# SIMULATION OF TURKISH LIP MOTION AND FACIAL EXPRESSIONS IN A 3D ENVIRONMENT AND SYNCHRONIZATION WITH A TURKISH SPEECH ENGINE

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# ABSTRACT

SIMULATION OF TURKISH LIP MOTION AND FACIAL EXPRESSIONS IN A 3D ENVIRONMENT AND SYNCHRONIZATION WITH A TURKISH SPEECH ENGINE

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In this thesis, 3D animation of human facial expressions and lip motion and their synchronization with a Turkish Speech engine using JAVA programming language, JAVA3D API and Java Speech API, is analyzed. A three-dimensional animation model for simulating Turkish lip motion and facial expressions is developed.

In addition to lip motion, synchronization with a Turkish speech engine is achieved. The output of the study is facial expressions and Turkish lip motion synchronized with Turkish speech, where the input is Turkish text in Java Speech Markup Language (JSML) format, also indicating expressions.

Unlike many other languages, in Turkish, words are easily broken up into syllables. This property of Turkish Language lets us use a simple method to map letters to Turkish visual phonemes. In this method, totally 37 face models are used to represent

the Turkish visual phonemes and these letters are mapped to 3D facial models considering the syllable structures.

The animation is created using JAVA3D API. 3D facial models corresponding to different lip positions of the same person are morphed to each other to construct the animation.

Moreover, simulations of human facial expressions of emotions are created within the animation. *Expression weight* parameter, which states the weight of the given expression, is introduced.

The synchronization of lip motion with Turkish speech is achieved via CloudGarden®'s Java Speech API interface.

As a final point a virtual Turkish speaker with facial expression of emotions is created for JAVA3D animation.

Keywords: 3D facial modeling, facial animation, lip motion, lip/speech synchronization, facial expression simulation.

# ÖZ

TÜRKÇE DUDAK HAREKETLERİNİN ve YÜZ İFADELERİNİN 3 BOYUTLU ORTAMDA BENZETİMİ VE BİR TÜRKÇE SES MAKİNASIYLA EŞ ZAMANLI HALE GETİRİLMESİ

Akagündüz, Erdem
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Ocak 2004, 100 sayfa

Bu tezde, Türkçe dudak hareketlerinin ve yüz ifadelerinin 3 boyutlu ortamda canlandırılması ve bir türkçe ses makinasıyla eş zamanlanması üzerinde çalışılmıştır. Bu çalışmada Java programlama dili, JAVA3D 3 boyutlu ortam kütüphanesi ve Java Speech API ara birimini kullanılmıştır. Türkçe dudak hareketlerini ve yüz ifadelerini canladıran, 3 boyutlu bir bezetim modeli geliştirilmiştir.

Dudak hareketlerine ek olarak, bir Türkçe ses makinası kullanılarak dudak hareketleri ve Tükçe konuşma eş zamanlı hale getirilmiştir. Çalışmanın çıktısı yüz ifadeleriyle birleştirilmiş eş zamanlı Türkçe dudak hareketi ve Türkçe konuşma olup, girdisi yüz ifadelerini de betimleyen Java Konuşma Modelleme Dili (JSML) yapısında Türkçe metin olmaktadır.

Diğer birçok dilden farklı olarak, Türkçe'de kelimeler kolayca hecelerine ayrılmaktadır. Türkçenin bu özelliği, Türkçe konuşma yüz modellerini Türkçe yazılı

metine basit bir yöntemle eşleştirmemizi sağlamıştır. Bu yöntemde Türkçe dudak hareketlerini temsil etmek için toplam 37 Türkçe konuşma yüz modeli kullanılmış ve bu eşleştirme işlemi sırasında hece yapıları göz önünde bulundurulmuştur.

Canlandırma JAVA3D API kullanılarak oluşturulmuştur. Aynı kişiye ait değişik dudak hareketlerine karşılık gelen yüz modelleri birbirlerine morf edilerek canlandırma oluşturulmuştur.

Ayrıca, canlandırmanın içinde duygusal yüz ifadelerinin benzetimi yapılmıştır. Bir yüz ifadesinin ne kadar ağırlıkta verildiğini temsil eden *ifade ağırlığı* parametresi tanımlanmıştır.

CloudGarden® şirketinin Java Speech API ara birimi kullanılarak Türkçe ses makinası dudak hareketleri ile eşzamanlı hale getirilmiştir.

Son olarak Türkçe dudak hareketlerini ve duygusal yüz ifadelerinin benzetimini yapan bir sanal Türkçe konuşmacı, JAVA3D canlandırmasında oluşturulmuştur.

Anahtar Kelimeler: 3 Boyutlu nesne morfu, insan yüzü canlandırması, dudak hareketleri, dudak/ses eşzamanlaması, yüz ifadelerinin benzetimi.

To My Father and My Mother

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# CHAPTER 1

# INTRODUCTION

## 1.1 Motivation

Communication is possibly the most important evolution of human kind. All other capabilities, developments, technologies created by our civilization were put together by this ability. Without a shred of doubt, modern world brought its new modern communication types. 80 years ago it was radio, 50 years ago it was television, just 10 years ago it was Internet and in near future it will become virtual character communication.

We as humans, communicate using our entire body. We use our face, our voice, our body, and our social states to communicate. But among all of these communication gifts, human face and human voice are the most fundamental ones. Essentially, the face is the part of the body we use to recognize the individuals; we can recognize a face from vast universe of similar faces and are able to detect very subtle changes in facial expression [Parke, Waters 1996]. These skills are learned early in life, and they rapidly develop into a major channel of communication. Actually that's why animators pay a great deal of attention to the face.

In recent years there has been considerable interest in computer-based three-dimensional facial character animation [Parke, Waters 1996]. These studies go back more than 30 years. However with the rapid growth of hardware and software computer technologies during the recent years, the outputs of these studies became

more evident. Facial animation, facial expression animation, lip motion for languages and lip/speech synchronization are some of the important applications.

Among these studies we found out that there has not been a total study on lip motion and lip/synchronization for Turkish language. For this reason we have decided to construct a system for Turkish lip motion animation, and lip/speech synchronization. Naturally we have decided to use 3D virtual environment to build up this system. The reason why we have chosen 3D environment is that we felt urgent need to catch up the state of the art technologies in computer-based three-dimensional facial character animation.

### 1.2 Related Studies

The difficulty of the modeling of human facial motion is mainly due to the complexity of the physical structure of the human face. Not only are there a great number of specific bones, but there is also interaction between muscles and bones and between the muscles themselves [Kalra, 1991]. Human facial expressions have been the subject of much investigation by scientific community. For more than 30 years researchers studied on creating models representing expressions and lip motion. Some milestone studies are listed below.

Long ago in 1872, Charles Darwin published “The Expression of the Emotions in Man and Animals, where he dealt precisely with these issues. Actually this was the very start of the studies that led us to today’s technology in character animation.

In 1972 Frederic I. Parke began with a very crude polygonal representation of the head, which resulted in a flip-pack animation of the face opening and closing eyes and mouth [Parke, Waters 1996].

In 1975 Paul Ekman stated that humans are highly sensitive to visual messages sent voluntarily or involuntarily by the face. Consequently, facial animation requires specific algorithms able to render the natural characteristics of the motion with a high degree of realism. Research on basic facial animation and modeling has been extensively studied and several models have been proposed [Ekman 1975].

Later, Platt and Badler have designed a model that is based on underlying facial structure. The skin is the outside level, represented by a set of 3D points that define a surface, which can be modified. The bones represent an initial level that cannot be

moved. Between both levels, muscles are groups of points with elastic arcs [Platt, Badler 1981].

Waters in 1987 represented the action of muscles using primary motivators on a non-specific deformable topology of the face. Two types of muscle were created: linear/parallel muscles that pull and sphincter muscles that squeeze [Waters 1987].

Magnenat-Thalmann et al. defined a model where the action of a muscle is simulated by a procedure, called Abstract Muscle Action procedure (AMA), which acts on the vertices composing the human face figure. It is possible to animate a human face by manipulating the facial parameters using AMA procedures. By combining the facial parameters obtained by the AMA procedures in different ways, we can construct more complex entities corresponding to the well-known concept of facial expression [Magnetat- Thalmann N. 1988].

In 1991 Prem Kalra, Angelo Mangili et al. introduced SMILE: A multilayered facial animation system. They described a methodology for specifying facial animation based on a multi-layered approach. Each successive layer defines entities from a more abstract point of view, starting with phonemes, and working up through words, sentences, expressions, and emotions. Finally, the high level allows the manipulation of these entities, ensuring synchronization of the eye motion with emotions and word flow of a sentence [Kalra 1991].

In 1994, the first version of VRML, virtual reality modeling language was presented. The lack of animation and interaction was leading to VRML 2.0 that became the ISO standard VRML-97 [VRML2.0 1996]. In succeeding years VRML-97 was added to the MPEG-4 standard which is an ISO/IEC standard developed by MPEG (Moving Picture Experts Group), the committee that also developed the Emmy Award winning standards known as MPEG-1 and MPEG-2. Specific extensions were related to the animation of artificial faces and bodies. The facial animation object in MPEG-4 can be used to render an animated face. Face animation in MPEG-4 provides for highly efficient coding of animation parameters that can drive an unlimited range of face models [MPEG-4 1998].

Other than these studies several 3D facial geometry representation techniques were introduced and are still being introduced.

## 1.3 Problem Definition

In this thesis, a three-dimensional character face with lip motion of Turkish language and facial expressions synchronized with real-time synthesized speech is aimed. Moreover, a system with text as input and an animation as output is proposed. A software animation system with adequate animation quality aspects is intended.

Furthermore the system to be constructed should be flexible in model and voice selection. Plainly a three-dimensional character animation system compatible to different facial models and different voices is meant. So the overall system is expected to be working well in Turkish lip motion, facial expressions and lip/speech synchronization for these different sets of facial models and synthetic voices.

In addition, to realize a simulation study like this, the structural properties of Turkish should be totally examined. Like every language Turkish has some syntactic properties and by this study these properties should be utterly parsed in our implementation system.

Besides visual animation system, a vocal synthesis system is required. As the system is intended to be a “text to speech and animation” system, real-time Turkish speech synthesis is obligatory. Additionally a system to synchronize this speech synthesis system with animation system must be defined and constructed.

## 1.4 The Study

The steps we have taken in order to fulfill the requirements of this well-defined problem, are written below.

In Chapter 2 human facial system is analyzed. Starting with the anatomical structure of the human skull, we have studied the facial bones and muscles. After understanding the structural properties of human facial anatomy, the nature of human facial expressions is examined. Paul Ekman’s studies on human facial expressions have been our major guide.

In Chapter 3 the vocal and structural properties of Turkish language are examined. In this chapter the visual phonemes, the visemes, of Turkish language are defined and described.

In Chapter 4 3D virtual systems, 3D facial models, 3D facial expression models and their different representation techniques are analyzed. In this chapter essential virtual world concepts like 3D points and texture are introduced. Also different techniques of representing 3D objects in virtual environments are explained. In this chapter the fundamentals of the morphing method are given in detail.

In Chapter 5, the theory behind our study and the methods we have used are explained. Furthermore the main structure of the software implementation, which has been detailed in Appendix A, is investigated. In addition screen captures of the animation are illustrated.

In Chapter 6, the results and the performance of the implementation are discussed. The visual quality and the software performance are analyzed according to some criteria, like frame rate, synchronization quality and vertex number. The numeric results obtained in Appendix C are discussed.

In Chapter 7, the conclusions of the study are presented. Moreover some future studies are introduced.

In Appendix A, the implementation software is analyzed in detail. The software system is totally described in block diagram figures.

In Appendix B the screen captures of Turkish visual phonemes, which we have used in our implementation are depicted.

Finally In Appendix C, the numeric results of sample animations are established. These animations are given in a compact disc, where they are viewable as movie clips.

# CHAPTER 2

# HUMAN FACIAL SYSTEM

In order to animate human facial system in a virtual or real environment, the geometry and the dynamics of Human facial system should be understood. To better understand human facial system, the anatomy of human face must be analyzed.

In this chapter, we will first present very brief information on the face anatomy in order to give an idea of what parts we may need to synthesize for a human face. Both the facial muscles used to construct facial dynamics and the bones of the face with one single important joint, namely chin will be analyzed. After we understand how human face is structured, we will consider how to represent the geometry for the face model in a 3D environment.

## 2.1 Human Face Anatomy

The form and function of human body has been studied in great detail by artists over the centuries. In particular the Renaissance artist began the rigorous tradition of figure drawing so that they could produce realistic and detailed interpretations of the human form [Parke, Waters 1996]. Although artist's perspective is important in understanding the human facial structure, twentieth-century medical anatomical reference books provide the most significant insight into human anatomy.

One of the most frustrating aspects of medical reference manuals is the overwhelming quantity of information that is difficult to follow and digest [Parke, Waters 1996]. In this section we will try to describe the anatomical features of the

human face that are useful for computer synthesis. Essentially the description breaks down into two parts:  the facial skeleton and the facial muscles.

### 2.1.1 Facial Skeleton

On top of human skeleton system, the bones of head are carried. Skull is the name given to this group of bones of human skeleton system. The skull is essentially a protective casing for the brain and provides a foundation for the face. The bones of the skull can be divided into two major parts: the cranium, which lodges and protects the brain, and the skeleton of the face, of which the mandible is the only freely joint structure, Figure 2.1.

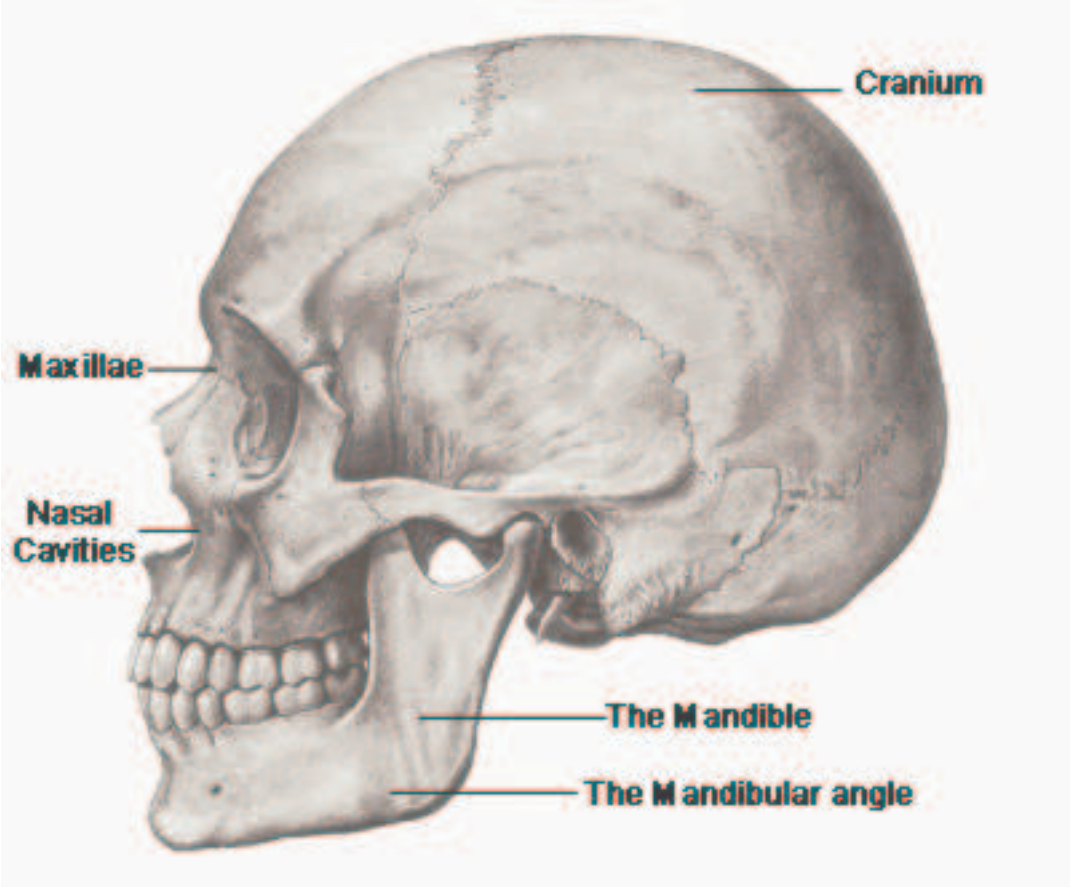



**Figure 2.1 The Cranium and the Facial Skeleton**

For the most part it is the facial skeleton that is of particular interest in 3D facial modeling as it provides the framework onto which the muscles and skin are placed.

Facial skeleton is positioned below and anterior to the cranial base. The upper third of the facial skeleton consists of the orbits and nasal bones, the middle third consists of the nasal cavities and maxillae, and the lower third consists of the mandibular region, Figure 2.1, 2.2 and 2.3.

The facial skeleton is composed of the sphenoid bone, the ethmoid bone, the palatine bone, the maxille, the inferior nasal concha, the sygomatic bones, the nasal bones, the lacrimal bone, the mandible, the hyoid bone and the vomer, Figure 2.2 and 2.3.

Together with the mandible, all other bones of the face construct the overall structure of human facial system. Each of these bones has complex shape. We have ordered them in most proximal to least, since the deeper bone structures have less influence on the overall face shape [Parke, Waters 1996].

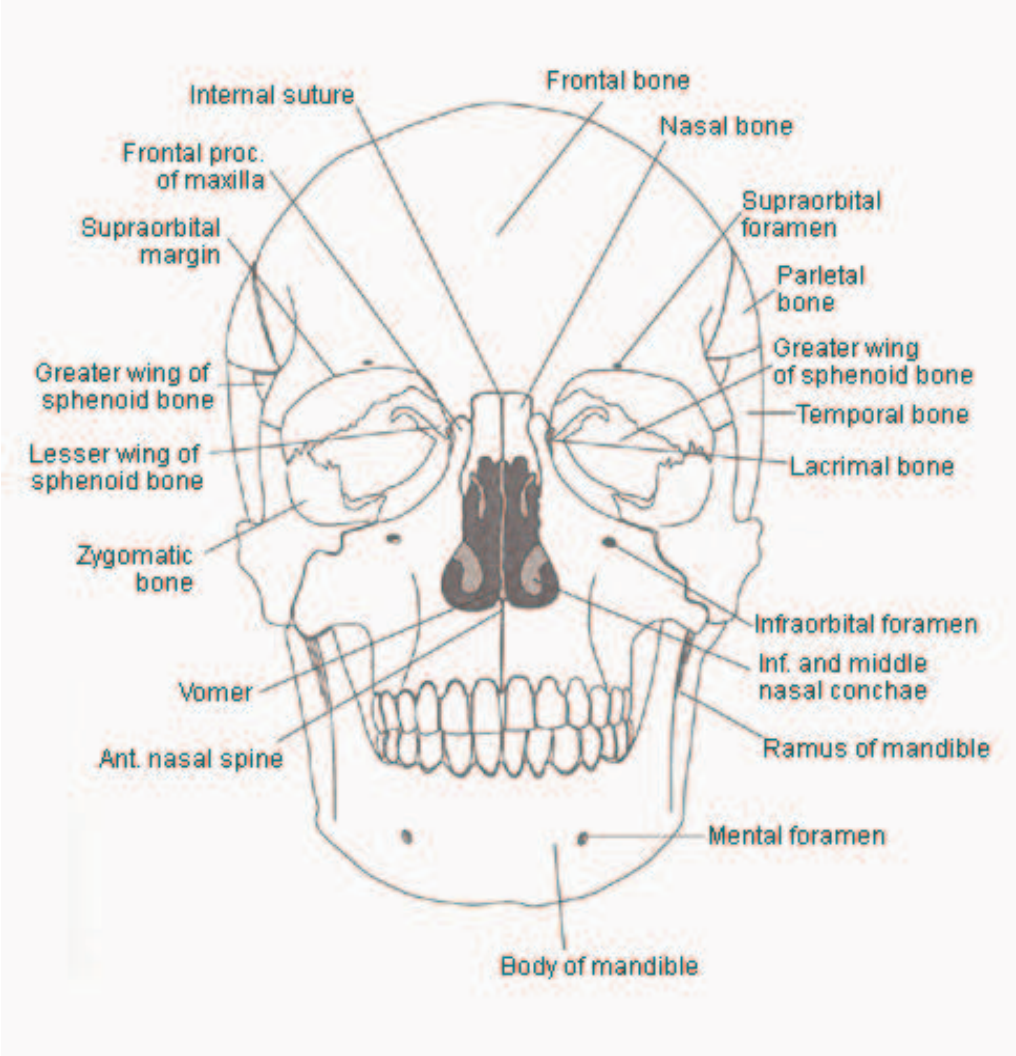



**Figure 2.2 Facial Bones**

Except for the mandible, further structure of these bones will not be discussed here. As the mandible is the most import bone on the face that affects 3D human speech modeling will be explained in detail.

