and varies by geography, race, culture, and individual [36], [86], [87], [88], [89], [90], [91], [92]. Also, the aesthetics of pictorial values should not be underestimated.

Finally, the techniques of facial modeling and animation were overviewed including 3D virtual and android face constructions. This cross-disciplinary research is adapted to the sympathetic face customization and action model discussed in Chapter 2 and 3.

II. BEZIER CURVE-BASED 3D FACIAL CUSTOMIZATION

1. *Introduction*

Facial models were proposed as powerful media enabling affective communication between humans and a human-computer interface (HCI) [93], [94], [95], [96], [97], [98], [99]. In addition, customization of facial models is crucial in terms of affective engagement with the face model since each individual has different preferences and familiarity with certain facial types and features constructed by his/her own experience, culture, background, and taste [36]. In this paper, we propose an intuitive, cost-effective, yet realistic 3D facial customization model for real-time interaction between the viewers and the facial action/emotion database [96], [100], [101], [102] and face robots [76], [77], [78]. As works reported in [103], [104] show, 3D models were found to be more effective in terms of real-time fitting, due to more compact, natural, and accurate parameterization, in comparison with 2D models.

The 3D scanning and blend shape techniques have been used for realistic facial modeling and customization, yet they have several weakness. The 3D scanning requires expensive devices and live performers. The facial models are therefore limited to the live models' faces and facial expression data. That means that 3D scanned facial models are limited to specific gender, race, and age groups and as a consequence they may not appeal to other viewers [105]. In addition, it takes a large amount of time and manual work to refine a large volume of raw data. The blend shape technique is popular techniques in facial customization programs such as Facegen [1] and Facial Studio [2], since it is intuitive and relatively easy to use. However, it is limited in variations of facial models and expressions and unrealistic for facial wrinkling and deformation of the model, especially when blending more than two facial models or expressions.

Based on the anatomical studies, we propose Bezier Curve-based 3D Facial Customization (BCFC). The BCFC model achieves realistic accuracy by the adaption of the Bezier curves-based anatomical measurement system. BCFC aims to morph a base face (skin layer) into a variety of faces with different genders, race, ages, and degrees of fat content. The lines from different layers of the anatomical structure: skeleton, muscle, fat, and skin surface are extracted to customize the face. BCFC model consists of three different types of lines: Principal Line of Force (PLoF) extracted from the facial skeleton, Facial Feature Line (FFL) extracted from facial features, and Fat/Wrinkle Line (FL) extracted from wrinkle lines and fat storage areas. I and S. Park analyzed anthropometric data of faces, reported in [106], [107], of different genders, races, ages, and degrees of fat and extracted specific patterns to adapt this information to our line-based customization system, which is described in detail in Section 3.

This research contributes to more affective human-computer interaction by enhancing realistic quality and cost-effectiveness of the Avatar, based on in-depth understanding of anatomical facial structures and movements, as illustrated in medical science and art textbooks [3], [6]. In comparison to surface-focused approaches such as 3D motion capturing, scanning, or blend shapes, our customization model achieves realistic accuracy by the adaption of the Bezier curves-based anatomical measurement system, rather than Cartesian coordinates-based measurement of facial features. The designed system is cost-effective since it does not require live models or 3D scanning/tracking devices.

The remainder of the chapter is organized as follows: Related Studies are covered in Section 2, and the BCFC model is introduced in Section 4. The evaluation of our system is in Section 5, and I end with conclusions in Section 6.

2. Related Studies

This section discuss on related works including virtual face animations and HCI models. In Table 5, 16 models, including facial animations [54], [61], [68], [72], [74], [75], [79], [85], [108], [109], [110] and human-computer interface models [95], [100], [111], [112], [113] were examined in terms of facial modeling. There are four 3D virtual modeling techniques: 3D scanning, remeshing of raw data, predefined single-layer model, and multi-layered anatomical model.

TABLE 5
FACIAL MODELING TECHNIQUES

Construction of Categories	Techniques
Virtual Facial Modeling	3D scanning [54], [108], [61], [111]
	Remeshing of Raw Data [54], [61], [111]
	Predefined single-layer model [68], [72], [110]
	Multi-layered anatomical model [75], [79], [85], [108], [109]

Works reported in [54], [108], [61] aimed to create realistic facial animation by using 3D scanning technology to obtain high-resolution surface texture data. Both used normal map blending technique for more realistic rendering of wrinkling in different facial expressions. Regardless of their realistic results, 3D scanning has limits due to the requirement of expensive devices and live performers. The facial models are therefore limited to the live models' faces and facial expression data. That means that 3D scanned facial models are limited to specific gender, race, and age groups and as a consequence they may not appeal to other viewers [105]. In addition, they require manual remeshing of a large volume of high-resolution surface data to a lower-polygon mesh and normal maps, which takes a large amount of time and effort.

Instead of using 3D scanning, we create the predefined single-layer model for the customization of the skin mesh as shown in previous works [68], [72], [75]. The base model was modeled and then adjusted to the given face data, such as motion capture data or photographs. Z. Deng et al. [72] customized NURBS [114] target face model using motion capture data and the PIEES system. Meanwhile, D. Sibbing et al. [68] reconstructed a triangle mesh model from different directions and a camera rig. However, performance-driven data also requires processing of raw data and errors. Therefore, we use anatomy-driven curves for users' more intuitive and effective manipulation.

For facial action which will be introduced in Chapter 4, we design the multi-layered anatomical models to enable physical simulation for facial expressions, as used in previous works [75], [79], [85], [108], [109], Y. Zhang et al. [85] and K. Kähler et al. [109] used spring systems to simulate the soft tissue of the multi-layered anatomical model. However, the models lack their realistic qualities since they used low-polygon models for effective manipulation. Works reported in [79], [108] used live models' 3D data to clone them, which achieved the realistic qualities, yet they are not cost-effective due to the process of a large volume of raw data. Our model aims to overcome their limits by achieving both realistic qualities and reduction of the process by designing a novel facial action system.

3. *Bezier curve-based 3D facial customization (BCFC)*

3.1 Facial Lines for Customization

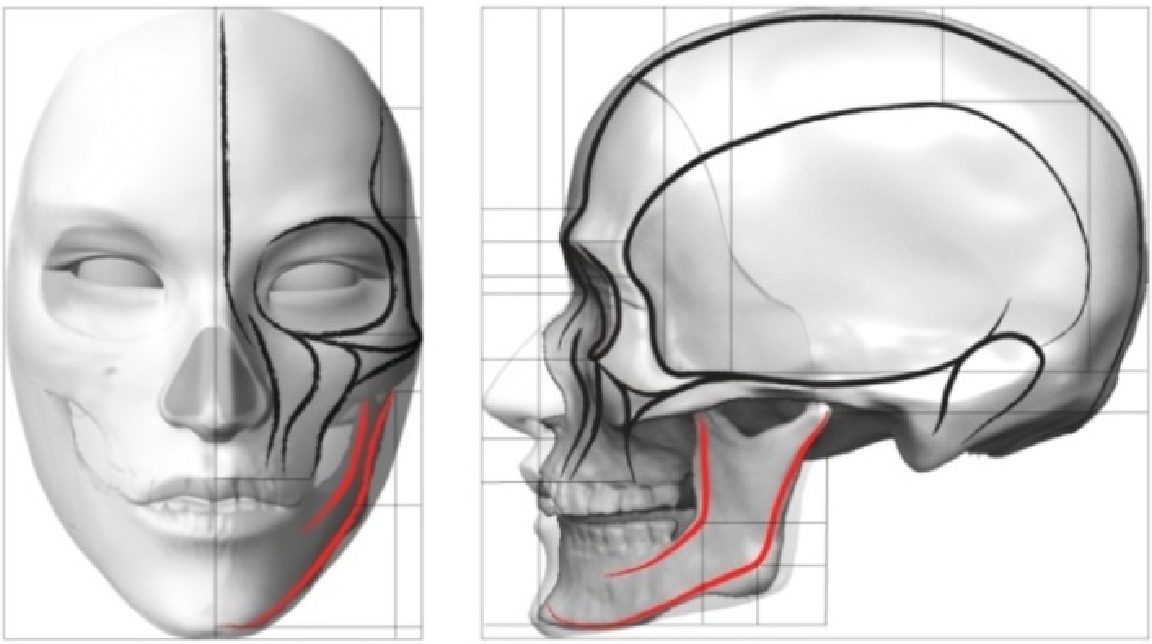
For facial modeling and its customization, we propose the three facial lines system: Principal Line of Force (PLoF) for bone structures, Facial Feature Line (FFL), and Fat/Wrinkle Line (FL). PLoFs, FFLs, and FLs are drawn using Bezier curves that are frequently used in computer graphics, which are defined in equation (1).

$$B(t)=\sum_{i=0}^{n}\binom{n}{i}(1-t)^{n-i}t^{i}P_i\,,\quad t\in[0,1]$$

(1)

where n is the number of *control points* on the curve $B(t)$ and P_i is coordination of the *control point*. t is between 0 and 1 and the Bezier curve goes from P_0 to P_n, according to values of t. There are different numbers of *control points* for PLoFs and FFLs, but all lines for FL have just four *control points*.

a. Principal Lines of Force (PLoFs)

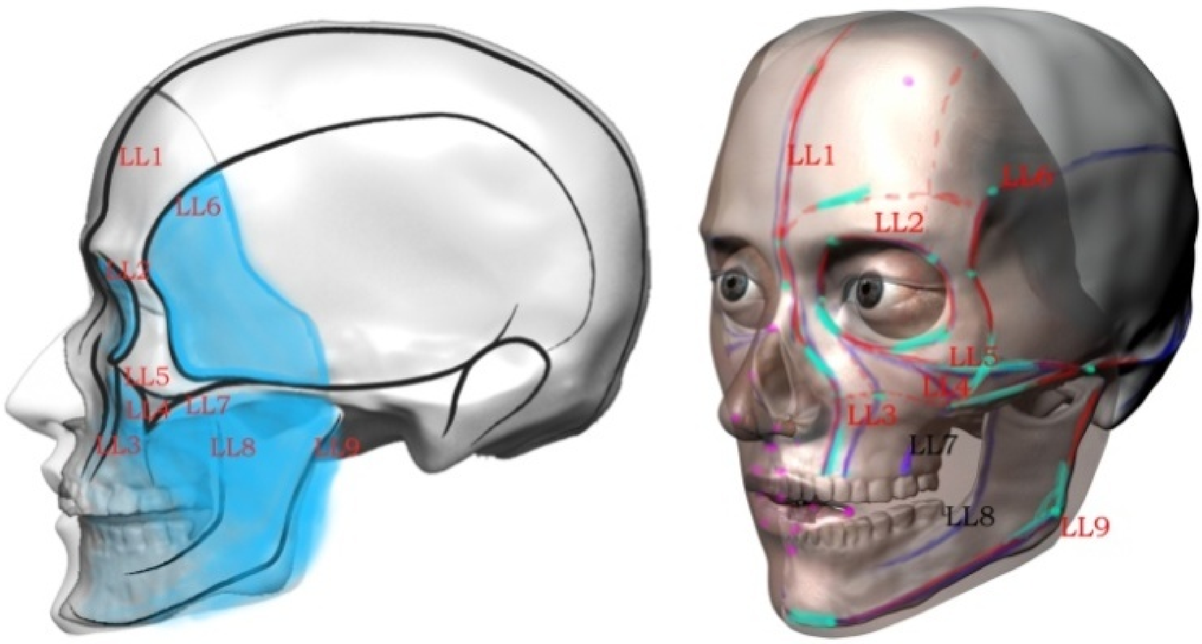


(a) Front view. (b) Side view

Fig. 9. PLoFs in the facial skeleton. (a) Front and (b) side faces overlapped with its facial skeleton.

Fig. 9 represents Principal lines of force in the facial skeleton, which are sometimes compared to the columns of a house [3]. We make a 3D facial skeleton model from visual inspection of the orthographic illustrations of a facial skeleton, by measuring proportions and angles of each part, which are described in medical [3] and art [6] textbooks. In Fig. 9, the proportion of width and height is calculated based on the horizontal and vertical guidelines drawn on the autographic views of the head. Then we adapt PLoFs introduced in [22] by drawing original PLoFs on the rendered images of top and side views of the 3D face-head contour. In Fig. 9, the black lines refer to the PLoFs on the skull, and red lines to the PLoFs on the mandible.

Among 18 PLoFs, we select the ones that have stronger “salient effects” for more efficient customization of facial skeletons. As illustrated in Fig. 10 (a), while the PLoFs on the skull (black lines) are relatively prominent, regardless of age and weight, the PLoFs on the mandible (red lines) are less prominent due to the development of muscles and fat. The thick area of muscles and fat is marked with light blue tone that decreases in saliency as it covers the PLoFs.



(a) PLoFs covered by muscles. (b) Decomposition of PLoF

Fig. 10 (a) Black lines represent prominent PLoFs in the facial skeleton. The arrangements, angles and ratios of these lines define the basic form of a face for different sexes and races. The lower part of LL8 and all of LL9 are hidden by facial muscles and fat, and are therefore usually unnoticeable.

In Fig. 10 (b), nine PLoFs on each side of the face are evaluated by the degree of saliency for the facial model. Red lines are the modified PLoFs, and green lines show salient angels of the PLoFs. LL8 is excluded from the salient PLoF since LL8 is hidden by muscles and fat. LL3 is also excluded since the angle overlaps with LL1 and LL2.

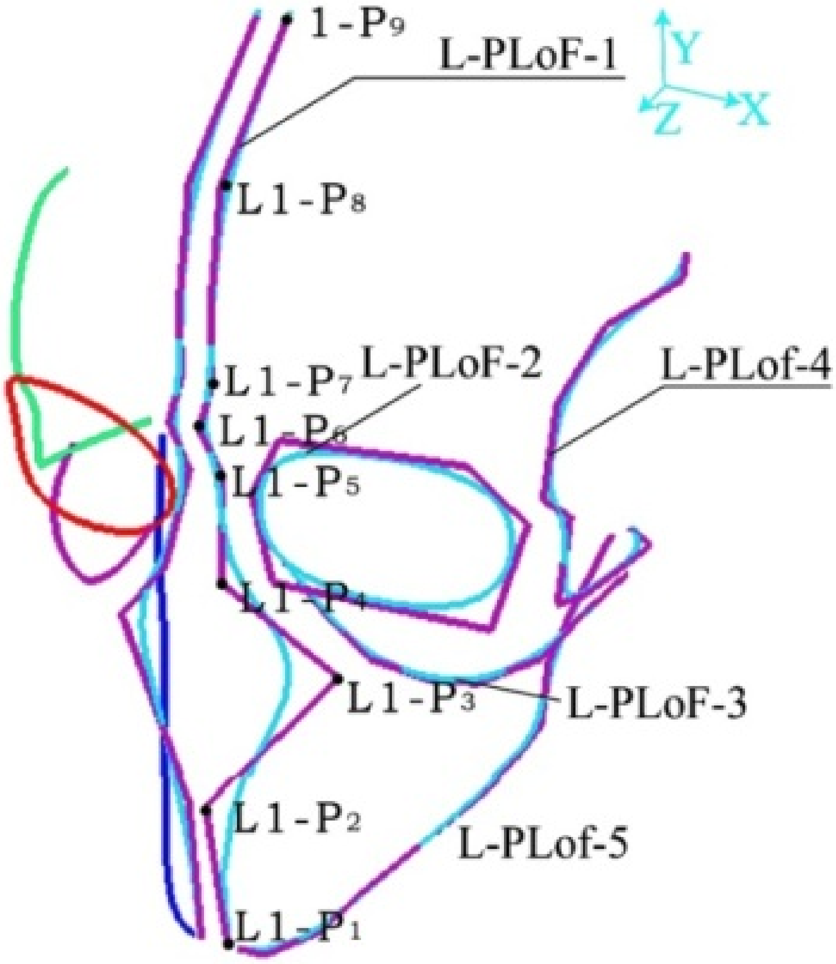


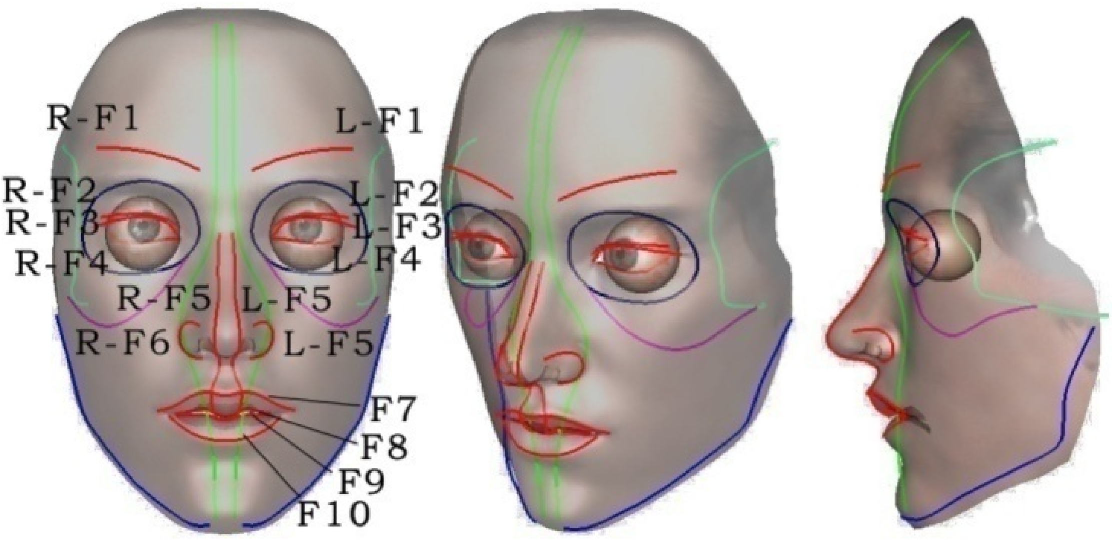
Fig. 11. 5 Salient PLoF (light blue lines) created in 3D space using cubic Bezier's curves. Pink lines represent lines connecting points that determine a curve between two anchors.

The saliency of the upper face is defined by these relationships: 1) less amount of muscle relevant to PLoF, and 2) the accumulated number of angle changes across the PLoF. The most salient feature, for example, is the one with the least amount of muscle relevant to the PLoF and with the large number of angle changes across PLoF.

Using these two proposed above two saliency criteria, eight PLoFs in Fig. 10 are redefined as five Salient PLoFs in Fig 11, and then converted to 3D cubic Bezier's curves in 3D graphic software, based on 2D Bezier curves of PLoF from orthographic views of a facial skeleton in Fig. 9. Light blue lines in Fig. 11 represent salient PLoFs. Pink lines represent lines connecting vertex points that determine a curve between two anchors. LL1 and LL3 from Fig. 10 (a) are merged into the salient PLoF-1, LL2 is marked as PLoF-2, LL4 through LL7 are merged into the salient PLoF-3, and LL8 and LL9 into PLoF-3.

The PLoFs were created based on the following equation of cubic Bezier's curve. The curve starts at $\mathbf{p}_1$ and moves towards $\mathbf{p}_2$ before it arcs toward $\mathbf{p}_4$ by way of $\mathbf{p}_3$. Each PLoF is tagged as R- (right) and L- (left) and numbered. Each point in a PLoF is tagged with numbers, right or left, and the PLoF number for future customization, like changing the coordinates of each point. For instance, the first point in PLoF-1 on the right side of a face is marked as RL1-P_1.

b. Facial Feature Line (FFL)

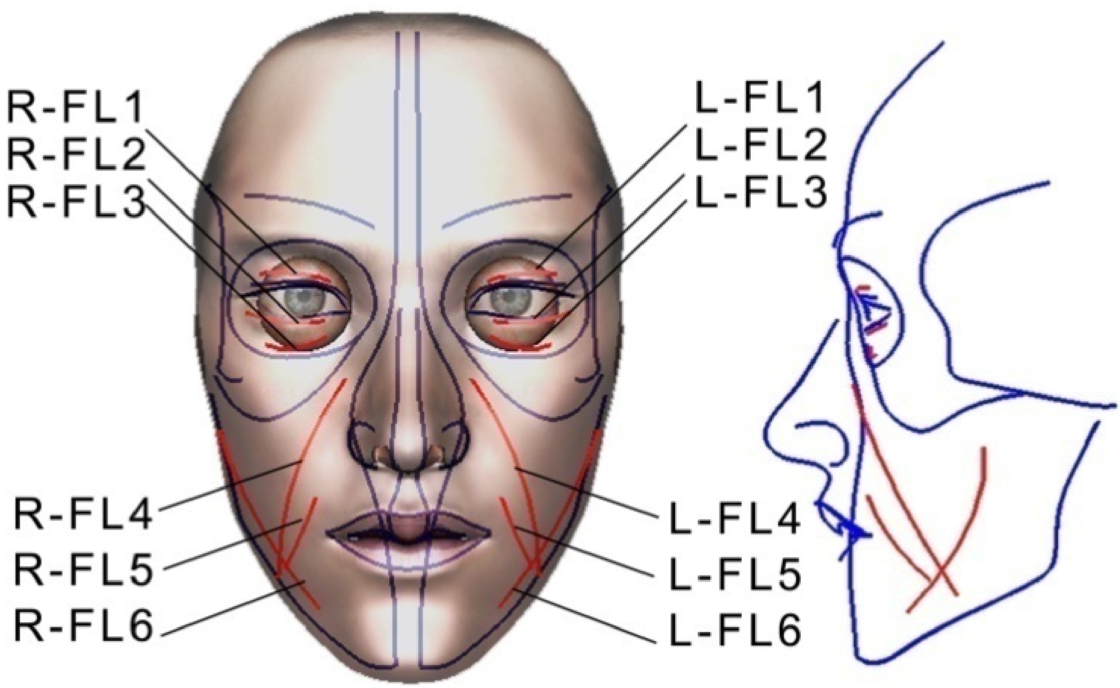


(a) front view (b) tilt view (c) side view

Fig. 12. Facial feature lines (red lines). Facial feature lines (FFLs) are added to the facial model with the PLoFs.

