On TAMEing Robots[*]

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Abstract - ***This paper presents a framework for affective robotic behavior (TAME) and describes an exploratory experimental study to identify relevant affective phenomena to include into the framework in order to increase ease and pleasantness of human-robot interaction.***

Keywords: Human-robot interaction, computational models of emotion and personality.

1 Introduction and Motivation

The recent decade has seen an upsurge of interest in affective computing; in particular, a number of computational models of emotion have been built and applied in a variety of artificially intelligent systems. In part, this interest was brought about by the growing importance of the idea of social interaction between humans and computers (be it interfaces, autonomous agents, or robots), and the acknowledgement that people treat computers as social actors [17], preferring to interact with agents that are expressive, at least in the entertainment domain [11]. These studies suggest that enabling machines to produce affective behaviors can be beneficial to human-machine interaction.

At present, we know of no computational models that capture the broad interaction between a wide range of time-varying affect-related phenomena, such as personality traits, attitudes, moods, and emotions. In humans, each of these components performs a distinct adaptive function and is characterized by a set of specific features potentially useful in the robotics domain. In particular, providing autonomous robots with easily recognizable affective cues may facilitate interaction and reduce cognitive overload associated with robot-human communication in complex environments.

This paper presents an integrative framework for affective robotic behavior, TAME, in which the aforementioned phenomena are modeled as separate components with explicitly defined interactions. TAME stands for Traits, Attitudes, Moods and Emotions, the four components of the Personality and Affect module that is responsible for producing affective behavior.

In order to identify the most relevant phenomena to include within TAME an experimental study is being conducted, which explores the complex interactions between an autonomous robot, a Sony AIBO robotic dog, and human subjects acting in an owner-dog bonding scenario, in order to identify the key aspects that contribute to an increase in user ease and pleasantness of human-robot interaction.

2 Related Work

One of the first fully developed social robotic systems is Breazeal's robotic creature Kismet [5]. Kismet is modeled after an infant, and is capable of proto-social responses, providing an untrained user with natural and intuitive means of communication. Kismet's motivation system consists of drives and emotions, where emotions are a result of its affective state. The affect space is defined along three dimensions: arousal, valence and stance; each emotion is computed as a combination of contributions from drives, behaviors, and percepts. The motivation system plays a role in the behavior selection process and attention selection process, and also provides activation for facial emotional expressions.

Kismet's emotion system is based, to a large extent, on Velasquez's Cathexis model [21]. Velasquez proposes an emotion-based approach to robotics and extends the role of emotion to range from emotional expression for communication purposes to serving as a determining factor in decision-making processes [22]. His model includes multiple mechanisms of emotion generation, based on Izard's [10] four types of elicitors of emotion in humans: neural, sensorimotor, motivational, and cognitive. This model can synthesize a number of emotions simultaneously, and allows for a number of different affective behaviors to be active at once.

Miwa, Takanishi, and Takanobu [15] proposed the notion of Sensing and Expression Personalities for a

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humanoid robot to achieve smooth and effective communication. Sensing personality provides a mapping from sensory input to emotion generation, and expression personality determines a particular emotional expression. Similar to Breazeal's work, emotion space is defined along three dimensions (with certainty replacing stance); however, unlike in Kismet, personality traits are used to bias emotion generation and expression.

Other related research in robotics includes modeling feelings and emotions based on an "internal secretion system" [18], mass psychology-based emotional group behavior [9], motivation and emotionality in a robotic pet [3], and utilizing emotional expression in spontaneous, short-term interaction in a museum tour-guide task [20]. Finally, there exists a large body of affect-related work in the domain of animation and autonomous agents, such as Koda's [11] poker-playing agents, the Oz project by Bates, Loyall and Reilly [4], Elliot's "Affective Reasoner" [7], Moffat's [16] Will system, and others.

3 Architectural Framework

To the best of our knowledge, none of the existing robotic or autonomous agent systems makes an attempt to integrate the entire affect-related space into a single model with explicitly defined interactions; in fact, most of these systems are emotion-centric, and tend to ignore such affective phenomena as moods, affect-based attitudes and personality traits. We contend that it is beneficial to incorporate these additional affective components to enhance human-robot interaction, general decision-making, and behavior-selection processes.