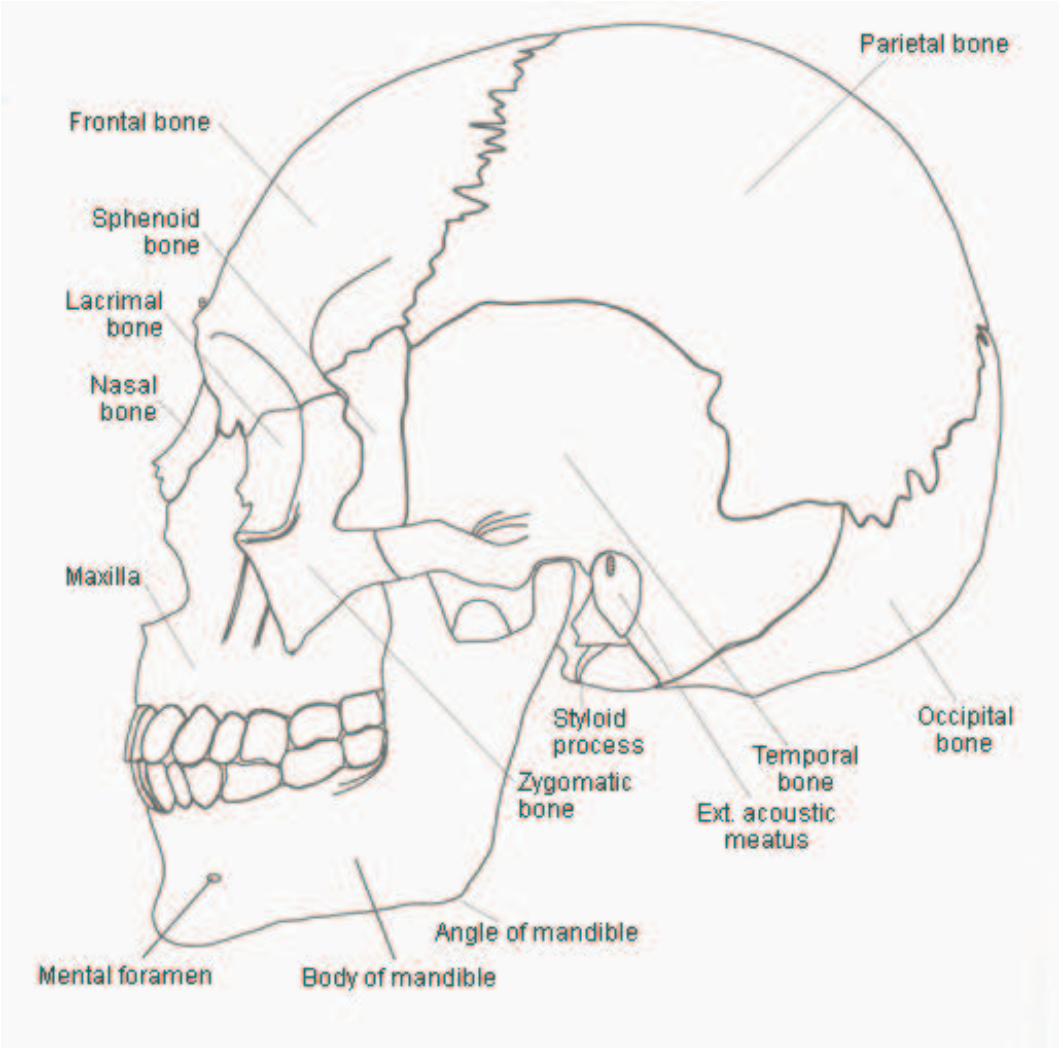



**Figure 2.3 The Lateral view of the Skull**

### 2.1.1.1 The Mandible

The mandible is the only movable joint on the human face. It is the major part of our chin and every chin-movement including event of human facial system occurs within the corporation of the mandible joint and its muscles.

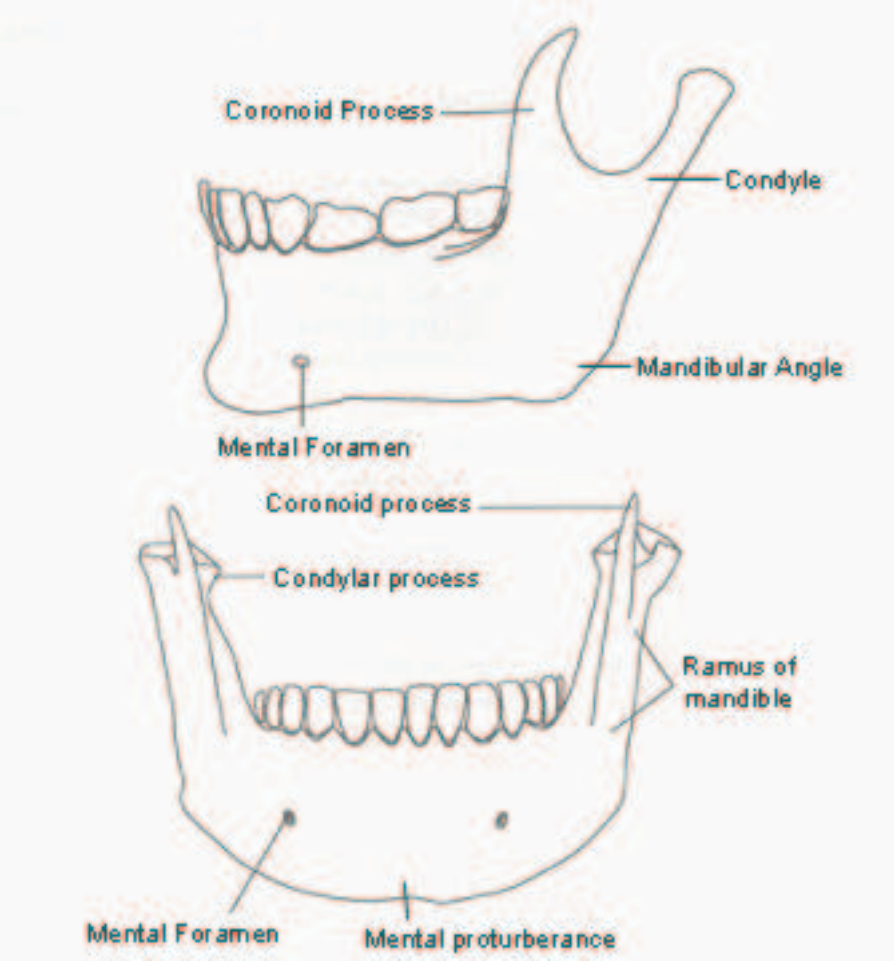



**Figure 2.4 The Mandible**

The mandible is a strong, horseshoe-shaped bone that is the largest and heaviest bone of the facial skeleton as depicted in Figure 2.4. The horizontal portion is known as the body and the right and left vertical sections are known are the *rami* [Parke, Waters 1996].

The ramus each has two terminal processes: one called the condyle, is blunt and somewhat rounded; the other, serving as the insertion of the temporalis muscle, is the coronoid process. The deep curved notch between the processes is the sigmoid notch. The condyle has a smooth rounded head that is attached to the ramus by a thinner elongated neck. The posterior border of the ramus meets the inferior border of the body at the mandibular angle. The right and left bodies meet at the chin point, the

symphysis, on which is a variably elevated area, the mental protuberance [Parke, Waters 1996].

On the lateral surface of the body, one sees the mental foramen lying just below the roots of the premolars. On the superior aspect of the body lies the alveolar process, which houses the mandibular teeth. The external oblique line begins just posterior to the mental foramen, passes posteriorly and superiorly to become the anterior border of the vertical ramus, and finally ends at the coronoid tip.

Medially, in the area of the symphysis, the bony mental (genial) tubercles or genial spines can be seen. Just posterior and lateral to these features is an oblique ridge of bone extending and superiorly to end at the crest of the alveolar ridge near the third molar. This area is the mylohyoid linear ridge. The depression on the medial aspect of the posterior portion of the body, just below the mylohyoid line, is the submandibular fossa. Above the line and more anteriori another depression, the sublingual fossa, is seen.

Almost exactly in the center of the medial surface of the vertical mandibular ramus, the inferior alveolar canal begins with a wide opening, the mandibular foramen. On its anterior surface is a bony process, the lingula. The inferior alveolar canal lies within the bone and follows the curvature of the mandible from the inferior alveolar foramen in the ramus to the mental foramen in the body. Here it begins a short canal to the mental foramen and then continues on in the bone to the symphysis region as the incisive canal.

Behind the last molar, on the crest of the alveolar process, is a small-roughened retomandibular triangle.

The movement characteristics of the mandible bone and its muscles are explained in detail, in the following section.

### 2.1.2 Facial Muscles

In the general sense muscles are the organs of motion. By their contractions, they move the various parts of the body. The energy of their contraction is made mechanically effective by means of tendons, aponeuroses, and fasci, which secure the ends of the muscles and control the direction of their pull. Muscles usually are

suspended between two moving parts, such as between two bones, bone and skin, two different areas of skin, or two organs.

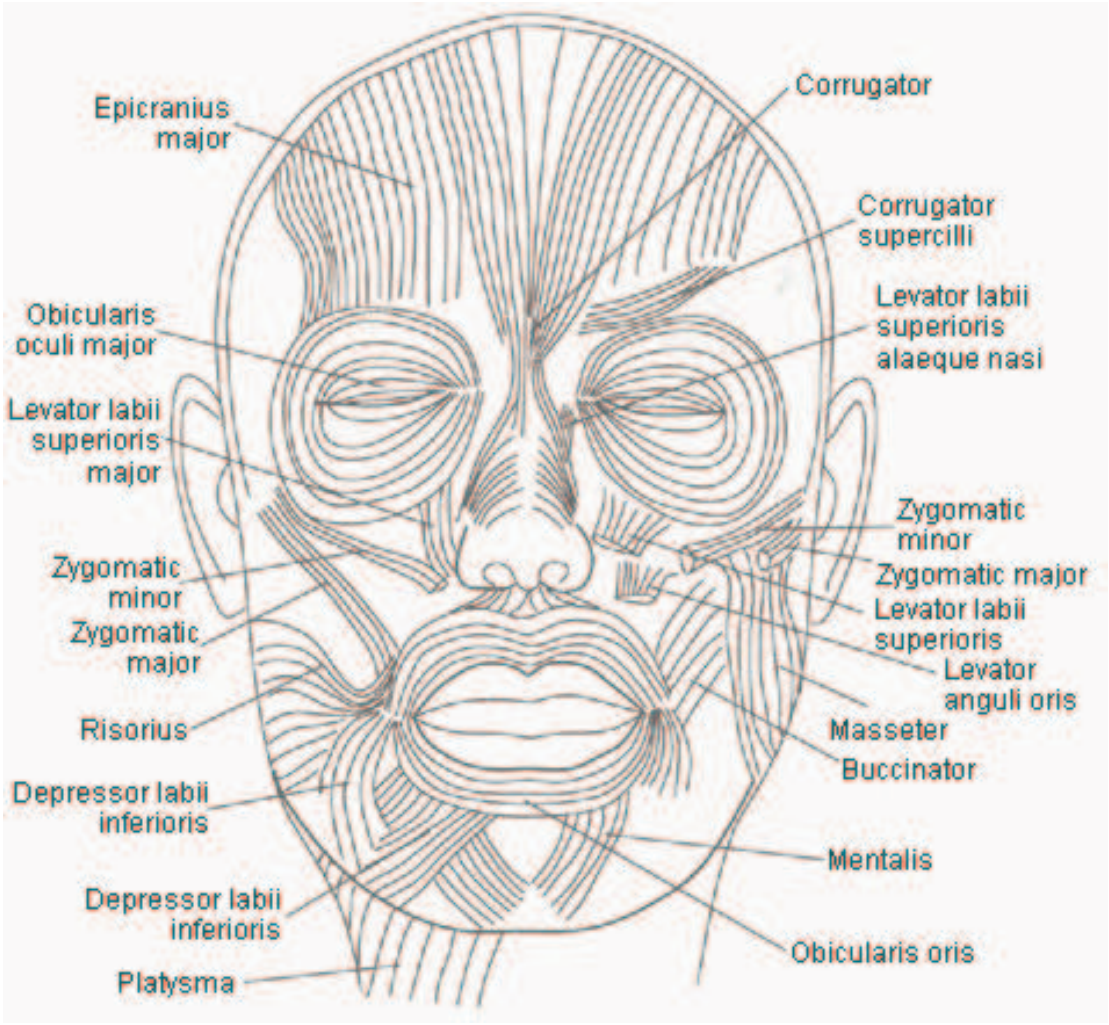



**Figure 2.5 Facial Muscles**

Actively, muscles contract. Their relaxation is passive and becomes about through lack of stimulation. A muscle usually is supplied by one or more nerves that carry the stimulating impulse and thereby cause it to contract. Muscles can also be stimulated directly or by any electrical activity emanating from any source. Usually the

stimulation for muscular contraction originates in the nerve supply to that muscle. Lack of stimulation to the muscle results in relaxation.

When a muscle is suspended between two parts, one of which is fixed and the other movable, the attachment of the muscle on the fixed part is known as the *origin*. The attachment of the muscle to the movable part is referred as the *insertion.*

#### 2.1.2.1 The Muscles of the Face

Facial muscles perform all of the functions of facial communication, such as moving the cheeks, moving lips during mastication and speech, blinking eyelids and all of the realizing all of the facial expressions.

The muscles of the face are superficial, and all attach to a layer of subcutaneous fat and skin at their insertion. Some of the muscles attach to skin at both the origin and the insertion such as the obicularis oris. When all the muscles are relaxed, the fatty tissues fill the hollows and smooth the angular transitions so as to allow the general shape of the skull to be seen.

The muscles of the face work synergistically and not independently. The group function as a well-organized and coordinated team, each member having specified functions, one of which is primary. These muscles interweave with one another. It is difficult to separate the boundaries between the various muscles. The terminal ends of these muscles are interlaced with each other.

In more general terms, the muscle of the face can be grouped according to the orientation of the individual muscle fibers and can be divided into the upper and lower face as depicted in Figure 2.5. Three types of muscle can be discerned as the primary motion muscles: linear/parallel, which pull in angular direction, such as the zygomatic major and the corrugator supercilii; elliptical/circular sphincter-type muscles, which squeeze, such as the obicularis oris; sheet muscles, which behave as a series of linear muscles spread over an area, such as the frontalis (see figure 2.5).

Since the focus of this thesis is mainly on visual speech modeling, the facial muscles are studied roughly.

#### 2.1.2.1.1 Circum-orbital Muscles of the Eye

*Orbicularis Oculi*. This muscle encircles the eye in concentric fibers that act as a sphincter to close the eye.

*Corrugator Supercilii*. This small-paired pyramidal muscle is located at the medial end of each brow. This muscle draws the brows medially and down, producing (with the orbicularis oculi) vertical wrinkles on the forehead.

*Levator Palpebrae Superioris*. This muscle arises within the orbit above the optic foramen and advances and spreads out to end in the upper eyelid. This muscle, when is contracts, lifts the upper lid.

#### 2.1.2.1.2 Muscles of the Nose

These muscles are quite rudimentary; however, they act to dilate and constrict the nasal openings. They are illustrated in Figure 2.5 and Figure 2.6.

*Procerus*. The procerus muscle originates from the nasal bone and passes superiorly to end in the brow and forehead. This muscle depresses the medial end of the eyebrow, producing transverse wrinkles over the nasal bridge and root. The action of this muscle aids in reducing the glare of bright sunlight.

*Nasalis*. The nasalis arises from the alveolar eminence over the lateral incisor and swings around the nose to insert on the superior surface of the bridge, at the tip of the nose and alar cartilages. The transverse part of this muscle compresses the nasal aperture at the junction of the vestibule and nasal activity.

*Depressor Septi*. This muscle is attached to the maxilla above the central incisor and ascends to the mobile part of the nasal septum. This muscle assists the alar part of the nasalis in widening the nasal aperture.

*Levator Labii Superioris Alaeque Nasi*. This muscle raises the upper lip, deepening the nasolabial furrows and slightly dilating the nostrils. This muscle is also counted as one of the muscles of the mouth.

#### 2.1.2.1.3 Muscles of the Mouth

The numerous muscles of the mouth are important in facial expression generation; while one group of these muscles opens the lips, another group closes them. The muscles closing the lips are the orbicularis oris and the incisive muscles. The

muscles opening the lips are known as the radial muscles, which are divided into radial muscles of the upper and lower lips, superficial and deep. These muscles are illustrated in Figure 2.5 and Figure 2.6.

*Orbicularis Oris*. This muscle consists of numerous strata of muscular fibers surrounding the orifice of the mouth (see figure). It consists in part of fibers derived from he other facial muscles that converge on the mouth. The action of the orbicularis oris produces an almost endless control of the lips. The varieties of lip shapes are used in speech and nonverbal communication. It is also important in chewing where it can hold food against the teeth. It also can narrow the lips and force them against the teeth, purse the lips, or protrude the lips.

