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Emotion Recognition and Synthesis Based on MPEG-4 FAPs

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ABSTRACT

In the framework of MPEG-4 hybrid coding of natural and synthetic data streams, one can include teleconferencing and telepresence applications, in which a synthetic proxy or a virtual agent is capable of substituting the actual user. Such agents can interact with each other, analyzing input textual data entered by the user and multisensory data, including human emotions, facial expressions and nonverbal speech. This not only enhances interactivity, by replacing single media representations with dynamic multimedia renderings, but also assists human–computer interaction issues, letting the system become accustomed to the current needs and feelings of the user. Actual application of this technology [1] is expected in educational environments, 3-D videoconferencing and collaborative workplaces, online shopping and gaming, virtual communities and interactive entertainment. Facial expression synthesis and animation has gained much interest within the MPEG-4 framework; explicit facial animation parameters (FAPs) have been dedicated to this purpose. However, FAP implementation is an open research area [2]. In this chapter we describe a method for generating emotionally enriched human–computer interaction, focusing on analysis and synthesis of primary [3] and intermediate facial expressions [4]. To achieve this goal we utilize both MPEG-4 facial definition parameters (FDPs) and FAPs. The contribution of the work is twofold: it proposes a way of modeling primary expressions using FAPs and it describes a rule-based technique for analyzing both archetypal and intermediate expressions; for the latter we propose an innovative model generation framework. In particular, a relation between FAPs and the *activation* parameter proposed in classical psychological studies is established, extending the archetypal expression studies that the computer society has concentrated on. The overall scheme leads to a parameterized

approach to facial expression synthesis that is compatible with the MPEG-4 standard and can be used for emotion understanding.

9.1 INTRODUCTION

Research on facial expression analysis and synthesis has tended to concentrate on primary or archetypal emotions. The categories that have attracted most interest in human–computer interaction environments in particular are sadness, anger, joy, fear, disgust and surprise. Very few studies that explore nonarchetypal emotions have appeared in computer science literature [4]. This trend may reflect the influence of work by Ekman [5], Friesen [6] and others, who proposed that the archetypal emotions correspond to distinct facial expressions that are supposed to be universally recognizable across cultures. However, psychological researchers working in different traditions [7–9] have investigated a broader variety of emotions. An extensive survey on emotion analysis can be found in Reference 10.

MPEG-4 indicates an alternative way of modeling facial expressions and the underlying emotions that are strongly influenced by neurophysiological and psychological studies. The FAPs that are utilized in the framework of MPEG-4 for facial animation purposes are strongly related to the action units (AUs) that constitute the core of the facial action coding system (FACS) [3].

Psychology contains various ideas that may help researchers in the area of computer graphics and machine vision to exploit the flexibility of MPEG FAPs. One of the best known is the idea that emotions are points in a space with a relatively small number of dimensions. Two dimensions, *activation* and *evaluation*, are sufficient for a first approximation. *Evaluation* summarizes how positive or negative the subject feels; *activation* indicates how energetically he or she is disposed to act. The scheme is useful partly because research such as Whissel's [8] has provided coordinates corresponding to a wide range of emotions.

In this chapter we present a methodology for analyzing both primary and intermediate expressions, taking into account the results of Whissel's study and in particular the *activation* parameter. The proposed methodology consists of four steps:

1. *Description of the archetypal expressions through particular FAPs*: In order to do this, we translate facial muscle movements – describing expressions through muscle actions–into FAPs and create a vocabulary of FAPs for each archetypal expression. FAPs required for the description of the archetypal expressions are also experimentally verified through analysis of prototype datasets. In order to make comparisons with real expression sequences, we model FAPs employed in the facial expression formation through the movement of particular FDP points – the selected FDP points correspond to facial area points that can automatically be detected from real images or video sequences. The derived models serve as a bridge between expression synthesis and analysis [11].
2. *Estimation of the range of variation of FAPs that are involved in each of the archetypal expressions*: This is achieved by analyzing real images and video sequences in a semiautomatic manner and by animating synthesized examples.

3. *Modeling of intermediate expressions*: This is achieved through combination, in the framework of a rule base system, of the *activation* parameter – known from Whissel's work – with the description of the archetypal expressions by FAPs.
4. *Understanding emotions*: Emotion models, created in steps (1) to (4), form the basis of a fuzzy rule system that recognizes the underlying (if any) emotion in facial video sequences.

Figure 9.1 illustrates the way the overall analysis and synthesis system functions. A facial video stream feeds a detection system, whose purpose is to recover the motion of prominent points lying in the facial area and corresponding to specific FDP points. Access to an appropriate facial video sequence is necessary for estimating, with acceptable accuracy, the movement of the facial points (in nonteleconferencing video sequences the solution to this problem is close to impossible). The motion of facial points is mapped to FAPs. A vector is produced consisting of FAP values, which is then compared to a predefined set of emotion profiles (models), by a fuzzy inference system. The output of the system is a decision about the specific emotion conveyed by the real subject or the belief values of the best matching emotions.

It should be noted that the system can be used for animation purposes in very low bit rate environments [12]. The emotion analysis system provides either information about the specific emotion expressed by the subject or simply the movement of particular points within the facial area. In the former case, the system provides the

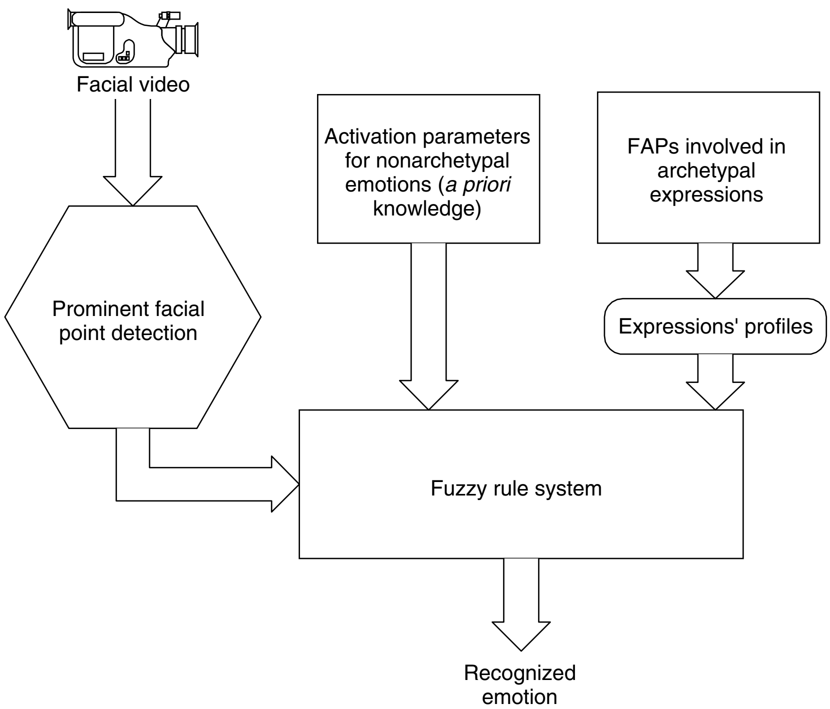

Figure 9.1 Block diagram of the proposed scheme

modification parameters – the FAPs and their appropriate range of variation that are required by the client side application to animate the emotion. In the latter case that corresponds to a failure to recognize a particular emotion, the system simply provides the estimated FAP values (animating the estimated FAP values does not guarantee the creation of a recognizable emotion).

This chapter is organized as follows: Sections 9.2 to 9.4 present the first three parts of the proposed methodology. Section 9.5 describes a way of utilizing the proposed scheme for emotion analysis purposes. Experimental results that illustrate the performance of the presented approach are given in Section 9.6. Finally, conclusions are presented in Section 9.7.

9.2 DESCRIPTION OF THE ARCHETYPAL EXPRESSIONS USING FAPs

In the framework of MPEG-4 standard, one can describe both the anatomy of a human face – basically through FDPs – and the animation parameters, with groups of distinct tokens eliminating the need to specify the topology of the underlying geometry. These tokens can then be mapped to automatically detected measurements and indications of motion on a video sequence; thus, they can help estimate a real expression conveyed by the subject and, if required, approximate it by means of a synthetic one.

Modeling facial expressions and underlying emotions through FAPs serves several purposes:

1. Given the FAP values describing the activation of a face one can form estimates of the emotion expressed by the subject.
2. The methodology ensures that the synthetic sequences created with it are compatible with the MPEG-4 standard.
3. Archetypal expressions occur rather infrequently: in most cases, emotions are expressed through variation of a few discrete facial features that are directly related to particular FAPs. Moreover, distinct FAPs can be utilized for communication between humans and computers in a paralinguistic form, expressed by facial signs.
4. Because FAPs do not correspond to specific models or topologies, synthetic expressions can be overlaid on models or characters other than the subject who originally made the gestures.

Two basic issues should be addressed when modeling archetypal expression: (1) estimation of FAPs that are involved in their formation, (2) definition of the FAP intensities. The former is examined in the current section, while the latter is explained in Section 9.5.

It is clear that the FACS has had a profound influence on research into the analysis of expression. The FACS is a system that tries to extract visually distinguishable facial movements using knowledge of facial anatomy. FACS uses AU as measurement units. Note that an Action Unit does not correspond to a single muscle. It could combine the movement of two muscles or work in the reverse way, that is, split into several muscle movements.

Table 9.1 FAP to AU mapping

Action Units	FAPs
AU1	raise_l_i_eyebrow + raise_r_i_eyebrow
AU2	raise_l_o_eyebrow + raise_r_o_eyebrow
AU3	
AU4	raise_l_o_eyebrow + raise_r_o_eyebrow + raise_l_m_eyebrow + raise_r_m_eyebrow + raise_l_I_eyebrow + raise_r_i_eyebrow + squeeze_l_eyebrow + squeeze_r_eyebrow
AU5	close_t_l_eyelid + close_t_r_eyelid
AU6	lift_l_cheek + lift_r_cheek
AU7	close_b_l_eyelid + close_b_r_eyelid
AU8	
AU9	lower_t_midlip + raise_nose + stretch_l_nose + stretch_r_nose
AU10	raise_nose (+stretch_l_nose + stetch_r_nose) + lower_t_midlip
AU11	
AU12	push_t_lip + push_b_lip(+lower_lowerlip + lower_t_midlip + raise_b_midlip)
AU13	
AU14	
AU15	lower_l_cornerlip + lower_r_cornerlip
AU16	
AU17	depress_chin
AU18	
AU19	
AU20	raise_b_midlip + lower_l_cornerlip + lower_r_cornerlip + stretch_l_cornerlip + stretch_r_cornerlip + lower_t_lip_lm + raise_b_lip_lm + lower_t_lip_lm_o + raise_b_lip_lm_o + raise_l_cornerlip_o + lower_t_lip_rm + raise_b_lip_rm + lower_t_lip_rm_o + raise_b_lip_rm_o + raise_r_cornerlip_o

MPEG-4 FAPs are also strongly related to AUs, as shown in Table 9.1. Description of archetypal expressions by means of muscle movements and AUs has been the starting point for setting the archetypal expression description through FAPs.

