Toward a Fuzzy Approach for Emotion Generation Dynamics Based on OCC Emotion Model

Ahmad Soleimani and Ziad Kobti

***Abstract*—This paper investigates using a fuzzy appraisal approach to model the dynamics for the emotion generation process of individuals. The proposed computational model uses guidelines from OCC emotion theory to formulate a system of fuzzy inferential rules that is capable of predicting the elicitation of different emotions as well as tracking the changes in the emotional response levels as a result of an occurred event, an action of self or other individuals, or a reaction to an emotion triggering object. In the proposed model, several appraisal variables such as event's desirability and expectedness, action's praise-worthiness and object's degree of emotional appealing were considered and thoroughly analyzed using different techniques. The output of the system is the set of anticipated elicited emotions along with their intensities. Results from experiments showed that the proposed OCC-based computational model for emotions is a an effective and easy to implement framework that poses an acceptable approximation for the naturally sophisticated dynamics for elicitation and variation of emotional constructs in humans.**

***Index Terms*—emotion elicitation, fuzzy computational models of emotion, emotional intelligence, OCC emotion theory**

I. Introduction

Emotions are inseparable building blocks of human personalities. They are deeply rooted in most of our desires and tendencies, and influence to a large extent our intentions and shape our actions. Conversely to the tenet adopted by most past philosophers, such as Descartes and Paolo who looked at the evil side of emotions and believed in an eternal conflict between intellect and emotions, contemporary research findings (e.g., [1], [2], [3], [4]) emphasize the important role of emotions and their direct involvement in the process of decision making. Furthermore, emotions help us to develop an effective coping system that is inevitable to adapt our behaviors to the different situations that arise from events and continuous changes in the the environment. According to some studies in the field of neuroscience, those individuals who were unable to feel and experience emotions due to a possible brain damage, have a clear impairment in making rational decisions [5]. These findings clearly rule out the tenet that emotions adversely affect the wisdom of individuals and prevent them from being rational. In short, it can be stated that an emotional component is existent in most cognitive activities [6].

Considering the fact that human behavior including emotional behavior is a complex and multifaceted construct [7], [8], it is necessary to look at the problem of modeling emotional behavior from different perspectives and consider as much as possible all its psychological, physiological, neurological and cognitive states and aspects in order to efficiently model such a complex interplay between the mind, brain, and the body of humans as well as the interaction between them and the environment.

Beside the traditional theories of emotions by philosophers and psychologists such as Aristotle, Freud and Darwin that can be tracked in the early stages of human civilization, studying emotions has recently attracted a great deal of research works across a variety of domains from applied sciences and engineering to commerce and business and arriving at public well being and healthcare. A great deal of affect-enabled applications and commercial products started to emerge in the market as a result of the recent "affect-awareness" research campaign that showed the high influence of emotions in almost all cognitive activities, e.g., decision making, within a broad spectrum of life affairs from entertainment and gaming to healthcare [9].

Within the field of information technology and computer science, an increasing number of rich research works in the area of emotions can be seen nowadays. According to Gratch et al. [10], computational models of emotions proposed by computer scientists are beneficial in three directions. First, they provide an effective framework for theorizing, testing and refining of emotion hypotheses often proposed within the field of psychology; second, they can promote the general research work in artificial intelligence (AI) by enriching it with new techniques and approaches derived from emotion dynamics modeling; and third, they provide a very effective mean for improving the facilities and methodologies used in human-computer interaction (HCI) [10].

Affective Computing (AC) can be considered the fruitful outcome of the vast endeavor of computer scientists in the field of studying emotions. Despite AC's relatively young age, it has managed to turn into a robust well-established research area with its own professional meetings and scholarly journals. According to its founder, R. Picard [11], AC is "computing that relates to, arises from, or deliberately influences emotions" [11].

An AC system strives to fill up the gap between highly emotional people and emotional challenged machines [12]. Hence, AC is about building computer artifacts that are more emotionally intelligent, i.e., to recognize (e.g., from person's facial expressions or physiological signals emitted from wearable sensors), represent (e.g., by building computational models) and respond to (e.g., in service robots or avatars) affective states.

In the process of building a computational model for emotions, different approaches such as appraisal (e.g., [13], [14], [8]), dimensional (e.g., [15], [16]), adaptation and coping (e.g., [17],) can be used. The proposed model is an appraisal based model that is inspired by the emotion theory

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suggested by Ortony, Clore and Collins known as OCC [13]. The essense of the proposed model, is to use fuzzy appraisal systems that evaluates the elicitation mechanisms for all the three sets of OCC emotions and by using guidelines from the background theory, it would be possible to anticipate the emotional behavior of the agent in different circumstances.

Fuzzy logic principles were applied by ElNasr *et al.* [18] to build their fuzzy computational model of emotion, FLAME. FLAME uses the concept of fuzzy sets in order to represent and quantify different emotions. At the core of this model, a set of learning and coping algorithms exist to be used for the purpose of adaptation performed by the agent in response to the changes of some aspects of the environment. Some of these aspects are event expectations, patterns of user actions and rewards. In [19], a fuzzy system was used to map some physiological signals into a point on a core affective space of arousal and valence. This point then is mapped again into a set of five emotions using a second fuzzy system.

With respect to the possible applications for the proposed model, two trajectories are possible. The first direction would be to track and come up with patterns for the affective responses in the subject individual as a result of the occurrence of a series of events or reactions to self or other agent's actions or possible exposures to emotion triggering objects. Such affective patterns pose the input to emotionally intelligent systems, e.g., interfaces used in HCI, robotics and computer gaming at which recognizing the affective state of human users is a crucial piece of information that is required in order to establish an efficient affective rapport between artificial agents and their human users [20], [21]. The other direction is the potential usage of such systems in the fields of neuro-therapeutics and social behavioral therapies through applying deliberate interventions to control and regulate hyper negative emotional responses as well as psychological complications [22], [23].

In brief, this article proposes a fuzzy computational model for anticipating the type and intensity of emotional states experienced by a subject individual as a result of the occurrence of an emotion triggering event; an action of self or other agent(s); or facing an emotion triggering object. Furthermore, it investigates the potentials for applying some regulatory mechanisms for emotion interventions at which external stimuli can be used as a mean for controlling negative hyper emotions. It would appear that this objective is of high importance considering its promising utilization in psychotherapy where these interventions can be some auxiliary elements such as audio or video clips similar to those used by Chakraborty et al.[24].

The rest of this article is organized as follows: in the next section, a breif review of some of the recent computational models of emotions that were built based on an appraisal approach is presented. Section III reflects the architecture of the proposed model and it dissects the appraisal processes in details. In section IV, a general formulation of the problem is presented along with the associated emotion computation modules and algorithms. Next, a detailed description of some of the simulation experiments that were conducted to verify the functionality and evaluate the performance of the system is given, followed by discussion and conclusion sections.

II. Computational models of emotions

An important challenge for psychological theories of emotion is their qualitative nature. A qualitative model of emotion does not address some key characteristics that are essential for a practical implementation in affect-enabled applications and affective agents. Some of these important aspects are the intensity level of emotional experiences, the duration of emotional experiences, the interplay between an elicited emotion and the behavior of the agent as well as the temporal dynamics for such influence, possible decay patterns for triggered emotions, etc. Such quantitative parameters are an inevitable part for a formal computational model of emotions.

As mentioned earlier in this article, computational models of emotions have managed to find their own way to many interdisciplinary applications. With respect to humanistic sciences such as psychology, biology and neuroscience, computational models of emotions have manifested themselves through models and processes that were used to test and improve the formalization of the hypothesis and background theories [25]. In the field of robotics and in the computer gaming industry, an increasingly number of affect-enabled applications built based on these computational models can be seen. These computational models are essential for improving the performance of Human-Computer Interaction (HCI) applications in order to develop intelligent virtual agents (e.g., avatars or service robots) that exhibit a maximal degree of human-like behavior [26]. A large number of these computational models were build based on an appraisal approach to emotions constructs. At this point, a brief description of the appraisal theory is presented.

A. Appraisal theory

Appraisal theory, non-arguably is the most widely used approach in the recent computational models of emotion [27]. Based on this theory, emotions are outcomes of previously evaluated situations attended by the subject individual and have the connection between emotions and cognition is highly emphasized. Therefore, emotional responses are generated based on an appraisal or assessment process performed continuously by the individual on situations and events that take place in the environment and are perceived relevant by the individual.

According to the appraisal theory which was formally proposed by Smith and Lazarus [28], in order to evaluate the different situations that arise in the relationship between an individual and its environment, a set of appraisal variables or dimensions needs to be considered. Scherer [29] and Frijda [30] argue that these appraisal variables should be able to address the affective-relevant aspects of the situation, such as those listed below, in order to be effectively used in studying the emotion elicitation process and the dynamics of changes in the emotional behavior of individuals as well as building computational models.