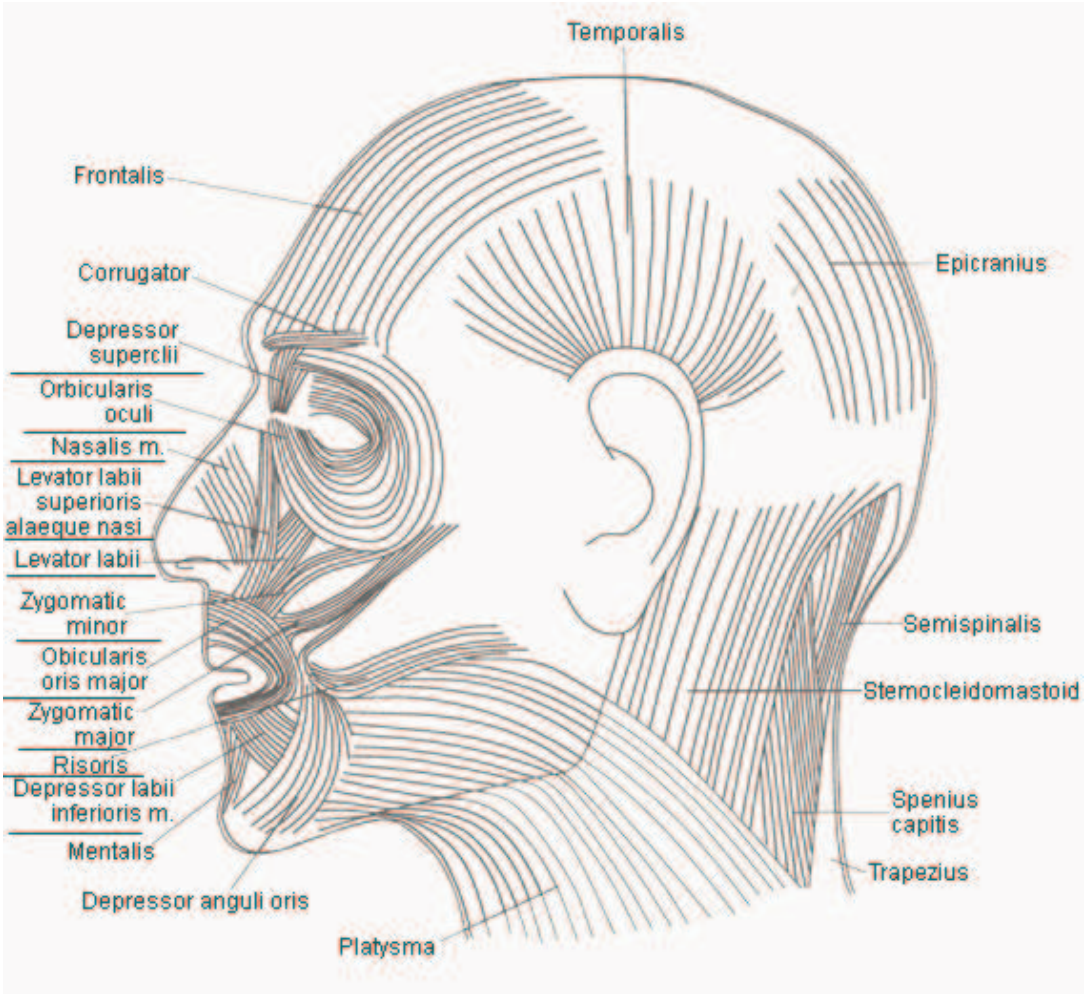



**Figure 2.6 Lateral view of the Facial Muscles**

*Buccinator*. The buccinator muscle is thin, wide, and flat, forming the major portion of the substance of the cheeks. The fibers run forward to blend with those of the orbicularis oris. The buccinators compress the cheeks against the teeth, thereby preventing the accumulation of food in the cheek.

*Zygomaticus Major*. This muscle arises from the malar surface of the zygomatic bone and is inserted into the corner of the mouth. This muscle elevates the modiolus and buccal angle, as in laughing.

*Levator Anguli Oris*. This muscle is slightly deeper than the overlaying zygomatic muscles. This muscle raises the modiolus and buccal angle, displaying the teeth and deepening the nasolabial furrows. This muscle is the only muscle in the deep layer of muscles that open the lips. Its function is to elevate the angle of the mouth.

*Depressor Anguli Oris and Depressor Labii Infeiroris*. These muscles arise from the mandible, and the fibers converge to the corners of the mouth. Both these muscles depress the corner of the lips downward and laterally

*Risorius*. This muscle is one of those located at the corner of the mouth. This muscle pulss the angle of the mouth laterally and is often referred to as “smiling muscle”.

*Mentalis*. This muscle originates in a circular area above the mental tuberosity. Its action is to elevate the skin of the chin aiding its protrusion/eversion, as in drinking.

*Depressor Anguli Oris*. This muscle arises from the area near the insertion of the platysma and inserts into the tendonous node at the angle of the mouth. It depresses the modiolus and buccal angle laterally in opening the mouth and the expression of sadness.

*Depressor Labii Inferioris*. This muscle originates near the origin of the triangular muscle. It pulls the lower lip down and laterally in mastication.

#### 2.1.2.1.4 The Muscles of Mandible and Mastication

The movement of the mandible is complex involving the coordinated action of the muscles attached to it. Four basic movements of the mandible are:

- Protraction: pulling the mandible forward so that the head articulates indirectly with the articular tubercle of the temporal bone.
- Retraction: pulling the mandible backward so that the head moves into the mandibular fossa.

- Elevation: closing the mouth.
- Depression: opening the mouth.

The various muscles around the mandible are responsible for these four basic movements of the mandible. These muscles are briefly:

*Masseter*. The action of this thick powerful muscle is to elevate the lower jaw.

*Medial Pterygoid*. This muscle acts as an elevator of the mandible so as to close the mouth.

*Temporalis*. The fibers are somewhat longer and therefore the temporal muscle is less powerful than the masseter, but it provides for rapid movement of the mandible.

*Digastric*. With the mandible fixed, the digastric raises the hyoid bone and, with it, the larynx, which is an important action in swallowing.

*Geniohyoid Muscle*. This muscle principally assists the mylohyoid muscle in elevating the tongue. It also elevates and fixes the hyoid bone depress the mandible.

*Lateral Pterygoid*. This muscle acts to open the jaw. It causes the mandible to shift to the opposite side when it contracts without the aid of its contra-lateral mate.

*Mylohyoid*. The primary function of this muscle is to elevate the tongue. When the fibers contract, the curvature is flatter; thus the floor of the mouth is elevated, and with it, the tongue.

*Platysma*. The action of the platysma is to raise the skin of the neck, as if to relieve the pressure of a tight collar. Also, this muscle draws the outer part of the lower lip down and depresses the mandible. This action is seen in the expression of horror.

The muscles listed above are the main muscles responsible for facial expression construction. But they are not the only ones. There are also several muscles of tongue, scalp, ear and the neck. As the deeper analyses of these muscles are beyond the scope of this thesis they are not examined here. But further information can be found in [Parke, Waters 1996], [Fleming, Dobbs 1999], [Ferner, Staubesand 1985].

## 2.2 Structure And Dynamics Of Human Facial Expressions

Human face is a multi-message system. The face broadcasts messages about emotions, mood, attitudes, character, intelligence, attractiveness, age, sex, race, and probably other matters as well [Ekman, 1975]. When we speak of emotions, we are

referring to transitory feelings, such as fear, anger, surprise, etc. When these feelings occur, the facial muscles contract and there are visible changes in the appearance of the face. Wrinkles appear and disappear, the location and/or shape of the eyebrows, eyes, eyelids, nostrils, lips, cheeks, and chin temporarily changes.

It is important to note that emotion messages are not dependent on whether a person has a thin or fat face, a wrinkled or smooth face, a thin-lipped face, an old or young face, a male or female face, a Black or Oriental face. As referred in the previous section, a human face is formed of certain muscles that generate these facial expressions. Generally human facial expressions are modeled according to these facial muscles.

Human face experiences some number of facial expression or emotions. How many of these specific emotions does the face show? The six emotions that are the subject of this thesis, namely happiness, sadness, surprise, fear, anger and disgust, were found by every investigator in the last fifty years who sought to determine the vocabulary of emotion terms associated with facial expressions [Ekman, 1975]. There are probably other emotions conveyed by the face –shame and excitement, for example; but these have not yet been firmly established.

### 2.2.1 Universal Facial Expressions

The first person, who tried to answer the question “are facial expressions of emotion the same for people everywhere”, was Charles Darwin. He mentioned that facial expressions of emotion are universal, not learned differently in each culture; that they are biologically determined, the product of man’s evolution [Ekman, 1975]. Also scientific investigations have conclusively settled this question, showing that the facial appearances of at least some emotions, those covered in this thesis, are indeed universal, although there are cultural differences in when these expressions are shown.

Studies of Paul Ekman on facial muscle movements in 1970’s showed that when people are alone Japanese and Americans had virtually identical facial expressions. When in the presence of another person, however, where cultural rules about the management of facial appearance would be applied, there was little correspondence between Japanese and American facial expressions. Japanese masked their facial

expression of unpleasant feelings more than did Americans. This study was particularly important in demonstrating what about facial expression is universal and what differs for each culture. With the materials gathered in one of the cross-cultural studies of facial expressions described earlier, Ekman and his colleagues managed to form a Facial Atlas from which they could model six facial expressions, which are happiness, sadness, anger, fear, surprise and disgust. This atlas is still used in many facial expression simulations and several facial expression extraction applications. As the examination of this Facial Atlas is beyond the scope of this thesis, we will only examine the facial state of six basic expressions.

*Surprise*: Surprise is the briefest emotion. It is sudden in its onset. If you have time to think about the event and consider whether or not you are surprised, then you are not. You can never be surprised for long, unless the surprising event unfolds new surprising events. It doesn't linger. When you cease being surprised, its disappearance is often as sudden as was it onset.

Different types of "surprised faces" can be observed like happy surprise, fearful surprise. This is because the face can experience more than one of these facial expressions at a time. But there is a distinctive appearance in each of three facial areas during surprise. The eyebrows are raised, the eyes are opened wide, and the jaw drops open, parting the lips, Figure 2.7.

**Figure 2.7 Surprise and Surprise blended with happiness.**

*Fear*: People fear harm. The harm may be physical or psychological, or both [Ekman, 1975]. Fear is so often experienced in advances of harm. Like surprise it can be experienced with other emotions on human face. Face may describe an angry-fearful face as illustrated in Figure 2.8. Still there is a distinctive appearance in each of these fearful faces. The eyebrows are raised and drawn together; the eyes are open and the lower lid is tensed; and the lips are stretched back.

**Figure 2.8 Fear blended with surprise.**

*Disgust*: Disgust is feeling of aversion. The taste of something you want to spit out, even the thought of eating something distasteful can make you disgusted. Disgust usually involves getting- rid-of and getting-away-from responses. Removing the object or oneself from the object is the goal.

The most important clues to disgust are manifested in the mouth and nose and to a lese extent in the lower eyelids and eyebrow. The upper lip raised, while the lower lip may be raised or lowered; the nose is wrinkled; the lower eyelids are pushed up, and the eyebrow is lowered, Figure 2.9.

**Figure 2.9 Disgust.**

*Anger*: Anger can be aroused in a number of different ways. Frustration resulting from interference with your activity or the pursuit of your goals is one route. Another major provocation to anger is a physical threat. Anger can blend with any of the other emotions, Figure 2.10.

In anger the eyebrows are lowered and drawn together, the eyelids are tensed, and the eye appears to stare in a hard fashion. The lips are either tightly pressed together or parted in a square shape, Figure 2.10

**Figure 2.10 Anger blended with sadness.**

*Happiness*: This is the emotion most people want to experience. It is a positive emotion. Happiness varies not only in type, but also in intensity. You can be mildly happy, and you can experience joy as illustrated in Figure 2.11. Happiness can be shown silently or audibly. It can vary from a smile to a broad grin.

Happiness often blends with surprise. Happiness also blends with anger. Most commonly, to mask fear, it may blend with it. Happiness is shown in the lower face and lower eyelids. Corners of lips are drawn back and up. The mouth may or may not be parted, with teeth exposed or not. The cheeks are raised and a wrinkle (the naso-labial fold) runs down from the nose to the outer edge beyond the lip corners. The lower eyelids show wrinkles below it, and may be raised but not tense. Wrinkles go outward from the outer corners of the eyes.

**Figure 2.11 Happiness.**

*Sadness*: In sadness your suffering is muted. You don't cry aloud but more silently endure your distress.

In sadness there is loss of muscle tone in the face. The distinctive appearances on face during sadness are; the inner corners of the eyebrows are raised and may be drawn together. The inner corner of the upper eyelid is drawn up, and the lower eyelid may appear raised. The corners of the lips are drawn down, or the lips appear to tremble, Figure 2.12.

**Figure 2.12 Sadness.**

By some psychologists excitement is considered to be a primary emotion, different from but equal in importance to surprise, anger, fear, disgust, sadness and happiness. But research on Ekman's facial Atlas showed that its appearance is not universal and also can be generated by the combination of the six basic emotions considered in this thesis [Ekman, 1975].

# CHAPTER 3

# TURKISH SPEECH AND LIP MOTION

Turkish is a very ancient language, with a flawless phonetic, morphological and syntactic structure, and at the same time possesses a wealth of vocabulary. The fundamental features which distinguish the Ural-Altaic languages from the Indo-European are as follows:

- Vowel harmony, a feature of all Ural-Altaic tongues.
- The absence of gender.
- Agglutination
- Adjectives precede nouns.
- Verbs come at the end of the sentence.

In this chapter we will briefly explain vocal and structural properties of Turkish language. As these features are beyond the scope of this thesis, we will avoid getting into detail. In addition we will explain lip motion in Turkish Language.

## 3.1 Vocal and Structural Properties of Turkish Language

Turkish is characterized by certain morphophonemic, morpho-tactic, and syntactic features: vowel harmony, agglutination of all-suffixing morphemes, free order of constituents, and head-final structure of phrases. Turkish is an agglutinative language with word structures formed by productive affixations of derivational and inflectional suffixes to root words. [Bilkent CTLP]. There is extensive usage of

suffixes in Turkish Language, which causes morphological parsing of words to be rather complicated, and results in ambiguous lexical interpretations in many cases.

Turkish can be characterized as being a subject-object-verb language. However, other orders for constituents are also common. In Turkish it is not the position, but the case of a noun phrase that determines its grammatical function in the sentence. Consequently typical order of the constituents may change rather freely without affecting the grammaticality of a sentence. Due to various syntactic and pragmatic constraints, sentences with the non-typical orders are not stylistic variants of the typical versions, which can be used interchangeably in any context.

The extensive usage of suffixes makes Turkish a difficult language for lip motion/speech synchronization. Compared to languages like Chinese, words lengths are longer in Turkish and phoneme-by-phoneme synchronization is required instead of word-by-word synchronization.

The duration of vowels is a characteristic property of that language. There is average duration of words for certain speaking rate. In vocal interpretation, we see that there is no pause between words of Turkish Language [Salor 1999]. This means that a foreigner, who cannot speak Turkish, won't be able to extract words from a Turkish speech sequence that she hears.

There are definite properties of Turkish language like duration, tone, intonation, accent etc. [Ergenç 1995]. As further analysis of Turkish language is beyond the scope of this thesis we will limit our explanations on vocal and structural properties of Turkish language to this point.

### 3.2 Lip Motion in Turkish Language

Like every other language, Turkish has specific properties of pronunciation and lip motion. In perception of any language besides the speech sound the body language and lip motion play important roles. We simply do not listen to only the vocal speech but observe the body movements and lip motion of the speaker. For this reason languages have certain styles of body language and lip motion.

Before introducing these visual movements on our facial system, we should understand the concept of phoneme. Phoneme is the smallest part of a grammatical system that distinguishes one utterance from another in a language or dialect

[Fleming, Dobbs 1999]. Phoneme represents both vocal part and visual part of the speaking action, that's why we will further examine it in two concepts as vocal phoneme and visual phoneme.

Modern standard Turkish is a phoneme-based language like Finnish or Japanese, which means phonemes, are represented by letters in the written language [Salor 1999]. It is also true to say that there is nearly one-to-one mapping between written text and its pronunciation. However, some vowels and consonants have variants depending on the place they are produced in the vocal tract [Salor 1999].

The vocal phonemes are the smallest part of our vocal speech sequence. In other words a phoneme is one distinguishable sound in a speech sequence. In English phonetic speech, combining phonemes, rather than the actual letters in the word, creates words [Fleming, Dobbs 1999]. In Turkish the case is somewhat different. In Turkish we have "syllables". Syllable is one part of a word, which can be pronounced with a single effort of our vocal system. In Turkish speech syllables contain only one single vowel. Actually this property is the most distinctive property of Turkish syllables. Turkish syllables may contain one or more than one number of phonemes.

The visual phoneme is the mouth position that represents the sound we hear in speech [Fleming, Dobbs 1999]. Under each visual phoneme one will find the audible phonemes that are associated to that specific mouth position. A visual phoneme includes the position of the mouth, the lips and the tongue. In next subsection Turkish phonemes are explained in detail.

### 3.2.1 Turkish Visual Phonemes

In this subsection Turkish visual phonemes will be examined in letter basis. Each letter will be matched to visual phoneme, which will later be used as models in our morphing simulation.

Visual phonemes are characterized with articulators. Articulators are the places where various obstructions take place in human mouth [Fleming, Dobbs 1999]. Some important ones of these places are:

Lips (labial)

Teeth (dental)

Hard Palate (palatal)

Soft palate (velar)

Back of throat (uvula/glottis)

Turkish alphabet has 29 letters. These 29 letters in the Turkish alphabet are represented by 45 phonetic symbols [Salor 1999]. Below we have made a list of visual phonemes mapping to every letter in Turkish language. This list is constructed according to our analysis in human facial system and daily Turkish speech. The information given for each visual phoneme only includes positions for mouth, lips, teeth and tongue. According to our simulation's visual needs, further information on human vocal system, like throat etc, is ignored. Some examples of these visual phonemes are illustrated in Figures 3.1, 3.2, 3.3, 3.4 and 3.5.

"A": The mouth is open and un-rounded. The tongue is passive.

"B": The mouth is closed. Lips touch each other.

"C": The lower jaw is closed. Lips are open and slightly curved forward. The tongue is raised, but it does not touch the palate.

**Figure 3.1 Visual Phoneme “c”**

“Ç”: Same as “C” the lower jaw is closed and the lips are open and slightly curved forward. But “ç” is a plosive sound so the tongue touches the palate.

“D”: The tongue touches the palate. Lower jaw is parted from the upper jaw with a little opening from which the tip of the tongue can be seen.

“E”: The mouth is open and un-rounded. The tongue is slightly forward and down.

**Figure 3.2 Visual Phoneme “f”**

“F”: The lower lips are bite between the teeth. The front teeth on upper jaw may be seen slightly. The tongue is passive.

“G”: The mouth is open. The middle part of the tongue touches the palate.

“Ğ”: In this visual phoneme all articulators of the human vocal system, except the throat, are passive. Its simulation will be analyzed in chapter 5.

“H”: In this visual phoneme all articulators of the human vocal system, except the throat, are passive. Its simulation will be analyzed in chapter 5.

“I”: The mouth is closed. The lips are open. The lower jaw touches the upper jaw. The teeth can be seen.

“İ”: The mouth is closed. The lips are open. The lower jaw touches the upper jaw. The teeth can be seen. The mouth is slightly wider than “I”.

**Figure 3.3 Visual Phoneme “i”**

“J”: This is very similar to “ç” and “c”. The visual model is the same. The lower jaw is closed. Lips are open and slightly curved forward. The tongue is raised, but it does not touch the palate, as the sound is fricative.

“K”: The mouth is open. The middle part of the tongue touches the palate. This visual phoneme is very similar to “g” but its simulation length is different.

“L”: The mouth is open. The tongue is visibly is touching the palate.