Since facial features are formed by muscles and skin tissue, additional lines are required to morph facial features. We propose Facial Feature Lines (FFL) that are extracted from the facial surface to customize facial features. In Fig. 12, FFL Bezier curves (red lines) are added to the facial model and the affected area of each curve is determined. F1 is added to customize the prominence of the eyebrow area. F2 (crease on the upper eyelid), F3 (upper eyelid), and F4 (lower eyelid) are added for eye customization. F5 (profile shape of nose) and F6 (nose wing) are added for nose customization. For lip customization, F7(top upper lip), F8 (bottom upper lip), F9 (top lower lip), and F10 (bottom lower lip) are added.

c. Fat/Wrinkle Line (FL)



(a) Front view (b) side view

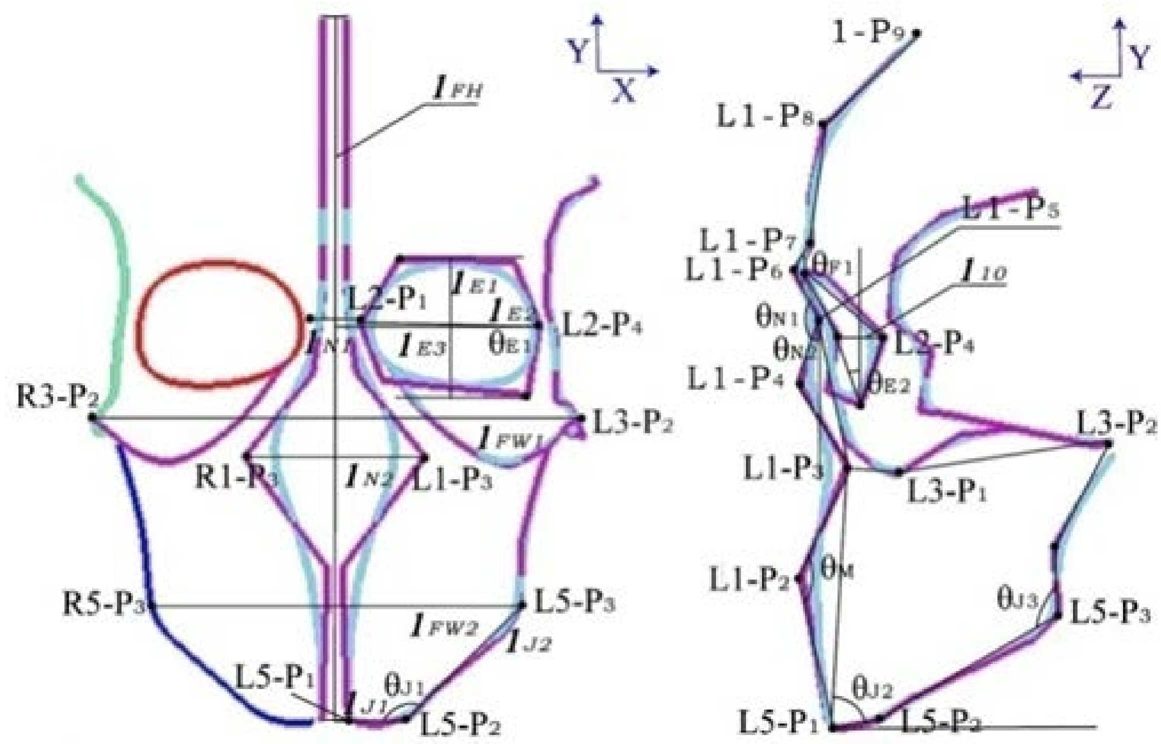
Fig. 13. .Fat/Wrinkle Lines (red); (a) front view, (b) side view

As the third extension, Fat/Wrinkle lines (FL) are added for the manipulation of fat on the face. PLoF and FFL are constraints that hold the structure of a face in place. In Fig. 13, 6 FL were added to each side of the face: upper eyelid, lower eye lid, eye bag, nasolabial fold, marionette line, and jaw bone area. The convexity of FL determines the degree of fat. If the convexity of FL increases, the fat amount of each area also increases. Additional lines can be added for more detailed manipulation of fat. FL can be described as the fourth-order polynomial, equation (2), since all lines of FL have four control points.

$$B(t) = (1-t)^3 P_0 + 3(1-t)^2 t P_1 + 3(1-t) t^2 P_2 + t^3 P_3 , \quad t \in [0,1] \tag{2}$$

where P_0,P_1, P_2, and P_3 correspond to control points, and Bezier curves FL go from P_0 to P_3 depending on the value of t.

The face customization is required to meet wide variations of the human anatomy, such as different gender, race, fat, and age characteristics, for adjustments of the base face. In this step, we customize salient PLoFs by manipulating points in the PLoFs for the following two enhancements: modification of PLoFs for different genders (male/female) and variation for different races. We propose a new method to calculate cranial anthropometric facial data by measuring angles and length between the salient points on the PLoFs.



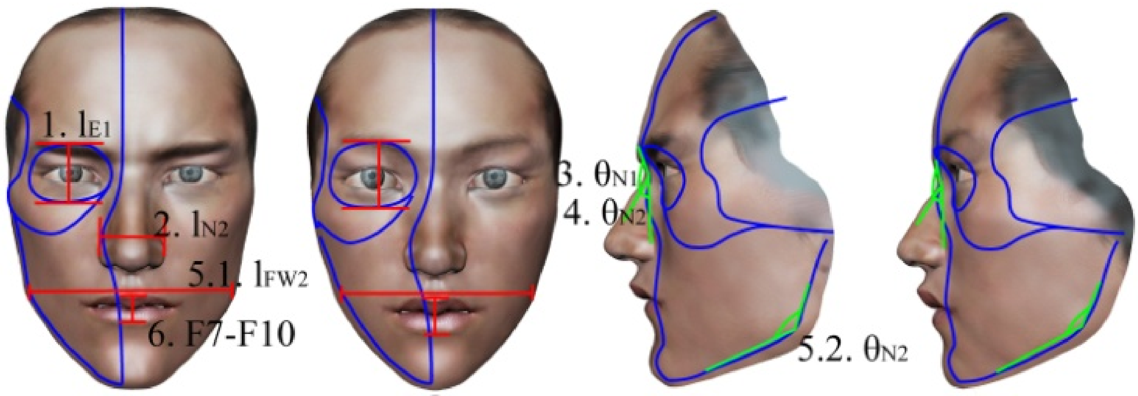
(a) (b)

Fig. 14. Salient PLoFs: (a) front view and (b) side view.

In Fig. 14, length (l) and angle (θ) of salient points in the PLoFs are measured from the orthographic views of salient PLoFs: (a) front view and (b) side view. In (a), l_{FH} and l_{FW1} define the overall ratio of the face. l_{E1}, l_{E2}, θ_{E1}, and θ_{E2} define shapes of the eye area. l_{N2} defines the width of the nose. θ_{J1}, θ_{J2}, θ_{J3} and l_{FW2} define the development of the jaw. In (b), coordinate changes from L1-P1 to L1-P9 define the profile contour of the face. θ_{E2}, θ_M, and θ_{J2} are important factors for customization of different races. θ_{J3} and l_{FW2} define development of the jaw, which is an important factor for gender customization; lowering θ_{J3} increases the masculinity of a face.

We came up with the following four extensions for customization corresponding to the following four subsections, as described below. One side of the face is customized and the other side is duplicated with coordinates X reversed, which may be adjusted separately for asymmetrical faces.

3.2 Gender Customization



(a) (b) (c)
(d)

Fig. 15. Gender customized faces: (a) Male front view, (b) Female front view, (c) Male side view, and (d) Female side view. While male facial features are increased in (a) and (c) such as bigger nose, more prominent supraorbital arch, and more developed jaw bones, female features are increased in (b) and (c) such as smaller nose, more smooth facial line from the forehead to the nose, and more oval face.

As the first extension, salient PLoFs are modified with different ratios and angles to create faces representing two distinct genders. Fig. 15 illustrates facial models of different sexes customized by our modification of the PLoFs attached to the default face: (a) front view of a male face, (b) front view of a female face, (c) side view of a male face, and (d) side view of a female face. While the masculinized model shown in (a) and (c) has male features such as a bigger nose, more prominent supraorbital arches, and a more developed jaw bone, the feminized model, shown in (b) and (d), has female features such as a smaller nose, a more smooth facial line from the forehead to the nose, and a more oval face. Faces shown in

Fig. 15 are adjusted by PLoF curves attached to the base face. The factors determining the sex can be defined as a facial feature vector described by equation (3)

$$\mathbf{g} = (l_{N2}, \theta_{N1}, \theta_{N2}, l_{FW2}, \theta_{J3}) \tag{3}$$

TABLE 6
AVERAGE FACIAL MEASUREMENTS OF MALE AND FEMALE FACES

Gender	l_{N2}	θ_{N1}	θ_{N2}	l_{FW2}	θ_{J3}
Male ($\mathbf{g}_M$)	**14.38**	130.5	**30.4**	**40.07**	128.83
Female ($\mathbf{g}_F$)	13.79	**134.3**	29.9	39.95	**132.65**

Bolded characters indicate higher values for each parameter that determines the gender: l_{N2}, θ_{N1}, θ_{N2}, l_{FW2}, *or* θ_{J3}.

where l_{N2} is the width of the nose, and θ_{N1} formed by L1-P4, L1-P5, and L1-P6 in PLoF-1 is an angle between a supraorbital arch and a nasal bone, θ_{N2} is an angle of the profile shape of a nose adjusted by moving L1-P4 and L1-P5 toward the Z axis. l_{FW2} and θ_{J3} are the width and the angle of the jawbone, respectively. These numerical values forming vector **g** are sizes when the overall length of a face is “100”.

The values in Table 6 are average facial measurements of male ($\mathbf{g}_M$) and female ($\mathbf{g}_F$) faces calculated using anthropometric data [41], [42]. The closer the values of **g** in (3) are to the measurements of $\boldsymbol{g}_M$, the bigger the musculinity of the face. Conversely, , if the values of **g** are closer to those of $\mathbf{g}_F$ it increases the femininity.

The probability, using Euclidean distance, of the facial muscularity P_M based on anthropometric measurements is formulated in equation (4):

$$P_M = 1 - \frac{d(\mathbf{g}, \mathbf{g}_M)}{d(\mathbf{g}, \mathbf{g}_M) + d(\mathbf{g}, \mathbf{g}_F)} \tag{4}$$

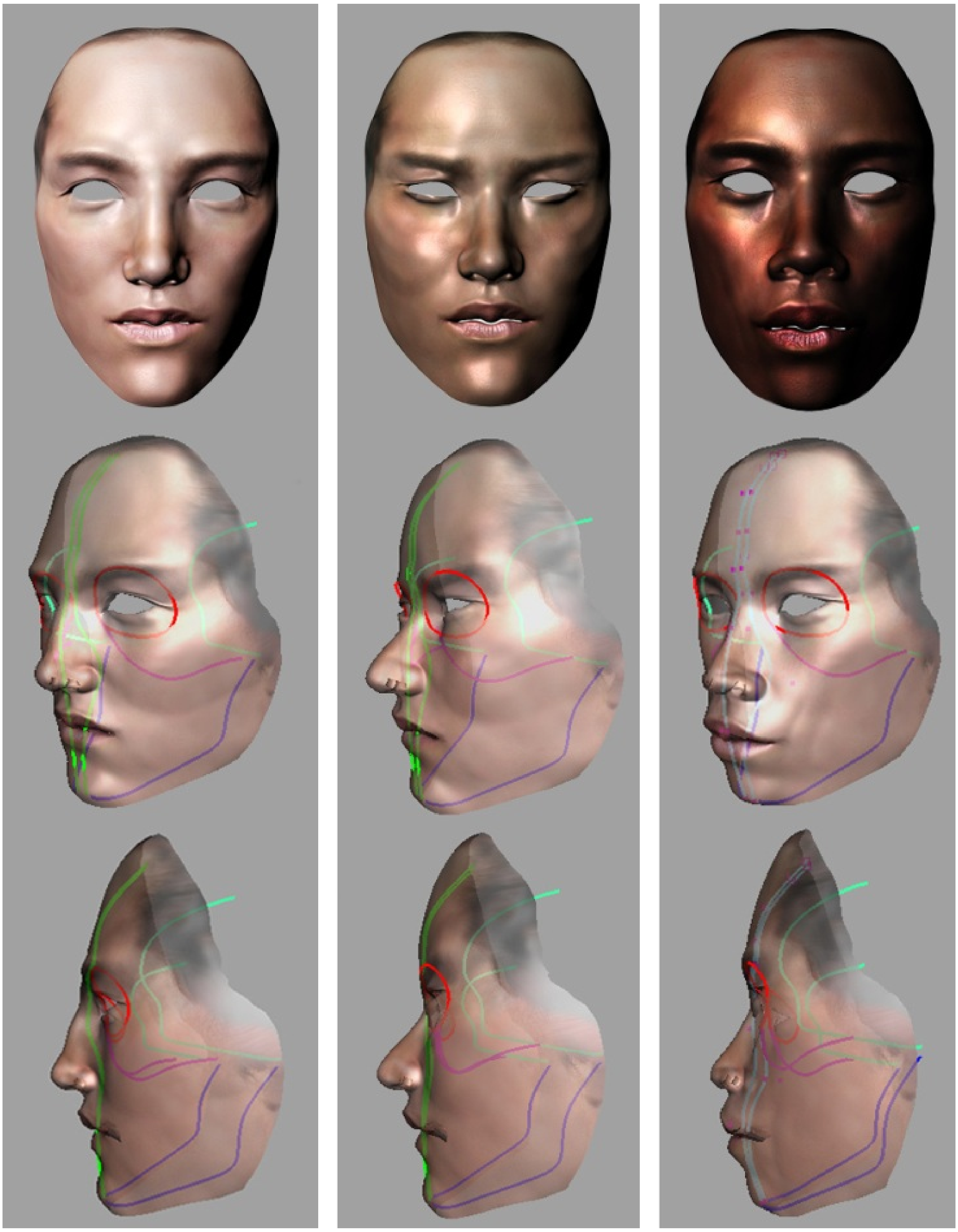
where $d(\mathbf{g}, \mathbf{g}_M)$ and $d(\mathbf{g}, \mathbf{g}_F)$ are Euclidean distances between $\mathbf{g}$ and $\mathbf{g}_M$, and $\mathbf{g}$ and $\mathbf{g}_F$, respectively. P_M value closer to “1” indicates increased masculinityof a face, while P_M closer to “0” indicates increase of femininity.

As shown in Table 6, the base face is masculinized by adjusting the following features:

1. Increasing the width of the nose: an increase of l_{N2}.
2. Dramatizing the supraorbital arch: a decrease of θ_{N1}.
3. Elevating the bridge of the nose: an increase of θ_{N2}.
4. Developing the jaw: an increase l_{FW2} and a decrease ofθ_{J3}.

Similarly, femininity of a face increases when the fourfeatures are adjusted in the opposite direction.

3.3 Racial Customization



(a) (b)

(c)

Fig. 16. Face customization of three different races: (a) Western. (b) Asian. (c) African. A base face with PLoF curves can be customized into (a), (b), and (c) by the manipulation of PLoF curves.

As the second extension, a face model can be modified to depict different races. We customize salient PLoFs attached to a default model to create three faces with distinctively different races: (a) Western, (b) Asian, and (c) African. The default face with PLoF curves attached can be customized into Fig. 16 (a), (b), and (c) by manipulation of PLoF curves.

The key factors for racial customization are overall angle of the face in profile, shape of the eye areas, size of the nose, and protrusion of the mouth. These factors can be described as a facial feature vector regarding race as follows:

$$\mathbf{r} = \left(\theta_{J2}, l_{E2}, l_{N2}, \theta_{N1}, \theta_{N2}\right) \tag{5}$$

where θ_{J2} defines the angle of the profile and has an influence on an angle of protrusion of the mouth. l_{E2} and l_{N2} are respectively widths of the eye area and the nose, θ_{N1} formed by L1-P4, L1-P5, and L1-P6 in PLoF-1 is an angle between a supraorbital arch and a nasal bone, and θ_{N2} is an angle of the profile shape of nose, which can be adjusted by moving L1-P4 and L1-P5 toward the Z axis. As in (3), numerical values forming **r** in (5) are sizes when the overall length of a face is “100”.

TABLE 7

AVERAGE FACIAL MEASUREMENTS OF WESTERN, ASIAN AND AFRICAN FACES

Race	θ_{J2}	l_{E2}	l_{N2}	θ_{N1}	θ_{N2}
Western ($\mathbf{r}_W$)	66.73	13.32	14.38	130.5	30.4
Asian ($\mathbf{r}_{As}$)	88.13	11.64	14.49	134.5	27.7
African ($\mathbf{r}_{Af}$)	**90.63**	**13.54**	**18.14**	**135.6**	**37.7**

Bold measurements present bigger values for each factor influencing racial features: θ_{J2}, l_{E2}, l_{N2}, θ_{N1}, *or* θ_{N2}.

Table 7 shows calculated average facial measurements of Western ($\mathbf{r}_W$), Asian ($\mathbf{r}_{As}$), and African ($\mathbf{r}_{Af}$) faces based on anthropometric data [41], [42]. The racial category of the target face is determined by the degree of approximation to $\mathbf{r}_W$, $\mathbf{r}_{As}$, or $\mathbf{r}_{Af}$.

The probabilities using Euclidean distance for the racial customization considering anthropometric data are expressed as

$$P_W = 1 - \frac{d(\mathbf{r}, \mathbf{r}_W)}{d(\mathbf{r}, \mathbf{r}_W) + d(\mathbf{r}, \mathbf{r}_{As}) + d(\mathbf{r}, \mathbf{r}_{Af})} \qquad (6)$$

$$P_{As} = 1 - \frac{d(\mathbf{r}, \mathbf{r}_{As})}{d(\mathbf{r}, \mathbf{r}_W) + d(\mathbf{r}, \mathbf{r}_{As}) + d(\mathbf{r}, \mathbf{r}_{Af})} \qquad (7)$$

$$P_{Af} = 1 - \frac{d(\mathbf{r}, \mathbf{r}_{Af})}{d(\mathbf{r}, \mathbf{r}_W) + d(\mathbf{r}, \mathbf{r}_{As}) + d(\mathbf{r}, \mathbf{r}_{Af})} \qquad (8)$$

Where $d(\mathbf{r}, \mathbf{r}_W)$, $d(\mathbf{r}, \mathbf{r}_{As})$, and $d(\mathbf{r}, \mathbf{r}_{Af})$ are Euclidean distances between $\mathbf{r}$ and $\mathbf{r}_W$, between $\mathbf{r}$ and $\mathbf{r}_{As}$, and between $\mathbf{r}$ and $\mathbf{r}_{Af}$, respectively. As the probability P_W in (6), P_{As} in (7), or P_{Af} in (8) are closer to 1, the face has more similarities to a Western, Asian, or African face, respectively.

As shown in Table 7, the base face is customized for each race by adjusting following features:

1. For Western faces, decreasing the protrusion of the mouth, the width of the nose, and the angle between the supraorbital arch and a nasal bone: decreases of θ_{J2}, l_{N2}, and θ_{N1}.
2. For Asian faces, decreasing the width of the eye area and the angle of the nose in profile: decreases of l_{E2} and θ_{N2}.
3. For African faces, increasing the protrusion of the mouth, the width of the eye area and the nose, the angle between a supraorbital arch and the nasal bone, and the bridge of the nose: increases of θ_{J2}, l_{E2}, l_{N2}, θ_{N1}, and θ_{N2}.

3.4 Fat and Aging Customization

As the third extension, Fat/Wrinkle lines (FL) are added to adjust the degree of fat and aging of the face. PLoFs and FFLs maintain the structure of the face as constraints.