Hints for this mapping were obtained from psychological studies [5, 13, 14] that refer to face formation during expression generation, as well as from experimental data provided by classic databases such as Ekman's and MediaLab's (see also Section 9.3). Table 9.2 illustrates the description of archetypal expressions and some variations of them using the MPEG-4 FAPs terminology. It should be noted that the sets shown in Table 9.2 consist of the vocabulary of FAPs to be used for each archetypal expression and not a particular profile for synthesizing–analyzing expressions. This means that, if animated, they would not necessarily produce the corresponding expression. In the following table we define an *expression profile* to be a subset of the FAPs vocabulary, corresponding to a particular expression, accompanied with FAP intensities, that is, the actual ranges of variation that if animated, creates the required expression. Several expression profiles based on the FAPs vocabulary proposed in Table 9.2 are shown in the experimental results section.

Table 9.2 FAPs vocabulary for archetypal expression description

Joy	open_jaw (F_3), lower_t_midlip (F_4), raise_b_midlip (F_5), stretch_l_cornerlip (F_6), stretch_r_cornerlip (F_7), raise_l_cornerlip (F_{12}), raise_r_cornerlip (F_{13}), close_t_l_eyelid (F_{19}), close_t_r_eyelid (F_{20}), close_b_l_eyelid (F_{21}), close_b_r_eyelid (F_{22}), raise_l_m_eyebrow (F_{33}), raise_r_m_eyebrow (F_{34}), lift_l_cheek (F_{41}), lift_r_cheek (F_{42}), stretch_l_cornerlip_o (F_{53}), stretch_r_cornerlip_o (F_{54})
Sadness	close_t_l_eyelid (F_{19}), close_t_r_eyelid (F_{20}), close_b_l_eyelid (F_{21}), close_b_r_eyelid (F_{22}), raise_l_i_eyebrow (F_{31}), raise_r_i_eyebrow (F_{32}), raise_l_m_eyebrow (F_{33}), raise_r_m_eyebrow (F_{34}), raise_l_o_eyebrow (F_{35}), raise_r_o_eyebrow (F_{36})
Anger	lower_t_midlip (F_4), raise_b_midlip (F_5), push_b_lip (F_{16}), depress_chin (F_{18}), close_t_l_eyelid (F_{19}), close_t_r_eyelid (F_{20}), close_b_l_eyelid (F_{21}), close_b_r_eyelid (F_{22}), raise_l_i_eyebrow (F_{31}), raise_r_i_eyebrow (F_{32}), raise_l_m_eyebrow (F_{33}), raise_r_m_eyebrow (F_{34}), raise_l_o_eyebrow (F_{35}), raise_r_o_eyebrow (F_{36}), squeeze_l_eyebrow (F_{37}), squeeze_r_eyebrow (F_{38})
Fear	open_jaw (F_3), lower_t_midlip (F_4), raise_b_midlip (F_5), lower_t_lip_lm (F_8), lower_t_lip_rm (F_9), raise_b_lip_lm (F_{10}), raise_b_lip_rm (F_{11}), close_t_l_eyelid (F_{19}), close_t_r_eyelid (F_{20}), close_b_l_eyelid (F_{21}), close_b_r_eyelid (F_{22}), raise_l_i_eyebrow (F_{31}), raise_r_i_eyebrow (F_{32}), raise_l_m_eyebrow (F_{33}), raise_r_m_eyebrow (F_{34}), raise_l_o_eyebrow (F_{35}), raise_r_o_eyebrow (F_{36}), squeeze_l_eyebrow (F_{37}), squeeze_r_eyebrow (F_{38})
Disgust	open_jaw (F_3), lower_t_midlip (F_4), raise_b_midlip (F_5), lower_t_lip_lm (F_8), lower_t_lip_rm (F_9), raise_b_lip_lm (F_{10}), raise_b_lip_rm (F_{11}), close_t_l_eyelid (F_{19}), close_t_r_eyelid (F_{20}), close_b_l_eyelid (F_{21}), close_b_r_eyelid (F_{22}), raise_l_m_eyebrow (F_{33}), raise_r_m_eyebrow (F_{34}), lower_t_lip_lm_o (F_{55}), lower_t_lip_rm_o (F_{56}), raise_b_lip_lm_o (F_{57}), raise_b_lip_rm_o (F_{58}), raise_l_cornerlip_o (F_{59}), raise_r_cornerlip_o (F_{60})
Surprise	open_jaw (F_3), raise_b_midlip (F_5), stretch_l_cornerlip (F_6), stretch_r_cornerlip (F_7), raise_b_lip_lm (F_{10}), raise_b_lip_rm (F_{11}), close_t_l_eyelid (F_{19}), close_t_r_eyelid (F_{20}), close_b_l_eyelid (F_{21}), close_b_r_eyelid (F_{22}), raise_l_i_eyebrow (F_{31}), raise_r_i_eyebrow (F_{32}), raise_l_m_eyebrow (F_{33}), raise_r_m_eyebrow (F_{34}), raise_l_o_eyebrow (F_{35}), raise_r_o_eyebrow (F_{36}), squeeze_l_eyebrow (F_{37}), squeeze_r_eyebrow (F_{38}), stretch_l_cornerlip_o (F_{53}), stretch_r_cornerlip_o (F_{54})

9.3 THE RANGE OF VARIATION OF FAPs IN REAL VIDEO SEQUENCES

An important issue, useful to both emotion analysis and synthesis systems, is the range of variation of the FAPs that are involved in facial expression formation. From the synthesis point of view, a study has been carried out [2] that refers to FAPs range definition. However, the suggested ranges of variation are rather loose and cannot be used for analysis purposes. In order to have clear cues about FAPs range of variation in real video sequences, we analyzed two well-known datasets showing archetypal expressions, Ekman's (static) [5] and MediaLab's (dynamic) [15], and computed statistics about the involved FAPs. Both sets show extreme cases of expressions, rather than everyday ones. However, they can be used for setting limits to the variance of the respective FAPs [16, 17]. To achieve this, a way of modeling FAPs through the movement of facial points is required. Analysis of FAPs range of variation in real images and video sequences is used next for two purposes:

1. To verify and complete the proposed vocabulary for each archetypal expression.
2. To define profiles of archetypal expressions.

9.3.1 Modeling FAPs through the Movement of Facial Points

Although FAPs are practical and very useful for animation purposes, they are inadequate for analyzing facial expressions from video scenes or still images. The main reason is the absence of quantitative definitions for FAPs as well as their nonadditive nature. Note that the same problem holds for the FACS AUs. This is quite reasonable, given the strong relationship between AUs and FAPs (see Table 9.1). In order to measure facial-related FAPs in real images and video sequences, it is necessary to define a way of describing them through the movement of points that lie in the facial area and that can be automatically detected. Such a description could gain advantage from the extended research on automatic facial point detection [18, 19]. Quantitative description of FAPs based on particular FDP points, which correspond to movement of protuberant facial points, provides the means of bridging the gap between expression analysis and animation−synthesis. In the expression analysis case, the nonadditive property of the FAPs can be addressed by a fuzzy rule system similar to the one described later in Section 9.5.

Quantitative modeling of FAPs is implemented using the features labeled as f_i ($i = 1, \ldots, 15$) in the third column of Table 9.3 [16]. The feature set employs FDP points that lie in the facial area and under some constraints, can be automatically detected and tracked. It consists of distances, noted as $s(x, y)$ where x and y correspond to FDP points shown in Figure 9.2b, between these protuberant points, some of which are constant during expressions and are used as reference points. Distances between reference points are used for normalization [see Figure 9.2a]. The units for f_i are identical to those corresponding to FAPs, even in cases where no one-to-one relation exists.

It should be noted that not all FAPs included in the vocabularies shown in Table 9.2 can be modeled by distances between facial protuberant points (e.g. *raise_b_lip_lm_o*, *lower_t_lip_lm_o*). In such cases, the corresponding FAPs are retained in the vocabulary and their ranges of variation are experimentally defined on the basis of facial animations. Moreover, some features serve for the estimation of the range of variation of more than one FAP (e.g. features f_{12} to f_{15}).

9.3.2 Vocabulary Verification

To obtain clear cues about the FAPs range of variation in real video sequences as well as to verify the vocabulary of FAPs involved in each archetypal emotion, we analyzed Ekman's and MediaLab's datasets, which show archetypal expressions. The analysis was based on the quantitative modeling of FAPs described in the previous section. Computed statistics are summarized in Table 9.4. Mean values provide typical values that can be used for particular expression profiles, while the standard deviation can

Table 9.3 Quantitative FAPs modeling (1) $s(x, y)$ is the Euclidean distance between the FDP points x and y shown in Figure 9.2b, (2) $D_{\text{i-NEUTRAL}}$ refers to the distance D_i when the face is its in neutral position

FAP name	Feature for the description	Utilized feature	Unit
squeeze_l_eyebrow (F_{37})	$D_1 = s(4.6, 3.8)$	$f_1 = D_{\text{1-NEUTRAL}} - D_1$	ES
squeeze_r_eyebrow (F_{38})	$D_2 = s(4.5, 3.11)$	$f_2 = D_{\text{2-NEUTRAL}} - D_2$	ES
lower_t_midlip (F_4)	$D_3 = s(9.3, 8.1)$	$f_3 = D_3 - D_{\text{3-NEUTRAL}}$	MNS
raise_b_midlip (F_5)	$D_4 = s(9.3, 8.2)$	$f_4 = D_{\text{4-NEUTRAL}} - D_4$	MNS
raise_l_i_eyebrow (F_{31})	$D_5 = s(4.2, 3.8)$	$f_5 = D_5 - D_{\text{5-NEUTRAL}}$	ENS
raise_r_i_eyebrow (F_{32})	$D_6 = s(4.1, 3.11)$	$f_6 = D_6 - D_{\text{6-NEUTRAL}}$	ENS
raise_l_o_eyebrow (F_{35})	$D_7 = s(4.6, 3.12)$	$f_7 = D_7 - D_{\text{7-NEUTRAL}}$	ENS
raise_r_o_eyebrow (F_{36})	$D_8 = s(4.5, 3.7)$	$f_8 = D_8 - D_{\text{8-NEUTRAL}}$	ENS
raise_l_m_eyebrow (F_{33})	$D_9 = s(4.4, 3.12)$	$f_9 = D_9 - D_{\text{9-NEUTRAL}}$	ENS
raise_r_m_eyebrow (F_{34})	$D_{10} = s(4.3, 3.7)$	$f_{10} = D_{10} - D_{\text{10-NEUTRAL}}$	ENS
open_jaw (F_3)	$D_{11} = s(8.1, 8.2)$	$f_{11} = D_{11} - D_{\text{11-NEUTRAL}}$	MNS
close_t_l_eyelid (F_{19}) − close_b_l_eyelid (F_{21})	$D_{12} = s(3.2, 3.4)$	$f_{12} = D_{12} - D_{\text{12-NEUTRAL}}$	IRISD
close_t_r_eyelid (F_{20}) − close_b_r_eyelid (F_{22})	$D_{13} = s(3.1, 3.3)$	$f_{13} = D_{13} - D_{\text{13-NEUTRAL}}$	IRISD
stretch_l_cornerlip (F_6) (stretch_l_cornerlip_o)(F_{53}) − stretch_r_cornerlip (F_7) (stretch_r_cornerlip_o) (F_{54})	$D_{14} = s(8.4, 8.3)$	$f_{14} = D_{14} - D_{\text{14-NEUTRAL}}$	MW
squeeze_l_eyebrow (F_{37}) and squeeze_r_eyebrow (F_{38})	$D_{15} = s(4.6, 4.5)$	$f_{15} = D_{\text{15-NEUTRAL}} - D_{15}$	ES

define the range of variation (see also Section 9.3.3). The units of the values shown are those of the corresponding FAPs [2]. The symbol (*) expresses the absence of the corresponding FAP in the vocabulary of that particular expression, while the symbol (−) shows that although the corresponding FAP is included in the vocabulary, it has not been verified by the statistical analysis. The latter case shows that not all FAPs included in the vocabulary are experimentally verified.