Appraisal variables:

- Relevance of the situation and its implication on individual's own goals, (i.e., beneficial or harmful)
- Self or others responsibility of the situation
- Degree of the situation expectancy by the individual
- Coping and adjustments potentials for the situation
- Changeability or reversibility of the situation

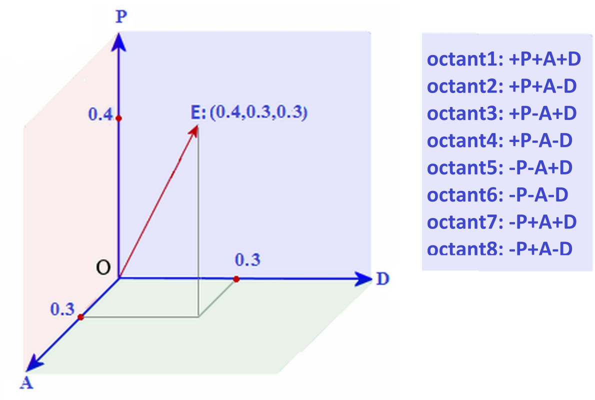

Figure 1. PAD vector and mood octant [32]

B. *Examples of appraisal computational models*

a) EMA: Emotion and Adaptation (EMA) [10] is a computational model of emotions that is built based on the emotion theory proposed by Lazarus[31]. In EMA, the agent-environment relationships are represented using causal rules that interpret the emotion elicitation dynamics as well as different adaptation and coping strategies. In this model, beliefs, desires and intentions of the agent beside past events, the current state, and possible future world states are all important role players in the emotional processes. In EMA, two types of causal interpretation exist. One type is a cognitive process that is slow and deliberative whereas the other is fast and reactive. Furthermore, it includes a highly detailed system for emotion adaptation and coping strategies which enables the emotionally intelligent agent to regulate its hyper negative emotions. In EMA, four categories of such regulation strategies were considered according to have either attention, belief, desire or intention of the agent to be the targeted of the regulation process [17].

b) ALMA : A Layered Model of Affect (ALMA) [15] is an OCC [13] based model that combines three affective components of emotion as short-term, mood as medium-term and personality as long-term factor to express the affective state of individuals. ALMA adopts the approach of Mehrabian [33] in which he describes the mood with the three traits of pleasure (P), arousal (A) and dominance (D). Hence, the mood state of the agent is described based on the classification of each of the three mood dimensions: +P and –P to reflect pleasant and unpleasant, +A and –A for aroused and unaroused, and +D and –D for dominant and submissive states. These three discrete components build the so called PAD space where each point represents a mood state called mood octant (see Fig. 1).

Furthermore, in order to initialize the mood states, ALMA uses a mapping between OCC emotions to the PAD components of the mood octant. Table I depicts such mapping between OCC emotions and the PAD space. In the proposed model, this approach is exploited to calculate the overall mood state of the agent. As dissected in the next section, this quantity is widely used in the calculations of emotion intensity levels.

Table I
MAPPING OF OCC EMOTIONS INTO PAD SPACE [15]

Emotion	P	A	D	Mood octant
Admiration	0.5	0.3	-0.2	+P+A-D Dependent
Anger	-0.51	0.59	0.25	-P+A+D Hostile
Disliking	-0.4	0.2	0.1	-P+A+D Hostile
Disappointment	-0.3	0.1	-0.4	-P+A+D Anxious
Distress	-0.4	-0.2	-0.5	-P-A-D Bored
Fear	-0.64	0.6	-0.43	-P+A+D Anxious
FearsConfirmed	-0.5	-0.3	-0.7	-P-A-D Bored
Gratification	0.6	0.5	0.4	+P+A+D Exuberant
Gratitude	0.4	0.2	-0.3	+P+A-D Dependent
HappyFor	0.4	0.2	0.2	+P+A+D Exuberant
Hate	-0.6	0.6	0.3	-P+A+D Hostile
Hope	0.2	0.2	-0.1	+P+A-D Dependent
Joy	0.4	0.2	0.1	+P+A+D Exuberant
Liking	0.4	0.16	-0.24	+P+A-D Dependent
Love	0.3	0.1	0.2	+P+A+D Exuberant
Pity	-0.4	-0.2	-0.5	-P-A-D Bored
Pride	0.4	0.3	0.3	+P+A+D Exuberant
Relief	0.2	-0.3	0.4	+P-A+D Relaxed
Remorse	-0.3	0.1	-0.6	-P+A-D Anxious
Reproach	-0.3	-0.1	0.4	-P-A+D Disdainful
Resentment	-0.2	-0.3	-0.2	-P-A-D Board
Satisfaction	0.3	-0.2	0.4	+P-A+D Relaxed
Shame	-0.3	0.1	-0.6	-P+A-D Anxious

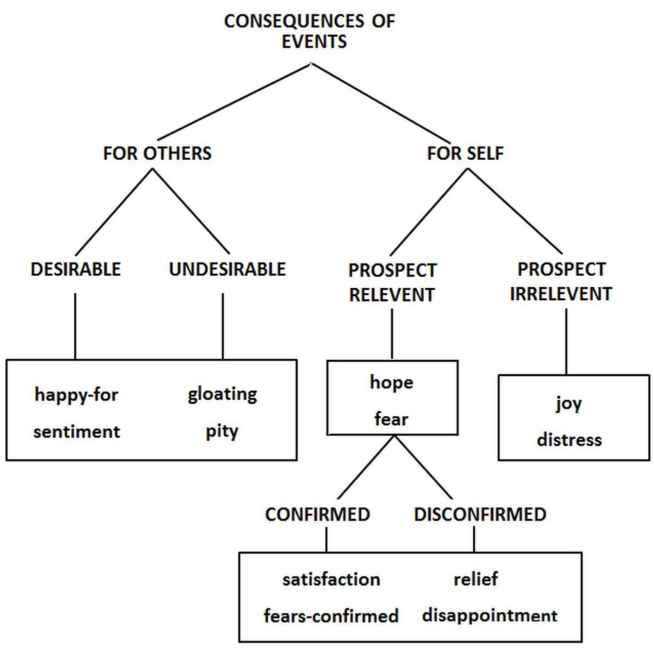

Figure 2. OCC action-originated emotions. Adopted partially from [13]

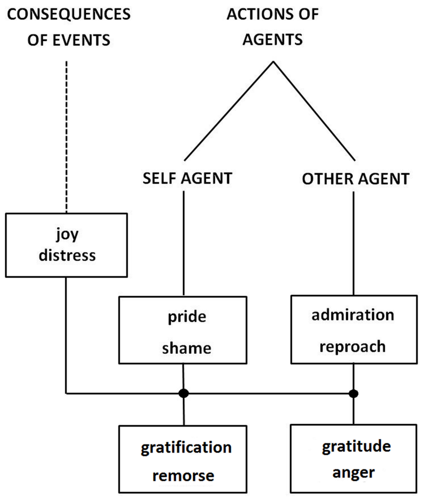

Figure 3. OCC event-originated emotions. Adopted partially from [13]

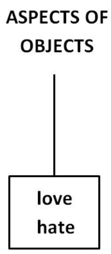

Figure 4. OCC object-originated emotions. Adopted partially from [13]

III. Proposed approach

A. OCC theory

The emotion process model suggested by Ortony, Clore and Collins known as OCC [13] is a robust and well-grounded appraisal theory for emotion dynamics that was highly influential in the field of studying emotions. This theory has managed to inspire many researchers in the field of affective computing. As a result of such influence, a considerable number of computational models of emotions can be seen today where OCC was the basis for them (e.g., [15], [17], [18]).

The popularity of OCC among computer scientists can be attributed to the fact that this theory was founded on a well-defined constraint-satisfaction architecture approach with a finite set of appraisal dimensions used as criteria for classifying different emotions. Such an approach taken in OCC makes it computationally tractable and hence, understandable by computer specialists.

The essence of the proposed model is to provide a computational method for the elicitation dynamics of all 22 emotions included in the OCC emotion theory [13]. The first step toward building a computational model for emotions was to split them into three categories according to their elicitation causes; those emotions elicited as a result of some occurred events (see Fig. 2); those emotions elicited as reactions to self or others actions (see Fig. 3); and those emotions elicited as a result of being exposed to emotion triggering objects (see Fig. 4).

The elicitation dynamics along with the intensity level calculations were designed using guidelines from the background theory beside a set of techniques and assessment

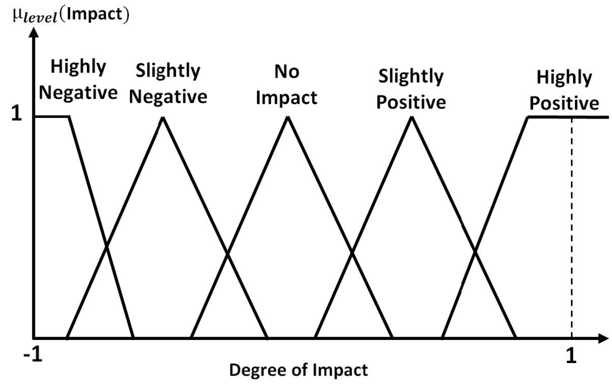

Figure 5. Event's fuzzy degree of impact on individual's goals [9]

processes made on the group of previously selected appraisal variables. An important point that must be clarified here is the fact that in the proposed computational model, positive or negative affective reactions or feelings are not considered emotional states unless they are above certain thresholds. According to such approach, an individual might feel pleased about an event but that feeling does not elevate to a realistic joy emotion due to below the threshold level for pleasure. This was the reason behind eliminating such intermediate feelings from the original OCC model.

With respect to event-originated emotions, according to Fig. 2, the first appraisal variable that differentiates the emotions of this group into two sets is the orientation of the event that take place in the system; meaning that whether the utility of the event is oriented toward the agent itself or some other agent(s). This evaluation process yields to a first level of classification of the emotions into *for self* or *for others* categories. Another classification takes place for *self* emotions group based on the prospective appraisal variable that indicates if the event has already taken place (prospect=False) or would possibly take place in the future (prospect=True). A prospective emotion, e.g., hope transforms into a post-prospect emotion of *satisfaction* in case of confirmation or *disappointment* in case of disapproval according to some temporal dynamics explained in section IV.

