Improving Adaptiveness in Autonomous Characters

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Abstract. Much research has been carried out to build emotion regulation models for autonomous agents that can create suspension of disbelief in human audiences or users. However, most models up-to-date concentrate either on the physiological aspect or the cognitive aspect of emotion. Another concern is the degree of control authors should have on modeling these agents. How much of the agents' behaviours or knowledge should be authored and how much should they learn from their environment or through interaction with the users? In this paper, an architecture to balance the Physiological vs Cognitive and Authored vs Learning-based dimensions for creation of life-like autonomous agents is proposed. Some related work of the most relevant existing architectures is reviewed focusing on the benefits and flaws of each architecture. This is followed by an explanation of the proposed architecture that takes the BDI architecture as a basis and combines it with OCC emotions and the PSI motivational system. A possible application for this architecture is then presented. Finally, a conclusion and directions for future work are given.

1 Introduction

The population of autonomous characters in games, interactive systems, and virtual world is rapidly increasing. The survival of an autonomous character requires that its systems produce actions that adapt to its environmental niche. At the same time, the character must appear to be able to 'think', has desires, motivations and goals of its own. A truely autonomous character will be able to react to unanticipated situations and perform life-like improvisational actions. This character will need a human-like regulation system that integrates motivation, emotion and cognition to generate behavioural alternatives. Damasio [1] proposes the existence of a body-mind loop in emotional situations and provides neurological support for the idea that there is no 'pure reason' in a healthy human brain. Therefore, the body-mind link - the link between lower-level physiological processes and cognitive processes is important for effective action regulation so that plausible, flexible and adaptive behaviour can be produced.

Authoring a complete set of behaviour for a truely autonomous character would be iterative and tedious if not impossible. The author will need to consider every possible actions and behaviours the character may perform which is usually non-exhaustive if a character is really autonomous. Additionally, the author needs to ensure that the relationship between one action and another is logically valid. On the other side of the coin, if the author provides full control to the character to learn from its environment, he/she can never be sure what actions or behaviours may emerge and a character could act in a completely different way from what he/she intended. In this paper, an architecture that bridges the gap between physiological and cognitive aspects of emotion and balances the Authored vs Learning-based dimension is proposed for creation of life-like autonomous agents.

2 Related Work

2.1 Non-cognitive architectures

Some examples of existing non-cognitive architectures are those by Cañamero [2], Velásquez's [3] and Blumberg [4]. Cañamero proposed a non-symbolic architecture that relies on both motivations and emotions to perform behaviour selection for an autonomous creature. Velásquez's [3] developed Cathexis, a comprehensive architecture of emotion based on Izard's four systems model [5], integrating both cognitive and non-cognitive emotion elicitors although he is more concerned with the neural mechanism underlying emotional processing than cognitive evaluation of emotional experiences. Blumberg proposed a simple mechanism of action-selection and learning combining the perspective of ethology and classical animation. All these architectures are useful for developing agents that have only existential needs but are insuffcient for controlling autonomous agents where intellectual needs are more important. Another problem of these architectures is that the resulting agents do not show emotional responses to novel situations because all behaviours are hard-coded except for Blumberg's architecture that includes developmental learning capability.

2.2 Cognitive architectures

The OCC cognitive theory of emotions [6] is one of the most used emotion appraisal model in current emotion synthesis systems. Emotions are viewed as valenced reactions that result from three types of subjective appraisals: the appraisal of the desirability of events with respect to the agent's goal, the appraisal of the praiseworthiness of the actions of the agent or another agent with respect to a set of standards for behaviour and the appraisal of the appealingness of objects with respect to the attitudes of the agent. Numerous implementations exist, beginning with the Affective Reasoner architecture [7], the Em component [8] of the Hap architecture [9], EMA [10] and many more.

At the center of deliberative agent architectures lies the Beliefs, Desires, Intentions (BDI) architecture [11, 12]. In this architecture, the process of determining what state of affairs an agent wants to achieve is called deliberative process while the process of deciding how to achieve these state of affairs is called means-ends reasoning. A BDI agent has beliefs and desires that may comform or conflict each other and establish intentions. The agent performs means-end reasoning by selecting actions that can accomplish its intentions. Several implementations of the BDI architecture include the IRMA architecture [12] and the PRS system [13, 14]. The ways BDI agents take their decisions, and the reason why they discard some options to focus on others, are questions that stretch well beyond artificial intelligence and nurture endless debates in philosophy and psychology. Furthermore, BDI agents do not learn from errors and experiences, an important requirement for autonomous agents to appear intelligent, adaptive and believable to human users. These problems are associated with the BDI architecture itself and not from a particular instantiation.

