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A Fuzzy Inference System for Synergy Estimation of Simultaneous Emotion Dynamics in Agents

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Abstract— This paper presents that emotions manifest the information processing mechanism of human mind that infers the synergic effect of simultaneous emotions to achieve focused communication and decision making. This proposed work considers integration mechanism of complex emotional dynamics for agents to communicate reason and decide in conflicting situations like humans. The proposed inference system is used to estimate the blended effect of simultaneously activated emotions in agents using fuzzy logic as it is an unsurpassed choice to deal with uncertain information and classification of non-deterministic events.

Index Terms— Fuzzy inference, Simultaneous emotion dynamics, Synergy estimation, blended emotions, PAD, Wheel of emotions, social cohorts.

1 Introduction

Emotional intelligence corresponds to the awareness and usage of emotions to make smart decisions in different situations. The segregation between an intelligent and non-intelligent mind is based on awareness that is an outcome of inference and regarding psychological viewpoint emotions are well thought out as inferential shortcuts [1].

An emotion is not an isolated feature of human mind; it is to be considered as a variable in nature. It grows or decays temporally due to the change in the environmental information absorbed by mind. Since this information is not always discrete and certain thus it may cause simultaneous emotion activation in mind. The dynamic mechanism of human mind can have a variety of emotional states simultaneously and can convey their shared or diverse effect [2]. To infer these effects it is required to blend these simultaneously active emotions. There could be one of the four varieties i.e. quick succession, superposition, masking and suppression that are plausible to the phenomenon of blended emotions [3].

To measure the blended effect of simultaneous emotions it is important to capture their properties. Each emotion is unique and can be distinguished in terms of their dynamic properties i.e. intensity, valence and dominance.

Therefore, fear, anger, sadness, and disgust are negative primary emotions while happiness and surprise are positive ones. Scherer modeled emotions as a continuous progression in three-dimensional space that consists of Pleasure/Valence (P), representing the overall valence information, Arousal (A), accounting for the degree of activeness of an emotion, and Dominance/ Power (D), describing the experienced “control” over the emotion itself or the situational context [4].

The association between primary emotions caters the possibility of complex or secondary emotions. The dynamics of secondary emotions emerged from the association of primary emotions and experience [5], which are possible to be mapped along the PAD coordinates for example, smugness might be considered a blend of the two elemental emotions: happiness, and contempt [6].

The fuzzy theory has been used recently by different researchers in emotion modeling for artificial agents. Arief has discussed visualization of emotional facial expression using Naive Bayes and Fuzzy logic [7]. Elisabetta presented an embodied conversational agent to show complex emotional facial expression[8].

Emotions are an important feature of non-verbal HCI. Ayesha has presented her research work in this area using rough fuzzy sets to resolve the complexity [9]. A fuzzy emotion model VISBER is presented by Natascha that is applicable for the real time facial emotion recognition in agents [10]. One of the advantages of Fuzzy logic includes that it captures the changes smoothly from the environment and generate even output instead of crisp values [11].

This research paper proposes an inference system using the fuzzy logic to process the dynamics of simultaneously active emotions and estimates their mixed effects

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or transitional succession. The output of the system could be used in artificial agency for the decision making etc.

The emotionless agents are simply considered as machines and not trustworthy for humans [12]. Therefore, in accordance with human psychology, the role of agents as our future social cohorts suggests that these are required to be equipped with integrated mechanism of complex emotional dynamics to communicate reason and decide in conflicting situations like humans.

This paper is structured as follows: Section 2 elaborates the approach adopted for emotion blends. Section 3 explains the fuzzy logic scheme. Section 4 argues about the fuzzy rule base scheme to infer the blended effect of simultaneous emotions. Section 5 provides the comparison of Matlab simulated and calculated results. Section 6 concludes this work and suggests some possible future directions.

