Asymmetric Facial Expressions: Revealing Richer Emotions for Embodied Conversational Agents

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Abstract

In this paper, we propose a method to achieve effective facial emotional expressivity for embodied conversational agents by considering two types of asymmetry when exploiting the Valence-Arousal-Dominance representation of emotions. Indeed, the asymmetry of facial expressions helps to convey complex emotional feelings such as conflicting and/or hidden emotions due to social conventions. To achieve such a higher degree of facial expression in a generic way, we propose a new model for mapping the Valence-Arousal-Dominance emotion model onto a set of twelve scalar Facial Part Actions (FPA)s built mostly by combining pairs of antagonist Action Units (AU) from the Facial Action Coding System (FACS). The proposed linear model can automatically drive a large number of autonomous virtual humans or support the interactive design of complex facial expressions over time. By design our approach produces symmetric facial expressions, as expected for most of the emotional spectrum. However more complex ambivalent feelings can be produced when differing emotions are applied on the left and right sides of the face. We conducted an experiment on static images produced by our approach to compare the expressive power of symmetric and asymmetric facial expressions for a set of eight basic and complex emotions. Results confirm both the pertinence of our general mapping for expressing basic emotions and the significant improvement brought by asymmetry for expressing ambivalent feelings.

Keywords: Asymmetric facial expression, VAD emotional model, Real-time application, Evaluation study, Embodied agent, Linear model

1 Introduction

This paper proposes a new model for mapping the expression of basic and complex emotions onto a set of twelve scalar **F**acial **P**art **A**ctions (**FPA**)s mostly based on the combination of antagonist Action Units from the Facial Action Coding System (FACS) [1]. Targeted applications are those requiring reactive on the fly emotional expression from embodied conversational agents for individual interaction as well as for large scale inhabited and shared virtual environments. Therefore, our first motivation is to offer a real-time technique to sustain a natural interaction flow. Our second major goal is to support the agent believability by synthesizing a large range of facial expressions that includes at least the six universal emotions [2] and the emotion corpus spanned by the **V**alence **A**rousal **D**ominance (**VAD**) emotion space [3, 4]. Indeed, we aim at also rendering those complex emotions resulting in very demonstrative expressions, often with facial asymmetry [5].

We distinguish two types of asymmetry in the expression of emotions. The first one is a systematic asymmetry mostly observed as a left bias in the facial expression [6]. The second type of asymmetry results from the simultaneous combination of two basic emotions, one on each side of the face, when an individual is unsuccessfully trying to hide one emotion by another one, *e.g.* sadness by fainted joy induced by social conventions (this was described as the "false smile" in [7]). The asymmetry we address in this paper is a complementary type of display compared to the upper/lower blend of facial emotion occurring in similar social situations as initially identified in [8] and developed in [9]. The Duchenne smile which is characterized as lacking the eye wrinkling is one illustration of the upper-lower blend of emotions [10, 11]. This latter modality is out of the scope of the present paper.

The next section recalls the scientific underpinning of facial asymmetry, the prior contributions in the field of real-time facial expression, and the definition of the VAD emotion space. Section 3 then presents the FPAs and the linear mapping from VAD dimension to the corresponding facial deformation. The case of asymmetric expression synthesis is developed in section 4 and its user study design and results are described in section 5. A performance test in a real-time crowd application is reported in section 6, before the discussion and conclusion in section 7.

2 Related Works

2.1 Asymmetry of human facial expression

Despite the intrinsic symmetry of the human skeleton and face with respect to the medial/sagittal plane, numerous experimental studies have reported with statistical significance first that the human face is seldom perfectly symmetrical [12] and second that the expression of emotions were more intense on one side of the face (see the survey from [13]). It was initially reported in [6] that emotion are more intense on the left side, and this, independently of the right or left handedness of the subjects. Given the brain organization of motor control, it characterizes a laterality effect with a greater involvement of the right brain hemisphere for emotional expression. It has been further refined that emotion with negative valence, are more left-biased than positive emotion [14, 15]. The percentage of left biasing on several emotional terms were also described after observing 51 normal adult subjects [16]. There was a different opinion that the left-biased tendency depends on how to settle the experimental environment [17]. However, it has been since further confirmed with experiments with trained judges and quantitative EMG measurements of facial muscles such as zygomatic(cheek to lip corner) or corrugator(near forehead inner brow) [18, 19]. Some other researches have conducted experiments on mouth [20] and FACS AU [21] asymmetries.

Asymmetry also spreads through the different time scales that are at play in the expression of emotions, from the small timing nuance of a smile [7] to the longer lasting emotional coloring that pervades emotional life [11].

2.2 Facial expression synthesis

A large body of work has been performed on facial expressivity in general [22, 23, 24, 25], and in real-time interaction with autonomous virtual humans in particular [26]. Pelachaud and Poggi provide a rich overview of a large set of expressive means to convey an emotional state [27] including head orientation. In [28] facially expressive agents with personality are used for sustained conversations. In this work the facial expression of emotion is obtained by blending predefined faces expressed in terms of MPEG4 facial parameters. Albrecht et al. [29] describe a text-to-speech system capable of displaying emotion by radially interpolating key emotions within a 2D emotion space (hence the paper title “mixed feelings” although the proposed approach does not simultaneously integrate two distinct emotions). In [30] Pelachaud acknowledges the whole body scale of emotion expression and its temporal organization of multimodal signals. She describes a componential approach where a complex expression is obtained by combining (symmetric) facial areas of source expressions, the final expression resulting from the resolution of potential conflicts induced by the context (e.g. due to social display rules). A recent study on emotion expression through gaze [31] stresses the relationship between a three-dimensional emotion model and multiple postural factors including the head and torso inclination and velocity [32]. However, the asymmetry is not acknowledged as a determinant factor in these studies. In [33], predefined asymmetrical facial expressions are exploited in a barycentric interpolation scheme which requires an important a priori design effort. The present paper extends our prior approach [34] with an experimental evaluation on 58 subjects.