The detection of the facial point subset used to describe the FAPs involved in the archetypal expressions was based on the work presented in Reference 20. To obtain accurate detection, in many cases, human assistance was necessary. The authors are working toward a fully automatic implementation of the FDP points detection procedure.

Figure 9.3 illustrates particular statistics, computed over the previously described datasets, for the expression *joy*. In all diagrams, the horizontal axis shows the indices of the features defined in the third column of Table 9.3, while the vertical axis shows the minimum, maximum and mean values of the corresponding feature. From this figure it is confirmed, for example, that *lower_t_midlip* (feature with index 3) that refers to lowering the middle of the upper lip is employed, because even the maximum value for this FAP is below zero. In the same way, the FAPs *raise_l_m_eyebrow, raise_r_m_eyebrow, close_t_l_eyelid*, *close_t_r_eyelid*,

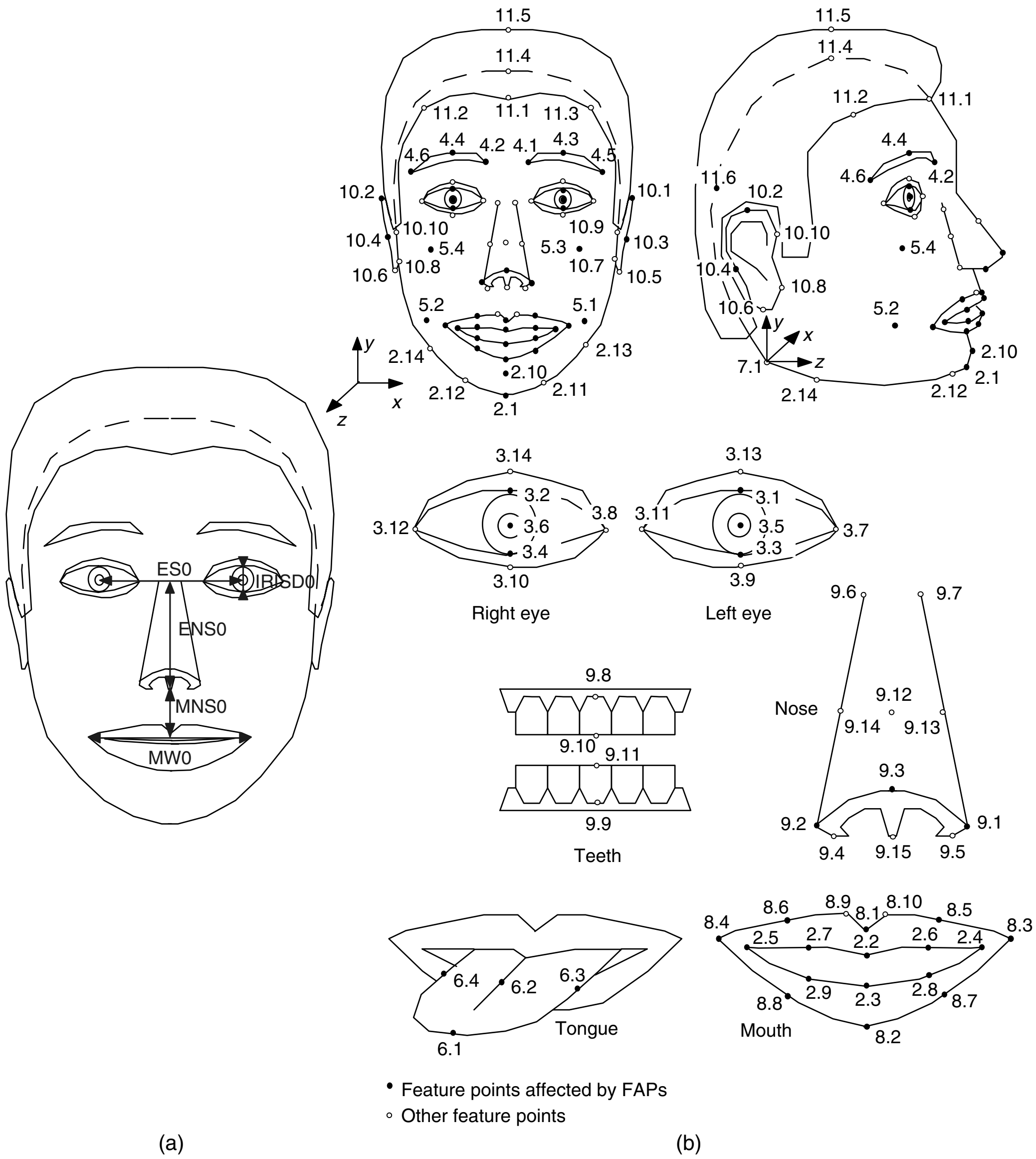

Figure 9.2 (a) Normalization distances; (b) FDP points

close_b_l_eyelid, *close_b_r_eyelid*, *stretch_l_cornerlip*, *stretch_r_cornerlip* (indices 9, 10, 12, 13, 14) are verified. Some of the aforementioned FAPs are described using a single variable. For example, the *stretch_l_cornerlip* and *stretch_r_cornerlip* are both modeled via f_{14} (their values, shown in Table 9.4, are equal to the half value of feature f_{14}). Similar to Figure 9.3, Figure 9.4 illustrates feature statistics for the expression *surprise*.

Table 9.4 Statistics for the vocabulary of FAPs for the archetypal expression. The symbol (*) expresses the absence of the corresponding FAP in the vocabulary of the particular expression while symbol (–) shows that although the corresponding FAP is included in the vocabulary, it has not been verified by the statistical analysis

FAP name (symbol)	Stats	Anger	Sadness	Joy	Disgust	Fear	Surprise
open_jaw (F_3)	Mean	*	*	–	–	291	885
	StD	*	*	–	–	189	316
lower_t_midlip (F_4)	Mean	73	*	−271	−234	–	*
	StD	51	*	110	109	–	*
raise_b_midlip (F_5)	Mean	*	*	–	−177	218	−543
	StD	*	*	–	108	135	203
stretch_l_cornerlip (F_6), stretch_l_cornerlip_o (F_{53}),	Mean	*	*	234	*	*	−82
stretch_ r_cornerlip (F_7), stretch_r_cornerlip_o (F_{54})	StD	*	*	98	*	*	39
lower_t_lip_lm (F_8)	Mean	*	*	*	–	*	*
	StD	*	*	*	–	*	*
lower_t_lip_rm (F_9)	Mean	*	*	*	–	*	*
	StD	*	*	*	–	*	*
raise_b_lip_lm (F_{10})	Mean	*	*	*	–	*	*
	StD	*	*	*	–	*	*
raise_b_lip_rm (F_{11})	Mean	*	*	*	–	*	*
	StD	*	*	*	–	*	*
close_t_l_eyelid (F_{19}),	Mean	–	−153	−254	203	−244	−254
close_b_l_eyelid (F_{21})	StD	–	112	133	148	126	83
close_t_r_eyelid (F_{20}),	Mean	–	−161	−242	211	−249	−252
close_b_r_eyelid (F_{22})	StD		109	122	145	128	81
raise_l_i_eyebrow (F_{31})	Mean	−83	85	*	*	104	224
	StD	48	55	*	*	69	103
raise_r_i_eyebrow (F_{32})	Mean	−85	80	*	*	111	211
	StD	51	54	*	*	72	97
raise_l_m_eyebrow (F_{33})	Mean	−149	–	24	−80	72	144
	StD	40	–	22	53	58	64
raise_r_m_eyebrow (F_{34})	Mean	−144	–	25	−82	75	142
	StD	39	–	22	54	60	62
raise_l_o_eyebrow (F_{35})	Mean	−66	–	*	*	–	54
	StD	35	–	*	*	–	31
raise_r_o_eyebrow (F_{36})	Mean	−70	–	*	*	–	55
	StD	38		*	*	–	31
squeeze_l_eyebrow (F_{37})	Mean	57	*	*	*	–	–
	StD	28	*	*	*	–	–
squeeze_r_eyebrow (F_{38})	Mean	58	*	*	*	–	–
	StD	31	*	*	*	–	–

Table 9.4 (*continued*)

FAP name (symbol)	Stats	Anger	Sadness	Joy	Disgust	Fear	Surprise
lift_l_cheek (F_{41})	Mean	*	*	–	*	*	*
	StD	*	*	–	*	*	*
lift_r_cheek (F_{42})	Mean	*	*	–	*	*	*
	StD	*	*	–	*	*	*
stretch_l_cornerlip_o (F_{53})	Mean	*	*	–	*	*	–
	StD	*	*	–	*	*	–
stretch_r_cornerlip_o (F_{54})	Mean	*	*	*	*	*	–
	StD	*	*	*	*	*	
lower_t_lip_lm_o (F_{55})	Mean	*	*	*	–	*	*
	StD	*	*	*	–	*	*
lower_t_lip_rm_o (F_{56})	Mean	*	*	*	–	*	*
	StD	*	*	*	–	*	*
raise_b_lip_lm_o (F_{57})	Mean	*	*	*	–	*	*
	StD	*	*	*	–	*	*
raise_b_lip_rm_o (F_{58})	Mean	*	*	*	–	*	*
	StD	*	*	*	–	*	*
raise_l_cornerlip_o (F_{59})	Mean	*	*	*	–	*	*
	StD	*	*	*	–	*	*
raise_r_cornerlip_o (F_{60})	Mean	*	*	*	–	*	*
	StD	*	*	*	–	*	*

9.3.3 Creating Archetypal Expression Profiles

An archetypal *expression profile* is a set of FAPs accompanied by the corresponding range of variation, which, if animated, produces a visual representation of the corresponding emotion. Typically, a profile of an archetypal expression consists of vocabulary definitions coupled with the appropriate ranges of variation for the corresponding subset of FAPs. The statistical expression analysis performed on the aforementioned datasets is useful for FAPs vocabulary completion and verification, as well as for a rough estimation of the range of variation of FAPs, but not for profile creation. In order to define exact profiles for the archetypal expressions three steps were followed:

1. Subsets of FAPs that are candidates to form an archetypal expression were defined by translating the face formations proposed by psychological studies [13, 14, 5] to FAPs.
2. Initial ranges of variation were computed on the basis of the statistics shown in Table 9.4 (see the following table for a detailed description).
3. The corresponding profiles were animated to verify the appropriateness of derived representations.