2 APROACH FOR EMOTION BLEND IN PSYCHOLOGY

According to evolutionary and developmental psychology it is known that a human mind may not experience just one basic emotion at a time rather it feels simultaneous or complex emotions while sensing the environmental events. The term "basic" has been used to describe elements that combine to form more complex or compound emotions for example, smugness might be considered a blend of the two elemental emotions, happiness, and contempt.[6] Considering psycho-evolutionary theory of emotions articulated by Plutchik there are eight primary emotions in humans i.e. anger, anticipation, joy, trust, fear, surprise, sadness and disgust,. Fig 1 presents the Plutchik's complete scheme of human emotions having eight basic emotions as "Wheel of Emotions". [13]

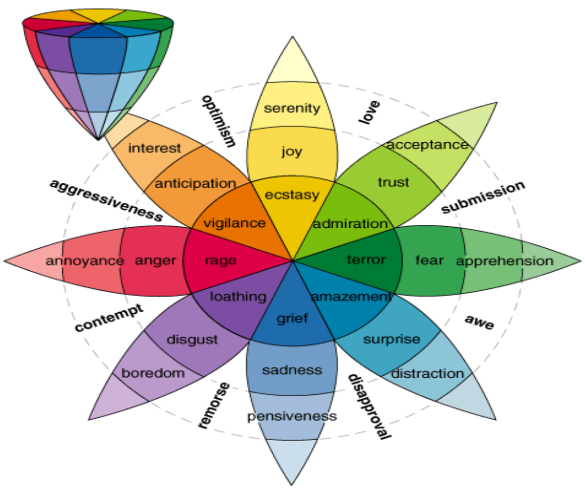

Figure 1: Wheel of Emotions

The blend of emotions at three different levels could be achieved through primary, secondary and tertiary dyads on the Wheel. [14] Each primary dyad shows the combinations of neighboring pairs of emotion on the wheel e.g. trust and fear leads to submission. The primary blend of eight basic emotions is presented in table I.

Table I: Primary Level Blended Emotions

	Primary Blend	Emotion Generated from Primary Blend
1	Anger + Anticipation	Aggressiveness
2	Anticipation + Joy	Optimism
3	Joy + Trust	Love
4	Trust + Fear	Submission
5	Fear + Surprise	Alarm / Awe
6	Surprise + Sadness	Disappointment
7	Sadness + Disgust	Remorse
8	Disgust + Anger	Contempt

Likewise secondary dyad combines two emotions with the gap of one emotion on the wheel and produces the complex emotions from primary ones as presented in table II.

Table II: Secondary Level Blended Emotions

	Secondary Blend	Emotion Generated from Secondary Blend
1	Anger + Joy	Pride
2	Anticipation + Trust	Hope
3	Joy + Fear	Guilt
4	Trust + Surprise	Curiosity
5	Fear + Sadness	Despair
6	Surprise + Disgust	Unbelief
7	Sadness + Anger	Envy
8	Disgust + Anticipation	Cynicism

The tertiary dyad combines emotions with the gap of two emotions on the Wheel, presented in table III.

Table III: Tertiary Level Blended Emotions

	Tertiary Blend	Emotion Generated from Tertiary Blend
1	Anger + Trust	Dominance
2	Anticipation + Fear	Anxiety
3	Joy + Surprise	Delight
4	Trust + Sadness	Sentimentality
5	Fear + Disgust	Shame
6	Surprise + Anger	Outrage
7	Sadness + Anticipation	Pessimism
8	Disgust + Joy	Morbidness

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3 Fuzzy Logic scheme

Fuzzy logic is based on Boolean logic and works with partially true or false values. The fuzzy systems deals with the truth values in Fuzzy logic or membership values in fuzzy sets that are indicated by a value on the range [0.0, 1.0], with 0.0 representing absolute Falseness and 1.0 representing absolute Truth.[15]

4 Fuzzy Inference System for synergy estimation of simultaneous emotions

From the literature it is clear that an emotion's attributes are usually not represented by crisp values rather these have fuzzy boundaries. Therefore, we propose a fuzzy inference system with the classification of primary emotional states that blends their intensities together and constitute the secondary emotion. The design of proposed system is represented in Fig. 2.