2.3 The Valence-Arousal-Dominance (VAD) emotion model

In the mid 1970’s, a number of psychologists challenged the issue of defining a dimensional model of emotion. An emotion space spanned by three independent dimensions has been proposed with slightly different terms depending on the authors [35, 36, 3]. The first axis represents the positivity or negativity of an emotion. The second describes the degree of energy of the emotion. Finally, the third axis indicates the feel of power of emotion. In the present paper, we use the terms **V**alence, **A**rousal, and **D**ominance (**VAD**) for these three axes.

Based on this 3D emotion space and the related works described above, we set the direction of our contributions as follow: 12 antagonist muscle groups are built from the Action Units (AU) identified in [2]. The normalized activity of the muscle groups is expressed as a linear mapping of the three VAD emotion parameters. Ambivalent feelings can be built either automatically from the VAD inputs or through a dedicated interface.

3 Facial Expressions in the VAD Space

In this section, we introduce how we relate the 3D emotional space to facial expressions. Figure 1 shows the entire pipeline of this VAD face generation.

3.1 Sample emotions

Eighteen sample emotions have been selected by choosing a set of experimentally quantified words in terms of their expressed Valence, Arousal and Dominance in the *Affective Norms for English Words* (ANEW)'s "all subjects table" [37]. In order to take advantage of a substantial amount of previous researches [2, 38, 39, 40], we first selected ANEW words representing the six basic emotions such as anger (adjective: angry), disgust (disgusted), fear (afraid), happiness (happy), sadness (sad), and surprise (surprised). Twelve other emotional adjectives – anxious, bored, consoled, gloomy, hopeful, indifferent, inspired, overwhelmed,

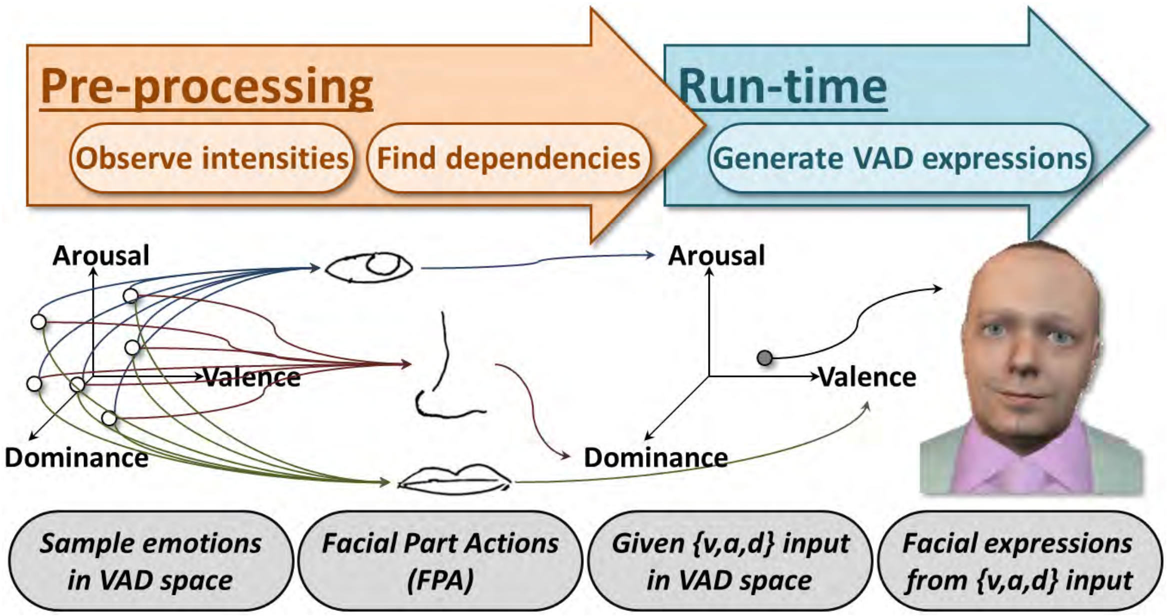

Figure 1: The overview of facial expression generation from a VAD input.

peaceful, pleasant, relaxed, shy – have been also selected to complete the uniform distribution over the VAD emotional space. All VAD coordinates were obtained from [37]. Given these input data, we now present how to relate them to the intensity of the twelve Facial Part Action (FPA) to produce the corresponding facial expressions.

3.2 Facial Part Actions (FPA)

According to [41], three main components have to be considered for representing facial emotions: upper face, lower face, and head orientation. These components are further decomposed into Action Units (AU) according to the Facial Action Coding System (FACS) [1]. We group mostly antagonist Action Units into twelve **F**acial **P**art **A**ctions (**FPA**)s (Figure 2) to obtain a set of independent scalar variables in charge of producing the facial expressions. The detail of the FPAs' moving area and intensity normalization are visible in Figure 2.