The initial range of variation for the FAPs was computed as follows: Let $m_{i,j}$ and $\sigma_{i,j}$ be the mean value and standard deviation of FAP F_j for the archetypal

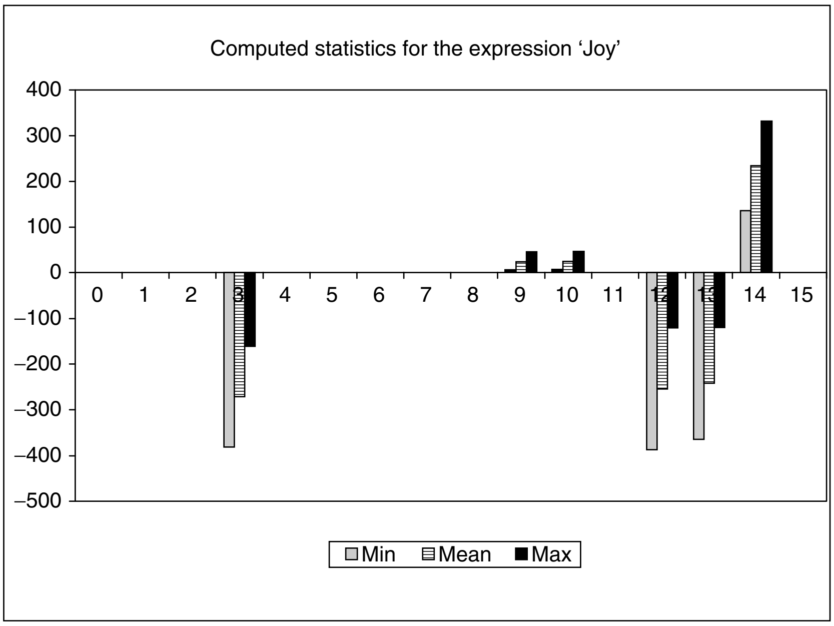

Figure 9.3 Computed statistics for the expression 'Joy'. Horizontal axis shows the indices of the features defined in the third column of Table 9.3 while vertical axis shows the value of the corresponding feature

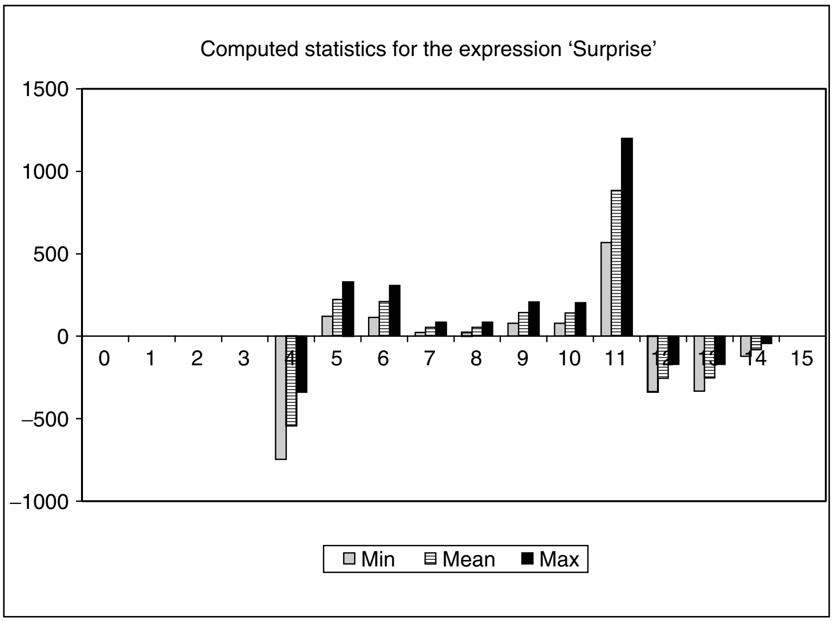

Figure 9.4 Computed statistics for the expression 'Surprise'. The horizontal axis shows the indices of the features defined in the third column of Table 9.3 while the vertical axis shows the value of the corresponding feature

expression i (where $I = \{1 \Rightarrow$ Anger, $2 \Rightarrow$ Sadness, $3 \Rightarrow$ Joy, $4 \Rightarrow$ Disgust, $5 \Rightarrow$ Fear, $6 \Rightarrow$ Surprise), as estimated in Table 9.4. The initial range of variation $X_{i,j}$ of FAP F_j for the archetypal expression i is defined as:

$$X_{i,j} = [m_{i,j} - \sigma_{i,j}, m_{i,j} + \sigma_{i,j}] \tag{9.1}$$

for bidirectional, and

$$X_{i,j} = [\max(0, m_{i,j} - \sigma_{i,j}), m_{i,j} + \sigma_{i,j}] \text{ or } X_{i,j} = [m_{i,j} - \sigma_{i,j}, \min(0, m_{i,j} + \sigma_{i,j})] \tag{9.2}$$

for unidirectional FAPs [2].

Following the procedure described in the preceding text, Table 9.5 was produced showing examples of archetypal expression profiles:

Table 9.5 Profiles for the archetypal emotions

Profiles	FAPs and range of variation
Anger ($P_A^{(0)}$)	$F_4 \in [22, 124]$, $F_{31} \in [-131, -25]$, $F_{32} \in [-136, -34]$, $F_{33} \in [-189, -109]$, $F_{34} \in [-183, -105]$, $F_{35} \in [-101, -31]$, $F_{36} \in [-108, -32]$, $F_{37} \in [29, 85]$, $F_{38} \in [27, 89]$
$P_A^{(1)}$	$F_{19} \in [-330, -200]$, $F_{20} \in [-335, -205]$, $F_{21} \in [200, 330]$, $F_{22} \in [205, 335]$, $F_{31} \in [-200, -80]$, $F_{32} \in [-194, -74]$, $F_{33} \in [-190, -70]$, $F_{34} =\in [-190, -70]$
$P_A^{(2)}$	$F_{19}[-330, -200]$, $F_{20} \in [-335, -205]$, $F_{21} \in [200, 330]$, $F_{22} \in [205, 335]$, $F_{31} \in [-200, -80]$, $F_{32} \in [-194, -74]$, $F_{33} \in [70, 190]$, $F_{34} \in [70, 190]$
$P_A^{(3)}$	$F_{16} \in [45, 155]$, $F_{18} \in [45, 155]$, $F_{19} \in [-330, -200]$, $F_{20} \in [-330, -200]$, $F_{31} \in [-200, -80]$, $F_{32} \in [-194, -74]$, $F_{33} \in [-190, -70]$, $F_{34} \in [-190, -70]$, $F_{37} \in [65, 135]$, $F_{38} \in [65, 135]$
$P_A^{(4)}$	$F_{16} \in [-355, -245]$, $F_{18} \in [145, 255]$, $F_{19} \in [-330, -200]$, $F_{20} \in [-330, -200]$, $F_{31} \in [-200, -80]$, $F_{32} \in [-194, -74]$, $F_{33} \in [-190, -70]$, $F_{34} \in [-190, -70]$, $F_{37} \in [65, 135]$, $F_{38} \in [65, 135]$
Sadness ($P_S^{(0)}$)	$F_{19} \in [-265, -41]$, $F_{20} \in [-270, -52]$, $F_{21} \in [-265, -41]$, $F_{22} \in [-270, -52]$, $F_{31} \in [30, 140]$, $F_{32} \in [26, 134]$
Joy ($P_J^{(0)}$)	$F_4 \in [-381, -161]$, $F_6 \in [136, 332]$, $F_7 \in [136, 332]$, $F_{19} \in [-387, -121]$, $F_{20} \in [-364, -120]$, $F_{21} \in [-387, -121]$, $F_{22} \in [-364, -120]$, $F_{33} \in [2, 46]$, $F_{34} \in [3, 47]$, $F_{53} \in [136, 332]$, $F_{54} \in [136, 332]$
$P_J^{(1)}$	$F_6 \in [160, 240]$, $F_7 \in [160, 240]$, $F_{12} \in [260, 340]$, $F_{13} \in [260, 340]$, $F_{19} \in [-449, -325]$, $F_{20} \in [-426, -302]$, $F_{21} \in [325, 449]$, $F_{22} \in [302, 426]$, $F_{33} \in [70, 130]$, $F_{34} \in [70, 130]$, $F_{41} \in [130, 170]$, $F_{42} \in [130, 170]$, $F_{53} \in [160, 240]$, $F_{54} \in [160, 240]$
$P_J^{(2)}$	$F_6 \in [160, 240]$, $F_7 \in [160, 240]$, $F_{12} \in [260, 340]$, $F_{13} \in [260, 340]$, $F_{19} \in [-449, -325]$, $F_{20} \in [-426, -302]$, $F_{21} \in [-312, -188]$, $F_{22} \in [-289, -165]$, $F_{33} \in [70, 130]$, $F_{34} \in [70, 130]$, $F_{41} \in [130, 170]$, $F_{42} \in [130, 170]$, $F_{53} \in [160, 240]$, $F_{54} \in [160, 240]$

(*continued overleaf*)

Table 9.5 (*continued*)