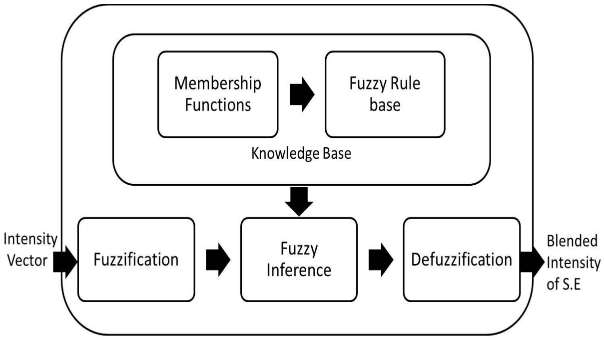

Figure 2: System Design

4.1 Fuzzification of Emotion Intensities

The fuzzification process is used to transform the crisp values of emotion intensities into degrees of membership for linguistic terms of fuzzy sets. We are considering the primary emotion identified by Plutchik represented in table IV as input to the proposed fuzzy inference system.

In the proposed scheme, we are assuming that the intensity of an emotion can be mapped to the interval [0, 1]. The following linguistic variables have been chosen for fuzzification of input intensities and divided into three types based on probability values of intensities of all eight primary emotions.

a. Low: 0.0 – 0.5
b. Medium:0.3 – 0.7
c. High: 0.5 – 1.0

These linguistic variables are used to decide the degree of membership in fuzzification set. The plot of membership functions for one of the fuzzy input variables is represented in Fig. 3.

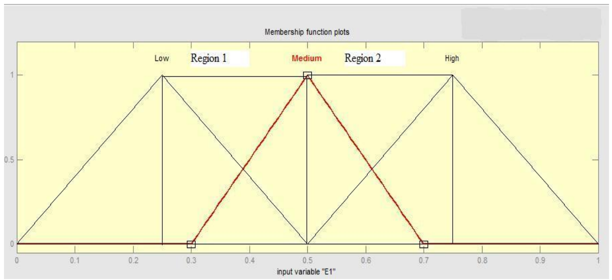

Figure 3: Membership Function Plot for Input Variable E1

The three membership functions, f1 [1] for Low, f1 [2] for Medium, and f1 [3] for High are used to show the various ranges of input fuzzy variable "E1" in a plot consisting of two regions as shown in Fig. 3. The number of membership functions and range values for each of the fuzzy input variables are taken same as E1,……..,E8 are representing the intensity of primary emotions.

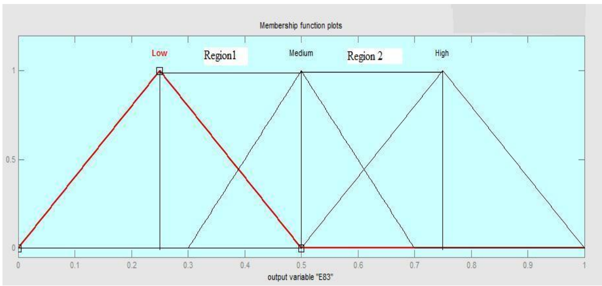

Figure 4: Membership Function Plot for Output Variable E83

Table IV: Fuzzy Input and Output Variables

Input Variables		Output Variables							
E1	Anger	E12	Aggressiveness	E13	Pride	E14	Dominance
E2	Anticipation	E23	Optimism	E24	Hope	E25	Anxiety
E3	Joy	E34	Love	E35	Guilt	E36	Delight
E4	Trust	E45	Submission	E46	Curiosity	E47	Sentimentality
E5	Fear	E56	Alarm / Awe	E57	Despair	E58	Shame
E6	Surprise	E67	Disappointment	E68	Unbelief	E61	Outrage
E7	Sadness	E78	Remorse	E71	Envy	E72	Pessimism
E8	Disgust	E81	Contempt	E82	Cynicism	E83	Morbidness

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For generalization, the range values of each output membership function plot are taken same. Therefore, the shape of the plot for each output variable, used in design is the same and shown in Fig. 4.The proposed system consists of eight input variables and their values may lie in any one of the two regions as listed in Table V.

The linguistic values are the plotting values of the fuzzy input variables with the membership functions employed in different regions. As eight variables are used, therefore sixteen linguistic values are represented in Fig. 5.