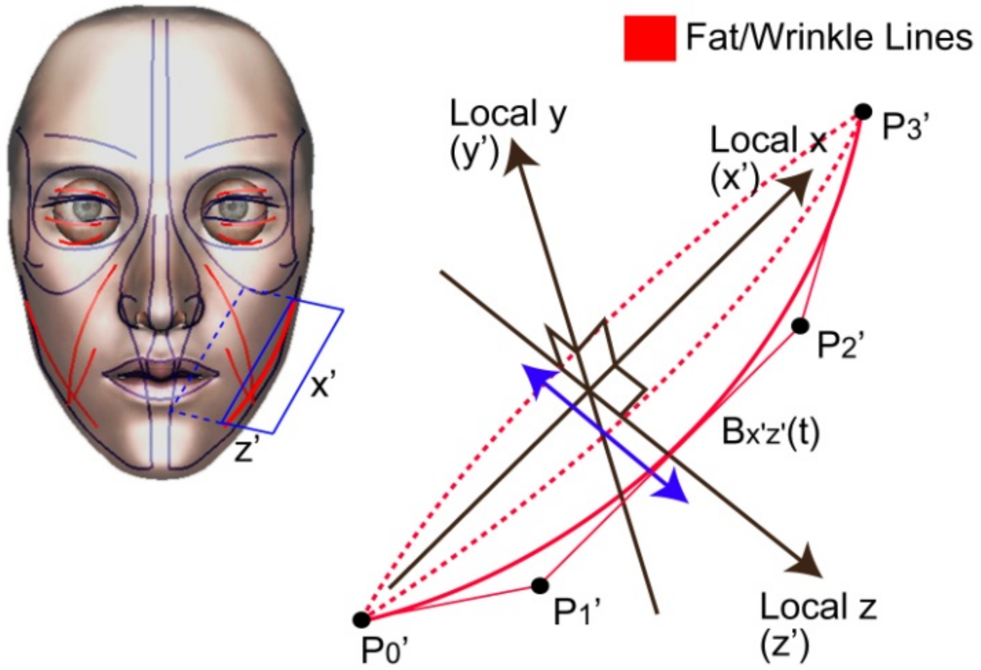


Fig. 17. Principle of Fat/Wrinkle lines for manipulation of fat. Convexity is adjusted by changing vertex coordinates of Local z (Z').

To adjust fat, as shown in Fig. 17, six FLs are inserted on each side of the face: upper eyelid, lower eye lid, eye bag, nasolabial fold, marionette line, and jaw bone area. The convexity of FL created by coordinates of P_1' and P_2' in the curve $B_{x'z'}$ (t) determines the degree of fat. The probability of fat has a relationship with the FL as follows:

$$P_{Fat} \propto \left|z'\right| - \left|z'_{default}\right|, \quad \text{for } P_1' \text{ and } P_2' \tag{9}$$

where P_{Fat} is the probability of fat, and z' and $z'_{default}$ of P_1' and P_2' are z' coordinates of the object model and the base model on a local x'z' plane.

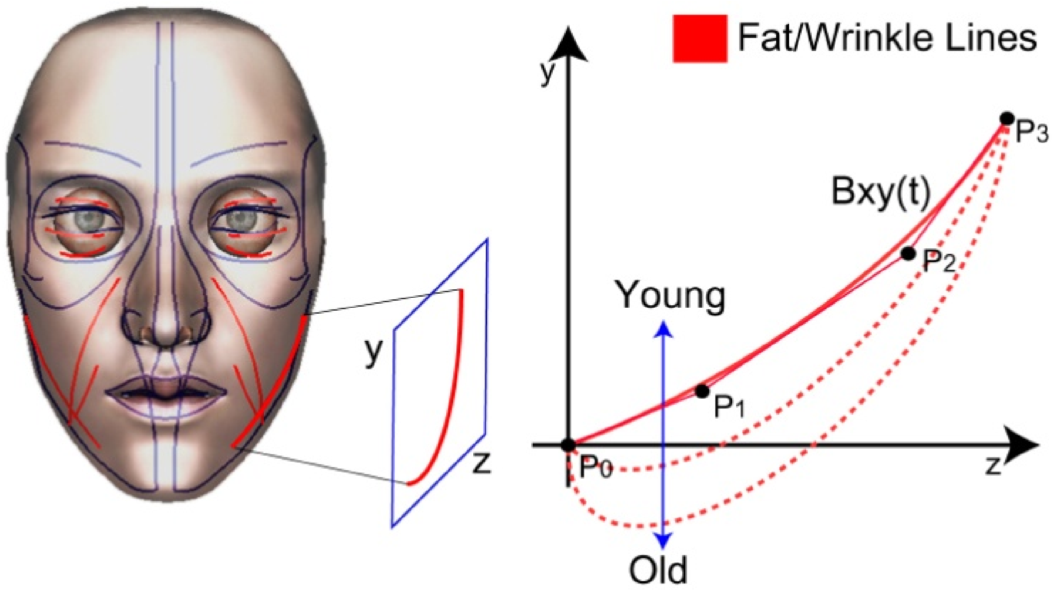


Fig. 18. Principle of Fat/Wrinkle lines for manipulation of aging. Sagginess is adjusted by changing vertex coordinates of Z.

As the convexity of FL increases, the amount of fat in the area increases. When the amount of fat and muscle decreases, it reveals the facial skeletal structure, and therefore PLoFs become more prominent. While a fat face has a large amount of convexity in the areas of fat and muscles without gravitational influence, a thin face has minus or low convexity. Additional FLs can be added for more detailed manipulation of fat.

The age of the facial model is customized by changing the degrees and gravity of muscles and fat. FFLs and FLs are sagged by gravity since they are extracted from a skin surface and soft tissues, while there is no change in PLoFs extracted from skeletal structures. Convexities of FLs can be increased or decreased by aging, which develops differently for each individual.

The degree of age can be adjusted by drooping the levels of FLs according to coordinates of P_1 and P_2 in the curve $B_{xy}(t)$ as shown in Fig.18. A relationship between the probability of age and the FL as follows:

$$P_{Age} \propto |y| - |y_{default}|, \quad \text{for } P_1 \text{ and } P_2 \tag{10}$$

Where $\boldsymbol{P_{Age}}$ is the probability of age, and y and $y_{default}$ of P_1 and P_2 are y coordinates of the object model and the default model on a local xy plane.

In summary, an aging face can be realized by the controls of 1) the convexity of FFLs and FLs relevant to PLoFs, and 2) the gravitational influence on FFLs and FLs relevant to PLoFs. A face whose FFLs and FLs are heavily influenced by gravity is an aging face. Convexity of FL develops differently in individuals, but in general, convexity of FL1, FL2, and F6 are decreased, and FL3, FL4, and FL5 increased. Fine wrinkles can be added as bump map or normal map images for more realistic rendering of aged faces.

4. Experiment and Discussions

In this section I describe experiments in customization. I collaborated with S. Park advised by Professor. Y. Motai in Electrical Engineering to present statistical analysis of our customization model BCFC for gender, race, fat, and age, and we compare performance of the proposed BCFC with that of existing facial customization programs, Facegen (FG) [1] and Facial Studio (FS) [2], in order to verify that realistic facial animation can be effectively customized by the proposed method.

A base model was customized by Bezier Curve-based 3D Facial Customization (BCFC) in Maya, and comparison models were generated by FG [1] and FS [2]. We used

Matlab to analyze numerical data including customized probabilities, accuracy of BCFC, FG, and FS models.

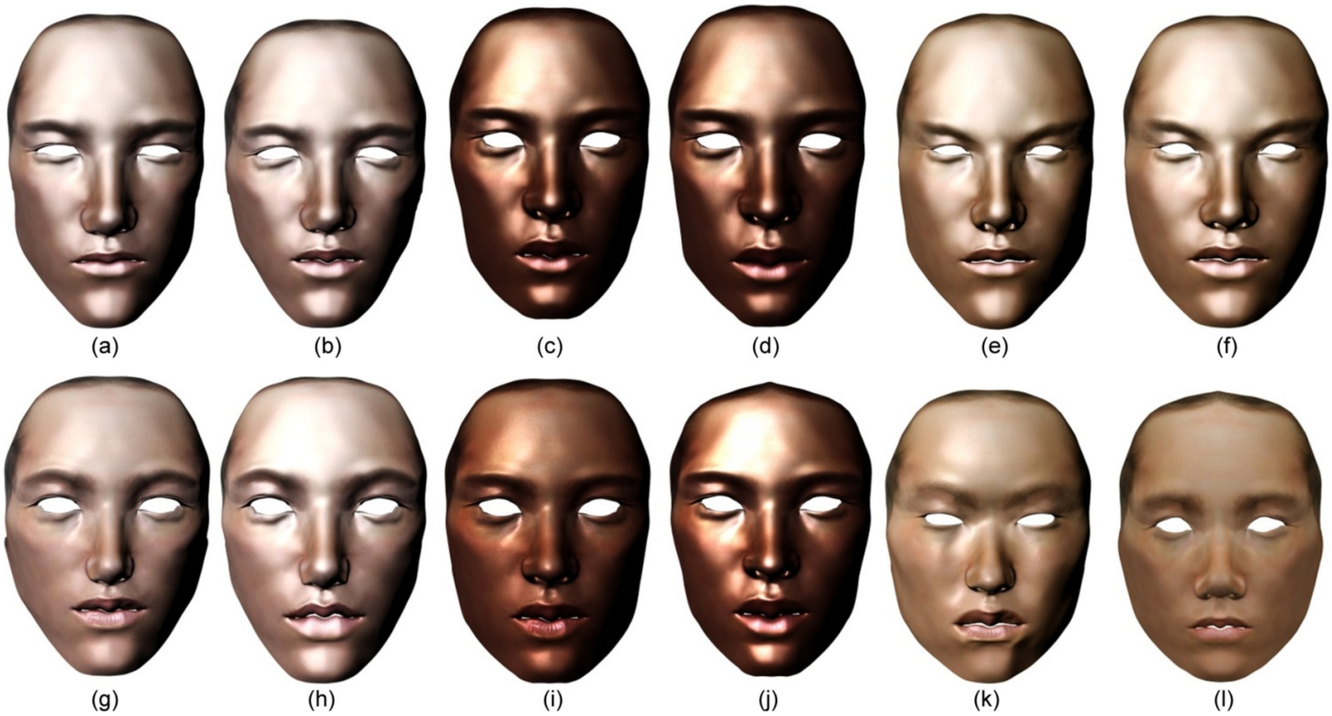
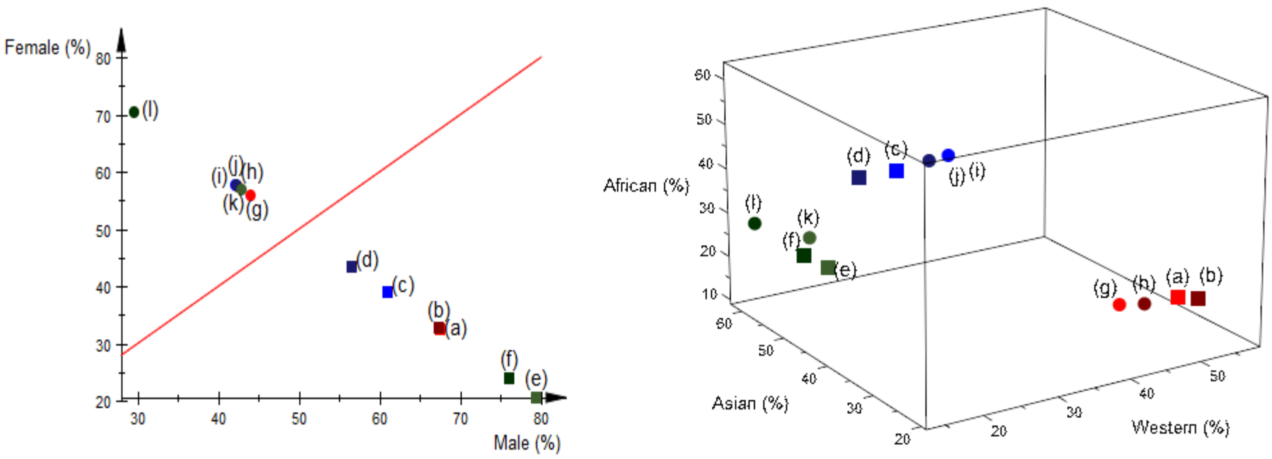


Fig. 19. Gender and race customized models. Each face was customized by manipulating PLoFs based on gender and race features. (a)-(f) are male, (g)-(l) are female, (a), (b), (g), and (h) are Western, (c), (d), (i), and (j) are African, and (e), (f), (k), and (l) are Asian faces.



(a) (b)

Fig. 20. Gender (a) and racial (b) customization probabilities. Both (a) and (b) are results from customized models in Fig. 19. Each point was calculated by equations (4), (6)-(8), and a black line in (a) is the dividing line for genders.

We customized the base face into 12 faces by modifying PLoFs and FLs as shown in Fig. 19 to alter gender and racial features. In Fig. 19, (a)-(f) are male, (g)-(l) are female, (a), (b), (g), and (h) are Western, (c), (d), (i), and (j) are African, and (e), (f), (k), and (l) are Asian faces.

To estimate customized probabilities for genders and races, we measured angles and proportions as described in (3) and (5) from models in Fig. 19: θ_{J2}, l_{E1}, l_{N2}, θ_{N1}, and θ_{N2} of the vector $\mathbf{g}$ and l_{N2}, θ_{N1}, θ_{N2}, l_{FW2}, and θ_{J3} of vector $\mathbf{r}$. Then using those derived values and equations (4), (6), (7), and (8), we calculated gender customization probabilities $\boldsymbol{P_M}$ and $\boldsymbol{P_F}$ and racial customization probabilities $\boldsymbol{P_W}$, $\boldsymbol{P_{As}}$, and $\boldsymbol{P_{Af}}$ for the 12 models in Fig. 19. Results are as shown in Fig. 20.

According to Fig. 20(a), male probabilities for (a)-(f) in Fig. 19 were 67.75%, 67.30%, 60.92%, 56.50%, 79.40%, and 75.98% and female probabilities for (g)-(l) in Fig. 19 were 56.16%, 57.78%, 58.03%, 57.93%, 57.19%, and 70.56% respectively. In other words, (a)-(f) in Fig. 19 had male features because their male probabilities were over 50%. The female probabilities of (g)-(l) in Fig. 19 were above 50%.

In the experiment to evaluate for different races, we got a satisfying result (Fig. 20(b)). Race probabilities for Western for (a), (b), (g), and (h) in Fig. 19 were 54.97%, 56.68%, 52.65%, and 54.18, respectively, and those values were higher than racial probabilities for Asian and African facial features. For faces (c), (d), (i), and (j) of Fig. 19, the highest racial statistic among three races was African, and their numerical values were 56.83%, 53.30%, 63.80%, and 61.38% for each face. Also, facial models in Fig. 19 with higher race probabilities for Asian than others were (e), (f), (k), and (l). Their computed race probabilities for Asian were 60.41%, 59.80%, 54.22%, and 56.25%, respectively.

Thus, not only could we get visible customization outcomes as shown in Fig. 23, which enable to distinguish various facial models according to genders and races by using the proposed method without the need to do other manual labor, but also we verified this by statistical values calculated using proposed equations related with modification of PLoFs.

(a) (b) (c) (d) (e)

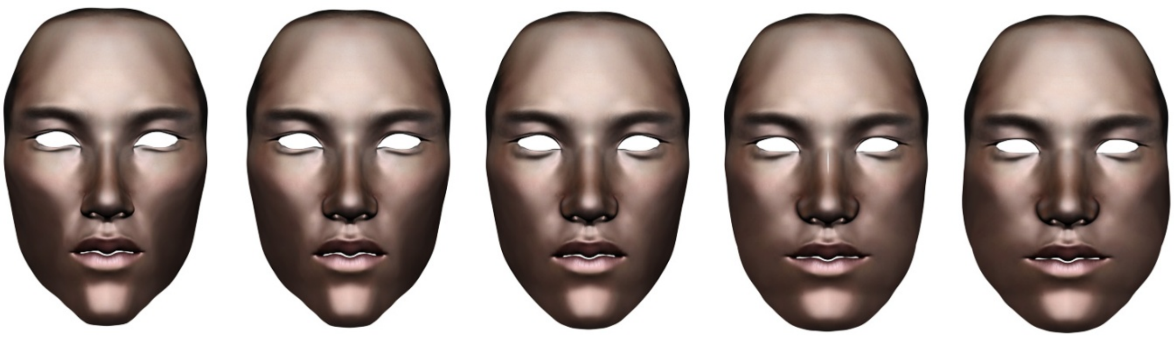


Fig. 21. Fat customized faces: the leanest to fattest from left to right. (c) is the default face.

(a) (b) (c) (d) (e)

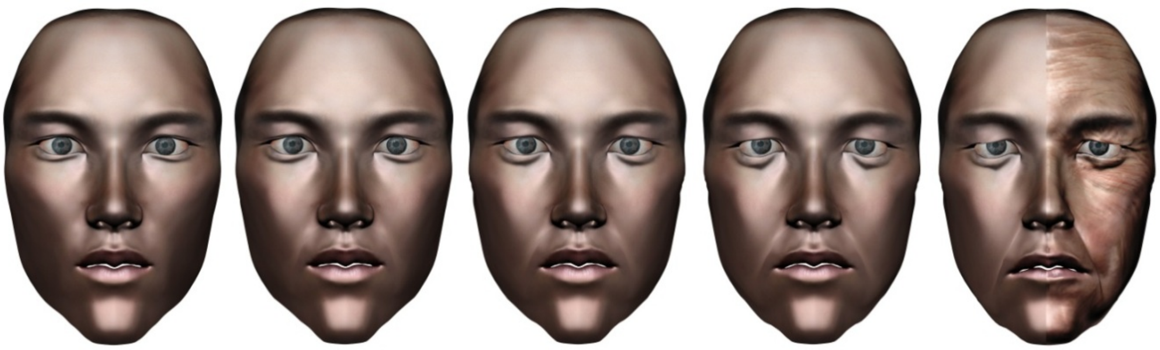


Fig. 22. Age customized faces: the youngest to oldest from left to right. (c) is the default face. In (e), the bump map with wrinkle texture was applied on the right side of the face.

For the evaluation of fat and age customization, we created five faces in different degrees of fat and age as shown in Fig. 21 and 22. Each (c) in both Fig. 21 and 22 is the default facial model. Faces in Fig. 21 are fatter toward the right direction, and faces are older toward the right side of Fig. 22. In Fig. 22(e), the bump map with wrinkle texture was applied on the right side of the face.

To analyze results of Fig. 21 and 22 numerically, we computed fat and age ratios to default faces by equations (9) and (10), respectively. Fig. 23 shows calculated percentages of different fat and age degrees. In Fig. 23, a blue dotted line with ‘x’ markers are fat customization results from faces in Fig. 21 and a red line with circle markers are age customization results from faces in Fig. 22.

Resulting rates of (a), (b), (d), and (e) in Fig. 21 were respectively 70.71%, 89.50%, 106.56%, and 111.79%, and the degree of fat increased from face (a) to (e). Ratios to the default face (c) of (a), (b), (d), and (e) in Fig. 22 were 90.30%, 93.52%, 107.62%, and 116.8%, and this also showed the same tendency to age customization.

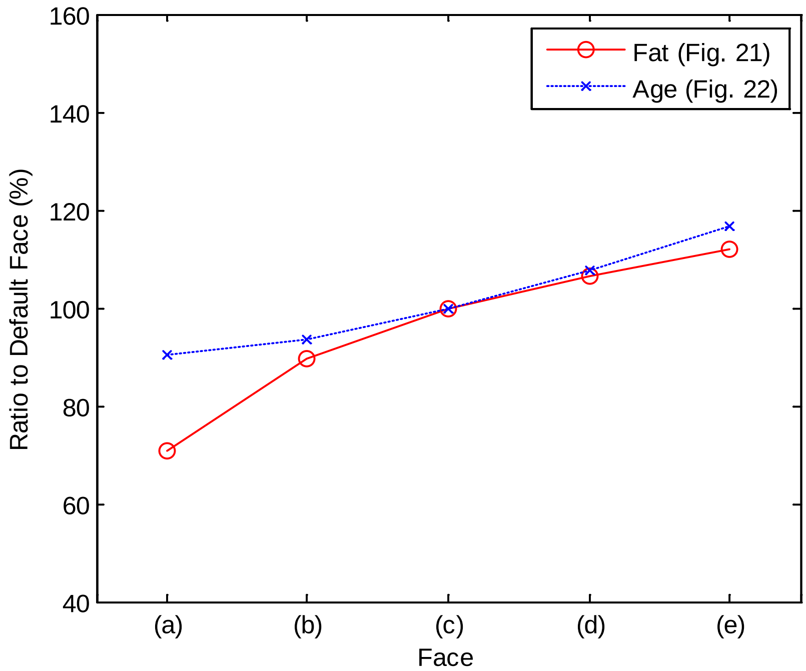


Fig. 23. Fat and age customization ratios relative to default faces: results of (a) the leanest/youngest to (e) the fattest/oldest faces. (c) represents the default face. A red line with circle markers and a blue dotted line with ‘x’ markers are fat customization results from faces

in Fig. 21 and age customization results from faces in Fig. 22, respectively. This figure is made by SeonYeong Park.