3.1 Overview and Psychological Foundations

As there exists no single unified theory of affect-related phenomena, the model of Personality and Affect presented in this paper takes inspiration from a number of related theories of personality, mood, emotion and attitudes. Moreover, even if such a single psychological theory did exist, it might not be directly applicable or useful in the robotics domain. The model presented here, therefore, is not intended to be a cognitive model of affect and personality, but rather to serve as a framework for modeling personality and affect in behavior-based autonomous robotic systems.

In the behavior-based paradigm, a robot's control program consists of a collection of behaviors and coordination mechanisms [1]. Primitive behaviors have a set of defining parameters (e.g., obstacle avoidance sphere-of-influence) and these behaviors can themselves be combined into behavioral assemblages, where each of the primitive behaviors' outputs is weighted and combined, resulting in coherent motor actions. Perceptual input not only serves as stimuli for behaviors, but also produces transitions between assemblages.

The Personality and Affect Module is composed of four interrelated components: Personality Traits, Attitudes, Moods, and Emotions (TAME). The input into this architectural module consists of relevant perceptual information, such as the categories of visible objects and distances to them (stimuli and their strengths). Instead of directly defining behavioral transitions, the personality and affect module rather modifies the underlying behavioral parameters, which, in turn, directly affect currently active behaviors. The conceptual view of the model is presented in figure 1.

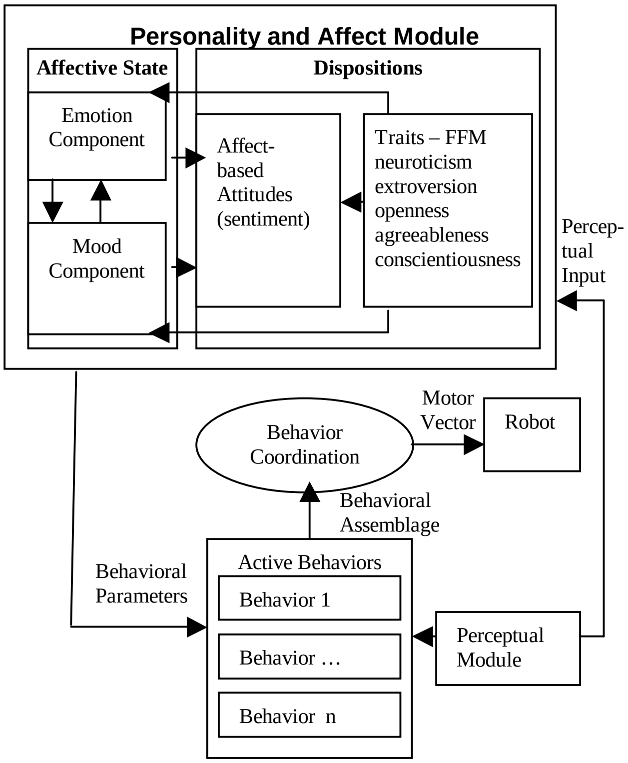

Figure 1: Integrated Model of Personality and Affect (TAME)

Emotions and moods represent the dynamically changing robot's affective state (high-activation and short-term for emotions, and low-activation and prolonged for moods). Traits and attitudes are more or less time-invariant, and define general dispositions. Each of these four components performs a distinct adaptive role (not limited to what is described below): traits serve as an adaptation mechanism to specialized tasks and environments; emotions mobilize the organism to provide a fast response to significant environmental stimuli; moods bias behavior according to favorable/unfavorable environmental conditions; and attitudes guide behavior towards desirable goals and away from aversive objects, as well as facilitate decision-making by reducing the decision space. For example, the "fight or flight" response (the choice between fleeing or fighting behavior in a threatening situation) may be viewed as being affected by traits (e.g., neuroticism and agreeableness) which determine fear and anger intensities, and also the emotions themselves based on the current incoming stimuli.