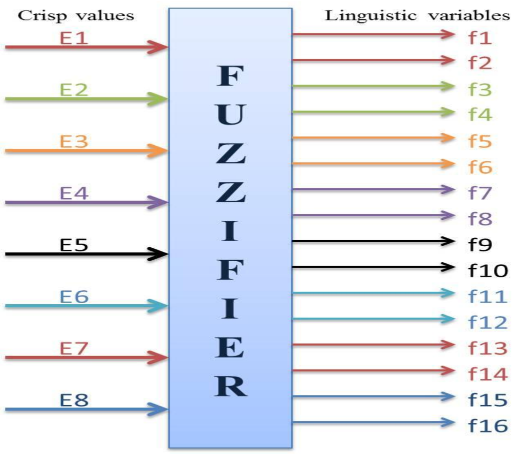

Figure 5: Block Diagram of Fuzzifier

The mapping of input fuzzy variables with the membership functions in two regions is listed in Table V.

Table V: Linguistic Values of Fuzzifier outputs in Two Regions

Input Variables	Linguistic Fuzzifier Outputs	Region 1	Region 2
E1	f_1	$f_1[1]$	$f_1[2]$
	f_2	$f_1[2]$	$f_1[3]$
E2	f_3	$f_2[1]$	$f_2[2]$
	f_4	$f_2[2]$	$f_2[3]$
E3	f_5	$f_3[1]$	$f_3[2]$
	f_6	$f_3[2]$	$f_3[3]$
E4	f_7	$f_4[1]$	$f_4[2]$
	f_8	$f_4[2]$	$f_4[3]$
E5	f_9	$f_5[1]$	$f_5[2]$
	f_{10}	$f_5[2]$	$f_5[3]$
E6	f_{11}	$f_6[1]$	$f_6[2]$
	f_{12}	$f_6[2]$	$f_6[3]$
E7	f_{13}	$f_7[1]$	$f_7[2]$
	f_{14}	$f_7[2]$	$f_7[3]$
E8	f_{15}	$f_8[1]$	$f_8[2]$
	f_{16}	$f_8[2]$	$f_8[3]$

Both of the regions are divided in two halves and each region consists of two membership functions at a time.

4.2 Fuzzy Inference Engine

After determining the degree of membership in the fuzzification process the subsequent step is to make linguistic rules to decide that which secondary emotion will be generated in response to the inputs provided to the system.

In inference process the value of intensity given to each emotion synergies and estimates the intensity of the secondary emotion produced with the help of inference rules. On the basis of number of inputs and linguistic variables, the number of fuzzy rules is determined.

In reference to the "Wheel of emotions" it is observed that secondary emotions cannot be highly intense rather these could be produced with medium intensity by blending two highly intense primary emotions. And if primary emotions are blended with medium intensity then the secondary emotion produced is comparatively less intense.

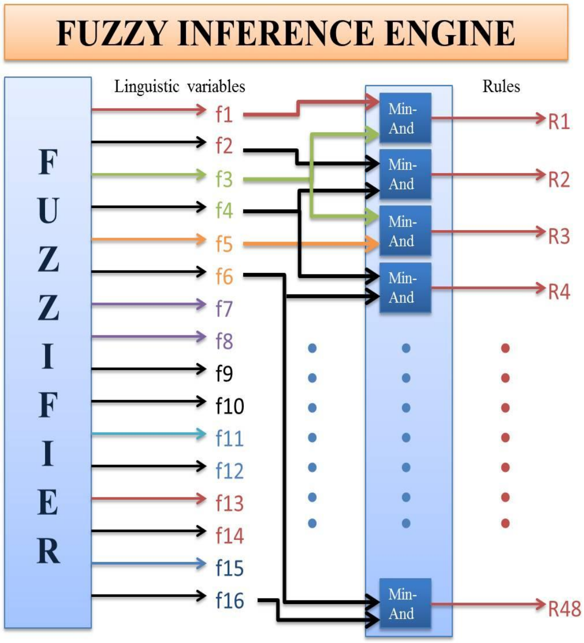

Figure 6: Block Diagram of Fuzzy Inference Process

In our proposed system there are 8 input variables i.e. E1, E2, ………, E8 and 3 linguistic variables therefore by using AND connector it is possible to have 6561 rules, but in reference to the combinations of emotions presented in table I, II, III only 24 combinations i.e. E12 . . . . E83 presented in table IV have been chosen to design the inference rules. These combinations cater the blend of only two primary emotions at three different levels.

