A Framework for a Robot's Emotions Engine

Ben SALEM, *Member, IEEE*

***Abstract*— An Emotions Engine is a modelling and a simplification of the Brain circuitry that generate emotions. It should produce a variety of responses including rapid reaction-like emotions as well as slower moods. We introduce such an engine and then propose a framework for its translated equivalent for a robot. We then define key issues that need addressing and provide guidelines via the framework, for its implementation onto an actual robot's Emotions Engine.**

I. Introduction

Modelling any the brain functions is both challenging and complex. To come up with a convincing model that is a good enough representation of the brain is impossible without some simplification and a focus on some aspects of the Brain functions. While there is evidently interest in understanding and modelling the whole range of brain functions (e.g. perception, regulation, cognition...) for the sake of achievability it is important to compromise on the granularity of the model and at the same time to constrain the model to a narrow-scope representation.

Currently, we focus on modelling an Emotions, as developed for a robot. There are clear motivations for doing so, as stated in the literature (e.g. [1,2]). Notably to ease the communication between the user and its robot via emotional expressions displayed by the robot. Also to create a pet-owner relationship, if the robot can behave in a way that its gait, postures, motions and noises, driven by emotions, are akin to those of a pet animal. We also envision emotion as one of the decision mechanisms the robot can rely on, particularly in case of insufficient or ambiguous information about a task or a situation.

A. *Understanding Emotions*

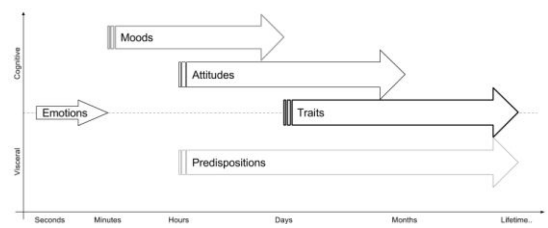
There has been a wide variety of definitions given to the concept of emotions. Some have associated them with decision making [3], other as a regulatory mechanism of behaviour [4], or cognition [5], finally as a mean to connect sensory inputs with action planning and action execution [6]. The consensus is that emotions are a fundamental part of our cognitive and behavioural capabilities. Emotions play a continuous role in defining who we are as individuals. The expression of emotions is essential in the social interaction that we take part into everyday. Body language, facial expressions and other non-verbal communication channels are used in conjunction with our spoken discourse to express emotions and emotional responses that we all experience.

There have been many attempts at defining emotions within the context of robotics. Notably and to list just a few, work on sociable humanoid robots [7], socially interactive robots [8,9,10], entertainment robots [11,12], pet-type robot [13], a neurocognitive affective system [14], an emotional engine [15], and for Human-Drone Interface [16]. Unfortunately, across the literature, there is a lack of consistency as to what an emotion is.

II. Some Definitions

Within the limited scope of this paper, one of an Emotions Engine for a robot, we will rely on the following definitions (see Fig. 1).

Figure 1. Emotions and other key concepts



1) *Emotions*

To give a comprehensive and widely accepted definition of emotions is rather challenging. However we propose a definition, which is limited in scope to the topic of this paper, of an emotion as: *A self-centred, instant to lasting* ***combination of a reflexive response and a cognitive appraisal of changes****, triggered by system-wide internal dynamics as a result of both internal and external events*. Such a definition is compatible with classical definitions (see for example [17]).

Basic emotions are those identified in the functional neuroanatomy of the human brain. These emotions are localised in specialised regions of the brain, these have been recognised as: Happiness, Sadness, Disgust, Fear, and Anger (see [17,18]). From a psychology perspective a similar identification can be found in some literature (e.g. [19]). Alternatively, emotions can be classified as basic, if they are communicated via universally recognised facial expressions. Anger, Surprise, Disgust, Happiness, Sadness and Fear were accordingly classified as such [20].

2) *Moods*

A mood is defined as a prevailing and relatively lasting emotional quality that is experienced over a longer period than an emotion, more pervasively and with less focus. It is more diffuse, of a lower intensity and less salient than an emotion [21]. In contrast to emotions, moods have slow dynamics and do not necessarily have a specific cause.

3) *Traits*

It is a key part of an individual personality. It is a set of a life-long, or at least enduring, affective biases, attitudes and predispositions. Traits include for example optimism,

B.S. is at the School of Engineering, University of Liverpool, L69 3GH, UK (corresponding author phone: +44 7971 199 164; e-mail: mail@bsalem.info).

extraversion, neuroticism, and flexibility. Fig. 1 illustrates the relative short duration of an emotion.