Profiles	FAPs and range of variation
$P_J^{(3)}$	$F_6 \in [160, 240]$, $F_7 \in [160, 240]$, $F_{12} \in [260, 340]$, $F_{13} \in [260, 340]$, $F_{19} \in [-449, -325]$, $F_{20} \in [-426, -302]$, $F_{21} \in [61, 185]$, $F_{22} \in [38, 162]$, $F_{33} \in [70, 130]$, $F_{34} \in [70, 130]$, $F_{41} \in [130, 170]$, $F_{42} \in [130, 170]$, $F_{53} \in [160, 240]$, $F_{54} \in [160, 240]$
Disgust ($P_D^{(0)}$)	$F_4 \in [-343, -125]$, $F_5 \in [-285, -69]$, $F_{19} \in [55, 351]$, $F_{20} \in [66, 356]$, $F_{21} \in [55, 351]$, $F_{22} \in [66, 356]$, $F_{33} \in [-123, -27]$, $F_{34} \in [-126, -28]$
Fear ($P_F^{(0)}$)	$F_3 \in [102, 480]$, $F_5 \in [83, 353]$, $F_{19} \in [-370, -118]$, $F_{20} \in [-377, -121]$, $F_{21} \in [-370, -118]$, $F_{22} \in [-377, -121]$, $F_{31} \in [35, 173]$, $F_{32} \in [39, 183]$, $F_{33} \in [14, 130]$, $F_{34} \in [15, 135]$
$P_F^{(1)}$	$F_3 \in [400, 560]$, $F_5 \in [333, 373]$, $F_{19} \in [-400, -340]$, $F_{20} \in [-407, -347]$, $F_{21} \in [-400, -340]$, $F_{22} \in [-407, -347]$
$P_F^{(2)}$	$F_3 \in [400, 560]$, $F_5 \in [307, 399]$, $F_{19} \in [-530, -470]$, $F_{20} \in [-523, -463]$, $F_{21} \in [-530, -470]$, $F_{22} \in [-523, -463]$, $F_{31} \in [460, 540]$, $F_{32} \in [460, 540]$, $F_{33} \in [460, 540]$, $F_{34} \in [460, 540]$, $F_{35} \in [460, 540]$, $F_{36} \in [460, 540]$
$P_F^{(3)}$	$F_3 \in [400, 560]$, $F_5 \in [-240, -160]$, $F_{19} \in [-630, -570]$, $F_{20} \in [-630, -570]$, $F_{21} \in [-630, -570]$, $F_{22} \in [-630, -570]$, $F_{31} \in [460, 540]$, $F_{32} \in [460, 540]$, $F_{37} \in [60, 140]$, $F_{38} \in [60, 140]$
$P_F^{(4)}$	$F_3 \in [400, 560]$, $F_5 \in [-240, -160]$, $F_{19} \in [-630, -570]$, $F_{20} \in [-630, -570]$, $F_{21} \in [-630, -570]$, $F_{22} \in [-630, -570]$, $F_{31} \in [460, 540]$, $F_{32} \in [460, 540]$, $F_{33} \in [360, 440]$, $F_{34} \in [360, 440]$, $F_{35} \in [260, 340]$, $F_{36} \in [260, 340]$, $F_{37} \in [60, 140]$, $F_{38} \in [60, 140]$
$P_F^{(5)}$	$F_3 \in [400, 560]$, $F_5 \in [-240, -160]$, $F_{19} \in [-630, -570]$, $F_{20} \in [-630, -570]$, $F_{21} \in [-630, -570]$, $F_{22} \in [-630, -570]$, $F_{31} \in [460, 540]$, $F_{32} \in [460, 540]$, $F_{33} \in [360, 440]$, $F_{34} \in [360, 440]$, $F_{35} \in [260, 340]$, $F_{36} \in [260, 340]$, $F_{37} \in 0$, $F_{38} \in 0$
$P_F^{(6)}$	$F_3 \in [400, 560]$, $F_5 \in [-240, -160]$, $F_8 \in [-120, -80]$, $F_9 \in [-120, -80]$, $F_{10} \in [-120, -80]$, $F_{11} \in [-120, -80]$, $F_{19} \in [-630, -570]$, $F_{20} \in [-630, -570]$, $F_{21} \in [-630, -570]$, $F_{22} \in [-630, -570]$, $F_{31} \in [460, 540]$, $F_{32} \in [460, 540]$, $F_{33} \in [360, 440]$, $F_{34} \in [360, 440]$, $F_{35} \in [260, 340]$, $F_{36} \in [260, 340]$, $F_{37} \in 0$, $F_{38} \in 0$
$P_F^{(7)}$	$F_3 \in [400, 560]$, $F_5 \in [-240, -160]$, $F_{19} \in [-630, -570]$, $F_{20} \in [-630, -570]$, $F_{21} \in [-630, -570]$, $F_{22} \in [-630, -570]$, $F_{31} \in [360, 440]$, $F_{32} \in [360, 440]$, $F_{33} \in [260, 340]$, $F_{34} \in [260, 340]$, $F_{35} \in [160, 240]$, $F_{36} \in [160, 240]$
$P_F^{(8)}$	$F_3 \in [400, 560]$, $F_5 \in [-240, -160]$, $F_{19} \in [-630, -570]$, $F_{20} \in [-630, -570]$, $F_{21} \in [-630, -570]$, $F_{22} \in [-630, -570]$, $F_{31} \in [260, 340]$, $F_{32} \in [260, 340]$, $F_{33} \in [160, 240]$, $F_{34} \in [160, 240]$, $F_{35} \in [60, 140]$, $F_{36} \in [60, 140]$
$P_F^{(9)}$	$F_3 \in [400, 560]$, $F_5 \in [307, 399]$, $F_{19} \in [-630, -570]$, $F_{20} \in [-623, -563]$, $F_{21} \in [-630, -570]$, $F_{22} \in [-623, -563]$, $F_{31} \in [460, 540]$, $F_{32} \in [460, 540]$, $F_{33} \in [460, 540]$, $F_{34} \in [460, 540]$, $F_{35} \in [460, 540]$, $F_{36} \in [460, 540]$
Surprise ($P_{Su}^{(0)}$)	$F_3 \in [569, 1201]$, $F_5 \in [-746, -340]$, $F_6 \in [-121, -43]$, $F_7 \in [-121, -43]$, $F_{19} \in [-337, -170]$, $F_{20} \in [-333, -171]$, $F_{21} \in [-337, -170]$, $F_{22} \in [-333, -171]$, $F_{31} \in [121, 327]$, $F_{32} \in [114, 308]$, $F_{33} \in [80, 208]$, $F_{34} \in [80, 204]$, $F_{35} \in [23, 85]$, $F_{36} \in [24, 86]$, $F_{53} \in [-121, -43]$, $F_{54} \in [-121, -43]$

Table 9.5 (*continued*)

Profiles	FAPs and range of variation
$P_{Su}^{(1)}$	$F_3 \in [1150, 1252]$, $F_5 \in [-792, -700]$, $F_6 \in [-141, -101]$, $F_7 \in [-141, -101]$, $F_{10} \in [-530, -470]$, $F_{11} \in [-530, -470]$, $F_{19} \in [-350, -324]$, $F_{20} \in [-346, -320]$, $F_{21} \in [-350, -324]$, $F_{22} \in [-346, -320]$, $F_{31} \in [314, 340]$, $F_{32} \in [295, 321]$, $F_{33} \in [195, 221]$, $F_{34} \in [191, 217]$, $F_{35} \in [72, 98]$, $F_{36} \in [73, 99]$, $F_{53} \in [-141, -101]$, $F_{54} \in [-141, -101]$
$P_{Su}^{(2)}$	$F_3 \in [834, 936]$, $F_5 \in [-589, -497]$, $F_6 \in [-102, -62]$, $F_7 \in [-102, -62]$, $F_{10} \in [-380, -320]$, $F_{11} \in [-380, -320]$, $F_{19} \in [-267, -241]$, $F_{20} \in [-265, -239]$, $F_{21} \in [-267, -241]$, $F_{22} \in [-265, -239]$, $F_{31} \in [211, 237]$, $F_{32} \in [198, 224]$, $F_{33} \in [131, 157]$, $F_{34} \in [129, 155]$, $F_{35} \in [41, 67]$, $F_{36} \in [42, 68]$
$P_{Su}^{(3)}$	$F_3 \in [523, 615]$, $F_5 \in [-386, -294]$, $F_6 \in [-63, -23]$, $F_7 \in [-63, -23]$, $F_{10} \in [-230, -170]$, $F_{11} \in [-230, -170]$, $F_{19} \in [-158, -184]$, $F_{20} \in [-158, -184]$, $F_{21} \in [-158, -184]$, $F_{22} \in [-158, -184]$, $F_{31} \in [108, 134]$, $F_{32} \in [101, 127]$, $F_{33} \in [67, 93]$, $F_{34} \in [67, 93]$, $F_{35} \in [10, 36]$, $F_{36} \in [11, 37]$

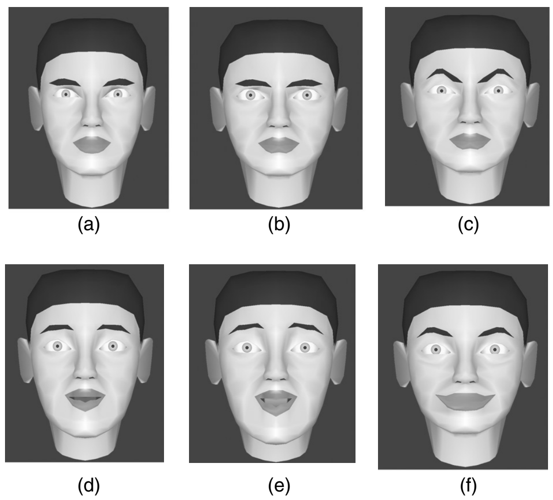

Figure 9.5 Examples of animated profiles (a)–(c) anger, (d)–(e) surprise, (f) joy

Generally, for animation purposes, every MPEG-4 decoder has to provide and use an MPEG-4-compliant face model whose geometry can be defined using FDP points or it should define the animation rules based on face animation tables (FAT). Using FATs, we can specify which model vertices should be moved for each FAP, and how. We can also define the transformed nodes of the face as well the kind of transformations. For our experiments on setting the archetypal expression profiles we used the face model developed in the context of the European Project *ACTS MoMuSys* [21]. This is freely available at the website *http://www.iso.ch/ittf*.

Figure 9.5 shows some examples of animated profiles. Figure 9.5a shows a particular profile for the archetypal expression *anger*, while Figures 9.5b,c show alternative profiles of the same expression. The difference between them is due to FAP intensities. Difference in FAP intensities is also shown in Figure 9.5d and e, both illustrating profiles of expression *surprise*. Finally, Figure 9.5f shows an example of a profile of the expression *joy*.

9.4 CREATING PROFILES FOR NONARCHETYPAL EXPRESSIONS

In this section we propose a method for creating profiles for nonarchetypal expressions. Since computer scientists and engineers have carried out a limited number of studies dealing with emotions other than the archetypal ones [10], it is necessary to search in other subject–discipline bibliographies. Psychologists have examined a broader set of emotions [17], but very few of the studies provide results that can be exploited in computer graphics and machine vision fields. One of these studies carried out by Whissel [8], suggests that emotions are points in a space spanning a relatively small number of dimensions that seem to occupy two axes: *activation* and *evaluation*, as shown in Table 9.6. *Activation* is the degree of arousal associated with terms such as *patient* (at 3.3) representing a midpoint, *surprised* (over 6) representing high activation and *bashful* (around 2) representing low *activation*. *Evaluation* is the degree of pleasantness associated with the terms *guilty* (at 1.1) representing the negative extreme and *delighted* (at 6.4) representing the positive extreme [8]. In our experience, the estimation of *evaluation* through gross facial attributes is difficult (even intractable). On the other hand, it does appear possible to estimate *activation* on the basis of facial points' movement.

The third column in Table 9.6 represents Plutchik's [7] observation that emotion terms are unevenly distributed through the space defined by dimensions such as Whissell's. Instead, they tend to form an approximately circular pattern called *emotion wheel*. Shown values refer to an angular measure that runs from *Acceptance* (0) to *Disgust* (180).

For the creation of profiles for intermediate emotions we consider two cases:

1. Emotions that are similar in nature to an archetypal one; for example, they may differ only in the intensity of muscle actions.
2. Emotions that cannot be considered as related to any of the archetypal ones.

In both cases we proceed by following the steps enumerated in the following text:

1. Utilize either the *activation* parameter or Plutchik's *angular* measure as *a priori* knowledge about the intensity of facial actions for several emotions. This knowledge is combined with the profiles of archetypal expressions through a rule-based system to create profiles for intermediate emotions.
2. Animate the produced profiles for testing/correcting their appropriateness in terms of the visual similarity with the requested emotion.