“M”: The mouth is closed. Lips touch each other. But different from visual phoneme “b”, the lips stay combined longer.

**Figure 3.4 Visual Phoneme “m”**

“N”: This visual phoneme is very similar to “l”, but the tip of the tongue touches the palate at a further point.

“O”: The mouth is open and rounded. The tongue is passive.

“Ö”: The mouth is open and rounded. The tongue is passive.

“P”: The mouth is closed. Lips touch each other.

“R”: The mouth and the jaw are slightly open. The tongue is very close to palate to make the fricative sound.

“S”: The mouth and the jaws are closed but the lips are open. The teeth can be seen closed.

“Ş”: The model is the same as “j”. The lower jaw is closed. Lips are open and slightly curved forward. The tongue is raised, but it does not touch the palate.

“T”: The visual model is the same as “d”. The tongue touches the palate. Lower jaw is parted from the upper jaw with a little opening from which the tip of the tongue can be seen. But the sound is more plosive than “d”.

**Figure 3.5 Visual Phoneme “o”**

“U”: The mouth is slightly open but not open big as “o”. The lips are extremely rounded. The tongue is passive.

“Ü”: The mouth is slightly open but not open big as “o”. The lips are extremely rounded. The tongue is passive.

“V”: The visual model is very similar to “f”. The lower lips are bite between the teeth. The front teeth on upper jaw may be seen slightly. The tongue is passive.

“Y”: The mouth is slightly open. The tongue touches the palate from the center.

“Z”: The visual model is very similar to “s”. The mouth and the jaws are closed but the lips are open. The teeth can be seen closed. But the tongue is not passive. Instead it is close to the teeth to make the fricative sound.

# CHAPTER 4

# 3D VIRTUAL SYSTEMS, 3D FACIAL MODELS AND 3D FACIAL EXPRESSIONS

## 4.1 3D Virtual Systems

3D virtual system refers to any system that represents 3D virtual geometries by means of any display device. The system can be a personal computer with a 3D rendering software used to render a 3D geometry object or a 3D projection device used to render a 3D scene. The basic features of these systems are; 3D objects and rendering. 3D object is a geometry that is formed of 3D points. 3D point is a three dimensional geometry object including three orthogonal space dimension values. Consequently a 3D object is simply an array of 3D points.

Rendering is a jargon word that has come to mean “the collection of operations necessary to project a view of an object or a scene onto a view surface” [Watt 1993]. For example; the object is lit and its interaction with a light source is calculated; in other words the object is rendered. In personal computers rendering is achieved via both software and hardware operations.

Briefly every 3D virtual system is a means of rendering device to visualize a 3D object via a display tool. A scene composed of 3D virtual objects and their behaviors over time or any kind of interrupt is called a 3D scene or a 3D virtual world, Figure 4.1.

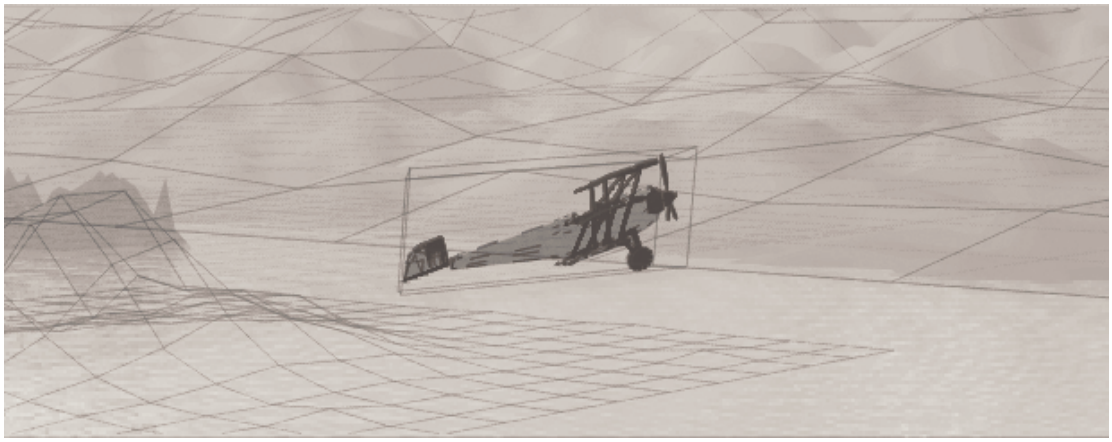


**Figure 4.1 3D virtual Scene including 3D objects**

### 4.2 3D Facial Models

The face has a very complex, flexible, three-dimensional surface. It has color and texture variation and usually contains creases and wrinkles. As presented in Chapter 2, the detailed anatomy of the head and face is a complex dynamic assembly of bones, cartilage, muscles, nerves, blood vessels, glands, fatty tissue, connective tissue and skin. Until now, no facial animation model, which represents and simulate this complete, detailed anatomy have been reported. For some applications, such as medical visualization and surgical planning, complete detailed models are the ultimate goal. Fortunately, a number of useful applications, such as character animation, can be accomplished with facial models that approximate only some aspects of the complete facial anatomy.

The goal of the various animation techniques is to control the modeled faces, over time, such that the rendered facial surfaces have the desired shapes, colors, and the textures in each frame of the animated sequence. Different representations of 3D facial geometry require different kinds of techniques to animate the facial geometry. These different kinds of representation models are discussed below.

#### 4.2.1 Volume Representations

One approach to representing faces is to use one of the many volume representation techniques. These include constructive solid geometry, volume element (voxel) arrays.

Constructive solid geometry is used successfully as the basis for a number of computer-aided mechanical design systems. For these systems the objects of interest are represented using boolean set constructions of relatively simple regular mathematical shapes, such as planes, cylinders or spheres. Unfortunately, realistic faces are not easily represented in this way. Therefore, this method has not been a popular geometric basis for faces. However, one can imagine a particular style of three-dimensional cartoon faces might be constructed using this technique.

Volume element, or voxel, representation is preferred way of describing anatomical structure in medical imaging. These representations may be assembled from two-dimensional data slices of three-dimensional structures. These two-dimensional slices may, for example, be obtained using multiple calibrated views [Mülayim 2002]. Detailed voxel representations typically require huge amounts of memory, Figure 4.2.

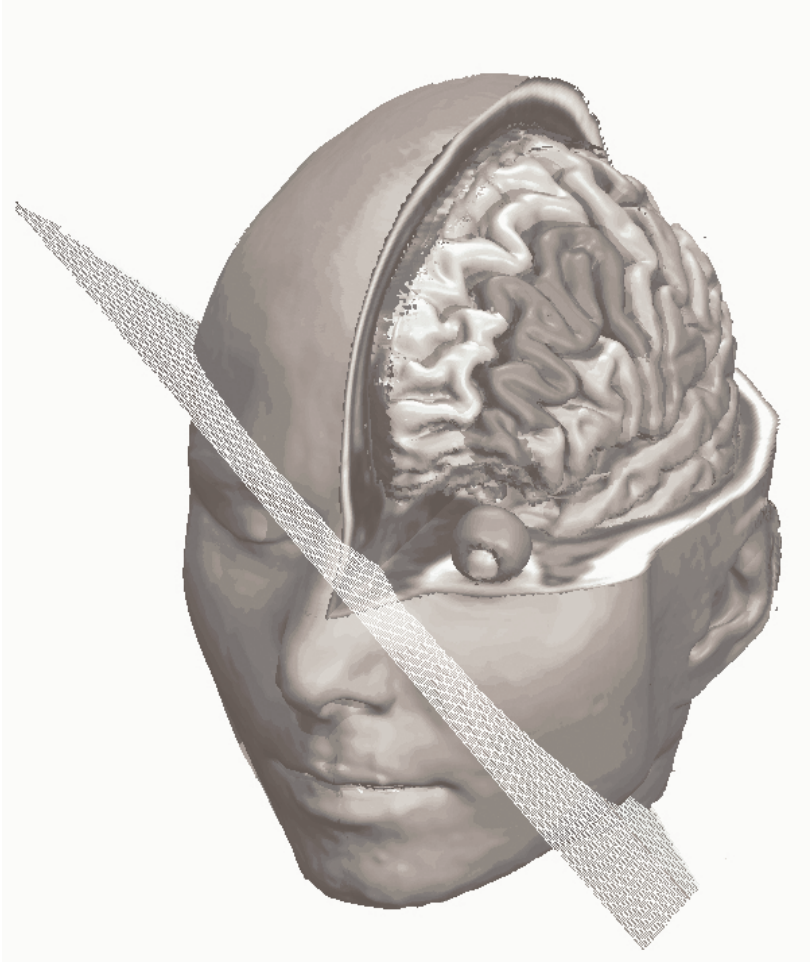


**Figure 4.2 3D Voxel Representation**

Direct voxel models are not currently used for facial animation. However voxel models can be used to extract the 3D geometry of the facial structure. Animation may then be done using the extracted surface models.

The extracted surfaces usually are constructed to follow specific structure boundaries in voxel data. The structure boundaries are associated with transitions between regions of specific constant densities within the voxel data.

### 4.2.2 Surface Representations

Possible surface description techniques include implicit surfaces, parametric surfaces and polygonal surfaces [Parke, Waters 1996]. Parametric surfaces include bivariate Bëzier, Beta-spline, B-spline and NURB surfaces [Parke, Waters 1996]. Polygonal surfaces include regular polygonal meshes and arbitrary polygon networks.

*Implicit Surfaces*: One approach is to find an analytical surface collection of surfaces to approximate the surface of the face. An implicit surface is defined by a function F(x,y,z,) that assigns a scalar value to each point in x, y, z space. The implicit surface defined by such a function set is the set of points such that:

$$F(x, y, z) = 0 \tag{4.1}$$

For example, a sphere of unit radius centered at $(0,1,-2)$ would be described by the implicit function

$$f(x, y, z) = x^2 + (y-1)^2 + (z+3)^2 - 1 \tag{4.2}$$

Any polynomial function $f(x, y, z)$ implicitly describes an algebraic surface. Although implicit surfaces are commonly expressed analytically, it is pointed out that the defining functions could be any procedure that computes a scalar value for every point in space. Models constructed with such procedures are called procedural implicit models [Ricci 1973].

The blending and constraint properties of implicit surfaces allow creation of models that would be difficult to build with other techniques [Parke, Waters 1996].

*Parametric Surfaces:* Bivariate parametric functions are used widely to define three-dimensional surfaces. These surfaces are generated by functions that are typically based on quadric or cubic polynomials.

Usually these surfaces are defined in terms of control values and basis functions. Examples of these include B-splines, Beta-splines, Bèzier patches and nonuniform rational B-spline surfaces, which are commonly called NURBS. These surface are generally expressed in the form

$$S(u,v) = \sum_i \sum_j V_{i,j} B_{i,k}(u) B_{j,m}(v) \tag{4.3}$$

where $S(u,v)$ is the parametric surface, $V_{i,j}$ are the control values and $B_{i,k}(u)$, $B_{j,m}(v)$ are the basis functions of polynomial orders *m* and *k*. In the matrix representation the formulation is seen as.

$$S(u,v) = [u]_{1\times k} [B_u]_{k\times i} [V]_{i\times j} [B_v]_{m\times j}{}^T [v]_{1\times m}{}^T \tag{4.4}$$

where [u] = [1 u $u^2$ ⋯ $u^{k-1}$] and [v] = [1 v $v^2$ ⋯ $v^{m-1}$]

and *i* and *j* are the number of control points.

Using parametric surfaces like these splines and patches have some trade-off. First of all the structure of the splines do fit the elastic form of the facial skin. The variable order of the splines and the continuity of the curves can directly control the softness of the skin. But creases in the face are difficult to implement since they require defeating the natural surface continuity properties. The control of facial expressions and speech can be organized by the control points of the parametric function. Due to the array structure of the control point, adding detail requires adding complete rows or columns to the control points array.

Real-time displays of these surfaces are difficult to render for today's personal computers. There are hardware rendering devices on video cards like GEFORCE or RODEON for rendering NURBS or other kinds of surface representations. But rendering analytically defined surfaces, like the ones above, require high performance computers. In order to test the performance of the NURBS, we have written a C++ program, which only calculates the point values and does not render the point mesh. The generated Bèzier surface is seen in Figure 4.3. The performance is very low. This has two main reasons. We did not use any hardware rendering

capabilities of the video card device. But one should remember that the NURB surface support of these video cards is still very inadequate. The second reason is that calculation of the parametric function is a huge amount of processing burden.

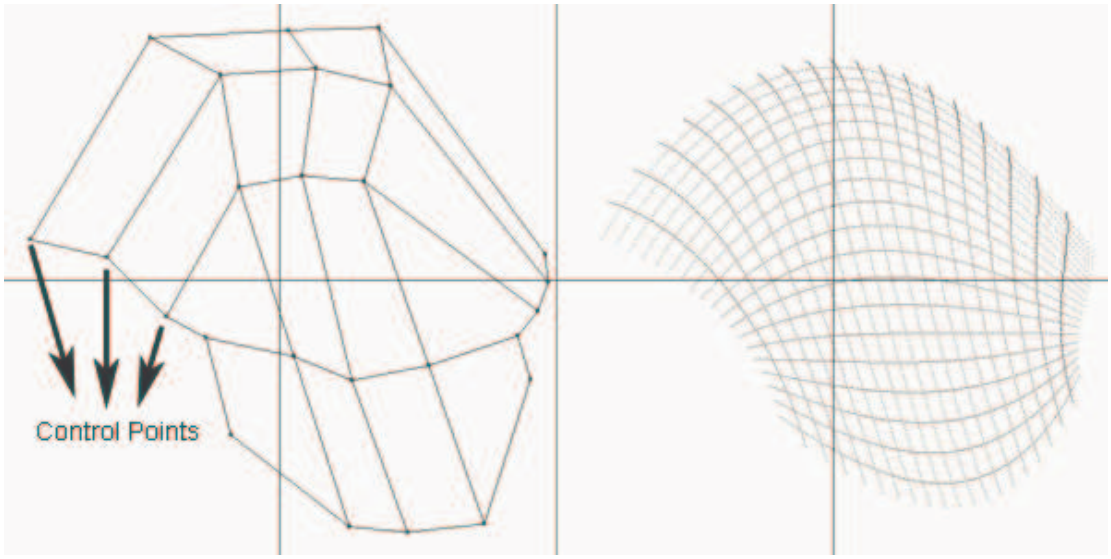



**Figure 4.3 Beizer Control Points and Bezier Surface Patch:** The surface patch seen above has 5x5, totally 25 control points. According to Bezier curve fitting formulas, the curves that form the surface patch seen above are of degree 5. The total time elapsed for calculation of this 5x5 Bezier surface patch took 812 milliseconds. This value corresponds to 1.23 frames/sec. As the degree of the curves and numbers control points increase, the elapsed time increases rapidly. We have tested the software on a P4, 2.4Ghz, 512 MB Intel machine.

### 4.2.3 Polygonal Representations

Modern graphic workstations are attuned to displaying polygonal surfaces and can update modest complexity facial models in near real-time [Parke, Waters 1996]. This effectiveness in real-time rendering caused virtually every facial model being displayed using polygonal surfaces. As a consequence of performance requirements,

even the non-polygonal surface techniques described above are approximated with polygonal surfaces for display.

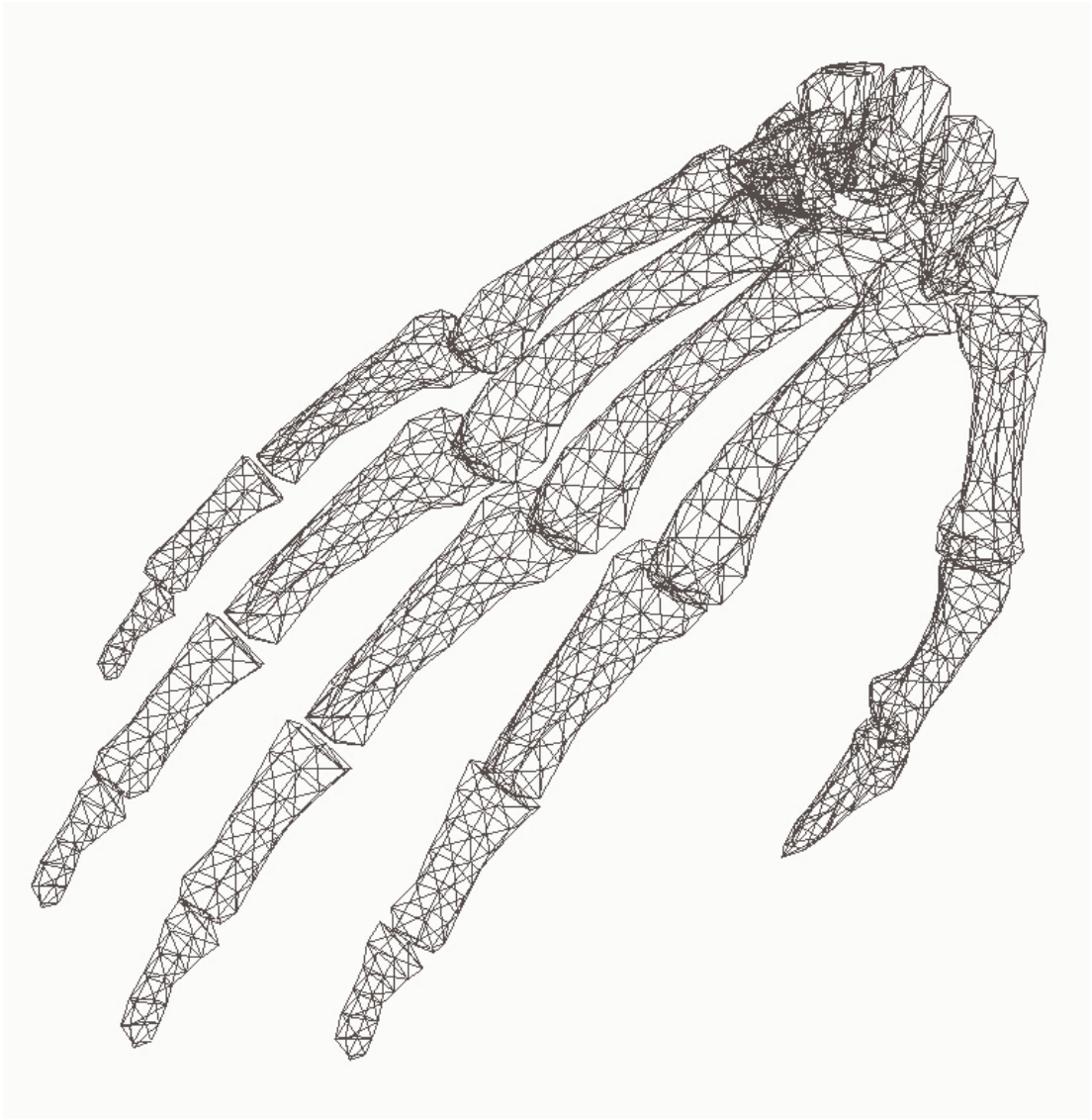


**Figure 4.4 A Polygonal Mesh**

Polygonal display is mainly based on forming polygons using the vertices of the 3D model. Vertices are the 3D point coordinates that build the 3D model. But a vertex does not only include the 3D point coordinate information, it also may include 3D normal coordinate information and it may or may not include the texture and color coordinates.