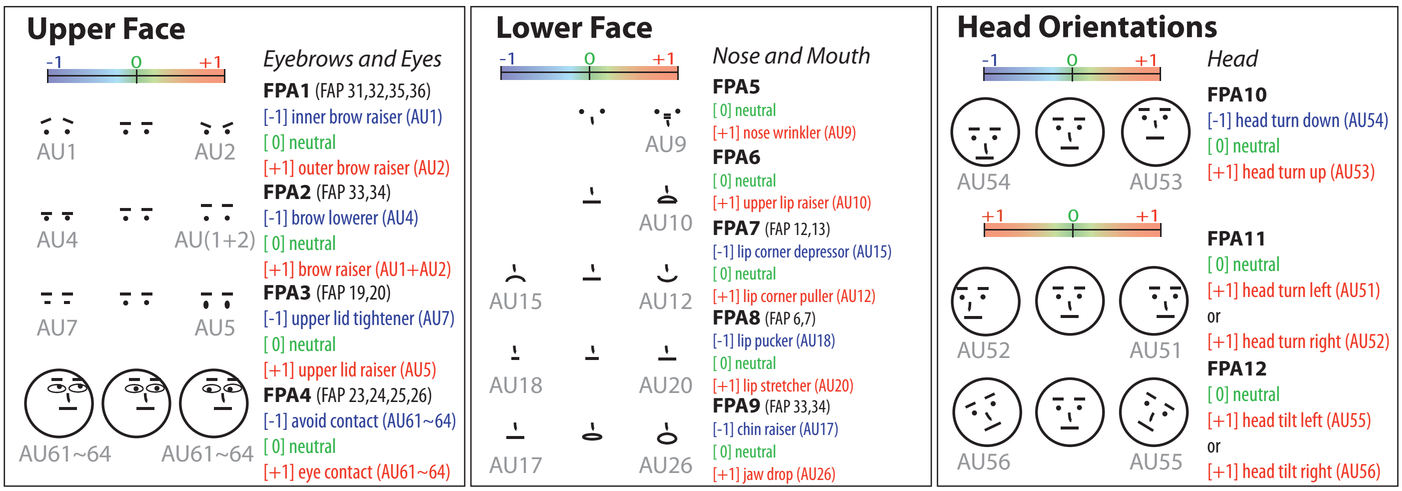

Figure 2: Illustration of the FPAs' moving range defined by intensities. Except some special cases (FPA5, 6, 11, 12, range [0,+1]), the intensity range of FPAs are [-1,+1]. We also compared FPAs to Facial Animation Parameters (FAP)s introduced in [42].

3.3 Finding linear dependencies

We propose to control facial expression by a column vector **y** consisting of twelve FPA intensities. The i^{th} element of **y** represents an FPAi intensity driven by a linear function (see Equation 1). A linear model is chosen instead of non-linear model for the following reasons: (1) consistent tendency of intensity along each VAD axis; (2) plausible change of emotional expression in between two VADs; and (3) simplified formulation for real-time applications (games, ECA, etc.). At run time, the input VAD is assigned to x_v, x_a, and x_d and generate a vector **y** for updating the facial expression.

$$y_i = \beta_{vi}x_v + \beta_{ai}x_a + \beta_{di}x_d \quad (1)$$

The coefficients β_{vi}, β_{ai}, and β_{di} are estimated by: (1) gathering the FPA intensities (total 12 FPAs $\times$ 18 sample emotions) displayed in Table 1; and (2) minimizing the multiple linear regression residual $\sum_{j=1}^{n} \|e_{ij}\|^2$ (see Equation 2), where n is the number of sample emotions, y_{ij} stands for an observed intensity of FPAi on j^{th} sample emotion, and x_{vj}, x_{aj}, and x_{dj} represent the VAD values of the j^{th} sample emotion. The regression intercept $\hat{\beta}_{0i}$ is assigned to 0, since we wanted to force the neutral FPA to zero intensities.

$$e_{ij} = y_{ij} - \hat{\beta}_{0i} - \hat{\beta}_{vi}x_{vj} - \hat{\beta}_{ai}x_{aj} - \hat{\beta}_{di}x_{dj} \quad (2)$$

The resulting $\hat{\beta}$ are normalized to obtain the β coefficients (Equation 3) needed to generate the intensity vector **y** from any VAD input.

$$(\beta_{vi}, \beta_{ai}, \beta_{di}) = \frac{(\hat{\beta}_{vi}, \hat{\beta}_{ai}, \hat{\beta}_{di})}{\|\hat{\beta}_{vi}\| + \|\hat{\beta}_{ai}\| + \|\hat{\beta}_{di}\|} \quad (3)$$

As illustrated in Figure 3–Left, Equation 1 describes a separating plane between a positive intensity half space (plane norm direction) and a negative intensity half space. The plane includes the origin $\{0, 0, 0\}$ of the VAD space which leads to a null intensity for the neutral VAD state (0,0,0).

Our model can be customized by varying the FPA intensities gathered in Table 1. In this

Emotions	**V**	**A**	**D**	FPA1	FPA2	FPA3	FPA4	FPA5	FPA6	FPA7	FPA8	FPA9	FPA10	FPA11	FPA12
Afraid	-0.75	0.42	-0.26	-0.5	1.0	1.0	-0.5	0.5	0.0	-0.5	0.0	1.0	1.0	1.0	0.0
Angry	-0.54	0.54	0.14	1.0	-1.0	0.5	1.0	1.0	1.0	-1.0	0.0	-0.5	1.0	0.0	0.0
Disgusted	-0.64	0.11	-0.17	1.0	-1.0	-1.0	-0.5	1.0	1.0	-1.0	0.5	0.5	1.0	1.0	0.0
Happy	0.80	0.37	0.41	-0.5	0.0	0.0	0.5	0.0	0.5	1.0	1.0	0.0	-0.5	0.0	1.0
Sad	-0.85	-0.22	-0.39	-0.5	0.0	-0.5	-0.5	0.0	0.0	-0.5	-0.5	-0.5	-1.0	0.0	0.0
Surprised	0.62	0.62	0.28	-0.5	1.0	1.0	0.5	0.5	0.5	0.0	0.0	0.5	1.0	0.0	0.0
Anxious	-0.05	0.48	0.08	0.5	-0.5	0.0	-0.5	0.0	0.5	-0.5	0.0	0.5	0.0	0.5	0.0
Bored	-0.51	-0.54	-0.22	-0.5	0.0	-0.5	-0.5	0.0	0.0	-0.5	0.0	0.5	-0.5	0.5	0.5
Consoled	0.20	-0.12	-0.14	-0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.5	0.5	-0.5	0.0	0.5
Gloomy	-0.78	-0.29	-0.36	-0.5	0.0	-0.5	-0.5	0.0	0.0	-0.5	0.0	0.5	-1.0	0.5	0.0
Hopeful	0.53	0.20	0.10	-0.5	0.5	0.5	0.5	0.0	0.0	0.5	0.5	0.0	0.5	0.0	0.5
Indifferent	-0.10	-0.46	-0.04	-0.5	0.0	-0.5	-1.0	0.0	0.0	0.0	0.5	0.0	0.0	0.5	0.5
Inspired	0.54	0.26	0.42	0.0	0.5	0.5	1.0	0.5	1.0	0.0	0.5	0.5	0.5	0.0	0.0
Overwhelmed	-0.20	0.50	-0.28	0.5	-0.5	0.0	-0.5	0.5	0.5	0.0	-0.5	0.5	-0.5	0.5	0.5
Peaceful	0.68	-0.51	0.11	-0.5	0.0	-0.5	0.0	0.0	0.0	0.5	0.5	0.0	-0.5	0.0	1.0
Pleasant	0.82	0.19	0.29	-1.0	1.0	0.5	0.5	0.0	1.0	1.0	1.0	0.5	0.5	0.0	0.5
Relaxed	0.50	-0.65	0.14	-1.0	0.5	-0.5	0.0	0.0	0.0	0.5	0.5	0.0	-0.5	0.0	0.5
Shy	-0.09	-0.31	-0.39	0.0	0.0	-0.5	-1.0	0.5	0.0	0.0	-0.5	1.0	-0.5	0.5	0.0
β_{vi}				-0.42	0.63	0.19	0.29	-0.32	0.13	0.55	0.48	-0.07	0.07	-0.46	0.52
β_{ai}				0.46	-0.02	0.49	0.25	0.59	0.51	-0.08	-0.00	0.35	0.56	0.06	-0.22
β_{di}				-0.12	0.35	0.32	0.46	-0.09	0.36	0.37	0.52	-0.58	0.37	-0.48	0.26