B. Events

The event-originated branch of OCC theory contains emotion types whose eliciting conditions are directly linked to an appraisal process performed on external events that take place in the environment and are perceived relevant events by the agent. Relevance appraisal variable is in fact an indicator for the degree of impact that an occurred event has on the set of agent's goals.

In order to present a quantifiable measure for this variable, the term desirability of events was used in the proposed model. Hence, desirability is a central variable accounting for the impact that an event has on an agent's goals, namely how it helps or impedes their achievements.

An event in the proposed approach, is a situation-changing condition that often takes place without explicit interventions by other agents. This definition differentiates this type of events from another group of conditions that still might be called events where they are caused by an agent or they are direct consequences of a deliberate and intentional action. According to OCC theory an event can have several aspects, each of them possibly triggering a different emotion. In this article it is assumed that what OCC calls *different aspects of an event* can be considered as consequences of the primary event.

1) Event's desirability: In OCC theory, the desirability of events is close in meaning to the notion of utility. When an event occurs it can satisfy or interfere with agent's goals, and the desirability variable has therefore two aspects; one corresponding only to the degree to which the event in question appears to have beneficial (i.e. positively desirable) consequences; and the other corresponding to the degree to which it is perceived as having harmful (i.e. negatively desirable, or undesirable) consequences.

The desirability of an occurred or prospective event poses the most influential factor in the specification of the emotion type that will be triggered along with its intensity. A fuzzy approach is adopted to determine the desirability level of an event. Accordingly, a fuzzy scale for the desirability consists of five fuzzy sets is considered as follows:

$$Desirability = \{HighlyUndesired,\, SlightlyUndesired,\\ Neutral, SlightlyDesired,\, HighlyDesired\}$$

The above desirability level is linked to an evaluation process that takes into account the impact (either positive or negative) of the event on the set of goals of the agent. Two other fuzzy variables are used to express this impact. Variable *Impact* that indicates the event's degree of influence on one or more goals of the agent (see Fig. 5); and variable *importance* that reflects the importance or preference of each goal. Hence,

$$Impact = \{HighlyNegative, SlightlyNegative,\\ NoImpact, SlightlyPositive, HighlyPositive\}$$

$$Importance = \{ExtremlyImportant,\\ SlightlyImportant, NotImportant\}$$

Considering the fact that an event can have an impact on multiple goals whereas each goal has its own importance level, the problem of measuring the desirability of an event would turn into solving a system of fuzzy rules [18].

With regards to the composition of the fuzzy rules in the resulted fuzzy system, a combination of the sup_min composition technique proposed by Mamdani [34] and the weighted average method for defuzzification [35] is considered. Using the composition approach explained in [18], we can apply the sup_min operator on *Impact*, *Importance* and *Desirability,* and hence, the matching degree between the input and the antecedent of each fuzzy rule can be determined. For example, consider the following set of n rules:

$$\begin{array}{ll} IF & Impact(G_1, E)\ is\ A_1 \\ & AND\ Impact(G_2, E)\ is\ A_2 \\ & ... \\ & AND\ Impact(G_k, E)\ is\ A_k \\ THEN & Impact(G_1, E)\ is\ C \\ ... & \end{array}$$

Where k is the number of agent's goals and A_i, B_i and C are fuzzy sets. This rule reads as follows: if event E affects goal G_1 to the extent of A_1 and it affects goal G_2 to the extent of A_2, etc., and that the importance of goal G_1 is B_1 and for goal G_2 is B_2, etc., then event E will have a desirability value of C.

It is clear that C will have a fuzzy value and hence needs to be defuzzified (quantified). In order to do so, we adopt the approach taken in [18] based on Mamdani model [34], but instead of using centroid defuzzification, the weighted average method for defuzzification was used in the proposed model. Hence, using the sup_min composition operator between the fuzzy variables of *Impact*, *Importance* and *Desirability,* the matching degree between the input and the antecedent of each fuzzy rule will be computed. For example, consider the following set of n rules:

$IF\ \ x\ is\ A_i\ THEN\ y\ is\ C_i$

...

$IF\ \ x\ is\ A_n\ THEN\ y\ is\ C_n$

Here, x and y are input and output variables respectively. A_i and C_i are fuzzy sets and i is the ith fuzzy rule. If the input x is a fuzzy set A', represented by a membership function $\mu_{A'}(x)$ (e.g. degree of desirability), a special case of A' is a singleton, which represents a crisp (non-fuzzy) value. Considering the definition of the sup_min composition between a fuzzy set $C \in \mathcal{F}(X)$ and a fuzzy relation $R \in \mathcal{F}(X \times Y)$ which is defined as:

$$C\, o\, R(y) = \sup_{x \in X} min \{C(x), R(x, y)\} \quad \text{for all } y \in Y$$

We can calculate the matching degree w_i between the input $\mu_{A'}(x)$ and the rule antecedent $\mu_{A_i}(x)$ using the equation below:

$$\sup_{x \in X} min \{\mu_{A'}(x), \mu_{A_i}(x)\}$$

which can be rewritten as:

$$\sup_x(\mu_{A'}(x)\ \wedge\ \mu_{A_i}(x))$$

The $\wedge$ operator calculates the minimum of the membership functions and then we apply the sup operator to get the maximum over all $x's$. The matching degree influences the inference result of each rule as follows:

$$\mu_{C_i'}(y) = w_i \wedge \mu_{C_i}(y)$$

Here, C_i' is the value of variable y inferred by the i^{th} fuzzy rule. The inference results of all fuzzy rules in the Mamdani model are then combined using the max operator $\vee$ as follows:

$$\mu_{comb}(y) = \mu_{C_1'}(y) \vee \mu_{C_2'}(y) \vee ... \vee \mu_{C_k'}(y)$$

Based on the definition of the $sup\, min$ composition between a fuzzy set $C \in \mathcal{F}(X)$ and a fuzzy relation $R \in \mathcal{F}(X \times Y)$, we have:

$$C\, o\, R(y) = \sup_{x \in X} min \{C(x), R(x, y)\} \quad \text{for all } y \in Y$$

We use the following formula based on the weighted average method for defuzzification in order to defuzzify the above combined fuzzy conclusion:

$$y_{final} = \frac{\sum \mu_{comb}(\overline{y}).\overline{y}}{\sum \mu_{comb}(\overline{y})}$$

where $\overline{y}$ is the mean of each symmetric membership function. Hence,

$$Desirability_f(e) = y_{final}$$

The result of above defuzzification process, y_{final} will return a number that is the value for the input event's desirability.

On the other hand, in order to enable the agent to make a good estimation for event expectation measure, we let it learn patterns of events. Next section describes briefly the function of the learning component in our model.

2) Events prospect: As discussed earlier in this article, a group of OCC emotions are prospective emotions, meaning that they are some transient emotional states that reflect a kind of uncertainty with respect to the occurrence possibility of some events. Hence, these emotional states eventually turn to a more stable emotions once the uncertainty factor was removed. The prospective attribute is directly linked to the degree of occurrence possibility perceived by the agent. In other words it reflects a mechanism for event expectedness by the agent. Event's expectedness is a sophisticated construct which involves several factors [4].

In the proposed model, a simple but acceptable estimation for this measure, similar to the one used in [18] is adopted. Based on this approach, a learning module is used to enable the agent to learn patterns for the events that take place in the environment and consequently to expect the occurrence of future events based on those identified patterns of events using a probabilistic approach. The event's patterns are constructed based on the frequency with which an event, say, e_1 is observed to occur right before previous events of e_2, e_3, etc.

A table data structure is used to count the number of iterations for each event pattern. The conditional probability of $p(e_3 \mid e_1, e_2)$ indicates the probability for event e_3 to happen, assuming that events e_1 and e_2 have just taken place. The first time that a pattern is observed, a corresponding entry for the event's pattern will be created, and the count is set to 1. This flag will be incremented for each future observation. These count flags can be used to compute the conditional probability for a new event Z to occur, given that events X and Y have already occurred. Therefore, The expected probability for event e_3 is:

$$Likelihood(e_3 \mid e_1, e_2) = \frac{C[e_1,e_2,e_3]}{\sum_i C[e_1,e_2,i]}$$

Where c denotes the count of each event sequence. Here, a length of three for the sequence of the event patterns was considered.

In case that the number of observations is low, only one previous event can be considered in the conditioned probability, hence:

$$Likelihood(Z \mid Y) = \frac{\sum_i C[i,Y,Z]}{\sum_j \sum_i C[i,Y,j]}$$

However, if the priori for event Y occurring right before event Z was never been observed, then we can use unconditional prior based on the mean probability for all events to calculate the probability of event Z as follows:

$$Likelihood = \frac{\sum_{i,j} C[i,j,Z]}{\sum_{i,j,k} C[i,j,k]}$$

For the sake of brevity, we refrain from providing a full detailed description of this approach and interested readers are referred to the above mentioned reference.