Point coordinates are simply the x, y, z values of the points that build a model. These are the space coordinates and they simply specify the position of the model in virtual space.

A polygonal model is formed of simply polygons, Figure 4.4. Some of these 3D points come together to form the polygons. These 3D point groups are distinct for each model. So besides the vertex information, which carries the space, normal, texture and color coordinate data, the information of "which vertices form groups to make the polygons" is also carried in the 3D object file.

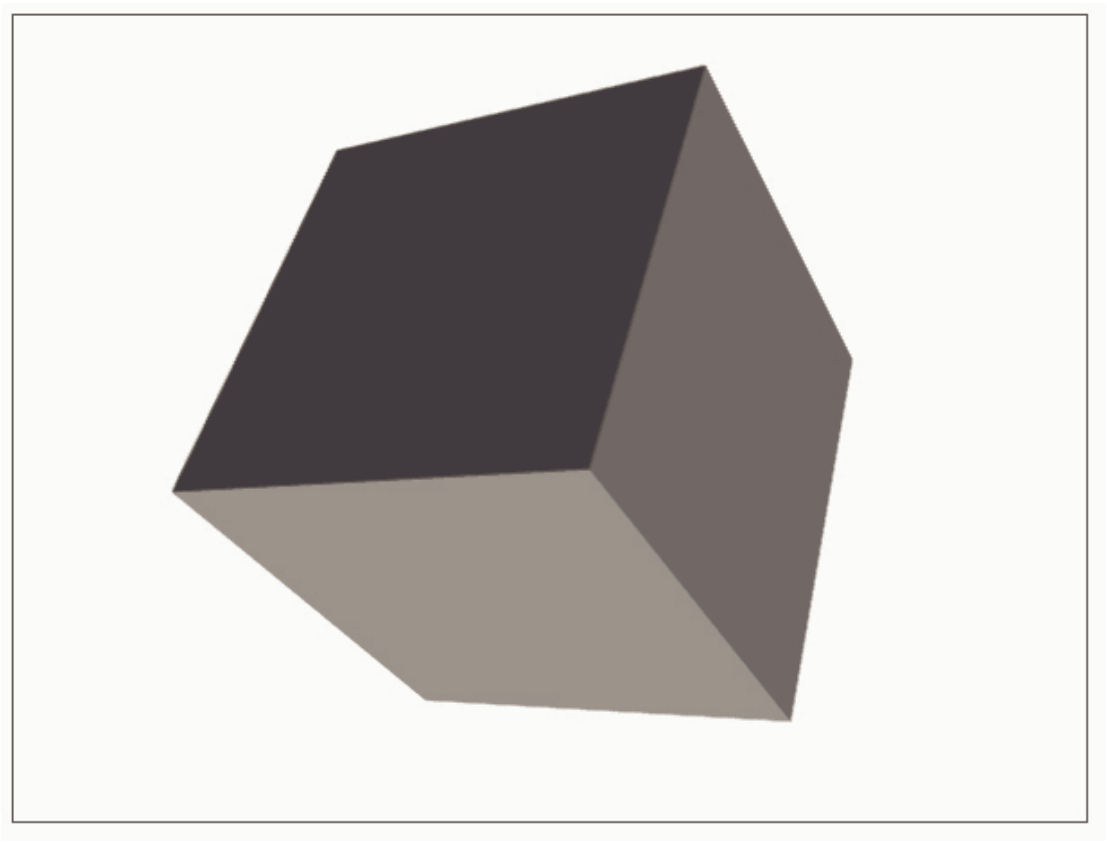


**Figure 4.5 Cube rendered with color properties**

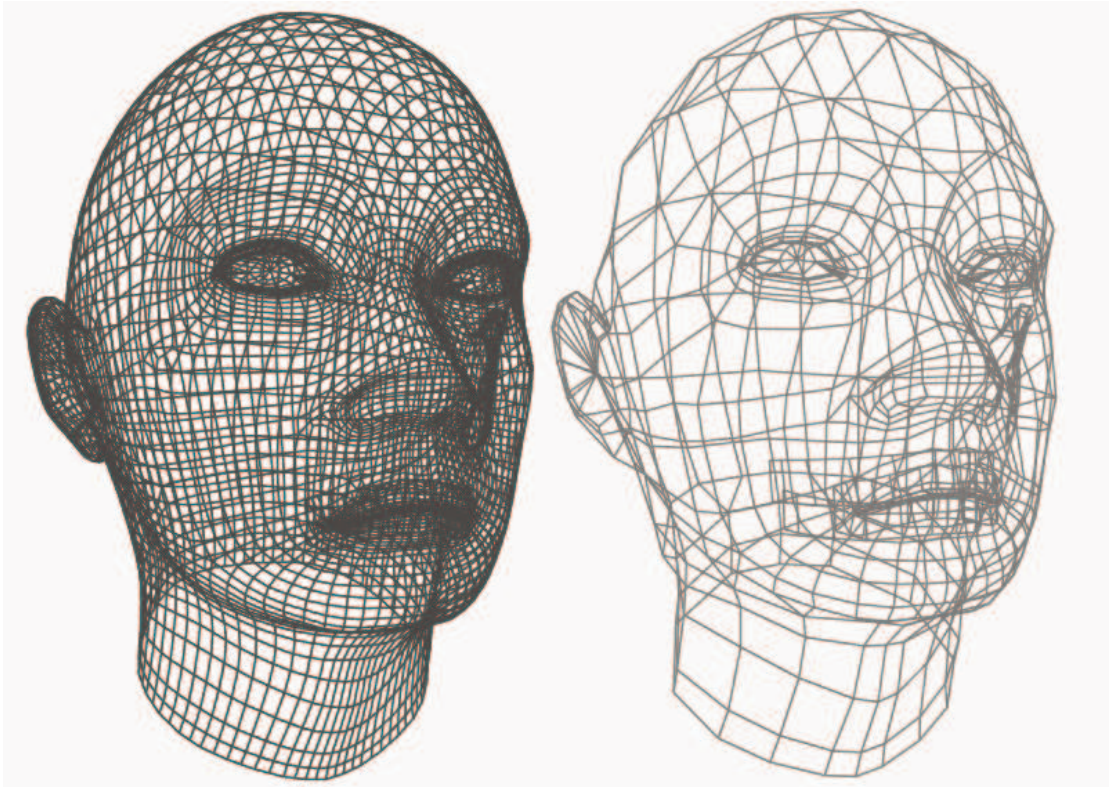
After the polygonal meshes are formed every polygon specifies a surface. Each of these surfaces has a normal vector. This normal vector is very important in light and other virtual world calculations. The normal values are calculated according to the polygonal mesh structure of the 3D object and stored as *normal coordinates*.

**Figure 4.6 Cube rendered with texture**

The polygon faces of a 3D object are subject to light and color. These surfaces may be defined as having a base color. You may have a cube, which has different color on each side, Figure 4.5. If this information is existent in the 3D object it is stored as *color coordinates* in the 3D object file.

For applications needing detailed graphical depiction, surface colors are not satisfactory. In these situations, the polygonal surfaces are covered with 2D pictures, which are called the texture, Figure 4.6. To map this 2D texture to the 3D model *texture coordinates* are used. The creation of texture coordinates is a difficult process. Both automatic tools [Mülayim 2002] and manual tools exist as 3D applications in building textures and texture coordinates.

Facial polygonal models are basically the 3D facial models constructed using polygonal meshes, Figure 4.7.



**a)** **b)**

**Figure 4.7 Facial Polygonal Meshes:** a) 22984 vertices, 11492 faces. b) 3070 vertices, 1490 faces.

### 4.3 Simulation of 3D Facial Expressions

Animating facial expression is the most challenging aspect of facial animation. When we animate facial expressions, several factors are taken into consideration, like personalities or motion or weight of the emotion or the kind of the emotion. Actually this is a subject of 3D modelers, cartoon animators, graphical designers. However, we will try to briefly understand the mechanical process behind simulation of 3D facial expressions.

The simulation process depends on the kind of animation you use. You may be using a 3D face with control parameters of virtual muscles. You may be using the method morphing with homeomorphic models [Akagündüz, Halıcı 2003]. Each method has its own advantages and disadvantages. There may be other known methods but in this chapter we will examine this two important methods. The first method is named

*control parameterization* and it is the most commonly used method. The other method is *morphing*, which is the one we have used in this study.

*Control parameterization:* In this method the development of facial animation may be viewed as two independent activities: the development of control parameterizations and associated user interfaces, and the development of techniques to implement facial animation based on these parameters [Parke, Waters 1996]. Basically in this method the movement on face is modeled in relation to some criteria. These criteria may be the movement of facial muscles, or the elastic movement of the facial skin. The main idea can be described as understanding the motion capabilities of the face and by extracting every independent motion on the face, implementing these parameters on a virtual face model.

As this method depends on the control parameters, only one facial model is kept at memory during software simulation. For this reason we may say that the method is a *memory-friendly* implementation. On this model the desired animation is achieved by controlling the parameters. But when it comes to the processor performance, it is not the same. Every frame requires parameter calculation, which requires extra CPU usage. This method is widely used for realistic and artistic animations. Today's Hollywood movies use this method to animate their computer-generated characters. Needless to say that real-time rendering is avoided in this method. There are real-time rendered examples of this implementation method, but the reality and artistic view of the animation is highly reduced in those examples.

*Morphing*: Animation of three-dimensional shapes involves the change of vertex attributes over time. Morphing represents such changes over time as the interpolation of two given shapes. We can extend this concept to more than two base shape and use morphing to produce blends of several objects. The interpolation function can be summarized as,

Let **I** be a geometry array formed of the vertices $\mathbf{I_i}$, the orthogonal coordinates being represented as $\mathbf{I_{ix}}$, $\mathbf{I_{iy}}$ and $\mathbf{I_{iz}}$.

Let **T** be the target object, **I** the initial object, the **O** the output object.

Let $\boldsymbol{\alpha}$ be the morphing weight, where $0 \leq \alpha \leq 1.0$

$$O_i = \alpha \cdot I_i + (1-\alpha) \cdot T_i \tag{4.5}$$

For this method we have to find the suitable set of necessary shapes for the animation. These suitable sets depend on the kind of animation. If the animation is speech animation of a certain language, the set is chosen in accordance with the visual phonemes of that language.

To morph various targets successively to form a complete animation, the method '*key-framing*' is used. Key-framing is the method of interpolating some key models successively due to some certain time. In Figure 4.8 an example of this key-frame animation is seen. This animation can be viewed as a video clip in Appendix C.

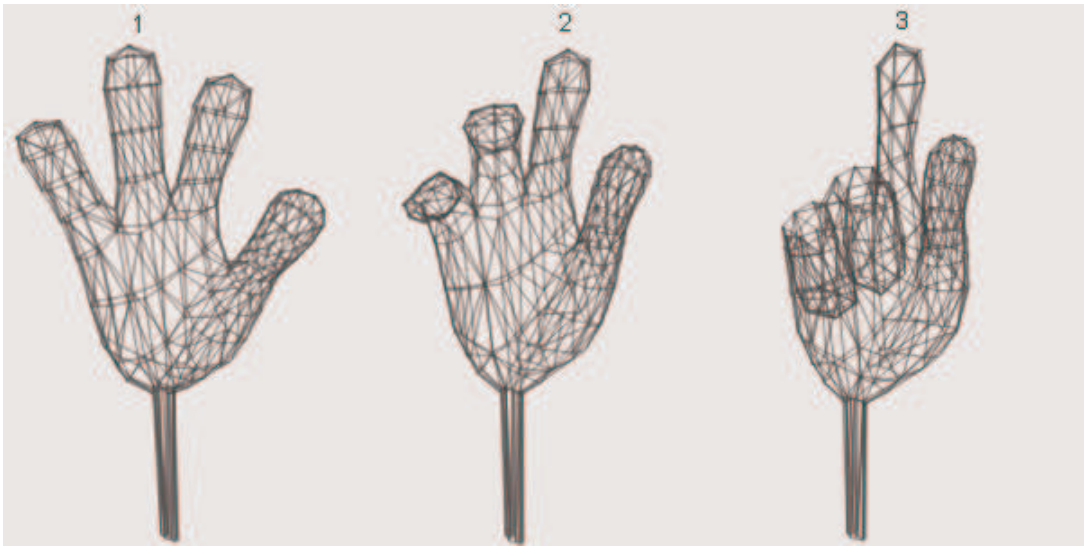



**Figure 4.8 Key-frame animation:** The numbers denote the key-frames. This animation is formed of three key-frames. These fey-frames form the "hand closing" animation.

The use of key poses and interpolation is among the earliest and still the most widely used schemes for implementing and controlling facial animation. The basic idea and the control parameterization for interpolation are very simple and also very limited.

This method requires extreme usage computer memory. Because for a high performance real-time animation, the entire key poses must be kept in computer memory. However the processor usage is lower in comparison to control

parameterization. Except for the rendering calculations, which are mainly calculated in video card processors, the only calculation is the simple interpolation function.

Further examination of this method is detailed in Chapter 5, as this method is the main animation method that we have used in this thesis.

# CHAPTER 5

# SIMULATION AND SYNCHRONIZATION OF TURKISH LIP MOTION IN A 3D ENVIRONMENT WITH A TURKISH SPEECH ENGINE

As it was mentioned in the previous chapter the main method of animation in this thesis is morphing. 3D morphing used with key-frame poses is a very efficient algorithm for facial animation. The theory and the implementation are explained in this chapter.

## 5.1 3D Weighted Morphing

Weighted morphing is the ability to morph a base or anchor model into two or more target models simultaneously [Fleming 1997]. This is a major advantage when you are creating lip-synchronized animation that includes both dialog and facial expressions.

The idea behind weighted morphing is very similar to that of single morphing. The only difference is that the target model is not a single model but a weighted sum of some number of different models. The weighted morphing function can be described as follows, Figure 5.1:

*Let **I** be a geometry array formed of the vertices **$I_i$**. The orthogonal coordinates are represented as **$I_{ix}$**, **$I_{iy}$** and **$I_{iz}$**.*

*Let **$T_n$** be the target objects, **I** the initial object, the **O** the output object.*

*Let **$\alpha_n$** be the morphing weights, where* $0 \le \sum_n \alpha_n \le 1.0$

$$O_i = (1-\alpha)\cdot I_i + \sum_n (\alpha_n \cdot T_{n,i}) \qquad (5.1)$$

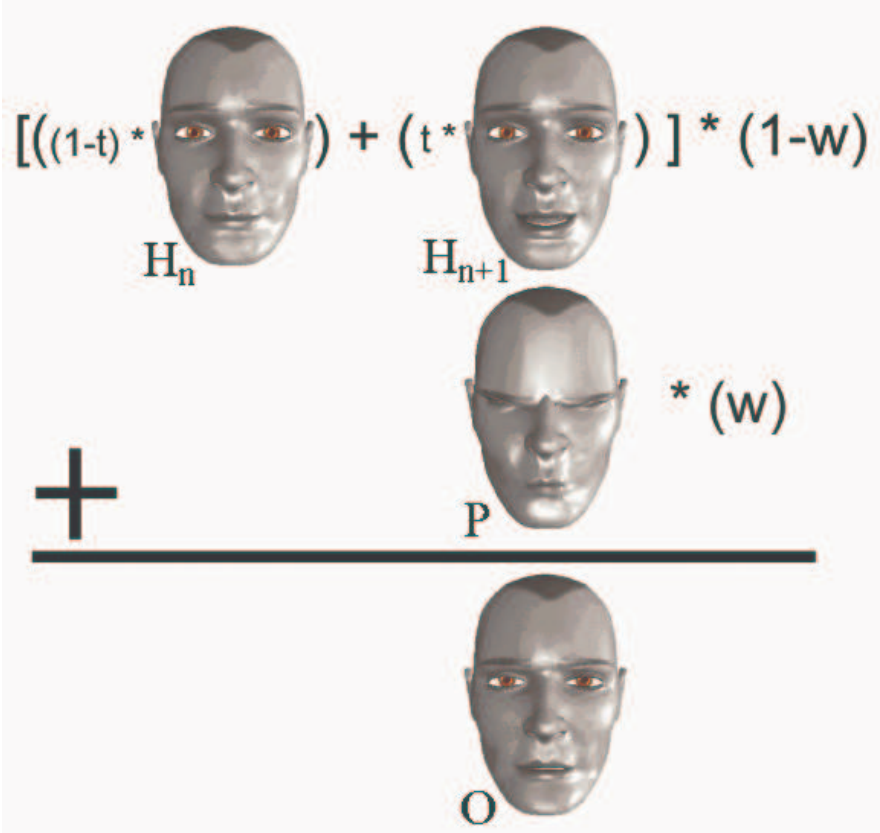



**Figure 5.1-Weighted Morphing**: In this figure the simple logic behind weighted morphing is explained. This captures are taken from the simulation of the sentence "Merhaba." The sentence is in "anger" emotion package. The jsml input is "*<SENT> <ANGRY> Merhaba </ANGRY> </SENT>*" The simulation position is between the first and second letters of the sentence. **$H_n$** denotes the 3D model of visual phoneme "M" stored in the object file "me.obj". **$H_{n+1}$** denotes the 3D model of visual phoneme "E" stored in the object file "e.obj". **P** denotes the 3D empowered emotion model. Finally **O** is the output. At the instant of the capture the parameter *t* and *w* were: **t = 0.199, w = 0.2**

An example of this weighted morphing is seen in Figure 5.1. The main problem of weighted morphing is as the number of morph targets increase, weight of each target decrease and the affect of these morph events become less evident in the final result. Let's give an example of morphing animation of speech with one single emotion. The speech requires lip motion that is morphing of visual phonemes to each other in time. But if you require a smiling lip motion in speech you need to morph the whole animation with an emotion model corresponding to smiling. Let's assume that the total lip motion sequence is weighted by the real number *w*, where $0<w<1$. Then naturally the emotion model will be weighted with *1-w*. If w is very close to 1 then the emotion will be very insignificant. On the other hand as we decrease w, the weight of emotion increases but the weight of lip motion sequence decreases and the animation quality of the lip motion decreases too. In other words the animation loses its understandability. To avoid this phenomenon two methods can be described in lip motion morphing.

*Segmented morphing*: Segmented morphing allows us to morph separate areas of the face individually. The morphing of the brows does not affect the morphing weight around the lips. Segmented morphing has two advantages over straight morphing; the ability to build a large number of expressions from a smaller set of targets and the ability to animate changing expressions while the character is talking. If it is somehow difficult to segment the model there is another method for the same purpose.

*Empowered emotion key-frame poses*: In this method the model is not segmented. The interpolation algorithm works for the whole model. But in this method instead of using traditional key-frame poses for the emotion models we use *empowered* models.