Table 1: An example of FPA intensities for each sample emotion. The VADs of eighteen sample emotions are described from the 2^{nd} to 4^{th} columns. The upper six rows are the six basic emotions; the mid twelve are additional emotions for ensuring a uniform distribution in the VAD space; and the lower three are the β coefficients.

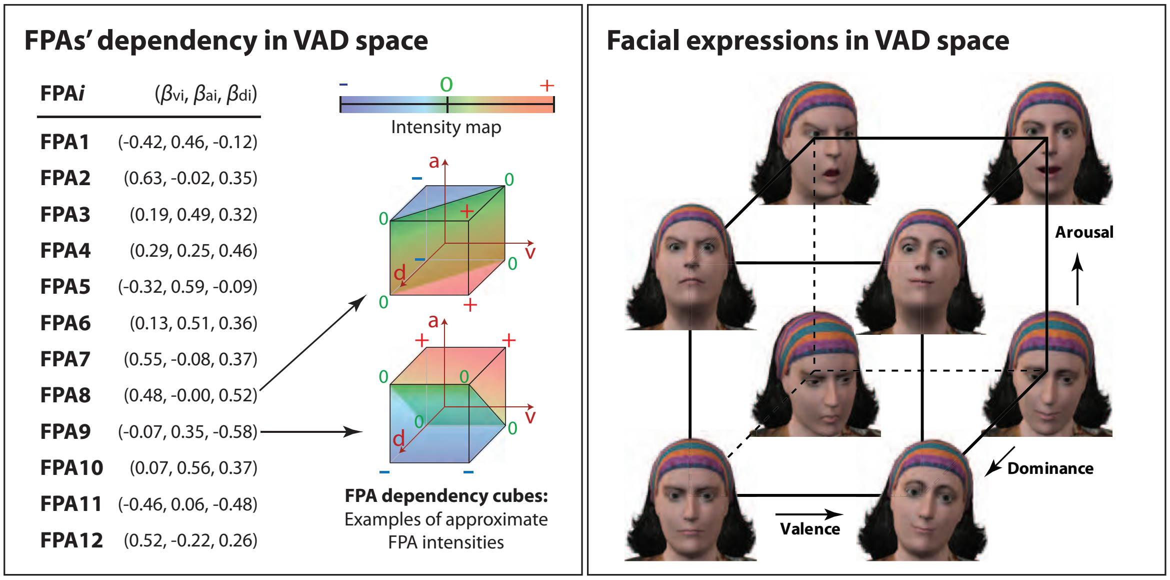

Figure 3: Left: The FPAs' β coefficients (Equation 3) and two examples of FPA dependencies in VAD space. A dependency cube shows how it generates the intensity of corresponding FPA from the VAD space. Green plane (0-corners) is a zero intensity plane as in Equation 1. Red (+) and blue (-) shaded area represents positive and negative intensity field. Right: various facial expressions in a VAD space.

paper, we have exploited the research findings listed hereafter to assign the FPA intensities of the six basic emotions.

- Six basic emotions and their relation to face are presented in [2].
- Movement of brows can affect emotions such as surprise, fear, sadness, or anger, however there is no affect to disgust or happiness emotion [38].
- Emotions effects on eye lids, lip, and jaw are documented in [39].

- A specific facial part AU 12 (lip movement) is described in [40].

For the additional sample emotions, we manually created facial expressions corresponding to each sample emotion by adjusting FPA values. Eight facial expressions in the corners of the VAD space are demonstrated in Figure 3–Right. A partial evaluation of our generic model is included in the user study described in 5. The next section first present how it can be exploited for the synthesis of ambivalent feeling through asymmetric facial expressions.

4 Facial Asymmetry for Ambivalent Feelings

The aesthetical debate about the respective merits of symmetry and asymmetry in the Arts is still vivid and very well reviewed by Mac Manus in [43]. Briefly summarized, symmetry can be seen as attractive indeed, as revealed by Grammer on real subjects [12], but often carries a sterile rigidity that better characterize the ancient forms of arts (e.g. greek kouroi vs the fluid style of classical sculpture, or byzantinium icons vs the slightly asymmetric smile of the Joconda).

In our field of real-time applications, economic constraints of character design cost, run-time computing cost and memory footprint have resulted into the return of a golden age of symmetric faces and facial expressions. Through this work we advocate for reconsidering asymmetry for both aesthetical purposes but above all for leveraging on the richer expressivity that asymmetry allows. In addition, if one takes a look at the emotional expressions from pictures, movies or the real world, there is no doubt that neither a face, nor its expression are always perfectly symmetric. Hence, restoring some degree of asymmetry in the facial expression could also be a means towards producing more ecologically valid expressions and therefore more plausible virtual human agents.