C. Actions

Another type of emotions in OCC theory are those originated by the consequences of purposeful actions. Some events that take place in the environment of an agent can be attributed to the actions of self or some other agent(s). Hence, the intentional and deliberate factor of the event is what differentiate this kind of events from those natural, unpurposeful, unattributable or with unknown source that are involved in the elicitation of event-originated emotions. This distinction is close in meaning to the variable of attribution or responsibility introduced in Lazarus theory of emotion [31], that is required to describe the behavior and justification for a group of emotions such as anger that are closely linked to an assessment process of an action.

According to this approach, a measure for the *praiseworthiness* attribute of the action needs to be defined. With respect to the valence of this attribute, it will be assigned a positive value when the action is in-line with the contextual standards or values, e.g., saving a drowning person which will elicit pride or admiration emotions; whereas it will be assigned a negative value if the action violates those standards or values, e.g., mocking a handicapped person which will trigger an emotion of shame or reproach (in this case it can be called the degree of blameworthiness). It is presumed though that these standards are adopted by the agent itself and are active in the evaluation process of the actions. It is important to be clarified that the proposed model keeps itself independent from these standards and for the sake of providing higher generality for the model, it is assumed that they are simply given to the system.

Other parameters that affect the value of *praiseworthiness* are the the degree of unexpectedness for the action being performed by the class type of the actor agent as well as the degree of the agent involvement in the action or its outcome.

D. Compound Emotions

According to OCC model, some emotions can be considered compound emotional states due to the fact that they are related to the consequences of regular events as well as actions-originated events. A compound emotion such as anger is triggered when the evaluating agent appraises both the desirability of the event and the attribution of the action led to the event. Hence, a state of anger is interpreted as a combination of distress and reproach emotions. Therefore, for this type of emotions, the appraisal parameters would include praiseworthiness of the performed action as well as the desirability of the occurred event.

E. Objects

The final set of emotions in the OCC model is a pair of complex states that indicates love and hate emotions. Love and hate can be considered as the hyper states of the general feelings of liking and disliking states toward an object [36]. The appraisal dimensions for this set of emotions are the degree of emotional attraction of the object and the degree of familiarity with the object by the evaluating agent. Emotional attraction can be considered as a function of dispositional attitudes toward a category or class that the object belongs to. Accordingly, appealing is set to value 'attractive' if the object has a positive 'object valence' along with a 'familiarity valence' less than a certain threshold; Conversely, it is set 'not attractive' if the object has a negative 'object valence' along with a 'familiarity valence' above a certain threshold [28].

In the next section, we use the above general hierarchy and the given approach of modeling emotion elicitation dynamics along with other guidelines from the base theory to formulate the problem formally in order to come up with the framework of the intended computational model.

IV. Problem formulation

As discussed earlier, emotions in OCC model are divided into three major groups. We strive to keep the formulation of this problem and the calculative modules inline with the original classification of emotions. At this point, it is affirmed that with each elicited emotional state, it would be necessary to apply its impact on the overall (global) emotional state of the agent according to some temporal dynamics. In emotion literature, this associated overall emotional state is often referred as the mood state of the individual. Mood is mid-term affective state [37] that stays for a longer period than an emotional state and it can be considered as the average valence of recent emotional states [38] along with some other attributes such as the personality traits [39]. According to research findings, the mood state influence to a large extent the way that an individual perceives his environment and reacts to an emotion-eliciting situation. Therefore, this measure was widely considered in the proposed model at which it is called mood-impact-factor.

A. Mood-impact-factor

According to [15], there exists a relationship between different emotions and the previously described PAD components of the agent's mood (see Fig. 1 and table I). Therefore, in order to calculate the mood of the agent, the following equation is proposed:

$$\Delta Mood_{Global} = \alpha.\sqrt{P^2 + A^2 + D^2}$$

Where α is a signed adaptation coefficient that would be positive if the experienced emotion was positive and it enhances the generic mood state of the agent, whereas a negative emotion will yield in a negative α with an adverse impact on the global mood state of the agent. the exact value for this quantity is left for the experiment phase.

B. Emotion calculations

In this section, a set of computational equations is proposed for each emotion in order to anticipate the elicitation of the competent emotion as well as its intensity level. These modules were designed based on the approach presented in the previous section along with some guidelines from the OCC emotion theory. In these formulas, e is an occurred event, subscript $_p$ stands for *potential* and subscript $_t$ stands for *threshold*, p_i reflects an agent and t is an indicator for time, a is an action performed by self or some other agent, and obj is an encountered object.

It is assumed that an emotional state will not be triggered unless its intensity is above a certain threshold level. This assumption was applied in accordance with the real world rule that not any desirable or undesirable feeling would yield into an explicit emotion [13]. Furthermore, according to the formalization of emotions proposed by Steunebrink *et al.* [40], it is necessary to differentiate between the actual experiences of emotions and those conditions that merely trigger emotions. Hence, a triggered emotion will not necessarily lead to a genuine experience of it, due to the fact that it was assigned an intensity below the minimum experience level.

$$Desirability(p, e, t) = Desirability_f(e) + \Delta Mood_{Global}(t)$$

$$Mood_{Global}(t) = Mood_{Global}(t-1) + \Delta Mood_{Global}(t)$$

1) *Event-originated emotions:* As elaborated before, according to the OCC model, event-originated emotions are classified into two groups of *self-related* and *others-related*. This classification was made by considering the consequences of an occurred event to be directed toward either the evaluating agent itself or some other agent. The diagram of Figure 2 shows that the first group includes the set of $\{joy, distress, hope, fear, satisfaction, disappointment, fearsconfirmed, relief\}$ emotions whereas the second group includes$\{happyfor, resentment, gloating, pity\}$ emotions.

Self-related: In this section, calculation modules for the self-related set of event-originated emotions are presented. Self-related addresses those emotional states that are being elicited in the evaluating agent itself.

a) Emotion Joy: An agent experiences joy emotion when it is pleased about a desirable event. Hence,

$$\begin{aligned}
&IF\ Desirability(p, e, t) > 0 \\
&THEN\ JOY_p(p, e, t) = Desirability(p, e, t) \\
&IF\ JOY_p(p, e, t) > JOY_t(p, t) \\
&THEN\ Intensity(p, e, t) = JOY_p(p, e, t,) - JOY_t(p, t) \\
&ELSE\ Intensity(p, e, t) = 0
\end{aligned}$$

b) Emotion Distress: An agent experiences distress emotion when it is displeased about an undesirable event. Hence,

$$\begin{aligned}
&IF\ Desirability(p, e, t) < 0 \\
&THEN\ DISTRESS_p(p, e, t) = -Desirability(p, e, t) \\
&IF\ DISTRESS_p(p, e, t) > DISTRESS_t(p, t) \\
&THEN\ Intensity(p, e, t) = DISTRESS_p(p, e, t) - \\
&DISTRESS_t(p, t) \\
&ELSE\ Intensity(p, e, t) = 0
\end{aligned}$$

As discussed earlier, *Prospect* in the following equations is a binary logical variable that reflects the occurrence prospect for a future event e. Hence, it merely indicates if person p believes that such event will occur (Prospect=TRUE) or will not occur (Prospect=FALSE) in the future. In case of $Prospect(p, e) = TRUE$, the function of $Likelihood(p, e)$ will return the probability for the occurrence of event e.

c) Emotion Hope: An agent experiences hope emotion when the occurrence of a desirable event in the future is expected. Hence,

$$\begin{aligned}
&IF\ Prospect(p, e, t)\ AND\ Desirability(p, e, t) > 0 \\
&THENHOPE_p(p, e, t) = Desirability(p, e, t) * Likeihood(p, e, t) \\
&IF\ HOPE_p(p, e, t) > HOPE_t(p, t) \\
&THEN\ Intensity(p, e, t) = HOPE_p(p, e, t) - HOPE_t(p, e) \\
&ELSE\ Intensity(p, e, t) = 0
\end{aligned}$$

d) Emotion Fear: An agent experiences fear emotion when the occurrence of an undesirable is expected. Hence,

$$\begin{aligned}
&IF\ Prospect(p, e, t)\ AND\ Desirability(p, e, t) < 0 \\
&THEN\ FEAR_p(p, e, t) = -(Desirability(p, e, t)) * \\
&Likeihood(p, e, t) \\
&IF\ FEAR_p(p, e, t) > FEAR_t(p, t) \\
&THEN\ Intensity(p, e, t) = FEAR_p(p, e, t) - FEAR_t(p, t) \\
&ELSE\ Intensity(p, e, t) = 0
\end{aligned}$$

e) Emotion Relief: An agent experiences relief emotion when the occurrence of an expected undesirable event is dis-confirmed. Hence,

$IF\ FEAR_p(p,e,t) > 0\ AND\ NOT(Occurred(p,e,t_2))$
$AND\ t_2 \geq t$
$THEN\ RELIEF_p(p,e,t_2) = FEAR_P(p,e,t))$
$IF\ RELIEF_p(p,e,t_2) > RELIEF(p,t_2)$
$THEN\ Intensity(p,e,t_2) = RELIEF_p(p,e,t_2) -$
$RELIEF_t(p,t_2)$
$AND\ reset\ FEAR_P(p,e,t_2) = Desirability(p,e,t_2)*$
$Likeihood(p,e,t_2)$
$ELSE\ Intensity(p,e,t_2) = 0$