Therefore, results from Fig. 23 support that the proposed BCFC approach effectively enable us to customize facial models in terms of fat and age by controlling FL simply, without the fine manual skill that previous customization techniques needed.

To better validate performance of the proposed customization method, we modeled an identical target face using our prototype system and other commercial facial customization programs, FG [1] and FS [2]. Then we compared consequently customized models by extracting Bezier curves from both models and original images and by computing discrepancies of the curves between the real photos and each result of MFAM, FG [1], and FS [2]. The experimental objects used were front, side, and tilted side photos of Michael Jackson's face.

TABLE 8
AVERAGE ERRORS AND IMPROVEMENT RATES OF BCFC, FAECEGEN, AND FACIAL STUDIO

View \ Technique		BCFC	Facegen [43]	Facial Studio [44]
Front	Error*	1.25	1.38	1.77
	Imp**	-	9.42	29.38
Side	Error*	1.07	2.50	2.09
	Imp**	-	57.09	48.59
Tilted	Error*	1.27	1.20	2.64
	Imp**	-	-5.49	52.08
Total	Error*	11.05	14.77	19.77
	Imp**	-	25.20	44.12

** Average error compared to the original photo (%), ** Improvement rate by BCFC (%)*

Table 8 shows average errors between a real picture and each 3D animation from BCFC, FG, and FS customization techniques, and improvement rates by the proposed

MFAM. In Table 8, the error was the difference proportion to a face full-length. While using FG was more accurate than using BCFC in the tilted view, the amount of improvement was slight. Also, enhancements by BCFC in other views and in total were much larger than others.

Consequently, the novel BCFC technique not only showed efficient performance in the single customization experiment for gender, race, fat, or age as described results above, but also achieved a higher level of accuracy and a larger amount of improvement rate than those of existing techniques in the complex customization experiment that targets one specific face.

5. Conclusion

This chapter presented a novel Bezier curve-based 3D facial customization. My goal was to achieve a realistic quality of facial customization by adapting anatomical information of facial structure and expression without using 3D scanned data. Our approach stands out from previous facial animation techniques such as motion tracking or blend shape since it dramatically reduces the amount of time needed to process data, and therefore is cost-effective.

In the experiments, results for the facial customization for gender, race, fat, and age showed that BCFC achieved enhanced performance of 25.20% compared to existing FG technique, and 44.12% compared to FS technique, by manipulation of three types of lines: PLoF for gender and race, FFL for individual differences in facial features, and FL controlling fat and age levels.

III. Multi-layered Facial Action Model

1. Introduction

In this Chapter, I propose a realistic 3D facial action model for real-time interaction between the viewers and the facial action/emotion database [96], [100], [101], [102] and face robots [76], [77], [78]. A 3D quad high-polygon model is used to achieve more realistic quality, as compared with 3D Morphable Models (3DMMs) [104]. The novel facial action system is designed inspired by Ekman's Facial Action Coding System (FACS) [115] and related works [76], [77], [78], [96], [101], and [116]. I realize more realistic and sophisticated facial movement using 3D physics simulation to animate the multi-layered model.

There have been many efforts to achieve realistic qualities of facial models and facial animation in the areas of entertainment, engineering, and in robotics to evoke the viewer' empathy. Especially, 3D facial animation based on performance-driven facial capturing technology, such as the Light Stage capture system and Image Metrics' video-based facial-animation system [54] developed by Institute for Creative Technology (ICT), and blend shape animation techniques, reached a close-to-realistic quality that seems to cross the so-called "uncanny valley" [62]. This technique was adapted in Hollywood movies such as Avatar and The Lord of the Rings, and resulted in impressive facial animation scenes.

MFAM was physically simulated for more cost-effective and intuitive manipulation of real-time facial animation. We aim to achieve realistic qualities equivalent to the results of performance-driven and blend shape techniques [54] that have limitations in terms of cost-effectiveness and application to HCI. Our facial action system achieves more realistic results compared with the previously reported results using physics-based facial animations [87], [83], [110] by designing a novel constraints-based motion unit system for a high-polygon model. For the MFAM, we used constraint-based physical simulation for the rendering of realistic facial expressions and wrinkling of the skin surface by manipulating muscle and skeletal motion units to overcome limitations of 3D scanning, motion tracking, and blend shape techniques.

Our contribution is to realize affective human-computer interaction through more effective facial action system based on the anatomical analysis, in comparison to performance-based, blend shape-based, and former anatomy-based approaches. MFAM is more effective than performance-based and blend shape-based techniques since it does not require live models and a large amount of time and effort to process raw data. Furthermore, due to its fundamental approach to the anatomical structures and movements, our system creates great variations and verisimilitude of facial forms and expressions. Due to its fundamental approach, our system can be applied to various areas including real-time animation, Embodied Conversational Agents [118], computer games, robots [76], [77], [78], and medical treatments such as the treatment of autism and other relevant symptoms, and psychological experiments.

The remainder of the paper is organized as follows: Related Studies are covered in Section 2, and Section 3 introduces MFAM. In Section 4, the system is evaluated, and I end with conclusions in Section 5.

2. Related Studies

As shown in Table 9, there are four different approaches to create facial action: performance-driven, anatomy-based, blend shape-based, and emotion-based. Many projects adapted more than one approach to achieve synergetic effects.

TABLE 9
FACIAL ACTION MODEL COMPARISONS

Construction of Categories	Techniques
performance-driven	3D Marker-based motion capture data [19],[28],[29],[30],[31],[33],[34]
	Facial Scanning [19], [24], [35]
	2D, 3DMarkerless video data [32]
Anatomy-based	Anatomical physical simulation [24], [26], [28], [29], [33], [34]
	Motion unit system [11],[12],[13], [25]
blend shape-based	Blend shaping 33[19], 22[30], 46[31] faces
Emotion-based	6 basic emotions [11],[12],[24],[28], [34],[36], (+1) [27],[37] (+2) [8], 11 emotions [35]

2.1 Performance-driven approach

Performance-driven facial animation focuses on the surface changes of the performer's face. There are two techniques that are used in this approach, namely, motion tracking and 3D scanning. While motion tracking tracks the movements of markers on the face, 3D scanning captures the surface coordinates and texture of a performer's face with different facial expressions.

Motion tracking enables real-time rendering of dynamic facial expressions. Nevertheless, it cannot achieve realistic quality by itself since it only captures the position changes of certain points on the skin surface, without capturing detailed surface and texture changes, such as wrinkles and creases. O. Alexander et al. [54] and K. Y. Liu et al. [61] combined maker-based motion capturing with blend-shape techniques to enhance realistic rendering of facial expressions. While several works [54], [61], [72], [74], [75], [79], [111] used the marker-based motion capture technique, D. Sibbing et al. [68] used marker-less motion tracking of 2D images and applied data to a 3D mesh.

3D scanning enhances the realistic quality of different facial expressions since it captures the detailed shape changes of the surface. The main drawback of this technique is, however, the large amount of data involved, which decreases the processing speed. For instance, O. Alexander et al. [20] explored 3D scanning for photo-realistic 3D facial animation; 33 different expressions of actor Emily were scanned and remeshed, and blend shaped. Regardless of its photo-realistic result, 3D scanning needs a considerable amount of time and effort for manual remeshing and remapping.

2.2 Bland shape-based approach

Blend shape, the animation technique used to morph more than two meshes, was frequently used in facial animation due to its intuitive and easy manipulation [54], [61], [72]. Blend shape requires multiple models with different facial expressions, which preserve the same number of vertices. In [54] and [61] blend shape was used with 3D scanning. Both remesh the scanned high-polygon data into a lower-polygon mesh, and blend shaped meshes and normal maps for realistic surface wrinkling. O. Alexander et al. [54] blended 33, K. Y. Liu et al. [61] blended 22, and Z. Deng et al. [72] blended 46 different facial expressions. In spite of its realistic results, blend shape is limited in variations of facial expression and unrealistic for facial wrinkling and deformation of the model, especially when blending more than two facial expressions. In addition, this technique by itself is unable to achieve real-time animation. The fundamental problem with both blend shape-based and performance-driven techniques is that they focus on the surface movement of a face, facial movements, however, are systemically created by movements of facial skeletons and muscles underneath.

2.3 Anatomy-based approach

Anatomy-based facial animations create facial expressions by physically simulating a multi-layered facial model’s movements, including skin, muscle, and skeletal structures. Previous researches [74], [75], [79], [87], [110], [111] used anatomical multi-layered models for facial animations. In 3D computer graphics, blend shape-based and performance-driven facial animations are more commonly used for facial animations. Many simulation-based facial animations were developed mainly for the purpose of planning and predicting facial surgery results [79].

Regarding humanoid face construction, in work such as those reported in [76], [77], [78], action units (AUs) were often used to create a realistic face and facial expressions. AUs were originally reported in [82] as the FACS and it was customized and modified by other researchers. Meanwhile, B. Bickel et al. [83] adapted the action unit system for their virtual 3D model to physically simulate a silicon rubber synthetic skin.

For both virtual and mechanical facial actions, anatomy-driven approach has potential due to its fundamental approach. However, there have not been realistic results yet in comparison to performance-driven and blend shape-based approaches, due to its challenging nature of the complex anatomical structure and skin surface simulation.

2.4 Emotion-based approach

In the fields of psychology, computer animation, and robotics, six basic emotions are typically used to define facial expressions: joy, sadness, anger, fear, disgust, and surprise, as proposed by Ekman in his FACS [85], [116], [82]. These six emotions are popularly used to create different facial expressions of 3D virtual [74], [87], [111], and android faces [76]. The analyses of facial expressions based on these basic expressions were conducted in [102], [118], [113], and [114]. In addition to the six expressions, C. Moridis et al. [118] and Y. Rahulamathavan et al. [114] added a neutral expression for comparison, while S. Wang et al. [102] added arousal and valence values. However, all these categories are still not able to cover complicated emotions and facial expressions that humans use in their daily lives. S.M. Mavadati et al. [103] suggested that one facial expression may signify different emotions, and can also be manipulated consciously by the person depending on different social factors and intentions.

3. Multi-layered Facial Action Model (MFAM)

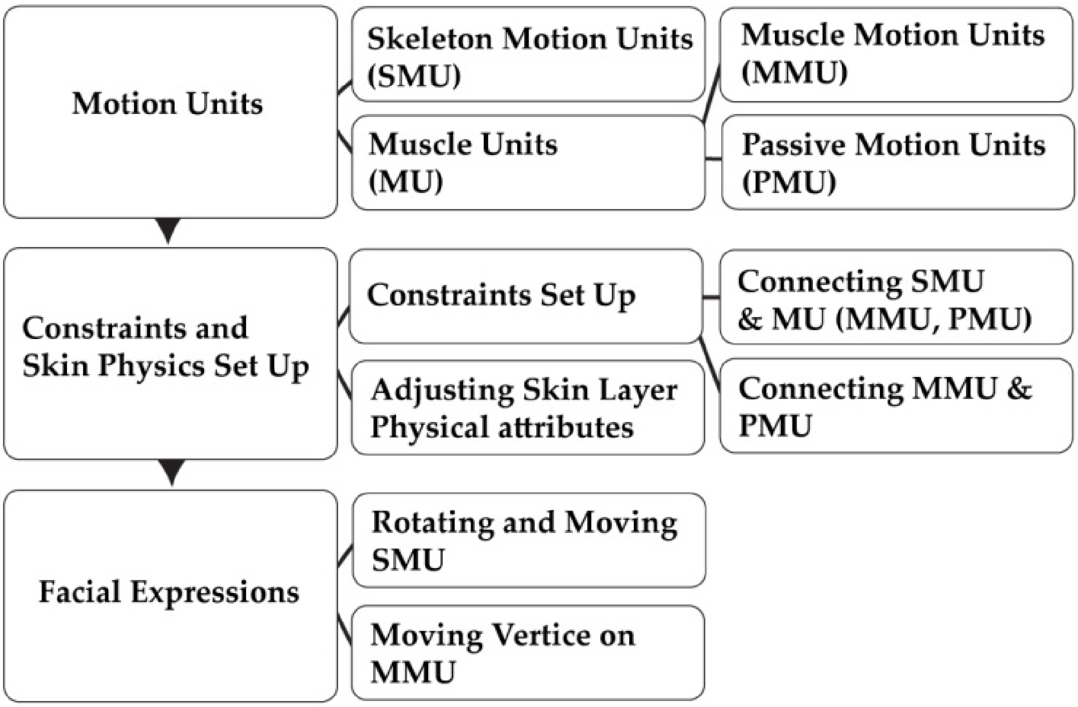
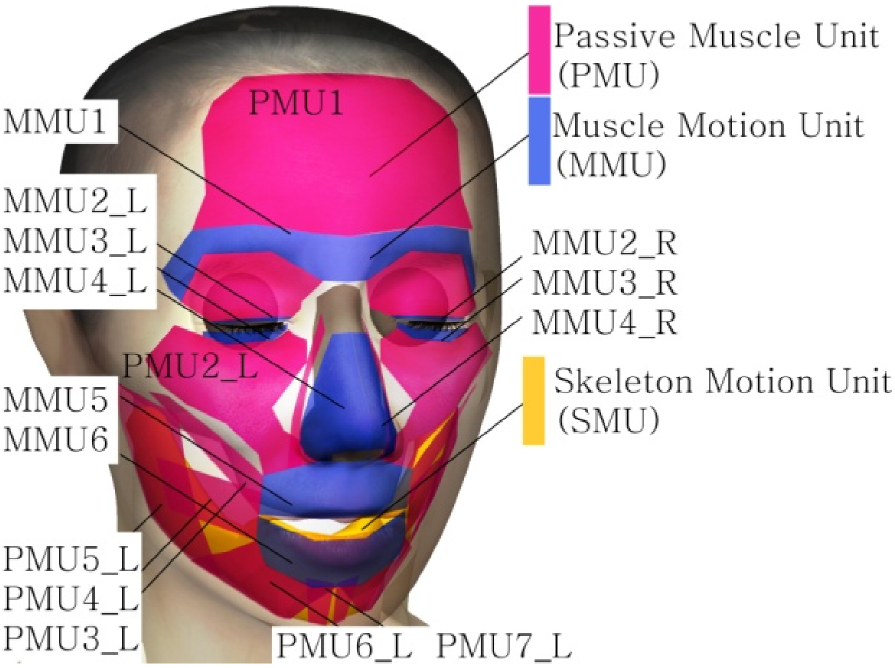


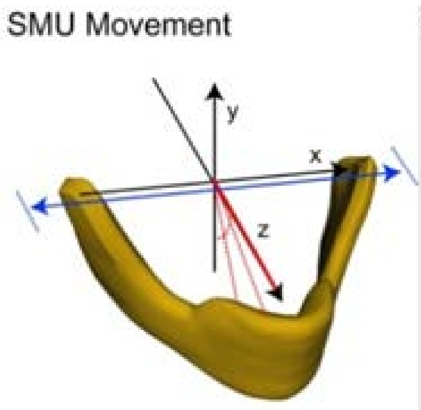
Fig. 24. MFAM Pipeline.

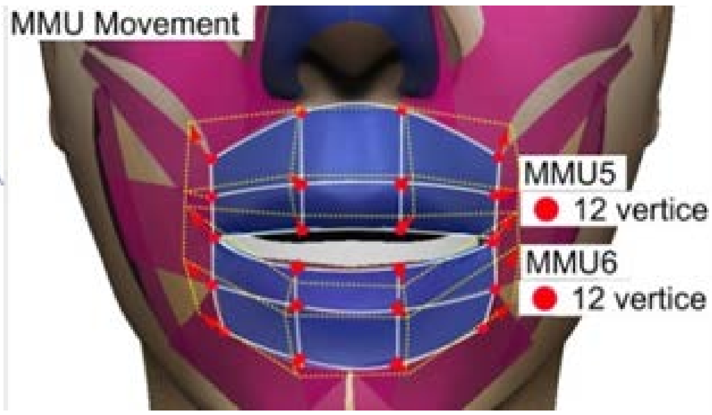
In this section, we describe Multi-layered Facial Action Model (MFAM) driven by Motion Units (MUs) and physics constraints for the realization of realistic facial expressions and wrinkling. MUs are attached beneath the skin mesh for facial skeleton and muscle movements. MUs and a skin mesh are intricately connected to each other using 291 constraints for realistic wrinkling. Then the soft body physics of a skin mesh is adjusted by combining preset physics properties of rubber and cloth to simulate human skin. Fig. 24 illustrates pipelines for MFAM. In the following subsections, we further discuss Motion Units, constraint and skin physics set up, and facial expressions.

3.1 Motion Units



(a) MUs overview





(b) SMU movement (c) MMU movement

Fig. 25. MUs Overview, SMU Movement, and MMU Movement. (a) 2 MUs: Skeleton Motion Unit (SMU) for muscle movements. MUs are inserted beneath a skin layer. (b) illustrates SMU movement. (c) illustrate movements of MMU5 and MMU6 when smiling.

Fig. 25 illustrates that our face model is animated by two types of units: Skeleton Motion Units (SMU) and Muscle Motion Units (MMUs). We use Passive Muscle Units (PMUs): passive physical soft bodies that are attached around MMUs and SMUs. Unlike actual muscles, PMUs are contracted and relaxed automatically by movements of MMUs and SMUs, while supporting the facial form to enhance anatomical accuracy.

For SMUs, we build low-polygon meshes for the skull, jaw, and neck. We limit our experiments to jaw movements only. The jaw rotates mostly toward axis X when opening one's mouth, but there is minor movement toward axes Y and Z, in addition to rotation of X when chewing.

TABLE 10
MUSCLE UNITS BASED ON FACIAL EXPRESSION MUSCLES

Muscle	Form	Facial Movement (MU)
Occipitofrontalis	PMU1	raise eyebrows, wrinkle forehead (MMU1)
Orbicularis oculi	MMU1-3 PMU2	open/close/medially pull eyelids (MMU2,3), furrow nose and eyebrows (MMU1)
Procerus, corrugator supercilii	MMU1	pull eyebrows in/down (MMU1)
Nasalis	MMU4	compresses/wideon nasal aperture (MMU4)
Levator labii superioris alaeque nasi	PMU4	raise upper lip (MMU5), flare nostril (MMU4)
Levator labii supurioris	PMU3	raise upper lip (MMU5)
Levator anguli oris	PMU3	raise angle of mouth (MMU5,6)
Zygomaticus major	PMU5	pull corner of mouth up/aside (MMU5,6)
Zygomaticus minor	PMU3	pull upper lip up (MMU5)
Orbicularis oris	MMU5,6	compress/protrude lip (MMU5,6)
Risorius	PMU6	pull corner of mouth aside (MMU5,6)
Depressor anguli oris	PMU8	pull angle of mouth down/aside (MMU5,6)
Depressor labii inferioris	PMU8	pull lower lip down/aside/forward (MMU6)
Mentalis	PMU9	raise/protrude lower lip (MMU6)
Masseter	PMU7	raise mandible (SMU), assist lower lip (MM6)

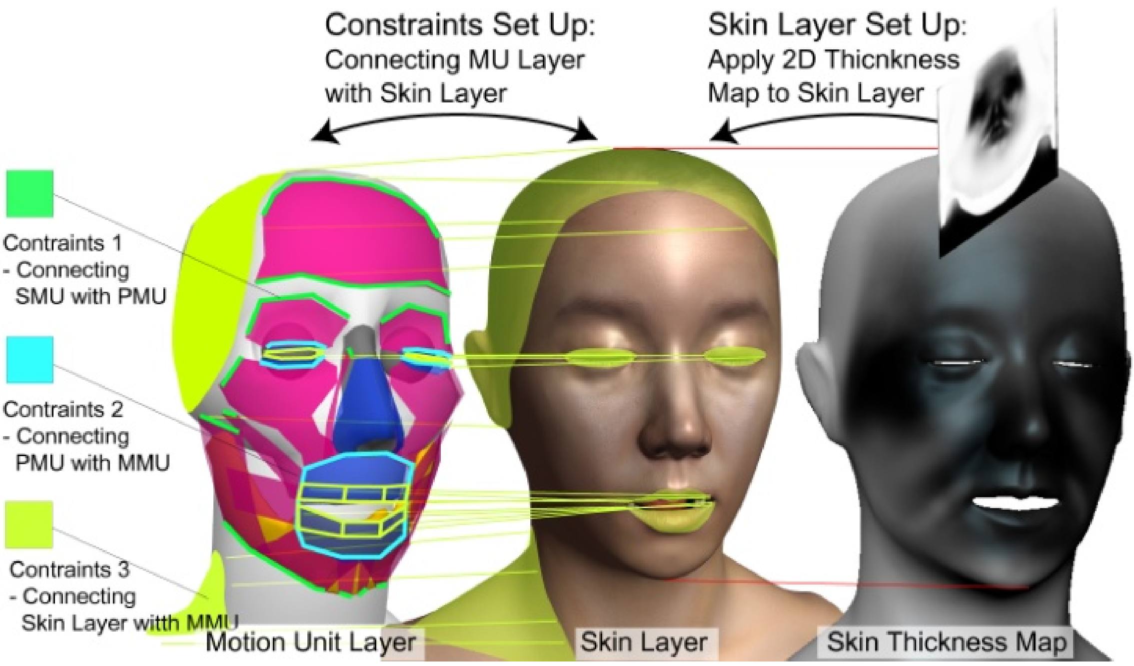
For MMUs and PMUs, we analyze forms, functions, origins, and insertions of 20 facial expression muscles reported in [3] and categorized muscles into two types: sphincter muscles that contract toward dynamic directions, and linear muscles that contract toward linear directions. We apply MMU to most sphincter muscles, and PMU to most linear muscles. Table 10 lists MUs corresponding to facial muscles and their functions for facial expressions.