Inspired by those motivations and the previous works described in sub-section 2.1, this paper presents an intuitive interface that facilitates transmission of complex emotional feelings to a virtual character. Among the twelve FPAs from Figure 2, five of them are used for asymmetric expressions. These asymmetric FPAs are related to corrugator, orbicularis, and zygomatic muscles, which are mostly observed for left/right asymmetric facial expression from EMG experiments [18, 19, 20].

- Corrugator supercilii: facial muscle placed on the inner side of the eyebrow (FPA1 and FPA2);
- Orbicularis oculi: facial muscle that closes the eyelids (FPA3); and
- Zygomatic major: facial muscle which draws the angle of the mouth upward and laterally (FPA7 and FPA8).

4.1 Overall pipeline

Based on the psychological findings gathered in the extensive review by Borod et al. [15], and on recent findings stating the possible simultaneous activation of emotions with positive and negative valence [44], we designed a pair of inputs which manage independently the left and right (controlled emotion) side of the face. Figure 4 shows the entire pipeline for this asymmetric facial animation. The proposed framework offers two different types of run-time input edited at pre-processing stage: (1) a pair of VAD values with *face-edit parameters* (see the next sub-section) are pre-defined in *face edit* phase; or (2) a pair of VAD flows manually designed by an animator. For an efficient *face edit* process, the proposed interface provides a list of 117 emotional keywords, each linked to a VAD value. These keywords were chosen among the 1,035 words provided in the ANEW table [37].

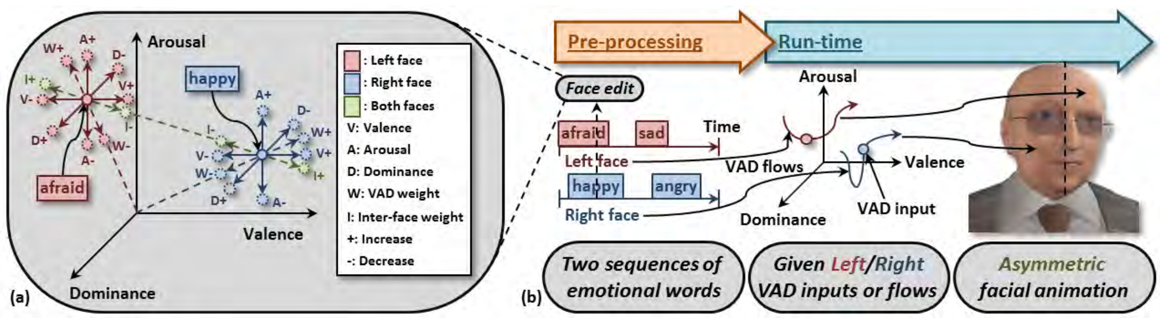

Figure 4: (a) Asymmetric *face-edit parameters*; (b) Asymmetric facial animation pipeline.

The right side of the face which expresses a controlled emotion (social conventions), is generated by five right face FPA intensities y_1^r, y_2^r, y_3^r, y_7^r, and y_8^r. An intensity value y_i^r represents the right face intensity of FPAi (left face intensity is y_i^l). In case of symmetric expression, a unique intensity y_i is used for both sides of face. The *face edit*ing process is explained in detail in the next subsection.

For the pre-processed VAD flows, we can take advantage of the VAD space, since an emotional keyword can easily be converted to a 3D vector form (VAD coordinate). It facilitates the interpretation of given keywords as control points for linear or non-linear VAD interpolation. In both left and right facial animation tracks, an animator can define starting time and duration of an emotional keyword, and thanks to those tracks an emotion animation can be played back at run time upon request.

4.2 Asymmetric face-edit parameters

The first step when building an ambivalent feeling is to choose an emotional keyword for each side of the face. However, we still need to adjust their combination to produce plausible facial expressions. As illustrated in Figure 4–(a), we defined five asymmetric face-edit parameters for increasing the expressivity of an asymmetric face.

Instead of moving a complex mesh structure or rigged face area, the proposed tool provides parameters ($V\pm$, $A\pm$, $D\pm$) which allow to adjust respectively valence, arousal, and dominance. A VAD weighting factor ($W\pm$) gives a more intense or weak feeling to a given emotional keyword. Moreover, an inter-face weighting factor ($I\pm$) interpolates or extrapolates feelings between two different keywords.

We also defined a special parameter b (see Equation 4), *i.e.* a left-bias factor ranged [-1,+1] which increases the left/right intensity of the face. If b is greater than 0, the expression is left biased. As was mentioned in [17], the facial expression on the left face is more intense when the emotion is negative (valence). Therefore, we applied a weighting factor on the negative emotion [45] by giving extra intensity when the valence is lower than zero. Here the constant c_i determines an additional weight of negative valence. Based on our experience 0.25 gives the most plausible results.

$$y_i^l = y_i(1 + b_i(1 - c_i x_{vi})) \quad (4)$$

$$y_i^r = y_i(1 - b_i(1 - c_i x_{vi}))$$

4.3 Ambivalent feelings

Six examples of ambivalent feelings are illustrated in Figure 5.

The faces in Figure 5a) shows the *smirk* expression which combines neutral and happy emotions. This mixed feeling expresses someone who is trying to smile about something that is not funny. After merging the two emotions the left-bias factor b was decreased by 0.3, resulting in a more intense smile on the right side of the face.

The top-right Figure 5b) demonstrates a feeling after a certain amount of time from a positive surprise. The arousal of surprised feeling was decreased by 0.6 and again the weighting surprise feeling are again decreased by 0.1. After these edit operations, a *relief* expression was generated.

The faces in Figure 5c) combine increased pleasure and decreased jealousy emotions. Those two opposite feelings generates a *vicious* expression as if someone would enjoy negative feelings.

In the right Figure of the second row (Figure 5d)), a character tries to hide his high ambition. The arousal value on the ambition was increased to express higher ambition and combined with displayed indifference for producing the *sneaky* expression.

The bottom-left faces in Figure 5e), expresses *too good to be true*. The expression is combined with surprised and unfaithful feelings, resulting in a complex emotion of someone who is positively surprised about something hard to believe.