To better understand this method let us return back to our question. The main problem was that as the weighting increases the speech lip motion becomes insignificant. In this method the lip motion weight is detained at a considerable value like %80 or more. The remaining %20 or less weight is used for the emotion models. Unfortunately %20 is a low weight with which the emotion of face will be insignificant. Instead of using traditional emotion models we use empowered emotion models. A traditional emotion model has the 3D shape of the face having an emotion as illustrated in Figure 5.3. But empowered emotion model is somehow

exaggerated version of this model, Figure 5.4. To obtain this model we make a simple difference calculation. To achieve an empowered emotion model we need the neutral facial model. Neutral facial model is the one with no lip motion, no emotions and no expressions as depicted in Figure 5.2. The method to acquire this empowered model can be briefly described as:

**Figure 5.2 Neutral Face Model, N**

**Figure 5.3 Emotion model for "Anger", E**

Let **N** be the neutral model and $\mathbf{N_i}$ be the $\mathbf{i^{th}}$ vertex

Let **E** be the emotion model and $\mathbf{E_i}$ be the $\mathbf{i^{th}}$ vertex

Let $\rho$ be the empowering constant

Then Empowered model vertex $\mathbf{P_i}$ can be calculated as

$$P_i = N_i + \rho \cdot (E_i - N_i) \tag{5.2}$$

*where* $\rho > 1$

When these models are used in the animation as the empowered vertices, they affect the animation even with a small weight value. And the rest of the simulation, which is the lip motion, is still weighted with a high value and the lip motion is still understandable.

**Figure 5.4 Empowered Emotion Model "Anger", P**

Actually this method was the method we used for our simulation. We simply chose the empowering constant $\rho$ as 3. The results can be seen, in Chapter 6 and in Appendix C.

### 5.1.1 Mapping Turkish visual phonemes to Turkish letters.

As we have previously discussed for morphing animation we need the suitable set of the models that we want to morph. For lip motion in speech, we must determine some base models to morph. During lip motion of speech what kind of motion we do or what base shapes the face takes are the essential questions we should answer. For simulation of a language actually, taking the visual phonemes as the base models is the most efficient way. With this method, the order of the animation is designed due to the structure of the sentence. The explanation of this design is explained in the next subsection.

In this thesis we have used the Turkish visual phonemes as the base set of models for our lip motion animation for Turkish language. In order to obtain these base models, different techniques can be used. Simply using 3D modeling software to design the 3D visual phonemes according to the information given in Chapter 3 is sufficient. But if we want to use our own talking head models, or if we do not have such a 3D design software we may use a 3D reconstruction device. This can be laser-scanning device or a vision based calibrated camera view system [Mülayim 2002]. Whatever the system is, before starting this animation we have to use a set of 3D face models for Turkish visual phonemes.

We have acquired the 3D models using a 3D modeling software. The screen captures of the entire models can be seen in Appendix B.

We have used totally 53 3D models. 36 models for the Turkish visual phonemes, 6 models for the empowered emotion models, 10 models for random facial mimics, like blinking etc, and one single neutral model. Some of the letters are mapped into the same model, like the letter ‘v’ and ‘f’. Moreover for some of the letters, it is needed to use more than one model. The reason for this is based on the structure of Turkish speech. For the letter ‘m’ in the word ‘mor’ and in the word ‘mert’ we have used different models. The reason for this is explained in detail in the next

subsection. The letters and the models that they are mapped are listed below in Table 5.1. The screen captures of these models are given in Appendix B

**Table 5.1 – Turkish letters mapped to Turkish Visual Phonemes.**

| Visual Phoneme | *Example* | object file | No |
|---|---|---|---|
| | | | |
| Neutral | *N/A* | Neutral.obj | 36 |
| "A" | *Kal* | a.obj | 0 |
| "Ba" + "aB" + "Ba" + "aB" | *bal, abla, bık, kılıbık* | bpa.obj | 1 |
| "Be" + "eB" + "Bi" + "iB" | *bel, tebliğ, bir, iblik* | bpe.obj | 13 |
| "Bo" + "oB" + "Bö" + "öB" + "Bu" + "uB" + "Bü" + "üB" | *böl, büst, bol...* | bpo.obj | 24 |
| "Ce" + "eC" + "Ci" + "iC" + "Ca" + "aC" + "Cı" + "ıC" | *cam, acemi, cimri, cılk...* | cjae.obj | 2 |
| "Co" + "oC" + "Cö" + "öC" + "Cu" + "uC" + "Cü" + "üC" | *coş, ücra, öc...* | cjo.obj | 25 |
| "Çe" + "eÇ" + "Çi" + "iÇ" + "Ça" + "aÇ" + "Çı" + "ıÇ" | *çam, çelim, içki, çıban...* | cjae.obj | 2 |
| "Ço" + "oÇ" + "Çö" + "öÇ" + "Çu" + "uÇ" + "Çü" + "üÇ" | *çocuk, öç, üç,uç* | cjo.obj | 25 |
| "Da" + "aD" + "Dı" + "ıD" | *dam, ad, dıt..* | dta.obj | 3 |
| "De + "eD" + "Di" + "iD" | *edil, delik, idrak, dilek* | dte.obj | 14 |
| "Do" + "oD" + "Dö" + "öD" + "Du" + "uD" + "Dü" + "üD" | *dobra, dün, dul, ödlek* | do.obj | 26 |
| "E" | *kel* | e.obj | 12 |
| "Fe" + "eF" + "Fi" + "iF" + "Fa" + "aF" + "Fı" + "ıF" | *fal, eflatun, fır, iffet...* | fvae.obj | 4 |
| "Fo" + "oF" + "Fö" + "öF" + "Fu" + "uF" + "Fü" + "üF" | *fol, üfle, futür, öfke...* | fvo.obj | 27 |
| "Ga" + "aG" + "Ga" + "aG" | *galip, gıl...* | gkya.obj | 5 |
| "Ge" + "eG" + "Gi" + "iG" | *gel, giriş...* | gkye.obj | 15 |
| "Go" + "oG" + "Gö" + "öG" + "Gu" + "uG" + "Gü" + "üG" | *gol, göl, gül, gul...* | gkyo.obj | 28 |
| "Ğa" + "aĞ" | *ağrı, yağmur* | a.obj | 0 |
| "Ğe" + "eĞ" | *eğri* | e.obj | 12 |
| "Ğı" + "ıĞ" | *tığ* | I.obj | 21 |
| "Ği" + "iĞ" | *iğne* | Ii.obj | 22 |
| "Ğo" + "oĞ" | *boğmak* | o.obj | 23 |
| "Ğö" + "öĞ" | *öğürmek* | oi.obj | 34 |
| "Ğu+ "uĞ" + "Ğü" + "üĞ" | *tuğra, öğüt* | u.obj | 35 |
| "Ha" + "aH" | *halı, ah* | a.obj | 0 |
| "He" + "eH" | *hepsi, ehli* | e.obj | 12 |
| "Hı" + "ıH" | *hıçkırık, ıhlamur* | I.obj | 21 |
| "Hi" + "iH" | *hile,ihtiyaç* | Ii.obj | 22 |
| "Ho" + "oH" | *hol, oh* | o.obj | 23 |
| "Hö" + "öH" | *köhne, öh* | oi.obj | 34 |
| "Hu+ "uH" + "Hü" + "üH" | *hüp, üh, hurma, uh* | u.obj | 35 |

| | | | |
|---|---|---|---|
| "I" | *kıl* | I.obj | 21 |
| "İ" | *kil* | Ii.obj | 22 |
| "Je" + "eJ" + "Ji" + "iJ" + "Ja" + "aJ" + "Jı" + "ıJ" | *jel, ajlan, jambon* | cjae.obj | 2 |
| "Jo" + "oJ" + "Jö" + "öJ" + "Ju" + "uJ" + "Jü" + "üJ" | *jöle...* | cjo.obj | 25 |
| "Ka" + "aK" + "Ka" + "aK" | *kal, kıl, ık, ak* | gkya.obj | 5 |
| "Ke" + "eK" + "Ki" + "iK" | *kel, kil, ek, iklim* | gkye.obj | 15 |
| "Ko" + "oK" + "Kö" + "öK" + "Ku" + "uK" + "Kü" + "üK" | *kol, kül, köle, küp...* | gkyo.obj | 28 |
| "La" + "aL" + "La" + "aL" | *lamba, al, ılgın, alım* | la.obj | 6 |
| "Le" + "eL" + "Li" + "iL" | *el, elit, ilgi, liret* | le.obj | 16 |
| "Lo" + "oL" + "Lö" + "öL" + "Lu" + "uL" + "Lü" + "üL" | *olgu, gül, lut, flüt* | lo.obj | 29 |
| "Ma" + "aM" + "Ma" + "aM" | *mal, anlam, mızrak...* | ma.obj | 7 |
| "Me" + "eM" + "Mi" + "iM" | *emlak,merak, misil...* | me.obj | 17 |
| "Mo" + "oM" + "Mö" + "öM" + "Mu" + "uM" + "Mü" + "üM" | *omlet, füme, um, ömür* | mo.obj | 30 |
| "Na" + "aN" + "Na" + "aN" | *nara, anlam, anı...* | na.obj | 8 |
| "Ne" + "eN" + "Ni" + "iN" | *nem, en, in, nil* | ne.obj | 18 |
| "No" + "oN" + "Nö" + "öN" + "Nu" + "uN" + "Nü" + "üN" | *on, ön, ün, un, not...* | no.obj | 31 |
| "O" | *kol* | o.obj | 23 |
| "Ö" | *köle* | oi.obj | 34 |
| "Pa" + "aP" + "Pa" + "aP" | *para, pısırık, apar...* | bpa.obj | 1 |
| "Pe" + "eP" + "Pi" + "iP" | *peloş, pıtır...* | bpe.obj | 13 |
| "Po" + "oP" + "Pö" + "öP" + "Pu" + "uP" + "Pü" + "üP" | *toprak, tüp, pul, öp...* | bpo.obj | 24 |
| "Ra" + "aR" + "Ra" + "aR" | *ar, ırmak, ray, arıt* | ra.obj | 9 |
| "Re" + "eR" + "Ri" + "iR" | *er,eriş, irin, reklam* | re.obj | 19 |
| "Ro" + "oR" + "Rö" + "öR" + "Ru" + "uR" + "Rü" + "üR" | *üre, örtü, rota, ruj...* | ro.obj | 32 |
| "Sa" + "aS" + "Sa" + "aS" | *sal, as, ısı, ıslak* | sza.obj | 10 |
| "Se" + "eS" + "Si" + "iS" | *es, sel, is, sil* | sze.obj | 20 |
| "So" + "oS" + "Sö" + "öS" + "Su" + "uS" + "Sü" + "üS" | *sol, us, süne, sök* | szto.obj | 32 |
| "Şe" + "eŞ" + "Şi" + "iŞ" + "Şa" + "aŞ" + "Şı" + "ıŞ" | *aşk, eş, iş, aşık, işe...* | cjae.obj | 2 |
| "Şo" + "oŞ" + "Şö" + "öŞ" + "Şu" + "uŞ" + "Şü" + "üŞ" | *koş, üşen, kuş, şölen...* | cjo.obj | 25 |
| "Ta" + "aT" + "Ta" + "aT" | *at,tay, tığ, kıt* | ta.obj | 11 |
| "Te" + "eT" + "Ti" + "iT" | *et, tek, it, tiz* | dte.obj | 14 |
| "To" + "oT" + "Tö" + "öT" + "Tu" + "uT" + "Tü" + "üT" | *ot, üt, şut, öt...* | szto.obj | 33 |
| "U" | *kul* | u.obj | 35 |
| "Ü" | *kül* | u.obj | 35 |
| "Ve" + "eV" + "Vi" + "iV" + "Va" + "aV" + "Vı" + "ıV" | *ev, av, viran, kıvrak...* | fvae.obj | 4 |
| "Vo" + "oV" + "Vö" + "öV" + "Vu" + "uV" + "Vü" + "üV" | *vole, övgü, övünç...* | fvo.obj | 27 |
| "Ya" + "aY" + "Ya" + "aY" | *yal, yıl, ıy, ay* | gkya.obj | 5 |
| "Ye" + "eY" + "Yi" + "iY" | *yel, yit, ey, giy* | gkye.obj | 15 |
| "Yo" + "oY" + "Yö" + "öY" + "Yu" + "uY" + "Yü" + "üY" | *yol, yün, yön, uy* | gkyo.obj | 28 |
| "Za" + "aZ" + "Za" + "aZ" | *az, zar, azı...* | sza.obj | 10 |

| | | | |
|---|---|---|---|
| "Ze" + "eZ" + "Zi" + "iZ" | *ez, zemin,iz, zil* | sze.obj | 20 |
| "Zo" + "oZ" + "Zö" + "öZ" + "Zu" + "uZ" + "Zü" + "üZ" | *zom, öz, üz, uzun...* | szto.obj | 33 |

## 5.2 3D Weighted Morphing Simulation of Turkish Lip Motion And Facial Expressions

In this section, the method of implementation is explained. The subsections of this section correspond to different blocks in Figures A.1, A.2 and A.3.

### 5.2.1 The Method

The theory behind this study depends on morphing of different 3D models to each other according to the timing parameters of a Turkish speech flow. The simulation can be separated to four steps:

- The Turkish text entered via an interface is broken into its syllables. For example the sentence “Benim adım Ahmet” becomes “Be-nim a-dım Ah-met.”
- The letters that exist in the text are mapped into some homeomorphic 3D models and these models are called from the database. For example in the sentence “Benim adım Ahmet” the letters “b”, “e”, “n”, … exits and the mapped 3D models are loaded into memory. The 3D model that has been mapped to the letter “b” is the 3D facial model that has the shape of a face saying “b”.
- Using “Morph Node Class” of JAVA3D library and “Behavior Class” which we have written, the simulation is synchronized. Morph Node Class is capable of interpolating the vertex values of two homeomorphic 3D models.
- The sentence is put into an expression package. If the sentence is put into the package of “happy” expression the sentence will be simulated with a smiling 3D face model. Again weighted morphing is used to achieve this result.

### 5.2.2 Extraction of Turkish Syllables

In Turkish, syllables correspond to voices we make with a single movement of our lips. Like every other alphabet, Turkish alphabet consists of consonants and vowels. By definition, a Turkish syllable consists of a single vowel and n number of consonants where n=0,1,2,3. The list of regular Turkish syllables is shown below.

*Let '**a**' denote a "vowel" and '**b**' denote a "consonant":*

- *a* "***u***ğur"
- *ab* "***er***dem"
- *ba* "***ka***lem"
- *abb* "***ilk***okul"
- *bab* "***yağ***mur"
- *babb* "***fark***lı"

Since the focal objective of our study is not the extraction of Turkish syllables from written text, we have used an uncomplicated algorithm in extraction of syllables. First of all our algorithm assumes that the Turkish text does not have any syntax error and is composed of only Turkish words. The algorithm can be summarized as:

- Partitioning of the text into sentences
- Partitioning of the sentences into words
- Partitioning of the words into syllables

To partition the text into sentences we have search for the full stops **'.'**, the question marks **'?'** and the exclamation marks **'!'**.

To partition the sentences we have searched for the spaces between words. As expected our algorithm assumes that only one space exists between two words in a sentence.

The algorithm which we have used to partition the words into syllables, can be summarized as follows:

START

1. Look at the last letter of the word (or the last letter of the previous syllable).
    i. if vowel, look at the previous letter,
        1. if vowel then the last letter is one letter syllable: *"a"*

        Jump to START
        2. if consonant the last two letters form a syllable: *"ba"*

        Jump to START
    ii. if consonant look at the previous letter,
        1. if vowel look at the previous one
            a. if consonant the last three letters form a syllable: *"bab"*

            Jump to START
            b. if vowel the last two letters form a syllable*: "ab"*

            Jump to START
        2. if consonant, look at the previous letter
            a. if vowel, look at the previous letter*"*
                i. if consonant then the last four letters form a syllable: *"babb"*

                Jump to START
                ii. if vowel of the beginning of the word the last three letters form a syllable: *"abb"*

                Jump to START

If the algorithm comes to the beginning of the sentence, it terminates.

The algorithm does not make any syntax error check but it is capable of extracting all regular syllables from a Turkish text. In this first step of the study, the written text

*"Merhaba, benim adım Erdem Akagündüz."*

becomes

"mer-ha-ba, be-nim a-dım er-dem a-ka-gün-düz."

### 5.2.3 Mapping of the letters to 3D models.

In this step, using the information of the edited text, we have mapped the letters of the sentences to the homeomorphic 3D models in our database. Considering that the word *"Merhaba"* became *"mer-ha-ba",* the letters of this word is ready to map to the 3D models. To better understand this step we should take a closer look on the movement of our lips, tongue and mouth when we are speaking Turkish.

As we have mentioned before, syllables correspond to voices we make with a single movement of our lips, tongue or mouth. For example in the word "mer-ha-ba" the syllable *"mer"* is pronounced with a single effort. When we are saying "mer", first our mouth takes the shape of saying the letter "m". After that we shape our mouth to say "e" and finally end the syllable with moving our tongue to say "r". Therefore we can assume that there exist three main states of our mouth when we say *"mer";* the state of our mouth when we say "m", the state of our mouth when we say "e" and the state of our mouth when we say "r". We can visualize the process of saying *"mer"*, just like morphing of our mouth from "m" to "e" and "e" to "r". Consequently with an idea similar to *key-framing*, which is mainly used in 3D animation, three 3D Human face models, which have the shapes of saying "m", "e" and "r", can be morphed to each other in appropriate order and proper timing, and they can form the 3D animation of a face saying *"mer"*.

As expected all syllables corresponded to voices we have made with a single effort. Furthermore we have realized that the single vowel of syllable affected pronunciation of all of the consonants of that syllable. To understand this phenomenon in detail let's look at two Turkish words: *"mor" and* "mert".

As we have explained above the word *"mor"* can be simulated by morphing of "m" to "o" and "o" to "r". Similarly the word *"mert"* can be simulated by morphing of "m" to "e", "e" to "r" and "r" to "t". Can we model the letter "m" in the word "mor" and the letter "m" in the word "mert" with the same 3D human face model? From our examinations from the video sequences, the answer seems to be negative. When

someone tries to say “mor”, mouth takes the shape of saying “m”. But the shape of saying “m” depends on the vowel of the syllable that letter “m” is in. As the letter “m” continues with “o” in the word “mor”, mouth takes a more circular shape to say “m”. Similarly when someone tries to say “mert”, when mouth tries to say “m”, it takes a wider shape because this “m” continues with an “e”. The difference of the letters “m” of different vowels can be seen in Figure 5.5**.** As expected a similar phenomenon does not occur for the vowel letters.


**Figure 5.5 Different Visual Phonemes for the letter “m” in different syllables:** The first model is ‘*m’* in a syllable with the vowel “a” or “ı” like in “***ma****sal”* or “***mı****sır”*. The second model is ‘*m’* in a syllable with the vowel “e” or “i” like in “***mert***” or “***mi****nik”*. The third model is ‘*m’* in a syllable with the vowel “o”, “ö”, “u” or “ü” like in “***mu****sallat,* “***mü****zik”*, “***mor***” or “***göm****lek”*.

*S*ubsequently with the information of the syllable-extracted sentences, the 3D models can be mapped to the words of the sentences. The algorithm of model mapping can be summarized as follows:

Let *shape[]* be the array of the 3D geometries which the letters of the sentence are matched in order.

- Start by looking at the first letter of the sentence:
    - Is the **i**$^{th}$ letter of the sentence a vowel or a consonant?
        - If vowel, load the related 3D model of that vowel to shape[i]

- If consonant
    1. Look at the vowel of the syllable the letter is in
    2. Load the related 3D model of that consonant to shape[i]

- Go to next letter…

After this step for a sentence with "**n**" letters, a file array of length **n** is ready.