III. THE HUMAN BRAIN EMOTIONS ENGINE

An understanding of the functional neuroanatomy of the brain helps comprehend the challenge of defining emotions [23, 2]. To somewhat attempt to do so, Fig. 2 illustrates a simplified architecture of the brain overall emotion pathways. While it is important to emphasise that the architecture is a simplification, it nonetheless demonstrates that different and specialised parts are all interacting together within the brain's Emotions Engine. Some parts play a role in the detection and sorting of stimuli, a sort of triage of the inputs, other parts play a role in the conscious or the unconscious processing. Finally and key to an emotional response there is an appraisal at a central level of the emotional stimuli, as illustrated in Fig. 2.

Figure 2. Overview of the Human Brain Emotion Pathways

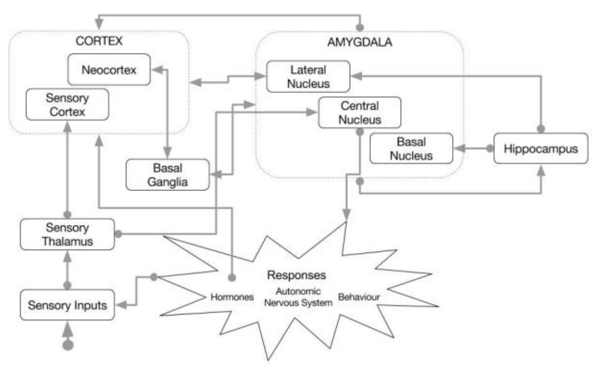
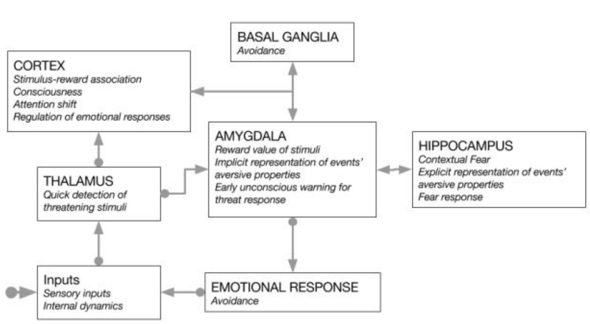


Fig. 3 provides a more simplified overview; it is made up of seven Brain areas, corresponding to key features of the Brain Emotion Pathways. It is important to bear in mind that the following explanations are simplifications, which are acceptable within the scope of this paper. Starting from the Inputs, both sensory inputs and internal dynamics are at the origin of emotions (as well as some of the emotional responses that feed back into the pathway). The inputs are then processed by the Thalamus for the detection of threatening stimuli (e.g. flight or fight). The Thalamus projects into the Amygdala for early response to threat particularly fear. The Thalamus project to the Cortex as well, where a more sophisticated and slower processing occurs for reward, attention shift and regulation of emotional responses. Both the Cortex and the Amygdala project to the Basal Ganglia, the centre of avoidance.

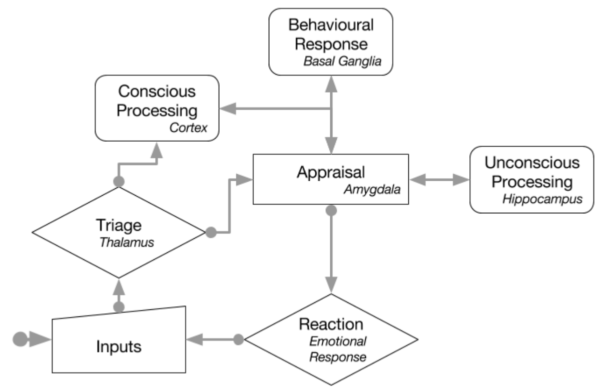
Figure 3. Simplified architecture of Brain Emotion Pathways



The Amygdala projects to the Hippocampus as well, it is an area dedicated to the processing of fear and its context. Finally from the Amygdala are projections to different centres of emotional responses: hormones, Autonomic, and motor responses.

Interestingly, the centres of emotional responses are to be found in the Autonomic and Enteric nervous systems, in the Sympathetic and Parasympathetic Divisions, as well as in the Premotor and Motor Cortex. These centres produce autonomic, endocrine, and muscular responses, thus clearly distinguishing Emotions from purely cognitive processes [22].