Each component is defined as Category/Intensity pairs, where category refers to the type of the component (e.g., extroversion for Traits, or fear for Emotions), and where intensity is the extent to which the associated category is expressed. Below are summary descriptions of each component:

Trait Component. The Five-Factor Model (FFM) of Personality developed by McCrae and Costa [14] serves as the basis for the trait component. The five dimensions of the FFM are: *Openness (O), Agreeableness (A), Conscientiousness (C), Extroversion (E), and Neuroticism (N).* Personality traits, according to [13], are mainly inherited or imprinted by early experience, and in the TAME model traits are viewed as constant, operator-defined values prior to execution. Traits influence a wide range of behavior, and are not limited to emotionally-charged situations.

Emotion Component. According to Watson [24], emotion is an organized reaction to an event that is relevant to the needs, goals, or survival of the organism; is short in duration and noncyclical; and is characterized by a high activation state and significant energy and bodily resources expenditure. A typical core set of emotions includes joy, interest, surprise, fear, anger, sadness and disgust. These are recognized by a number of theorists, such as Ekman, Friesen, Izard, Plutchik and Tomkins [24]. Emotions are continuously and dynamically generated as emotion-eliciting stimuli are detected.

Mood Component. According to Watson [24], mood is a continuous variable affective state that represents low activation state and is less intense, thus expending less energy and bodily resources than emotion. The two categories of moods are positive affect and negative affect, which are fairly independent of each other [24]. Moods are mainly stimulus-independent, and exhibit cyclical (circadian) variation according to time of day, day of the week, and season.

Attitude Component. Attitude can be defined as a "learned predisposition to respond in a consistently favorable or unfavorable manner with respect to a given object", [6] and as "a general and enduring positive or negative feeling about some person, object or issue" [6]. Thus, attitudes are relatively time-invariant ("enduring"), object/situation specific, influenced by affect, and result in a certain behavior towards the object.

To summarize, each component occupies a distinct position in the two-dimensional space defined by duration and specificity [12, 16]. Traits and emotions are at the opposite ends of the spectrum: traits are life-long, stable over time, and global (independent of specific objects/events), whereas emotions are short-term, dynamically changing and focused; and moods and attitudes occupy the intermediate positions (fig. 2).

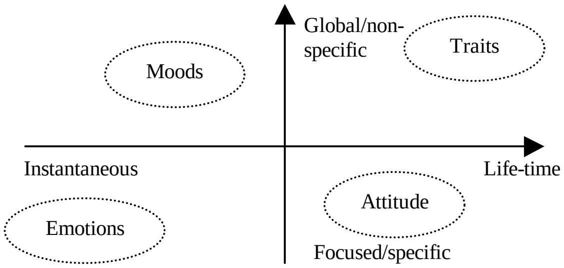

Figure 2: Components Relative to Specificity and Time

3.2 Integration into AuRA

To test this approach, a partial integration of the personality and affect module into the *MissionLab* system was undertaken, which is a version of *AuRA* (Autonomous Robot Architecture) [2]. This hybrid architecture consists of a low-level schema-based reactive behavioral control system combined with a high-level deliberative component.

On the reactive level, each TAME component is implemented as a set of primitive behaviors; however, unlike motor schemas, these affective behaviors do not output motor vectors, but instead change the control parameters for the corresponding active motor schemas. Each component of the model is implemented as a separate FSA, (except for the Trait Component which is a part of the high-level plan) and runs as a separate thread continuously throughout the execution. We also plan to use the output of TAME to guide action selection in the future. The modification of the behavioral control parameters is described below.

First, how personality traits influence relevant behaviors is described. Prior to execution, the user defines a personality configuration by selecting a percentage to which each trait is represented, with 0% representing the absence of a trait, and 100% representing its maximum (saturation). For example, a low value of Neuroticism signifies that an individual is calm, unemotional, and has low avoidance tendencies, as opposed to being fearful, worrisome and having a high tendency to avoid negative stimuli. In a mobile robot, a higher level of Neuroticism may be expressed as exhibiting more prominent obstacle avoidance (i.e., keeping a greater distance between robot and obstacles). As a simplifying assumption, personality traits are independent of each other.