9.4.1 Universal Emotion Categories

As a general rule, one can define six broad categories, each one characterized by an archetypal emotion. Within each of these categories, intermediate expressions are described by different emotional and optical intensities, as well as minor variation in expression details. From the synthetic point of view, emotions that belong to the same category can be rendered by animating the same FAPs using different intensities. For example, the emotion group *fear* also contains *worry* and *terror* [14]; reducing or increasing the intensities of the relevant FAPs allows these two emotions to be

Table 9.6 Emotion words from Whissel's [8] study

	Activation	Evaluation	Angle		Activation	Evaluation	Angle
Accepting			0	Disgusted	5	3.2	161.3
Adventurous	4.2	5.9	270.7	Disinterested	2.1	2.4	127.3
Affectionate	4.7	5.4	52.3	Disobedient			242.7
Afraid	4.9	3.4	70.3	Displeased			181.5
Aggressive	5.9	2.9	232	Dissatisfied	4.6	2.7	183
Agreeable	4.3	5.2	5	Distrustful	3.8	2.8	185
Amazed	5.9	5.5	152	Eager	5	5.1	311
Ambivalent	3.2	4.2	144.7	Ecstatic	5.2	5.5	286
Amused	4.9	5	321	Elated			311
Angry	4.2	2.7	212	Embarrassed	4.4	3.1	75.3
Annoyed	4.4	2.5	200.6	Empty	3.1	3.8	120.3
Antagonistic	5.3	2.5	220	Enthusiastic	5.1	4.8	313.7
Anticipatory	3.9	4.7	257	Envious	5.3	2	160.3
Anxious	6	2.3	78.3	Exasperated			239.7
Apathetic	3	4.3	90	Expectant			257.3
Apprehensive			83.3	Forlorn			85
Ashamed	3.2	2.3	83.3	Furious	5.6	3.7	221.3
Astonished	5.9	4.7	148	Generous			328
Attentive	5.3	4.3	322.4	Gleeful	5.3	4.8	307
Awed			156.7	Gloomy	2.4	3.2	132.7
Bashful	2	2.7	74.7	Greedy	4.9	3.4	249
Bewildered	3.1	2.3	140.3	Grief-stricken			127.3
Bitter	6.6	4	186	Grouchy	4.4	2.9	230
Boastful	3.7	3	257.3	Guilty	4	1.1	102.3
Bored	2.7	3.2	136	Happy	5.3	5.3	323.7
Calm	2.5	5.5	37	Helpless	3.5	2.8	80
Cautious	3.3	4.9	77.7	Hesitant			134
Cheerful	5.2	5	25.7	Hopeful	4.7	5.2	298
Confused	4.8	3	141.3	Hopeless	4	3.1	124.7
Contemptuous	3.8	2.4	192	Hostile	4	1.7	222
Content	4.8	5.5	338.3	Humiliated			84
Contrary	2.9	3.7	184.3	Impatient	3.4	3.2	230.3
Cooperative	3.1	5.1	340.7	Impulsive	3.1	4.8	255
Critical	4.9	2.8	193.7	Indecisive	3.4	2.7	134
Curious	5.2	4.2	261	Indignant			175
Daring	5.3	4.4	260.1	Inquisitive			267.7
Defiant	4.4	2.8	230.7	Interested			315.7
Delighted	4.2	6.4	318.6	Intolerant	3.1	2.7	185
Demanding	5.3	4	244	Irritated	5.5	3.3	202.3
Depressed	4.2	3.1	125.3	Jealous	6.1	3.4	184.7
Despairing	4.1	2	133	Joyful	5.4	6.1	323.4
Disagreeable	5	3.7	176.4	Loath	3.5	2.9	193
Disappointed	5.2	2.4	136.7	Lonely	3.9	3.3	88.3
Discouraged	4.2	2.9	138	Meek	3	4.3	91

(*continued overleaf*)

Table 9.6 (*continued*)

	Activation	Evaluation	Angle		Activation	Evaluation	Angle
Nervous	5.9	3.1	86	Self-conscious			83.3
Obedient	3.1	4.7	57.7	Self-controlled	4.4	5.5	326.3
Obliging	2.7	3	43.3	Serene	4.3	4.4	12.3
Outraged	4.3	3.2	225.3	Shy			72
Panicky	5.4	3.6	67.7	Sociable	4.8	5.3	296.7
Patient	3.3	3.8	39.7	Sorrowful	4.5	3.1	112.7
Pensive	3.2	5	76.7	Stubborn	4.9	3.1	190.4
Perplexed			142.3	Submissive	3.4	3.1	73
Playful			269.7	Surprised	6.5	5.2	146.7
Pleased	5.3	5.1	328	Suspicious	4.4	3	182.7
Possessive	4.7	2.8	247.7	Sympathetic	3.6	3.2	331.3
Proud	4.7	5.3	262	Terrified	6.3	3.4	75.7
Puzzled	2.6	3.8	138	Timid			65
Quarrelsome	4.6	2.6	229.7	Tolerant			350.7
Ready			329.3	Trusting	3.4	5.2	345.3
Receptive			32.3	Unaffectionate	3.6	2.1	227.3
Reckless			261	Uncertain			139.3
Rebellious	5.2	4	237	Uncooperative			191.7
Rejected	5	2.9	136	Unfriendly	4.3	1.6	188
Remorseful	3.1	2.2	123.3	Unhappy			129
Resentful	5.1	3	176.7	Unreceptive			170
Revolted			181.3	Unsympathetic			165.6
Sad	3.8	2.4	108.5	Vacillating			137.3
Sarcastic	4.8	2.7	235.3	Vengeful			186
Satisfied	4.1	4.9	326.7	Watchful			133.3
Scared			66.7	Wondering	3.3	5.2	249.7
Scornful	5.4	4.9	227	Worried	3.9	2.9	126

synthesized or discriminated. In the case of expression profiles, this affects the range of variation of the corresponding FAPs that is appropriately translated. The fuzziness that is introduced by the varying scale of the change of FAP intensity, also provides assistance in achieving some differentiation between outputs associated with similar situations. This ensures on the one hand, that synthesis will not render ‘robotlike’ animation, but noticeably more realistic results; and on the other hand, that analysis systems could in principle discriminate ‘neighboring’ emotions.

Let $P_i^{(k)}$ be the kth profile of emotion i and $X_{i,j}^{(k)}$ be the range of variation of FAP F_j involved in $P_i^{(k)}$. If A, I are emotions belonging to the same universal emotion category, A being the archetypal and I the intermediate one, then the following rules are applied:

Rule 1: $P_A^{(k)}$ and $P_I^{(k)}$ employ the same FAPs.

Rule 2: The range of variation $X_{I,j}^{(k)}$ is computed by $X_{I,j}^{(k)} = \frac{a_I}{a_A} X_{A,j}^{(k)}$

Rule 3: a_A and a_I are the values of the *activation* parameter for emotion words A and I obtained from Whissel’s study [8].

9.4.2 Intermediate Emotions

Creating profiles for emotions that do not clearly belong to a universal category is not straightforward. Apart from estimating the range of variations for FAPs, one should also define the vocabulary of FAPs for the particular emotion. In order to proceed we utilize both the *emotion wheel* of Plutchik [7], especially the *angular* measure (shown also in Table 9.6); and the *activation* parameter. Let I be an intermediate emotion lying between archetypal emotions A_1 and A_2 (that are supposed to be the nearest, with respect to the two sides of emotion I) according to their *angular* measure. Let also V_{A_1} and V_{A_2} be the vocabularies (sets of FAPs) corresponding to A_1 and A_2, respectively. The vocabulary V_I of emotion I emerges as the union of vocabularies V_{A_1} and V_{A_2}, that is, $V_I = V_{A_1} \cup V_{A_2}$.

As already stated in Section 9.2, defining a vocabulary is not enough for modeling expressions–profiles should be created for this purpose. This poses a number of interesting issues, such as: (1) what happens if an FAP is included in both V_{A_1} and V_{A_2}, but, with contradictory motion directions? (2) What happens if an FAP is included in only one of the vocabularies? In our approach, FAPs included in both V_{A_1} and V_{A_2}, that also have a common motion direction are retained in the new profile (their range of variation emerges as a weighted average of the consisting ones). FAPs included in only one of the vocabularies are averaged with the respective neutral position. The same applies in the case of contradictory FAPs (FAPs included in both V_{A_1} and V_{A_2}, but that have, however, contradictory motion directions). Averaging of the intensities usually favors the most exaggerated of the emotions that are combined, whereas FAPs with contradicting intensities cancel out. In practice, this approach works successfully, as shown in the actual results that follow. In the following table we describe the way to merge profiles of archetypal emotions and create profiles of intermediate ones:

Let $P_{A_1}^{(k)}$ be the kth profile of emotion A_1 and $P_{A_2}^{(l)}$ the lth profile of emotion A_2, then the following rules are applied so as to create a profile $P_I^{(m)}$ for the intermediate emotion I:

Rule 1: $P_I^{(m)}$ includes FAPs that are involved either in $P_{A_1}^{(k)}$ or $P_{A_2}^{(l)}$.

Rule 2: If F_j is an FAP involved in both $P_{A_1}^{(k)}$ and $P_{A_2}^{(l)}$ with the same sign (direction of movement), then the range of variation $X_{I,j}^{(k)}$ is computed as a weighted translation of $X_{A_1,j}^{(k)}$ and $X_{A_2,j}^{(l)}$ (where $X_{A_1,j}^{(k)}$ and $X_{A_2,j}^{(l)}$ are the ranges of variation of FAP F_j involved in $P_{A_1}^{(k)}$ and $P_{A_2}^{(l)}$, respectively) in the following way: (1) the translated range of variations $t(X_{A_1,j}^{(k)}) = \frac{a_I}{a_{A_1}} X_{A_1,j}^{(k)}$ and $t(X_{A_2,j}^{(k)}) = \frac{a_I}{a_{A_2}} X_{A_2,j}^{(k)}$ of $X_{A_1,j}^{(k)}$ and $X_{A_2,j}^{(l)}$ are computed, (2) the center and length $c_{A_1,j}^{(k)}, s_{A_1,j}^{(k)}$ of $t(X_{A_1,j}^{(k)})$ and $c_{A_2,j}^{(k)}, s_{A_2,j}^{(k)}$ of $t(X_{A_2,j}^{(k)})$ are also computed, (3) the length of $X_{I,j}^{(k)}$ is $s_{I,j}^{(m)} = \frac{\omega_I - \omega_{A_1}}{\omega_{A_2} - \omega_{A_1}} s_{A_1,j}^{(k)} + \frac{\omega_{A_2} - \omega_I}{\omega_{A_2} - \omega_{A_1}} s_{A_2,j}^{(l)}$ and its midpoint is $c_{I,j}^{(m)} = \frac{\omega_I - \omega_{A_1}}{\omega_{A_2} - \omega_{A_1}} c_{A_1,j}^{(k)} + \frac{\omega_{A_2} - \omega_I}{\omega_{A_2} - \omega_{A_1}} c_{A_2,j}^{(l)}$

Rule 3: If F_j is involved in both $P_{A_1}^{(k)}$ and $P_{A_2}^{(l)}$ but with contradictory signs (opposite directions of movement), then the range of variation $X_{I,j}^{(k)}$ is computed by $X_{I,j}^{(m)} = \frac{a_I}{a_{A_1}} X_{A_1,j}^{(k)} \cap \frac{a_I}{a_{A_2}} X_{A_2,j}^{(l)}$. In case $X_{I,j}^{(k)}$ is eliminated (which is the most possible situation) then F_j is excluded from the profile.