In the above rules it is simply assumed that once a prospective negative event was disproved, the relief level of the agent would be directly proportional to the level of fear that was experienced by the agent in an earlier time. It is clear that such an assumption was made for simplicity and in reality the relationship between these two constructs is more sophisticated. In addition, although the agent has experienced some relief emotion at time t_2 as a result of dis-confirmed negative event e, but we would need to consider the possibility of its occurrence in a later time. This was the reason for recomputing the value of $Fear_p$ since at least one of its parameters (i.e., Likelihood) was changed.

f) Emotion Disappointment: An agent experiences disappointment when the occurrence of an expected desirable event is dis-confirmed. Hence,

$IF\ HOPE_p(p,e,t) > 0\ AND\ NOT(Occurred(p,e,t_2))\ AND$
$t_2 \geq t$
$THEN\ DISAPPOINTMENT_p(p,e,t_2) = HOPE_P(p,e,t))$
$IF\ DISAPPOINTMENT_p(p,e,t_2) >$
$DISAPPOINTMENT_t(p,t_2)$
$THEN\ Intensity(p,e,t_2) = DISAPPOINTMENT_p(p,e,t_2)$
$-DISAPPOINTMENT_t(p,t_2)$
$AND\ reset\ HOPE_p(p,e,t_2) = Desirability(p,e,t_2)*$
$Likeihood(p,e,t_2)$
$ELSE\ Intensity(p,e,t_2) = 0$

In the above rules, it was assumed that the level of disappointment emotion elicited as a result of dis-confirmed positive event is directly proportional to the level of hope that the agent had for that event. It would appear that such an assumption is in line with the rule of thumb, the higher the hope for an expected event, the higher the disappointment at its dis-confirmation.

g) Emotion FearsConfirmed: An agent experiences fears-confirmed emotion when the occurrence of an expected undesirable event is confirmed. Hence,

$IF\ FEAR_p(p,e,t) > 0\ AND\ (Occurred(p,e,t_2))\ AND$
$t_2 \geq t$
$THEN\ FEARSCONFIRMED_p(p,e,t_2) =$
$-(Desirabiklity(p,e,t_2))$
$IF\ FEARSCONFIRMED_p(p,e,t_2) >$
$FEARSCONFIRMED_t(p,t_2)$
$THEN\ Intensity(p,e,t_2) = FEARSCONFIRMED_p(p,e,t_2)$
$-FEARSCONFIRMED_t(p,t_2)$
$ELSE\ Intensity(p,e,t_2) = 0$

h) Emotion Satisfaction: An agent experiences satisfaction emotion when the occurrence of an expected desirable event is confirmed. Hence,

$IF\ HOPE_{pot}(p,e,t) > 0\ AND\ (Occurred(p,e,t_2))\ AND\ t_2 \geq t$
$THEN\ SATISFACTION_p(p,e,t_2) = Desirability(p,e,t_2)$
$IF\ SATISFACTION_p(p,e,t_2) > SATISFACTION_t(p,t_2)$
$THEN\ Intensity(p,e,t_2) = SATISFACTION_p(p,e,t_2) -$
$SATISFACTION_t(p,t_2)$
$ELSE\ Intensity(p,e,t_2) = 0$

Here, it can be argued that a simple approximation for the intensity of the above two emotions at the realization of the occurred event by the agent, is to remove the prospect factor from the calculations and link them directly to their initial desirability measures.

Others-related: In this section, calculation modules for the others-related set of event-originated emotions are presented. Others-related addresses those emotional states that are being elicited in a different agent from the evaluating one.

i) Emotion HappyFor: An agent experiences happyfor emotion if it is pleased about an event presumed to be desirable for a friend agent. Hence,

$IF\ Desirability(p_2,e,t) > 0\ AND\ Friend(p_1,p_2)$
$THEN\ IF\ Desirability(p_1,e,t) > 0$
$THEN\ HAPPYFOR_p(p_1,e,t) =$
$(Desirability(p_2,e,t) + Desirability(p_1,e,t))/2$
$ELSE\ THEN\ HAPPYFOR_p(p_1,e,t) =$
$|Desirability(p_2,e,t) - Desirability(p_1,e,t)|$
$IF\ HAPPYFOR_p(p_1,e,t) > HAPPYFOR_t(p_1,t)$
$THEN\ Intensity(p_1,e,t) = HAPPYFOR_p(p_1,e,t,) -$
$HAPPYFOR_t(p_1,t)$
$ELSE\ Intensity(p_1,e,t) = 0$

j) Emotion Pity: An agent experiences pity emotion if it is displeased about an event presumed to be undesirable for a friend agent. Hence,

$IF\ Desirability(p_2,e,t) < 0\ AND\ Friend(p_1,p_2)$
$THEN\ IF\ Desirability(p_1,e,t) < 0$
$THEN\ PITY_p(p_1,e,t) =$
$|(Desirability(p_2,e,t) + Desirability(p_1,e,t))|/2$
$ELSE\ PITY_p(p_1,e,t) = |Desirability(p_2,e,t) -$
$Desirability(p_1,e,t)|$
$IF\ PITY_p(p_1,e,t) > PITY_t(p_1,t)$
$THEN\ Intensity(p_1,e,t) = PITY_p(p_1,e,t,) - PITY_t(p_1,t)$
$ELSE\ Intensity(p_1,e,t) = 0$

For the above two emotions, we argue that in case of compatible desirability for both agents, the emotion level would be obtained by averaging the two desirability measures *[9]*. The other scenario would be when the two agents have opposite desirability for event e at which the algebraic sum of the two would determine the intensity level of the resulting emotion. It needs to be clarified that these computational rules hold even when event e is irrelevant to agent p_1(i.e., $Desirability(p_1,e,t) = 0$).

k) Emotion Gloating: An agent experiences gloating emotion if it is pleased about an event presumed to be undesirable for an non-friend agent. Hence,

$IF\ Desirability(p_2,e,t) < 0\ AND\ NOT(Friend(p_1,p_2))$
$THEN\ IF\ Desirability(p_1,e,t) < 0$
$THEN\ GLOATING_p(p_1,e,t) =$
$|(Desirability(p_2,e,t) - Desirability(p_1,e,t)|$
$ELSE\ GLOATING_p(p_1,e,t) =$
$|Desirability(p_2,e,t) + Desirability(p_1,e,t)|$
$IF\ GLOATING_p(p_1,e,t) > GLOATING_t(p_1,t)$
$THEN\ Intensity(p_1,e,t) =$
$GLOATING_p(p_1,e,t,) - GLOATING_t(p_1,t)$
$ELSE\ Intensity(p_1,e,t) = 0$

l) Emotion Resentment: An agent experiences resentment emotion if it is displeased about an event presumed to be desirable for an non-friend agent. Hence,

$IF\ Desirability(p_2, e, t) > 0\ AND\ NOT(Friend(p_1, p_2))$
$THEN\ IF\ Desirability(p_1, e, t) < 0$
$THEN\ RESENTMENT_p(p_1, e, t) =$
$|(Desirability(p_2, e, t) - Desirability(p_1, e, t))|$
$ELSE\ RESENTMENT_p(p_1, e, t) =$
$|Desirability(p_2, e, t) - Desirability(p_1, e, t)|$
$IF\ RESENTMENT_p(p_1, e, t) > RESENTMENT_t(p_1, t)$
$THEN\ Intensity(p_1, e, t) =$
$RESENTMENT_p(p_1, e, t,) - RESENTMENT_t(p_1, t)$
$ELSE\ Intensity(p_1, e, t) = 0$

2) Action-originated emotions:

Non-compound emotions: For this set of emotions, we consider a function called *Praise* that evaluates and sets the degree of praiseworthiness of an action. A negative value for this function indicates the degree of blameworthiness of the action.

a) Emotion Pride: An agent experiences pride emotion if it is approving its own praiseworthy action. Hence,

$IF\ Praise(p_1, p_2, a, t) > 0\ AND\ (p_1 = p_2)$
$THEN\ PRIDE_p(p_1, p_2, a, t) = Praise(p_1, p_2, a, t)$
$IF\ PRIDE_p(p_1, p_2, a, t) > PRIDE_t(p_1, p_2, a, t)$
$THEN\ Intensity(p_1, p_2, a, t) =$
$PRIDE_p(p_1, p_2, a, t) - PRIDE_t(p_1, p_2, a, t)$
$ELSE\ Intensity(p_1, p_2, a, t) = 0$

b) Emotion Shame: An agent experiences shame emotion if it is disapproving its own blameworthy action. Hence,

$IF\ Praise(p_1, p_2 a, t) < 0\ AND\ (p_1 = p_2)$
$THEN\ SHAME_p(p_1, p_2, a, t) = -Praise(p_1, p_2 a, t)$
$IF\ SHAME_p(p_1, p_2, a, t) > SHAME_t(p_1, p_2, a, t)$
$THEN\ Intensity(p_1, p_2, a, t) =$
$SHAME_p(p_1, p_2, a, t) - SHAME_t(p_1, p_2, a, t)$
$ELSE\ Intensity(p_1, p_2, a, t) = 0$

c) Emotion Admiration: An agent experiences admiration emotion if it is approving a praiseworthy action of another agent. Hence,

$IF\ Praise(p_1, p_2, a, t) > 0\ AND\ NOT(p_1 = p_2)$
$THEN\ ADMIRATION_p(p_1, p_2, a, t) = Praise(p_1, p_2 a, t)$
$IF\ ADMIRATION_p(p_1, p_2, a, t) >$
$ADMIRATION_t(p_1, p_2, a, t)$
$THEN\ Intensity(p_1, p_2, a, t) =$
$ADMIRATION_p(p_1, p_2, a, t) - ADMIRATION_t(p_1, p_2, a, t)$
$ELSE\ Intensity(p_1, p_2, a, t) = 0$

d) Emotion Reproach: An agent experiences reproach emotion if it is disapproving a blameworthy action of another agent. Hence,