As each behavioral gain/parameter may be affected by more than one trait, we need to define the combined personality value affecting a behavior. First, we define a dependency matrix $\mathrm{T} = [\tau_{ij}]$, which specifies the presence/absence and direction of influence of personality traits on behavioral parameters. $\tau_{ij} \in \{-1,0,1\}$, where 0 signifies absence of trait influence, +1 means direct influence, and -1 is inverse influence. For example, the trait of agreeableness may affect MoveToObject behavior in an “attack” situation inversely: the larger the intensity of agreeableness, the less MoveToObject is exhibited. The intensity/weight of each trait is user defined, and is specified in the following matrix: $\Omega = [\omega_j]$, $-\infty < \omega_j < \infty$ (0 weight signifies average, or normal intensity of a trait). A weighted summation of personality traits is utilized, affecting a particular behavioral parameter:

$$\Pi_i = \sum_{j=1}^{p} \tau_{ji}\omega_j \qquad (1)$$

where Π_i is the combined personality value for parameter i, T is the trait dependency matrix, Ω is the trait intensity matrix, and p is the number of traits in Ω.

As there are no specific psychological data on how each personality trait affects particular behaviors, it is intended that the exploratory study described in Section 4 will shed some light on which traits are relevant to which behaviors, and what weights are reasonable in the case of multiple trait affecting the same behavior.

As trait values remain invariant throughout execution, the corresponding behavioral gains/parameters are computed only once at the beginning of execution. The new trait-based values modify the default values:

$$B_{i,new} = B_{i,def} + \Pi_i \qquad (2)$$

For practical purposes we generally restrict the range of behavioral parameters by forcing the new behavioral parameters to remain between minimum and maximum bounding values as follows:

$$B_{i,new} = \left\{ \begin{array}{ll} B_{i,\max}, & if \ B_{i,new} \geq B_{i,\max} \\ B_{i,\min}, & if \ B_{i,new} < B_{i,\min} \end{array} \right\} \qquad (3)$$

where $B_{i,new}$ is parameter/gain replacing the default value, $B_{i,\max}$ is the bounding maximum value for parameter i, and $B_{i,\min}$ is the minimum bounding value for parameter i.

We employ a simple linear relationship initially. However, more complex exponential or threshold relationships may be defined if proven more plausible through our experiments, or if more data becomes available.

Looking at an example of obstacle avoidance, the magnitude of the obstacle avoidance vector is defined as follows:

$$O_{magnitude} = \left\{ \begin{array}{ll} 0, & if \ \ d > S \\ \dfrac{S-d}{S-R} G, & if \ \ R < d \leq S \\ \propto, & if \ \ \mathrm{d} \leq \mathrm{R} \end{array} \right\} \qquad (4)$$

where S is the default sphere of influence, *R* is the radius of the obstacle, G is the default avoidance gain, and *d* is the distance of robot to center of obstacle. In the following examples we use *G* instead of B_G, and *S* instead of B_S, to represent the parameters of obstacle avoidance gain and sphere of influence, respectively.

The Personality dimension of Neuroticism has been found to influence avoidance behavior [8], which in case of a mobile robot may be expressed as a tendency to stay away from obstacles. The obstacle avoidance gain *G* is therefore affected by this trait only: it grows as the value of Neuroticism increases. If the user specifies that the intensity of N = 5, then Π_G is computed as follows:

$$\Pi_G = \sum_{j=1}^{5} \tau_{jG}\omega_j = \tau_{NG}\omega_{\mathrm{N}} = 1 * 5 = 5$$

where Π_G is the combined personality value for the obstacle avoidance gain; T is the trait dependency matrix, and Ω is the trait intensity matrix.

Assume the default value of G is 3. The new obstacle avoidance gain is then:

$$B_{G,new} = B_{G,def}\Pi_G = 3 + 5 = 8$$

For the purpose of illustration, suppose that the sphere of influence S is affected by two personality traits: Neuroticism (N) and Agreeableness (A), with N having a direct influence, and A an inverse one. Thus N's value in the dependency matrix is 1, and A's is 0. If the user specifies N's intensity as 3 and A's intensity as 2, then Π_S is computed as follows:

$$\Pi_S = \sum_{j=1}^{5} \tau_{jS}\omega_{jS} = \tau_{NS}\omega_{\mathrm{N}} + \tau_{AS}\omega_{\mathrm{A}} =$$
$$= 1*3 + (-1)*2 = 1$$