The fuzzified intensity of emotions E1 …… E8 is provided as input to each rule and the intensity of one of the relevant secondary emotion provided in table 5 is produced.

For example the inference rules could be

- If E1 is Medium AND E2 is Medium THEN E12 is Low
- If E6 is High AND E7 is High THEN E67 is Medium

There are 48 rules that has been used for 24 combinations because of the usage of AND connector that caters the minimum value of variables.

The inference engine contains 48 AND gates, it accepts sixteen inputs from the fuzzifier and produce R values by applying min-max composition. Each rule takes two input values, synergies these and inferences the final output using min-AND operation. Following is the calculation of R values from some of the selected rules out of 48 rules with the values E1 = 0.65, E2 = 0.7, E8 = 0.7, E3 = 0.6 in region2.

$$R_1 = f_1 \wedge f_3 = f_1[2] \wedge f_2[3] = 0.6 \wedge 0.8 = 0.6$$
$$R_2 = f_2 \wedge f_4 = f_1[2] \wedge f_2[3] = 0.4 \wedge 0.2 = 0.2$$

$$R_{47} = f_5 \wedge f_{15} = f_3[2] \wedge f_8[2] = 0.4 \wedge 0.8 = 0.4$$
$$R_{48} = f_6 \wedge f_{16} = f_3[3] \wedge f_8[3] = 0.6 \wedge 0.2 = 0.2$$

By applying the Mamdani-min process we get the minimum value from the membership function values using AND operation. The sign ^ between the membership function values represents the Min-ANDing process.

4.3 Rule Selector

The rule base works with eight crisp input values, dividing the universe of discourse into two regions, each containing two fuzzy variables, fires the rules, and gives the output singleton values corresponding to each output variable as presented in Fig. 7.

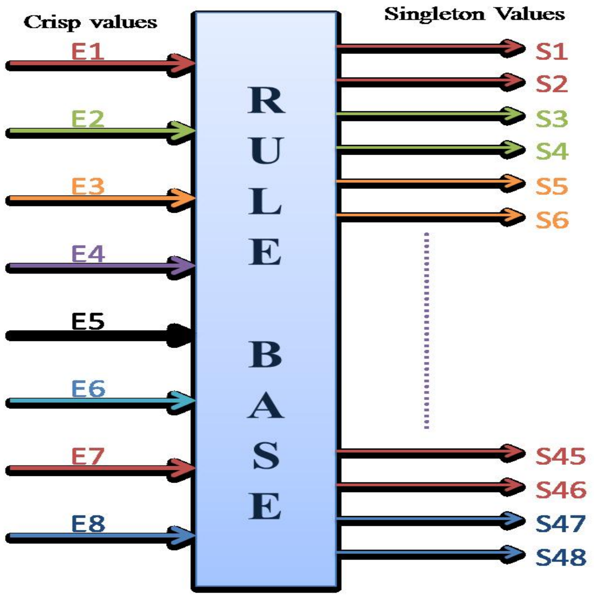

Figure 7: Block Diagram of Rule Base

The rule selector for the proposed system receives eight crisp values from the input variables. It provides singleton values of output functions according to the forty eight rules. According to the division of the regions for each output variables there are forty eight singleton values S1, S2, S3, ……., S48.

4.4 Defuzzification

After the estimation of inputs the defuzzification process generates the crisp values for output variables. In the proposed system there are 96 inputs that are provided to each of 48 defuzzifiers, forty Eight values of R1,R2,……..,R48 from the outputs of inference engine and forty eight singleton values S1, S2, ………,S48 from the rule selector as shown in Fig.7. Each defuzzifier estimates the crisp value output according to the center of average (C.O.A) method using the mathematical expression, Σ Si * Ri / Σ Ri, where i = 1 to 48.