Figure 4. Simplified Control Architecture of the Brain Emotions Engine



A further simplification the control architecture of the Brain Emotions Engine is illustrated in Fig. 4. Inputs are fed into a triage module, that projects into an appraisal unit, and a conscious processor. The conscious processor projects into a behavioural response unit and both into the appraisal unit, which is connected to an unconscious processor. The outcome is then projected into the centres of emotional responses to produce outputs.

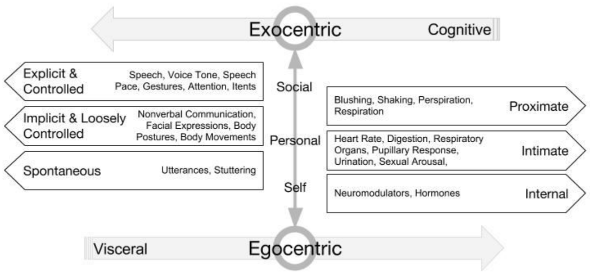
The Brain Emotions Engine can be looked at differently; we propose next to translate the architecture into its resulting flows of changes (in other words the outputs from the engine).

A. *The Brain's Emotion Dynamics*

We call Emotion Dynamics the combination of changes from visceral to cognitive elements of the Brain that contribute to different degrees to the production of emotions. Fig. 5 illustrates the different elements from the visceral, which produce internal, intimate and proximate emotion responses. The figure also includes cognitive elements that produce spontaneous, implicit and explicit responses. Visceral responses are primarily egocentric, while cognitive responses are primarily exocentric (here, for the sake of simplification, we exclude inner thoughts about one's own emotions).

Visceral responses include Internal, Intimate, and Proximate dynamics. Internal dynamics relate to hormones that are distributed in the bloodstream and neuromodulators that are diffused in various brain regions. These changes have a direct effect on the brain functioning and on the intimate changes that the body will experience. These changes in turn can have an effect on behaviour and actions as they can hinder or alter the normal functioning of the body. These dynamics results in changes that are experienced by the individual involved: Blushing, shaking, perspiration, changes in respiration and body postures. Others, within proximity, can perceive these changes.

Figure 5. Simplified Overview of the Brain's Emotion Dynamics



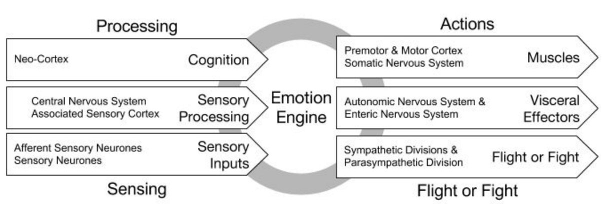
Cognitive responses include spontaneous, implicit, and explicit dynamics. Spontaneous dynamics relate to hindrances to communication skills, such as momentary speech difficulties, these expand into implicit dynamics, such as postures, gait, and expressions. Finally Explicit Dynamics relate to changes in the tone of speech, hand gestures, speech content, attention and intent. These are the modalities with the highest semantic content.

At this stage, it is possible to revisit the combination of pathways and dynamics into a simplification of the Brain Emotions Engine.

B. *The Brain Emotions Engine*

A Brain Emotion Engine should be understood as a multi-level simplified representation of the functional anatomy of the Brain emotional pathways, with emphasis on Inputs and Outputs. Fig. 6 illustrate the proposed Engine, where Inputs include sensory inputs, Sensory processing, Cognition. As for the Outputs, they are made up of Flight or Fight preparedness, Visceral and Muscular changes.

Figure 6. Simplified overview of the brain Emotion Engine



At the centre of the Engine is the processing of Inputs, and the generation of Outputs. Here the Engine should be understood as the combination of the Brain regions dedicated to the Inputs, to the Outputs as well as to the connections between them via the Brain Emotion Pathways.

Having introduced a simplified representation of the Brain Emotions Engine, the next step is to translate such an understanding into an Emotion Engine for a robot.

IV. EMOTIONS ENGINES

Within a Robot context, an Emotions Engine is relevant in the following domains: Internal Processing, External Processing, Behaviour, and Expression. The Internal Processing domain includes all the processing and merging of the internal data such as the power supply level, the control feedback of the motors, the sensors that relate to the robot operation, such as temperature, strain, weight distribution.

The External Processing domain specialise in the processing and merger of proximity and distance sensors, location and orientation, interaction with the user, attention, and actions' planning.