### 5.2.4 Morphing of the Facial Expressions

Having the array of the required models for the lip motion we are ready to morph these models to generate the animation. The next step is the addition of the facial expressions. The idea behind the weighted morphing of these expressions was explained in the beginning of this chapter. Adding our visual phoneme array to this former formula we get the total formula.

Let $\mathbf{H_n}$ be the n length array of letter objects where $\mathbf{H_{ni}}$ be the $\mathbf{i^{th}}$ vertex of the $\mathbf{n^{th}}$ letter.
Let **E** be the empowered emotion model and $\mathbf{E_i}$ be the $\mathbf{i^{th}}$ vertex of the emotion model.
Let ω be the emotion weight constant

For the sample sentence "Merhaba, benim adım Erdem." There are 23 objects in the array $\mathbf{H_n}$ (n=23), where 21 of them are the letters and 2 of them are the neutral models in the beginning and the end of the sentences. The array of letters is described in Table 5.2.

**Table 5.2 – Sentence "Merhaba, benim adım Erdem." visual phoneme mapping**

"Merhaba, benim adım Erdem."

| | | | |
|---|---|---|---|
| 0 | - | @ | Neutral.obj |
| 1 | m | Me | me.obj |

| | | | |
|---|---|---|---|
| 2 | e | E | e.obj |
| 3 | r | eR | re.obj |
| 4 | h | Ha | a.obj |
| 5 | a | A | a.obj |
| 6 | b | Ba | bpa.obj |
| 7 | a | A | a.obj |
| 8 | b | Be | bpe.obj |
| 9 | e | E | e.obj |
| **10** | **n** | **Ni** | **ne.obj** |
| **11** | **i** | **İ** | **Ii.obj** |
| 12 | m | iM | me.obj |
| 13 | a | A | a.obj |
| 14 | d | Dı | da.obj |
| 15 | ı | I | I.obj |
| 16 | m | ıM | ma.obj |
| 17 | e | E | e.obj |
| 18 | r | eR | re.obj |
| 19 | d | De | dte.obj |
| 20 | e | E | e.obj |
| 21 | m | eM | me.obj |
| 22 | - | @ | Neutral.obj |

Let the simulation be at the position shown in Figure 5.6

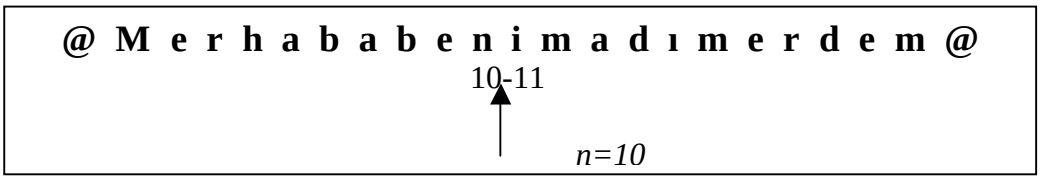



**Figure 5.6** The position of the simulation of the sentence in Table 5.2

The letter “n” is morphing to letter “i” at this instant. Let’s assume that the total morphing duration from the letter “n” to letter “i” takes $t_H$ milliseconds. And let the

parameter t be $t = \frac{t_0}{t_H}$ where $t_0$ is any time instant inside the morphing duration of letter "n" to letter "i". $0 \le t \le 1$

*n=10*

Then at time $t_0$ the Output object **O,** which has the vertices $\mathbf{O_i}$ is calculated as:

$$O_i = (1-\omega)\cdot\left[\left(H_{n,i}\cdot t\right)+\left(H_{n+1,i}\cdot(1-t)\right)\right]+\omega\cdot E_i \quad (5.3)$$

The above formula depicts the main calculation algorithm of our simulation. But in fact the actual formula is a bit extended. Different emotions may be simulated in one sentence. The first word may be in a "smiling" emotion package, where the second word has the "surprise" emotion package. Between the first and the second words as the emotion object **E** changes, the simulation experiences a non-smooth flow. In order to avoid this phenomenon in our algorithm, instead of using one single emotion object E, we have used two objects, namely $\mathbf{E_{pre}}$ the previous emotion and $\mathbf{E_{next}}$ the next emotion. Then again for the same $\mathbf{H_n}$, **E, t** and $\omega$ the formulation becomes:

$$O_i = (1-\omega)\cdot\left[\left(H_{n,i}\cdot t\right)+\left(H_{n+1,i}\cdot(1-t)\right)\right]+\omega\cdot\left[\left((1-t)\cdot E_{pre,i}\right)+t\cdot E_{next,i}\right] \quad (5.4)$$

So when the previous and the next emotions are different a smooth transform is observed between the emotions and the lip motion.

The above formula summarizes the overall animation sequence. The screen capture results can be seen in Figure 5.7. Also animation sequences can be viewed as movie clip in Appendix C.

### 5.2.5 Speech Markup Language Implementation

A speech markup language allows applications to annotate text with additional information that can improve the quality and naturalness of synthesized speech or lip motion. In this thesis lip motion is synchronized and morphed with emotions and

synchronized with speech. Since the input was text and the output is lip motion with emotions and synthesized speech we needed a markup language, which should handle emotions, delay and similar natural speech event during simulation. We have constructed the whole simulation in java programming language [SUN JAVA]. In order to build the 3D virtual world we have used JAVA3D API [SUN JAVA3D]. In addition to 3D lip motion simulation we have synchronized this animation with synthesized speech. We have used Turkish speech synthesis engine of G.V.Z company [G.V.Z]. As an interface between this speech engine and our simulation program, we have used CloudGarden Java Speech API [CloudGarden JSAPI]. Since our entire application is written in JAVA programming language, we have chosen JAVA Speech Markup Language [JSML] to use in our application.

JSML has been developed to support as many types of applications as possible, and to support text markup in many different languages. It has certain structural rules. Container elements, empty elements, white spaces and etc are defined by some specific language rules. More importantly some default tags exist for this markup language. But new tags can be defined for certain applications.

For our application we simply needed to use SENT tag and defined our basic six emotion tags, namely happiness, fear, sadness, surprise, anger and disgust. So according to JSML format rules a sample input text to our application was like:

***"<SENT>Animasyon programımız, <SAD>hüzün</SAD> <HAPPY>sevinç</HAPPY> <ANGER>sinir</ANGER> gibi duyguları aynı cümle içinde simüle edebilmektedir.</SENT>"***

This is a sample input text to our application. This animation is given in Appendix C as a movie clip. We have written a simple JSML parser code to parse the markup text. Details of this code can be found in Appendix A together with details of the simulation software. Accordingly the markup tag names for six emotions are:

**Table 5.3 – JSML Emotion tags.**

Anger: <ANGRY>*jsml text*</ANGRY>

Fear: <AFRAID>*jsml text*</AFRAID>

Sadness: <SAD>*jsml text*</SAD>

Happiness <HAPPY>*jsml text*</HAPPY>

Surprise <SURPRISED>*jsml text*</SURPRISED>

Disgust <DISGUSTED>*jsml text*</DISGUSTED>

### 5.3 Turkish Lip Motion-Speech Synchronization

In this thesis simulation of Turkish lip motion is achieved. To further study the synchronization of this text we needed Turkish speech sound.

At the start in order to make the synchronization available we have recorded our own Turkish speaking voice. We have simply recorded the word “merhaba” and extract the phoneme durations. The “merhaba” speech sequence and the places and the durations of the phonemes can be seen in Figure 5.7. The result was satisfying. This animation can be viewed as a movie clip in Appendix C with Erdem Akagündüz’s voice as saying “merhaba”.

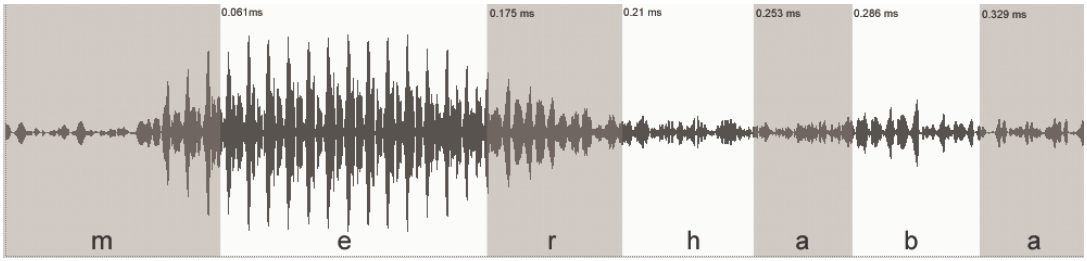



**Figure 5.7 Audio Signal of “Merhaba” sound Sequence:** The sequence is 364 milliseconds long.

Essentially synchronizing pre-recorded speech with our simulation was not our absolute objective. As a final goal we wanted to construct a system that was capable of simulation Turkish speech both in lip motion and speech. As building a Turkish speech engine was beyond the scope of this thesis, we have used GVZ Speech SDK, which is a speech engine product of the firm GVZ Speech Technologies Software Company [GVZ]. The product was a Microsoft speech engine capable of synthesizing and recognizing Turkish speech. Obviously we have only used the synthesizing ability of this engine in this study. With this speech synthesizer engine

we had to revise our animation to make it capable of running synchronized with this synthesized speech.

### 5.3.1 Synchronization with GVZ Speech SDK

Synchronization means temporal calibration of one or more events to other events, according to some criteria. In our case synchronization is simply sequential matching of the vocal phonemes to the visual phonemes of Turkish language.

To better understand how to synchronize speech with lip motion we should know or be able to guess the vocal phoneme durations. Knowing the duration of a certain phoneme inside a certain word, we can easily synchronize the lip motion with speech. Unfortunately Turkish vocal phonemes do not have certain lengths and their duration changes consistent with the word that includes that phoneme [Salor 1999]. So we cannot indicate some average values for the phoneme duration before run-time. Instead we should be able to get speaking event during run-time as speech events occur. Fortunately our speech engine was capable of sending phoneme-start and word-start events. This capability of the speech engine lets us to make both phoneme-by-phoneme and word-by-word synchronization. Unfortunately the interface program CloudGarden was only capable of listening word-start events. For this reason we have worked on word-by-word synchronization. We have taken average values for phoneme durations. We have used the mean durations calculated in [Salor 1999]. These values are established in Table 5.4. The results were satisfactory except for very long words.

**Table 5.4 Turkish phones and their mean durations**

| Phone | Duration (msec) | | Turkish Letter | Duration that we used (msec) |
|---|---|---|---|---|
| AA | 54 | | | |
| AAG* | 108 | | | |
| A | 46 | | | |
| AG* | 92 | | "A" | 55 |
| E | 50 | | | |
| EG* | 98 | | | |
| EE | 45 | | | |
| EEEG* | 93 | | "E" | 50 |

| | | | | |
|---|---|---|---|---|
| I | 34 | | | |
| IG* | 75 | | "I" | 34 |
| IY | 35 | | | |
| IYG* | 70 | | "İ" | 35 |
| O | 61 | | | |
| OG* | 123 | | "O" | 61 |
| OE | 62 | | | |
| OEG* | 124 | | "Ö" | 62 |
| U | 39 | | | |
| UG* | 79 | | "U" | |
| UE | 35 | | | |
| UEG* | 71 | | "Ü" | 35 |
| B | 66 | | "B" | 66 |
| C | 78 | | "C" | 78 |
| CH | 105 | | "Ç" | 105 |
| D | 56 | | "D" | 56 |
| F | 91 | | "F" | 91 |
| G | 68 | | "G" | 68 |
| GG | 61 | | "Ğ" | 61 |
| H | 58 | | "H" | 58 |
| J | 94 | | "J" | 94 |
| K | 91 | | | |
| KK | 90 | | "K" | 90 |
| L | 47 | | | |
| LL | 50 | | "L" | 47 |
| M | 68 | | "M" | 68 |
| N | 76 | | | |
| NN | 59 | | "N" | 59 |
| P | 96 | | "P" | 96 |
| R | 55 | | | |
| RR | 42 | | | |
| RH | 76 | | "R" | 55 |
| S | 118 | | "S" | 118 |
| SH | 114 | | "Ş" | 114 |
| T | 84 | | "T" | 84 |
| V | 63 | | "V" | 63 |
| W | 51 | | "W" | 51 |
| Y | 58 | | "Y" | 58 |
| Z | 88 | | | |
| ZH | 129 | | "Z" | 129 |
| GH | NA | | | NA |
| SILENCE | 607 | | | 607 |

* All of the vowels in Turkish may be pronounced longer with a “ğ”, like “eğ”, “ağ”. The vowels having the * sign means the phone duration of that vowel continued with “ğ”.

Apparently in Turkish, the phone durations may differ for a letter in different words. For this reason one letter may have different pronunciation types. There is open “a” and closed “a” in Turkish, like in ”kağıt” and “kal”. The letter “a” is pronounced differently and has different duration. We have taken the smallest mean duration for a word in our application.

The CloudGarden JAVA Speech API is able to send word-start events during speech run-time. So we have changed our application in a way that it became able to wait for the new word event to come before starting a new lip motion for the new word. As the syllables and phonemes inside the words need synchronization, the timing issue for our application was not completed. Inside the words we have used average values for the phonemes. As we have discussed before using average values may cause errors since the duration of phonemes may vary from word to word. But this error inside the words was negligible because the error was cleared before each word-start as word-start events were waited from the speech engine. The average values we have used for these words are taken from the studies of Özgül Salor [Salor 1999]. The results are discussed in the next chapter and can be viewed as video clips in Appendix C.

# CHAPTER 6

# RESULTS AND PERFORMANCE

In this chapter the output of this study is examined according to esthetic look, understandability (usability) and software performance. Needless to say that all these three criteria affect each other controversially, meaning each of them is a trade-off for the other one. We will analyze the results of this study according to these standards.

As this thesis was a study of creating a communication device, the usability or in other words the understandability of this study was our primary concern. The usability can be examined according to some technical properties of the output.

- Lip/Speech Synchronization
- Number of frames/seconds (frame rate) in the animation.
- Synthesized sound quality

Before examining these usability issues of the output of this study, we should understand the trade-off we make. High software performance is required to obtain high number of frames per second in the animation. Also synchronization of lip motion with the synthesized speech requires high software performance. As the system is working in real-time the overall output should be over a certain quality concern to pass the usability standards.

### 6.1 Lip/Speech Synchronization

Actually synchronization quality is the primal concern of understandability. In communication we humans are adapted to perfect synchronization of speech and lip motion. The articulators we have defined in chapter 3 of the human system have specific states in generating the speech sound. When some certain shapes taken by these articulators produce the vocal sound, the visual and vocal phonemes are synchronized naturally. When we try to say “a” our articulators, namely, lips, teeth, palate and throat, take some shapes in order to produce the desired sound. This is the natural way that the synchronization among visual and vocal phonemes happens. In our virtual world things do not happen this way.

As we have explained in the previous chapters in our simulation, the systems that produce the lip motion and the speech sound are definitely distinct. Lip motion is created via the Java3D virtual engine, which uses OpenGL to use the video card hardware to render the 3D scene. Java3D virtual engine is actuated via our Java code. On the other hand the sound is produced via the Microsoft Speech engine named “GVZ Levent16k”. The speech sound is triggered using this speech engine via the CloudGarden Java Speech API interface in our Java code. Noticeably the two sources of the synchronization are generated from two totally separate engines.

To synchronize these two separate engines we need a certain communication protocol between the two sources. Fortunately Microsoft Speech Engines 4.x and 5.x send some *speech events* during the simulation. Generally different events are thrown when new words are to be synthesized or a new phoneme is in the event queue of the speech engine output buffer. As we have previously stated, we have used a word-by-word synchronization based system. In our code we have listened to the *wordStarted* event thrown by the Speech Engine via the java Speech API interface. When a new word started to be synthesized by the speech engine, we have triggered the simulation. The results are captured in some movie clips and can be seen in Appendix C.

According to our analysis if the software performance is low, somehow the CPU usage of the software is very extreme and the synchronization experiences some lags. The reason for this is that the word start events are thrown according to some speech

engine properties and if the processor usage is above some value then these event-throwing durations may experience some lags. The processor load may increase according to the size of JAVA3D window that is rendered. In Appendix C the results can be analyzed according to rendering window size, the JSML input, the number of frames per second and the captured movie clip of the simulation.

### 6.2 Number of frames / second

When the output object is an animation or a moving picture, one of the most important performance issues is the number of frames per second of the animation. Human visual system has a certain sampling rate, which enables it to realize 24 frames per second. Above this rate some images cannot be realized by the neural system in conscious level. But psychologists insist that when frame rate is above 24 frames per seconds, human brain realizes these images in subconscious level. However as an end user we comprehend high frame rate as a high quality animation. In a 3D animation the frame rate is directly related to the processor usage. In other words, the ratio between the number of operations the software system can accomplish in one second and the number of operations needed to render one frame and synthesize sound indicate the frame rate. In Appendix C the results can be analyzed according to rendering window size, the JSML input, the number of frames per second and the captured movie clip of the simulation.

### 6.3 Synthesized Sound Quality

Speech synthesis is the process of conversion of written text into spoken language. It is also referred as text-to-speech (TTS) conversion. Like other computer-synthesized events, TTS conversion is also a case of digital-to-analog conversion (DAC). Similar to other DAC applications, TTS conversion has the attributes like resolution, etc. The speech system that we used was GVZ Speech SDK, which is a speech engine product of the firm GVZ Speech Technologies Software Company [GVZ]. The name of the speech voice they have created was "*Levent16k*". The engine is streaming, Multi-Lingual and Microsoft SAPI 4, SAPI 5 compliant. Detailed features of this speech engine can be reached from [GVZ]. The vocal results can be examined in the captured movie clips in Appendix C.

### 6.4 Software Performance

Since the output of this study was a real-time rendered software application with vocal synchronization, the software performance was one of our important concerns.

We have run this application in a computer with a Pentium® 4 CPU having a 2.00 GHz clock, DELL OPTIPLEX GX260 INTEL main board, 512 MB RAM and NVIDIA GEForce2 MX/MX 400 video card.

For different window sizes the frame rates, CPU and Memory usage are given in Appendix C.

As can be seen from appendix C, the CPU usage is always %100. This is a processing issue of JAVA3D. We have experienced that a live scene of JAVA3D rendered on screen takes CPU usage to %100.

Similarly as seen in Appendix C the memory usage is same for the entire samples. The reason is that we have constructed a system using fixed size memory. The 3D models are taken into memory for once. This let us construct a real-time speaker. The memory requirements of the captures seen in Appendix C are approximately 267 MB. This doesn't depend on how long the input JSML text is. This requirement only depends on the number of vertices of the homeomorphic 3D model set.

As it can be seen in Appendix C, the frame rate is over 40 frames per second. This rate is far more than what we need. With the given hardware and software configuration such a rate is achieved. The rate falls with the window size very slightly. Similarly the effect of speaking rate on frame rate is very slight but evident. As the speaking rate increases, since the working load of the processor increase, frame rate falls down vaguely. We think that this is an optimization issue of internal JAVA3D engine

Since 3D rendering is a computationally difficult task, real time 3D animation requires remarkable effort on optimization. Some optimization issues are presented in [Alexa et al 1996]. We have used only one of their optimization issues. The Java3D morph node interpolates all vertex coordinates, normal coordinates and texture coordinates. Mark Alexa, et al proposes that only necessary coordinates can be interpolated and others could be taken out of the morphing algorithm. As we are using 3D facial models, the texture coordinates does not change. The model is

interpolated and in the end it is mapped to a texture. So if texture coordinates are not interpolated in the morphing algorithm, much swiftness may be achieved in the simulation.