S1 = 0.25
S2 = 0.5
S3 = 0.75

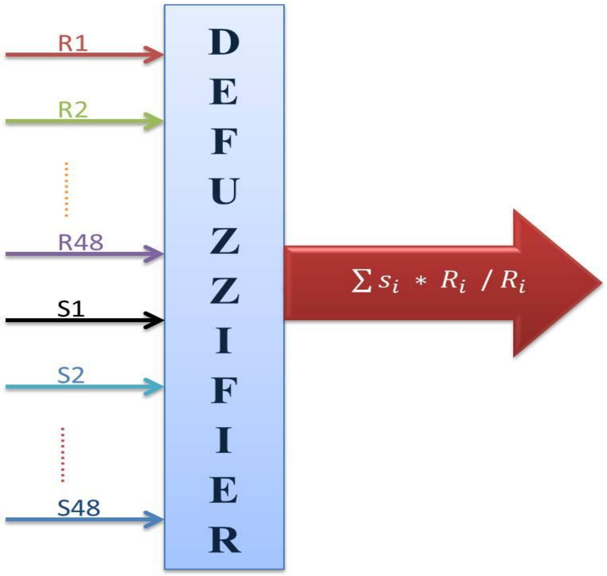

Figure 8: Block Diagram of Defuzzifier

The design formation of defuzzifier is represented in Fig. 9. Each defuzzifier consists of 48 multipliers for $S_i * R_i$ one adder to sum up, one adder for $\Sigma S_i * R_i$ and one divider for $\Sigma S_i * R_i / \Sigma R_i$ to provide the final estimated output crisp value.

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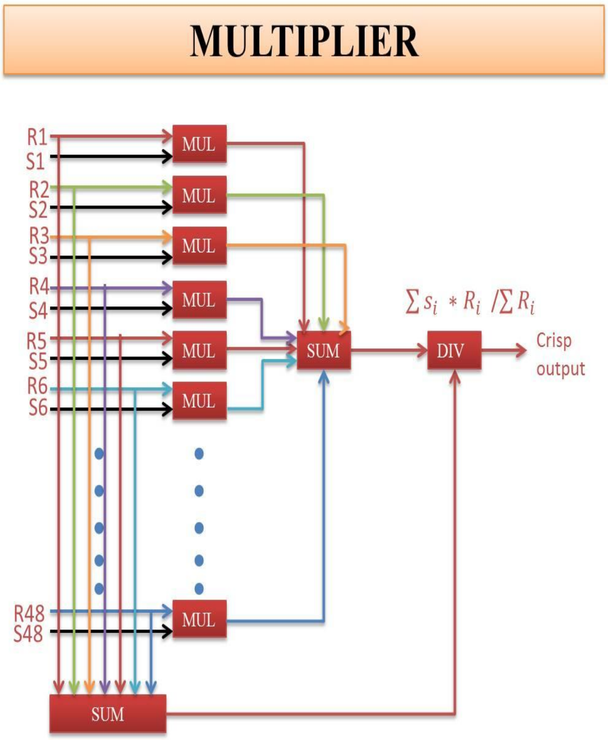

Figure 9: Defuzzifier Design

5. Comparison of Simulated and Calculated Results

The results calculated from the fuzzy inference engine

$$\sum R_i = R_1 + R_2 + \ldots + R_{48}$$

Two output variables E12 and E83 have been chosen for the comparisons. The crisp values for E12 and E83 are determined using mathematical expression Σ Si *Ri / Σ Ri from the values of the input variables that are provided in the fuzzy inference process.

These calculated results according to the system design are compared with the results according to the MATLAB simulation in Table VI and found correct. Fig. 10 represents the input variables & Fig. 11 represents the output variables from the Rule Viewer in MATLAB.