The Expression domain relates to postures, movements, sounds and appearance of the robot that are prototypical, predetermined, and closely associated with an emotion; as such there will be a limited set of emotions that can be expressed, and it makes sense to rely on a subset of emotions, the Basic Emotions.

The Behaviour domain is about the Robot's Gait, Speed, Reaction Times, and the likes. Unfortunately, unlike humans, there is no one to one mapping of the Behaviour into emotions. It is more akin to various sets of behaviours (e.g. choreographies) associated with different emotions.

A. *Similar Work*

There has been some previous work related to the development of Emotions Engines. The Kismet Emotion Engine is integrated with the cognitive and motor systems of the robot [1]. It relies on the recognition of affective qualities of speech, and indirectly via the cognitive system, on attention, drives, and behaviour. The Engine then outputs an emotional expression to the motor system.

The Artificial Emotion Engine architecture includes several interconnected modules [23]. The sensory Inputs are fed into the self-state module, which project to the punishment and rewards module. The latter is interconnected with the memory, motivations, mood, personality, and emotional reactions modules. The self-state module represents the current emotional state and is connected to outputs.

Inspired from a dog's basic emotion and behaviour, an Emotion Engine based on a discrete state model is proposed [15]. The engine represents emotions as a discrete sequence of events in time. It includes short, medium, as well as long-term emotional responses.

The EmotiRob is a robot with an emotion interaction module that includes Emotional Experience Selector (actions and concepts), Emotional Experience generator (emotive experiences, scheduler), Moderator (Influence, character and history) and Behaviour (reactions and modulator) modules [24]. The outputs of the emotion interaction module are voice tones, postures, and facial expressions of the robot.

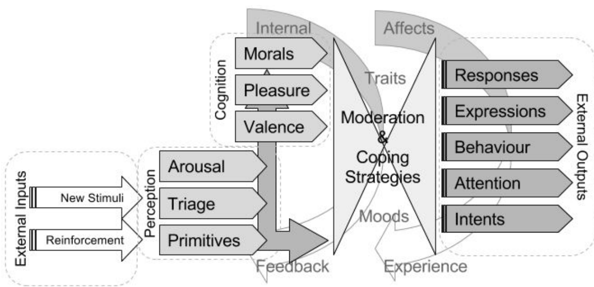
These examples have delivered some success, however, there are sparse explanations on the working principles of the engines and in particular their source of inspiration from the Brain.

V. FRAMEWORK FOR AN EMOTIONS ENGINE

We propose a framework that defines guidelines and requirements for an Emotions Engine, as well as explicitly connects with the Brain working principles as reviewed in previous sections of this paper (see Fig. 7).

The proposed framework should be understood as a tool for the design, development, and implementation of an Emotions Engine. It framework includes several modules that are correlated, interdependent and should be considered in various combinations depending on the desired outcome. It implements elements from existing appraisal and dimensional Models of emotions (see details in respective sections).

Figure 7. Framework for an Emotions Engine



The framework is made of the following modules: A. External Inputs, B. Perception, C. Cognition, D. Moderation and Coping Strategies, E. External Outputs, and F. Internal Outputs. In this version of the framework, both Short and Long Term memories are not represented. They are connected to the Engine via Internal as well as the External Outputs. Furthermore, the framework is such designed that A, B and E are part of the External Processing, C, D and F are part of the Internal Processing, E is also part of the Behaviour and Expression domains (in relation to section IV). In the following sections some of the modules are further explained:

A. *External Inputs*

Here external is relative to the Emotions Engine and includes both Robot's related sensory information as well as proximal and distal environment information. User inputs are also to be included here, alongside with outputs from the Robot processors that have relevance to the current task (e.g. previous outputs).

B. *Perception*

The perception of emotion is based on the anatomic model of emotions (e.g. [25,26]).

1) *Primitives*

The primitives relate to the basic emotions as identified in the functional neuroanatomy of the human brain (see [17,18]), they are revisited in the context of a robot and listed in Table I.

TABLE I. PRIMITIVES DIMENSION OF THE FRAMEWORK

	Proposed Purposes	***Examples***
Happiness	Succesfull outcome or completion of a task	Mission complete
Sadness	Unsuccesful or ambiguous outcome of a task	Mission cannot be completed
Disgust	Unexpected External Problem	Obstacle preventing an action
Fear	Dangerous situation where the robot is operating	Collapsed structure
Anger	Unexpected Internal Problem	Jammed moving part

While a set of five emotions is a clear limitation, these are primitives that directly result in specific outputs from the engine. This is inspired from the Basic Emotions that are localised in specialised regions of the Brain. These primitives have specific triggers (in the context of a robot) described in Table II. The triggers were selected from a scenario of a robot performing a specific task according to some user instructions. These emotions are necessary and sufficient to allow for the performance and completion of the task, they are inspired from theories and models of emotions [27-30].