Finally, on the bottom-right (Figure 5f)), we see a face hiding its anxious feeling and trying to *pretend to be cool*. This mixed feeling is combining the anxious and relaxed emotions. All four operations help to intensify relaxed feeling against anxious feeling.

5 Evaluation of the Expressions

In this section, we describe the evaluation and validation of the proposed VAD framework and asymmetric facial expressions.

5.1 Experiment design

We have asked 58 experimental subjects (33M, 25F) to score both symmetric and asymmetric facial expressions for 64 illustrations of a keyword with a short definition (full list in Appendix A). The score range was from 0.0 (incorrect) to 10.0 (correct). Each subject was asked to sign the consent form and paid 10 CHF for 30 minutes of their evaluation time. They were also informed to spend in average 25 seconds per question and to focus more on facial expression itself rather than graphical realism.

Figure 6 depicts one of the four combinations of the keyword "vicious" for the male con-

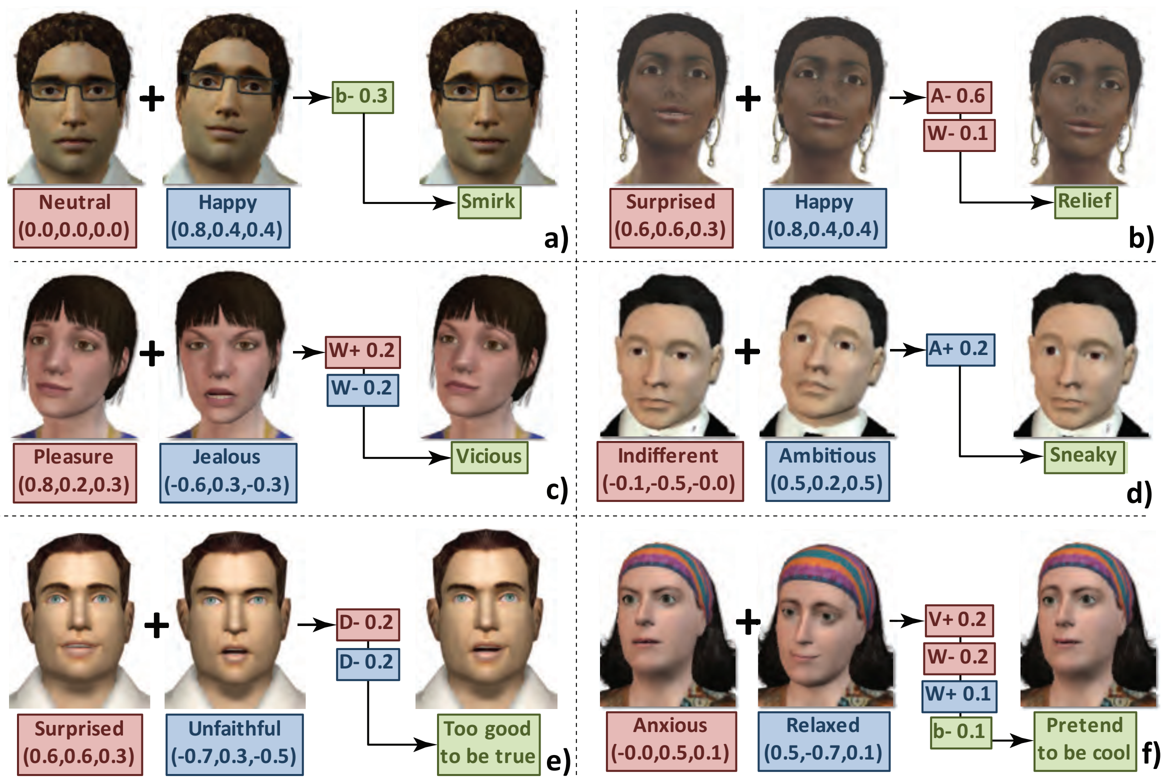

Figure 5: Six ambivalent feelings generated by the proposed framework. The VAD coordinates are described in the boxes with the emotional keywords. Red boxes represent emotion and edit parameters applied to the left face (from the avatar's point of view); Blue and green boxes correspond to the right face and both faces, respectively; $W+$, $W-$, $A+$, $A-$, and $V+$ are face edit operators illustrated in Figure 4(a); $b-$ is the left-bias parameter defined in Equation 4.

versational agent. The other three combinations for this agent and keyword were obtained by swapping the location of the two faces (Figure 6(a)) and by swapping the left and right sides of the asymmetrical face (Figure 6(b)).

In total, eight emotional expressions were shown four times for both the male and the female virtual agents in random order (8 emotions x 4 combinations x 2 agent genders = 64 questions). Among these eight emotions, three (sadness, peaceful, and fear) were basic emotions and the other five (smirk, vicious, pretend to be cool, too good to be true, and suspicious) were complex emotions.

The symmetric and asymmetric face pairs for basic and complex emotions were generated differently as follows. For a basic emotion such as sadness, the asymmetric facial expression is built by biasing the symmetric one. Both possible asymmetric biases are compared to the control condition (symmetric). For a complex feeling described by the keyword vicious (Figure 6), the asymmetric facial expression is built by combining two distinct emotions, namely the one corresponding to the ANEW word *jealousy* on the left side and the one corresponding to the ANEW word *pleasure* on the right side. The symmetric facial expression (Figure 6 left face) is obtained from the average VAD value of the two asymmetric components. Both this asymmetric facial expression and its mirror image are compared to the control condition (symmetric).