For muscles that contract to dynamic directions, such as around the eyes, nose, and mouth, we design nine MMU – the pink and blue-colored muscles shown in Fig. 25 (a), and apply rigid body physics for direct manipulations of the vertices. While several muscles are merged into one MMU, some muscles are divided into several. For instance, MMU1 includes three different muscles: Orbicularis Oculi, Procerus, and Corrugator Supercilii. While Orbicularis Oculi, the muscle around eyes, is characterized into four MUs: MMU1 for eyebrows, MMU2 for upper eyelids, MMU3 for lower eyelids, and PMU2 for upper cheeks.

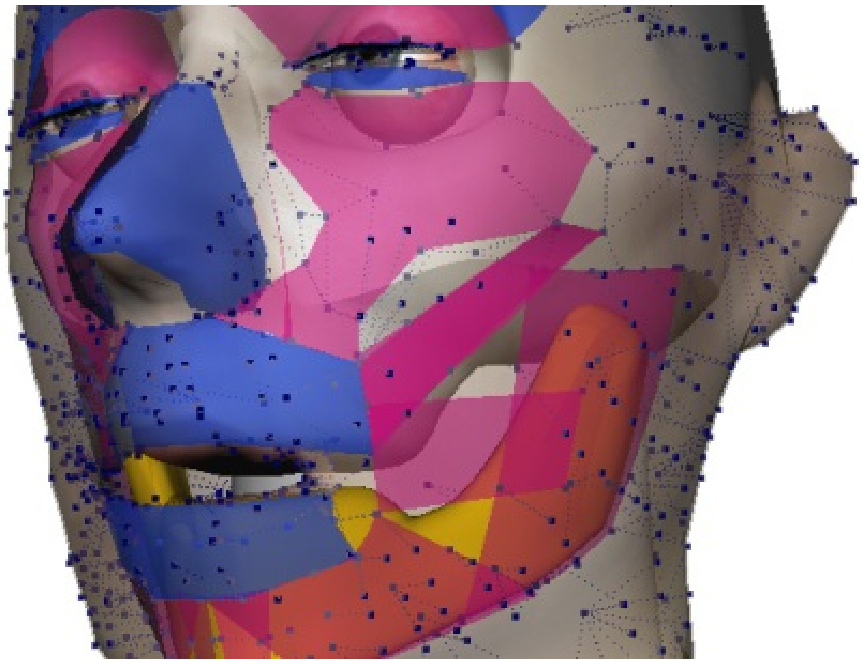
Instead of manipulating all facial expression muscles shown in Table 10, only MMUs are manipulated and PMU is adjusted automatically. This reduces a large amount of time and effort for adjustments of entire muscles. MMUs can be manipulated in various ways: direct vertex manipulation, motion capture data, blend shapes, and deformers.

3.2 Constraint and Skin Physics Set Up

For the realistic physical simulation of a skin layer, MUs and a skin layer are constrained by each other based on the anatomical origins and insertions of facial expression muscles. A total of 291 constraints are used and modified manually in simulation tests. The accuracy of the constraints set up is a crucial step since it determines shapes and locations of dents and wrinkles on the skin layer. This step requires a large amount of time for the refinement of connections among MUs to create the realistic wrinkling. The constraints set up has three steps: Constraint 1 connecting SMUs with PMUs, Constraint 2 connecting PMUs with MMUs, and Constraint 3 connecting a skin layer with MMUs.



(a) (b) (c)



(d) Detailed view of Constraints (dark blue points and dotted lines)

Fig. 26.Constraint and skin physics set up. As shown in (a) and (b), Constraint 1 connects SMUs with PMUs, Constraint 2 connects PMUs with MMUs, and Constraint 3 connects the skin layer with MMUs. In skin physics set up, a 2D thickness map is applied to the skin layer. In (c), the white part is the thickest area and the black part is the thinnest area of the skin. Dark blue points and dotted lines in (d) are the 291 constraints used in our system.

Fig. 26 illustrates that in Constraint 1 the vertices on the borders of PMUs are connected to SMUs by spring constraints to simulate realistic connection of muscles to skeletons. In Constraint 2, MMUs and PMUs are connected by weld constraints so that they can contract and relax together as connected muscles. In Constraint 3, a skin layer is constrained to the MUs underneath by spring constraints. Fig. 26 (d) shows a detailed view of constraints, marked as dark blue points and dotted lines.

Then soft body physics is used for the skin layer so that it is automatically deformed by the movements of MMUs and SMUs. Skin physics attributes such as thickness, friction, stickiness, stretchiness, and rigidity of the skin layer are adjusted by empirical experiments and visual observations by combining rubber and cloth physics properties.

Since the thickness of the skin is different in each area, a grayscale 2D thickness map is used to account for it. As shown in Fig. 26 (c), white areas around the chin and cheek are the thickest parts and black areas around the eyes, nose, and lips are the thinnest. This map significantly improves the physical simulation of the skin layer.

3.3 Facial Expression

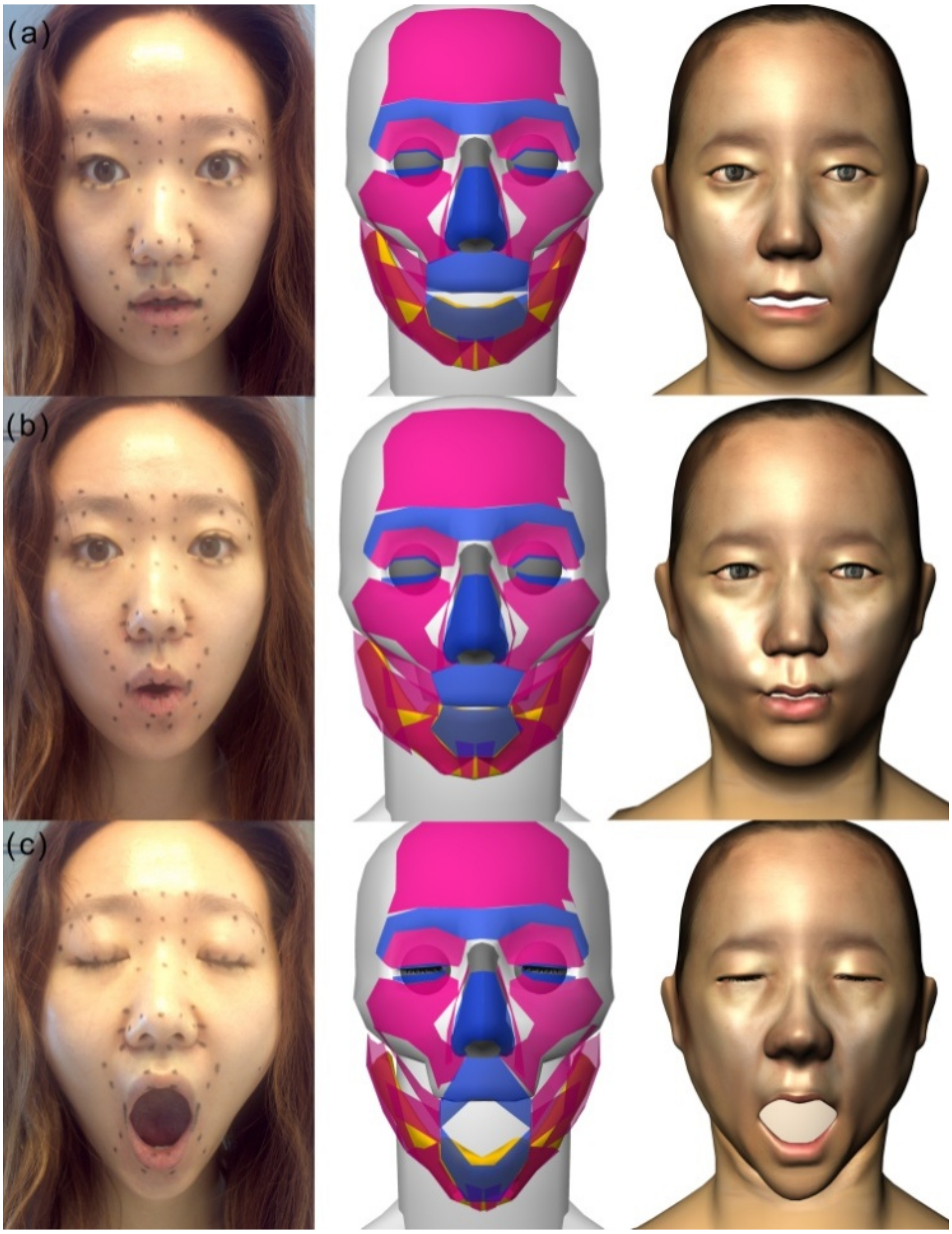
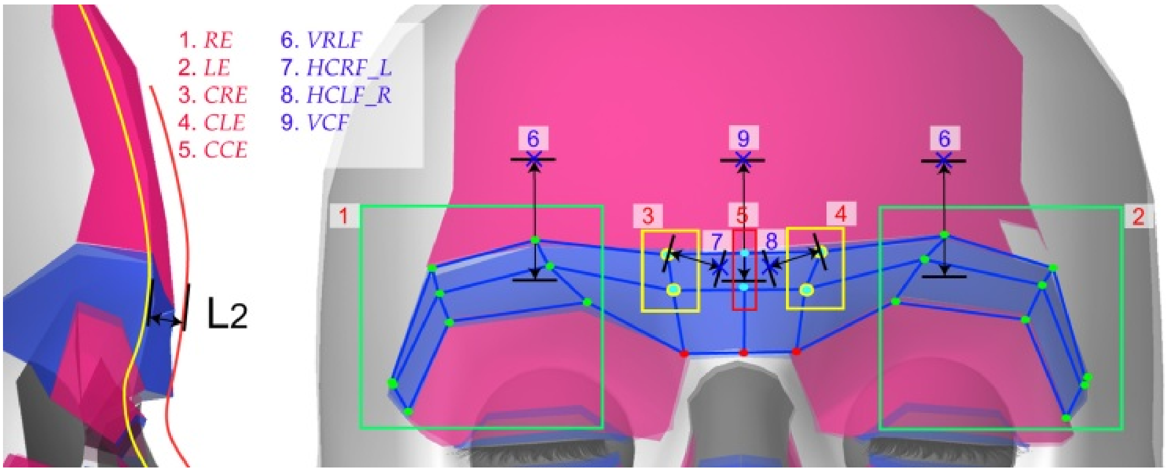


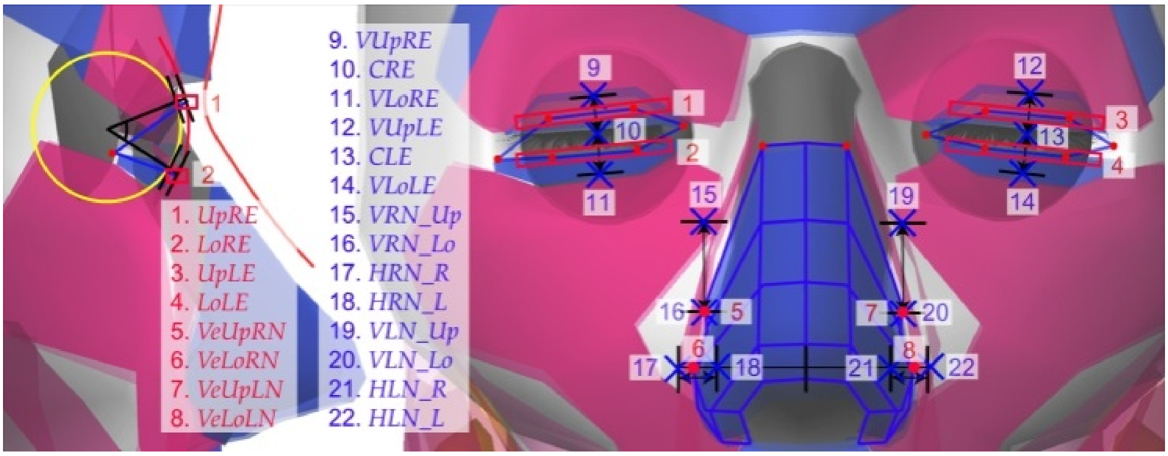
Fig. 27. Process of facial simulation of MFAM based on motion captured data of markers on the real face.

After the constraint and skin physics set up, moving ranges of MUs are determined. As shown in Fig. 27 (a), we added markers on the real face in the positions of vertices in MMU for movement analysis. 54 points are marked on a real face, locations of which are equivalent to the salient vertex locations of MMUs. Next, the skin layer is physically simulated by animation vertices of MUs.



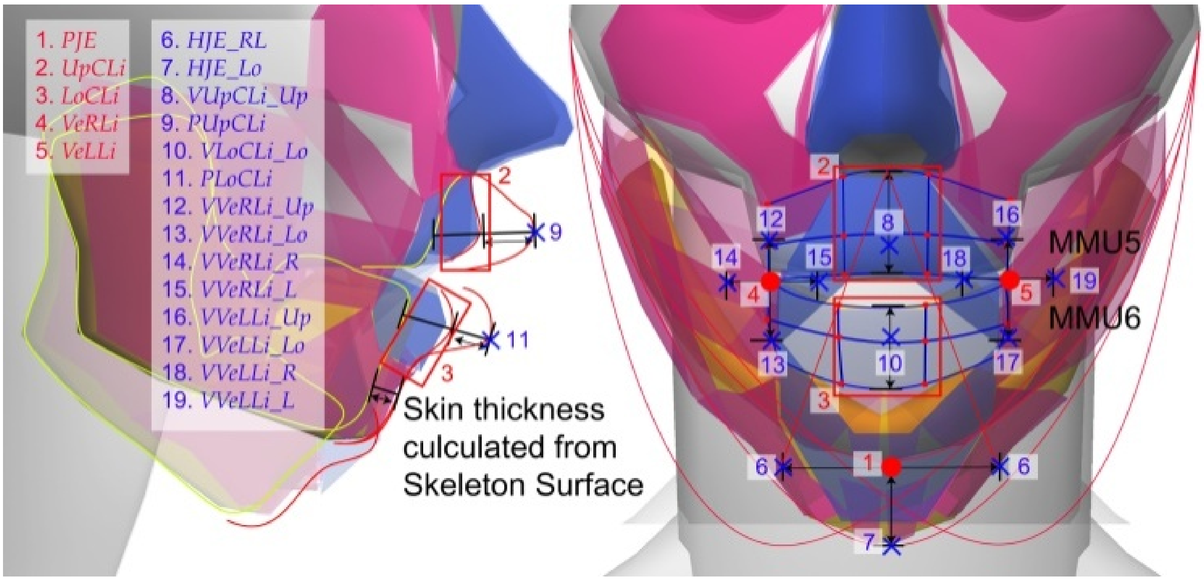
(a) (b)

Fig. 28. Eyebrow and forehead movement analysis: (a) side view eyebrow and forehead movement analysis. Z coordinates are estimated by adding the thickness of skin to the coordinate value of the skeleton surface. (b) front view eyebrow and forehead movement analysis. Ranges of possible movements of eybrow/forhead areas: MMU1 were analyzed based on motion capture data of the front view of the face



(a) (b)

Fig. 29. Eye and nose movement analysis: (a) side view eye and nose movement analysis. Z coordinates are estimated by adding the thickness of skin to the coordinate values of eye balls and skeleton surface. (b) front view eye and nose movement analysis. Ranges of possible movements of eye and nose areas: MMU2, MMU3, and MMU4 were analyzed based on motion capture data of the front view of the face



(a) (b)

Fig. 34. (a) side view lip movement analysis. Z coordinates are estimated by adding the thickness of skin to the coordinate value of the skeleton surface. (b) front view lip movement analysis. Ranges of possible movements of lip areas: MMU5, MMU6 were analyzed based on motion capture data of the front view of the face

The ranges of possible vertex movements of MMUs for eyebrow, eye, nose, and lip areas are estimated from the motion capture data, as shown in Figs. 28, 29 and 30. x and y coordinates are estimated from the front view of the facial motion, while z coordinates are estimated by adding the skin thickness values to the skeleton surface coordinate values of SMU.

In Fig. 28, vertices of MMU1 are categorized into five groups to animate the forehead and eye brows: *RF* and *LF* for each side of the eye brows, and *CRF*, *CLF*, and *CCF* for the center part of the eye brows to simulate frowning, and raising brows. These groups have vertical motion to the degree of *VRLF* for *RF* and *LF*, and *VCF* for *CRF*, *CLF*, and *CCF*. *CRF* and *CLF* also move toward the lower center to the degree of *HCRF_L* and *HCLF_R*, to create a frowning.

In Fig. 29, MMU2 and MMU3 movements are estimated to animate opening and closing of eyes, and MMU4 movements for wrinkling, compressing, and flaring of the nose. For eyelid movements, two vertices per upper and lower eyelids on each side move along the lines of *UpRE*, *LoRE*, *UpLE*, and *LoLE*. From the side view, z coordinates are defined by adding the thickness values of the skin of the eyelids to the coordinate values of spheres that represent eye balls. For nose wrinkling, the distance between *VR/LN_Up* and *VR/LN_Lo* is adjusted. For compressing and flaring of the nose, the distance between *HR/LN_R and HR/LN_L* is adjusted.

In Figure 30 (b), ranges of possible lip and jaw movements are analyzed based on motion capture data of the front view of the face and applied to MMU5, MMU6, and SMU (jaw). The lip and jaw movements are more dynamic since they are affected by both SMU and MMUs. Vertex group *UpCLi* and *LoCLi* move toward all x, y, z coordinates, since the skin thickness of this area can be changed. We determine salient vertices *VeRLi* and *VeLLi* which will affect the rest of the vertices in MMU 5 and MMU 6.

TABLE 11
MOVING RANGE OF MUSCLE UNITS

MU	Expression	Vertex/Point	Range
SMU (jaw)	Left/ Right/ Open/ Close	$PJE(x, y, z)$	$\frac{x^2}{HJE\_RL^2} + \frac{y^2}{VJE\_Lo^2} < 1$ and $y < 0$
MMU1 (forehead, eyebrows)	Frowning/ Raising brows	$vertex(x, y, z) \in RF \cup LF$	$0 < y < VRLF$
		$vertex(x, y, z) \in CRF$	$0 < x < HCRF\_L$ $0 < y < VCF$
		$vertex(x, y, z) \in CLF$	$HCLF\_R < x < 0$ $0 < y < VCF$
		$vertex(x, y, z) \in CCF$	$0 < y < VCF$
MMU2 & 3L (upper eyelid & lower eye lid)	Open/ Close	$vertex(x, y, z) \in UpRE$	$CRE < y < VUpRE$
		$vertex(x, y, z) \in UpLE$	$CLE < y < VUpLE$
		$vertex(x, y, z) \in LoRE$	$VLoRE < y < CRE$
		$vertex(x, y, z) \in LoLE$	$VLoLE < y < CLE$
MMU4 (Nose)	Flare/ Wrinkle	$VeUpRN(x, y, z)$	$VRN\_Lo < y < VRN\_Up$
		$VeLoRN(x, y, z)$	$HRN\_R < x < HRN\_L$

		$VeUpLN(x, y, z)$	$VLN\_Lo < y < VLN\_Up$
		$VeLoLN(x, y, z)$	$HLN\_R < x < HLN\_L$
MMU5& 6 (upper lip, lower lip, left lip-end, & right lip-end)	Widen/ Purse	$vertex(x, y, z) \in UpCLi$	$0 < y < VUpCLi\_Up$ $0 < z < PUpCLi$
		$vertex(x, y, z) \in LoCLi$	$VLoCLi\_Lo < y < 0$ $0 < z < PLoCLi$
		$VeRLi(x, y, z)$	$VVeRLi\_R < x < VVeRLi\_L$ $VVeRLi\_Lo < y < VVeRLi\_Up$
		$VeLLi(x, y, z)$	$VVeLLi\_R < x < VVeLLi\_L$ $VVeLLi\_Lo < y < VVeLLi\_Up$

* *R: right, L: left, C: center, Up: upper, Lo: lower, H: horizontal, V: vertical, and P: prominent*

From our analysis, illustrated in Figs. 28, 29 and 30, moving ranges of MUs are defined and shown in Table 11. The movement of the jaw by SMU is within the scope of an ellipse, and coordinates for vertices on MMU1 regarding the movement of the forehead and eyebrows can be manipulated horizontally or vertically, within ranges shown in Table 11. Upper and lower eyelids can move only in vertical direction so that vertex ranges of corresponding MUs, MMU2 L and MMU3 L, are analyzed as shown in Table 11. Flaring and wrinkling the nose by MMU4 and widening and pursing the mouth by MMU5 and MMU6 have horizontal and vertical thresholds.