$IF\ Praise(p_1, p_2 a, t) < 0\ AND\ NOT(p_1 = p_2)$
$THEN\ REPROACH_p(p_1, p_2, a, t) = -Praise(p_1, p_2 a, t)$
$IF\ REPROACH_p(p_1, p_2, a, t) > REPROACH_t(p_1, p_2, a, t)$
$THEN\ Intensity(p_1, p_2, a, t) =$
$REPROACH_p(p_1, p_2, a, t) - REPROACH_t(p_1, p_2, a, t)$
$ELSE\ Intensity(p_1, p_2, a, t) = 0$

Compound emotions: For this class of emotions, as stated earlier, we deal with two other implicit emotional states that are involved in the calculations and the intensity level would include an average-like operation between these two emotions. Therefore, beside the value of function *Praise* used in the above equations, it will be necessary to calculate the desirability of the resulted events in the same way that was performed for the set of event-originated emotions.

e) Emotion Gratification: An agent experiences gratification emotion if it is approving its own praiseworthy action that led to a desirable event. Hence,

$IF\ Praise(p_1, p_2 a, t) > 0\ AND\ (p_1 = p_2)\ AND$
$Desirability(p, e, t) > 0$
$THEN\ GRATIFICATION_p(p_1, p_2, a, t) =$
$(PRIDE_p + JOY_p)/2$
$IF\ GRATIFICATION_p(p_1, p_2, a, t) >$
$GRATIFICATION_t(p_1, p_2, a, t)$
$THEN\ Intensity(p_1, p_2, a, t) =$
$GRATIFICATION_p(p_1, p_2, a, t)-$
$GRATIFICATION_t(p_1, p_2, a, t)$
$ELSE\ Intensity(p_1, p_2, a, t) = 0$

f) Emotion Remorse: An agent experiences remorse emotion if it is disapproving his own blameworthy action that led to an undesirable event. Hence,

$IF\ Praise(p_1, p_2 a, t) < 0\ AND\ (p_1 = p_2)$
$AND\ Desirability(p, e, t) < 0$
$THEN\ REMORSE_p(p_1, p_2, a, t) =$
$(SHAME_p + DISTRESS_p)/2$
$IF\ REMORSE_p(p_1, p_2, a, t) > REMORSE_t(p_1, p_2, a, t)$
$THEN\ Intensity(p_1, p_2, a, t) =$
$REMORSE_p(p_1, p_2, a, t) - REMORSE_t(p_1, p_2, a, t)$
$ELSE\ Intensity(p_1, p_2, a, t) = 0$

g) Emotion Gratitude: An agent experiences gratitude emotion if it is approving a praiseworthy action of another agent that led to a desirable event. Hence,

$IF\ Praise(p_1, p_2 a, t) > 0\ AND\ NOT(p_1 = p_2)$
$AND\ Desirability(p, e, t) > 0$
$THEN\ GRATITUDE_p(p_1, p_2, a, t) =$
$(ADMIRATION_p + JOY_p)/2$
$IF\ GRATITUDE_p(p_1, p_2, a, t) > GRATITUDE_t(p_1, p_2, a, t)$
$THEN\ Intensity(p_1, p_2, a, t) =$
$GRATITUDE_p(p_1, p_2, a, t) - GRATITUDE_t(p_1, p_2, a, t)$
$ELSE\ Intensity(p_1, p_2, a, t) = 0$

h) Emotion Anger: An agent experiences anger emotion if it is disapproving a blameworthy action of another agent that led to an undesirable event. Hence,

$IF\ Praise(p_1, p_2 a, t) < 0\ AND\ NOT(p_1 = p_2)$
$AND\ Desirability(p, e, t) < 0$
$THEN\ ANGER_p(p_1, p_2, a, t) =$
$(REPROACH + DISTRESS_p)/2$
$IF\ ANGER_p(p_1, p_2, a, t) > ANGER_t(p_1, p_2, a, t)$
$THEN\ Intensity(p_1, p_2, a, t) =$
$ANGER_p(p_1, p_2, a, t) - ANGER_t(p_1, p_2, a, t)$
$ELSE\ Intensity(p_1, p_2, a, t) = 0$

3) Object-originated emotions: As discussed earlier in this article, this type of emotions are related to the attraction and aversion aspect of the emotion-eliciting objects from the perspective of the evaluating agent. This kind of emotions can be distinguished from the other two types (i.e., events-originated and actions-originated) with respect to the fact that they are directly experienced as a result of dispositional liking or disliking attribute toward the category or class that the object belongs to along with some self characteristics of the object itself. Although in the base theory, the attribute of familiarity (vs novelty) between the object and the evaluating agent was considered as a factor that affects the elicitation and intensity of these emotions, but due to the complex and uncertain attitude of OCC with respect to relationship between this factor and the appealing of the object (e.g., directly or reversely proportional or being highly contextual), we refrain from considering this attribute in the calculations of this type of emotions and focus merely on the appealing attribute of the objects.

a) Emotion Love: An agent experiences love emotion if it is attracted to an appealing and object (agent). Hence, we have

$$
\begin{aligned}
&IF\ Appealing(p, obj, t) > 0\\
&THEN\ LOVE_p(p, obj, t) = Appealing(p, obj, t)\\
&LOVE_t = k/Familiar(p, obj, t),\ k = constant\\
&IF\ LOVE_p(p, obj, t) > LOVE_t(p, obj, t)\\
&THEN\ Intensity(p, obj, t) =\\
&LOVE_p(p, obj, t) - LOVE_t(p, obj, t)\\
&ELSE\ Intensity(p, obj, t) = 0
\end{aligned}
$$

b) Emotion Hate: An agent experiences hate emotion if it is attracted to an appealing and object (agent). Hence, we have

$$
\begin{aligned}
&IF\ Appealing(p, obj, t) < 0\\
&THEN\ HATE_p(p, obj, t) = -Appealing(p, obj, t)\\
&HATE_t = k/Familiar(p, obj, t),\ k = constant\\
&IF\ HATE_p(p, obj, t) > HATE_t(p, obj, t)\\
&THEN\ Intensity(p, obj, t) =\\
&HATE_p(p, obj, t) - HATE_t(p, obj, t)\\
&ELSE\ Intensity(p, obj, t) = 0
\end{aligned}
$$

C. Algorithms

Event-Track-State: to determine triggered emotions along with their intensities as a result of the occurrence of a series of events

Input: $q_0 = < m_0, I_0 >$, $Mood_{global}$, $E = \{e_1, e_2, ..., e_k\}$, $E\, is\, list\, of\, occurring\, events$
$Q = \{< m_i, I_i >, m_i \in Event\_Competent\_Emotions, I_i \in Intensity_{fuzzy}\}$
Output: $q_f = \{< m_1, I_1 >, < m_2, I_2 >, ... < m_k, I_k >\} \subset Q$
Begin
Defuzzify state $q_i = q_0$ using weighted average method
For each event $e \in E$
Begin
Calculate $Desirability_f$ for event e
Based on the variables of $Orientation$, $Prospect$ do:
Determine possible emotional state $< m_i, I_i >$from emotion derivation rules
Obtain $\Delta MoodR_{global}$ for e using PAD look-up table
Update $\Delta MoodR_{global}$
End For;
For each m_i where $I_i > 0$
Begin
Print $< m_i, I_i >$
End For;
End.

Agent-actions emotions: **Action-Track-State:** to determine triggered emotions along with their intensities as a result of the occurrence of a series of actions

Input: $q_0 = < m_0, I_0 >$, $Mood_{global}$, $A = \{a_1, a_2, ..., a_k\}$, $A\, is\, list\, of\, actions$
$Q = \{< m_i, I_i >, m_i \in Action\_Competent\_Emotions, I_i \in Intensity_{fuzzy}\}$
Output: $q_f = \{< m_1, I_1 >, < m_2, I_2 >, ... < m_k, I_k >\} \subset Q$

Table II
LIST OF AGENT'S GOALS AND EVENTS ALONG WITH THEIR IMPACT ON EACH GOAL FOR BOTH AGENTS

Goal		G1	G2	G3
Importance		HighlyImportant	SlightlyImportant	HighlyImportant
Event/Person		*Impact*(G1)	*Impact*(G2)	*Impact*(G3)
e_1	p_1	HighlyPositive	NoImpact	HighlyPositive
	p_2	SlightlyPositive	SlightlyNegative	NoImpact
e_2	p_1	HighlyNegative	SlightlyPositive	SlightlyNegative
	p_2	HighlyNegative	HighlyPositive	HighlyPositive
e_3	p_1	NoImpact		
	p_2	HighlyPositive	NoImpact	HighlyPositive
e_4	p_1	HighlyNegative	HighlyPositive	HighlyNegative
	p_2	HighlyNegative	SlightlyPositive	SlightlyNegative
e_5	p_1	HighlyPositive	HighlyPositive	NoImpact
	p_2	NoImpact	HighlyNegative	SlightlyPositive

Table III
TEMPORAL DYNAMICS OF THE OCCURRING EVENTS

time	0	10	20	30	40	50	60	70	80	90
Occurrence			e_1		e_3	e_4	e_2		e_5	e_1
Prospect		e_2	e_5		e_4		e_5			

Begin
Defuzzify state $q_i = q_0$ using weighted average method
For each event $a \in A$
Begin
Based on the variables of $Degree\_involvement$, $Unexpectedness$ do:
Calculate $Praiseworthiness$ for action a
Determine possible emotional state $< m_i, I_i >$from emotion derivation rules
Obtain $\Delta MoodR_{global}$ for a using PAD look-up table
Update $\Delta MoodR_{global}$
If $a \in \beta\ set\, of\, actions$
Begin
calculate compound emotions
End;
End For;
For each m_i where $I_i > 0$
Begin
Print $< m_i, I_i >$
End For;
End.