Given G's default value of 5, the new sphere of influence is:

$$B_{S,new} = B_{S,def} + \Pi_S = 6$$

Once the new parameter values are computed, the default values in the obstacle avoidance equation are replaced by the new trait-based values, leaving the rest of the equation unchanged. The new equation to be used subsequently during the robot's execution is as follows:

$$O_{magnitude} = \begin{Bmatrix} 0, & if\ d > 6 \\ \dfrac{6-d}{6-R}8, & if\ R < d \le 6 \\ \infty, & if\ \mathrm{d} \le \mathrm{R} \end{Bmatrix} \qquad (5)$$

Emotion values are not user-defined, but are dynamically generated throughout the execution based on the presence and strength of environmental stimuli. Similar to traits, an emotion can have no, direct, or inverse influence on a behavioral parameter. An emotion dependency matrix $\mathrm{E} = [\varepsilon_{ik}]$, where $\varepsilon_{ik} \in \{-1,0,1\}$ is defined. Each emotion's intensities are stored in the emotion intensity matrix: $\mathrm{I} = [\eta_k]$, where $0 < \eta_k < \infty$. Some emotions may reinforce each others behavioral response; e.g., both fear and disgust may be elicited by a certain aversive stimulus, and the overall response to the stimulus will be greater than that of each emotion alone. This combination is treated as additive. The overall emotion (affect) value A_i for a parameter i is computed as follows:

$$A_i = \sum_{k=1}^{e} \begin{Bmatrix} \varepsilon_{ki}\eta_k, & if \eta_k \ge h_k \\ 0, & if \eta_k < h_k \end{Bmatrix} \qquad (6)$$

where A_i is the overall emotion value affecting a behavioral parameter i ε_{ki} is the dependency matrix value of emotion k, η_k is the intensity of emotion k, e is the total number of emotions, and h_k is the threshold for emotion j above which the emotion starts influencing behavior.

As in the case of traits, new emotion-based values of behavioral gains/parameters replace the existing defaults in a similar manner, with the difference lying in the fact that the emotions, and thus the behavioral values, *change throughout the execution* based on the presence of incoming affecting stimuli:

$$B_{i,new} = B_{i,def} + \mathrm{A}_i \qquad (7)$$

where $B_{i,new}$ is parameter/gain replacing the default value, $B_{i,def}$ is the original default value, and A_i is the overall emotion intensity affecting parameter *i.*

As before, for practical purposes, the new behavioral parameter values are bounded as follows:

$$B_{i,new} = \begin{Bmatrix} B_{i,\max}, & if\ B_{i,new} > B_{i,\max} \\ B_{i,\min}, & if\ B_{i,new} < B_{i,\min} \end{Bmatrix} \qquad (8)$$

where $B_{i,new}$ is parameter/gain replacing the default value, $B_{i,\max}$ the bounding maximum value for parameter i, and $B_{i,\min}$ is the minimum bounding value for parameter i.

Consider an example of object avoidance behavior. This behavior is similar to obstacle avoidance behavior, but objects, as opposed to obstacles, are designated as emotion-eliciting stimuli (e.g., color-coded, with a color linked to a particular emotion). The magnitude of the object avoidance vector is defined as follows:

$$Obj_{magnitude} = \left\{ \begin{array}{ll} 0, & if \;\; d > S \\ \dfrac{S-d}{S-R} G, & if \;\; R < d \le S \\ \propto, & if \;\; \mathrm{d} \le \mathrm{R} \end{array} \right\} \quad (9)$$

where S is default sphere of influence, R is radius of the object, G is the default gain, and d is the distance of the robot to the center of the object in question.

An aversive stimulus may elicit both fear (F) and disgust (D), resulting in object (i.e., stimulus) avoidance behavior. Both of these emotions have a direct influence and are combined to produce a total emotion value affecting the avoid object gain. For example, if at a particular time step $\eta_F = 9, \eta_D = 4$, and both fear threshold h_F and disgust threshold h_D equal 4, then the total emotion intensity A_G affecting object avoidance is computed as follows:

$$A_G = \sum_{k=1}^{e} \left\{ \begin{array}{ll} \varepsilon_{kG}\eta_k, & if \;\; \eta_k \ge h_k \\ 0, & if \;\; \eta_k < h_k \end{array} \right\} =$$

$$= \eta_F(> h_F) * \varepsilon_{FG} + \eta_D(= h_D) * \varepsilon_{DG} = 9 + 4 = 13$$

Given the original default gain of 3, the new object avoidance gain is then:

$$B_{G,new} = B_{G,def} + \mathrm{A}_G = 3 + 13 = 16$$

The object avoidance gain G is computed similarly to obstacle avoidance gain from the previous example, where A_G is used instead of Π_G, and is then substituted into the above equation for object avoidance vector magnitude calculation.