4. Experiment and Discussions

In this section I and Seonyeong Park evaluate the performance of our facial action model MFAM by comparing two primary facial expressions with a blend-shaped model, the most commonly used technique in facial animation. We analyzed differences in surface changes of our MFAM and a facial model animated by blend shaped techniques.

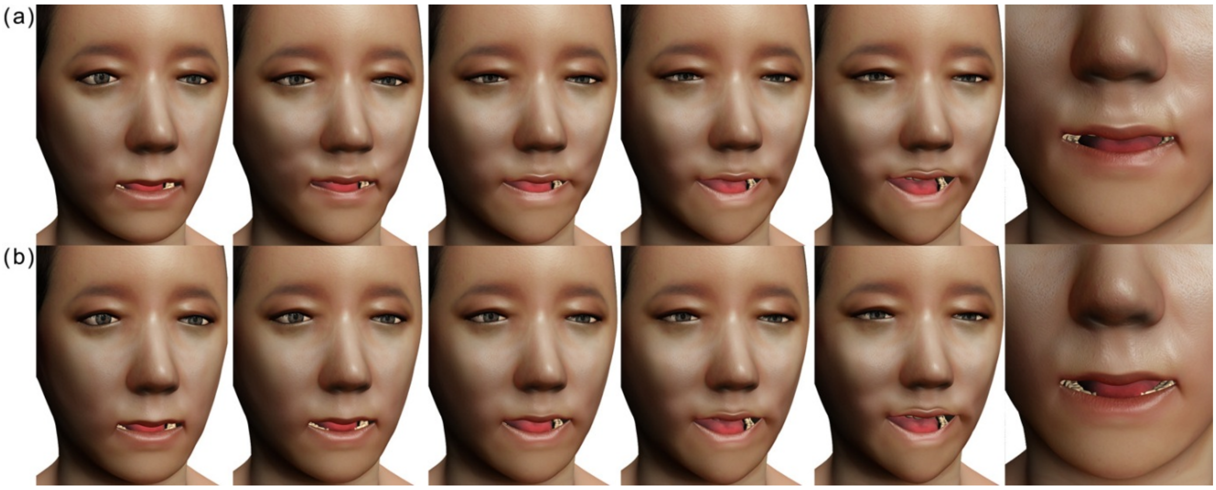


Fig. 31. Happiness expression comparison of (a) the MFAM and (b) the blend shaped model. From the left, the animation is compared at the 1st, 9th, 15th, 23rd, and 26th frames. The detailed images are from the 9th frame.

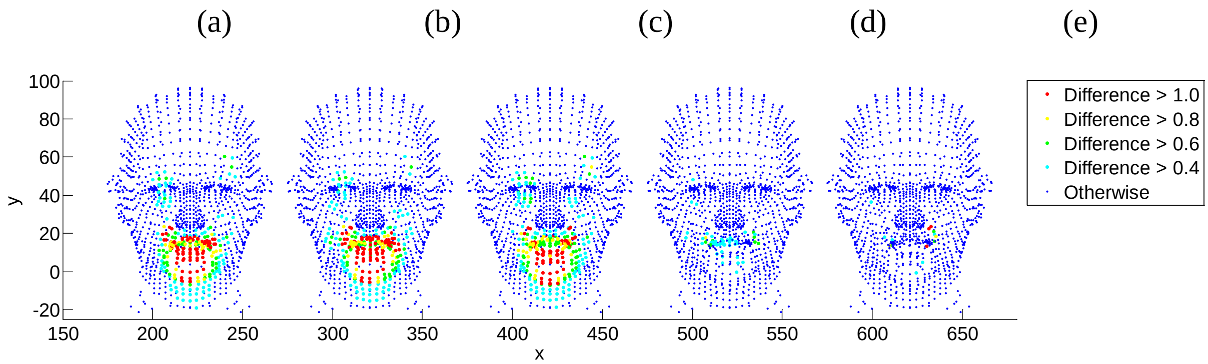


Fig. 32. Happiness expression vertex differences between the MFAM and the blend shaped model. Points are differences of vertices at (a) 11th, (b) 13th, (c) 19th, (d) 25th, and (e) 27th frame. Figure made by Seonyeong Park.

To verify performance for facial movements of the proposed MFAM, we animated and compared models with facial expressions using the method described in Section 3 and the blend shape method frequently used in facial animation. The used models had 1,336 polygons and the running time for expressions in both models was 26 frames. In this simulation, we conducted experiments on two major expressions: happiness and anger. We extracted facial models from the 1st and the 26th frame of our simulated model and blend shaped them, and the 1st and 26th frames of both animations were identical.

Fig. 31 shows the animated models with happiness: (a) the MFAM and the blend shaped model. In Fig. 32, we also show differences of vertices at the 11th, 13th, 19th, 25th, and 27th frame. Those five time frames were chosen based on the maximum and average difference graphs in Fig. 31. To observe differences in various facial areas, we selected the frames with positive extrema of the maximum and average differences since there were only discrepancies around the mouth area of two models at frames with the greatest values of graphs in Fig. 33. Red, yellow, green, cyan, and blue points in Fig. 32 show differences of coordinates that are larger than 1.0, 0.8 to 1.0, 0.6 to 0.8, 0.4 to 0.6, and below 0.4, respectively. Fig. 32 shows that facial movements around the mouth, eyes, and the nose of the two models considerably differed at the 11th, 13th, and 19th frame and those around the upper lip and the nose were dissimilar at the 25th and 27th frame.

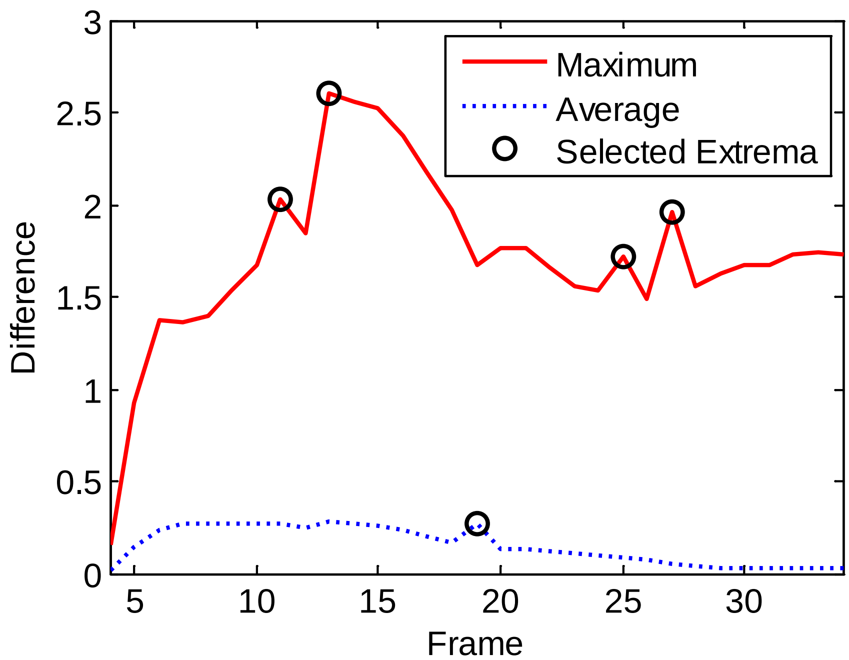


Fig. 33. Happiness expression maximum and average differences per frame between the MFAM and the blend shape model. A red line, a blue dotted line, and black circles indicate

the maximum difference, the average one, and the positive extrema for each line, respectively. Figure made by Seonyeong Park.

Fig. 33 presents the maximum and the average of differences between the MFAM and the blend shaped model per frame for happiness. We extracted only results from the 4th to 34th frame because variations were close to "0" at the beginning of having a positive expression (before the 4th frame) and when laughing fully (after the 34th frame). The red line, the blue dotted line, and black circles in Fig. 33 indicate the maximum difference, the average one, and the positive extrema for each line, respectively. The reason why dissimilarity in two models occurred as shown in Fig. 33 is that realistic distortion around the mouth, eyes, and the nose of the MFAM such as wrinkles and smile lines is not seen in the blend shaped model.

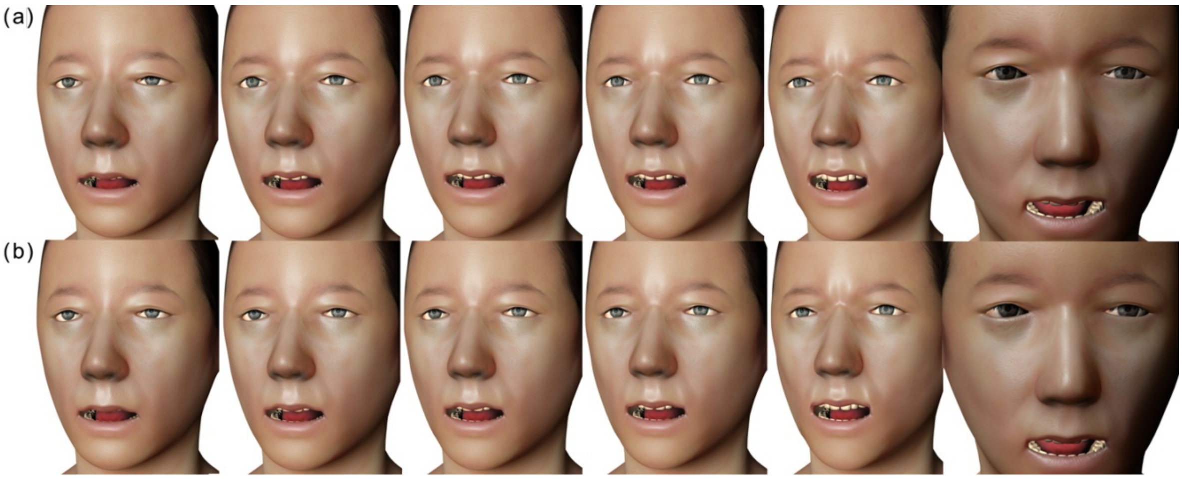


Fig. 34. Anger expression comparison of (a) MFAM and (b) blend shaped model. From the left, the animation is compared at 1st, 11th, 16th, 18th, and 26th frames. The detailed images are at 9th frame.

(a) (b) (c) (d) (e)

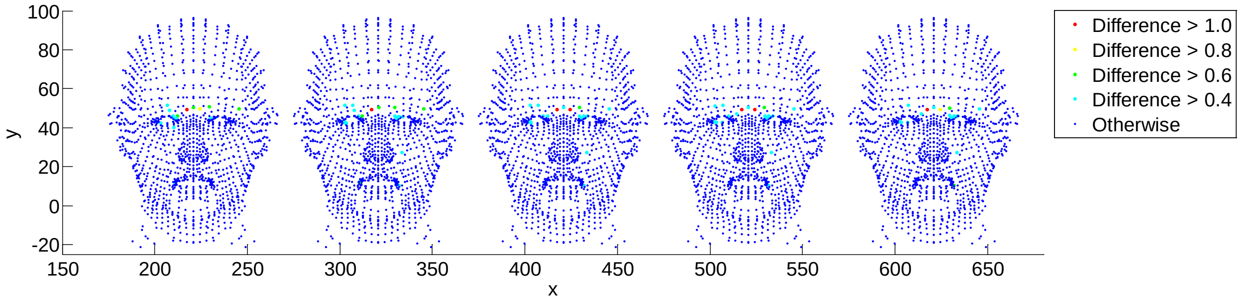


Fig. 35. Anger expression vertex differences between MFAM and blend shaped model. Points are differences of vertices at (a) 17th, (b) 18th, (c) 20th, (d) 21st, and (e) 22nd frames.

In Fig. 34, (a) and (b) are respectively the proposed model and the blend shaped model for an anger expression. Fig. 35 presents detailed vertex gaps between the MFAM and the blend shaped model at the 17th, 18th, 20th, 21st, and 22nd frame. Those five frames were chosen by the greatest values of the maximum (red line in Fig. 36) and average differences (blue dotted line in Fig. 36). Red, yellow, green, cyan, and blue points in Fig. 35 show identical differences of coordinates with those in Fig. 32. The result from Fig. 35 indicates that facial movements between eyebrows and around the mouth and the nose of two models differ at the 17th, 18th, 20th, 21st, and 22nd frame.

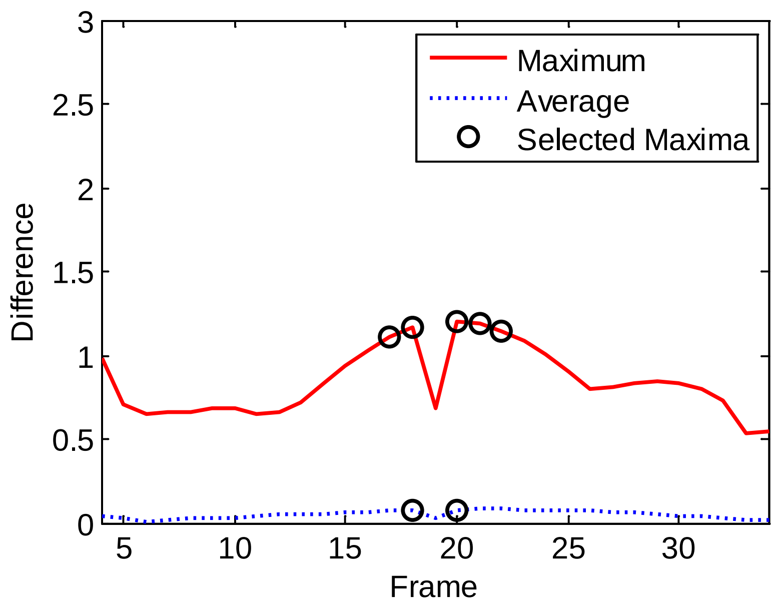


Fig. 36. Anger expression maximum and average differences per frame. A red line, a blue dotted line, and black circles indicate the maximum difference, the average one, and greatest values for each line, respectively.

Fig. 36 shows the maximum and the average of differences between the MFAM and the blend shaped model per frame for anger, and we extracted results between the 4th and 34th frames. The red line, the blue dotted line, and black circles in Fig. 36 are same to those in Fig. 33. In Fig. 36, we can see that overall average difference of the anger expression was highly low: while the highest maximum and average values for happiness in Fig. 33 were 2.71 and 0.29, those for anger in Fig. 36 were 1.25 and 0.08, respectively. Accordingly, we determined the rendering time with maxima, not positive extrema as marked with black circles in Fig. 36 because it was hard to observe dissimilarity at other frames. Like results for the happiness experiment, the proposed model had more realistic distortion of the skin from the 4th to 34th frame.

TABLE 12
ENHANCEMENT AREA PROPORTION IN COMPARISON WITH BLEND SHAPE

Expression	Difference level (%)	1.0	0.8	0.6	0.4
Happiness	Number of Vertices	29.10	53.71	86.90	146.29
	Enhancement Proportion	2.87	5.30	8.58	14.44
Anger	Number of Vertices	0.26	0.71	2.35	7.48
	Enhancement Proportion	0.03	0.07	0.23	0.74

Table 12 shows the enhancement area ratio of the proposed method in comparison with the blend shape methodfor happiness and anger. According to average difference degrees: above 1.0%, 0.8%, 0.6%, or 0.4%, we presented the average numbers of vertices that could express realistic facial distortions in the proposed method, but not in the blend shape method in Table 12. We also calculated corresponding ratio to the number of overall vertices for the front face. Here, the total number of vertices on the front side of the face used in the experiment was 1,013, and difference levels were proportions to the overall length of the face.

When average difference levels were above 1.0%, 0.8%, 0.6%, and 0.4%, enhancement area proportions of the proposed approach for happiness were 2.87%, 5.30%, 8.58%, and 0.4%, and those for anger were 0.03%, 0.07%, 0.23%, and 0.74%, respectively. Results in Table 12 of both happiness and anger expressions mean that the MFAM is able to express more subtle facial movement than the blend shaped model as amounts of corresponding area ratios. Furthermore, improvement degrees for happiness were greater than those for anger in common with results from Fig. 33 and 36.

5. Conclusions

We have presented the Multi-layered Facial Action Model based on analysis of human anatomy. Our goal was to achieve a realistic quality of facial animation by adapting anatomical information of facial structure and expression without using 3D scanned data. Our approach differs from the previous facial animation techniques, such as motion tracking or blend shape, since it significantly reduced the amount of time needed to process data.

The experimental results for the MFAM method showed its realistic quality and effectiveness as compared with performance-based and blend shape-based approaches, and existing motion unit systems such as those described in [76], [77], [78], and [83]. MFMA realized facial motions better: by 2.87% and 0.03% of facial area for happiness and anger expressions, respectively, when compared with the blend shape technique.

IV. OVERVIEW OF CULTURALLY-SPECIFIC ATTRACTIVE FACE: *KOT-MI-NAM* - MALE FACES IN KOREAN POPULAR CULTURE

1. Introduction

This section gives an overview of the culturally-specific attractive face by both quantitative and qualitative analysis on related terms, facial forms, and contextual overview. Korean “kot-mi-nam [119]” phenomena emerging from female youth pop culture since the 2000s was selected as a case study. ABC News reported the visibility “kot-mi-nam (flower men) culture while stressing that Korean men purchased nearly 21 percent of global sales of men’s cosmetics in 2011 [120].

Regardless of hypotheses that there are universal values in terms of facial attractiveness such as ratio [121], averageness [33], [34], symmetry [39], [122] and sexual dimorphism [42], [39], [43], many recent studies produced contrary evidences that the facial attractiveness in fact varies depending on time, race, culture, gender, and personal preference [36], [88], [89], [90], [91], [92], [93], [94]. W. Dawei et al. [89], L.G. Farkas et al. [90], L. Le et al. [91] suggested that the classic or neoclassical canons are not applicable to other races, and C. Apicella et al. [36] and C G. Rhode et al. [92] concludes that the perception of attractiveness of own/other/mixed race is different in each culture. S. Rhee et al. [93], [94] proposes a new photogrammetric facial analysis of attractive Korean celebrities’ faces, arguing that facial analysis should consider the demographic factors of the subjects and the scales of attractiveness rather than on average values.

Through textual, visual, and contextual overviews, the subjective values of attractive faces in different genders, cultures, and races are suggested in the context of “glocalized [123]” culturally-specific markets. As T. Friedman [124] defined glocalization: if a culture encounters other strong cultures, it absorbs strong cultures’ influences into the original and metamorphoses, so that it could enrich its own culture. As the cultural trade increases among

Asian countries, female Asian pop culture and images of kot-mi-nam seems not only to globalize, but also to localize, which will be further discussed in following sections.

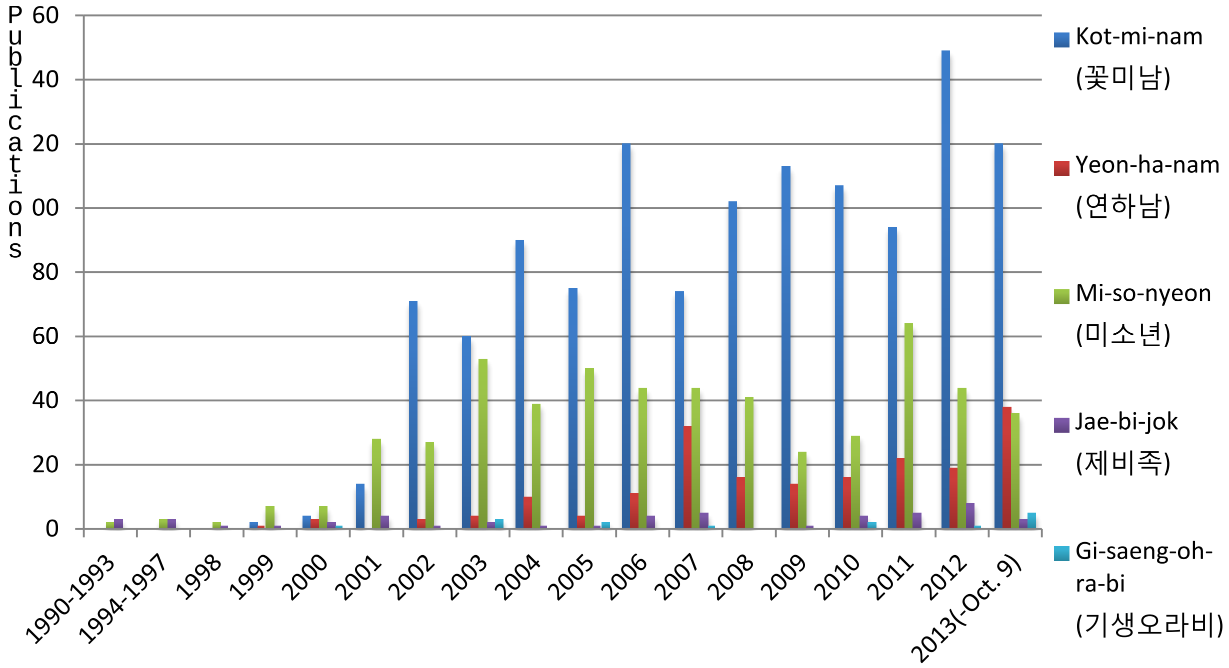
Section B introduces Korean terms illustrating men's certain looks and facial expressions, which cannot be translated to single English terms. While Section B. 1. discusses meanings and frequencies of usage of the term kot-mi-nam and its related terms in the Korean publications, Section B. 2. discusses Korean terms illustrating certain facial expressions or gestures that sexually appeal to the opposite sex. Section C. analyzes the average 3D face of Kot-mi-nam. Section D. gives an overview of cultural and historical context of Korean pop culture: korean female subculture and foreign influences including Japanese idols, Visual Kie, Western pop culture, and girls manga culture from Japan. In Section E. I conclude my discussion of kot-mi-nam culture.