V. SIMULATION EXPERIMENTS AND DISCUSSION

In order to test the performance of the model and verify its functionality under different circumstances, a series of simulation experiments were conducted. For brevity, two of these experiments are considered here. The goal of the first experiment is study the emotional behavior of the agent as a result of the occurrence of some independent events. The second experiment includes those events where their occurrence was a result of some actions performed by the evaluating agent itself or some other agents. Situations at which the subject agent was exposes to emotion-eliciting objects are also included.

A. Scenario 1 unattributed Events

In this experiment, a scenario where the subject agent does not attribute the events to the actions of itself or other agents is considered. Consequently, the appraisal process is merely being performed based on the occurred events through their

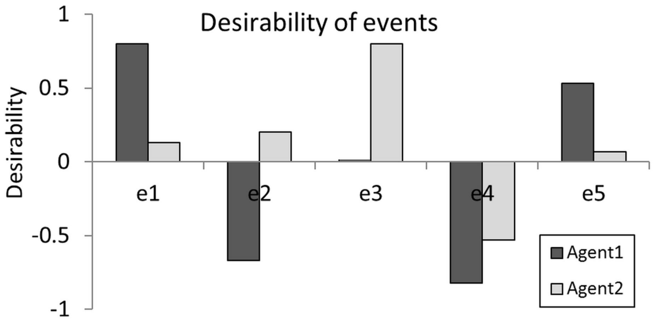

Figure 6. Calculated event's desirability for both agents

desirability and expectedness measures. p_1 is the subject (evaluating) agent, p_2 is the other agent, $G = \{G_1, G_2, G_3\}$ are the goals of the agents and $E = \{e_1, e_2, e_3, e_4, e_5\}$ is the set of possible events. The fuzzy values of *Importance* and *Impact* for these goals and events are described in Table II. Table III shows the temporal dynamics of both real and prospect events that take place in the system during the simulation time. It is assumed that the time duration for a prospect event is 20 time-steps; meaning that the agent will experience the competent prospect emotion for 20 time-steps before it turns into a deterministic emotion. In addition, it is assumed that the life-time for each deterministic emotion is 20 time-steps as well; emotional responses start to deteriorate through a linear function due to normal decay and vanishes completely after that period.

As the first step, the desirability level for all events of E for both agents were calculated and the results are reflected in the graph of Fig. 6.

According to Table III, at time-step=10, since there is a possibility for the occurrence of e_2 as a negative event, the agent experiences fear emotion. The actual occurrence of positive event e_1 at step=20, caused emotion joy to be triggered in agent p_1. In addition, at the same step, a certain level of emotion hope was elicited in the agent for the prospect positive event of e_5. At step=30, due to disconfirmed e_2, the fear emotion will disappear and gives its room to the relief emotion. At step=40, the occurrence of e_3, which was initially an irrelevant event for agent p_1, but considering the fact that it is a positive event for a friend agent (p_2) will yield in triggering the emotion of *happyfor* in p_1. Furthermore, prospective event e_4 will cause p_1 to experience a relatively high level of fear emotion which converts into *fearsconfirmed* at step=50. At step=60, negative event e_2 took place and caused p_1 to experience a high level of distress emotion. Unlike the earlier prospective occurrence of this event, it was not proceeded by a fear emotion since it was not predicted by the agent. At the same step, the prospective event of e_5 resulted in some degree of hope emotion. This emotion was converted into satisfaction at step=80 when the occurrence of e_5 was confirmed. Finally, at step=90, positive event $e_1$took place and caused the agent to experience a high level of joy. Fig. 8 depicts the changes in the global mood level of agent p_1 as a result of the occurred events. As elaborated before, the changes in the global mood of the agent is proportional to the PAD components of the triggered emotions which in turn were elicited as a result of occurred events. Fig. 7 shows a complete list of all events-originated emotions that were experienced by agent p_1 during

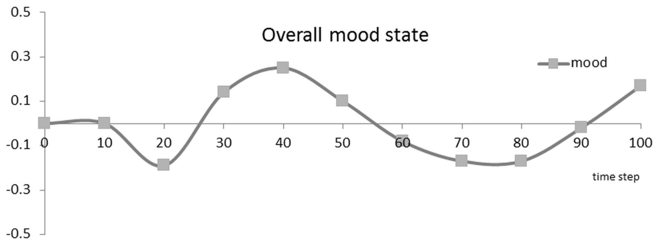

Figure 8. Global mood level changes as a result of occurred events

the simulation time along with the intensity of each. For instance, it can be seen that the agent experienced emotion joy for the first time at step=20 with a high intensity of 0.7 as a result of the occurrence of event e_1. The joy emotion started to deteriorate due to the normal decay and it completely disappeared by step=40. The agent ended the simulation with another wave of joy emotion as a result of the re-occurrence of e_1.

In this scenario, it can be noticed that the emotional behavior of the agent was directly influenced by appraisal processes performed by the agent itself on the set of events that took place in the environment and were perceived relevant by the agent. Furthermore, it can be clearly seen that the fact whether an event is directed towards the agent itself or some other agents, plays a critical role in the set of elicited emotions and their intensities.

B. Scenario 2 - attributed events and emotion-eliciting objects

In this scenario, the subject attributes the occurred emotion relevant events to the actions of self or other agents. Table IV describes all type of actions that can be performed by both agent p_1 as the evaluating agent and agent p_2 as the other agent. According to this table, there are two sets of actions; set α_i where $i \in \{1, 2, 3\}$ which represents those actions that are not associated with regular events and hence will generate non-compound actions-originated emotions; and set β_j where $j \in \{1, 2, 3, 4, 5\}$ which represents those actions that generate compound emotions.

Furthermore, according to Table IV, each action is associated with four appraisal dimensions that are necessary for computing the praiseworthiness appraisal function. These four dimensions are: (1) a binary variable to determine compliance with the contextual standards with TRUE or FALSE values; (2) a pair of fuzzy variables to determine the degree of responsibility of each agent separately in the performed action which will take a fuzzy value from the fuzzy sets of $\{solely, highly, moderately, slightly\}$; (3) possible outcome event of the action; and (4) a pair of fuzzy variable that determines the degree of unexpectedness for the action being performed by any of the two agents which will take a value from the fuzzy sets of $\{highly, moderately, slightly\}$.

Additionally, Table V reflects all the actions that were performed by both agents during the simulation period.

It is clear that in the occasion of having actions of type β, it would be necessary to consider the desirability of the outcome emotions also, in a similar way to the experiment of scenario 1 beside evaluating the praiseworthiness function.

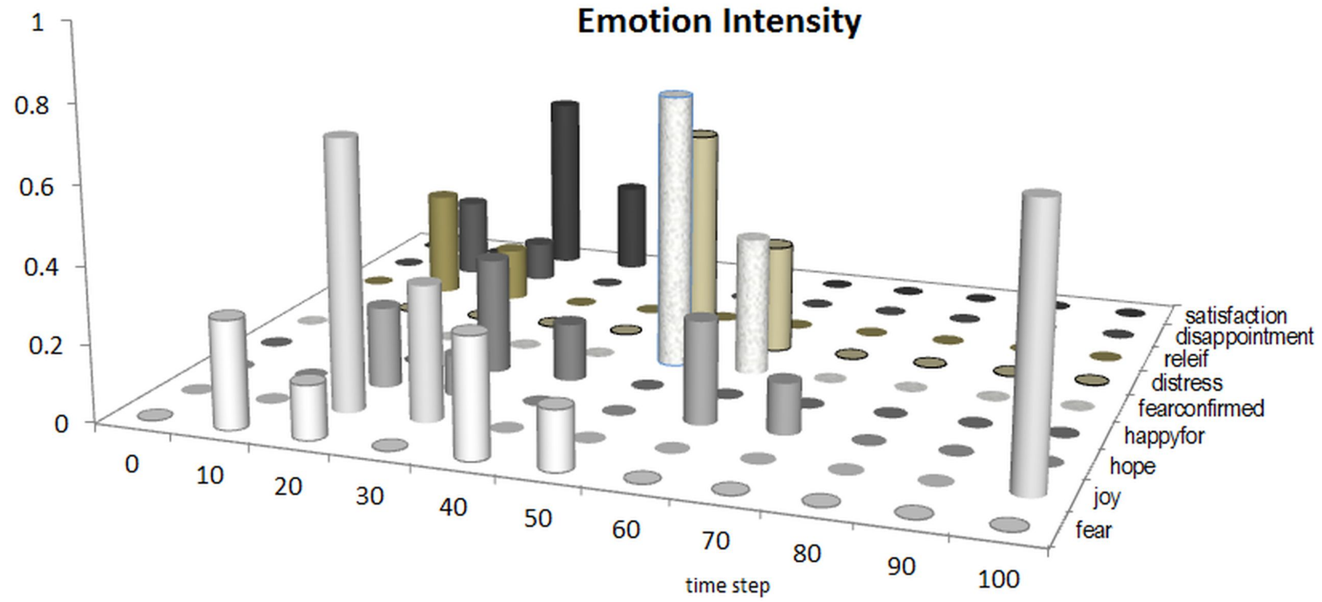

Figure 7. Intensity of all events-originated emotions for agent p_1 during the simulation