TABLE II. TRIGGERS OF PRIMITIVES

Triggers[a]	**Emotional Outputs**				
	Hap.	***Sad.***	***Dis.***	***Fear***	***Ang.***
Power Supply	+	-	⊘	-	⊘
Task Urgency	-	-	++	++	+
Agency	+	⊘	--	⊘	-
Task Control	+	--	--	⊘	+
Adaptation to Task	+	--	--	--	+
Task Outcome certainty	+	++	++	+	++
Task successful Outcome	+	--	--	--	--
Scenario Novelty	+	-	++	+	+
User Feedback	+	-	⊘	⊘	⊘

a. As inspired by [27,28, 29, 30]. ++ Very High + High, - Low, -- Very Low, ⊘Not Applicable

2) *Triage*

The main purpose of the triage is to rank the external and internal inputs in terms of range, duration, and intensity. It is dedicated to the detection and prioritisation of fast changing, high relevance inputs. It also ensures that sufficient weight is given to user interaction. The triage is conducted via Tuning (of external event with weighting in relation to range duration and intensity), Conversion (of inputs with different characteristics such as continuous vs. discrete), and sorting (e.g. order of priorities, timings, values). The triage will also process the triggers in table II. This later function has to be understood as part of a translation of the early response mechanism of the Brain.

3) *Arousal*

The Arousal is based on the Dimensional Model of emotions, specifically parts of the Circumplex Model [27,28]. It has five levels, as explained in Table III, in relation to the External Outputs: **R**esponse, **E**xpression, **B**ehaviour, **A**ttention, and **I**ntent.

TABLE III. AROUSAL DIMENSION OF THE FRAMEWORK

Arousal levels	**External Outputs**				
	R	***E***	***B***	***A***	***I***
V. High	R/T	C	Adapting	Shifting	D
High	R/T	HF	Adapting	Shifting	Ch
Moderate	Latent	MF	Efficient	Local	Ch
Low	Latent	Periodic	Efficient	Local	Fixed
Very Low[a]	None	Periodic	At Rest	Global	None

a. When the Robot is Idle. C Continuous, HF High Frequency, MF Medium Frequency, D Dynamic, Ch Changing, R/T Real Time

In table III, A very high state of arousal results in a real time Emotional Response, a continuous Emotional Expression, an adaptive Behaviour, a shifting Attention and a Dynamic and changing intent. Within the proposed scenario, the arousal should be understood at the pace at which events occur.

C. *Cognition*

The cognition of emotions proposed in the framework is based on a combination of the Appraisal Model of emotions [29,30], and part of the Dimensional model – The Circumplex Model [27,28]. It includes Valence, Pleasure and Morals, and is a partial translation of the Brain circuit's conscious and unconscious processing elements. There is however, an overlap of the Dimensional model (namely the evaluation of arousal), with the perception of emotion part of the framework.

Tables IV and V show what influence Valence and Pleasure dimensions have on the engine's External Outputs. The items from table II are used as triggers for changes in the valence. The tables show the effects of the changes in the triggers in the external outputs of the framework. For examples, a decrease in the power supply will results in a similar decrease in the Emotional Response and Expression, a change of Behaviour from adaptive to efficient. It also results in a focus of Attention, and a change of Intent from dynamic and changing to fixed and focused, it does so in order to save energy while completing a task.

TABLE IV. VALENCE DIMENSION OF THE FRAMEWORK (IN ORDER OF PRECEDENCE)

Triggers	External Outputs				
	R	***E***	***B***	***A***	***I***
Power Supply[a]	±	±	A|E	S|Fc	D|Fx
Task Urgency	±	±	A|E	Fc|G	Fx|D
Agency	±	±	A|E	Fc|L	Fx|C
Task Control	-|+	-|+	E|A	Fc|S	Fx|D
Adaptation to Task	±	±	A|E	S|Fc	D|Fx
Task Outcome certainty	±	±	E|A	Fc|S	Fx|D
Task successful Outcome	±	±	E|A	Fc|S	Fx|D
Scenario Novelty	±	-|+	A|E	S|Fc	D|Fx
User Feedback	±	±	A|E	S|Fc	D|Fx

a. We ignore the case where power supply collapses. ± Positive correlation, -|+ negative correlation, A Adaptive, D Dynamic, E Efficient, Fc Focused, Fx Fixed, G Global, L Local, S Shifting.