2. Korean terms illustrating men's certain looks and facial expressions

2.1 Terms denoting Men's particular looks - Kot-Mi-Nam, Gi-saeng-o-ra-bi, Je-bi-jok, and Idol, Yun-ha-nam, Mi-so-nyeon, Yeon-ha-nam

TABLE 13

FREQUENCIES OF THE TERMS KOT-MI-NAM AND RELATED TERMS APPEAR IN THE BOOK TITLESOR SUMMARIES



In this section, the frequencies of usage of the Korean term "kot-mi-nam(꽃미남, 花美男))" and related terms in publications in Korea have dramatically increased recently. In my research I counted frequencies in publications, including novels, essays, magazines, periodicals, and visual novels, each year using book search engine Naver Book, covering approximately 6,000,000 books published in Korea. As shown in Table 13, the quantity of usage of five terms in publications were counted: "kot-mi-nam" referring to a flower-like beautiful guy, "yeon-ha-nam" referring to a younger guy, "mi-so-nyeon" referring to a pretty boy, "jae-bi-jok" meaning similar to "kept man," and "gi-seng-oh-ra-bi" negatively referring to an effeminate guy. The detailed meanings and context will be further explained.

Kot-mi-nam denotes a certain men's look, which used to be slang but became a popular word in the mainstream culture in the early 2000s. The word "kot-mi-nam" is composed of three Chinese characters: 花, flower, 美, beauty, 男, male. Literally, it means flower-like beautiful guy. As "flower" in this word conflicts the conventional image of masculinity both in Korea and in the West, this word involves a lot of controversial issues including commercialization of male sexuality, subversion of the dichotomies of masculinity and femininity; and westernization and globalization of gender images and sexuality, etc.

Kot-mi-nam denotes a specific young male who has a pretty and relatively small face, usually has a slim body line and clean skin which is closer to females' beauty, rather than males. It is often used by young women as their preference of male types. As the most frequent users of the word are young Korean females, the word itself and the images associated with the word often appear in products of young female cultures: Manga (Japanese-style comic book), TV drama, idol stars, and so on. K. Kim et al. explains that Korean women in the twenty-first century are fanatical about effeminate looks of Kot-mi-nam that resemble looks of the male characters Terry or Anthony in the Japanese manga series “Candy Candy [125],”one of the most famous teenage manga series, first released in 1975, instead of “macho” looks, which many Korean women used to love for several decades [126].

Meanwhile, in the west, images of kot-mi-nam may look like feminine, androgynous, metrosexual or even homosexual by their standards. The meaning of the word may be closer to “Adonis” or “metrosexual,” but the images of the word may be much more feminine, pubescent or pre-pubescent than the Western images of “Adonis” or “metrosexual.” In addition, the fashion styles of commercial images of kot-mi-nam and their poses are visibly different from those of “Adonis” or “metrosexual” in the west as they contain many elements usually associated with western females. In fact, many westerners merely can read the images of “kot-mi-nam” in terms of Westernization, as many of them do not have any background knowledge of modern Korean culture.

As shown in Table 13, the term Kot-mi-nam first appeared in Korea in 1999, in the official publication, Japanese manga “Boys over Flower [127],” originally published in Japan from 1992-2003. “Boys over Flower” played an important role to firm “glocalized [123]” market for young women in East and South East Asia. The frequency of the term appearing in publications has dramatically increased since 2000; in 2013, it appeared in the title or summary of 149 publications including essays, novels, magazines, journals, and visual novels.

Increasing usage of the term “kot-mi-nam” also represents a growing market of Korean young females’ subculture, as the term is often used by young females to express taste and culture. Many teen females in Korea adore male idols and fantasize about “kot-mi-nam” reading “sun-jung man-hya” in Korean or “bishonen manga” in Japanese. These are comic books in which pretty young boys have romantic encounters with relatively ordinary girl or sometimes another pretty boy.

“Mi-so-nyeon” means a pretty boy, which often appears in “sun-jung man-hya.” As shown in Table 13, the usage of the term in publications has steadily increased since 1990; with an average usage of about 40 times per year since 2001. Yeon-ha-nam is used when a woman refers to a man who is younger than her, especially men she is dating. The usage of the term yeon-ha-nam in publications has been also fairly increased since 1999.

Meanwhile, older generations in Korea used to call the indicator as “gi-saeng-oh-ra-bi (기생오라비)” which literally means Gisaeng’s brother. Gisaeng indicates the class of Korean traditional women similar to Japanese geisha or the ancient Greek hetaerae, who are entertainers and often engage in prostitution for high class males. Gisaeng was educated to be “Gisaeng” to behave, write poems, draw, sing, and dance so that they can entertain high-class men properly. “Gisaeng” disappeared at the end of the Joseon Dynesty at the beginning of

Japanese colonization [128]. However, the origin of the term “gi-saeng-o-ra-bi” is still ambiguous as it indicates not “Gisaeng” but her brother or lover. Nowadays, “gi-saeng-oh-ra-bi” is mostly used negatively, when the man adorns himself too much and looks effeminate.

There is another term which emerged around early 1970s, which is “jae-bi-jok (제비족)” indicating male groups who hang around Korean style night clubs and are paid to be the lover of rich, older and usually married women, similar to ‘gigolo’ or ‘kept man’ in the west. The stereotyped image of “jae-bi-jok” is a young dandy guy wearing a swallow-tailed coat, dancing with an older woman on the stage, and seducing her for economic purpose. The word itself directly reflects the stereotyped image of the word as it consists of “jae-bi” which means “swallow,” which might come from a swallow-tailed coat, and “jok” which means “group.”

Both “gi-saeng-oh-ra-bi” and “jae-bi-jok” are used negatively, and are related to a male prostitute directly or indirectly. As shown in Table 13, while “gi-sang-oh-ra-bi” appeared an average of 2.7 times per year in publications, “jae-bi-jok appeared an average of 2.15 times per year, which is relatively low. Even though publications use both terms occasionally, both terms are not popularly used among the younger generation born after the late 1970’s, and many prefer to use “kot-mi-nam” as a positive term fantasizing about the images of “kot-mi-nam.”

Meanwhile, there is a term being used for new contexts since the 1990s: “idol.” Even though “idol” is originally an English term, it is used differently in Korea. Koreans often use “idol” when singers are especially popular among teenagers and formed by talent agencies, not by themselves. Members of recent male “idol” groups are mostly in their teens or twenties and their looks are often considered as “kot-mi-nam.” Also, those idol singers or groups have specific characteristics distinguished from other singers, as they have been formed by several talent agencies such as SM Entertainment and YG Entertainment, especially targeting teenagers. In fact, systems of talent agencies have many similarities with those of Japanese, as they use “idol” in terms of similar meaning to that of Korean, which will be further discussed later in the contextual analysis. The term “idol” was not included in Table 13 since the term is not gender-specific, and it still have meanings of “idol” in English.

2.2 Korean Terms for Attractive/Adorable Facial Expressions and gestures: ae-gyo, zzing-gut, and me-rong

The Korean word “ae-gyo (애교),” which indicates “charms,” “winsomeness,” or “attractiveness” in Dong-a’s Prime Korean-English dictionary, has different nuance from those English words. “Ae-gyo” has been usually used in describing young females’ behaviors especially when young females ask males to do something for them. For example, if the girl’s boyfriend got upset because she was late, she says ‘sorry’ with a nasal voice and shakes her shoulder slightly. The main point of having “ae-gyo” is acting like a lovely child. Therefore, the words like “shyness,” “cuteness,” or “immatureness” are closely related to “ae-gyo.” However, recently “ae-gyo” is also used in describing young males’ behavior which is similar to females’, and those behaviors are considered positively as “cute” or “ae-gyo,” rather than “girly” among young females.

There are many Korean words which describe behaviors of “ae-gyo”, which are untranslatable into direct English words. “zzing-gut(찡긋)” describes the act of squinching one’s nose and eyes for a short time while smiling. “me-rong(메롱)” describes the act of sticking out one’s tongue and also used as the word itself by means of teasing others. Its meaning is similar to saying “neh neh neh boo boo,” but the intention of saying “me-rong” is more likely to be “cute” by using a child’s term, not to actually tease others.

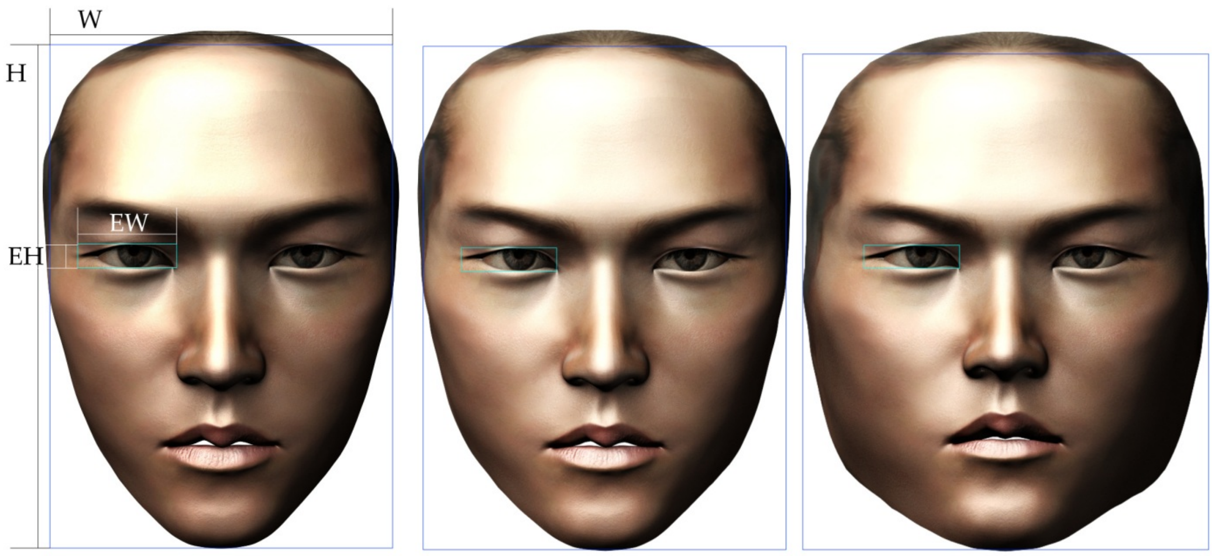
Therefore, even if one uses the same gestures and wears the same clothes, people in different cultures interpret them in different ways according to their logic of interpretation of gestures and clothes. Furthermore, people in different culture differently select the recognizable elements among his whole image, and understand his image according to the elements they have found. The degree of different interpretation is connected to the degree of cultural differences.

3. Visual Analysis of Kot-mi-nam Images

3.1 Facial Analysis of an average 3D kot-mi-nam face

This section analyzes an average 3D face (Fig. 37) of three male celebrities: two korean celebrities Jaejoong Kim and Junki Song, and Japanese visual rocker Hyde, who are considered Kot-mi-nam in East Asia. Three faces were modeled in Maya and Mudbox using the Bazier Curve-based Facial Customization (BCFC) model, which will be illustrated in Chapter 2. The three models were blended using the blend shape tool in Maya.

(a) (b)
(c)
Fig. 37. (a) front, (b) front-side, and (c) side views of an average 3D face of Hyde, Jaejoong Kim, and Junki Song



(a) (b) (c)
Fig. 38. An average 3D face of Hyde, Jaejoong Kim, and Junki Song in different camera angels and focal lengths: (a) angle of view: 37°, focal length: 54 mm, (b) angle of view: 24°, focal lengh: 85 mm, and (c) orthographic view (W: face width, H: height, EW: eye width, and EH: eye height).

There is a problem when modeling celebrity faces from photo references; each photograph has a different focal length and angle of view that changes the ratio and shapes of facial features and contours. As shown in Fig. 38 (a), (b), and (c), front views of a model look significantly different from each other in different camera settings. Fig. 38 (a) used 37° for the angle of view and 54 mm in focal length, while Fig. 38 (b) used 24° for the angle of view and 85 mm in focal length. Fig. 38 (c) is an orthographic view of the model using pallallel projection of two axes: X and Y.

TABLE 14
FACIAL RATIO OF FIG 38 (A), (B), AND (C)

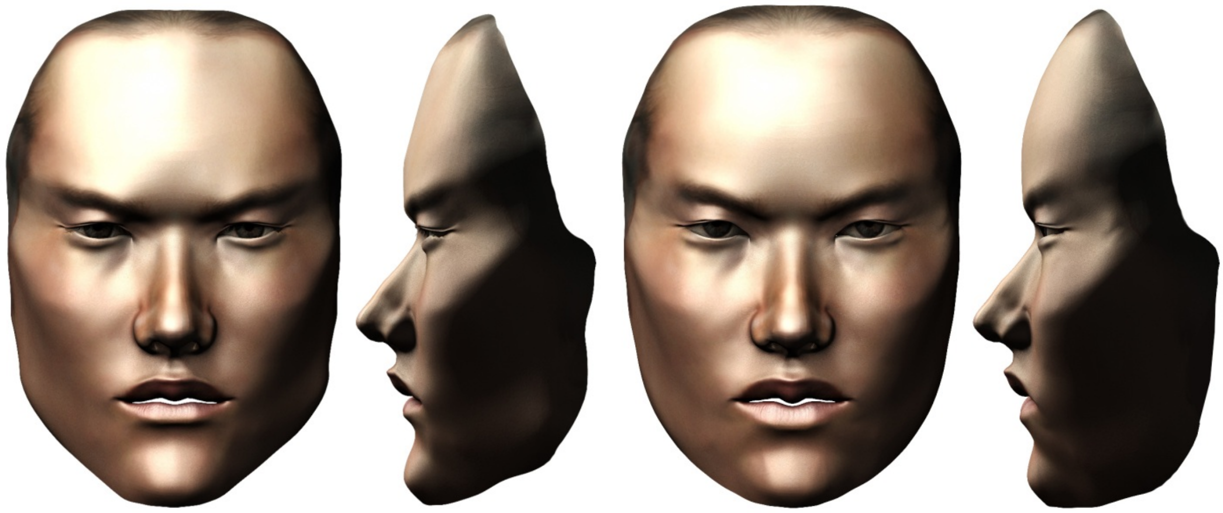
File name	Fig. 38 (a)	Fig. 38 (b)	Fig. 38 (c)
W/H	0.68	0.72	0.82
EW/EH	4.23	4.28	4.11
W/EW	3.46	3.80	4.25

As listed in Table 14, the width to height ratio of the face, eye, and the ratio of the face width to the eye width are different in Fig. 38 (a), (b), and (c). The higher angle of view and lower focal length the camera has, the longer face, longer eye width, and larger facial features the face has. Therefore, it can be concluded that there may be substantial differences between the facial ratio measured from the photographs and the ratio measured from actual models.

TABLE 15
GENDER AND RACIAL PROBABILITIES OF KOT-MI-NAM AVERAGE FACE IN COMPARISON TO BCFC ASIAN MALE FACES

File name		Fig. 38 (a)	Fig. 38 (b)	Fig. 38 (c)	BCFC Asian male 1	BCFC Asian male 2
Gender	Male	**50.38**	**50.38**	**50.38**	**79.40**	**75.98**
	Female	49.62	49.62	49.62	20.60	24.01
Race	Western	**66.50**	**66.42**	**66.42**	24.96	21.18
	Asian	16.63	16.68	16.68	**60.41**	**59.80**
	African	16.87	16.90	16.90	14.63	19.02

The gender and racial specificity of the average kot-mi-nam face was analyzed in Table 15, using BCFC, developed while collaborating with S. Park.. The facial images in different camera settings (Fig. 38 (a), (b), (c)) and BCFC Asian male 1 and 2 were compared. Regarding BCFC Asian male 1 and 2, the base model was morphed into two Asian models using BCFC which are illustrated in Chapter 2. Fig. 39 shows (a) front (angle of view: 25°, focal length: 81 mm) and (b) side views of Asian male face 1, and (c) front (angle of view: 25°, focal length: 81 mm) and (d) side views of Asian male face 2. As shown in Table 15, an average kot-mi-man face is close to gender neutral (50:38 male and 49.62 female) and Western (66.42~66.50). Meanwhile, BCFC Asian model 1 and 2 is close to male (79.40 and 75.98) and Asian (60.41 and 59.80).



(a) (b) (c)

(d)

Fig. 39. Customized Asian male faces using Bezier Curve-based Facial BCFC model. The base model was morphed into two Asian models: (a) front (angle of view: 25°, focal length: 81 mm) and (b) side views of Asian male face 1, and (c) front (angle of view: 25°, focal length: 81 mm) and (d) side views of Asian male face 2.

In fact, a range of heterosexual male sexuality in thepopular and commercial market in Korea is much wider than that of the West. Since there is no definite stereotype of homosexual images and heterosexual images, male idols and actors produce both feminine and masculine images to attract female consumers. S. Jung discusses that versatile masculinity has been produced from disguised female to muscular male images in South

Korean idol culture [129]. While kot-mi-nam's facial features are also closer to the Western female beauties, there are male celebrities who are considered "handsome," who usually have more masculine facial and body features. S. Rhee [130] released two average faces: from sixteen Korean male celebrities considered kot-mi-nam and from sixteen Korean male celebrities considered handsome "Korean wave" [131], [132] male stars. Using online face analyzing program BAPA (Balanced Angular and Proportional Analysis), he analyzed differences between the two faces. He concluded that his average kot-mi-nam face has a longer face, a shorter and smaller jaw bone, sharper eyes, a sharper and longer nose, smaller lips, less prominent cheek bones, and a slimmer chin line. Unlike research from the West [133], [134], [135] suggesting that attractive faces of both sexes tend to have prominent cheek bones, kot-mi-nam faces tend to have less prominent cheek bones and slender chin lines which seems to be related to neotony [48], [49].

The analysis of an average kot-mi-nam face has an issue: it does not contain the information of skin condition, hairstyle, make up, and ornaments. The skin condition and hairstyle is a crucial factor when defining kot-mi-nam; kot-mi-nam males tend to have lighter and youthful skin conditions and spend a considerable amount of time and effort to style their hair. The importance of men's skin condition and hairstyle resulted in the abrupt growth of the men's skincare and beauty market [119], which will be further discussed in the following section.

3.2 Commercialization of male sexuality in kot-mi-nam images: pose, gaze, and pictorial values.

In addition to the structural codes of the face, such as facial form and features, pictorial codes such as pose, perspective, composition, light, contrast, and color scheme [10],

[12] also construct images of kot-mi-nam. Since the main consumers of kot-mi-nam images are women, their desires and fantasies are often projected to images of kot-mi-nam, while objectifying them.

Fig. 40. Outline drawings based on photographs of Korean actor Jong Suk Lee (a), (b), and singer Jaejoong Kim (c), (d).

In fact, poses and gestures of male idols vary from submissive to macho. As shown in Fig. 40, male idols, especially those who are considered kot-mi-nam or yeon-ha-nam (younger man), often have submissive poses in their photos such as lying down on the ground, sofa, or bed or leaning on the wall or furniture, which may be considered feminine or vulnerable poses from the Western viewpoint. Even when they stand up, they usually relax their bodies to create soft silhouette to invite viewers, noticeably different from heroic poses of Superman or body builders showing off their muscles. Male idols who are considered more masculine tend to have more macho poses (see [136]).

Now a large portion of scriptwriters of TV dramas and TV shows for mainstream broadcasters, photographers, editors, and steps of magazines are females, and dominant consumers of TV dramas and male idol products are also females of various ages. It is natural that main consumers and producers of images of Kot-mi-nam are female, since the term itself was coined in teen female culture. I will discuss several photographs of male idols and actors taken by female photographers to illustrate how female gaze and female tastes are becoming visible.