Table IV
LIST OF EMOTION-ELICITING ACTIONS ALONG WITH THEIR VALENCE, DEGREE OF INVOLVEMENT, POSSIBLE OUTCOME EVENT AND DEGREE OF ACTION UNEXPECTEDNESS

Action	Stand. comp.	Degree of resp.		outc. event	Unexpectedness	
		p_1	p_2		p_1	p_2
α_1	✔	solely	highly	—	highly	highly
α_2	✗	highly	solely	—	mod.	highly
α_3	✔	solely	slight.	—	slightly	slightly
β_1	✔	solely	solely	e_1	highly	slightly
β_2	✗	sligt.	mod.	e_2	highly	mod.
β_3	✔	highly	highly	e_3	sligtly	highly
β_4	✗	mod.	mod.	e_4	mod.	mod.
β_5	✔	solely	highly	e_5	slightly	slightly

Table V
TEMPORAL DYNAMICS OF ACTIONS PERFORMED BY BOTH AGENTS

time	0	10	20	30	40	50	60	70	80	90
A(p_1)			β_2		β_3				α_2	β_1
A(p_2)		α_2	α_3		β_5	α_1	β_1		β_2	

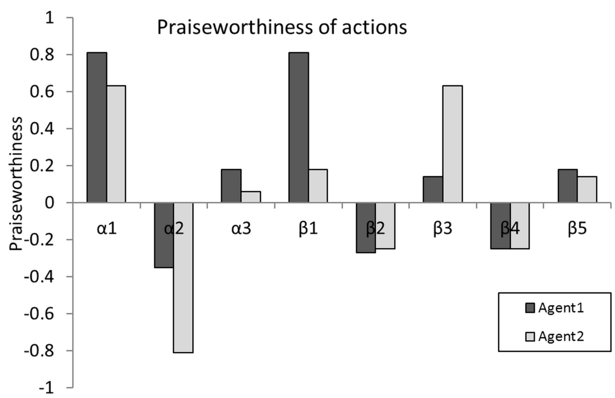

Figure 9. Calculated praiseworthiness of actions for both agents

Furthermore, considering the fact that β set of actions responsible for generating compound emotions are associated with the same set of events used in the previous experiment (i.e., e_is), there will be no need to calculate the desirability of those events this task was performed in the experiment of scenario 1. Therefore, these desirability quantities will be used along with the newly calculated praiseworthiness of actions to anticipate the type and intensity of the compound emotions in this experiment. For simplicity, other unaddressed conditions of this experiment were considered identical to those of the previous experiment.

The first step in this scenario will be to calculate the value of praiseworthiness for each action of α_i as well as β_i. Fig. 9 represents the actions praiseworthiness values calculated for both agents.

According to Table V, at time-step=10, action α_2 was performed by p_2. Considering the fact that α_2 is a norm violating action, and also the fact that p_2 was highly involved in this action while it is highly unexpected to be conducted by this agent, a strong emotion of reproach was elicited in agent p_1 as a result of this action. At step=20, agent p_2 performed the positive action of α_3 but considering the weak role of agent p_2 in performing this action as well as its low unexpectedness to appear from the class type of agent p_2, a potential weak signal for emotion admiration was triggered in agent p_1 but it did not reach the threshold level of admiration, hence, no genuine admiration emotion was elicited in p_1 as a result of this action. Concurrently, action β_2 was performed by agent $p_1$itself which is a norm-violating action and hence it triggers the emotion shame in , but since the responsibility of $p_1$in this action was low, hence the intensity of shame will be low.

Furthermore, this action as expected will also generate emotion remorse considering its role in the occurrence of the negative event of e_2. The intensity level of emotion remorse will by high though since event e_2 is highly undesirable for agent p_1. at time step=40, all previously elicited emotions

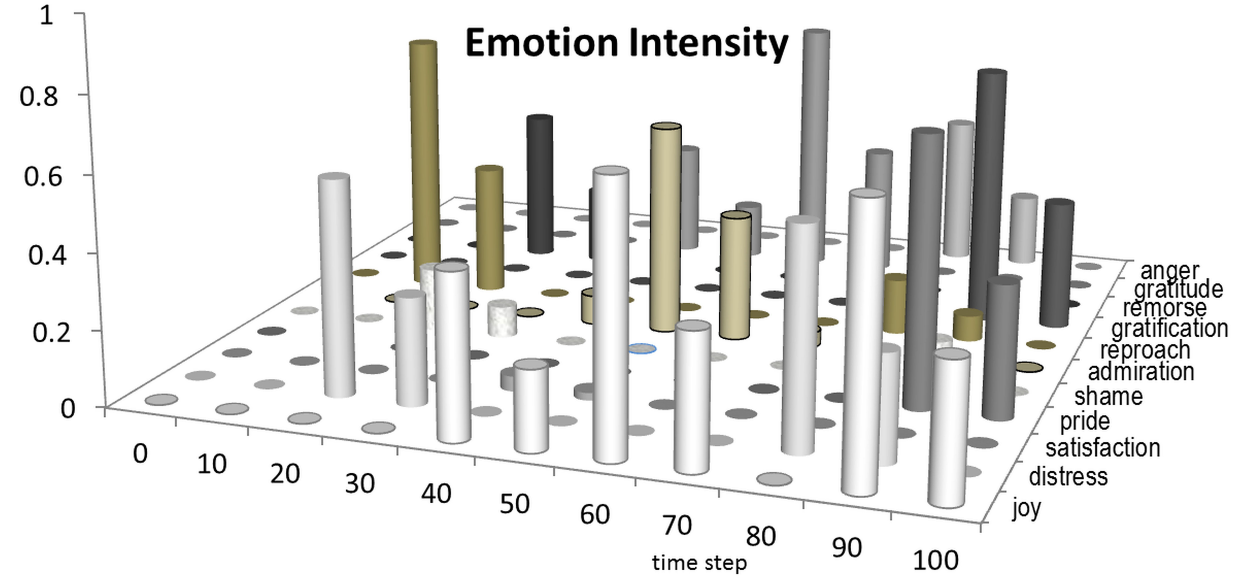

Figure 10. Intensity of all actions-originated emotions for agent p_1 during the simulation

will be vanished due to the normal decay factor discussed earlier in first experiment. On the other hand, at this step two actions of β_3 and β_5 was performed by p_1 and p_2 respectively. Both of these actions are expected to generate compound emotions. With respect to action β_3, it generates a weak emotion of pride since the unexpectedness factor is low for the class of agents that $p_1$belongs to. Furthermore, although this action is associated with event e_3 but since this event has no impact on the agents goals and consequently it is neither a negative nor a positive event for $p_1$with desirability measure=0. Therefore, no emotion of events-originated type will be generated as a result of this action. Concurrently at this step, the positive action of β_5 by p_2 will create a weak admiration emotion in agent p_1 as well as a stronger gratitude emotion due to the occurrence of the highly desirable event of e_5 that took place as a result of this action. At step=50, action $\alpha_1$was performed by p_2 and as a result, emotion admiration was elicited in agent p_1.

The situation continues with the actions of β_1, β_2 performed by p_2 which elicit emotions of admiration, gratitude, reproach and anger in agent p_1 as well as actions α_2, β_1 performed by p_1 itself which elicit the emotions of shame, pride and finally gratification respectively. Fig. 10 shows a complete list of all actions-originated emotions that were experienced by agent p_1 during the simulation time along with the intensity level of each. With respect to all events-originated emotions, it is worth noted that they were generated with the same mechanism as described in the previous scenario.

In this scenario, it can be noticed that the emotional behavior of the agent was directly influenced by the praiseworthiness of the emotion triggering actions performed either by the agent itself or some other agents. It can be seen for instance, how the same action generated different emotions as a result of being performed by the evaluating agent itself or by another agent.

VI. Conclusion

In this article a fuzzy appraisal approach for anticipating the emotional states that will be experienced by an individual based on OCC emotion theory was proposed. These emotions are elicited as a result of either the occurrence of some goal-relevant events; evaluating an action of self or other individuals; or a dispositional reaction to some emotion-eliciting objects. Emotion generation modules were formulated for all 22 emotions of the OCC model according to this ternary classification. The problem formulation was performed based on some guidelines from the OCC emotion theory along with different appraisal methods and techniques such as measuring the desirability of events, degree of event's expectedness, action's degree of compliance with standards, level of involvements, etc.

At the core of each assessment process in the proposed computational model there exist a fuzzy evaluation system that analyzes the competent appraisal variables and generates the value for the output parameters. Furthermore, a probabilistic learning approach was used to enable the agent to come up with an event prediction model based on the previously learnt patterns of events.

The proposed model was able to determine the set of triggered emotions along with their intensities at any point of time as well as the overall mood state of the agent during the simulation interval. The authors of this article believe that this work is still at the preliminary level and there is much room for further development and research that can use the obtained methods and results to bridge to the relevant disciplines, especially psychology and healthcare.

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