Logically using low-resolution texture and low-resolution 3D models will result in low esthetic quality but higher frame rates.

### 6.5 3D Esthetic model and animation quality

Since the output of this study is an animation, a moving picture, esthetic quality is one of the important characteristics of the study. The characteristics of esthetic quality would be the quality of the 3D model, the quality of the chosen 3D visual phonemes and the quality and smoothness of the animation.

In this study we have acquired the 3D models from a 3D modeling software. But it is important to note that this study is designed to work with any set of homeomorphic 3D models, which represent the visual phonemes of Turkish language. This property of the system enables us to work with any set of 3D models.

The models we have used were detailed models having 20784 numbers of vertices. But artistically the model was a cartoon face and the texture was low detailed. So the animation was a high detailed cartoon animation.

With a 3D model set, which has more detailed texture coordinates; the esthetic quality of the system might be tremendously increased. By using a high quality capture system, high quality visual phonemes can be acquired and the system will be similar to a real head animation more than a carton talking head. Actually this is our nearest future study.

In addition using a high quality 3D modeling software for creation of the 3D homeomorphic models, the esthetic results may be improved.

# CHAPTER 7

# CONCLUSIONS AND FUTURE STUDIES

In this thesis we analyzed a method for 3D animation of Turkish speech, human facial expressions and synchronization with a Turkish Speech engine using JAVA programming language, JAVA3D API and Java Speech API. We developed a 3D animation model that was able to simulate Turkish speech together with visual and audio components. To generate the simulation we have used OpenGL via JAVA3D API classes and interfaces. Also we have used G.V.Z Speech Technology's Turkish Speech engine GVZ SDK for human voice synthesis. Using these two interfaces we have constructed the animation and synchronization software in Java programming language.

The implementation block system has JSML Turkish text input and it has the output of real-time 3D Turkish speaker animation.

In order to model Turkish lip motion we have first defined the Turkish visual phoneme by inspection. We have mapped all the letters of Turkish alphabet to a single or multiple numbers of 3D visual phoneme models. In this mapping operation we have taken the syllable structure of Turkish language in consideration. To extract syllables from a Turkish sentence, we have defined an algorithm.

Finally we have synchronized the animation with synthesized Turkish speech on a word-by-word synchronization basis. The simulation we have constructed can be

animated with any suitable set of 3D homeomorphic set of 3D models as we have defined.

We have captured these animations with an external video camera from the computer monitor. The reason we have used an external video camera instead of using capturing software which could capture desktop events, was that we did not want our software performance analysis to be affected from the processor load of this capture application. We have represented these results. Through out the animations we have achieved a frame rate over than 40 frames/seconds. We have constructed an implementation software with a fixed size memory requirement of 267 MB. We have used 3D homeomorphic models with 20784 vertices.

Even though the 3D morphing animation system we have proposed is not a new system, as far as we know a simulation and synchronization system for real-time Turkish speaker is a brand new study. Today's communication devices are getting complicated everyday. In every application humans need human-like communication. Even today mail reading speech synthesizer applications and real time facial animations are being used. But the usages of these applications are limited to certain languages.

As the system we have proposed is simple, model-independent and implemental on any software system we think that it can be used in many important applications. Some of these applications can be listed as virtual chat machines with personalized 3D models and Turkish voices, a Turkish speaker as an interface for an artificial intelligent system, Turkish speaker desktop applications etc. These studies happen to be among our future study schedule in our Computer Vision and Intelligent Systems Research Laboratory.

Another future study could be implementing this software to an embedded hardware system, which could be utilized by cellular phones. So a visual Turkish speech animating message service will be applicable in cellular phones

In addition to these future studies we think of constructing 3D homeomorphic model sets compatible to this thesis. Using the calibrated camera system proposed by [Mülayim 2002] we think of capturing the visual phonemes, emotion models and Neutral models of different people, we plan to construct a library for our model-selectable speaker applications.

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# APPENDIX A

# DETAILS OF THE SIMULATION SOFTWARE

As we have mentioned before, in this thesis we analyzed a method for 3D animation of Turkish speech, human facial expressions and synchronization with a Turkish Speech engine using JAVA programming language, JAVA3D API and Java Speech API. The implementation software was written in JAVA language. In this chapter we will analyze the block diagram of the total study.

The implementation can be divided into two parts, Figure A.1. The first part is the parsing of the sentences. The input of the total system is Turkish JSML text. In the first part this text is parsed and the emotion packages are detected for each word. Moreover, the parsed sentenced is split into its syllables. In the end of the first part we have the syllable extracted sentence and the word emotion array which carries the emotion package information for each word, Figure A.2.

In the second part the syllable extracted sentence is broken into its letters, and the visual phonemes are matched to the 3D visual phoneme letters. At the same time the speech sound is synthesized. Finally the animation is run synchronized with the speech sound, Figure A.3.

These steps are explained in detail below.

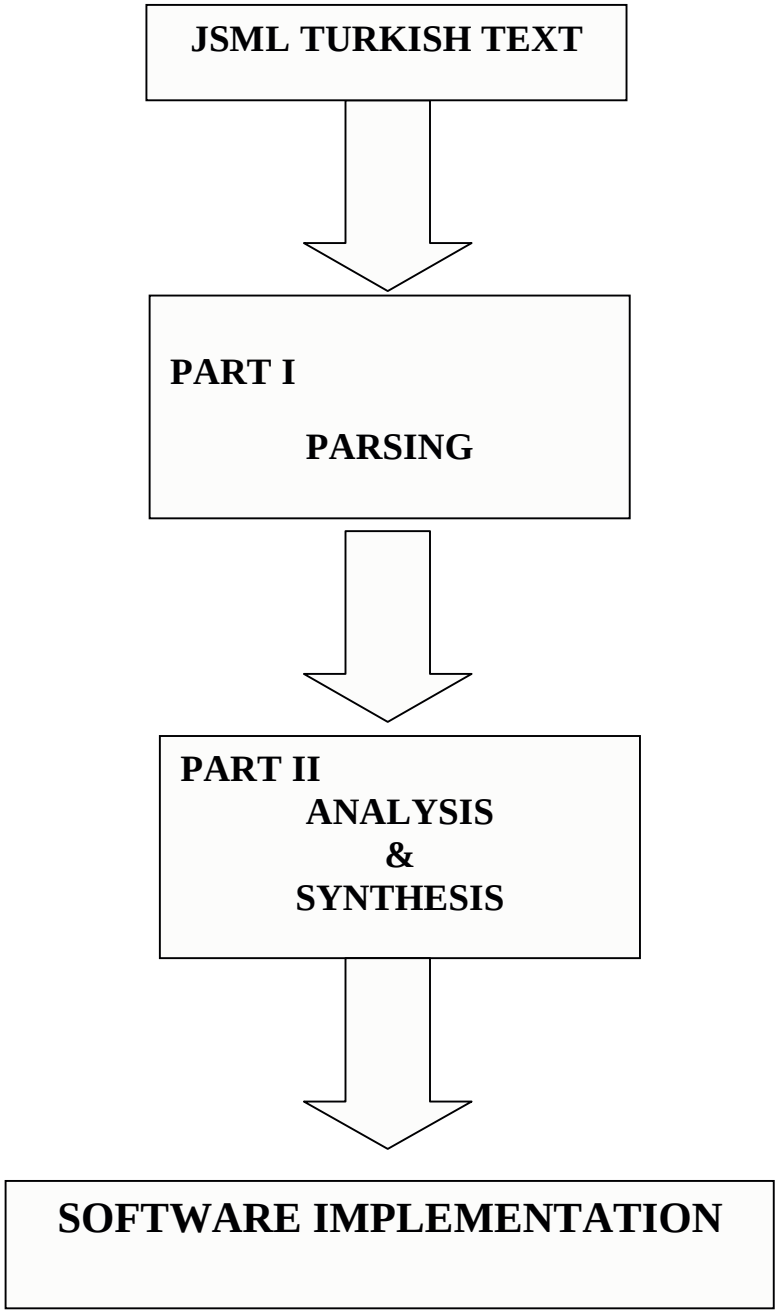


**Figure A.1** Software Implementation

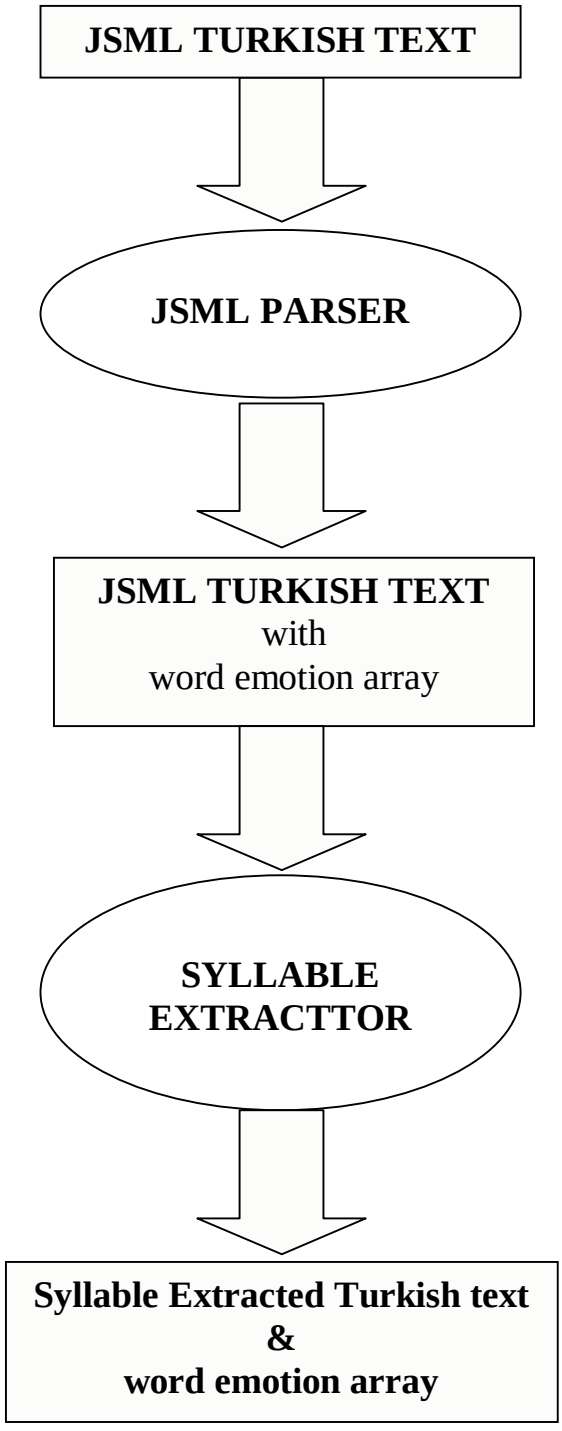


**Figure A.2** Software Implementation – PART I – PARSING

**Part I**

- Turkish JSML text is entered as the input of the system.
- JSML parser object “jsml_text” JAVA class that we have written is used to parse this sentence. This block creates the array variable that has a length same as the number of words of the sentence. In each index it carries the information of emotion type and emotion weight for each word. In addition to this emotion array, the plain sentence without the JSML tags is at hand in the end of this step.
- This plain text is extracted into its syllables by the JAVA classes we have written. In the end of this step, the syllable-extracted sentence is obtained. With the entire parsing and the text operations the first part is done.

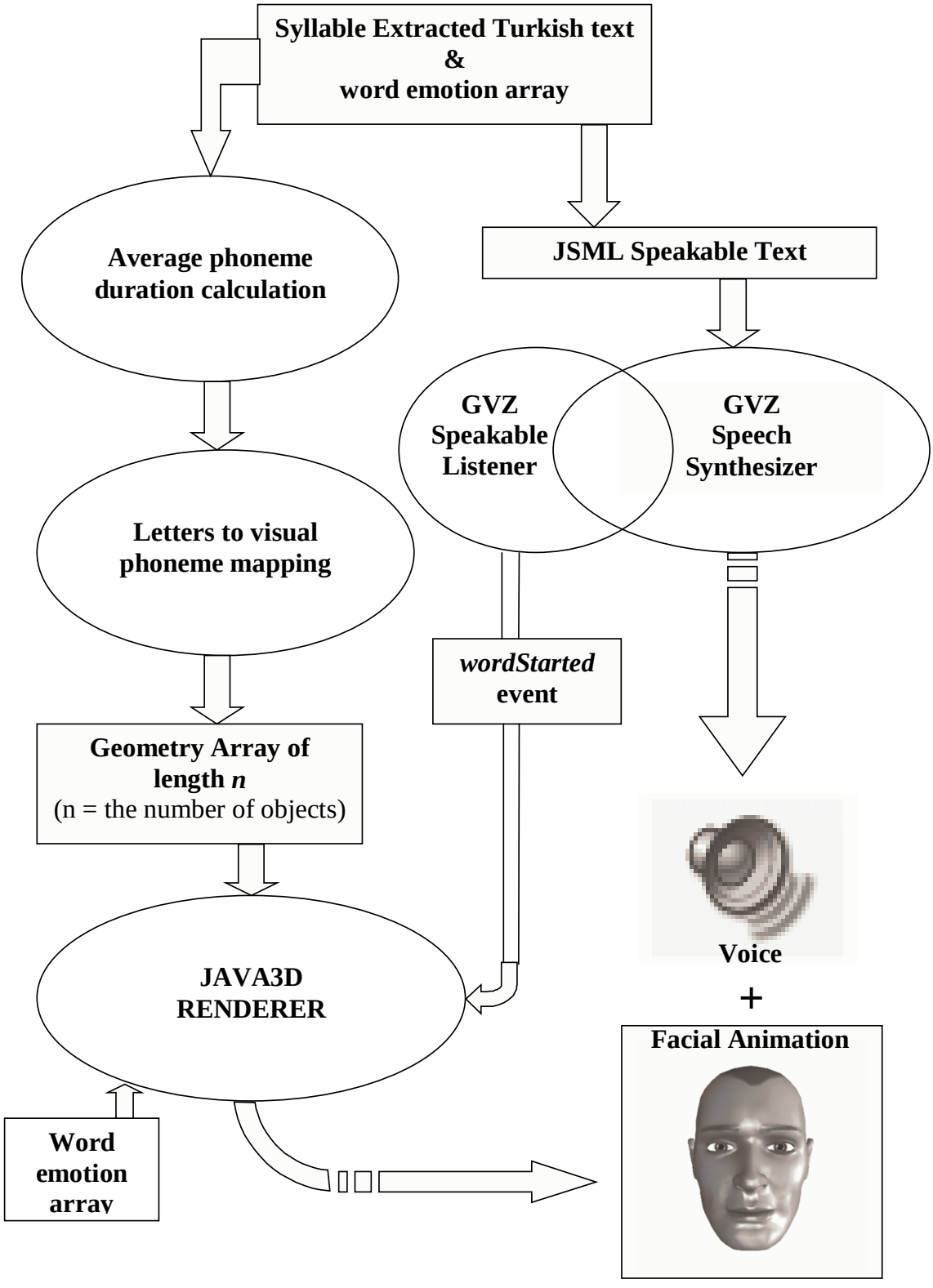


**Figure A.3** Software Implementation – PART II – Analysis & Synthesis

**Part II**

- The inputs of the second part are syllable-extracted Turkish text and the emotion array.
- The plain text of the previous step is sent to the GVZ speech engine as a *speakable* text to be synthesized.
- At the same time the syllable extracted text is used to calculate the average phoneme durations inside each word. As the system is word-by-word synchronization based the phoneme duration inside the words are calculated using a look-up table. After this step the phoneme duration array is ready.
- As the information of the information of each vowel inside the syllables the words are mapped to their related 3D visual phonemes. According to the flow of the sentence, a geometry array in the length of the number of letters in the sentence is created and ready to be morphed and rendered.
- In this step the rendering is done.
    - GVZ speech engine starts playing the speech voice. Before each word it sends the *wordStarted* event.
    - Using the geometry array, the word emotion array, and the phoneme durations array the scene is rendered in consistent with the formula 5.4. Before each word start the *wordStarted* event is awaited.

  As the output, the voice and the animation of the Turkish speaker is generated.

# APPENDIX B

# TURKISH VISUAL PHONEMES

In appendix B, the pictures of the visual phonemes defined in Table 5.1 are given. Refer to Table 5.1 to understand the mapping between these visual phonemes and Turkish letters. In our implementation we have used these models as the 3D visual phonemes.

a.obj – object no: 0

bpa.obj – object no: 1

cjae.obj – object no: 2

da.obj – object no: 3

fvae.obj – object no: 4

gkya – object no: 5

la.obj – object no: 6

ma.obj – object no: 7

na.obj – object no: 8

ra.obj – object no: 9

sza.obj – object no: 10

ta.obj – object no: 11

e.obj – object no: 12

bpe.obj – object no: 13

dte.obj – object no: 14

gkye.obj – object no: 15

le.obj – object no: 16

me.obj – object no: 17

ne.obj – object no: 18

re.obj – object no: 19

sze.obj – object no: 20

I.obj – object no: 21

Ii.obj – object no: 22

o.obj – object no: 23

bpo.obj – object no: 24

cjo.obj – object no: 25

do.obj – object no: 26

fvo.obj – object no: 27

gkyo.obj – object no: 28

lo.obj – object no: 29

mo.obj – object no: 30

no.obj – object no: 31

ro.obj – object no: 32

stzo.obj – object no: 33

oi.obj – object no: 34

u.obj – object no: 35

# APPENDIX C

## SAMPLE SIMULATONS

In this part the movie clips captured from our implementation are given as movie clips. In capturing these movie clips we have used two methods. First with a Handy Cam we have taken the monitor of the computer the implementation is running. In these examples the real-time performances can be examined. But the visual and vocal quality is incompetent as expected. The list below shows the files included inside the CD.

*CD/handycam*

- *morphinghand.avi : Key-frame animation depicted in Figure 4.8.*
- *jsmltext.avi : The JSML text simulation mentioned in Section 5.2.5.*
- *merhaba.avi : The voice synchronization mentioned in Section 5.3.*
- *sample001.avi*
- *sample002.avi*
- *sample003.avi*
- *sample004.avi*
- *sample005.avi*
- *sample006.avi*

These simulation samples taken from the study are viewable in the CD added to this thesis. Below lies the certain parameters for each sample simulation, indicating the input JSML text, CPU usage, memory usage, rendering window size, frame rate and speaking rate. For better comprehension of the results, the JSML text is taken to be same for each of them.

JSML text input :

*<**SENT**><**SURPRISED**>merhaba<**/SURPRISED**>, benim adım erdem<**/SENT**>*

| filename | Speaking rate (word/min) | Window size (x,y) | CPU usage (%) | Memory usage (MB) | Frame rate (fps) |
|---|---|---|---|---|---|
| | | | | | |
| sample001.avi | 75 | 390,397 | 100 | 267 | 46.28 |
| sample002.avi | 100 | 390,397 | 100 | 267 | 45.81 |
| sample003.avi | 150 | 390,397 | 100 | 267 | 43.56 |
| sample004.avi | 75 | 190,197 | 100 | 267 | 48.97 |
| sample005.avi | 100 | 190,197 | 100 | 267 | 48.82 |
| sample006.avi | 150 | 190,197 | 100 | 267 | 46.33 |