For simplicity, we assume that the set of gains/parameters affected by traits is different from those affected by emotions, and that personality effect on emotional behavior is indirect – i.e., it influences emotion generation rather than the behaviors themselves.

4 Exploratory Experimental Study

In order to identify the most relevant affective phenomena that facilitates interaction between humans and autonomous robots in real-life situations a longitudinal experimental study has been designed. It focuses on the human participants forming an emotional connection with a robot in a series of interaction sessions.

The IRB-approved study is set up as a "robot as pet and personal protector" scenario. A Sony entertainment robotic dog, AIBO ERS-210A, is used, which has 20 degrees of freedom and a number of expressive features, such as variable gaits, movable mouth, ears, and tail. The robot's role as a pet and personal protector allows the exploration of relevant phenomena in a relatively constrained domain. In this longitudinal study, the subjects participate in four 25-45 minute interaction sessions. During each session, the participants are asked to interact with the robot by petting it, playing with it, addressing it, and otherwise engaging with it to help establish the pet-owner relationship. To focus their interaction, the subjects are asked to perform certain tasks, with a new task introduced each session. In particular, the participants make the dog perform the following commands: "follow me" (the dog follows the user around), "come to me" (the dog approaches the user and stops), "follow the pink ball" (the dog follows a small toy ball around while the user is pushing the ball), and "kick the pink ball" (the dog approaches the ball and kicks it). During the third session an "unfriendly stranger" is introduced (another small robot, an Amigobot, in this case) to test the robot's role as a protector. At the user's command, the dog should intercept the stranger thus "protecting" the user. Finally, during the last session the participants are asked to combine any of the commands in any way they choose.

There will be two conditions: control (no emotional personality exhibited) and affective (emotion and personality expressed). Emotion and personality expression will be achieved via various gaits (combination of posture and speed), head and tail position, barking style and behavior sequences (e.g., at the end of "come to me" command, the dog sits in front of the user and wags its tail).

Evaluation is performed using both introspection (questionnaires) and observation (videotapes analysis) methods, with respect to ease and pleasantness of interaction. At the beginning of the study the participants are asked to complete a demographics questionnaire and a brief version of Goldberg's Unipolar Big-Five Markers (personality questionnaire) [19]. In order to evaluate pleasantness of interaction and user's level of attachment, PANAS-T (positive/negative emotionality measure) [23] is given to assess the subjects' mood after each session. Finally, a post-questionnaire designed to evaluate the users' attitude towards the robotic dog with respect to ease and pleasantness of interaction will be given, along with the same personality questionnaire (only this time, the participants are asked to assess the dog and not themselves). Assessing both the user's and the robot's personality will help determine whether the users' project their own personality onto the robot. Each session is also videotaped and rated in order to compare subjective evaluations with observation of participants' behavior. Protocol analysis is then conducted on the videotaped sessions to extract the relevant features for this study. In particular, it would be useful to note whether the interaction style changes from session to session, i.e., do people become more playful with the robot, do they pet it/talk to it more, etc. The method of semantic differential is then used to extract users' attitude by evaluating the statements made in the course of the interaction (positive vs. negative).

At the time of this writing, the study has been approved and is ready to commence. Specific results will be presented in a subsequent report.

5 Conclusions and Future Work

In this paper, a range of issues has been addressed regarding human interaction with autonomous robots, noting the lack of a coherent model to incorporate time varying and local/global effects on behavior. In particular, an experimental study to identify relevant affective phenomena that may increase ease and pleasantness of such interaction is being conducted, and a novel framework, TAME, for integrating a variety of these phenomena into behavior-based robotic systems has been described.

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