Rule 4: If F_j is involved only in one of $P_{A_1}^{(k)}$ and $P_{A_2}^{(l)}$, then the range of variation $X_{I,j}^{(k)}$ will be averaged with the corresponding of the neutral face position, that is, $X_{I,j}^{(m)} = \frac{a_I}{2 * a_{A_1}} X_{A_1,j}^{(k)}$ or $X_{I,j}^{(m)} = \frac{a_I}{2 * a_{A_2}} X_{A_2,j}^{(l)}$

Rule 5: a_{A_1}, a_{A_2} and a_I are the values of the *activation* parameter for emotion words A_1, A_2 and I, obtained from Whissel's study [8].

Rule 6: $\omega_{A_1}, \omega_{A_2}$ and $\omega_I, \omega_{A_1} < \omega_I < \omega_{A_2}$ are the *angular* parameters for emotion words A_1, A_2 and I, obtained from Plutchik's study [7].

It should be noted that the profiles, created using the aforementioned rules have to be animated for testing and correction purposes. The final profiles are those that present an acceptable visual similarity with the requested real emotion.

9.5 THE EMOTION ANALYSIS SYSTEM

In this section we present a way of utilizing profile-based emotion modeling for emotion understanding purposes. By doing so, we show that modeling emotions serves purposes related to both synthesis and analysis.

Figures 9.6 and 9.7 show the way the emotion analysis system functions. Let us consider as input to the emotion analysis system a 15-element length feature vector $\underline{f}$ that corresponds to the 15 features f_i shown in the third column of Table 9.3. The particular values of $\underline{f}$ can be rendered to FAP values as shown in the first column of the same table (see also Section 9.3.1) resulting in an input vector $\underline{G}$. The elements of $\underline{G}$ express the observed values of the corresponding FAPs (for example G_1 refers to the value of F_{37}).

Let $X_{i,j}^{(k)}$ be the range of variation of FAP F_j involved in the kth profile $P_i^{(k)}$ of emotion i. If $c_{i,j}^{(k)}$ and $s_{i,j}^{(k)}$ are the middle point and length of interval of $X_{i,j}^{(k)}$, respectively, then we describe a fuzzy class $A_{i,j}^{(k)}$ for F_j, using the membership function $\mu_{i,j}^{(k)}$ shown in Figure 9.8. Let also $\Delta_i^{(k)}$ be the set of classes $A_{i,j}^{(k)}$ that correspond to profile $P_i^{(k)}$; the beliefs $p_i^{(k)}$ and b_i that are observed through the vector $\underline{G}$ facial state corresponds to profile $P_i^{(k)}$ and emotion i respectively and are computed through the following equations:

$$p_i^{(k)} = \prod_{A_{i,j}^{(k)} \in \Delta_i^{(k)}} r_{i,j}^{(k)} \tag{9.3}$$

$$b_i = \max_k (p_i^{(k)}) \tag{9.4}$$

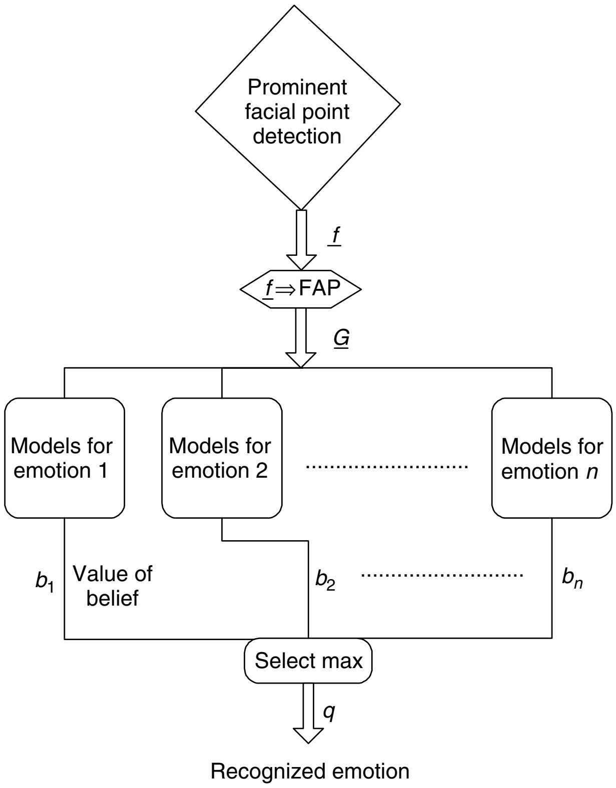

Figure 9.6 The emotion analysis system

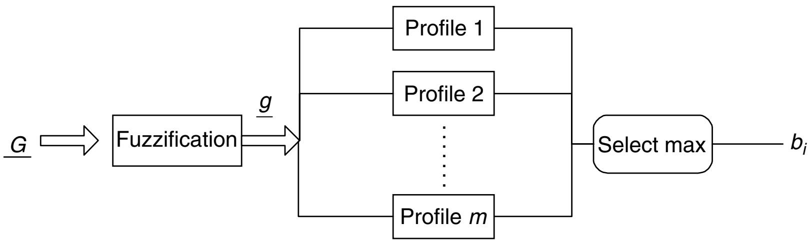

Figure 9.7 The fuzzy inference subsystem

where

$$r_{i,j}^{(k)} = \max\{g_i \cap A_{i,j}^{(k)}\} \tag{9.5}$$

expresses the *relevance* $r_{i,j}^{(k)}$ of the ith element of the input feature vector with respect to class $A_{i,j}^{(k)}$. Actually $\underline{g} = A'(\underline{G}) = \{g_1, g_2, \ldots\}$ is the fuzzified input vector resulting from a *singleton* fuzzification procedure [22].

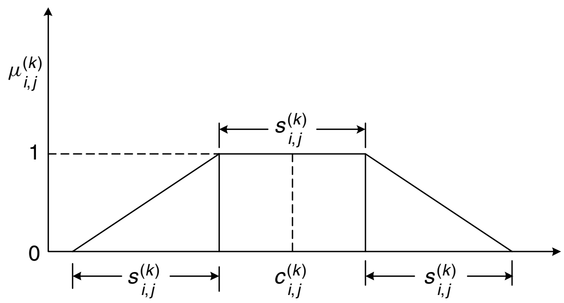

Figure 9.8 The form of membership functions

If a final decision about what is the observed emotion has to be made then the following equation is used:

$$q = \arg\max_i b_i \tag{9.6}$$

It is observed through Equation (9.3) that the various emotion profiles correspond to the fuzzy intersection of several sets and are implemented through a τ-*norm* of the form $t(a, b) = a \cdot b$. Similarly, the belief that an observed feature vector corresponds to a particular emotion results from a fuzzy union of several sets (see Equation 9.4) through an σ-*norm* that is implemented as $u(a, b) = \max(a, b)$.

It should be noted that in the previously described emotion analysis system no hypothesis has been made about the number of recognizable emotions. This number is limited only by the number of profiles that have been modeled. Thus, the system can be used for analyzing either a few of the archetypal emotions or many more, using the methodology described in Section 9.4 to create profiles for nonarchetypal emotions.

9.6 EXPERIMENTAL RESULTS

In this section we show the efficiency of the proposed scheme in modeling archetypal and intermediate emotions according to the methodology described in the previous sections. Animated profiles were created using the face model developed in the context of the European Project *ACTS MoMuSys* [21], as well as the 3-D model of the software package *Poser*, Edition 4 of Curious Labs Company. This model has separate parts for each moving face part. The Poser model interacts with the controls in Poser and has joints that move naturally, as in a real person. Poser mirrors real-face movements by adding joint parameters to each face part. This allows us to manipulate the figure based on those parameters. We can control the eyes, the eyebrows and the mouth of the model by filling the appropriate parameters. To achieve this, a mapping from FAPs to Poser parameters is necessary. We did this mapping mainly experimentally. The relationship between FAPs and Poser parameters is more or less straightforward.

The first set of experiments shows synthesized archetypal expressions (see Figure 9.9) created by using the Poser software package. The 3-D nature of the face

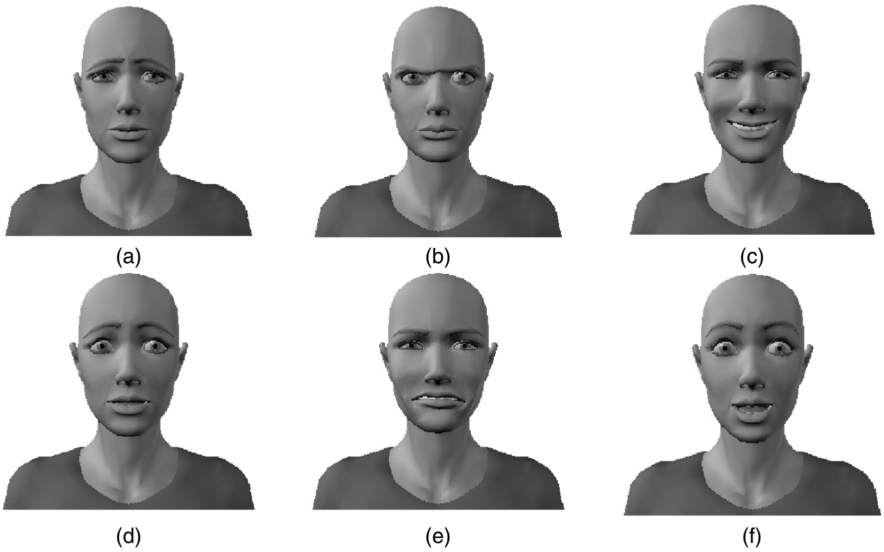

Figure 9.9 Synthesized archetypal expressions created using the 3-D model of the POSER software package (a) sadness; (b) anger; (c) joy; (d) fear; (e) disgust and (f) surprise

model renders the underlying emotions in a more natural way than the MPEG-4 compatible face model (compare Figures 9.5e and f for the emotions *surprise* and *joy* with the Figures 9.9f and 9.9c respectively). However, in both cases the synthesized examples are rather convincing.

The second set of experiments show particular examples in creating nonarchetypal expressions based on our proposed method. More details are given in the following sections.

9.6.1 Creating Profiles for Emotions Belonging to a Universal Category

In this section we illustrate the proposed methodology for creating profiles for emotions that belong to the same universal category as an archetypal one. Emotion terms *afraid*, *terrified* and *worried* are considered to belong to the emotion category *fear* [14] whose modeling base is the term *afraid*. Table 9.7 shows profiles for the terms *terrified* and *worried* that have been generated from the basic profile of *afraid* (in particular $P_{\mathrm{F}}^{(8)}$). The range of variation $X_{\mathrm{T},j}^{(8)}$ of FAP F_j belonging to the eighth profile of the emotion term *terrified* is computed by the equation $X_{\mathrm{T},j}^{(8)} = (6.3/4.9)X_{\mathrm{F},j}^{(8)}$, where $X_{\mathrm{F},j}^{(8)}$ is the range of variation of FAP F_j belonging to the eighth profile of the emotion term *afraid*. Similarly $X_{\mathrm{W},j}^{(8)} = (3.9/4.9)X_{\mathrm{F},j}^{(8)}$ is the range of variation of FAP F_j belonging to the eighth profile of the emotion term *worried.* Figures 9.10 (a) to (c) and 9.11 (a) to (c) show the animated profiles for the emotion terms *afraid*, *terrified* and *worried* respectively. The FAP values that we used are the median ones of the corresponding ranges of variation.