The purposes of the evaluation were twofold: (1) in case of basic emotions, validating the VAD-to-face framework and finding out the effect of asymmetric bias factor; and (2) in case of complex emotions, validating the asymmetric face-edit framework and assessing the

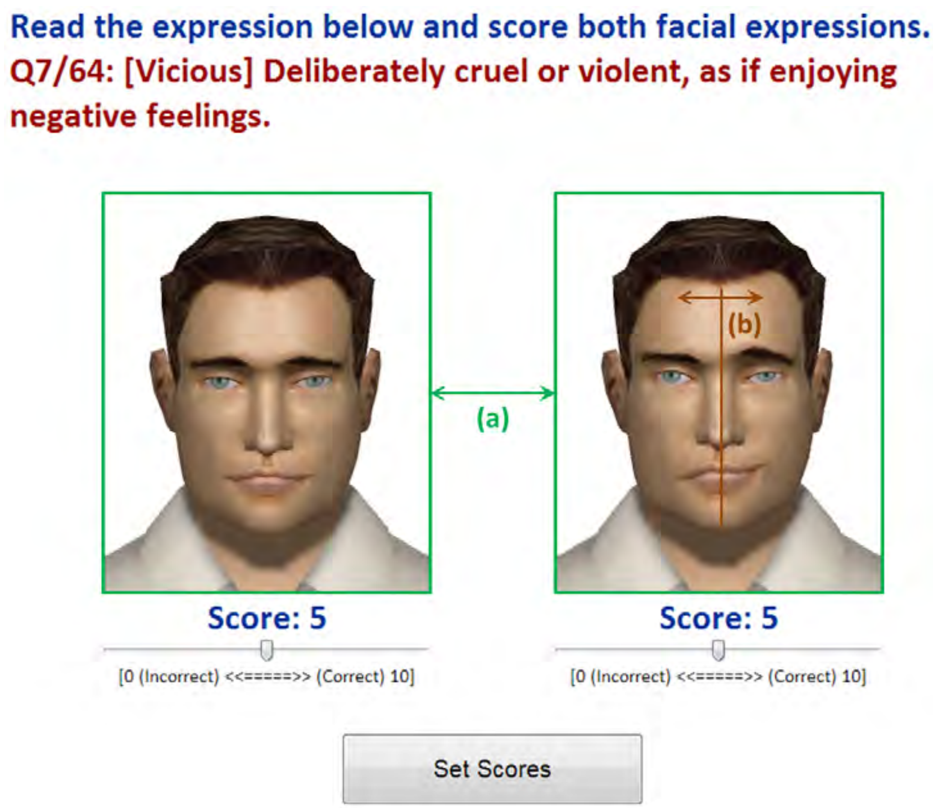

Figure 6: One of the four illustrations of an emotional keyword showing a symmetric and an asymmetric facial expression on the male agent.

expressivity power of this type of asymmetry for conveying ambivalent feelings.

For basic emotions a slight asymmetry that does not alter the nature of the displayed emotion should produce a similar score than the symmetric facial expression. However, there is a risk of introducing an alteration of the displayed emotion through asymmetry, i.e. transforming it into a complex emotion. In such a case the symmetric facial expression should be considered as more faithful to the basic emotion and obtain a higher score than the asymmetric one. For complex emotions we expected a higher score for asymmetric facial expression

5.2 Evaluation results and data analysis

Although not always the case, results tend to confirm the preference for symmetric face for expressing basic emotions, whereas asymmetric faces are preferred only for a subset of the studied complex emotions (Figure 7). The top of each bar is the average score per keyword (for both agents). The error lines indicate the standard deviation of each case.

A paired-samples t-test was conducted to compare scores of facial expressions in symmetric and asymmetric conditions of each emotion. As described in the Table 2, for the male character James, there was a significant difference for sadness, peaceful, fear, smirk, vicious, and suspicious emotions. Likewise, for the female character Kamila, there was a significant difference for sadness, peaceful, smirk, vicious, and suspicious.

The average differences were important for some complex emotions (vicious, smirk, sus-

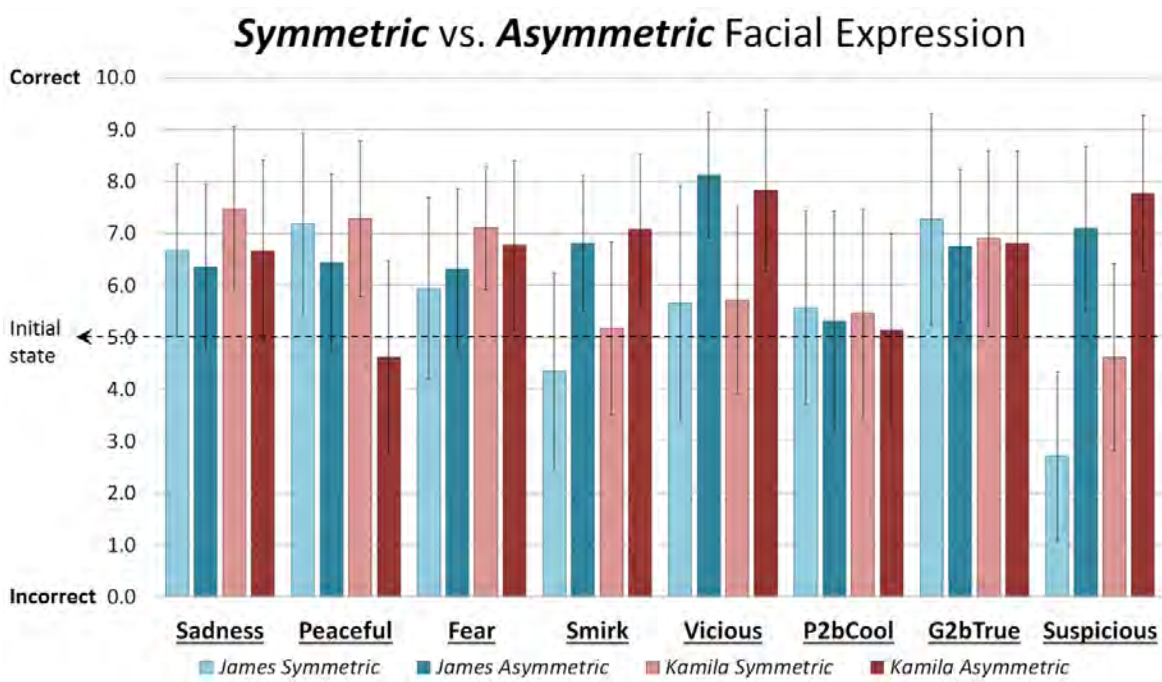

Figure 7: Average scores of the eight emotions' symmetric and asymmetric facial expressions. Each emotion include symmetric-asymmetric pair of two different conversational agents James (male character) and Kamila (female character). The initial score state was set at 5, halfway between incorrect (0) and correct (10) with a step size 0.1.