Table VI: Comparison of Simulated and Calculated Results

Results	E12	E83
MATLAB Simulation	0.5	0.5
Calculated Values	0.56	0.58

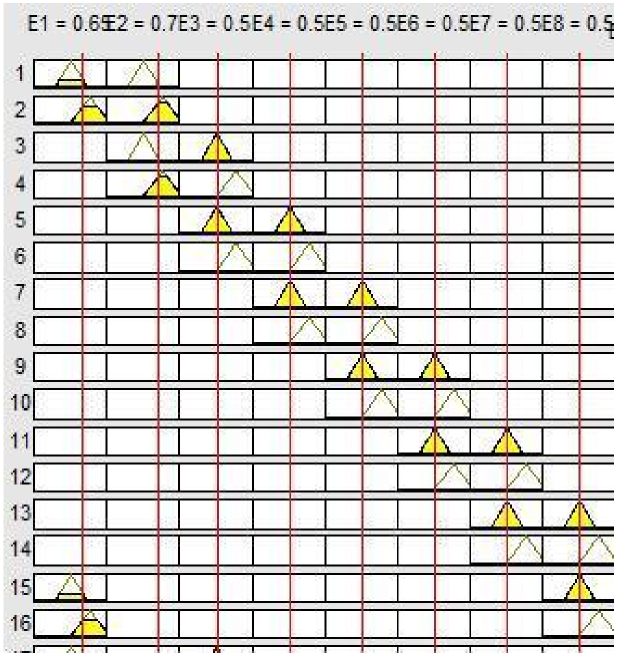

Figure 10: MATLAB Rule Viewer for Input Variables

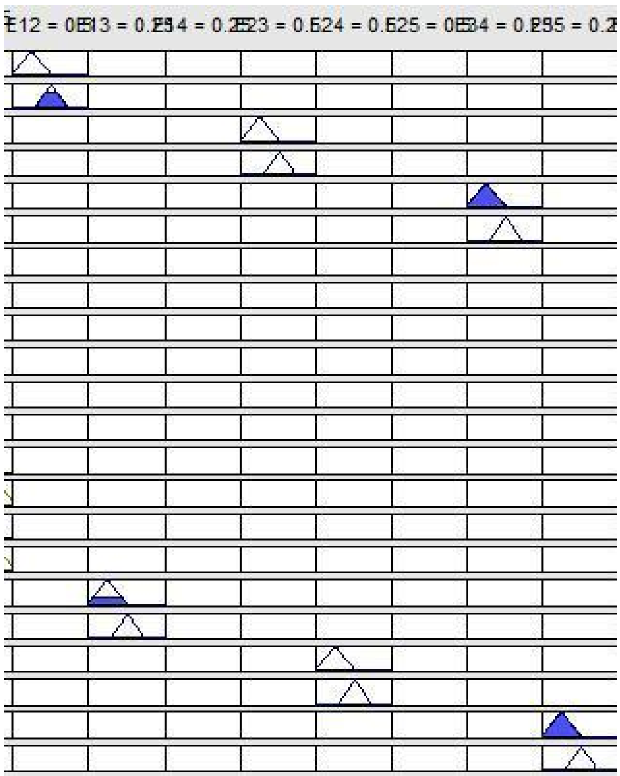

Figure 11: MATLAB Rule Viewer for Output Variables

5. Simulated Graphs

Following is one of the simulated graphs for output E12 for the proposed inference system according to the values of E1 and E2 provided for inference process mentioned above.

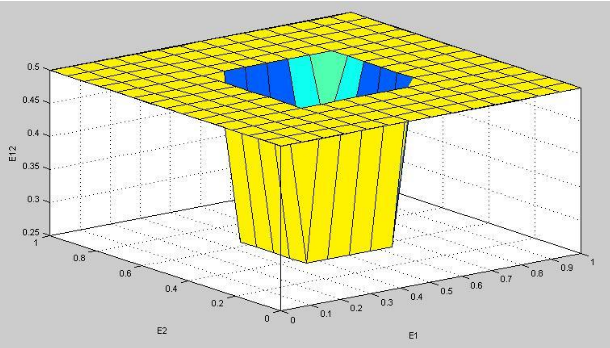

Figure 12: Plot between E1 and E2

6. Conclusion

There are several emotion inference systems presented by researchers but these do not infer and verify the coexistence of numerous emotions and their blends according to Plutchik theory of emotional blend. However our proposed fuzzy inference system estimates the synergy of two emotions that activates simultaneously quite efficiently.

The comparisons between calculated and simulated values afford it a role in estimation authenticity for blended emotions.

The proposed system design and simulation work could also lead to the new avenues in the field of modeling complex emotion dynamics for agency.

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