L. Mulvey discussed the psychoanalytic mechanism of “the images of woman as (passive) raw material for the (active) gaze of man” in traditional narrative films. She argues that the representation of woman in films signifies castration, which allows the viewer’s fetishistic and voyeuristic pleasure. She successfully pointed out the mechanisms of the invisible viewer’s gaze toward the object in visual media. However, regardless of her discussions of patriarchic power struggles between the active male viewer and the passive female object, kot-mi-nam images show that this mechanism can apply regardless of genders.

A photograph of an actor Chun-hee Lee by the female photographer Bo Lee, released in the magazine W in September 2008, explicitly shows female gaze (see [137].) In this medium shot, Chun-hee Lee is lying on his stomach on the tall grass, exposing his naked upper body. In her interview in the GQ magazine [138] she selected Chun-hee Lee as a model due to his "light and clean" body shape. She added that she discovered the new aspect of

Chun-hee Lee from his "sophisticated and emotional" naked back. The title of this work is "Heavenly Creature." The model is objectified and beautified. The pose of the model is vulnerable while inviting the gaze of female viewers.

Meanwhile in a photograph series of one of the top male idol dance groups, 2PM, titled "Projection of Desire," taken by the photographer Sun-hee Lee, shows women's fantasies of male sexuality, see [136]. 2PM members are called "animal idols" due to their muscular bodies and their performance of tearing their shirts off on stage. The photographer Sun-hee Lee intentionally put popular elements of Kot-mi-nam images such as a flower, covering one eye, and two boys touching each other in her photographs. Many photographers often concentrate on capturing moments of idol group members playing with each other while naturally hugging or touching each other, sometimes like friends and sometimes like lovers. However, washed out and grayish color tones and the strong contrast in these photographs are not stereotypical settings of images of Kot-mi-nam.

4. Contextual overview of kot-mi-nam culture

4.1 Korean Subculture

a. Glocalzation of East and South East Asian Market

This section illustrates social circumstances of Korea to understand the phenomena in a broader sense. Since the 1990s, idol singers have dominated markets of Korean music industries. They are not only active in Korea, but have also successfully entered the mainstream market in neighboring countries such as Japan, China, Taiwan, and Thailand. They are active both in Korea and Japan, frequently having Asia concert tours and receiving numerous music awards throughout East and South Asia. For instance, Korean idol male dance group, TVXQ, has released albums in the native languages of Japan and Korea. To be localized in Japan, many members have learned Japanese intensively so proficiently that they perform on TV shows, dramas, and popular radios. In 2008, they became the fifth non-Japanese Asian artist and the first male foreign group to have a number-one single on the chart [139].

S.M Entertainment [140], a Korean entertainment enterprise established in 1995, has produced numerous top idol groups including “H.O.T.,” “Sin-hwa,” “TVXQ,” and “Super Junior” and have played an important role in forming a Korean version of “idol” singers. SM Entertainment includes business of planning/making/distributing music CD, publishing, licensing, singer/actor management, agency, star marketing, and internet/mobile contents. SM Entertainment listed in KOSDAQ in April 2000, for the first time as a Korean entertainment enterprise. As S.M mainly focused on Asian markets, it established S.M Japan office in 2001 and S.M China office in 2003 [140].

S.M. has used localizing tactics, rather than just exporting Korean contents produced in Korean language and in Korean contexts. To do so, they have recruited preliminary singers from many countries including Korea, China, Japan, and even in Korea towns in the USA to overcome linguistic and cultural differences, and made an effort to educate preliminary singers about foreign languages and cultures. For instance, the most successful case is a female singer Boa who has been active both in Japan and Korea since 2000. She had her official debut at the age of thirteen in Korea, and launched her debut next year in Japan. Since Boa was groomed to be a superstar by S. M since her childhood, she fluently speaks Japanese, proficient English, and shows outstanding performance of singing and dancing as the result of hard training. In Japan, all four albums she released have been top-ranked in Oricon, which is similar to the Billboard top 100 chart in the USA, which shows that their localizing tactics are successful [141].

As success of Boa and TVXQ in East and South East Asia demonstrates, "pretty-boy-loving" phenomena are recognizable throughout East and South East Asian countries. For instance, "Boys over Flowers," the Japanese Bishonen (pretty boy) manga series popular among Asian school girls published in 1992 to 2003, has been adopted into a TV drama in Taiwan in 2001. Later, the drama was exported to Japan, Korea, China, and South Asia. Japan also produced a TV drama in 2007, and Korea released their version in 2009. It shows the possibility of more interactive cultural trade among Asian countries. Following the export of Japanese pop culture to other Asian cultures, Korean pop cultural products, especially TV dramas and idol, successfully made inroads to East Asian markets, which is called *hanryu*, "Korean Wave" in Chinnese [131], [132].

Therefore, it is more proper to understand Asian pop culture in the context of "glocalization [123], [124]," rather than "globalization." As the cultural trade increases among Asian countries, Asian pop culture and images of kot-mi-nam seem not only to globalize, but also to localize.

b. Jun-gi Lee Phenomenon in 2005

There was a significant turning point in Korea that the androgynous images of male bodies and boy-loves-boy fantasies became phenomenally popular in Korea. The origin of this phenomenon could be attributed to Jun-gi Lee's movie, *The King and the Clown* in 2005. The story is a fiction based on a real historical figure, Yeonsangun of Joseon. In the movie, a Joseon dynasty king falls in love with a male court clown, Jun-gi Lee, who mocks him. Despite the story's focus on homosexual themes, the film gained an unexpectedly huge popularity in Korea that grossed more than any South Korean movies before it [142], [143]. However, the film was banned from screening in China due to the homoerotic content in it.

Following his special popularity among females, Jun-gi Lee emerged as an iconic image of kot=mi-nam. His unique aesthetic qualities served as distinctions from the established male actor; a key difference is Jun-gi Lee's cosmetic make-up including eye lines. Since Jungi Lee phenomenon, female transvestites, cross-dressing, love between boys became popular subjects in TV dramas and shows in mainstream broadcasters, and the majorities of scriptwriters and steps are females in these kinds of dramas [144].

The ubiquity and popularity of Kot-mi-nam images not only influence on female cultures, but also on young male culture. After Jun-gi Lee phenomena, many young males in Korea became interested in cosmetics, fashion, and taking photos of themselves. Cleansing foams, toners and lotions, and wearing tinted lotions, called BB cream, are commonly used among young males, and some of them even wear eye make-up. Recently, it was reported that South Korean men spent $495.5 million on skincare in 2012, accounting for nearly 21 percent of global sales, according to global market research firm Euromonitor International; one-tenth of them wear makeup on a daily basis [119].

There is another important phenomenon: growing markets of female night culture. Since women gained social and economic power, the bars and nightclubs only targeting female consumers emerged. Some of them like Host bar(호스트바/호빠), originated from Japan, involve male prostitution, and others such as Model bar(모델바) and Bar for women(여성전용바) just offer services like good looking guys pouring drinks, singing, dancing, and talking to amuse female consumers (Seo 2009).

4.2 Foreign Influences

The phenomena of commercialization of male bodies and a variety of growing markets for female consumers, in fact, influenced by various sources. There are four noticeable influences from outer cultures: Japanese male idols, Visual Kie (visual rock in Japan), Western pop culture, and girls' Manga - Bishonen, Yaoi, and BL.

a. Male Idols in Japan

Looks of Korean male idols have many similarities with Japanese, as they use “idol” in terms of similar meaning to that of Korean. Johnny’s Jimusho, established by Johnny Kitagawa in the early 1960s, is initiative enterprise which have formed the idea of Asian version of “a male idol.” Johnny’s Jimusho has dominated the boy-band market for four decades, annually making in excess of 3 billion yen. It is within bounds to say that most Japanese male idols are members of Johnny’s Jimusho. Over 90 percent of male models in teenage magazines including Myojo, Potato and Wink-up are Johnny’s juniors, and those magazines are actually leading the young males’ fashion trend [145], [146].

Even if they form “singers,” Johnny’s Jimusho has used a unique way to form them; it forms boy-bands “after” members of the band gain popularity. To take an instance, when the popular TV show “the shounen (boy) club [147]” broadcasted by NHK once a week (a main broadcaster in Japan) opens, about 50 boys are dancing on the stage. Behind and in front of them, numerous girl fans are raising their arms, clapping and screaming. All performers are 11 to 18 years old boys called “Johnny’s juniors,” who are members of Johnny’s Jimusho talent agency. As they sing, dance, chat with each other, and act in the show, girl fans figure out each member’s appeal and talents. In fact, Johnny’s juniors are that they are not officially debuted. Only a few of them who gain enough popularity from fans make official debuts later as singers. Because fans watch the star growing up since his childhood, they have strong affection for the star as if they are acquainted with him.

In the images of Japanese male idols published in Japanese teen Magazine such as ANAN [148] , Wink Up [149], Potato, and News, products of Johnny's Jimusho background and text colors are usually pastel colors such as pink, lilac, or light blue which are considered as girly colors. The models usually have pretty oval faces and slender bodies. Their poses are also effeminate: resting his chin on his hand or lying and gazing at the camera. As they are in their teens, they often wear high school uniforms in TV and magazines, which may relate to fantasies around high school uniforms.

Even if images of Johnny's juniors are far from stereotypical masculine sexuality, they definitely imply certain sexuality often used by female models. The facial expression such as gazing the camera with half opened mouth and a submissive pose such as lying on the ground often have been used for feminine sexuality. However, those behaviors are in fact more related to power game: being docile and submissive to the viewers. For instance, in the photograph of Yamashita took in 2004, the photographer juxtaposed seminude Yamashita with colorful flowers which generally implies female sexuality. Nevertheless, the red flower that Yamashita is holding evokes a phallic figure. Even if it is still ambiguous, he seems to be lying down and camera is looking down his face. He is gazing at the camera with half-opened mouth which seems to wears lipsticks. His necklace is also very delicately thin which women usually wear. The high contrast and vividness of the picture create exotic mood.

b. Visual Kie in Japan

Visual Kie denotes a Japanese rock trend popular in the 1980s and the 1990s. It may be similar to glam rock in England in the 1970s. Visual rockers concentrated on their visual looks as much as their music as a means of expression [150]. They usually donned heavy make-up, dyed and puffed their long hair, and wore provocative or androgynous costumes, many of which had historical themes. They have both enthusiastic male and female fans, while male “idols” in Japan and Korea mostly have female fans.

Visual Kie explored various costumes from female clothing to French Gothic. For instance, Gackt, a vocalist of Malic Mizer, explores traditional costumes in different eras and areas ranging from Japanese Kimono to French Gothic , and enjoys combining costumes from various cultures in different era. His image has been adopted by video game characters such as prince “Scar” in “Final Fantasy 7.” This three-dimensional virtual character is a direct model of Gackt’s face and style.

Meanwhile, in the photograph of Hide took in 1989, another member of X Japan, does not exactly look like a drag, even though he is wearing make up with long hair. The reason is that the way he makes up does not fit in any conventional images of people in specific status. Hide is wearing a bindi in the center of the forehead close to the eyebrows from India, headband with oriental patterns and ornaments, with puffed dyed hair such as western heavy metal rockers’. Furthermore, his elaborate make-up evokes Japanese traditional theatre “Kabuki,” rather than western females’ make-up. X Japan often combined various visual sources from Western and Eastern cultures into one unique image by their own manner.

c. Western Pop Culture

Even if dominant consumers of male idols are heterosexual, Queer or gender-challenging images in the West have directly or indirectly influenced male “idols” in Japan and Korea, rather than the dominant ideal American male images such as muscular heroes. The unconventional gender images broadly range from the monstrous characters in literature such as witches and Dracula to 1970's political images representing gay liberation. For instance, a 1969 subscription advertisement for Gay Power represents a nude male who has a long hair with purple wings that symbolize the utopian concept of a gay person who is free from sexual and racial stereotypes [151]. Images of young or pubescent males with wings have popularly appeared in bishonen manga, Visual Kie, and Japanese and Korean male idols' images. The types of wings are various including white angelic wings, black satanic wings or butterflies' wings, and each wing may denote and connote different things. Nowadays, wings are broadly used in commercialized body images and mean various things, but it broadly still means "a person free from or above something conventional." Meanwhile, another subscription advertisement of Gay Power in 1970 shows more prominent similarities with images of Japanese and Korean male idols in that they both have effeminate slim body shapes, long hair, and feminine delicacy and decorative patterns and fashions [152].

While many of their images have been used as political representations in the West, those images have flown into Asian pop cultures without any information of the specific politics behind them. Therefore, Asian females' pop cultures could adopt queer images selectively which especially have appealed to Asian female consumers. It is not about politics anymore, but about taste.

d. Girl's manga - bishonen, yaoi, and BL

The forth influence, female manga culture, will be the most crucial in terms of kot-mi-nam culture, since it enables viewers and producers actively objectify and fantasize male body images. In fact, many teen females in the Korea fantasize about "kot-mi-nam" reading "Sun-Jung Man-hya" in Korean or "Bishonen Manga" in Japanese (comic books in which pretty young boys have romantic encounters with relatively ordinary girl or sometimes another pretty boy), and adore male idols. Kot-mi-nam images of Male idols and Sun-gung Man-hya are considered representative emblems female teen culture in Korea.

In terms of bishonen manga, majority of aritsts are female and they developed their unique styles of beatifying male bodies. For instance, in famous bishonen Manga, *Angel Santuary*, the woman artist Kaori Yuki beautifies effeminate young male bodies in her drawings. She likes to draw elements of floating movement of hair, clothes, flower petals, and strings. Figures of her male characters are mostly lean, feeble, and feminine.

Meanwhile, there is a subgenre of Bishonen manga which is called Yaoi or BL (Boy love). Yaoi was a genre that focuses on homoerotic male relationships produced by female artists and writers and consumed mostly by female consumers. The term Yaoi emerged in the late 1970s from dojinshi, self-published works by amateur artists, that often make parody of mainstream anime and manga. While the original Yaoi works focused on the pornographic portrayal of male characters, after Yaoi magazines June gained the great popularity among young females, the sexually explicit scenes are toned down for larger audiences. However, hardcore Yaoi works are still published as was as soft Yaoi. The main characteristic of Yaoi is the excessive beautification of male bodies and description of sexual relations, and the decadent atmosphere throughout works [153], [154]

After 1990s, a new subgenre of Yaoi, emerged for even larger female audience, which is called BL. The main feature of BL works is that there is no explicit portrayal of sexual intercourse. The portrayal is indirect or symbolic. Therefore, scenario became more organized and sophisticated in BL works.

Common relationships between two male characters in Yaoi or BL works are not equal but gong-su (공수), which means offense and defense or attack and receive. In Korea, Yaoi or BL works are often called Yeo-Yeong-Hyang(여성향), which means Females' taste [155], [156].

5. Conclusion

In this chapter, a culturally-specific attractive “kot-mi-nam” face was overviewed in textual, visual, contextual aspects in the context of “glocalization.” In the early 2000s in Korea, the terms denoting epicene looks of men was replaced from negative terms such as gi-saeng-o-ra-bi and je-bi-jok to the positive terms such as kot-mi-nam and mi-so-nyeon. As the popularity of the term kot-mi-nam implies, the male sexuality is rapidly commercialized and diversified. According to the analysis based on BCFC, the 3D average kot-mi-nam face is closed to gender neutral (male: 50.38%, female: 49.62%) and Western (66.42-66.40%). Major consumers of kot-mi-nam images and related cultural products are females, and their tastes are often reflected on the images through not only facial forms, but also pictorial codes such as pose, expression, perspective, composition, light, contrast, and color scheme. Emerging from female subculture such as sun-jung-man-hwa, male idols, and TV dramas, images of kot-mi-nam become a significant part of mainstream pop culture in Korea. The images of kot-mi-nam are linked to foreign cultures such as Japanese male idols, Visual Kie, Western pop culture, and girls’ manga culture in Japan.

Recently, cultural trade has been dramatically increased globally due to the Internet penetration and international policies. However, culturally-specific images can be misinterpreted in different cultures, due to their different languages, histories, and contexts. Regardless of numerous theories and discussions on universality of attractive faces, the concept of beauty differs in each culture, race, location, and time. Terms and images related to kot-mi-nam shows how the same image can subvert their meanings and contexts.

CONCLUSION

In this research, there were discussions on the anatomical, psychological, and cultural aspects of a human face. Based on the analyses, the 3D virtual face customization and action model were developed with anatomy-driven method. Based on multi-disciplinary researches on the human face, the Bezier Curve-based Facial Customization (BCFC) model and the Multilayered Facial Action Model (MFAM) were developed. BCFC was applied to illustrate the psychological theories of an attractive face in Chapter 1. This was also applied to the analysis of a culturally-specific “kot-mi-nam” face in Chapter 4.

Chapter 1 introduced anatomical studies of a human face, psychological theories of face recognition and an attractive face, and state-of-the-art face construction projects in the various fields. All related works -from various fields including medical science and art have been studied, since there were not sufficiant anatomy books specifically for the anatomical face construction as shown in Table 1. Psychological theories of facial recognition and facial attractiveness are strongly linked to the artists’ process of making potraits, since artists visualize the anatomical, structural, cultural, and pictorial information of a face. Finally, cross-disciplinary researchon face construction and action models were analyzed for the BCFC and MFAM development.

Chapter 2 and 3 presented the BCFC and the MFAM based on analysis of human anatomy. The BCFC and the MFAM differs from all the existing facial animation techniques, such as motion tracking and blend shape, since it significantly saved time to process data. The experimental results of facial customization for gender, race, amount of fat, and age showed that the BCFC method achieved better accuracy, as compared with a real picture, by 25% as compared to Facegen, and by 44% compared to Face Studio. It was achieved by manipulating three types of lines: PLoF for gender and race, FFL for individual differences in facial features, and FL for controlling fat and age levels. In addition, experimental results of the MFAM method showed its realistic quality and effectiveness as compared with existing motion unit systems. MFAM realized facial motion better: by 2.87% of facial area for the expression of happiness, and 0.03% of facial area for the expression of anger, respectively, when compared with the BS technique.

In Chapter 4, a culturally-specific attractive face;“kot-mi-nam” was discussed in the textual, visual, and contextual aspects of “glocalization.” According to the analysis based on BCFC, the 3D face of an average kot-mi-nam is close to gender neutral (male: 50.38%, female: 49.62%), and Caucasian (66.42-66.40%). Regardless of many attempts to find the universal criteria of facial attractiveness, many recent studies showed that what is considered attractive is be universal because the facial attractiveness varies depending on time, race, culture, gender, and personal preferences. Emerging from female subculture, images of kot-mi-nam become a significant part of mainstream pop culture in Korea. However, culturally-specific images can be misinterpreted in different cultures, due to their different languages, histories, and contexts. This research demonstrates that facial images can be affected by the cultural tastes of the makers and can also be interpreted differently by viewers in different cultures.

This dissertation mainly incorporates methodologies from art and engineering due to the similarities in these disciplines: their practice-based and experimental features, and their constant adaptations of new methods and technologies. First, both disciplines are practice-driven; the ultimate goal is to make, rather than to analyze. Second, both fields have experimental features. While art disciplines experiment with new ways of expressions, thinking, and techniques, engineering disciplines experiment with new technologies and approaches. Third, both fields constantly adapt new media and new technology to improve their projects.

At the same time, there are discrepancies between art and engineering methodologies in terms of objectivity, process, proof and adaptation of projects, and definition of contributors. While art methodologies focus on subjective interpretation of subject matters, engineering disciplines have developed systematic methodologies of technical writing to share up-to-date technologies and approaches. Engineering researchers share their projects and research through international journals published by professional associations such as the Institute of Electrical and Electronics Engineers (IEEE), the Association for Computing Machinery (ACM), and the Special Interest Group on Graphics and Interactive Techniques (SIGGRAPH). Through these journals, researchers prove the nobility of their researchand introduce their finding to their communities for the purpose of possible adaptation to industries and other fields.

One crucial difference between writings from engineering and art/humanities is the way they handle contributors. While in the fields of art and humanities, one considers the work of art or writing as an achievement of a single author or artist, engineering writings typically include all contributors for their research. In this way, they give some tangible credit for all the participants who contribute to their writings to a greater or lesser degree. The order of contributors' list signifies the degree of contribution: the first author is considered as the most contributing author for the paper. Regarding disciplines of art and humanities, the modernistic concept of an "artist" or "author" as genius and original may result in exclusion of other contributors' names from their paper. This difference reveals different concepts of collaboration in different fields.

In the Renaissance, anatomical studies were for both artists and scientists. Now researches on the anatomical facial forms and movements are often conducted in individual disciplines and conducted separately, limiting the accessibility of information from other fields. However, cross-disciplinary collaborations across art, medical science, computer graphics, and engineering will bring about technological and cultural innovation of the artificial face construction.

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