Emotions		James		Kamila	
		t	*p*	*t*	*p*
Basic	Sadness	2.1	0.044	3.1	0.003
	Peaceful	3.3	0.002	9.8	< 0.001
	Fear	-2.2	0.029	1.5	0.152
Complex	Smirk	-8.3	< 0.001	-5.9	< 0.001
	Vicious	-7.5	< 0.001	-7.3	< 0.001
	P2bCool	0.7	0.509	0.9	0.390
	G2bTrue	1.6	0.115	0.3	0.781
	Suspicious	-15.1	< 0.001	-9.5	< 0.001

Table 2: Results of t-test expressing whether a significant difference exists or not between the symmetric and asymmetric facial expression for an emotion keyword and for a given virtual character (James or Kamila).

picious). This result tends to reflect the finding of the co-existence of conflicting emotions. However the presented asymmetric expressions didn't always convince subjects; it might come partly from the static nature of the image medium or from the chosen combination of conflicting emotions (Pretend to be cool, Too good to be true).

From the basic emotions, we observe that the biasing gives a strong difference (a decrease of believability of the expressed emotion) when the symmetric expression is positive (peaceful). For the other expressions, the biased expression is as good as the symmetric one (fear), or slightly weaker (sadness). Hence biasing basic emotions should be avoided when one wants to truly express the original basic emotion otherwise there is a risk for introducing hints of a simultaneous and conflicting negative emotion.

Figure 8: Left: Emotion variation to a pre-existing "excited" animation. We applied different face edit parameters onto the original (*"neutral"* in terms of delta intensity) animation; Right: complex facial expression simulated in a crowd scene.

6 Applications and Experiment

As we demonstrates in a video provided in `http://youtu.be/ycUoZ4jAU_E` our approach can easily be plugged into a real-time system dedicated to the control of avatars or autonomous virtual humans. As depicted in Figure 8–Left, the role of the elements of the FPA vector **y** are used as offset intensities of animated postures. In this way, we are not only able to modify the emotional feeling of an existing body animation, but also able to express complex feeling of a virtual character at run time. Moreover, thanks to a simple VAD interface and the emotional keywords, the proposed framework can easily be embedded into a game or VR application with text sentiment analysis [46].

As we focus on a real-time environment such as games or VR applications supporting the interaction with conversational agents, we measured the display rate of a scene with 200 characters. As depicted in Figure 8–Right, the users' emotional VAD input are continuously updated at run time. With an NVidia GTX 460 1–GB hardware, we were able to simulate and edit facial expression at > 60 fps.

7 Conclusion and Discussion

In this paper, we presented a novel approach enlarging the spectrum of facial expressions that allows the synthesis of *emotional asymmetric facial expression* from the input of a 3D emotional model. In order to achieve this, we examined a number of literature surveys on social and neuro psychology for: (1) choosing a suitable 3D emotional model; (2) identifying a model of the animation of each facial part; and (3) exploiting the effect of asymmetry for emotion expression.

We retained *eighteen emotion samples* evenly distributed in the **VAD** model space and grouped the facial AUs into *twelve FPAs* representing antagonist muscle groups. Each FPA's dependency on emotional dimensions has been analyzed independently from its eighteen intensities. From the analysis, each FPA normalized activity has been modeled as a linear function and exploited for facial expression. In some cases an additional linear inequality constraint has been specified. We estimate that the proposed approach will not only assist the game players who want to transfer their emotion into their avatar, but also help the designers of embodied conversational agents to convey complex emotions through the added nuances made possible with the proposed emotion model.

Comparison with earlier references in facial expression [27, 30, 31] highlights the lack of considering the left/right asymmetry in the emotional expressions for real-time conversational agents. The model we propose induces a very little overhead in terms of computing cost compared to the use of the 3D emotion model for a real-time application with multiple avatars and autonomous agents. Besides, a user study was conducted to evaluate the proposed asymmetric facial expressions. The results validated not only the efficiency of our VAD-to-face framework, but also the effect of the simulated ambivalent feelings. Although we notice some consistency with respect to the evaluations for male and female virtual characters, we also noticed a large difference for the evaluation of the asymmetric peaceful emotion. More studies are necessary to fully understand the influence of factors related to the character appearance.

There are still limitations and further improvements to do on asymmetric facial expression control. We tried to mix two different emotional representations (categorical and dimensional approach). Further evaluation is needed to determine whether this is valid from a psychological point of view. In terms of facial expression, the proposed method did not consider an appropriate synthesis for the lip movement of a highly aroused (mouse-opened expressions) talking character. Moreover, we took direction to simplify the complex mechanism of emotional expression as a linear model to provide an efficient way of controlling facial expressions. We may explore nonlinear model to better reflect the interactions between simultaneous or successive conflicting emotions.

In the future, we plan to: (1) increase the number of sample emotions and observe FPA intensities for finer analysis; (2) exploit automated simulation of asymmetric facial expressions; and (3) perform more profound user study validation from the remaining data set.

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Appendix A: Keywords and short definitions provided for the eight facial expressions in the experiment

Most of our subjects were able to speak English fluently. In case they had doubts about a word, they could access a web dictionary. Around 10% of the subjects used this possibility.

- [**Sadness**] Emotions experienced when not in a state of well-being.

- [**Peaceful**] Free from disturbance.
- [**Fear**] An unpleasant emotion caused by the belief that someone or something is dangerous, likely to cause pain, or a threat.
- [**Smirk**] A forced smile expressing self-satisfaction or disdain rather than pleasure.
- [**Vicious**] Deliberately cruel or violent, as if enjoying negative feelings.
- [**Pretend to be cool or okay**] Anxious deep inside but try to show off his/her calm.
- [**Too good to be true**] A positive surprise but hard to believe.
- [**Suspicious**] Having or showing a cautious distrust of someone or something.

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