Pleasure and morals are obviously more abstract concepts. Within the proposed scenario, it makes sense to relate pleasure to the robot's performance of a task as well as to the user's satisfaction of such a performance. For example, for the pleasure dimension, an increase in Efficiency results in a decrease of Emotional Responses and Expressions, a more parsimonious Behaviour, as well as a focused Attention and Fixed Intent.

As for morals, we relate them to the overall performance of the robot and its context. Criteria such as user satisfaction, the robot's integrity, the sharing of date, should be considered.

TABLE V. PLEASURE DIMENSION OF THE FRAMEWORK (IN ORDER OF PRECEDENCE)

Criteria	External Outputs				
	R	***E***	***B***	***A***	***I***
Efficiency	-|+	-|+	-|+	S|Fc	D|Fx
Effectiveness	-|+	-|+	A|Fx	Fc|G	Fx|D
Task success	±	±	⃠	Fc|G	Fx|C
Sensor Merger	±	±	±	G|Fc	⃠
Routine Task	±	±	A|E	⃠	⃠
User Satisfaction	±	±	E|A	⃠	Fx|D

C Changing.

D. *Moderation & Coping Strategies*

Two parameters influence the Moderation and Coping Strategies of the Emotions Engine (here we revisit their definitions from section II) :

1) *Traits & Moods*

Traits are combining long-term memory, and user requirements. They provide a bias to the engine as a weighting given to the outputs. Resulting in a tendency towards some emotions rather then others (e.g. Happiness and Sadness rather than Disgust and Anger). At the same time, the moods are made up of short-term memory (e.g. last emotions rendered), as well as user interaction with the robot. They help define the default emotion rendered by the robot. Both Traits and Moods influence the Emotions Engine External Outputs, they should be seen as a partial translation of the Conscious and Unconscious processing functions of the Brain.

E. *External Outputs*

These are the outputs from the Emotions Engine that go beyond the engine into the reminder of the robot functions (e.g. control, and task performance). These are also the outputs that user can perceive and act upon. The emotional responses as well as the emotional expressions described in the next section are relying on the Communicative theory of emotion (e.g. [31]). Table VI list the outputs as well as some explanations.

TABLE VI. EXTERNAL OUTPUTS DIMENSION OF THE FRAMEWORK

	Focus on	***Examples***
Emotional Responses	Changes such as apperance and background noises	Colour
Emotional Expressions	Prototypical and predetermined changes	Posture
Behaviour	Changes in Gait, speed, reaction-time	Pace
Attention	Changes in sensory data gathering	Orientation
Intent	Changes in task planning	Path Planning

F. *Internal Outputs*

1) *Feedback*

One of the key roles of the Internal Feedback is to provide for system-wide regulation and preparedness. The resulting effect of the Internal Feedback is that of biasing Moderation and Coping Strategies via Short-Term Memory (what has just happened) and Long-Term Memory (what has usually happened, or happened a while ago).

2) Affects & Experience

The experience of emotion depends on the intensity, the context dependence, the object of focus, and the time duration of the emotion. The Affect is the combination of the experience with qualities of the user interactions that are relevant to the engine (Interaction scope, frequency, duration), efficiency and effectiveness of the interaction as well as the complexity and outcome of a current task. The resulting effect of Affects and Experience is that of biasing cognition and Long-Term Memory.

VI. CONCLUSION

We have proposed a Framework for an Emotions Engine that is a combination of various approaches to the understanding of Emotions. The Anatomic, Dimensional, Appraisal, Communicative, and Behavioural understanding of Emotions all made a contribution to the framework. While there are many shortcomings to the current version of the framework, it is an attempt at providing a tool and a set of guidelines for the development of a Robot's Emotions Engine.

Future work will focus on refining the framework, notably the Morals, Affects and Experience Modules. These have been the most challenging ones to comprehend and translate for implementation into a robot's Emotion Engine. The framework is being used as a design and evaluation tool for an Emotions Engine co-currently in development, whereby the framework helps formulate the specifications and define the architecture of the engine. Developing such an engine will, it is hoped, help refine and validate the framework.

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