Table 9.7 Created profiles for the emotions terror and worry

Emotion term	Activation	Profile
Afraid	4.9	$F_3 \in [400, 560]$, $F_5 \in [-240, -160]$, $F_{19} \in [-630, -570]$, $F_{20} \in [-630, -570]$, $F_{21} \in [-630, -570]$, $F_{22} \in [-630, -570]$, $F_{31} \in [260, 340]$, $F_{32} \in [260, 340]$, $F_{33} \in [160, 240]$, $F_{34} \in [160, 240]$, $F_{35} \in [60, 140]$, $F_{36} \in [60, 140]$
Terrified	6.3	$F_3 \in [520, 730]$, $F_5 \in [-310, -210]$, $F_{19} \in [-820, -740]$, $F_{20} \in [-820, -740]$, $F_{21} \in [-820, -740]$, $F_{22} \in [-820, -740]$, $F_{31} \in [340, 440]$, $F_{32} \in [340, 440]$, $F_{33} \in [210, 310]$, $F_{34} \in [210, 310]$, $F_{35} \in [80, 180]$, $F_{36} \in [80, 180]$
Worried	3.9	$F_3 \in [320, 450]$, $F_5 \in [-190, -130]$, $F_{19} \in [-500, -450]$, $F_{20} \in [-500, -450]$, $F_{21} \in [-500, -450]$, $F_{22} \in [-500, -450]$, $F_{31} \in [210, 270]$, $F_{32} \in [210, 270]$, $F_{33} \in [130, 190]$, $F_{34} \in [130, 190]$, $F_{35} \in [50, 110]$, $F_{36} \in [50, 110]$

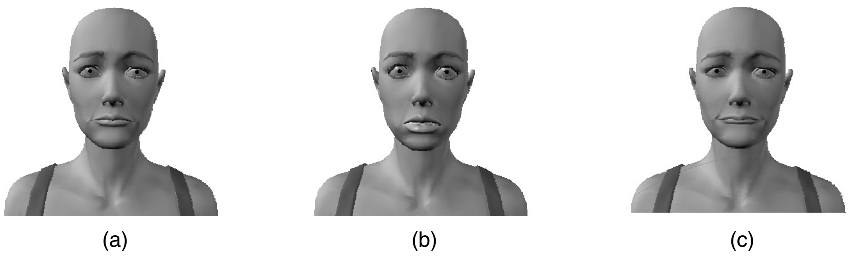

Figure 9.10 Poser face model. Animated profiles for emotion terms (a) afraid; (b) terrified and (c) worried

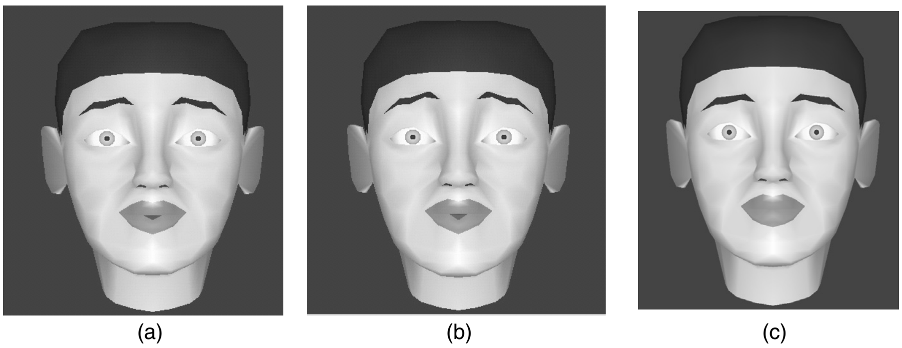

Figure 9.11 MPEG-4 face model. Animated profiles for emotion terms (a) afraid; (b) terrified and (c) worried

9.6.2 Creating Profiles for Nonarchetypal Emotions

In this section we describe a method for creating a profile for the emotion *guilt*. According to Plutchik's *angular* measure (see Table 9.6), the emotion term *guilty* (angular measure 102.3 degrees) lies between the archetypal emotion terms *afraid* (angular measure 70.3 degrees) and *sad* (angular measure 108.5 degrees), being closer to the latter. According to Section 9.4.2 the vocabulary V_G of emotion *guilt* emerges as the union of

Table 9.8 Created profile for the emotion guilt

Emotion term	Activation	Angular measure	Profile
Afraid	4.9	70.3	$F_3 \in [400, 560]$, $F_5 \in [-240, -160]$, $F_{19} \in [-630, -570]$, $F_{20} \in [-630, -570]$, $F_{21} \in [-630, -570]$, $F_{22} \in [-630, -570]$, $F_{31} \in [260, 340]$, $F_{32} \in [260, 340]$, $F_{33} \in [160, 240]$, $F_{34} \in [160, 240]$, $F_{35} \in [60, 140]$, $F_{36} \in [60, 140]$
Guilty	4	102.3	$F_3 \in [160, 230]$, $F_5 \in [-100, -65]$, $F_{19} \in [-110, -310]$, $F_{20} \in [-120, -315]$, $F_{21} \in [-110, -310]$, $F_{22} \in [-120, -315]$, $F_{31} \in [61, 167]$, $F_{32} \in [57, 160]$, $F_{33} \in [65, 100]$, $F_{34} \in [65, 100]$, $F_{35} \in [25, 60]$, $F_{36} \in [25, 60]$
Sad	3.9	108.5	$F_{19} \in [-265, -41]$, $F_{20} \in [-270, -52]$, $F_{21} \in [-265, -41]$, $F_{22} \in [-270, -52]$, $F_{31} \in [30, 140]$, $F_{32} \in [26, 134]$

vocabularies V_F and V_S, that is, $V_G = V_F \cup V_S$, where V_F and V_S are the vocabularies corresponding to emotions *fear* and *sad* respectively. Table 9.8 shows a profile for the term *guilty* generated from an underlying profile of the term *afraid* (in particular $P_F^{(8)}$) and *sad* ($P_S^{(0)}$). FAPs F_3, F_5, F_{33} to F_{36} are included only in the $P_F^{(8)}$ and therefore the corresponding ranges of variation in the emerging *guilty* profile $P_G^{(m)}$ (mth *guilty* profile) are computed by averaging the ranges of variation of $P_F^{(8)}$ with the neutral face, according to *Rule 4* (see Section 9.4.2); for example $X_{G,3}^{(m)} = (4/2 * 4.9)X_{F,4}^{(8)}$. FAPs F_{19} to F_{22}, F_{31}, F_{32} are included in both $P_F^{(8)}$ and $P_S^{(0)}$, with the same direction of movement, thus *Rule 2* is followed. For example, the range of variation $X_{G,19}^{(m)}$ for FAP F_{29} term is computed as follows:

$$t(X_{F,19}^{(8)}) = \frac{4}{4.9} X_{F,19}^{(8)} => [-510, -460], c_{F,19}^{(8)} = -485, s_{F,19}^{(8)} = 50,$$

$$t(X_{S,19}^{(0)}) = \frac{4}{3.9} X_{S,19}^{(0)} => [-270, -42], c_{S,19}^{(0)} = -156, s_{S,19}^{(9)} = 228,$$

since $\omega_F = 70.3°$, $\omega_S = 108.5°$, $\omega_G = 102.3°$, $c_{G,19}^{(m)} = [(102.3 - 70.3)/(108.5 - 70.3)] * (-156) + [(108.5 - 102.3)/(108.5 - 70.3)] * (-485) = -209 s_{G,19}^{(m)} = [(102.3 - 70.3)/(108.5 - 70.3)] * 228 + [(108.5 - 102.3)/(108.5 - 70.3)] * 50 = 199$, and $X_{G,19}^{(m)}$ corresponds to the range $[-110, -310]$.

9.7 CONCLUSION–DISCUSSION

In this chapter we have proposed a complete framework for creating visual profiles based on FAPs for intermediate (not primary) emotions. Emotion profiles can serve either the vision part of an emotion recognition system or a client side application that creates synthetic expressions. The main advantage of the proposed system is its flexibility:

- No hypothesis needs to be made about what the facial points detection system is (see Figure 9.1); it is enough to detect the movement of a predefined set of FDP points.

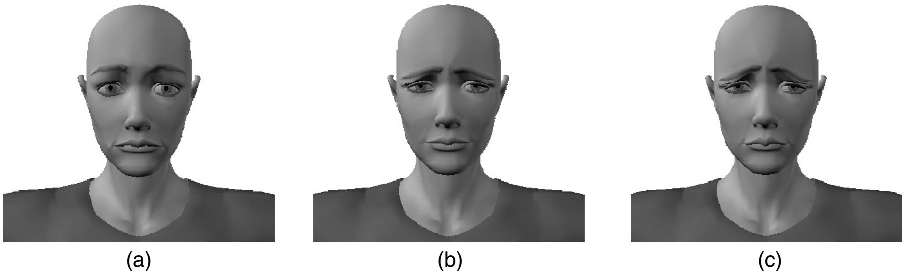

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Figure 9.12 Poser● face model: Animated profiles for emotion terms (a) afraid; (b) guilty and (c) sad

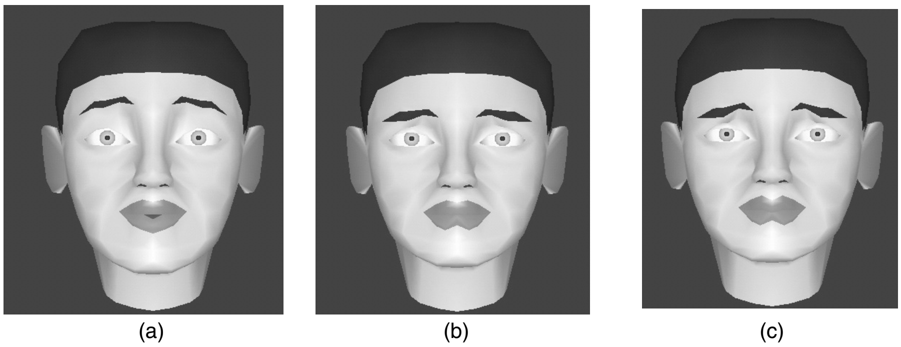

Figure 9.13 MPEG-4 face model. Animated profiles for emotion terms (a) afraid; (b) guilty and (c) sad

- The system is extensible with respect to completing (or modifying) the proposed vocabulary of FAPs for the archetypal expressions
- The range of variation of FAPs that are involved in the archetypal expression profiles can be modified. Note, however, that this modification affects the profiles of the nonarchetypal emotions.
- The system is extensible with respect to the number of nonarchetypal expressions that can be modeled.
- The system can be used either for expression synthesis or for expression analysis. In the former case, a rule-based procedure serves as an agent for synthesizing expressions, while in the latter case a fuzzy inference system provides the means of an autonomous emotion analysis system.

Exploitation of the results obtained by psychological studies related with emotion recognition from computer scientists is possible, although not straightforward. We have shown that terms such as the *emotion wheel* and *activation* are suitable for extending the emotions that can be visually modeled. Extension of these results combining audio and visual emotion analysis systems is currently under investigation in the framework – an EC-funded project called ERMIS [23].

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