FAtiMA [15] is an extension of the BDI deliberative architecture in that it incorporates a reactive component mainly responsible for emotional expressivity and it employs the OCC emotional influences on the agent's decision making processes. The reactive appraisal process matches events with a set of predefined emotional reaction rules while the deliberative appraisal layer generates emotions by looking at the state of current intentions, more concretely whether an intention was achieved or failed, or the likelihood of success or failure. The emotions and outputs of appraisal phase are stored in Autobiographic Memory [16] for future reference. After the appraisal phase, both reactive and deliberative components perform practical reasoning. The reactive layer uses simple and fast action rules that trigger action tendencies. On the other hand, the deliberative layer uses the strength of emotional appraisal that relies on importance of success and failure of goals for intention selection. A goal is activated only if its start conditions are satisfied. Each goal also contains success and failure conditions. The means-ends reasoning phase is then carried out by a continuous planner [17] that is capable of partial order planning and includes emotion-focused coping [18]. The main problem with FAtiMA is the tedious authoring process of the character's goals, emotional reactions, actions and effects, and action tendencies so that the final behaviour of the characters is as intended. There is usually no theoretical ground for the importance of success/failure of goals and desirability of events, which means authors have to assign values that seem reasonable and adjust them by trying out the agent's behaviour and seeing if it corresponds to what they want. Furthermore, having some of these values scripted reduces the dynamicity of some of the core aspects modeled, resulting in less adaptive agents.

2.3 Body-mind architectures

PSI [19] is a psychologically-founded theory that incorporates all basic components of human action regulation such as perception, motivation, cognition, memory, learning and emotions in one model of the human psyche. It answers the questions raised in the BDI architecture and allows for modelling autonomous agents that adapt their internal representations to a dynamic environment. A few successes of the 'Psi' model in replicating human behaviour in complex task can be found in [19, 20, 21].

PSI agents derive their goals from a set of basic drives that guide their actions. These drives include: existence-preserving needs (survival); species-preserving need (sexuality); need for affiliation (social experiences); need for certainty (prediction of certain situation and consequences of one's own actions) and need for competence (able to master problems and tasks). A deviation from set point constitutes the strength of each need. Needs can emerge depending on activities of the agent or grow over time. To be able to produce actions that are able to satisfy needs in a certain situation, the agent builds up intentions that are stored in memory and are - when selected - the basis of plan. Unlike the BDI architecture that does not provide information about intention choices, in PSI, an intention is selected based on strength of activated needs, success probability and urgency.

Once an intention is selected, three levels of goal-oriented action execution can be distinguished. First, the agent tries to recall an automatic, highly ritualised reaction to handle the intention. If this is not possible, an action sequence may be constructed by combining parts of other action sequences (planning). If planning also fails, particularly when the agent is in a completely new and unknown environment, it acts according to the principle of trial and error. While doing this, PSI agent learns: after having experienced successful operations, the corresponding relations are consolidated, serving as indicators for the success probability of satisfying a specific need. Based on the knowledge stored in memory, abstractions of objects or events can be built. Moreover, PSI agents forget content with time and lack of use.

Emotions within the PSI theory are conceptualised as specific modulations of cognitive and motivational processes. These modulations are realised by so called emotional parameters. Different combinations of parameter values result in the subjective experience of emotions. These parameters that produce emotions from cognitive processes are: *arousal* which is the preparedness for perception and reaction; *resolution level* that determines the accuracy of cognitive processes; and *selection threshold* that prevents oscillation of behaviour by giving the current intention priority. Depending on the cognitive resources and the motivational state of the agent in a given situation, these parameters are adjusted, resulting in more or less careful or forceful ways of acting, as well as more or less deliberate cognitive processing.

Hence, a PSI agent does not require any executive structure that conducts behaviour, rather, processes are self-regulatory and parallel driven by needs, and rely on memory as a central basis for coordination. Its other advantage over FAtiMA is that it does not require much authoring except feeding the agents with some prior knowledge to start with. PSI agents' differences in behaviour will then correspond to different life-experiences that lead to different learned associations. Additionally, the need for specification of goal activation conditions or success conditions is omitted. Unfortunately, this means there is an effective lack of control over the agent's expected behaviour, a limitation for applications where agents need to behave in certain ways.

Some other examples of body-mind architectures are those by Sloman [22], Jones [23] and Oliveira [24]. Sloman presented a three-layered architecture consisting of a reactive layer, a deliberative layer and a meta-management layer. Jones investigated improved realism in generating complex human-like behaviour by integrating behaviour moderators (sub-symbolic components - arousal system, a pleasure/pain system and a clarity/confusion mechanism) with higher cognitive processes (symbolic components - an appraisal system and a response system). In the model proposed by Oliveiro, emotion elicitation involves evaluating the chances of achieving a given goal regardless of the nature of the eliciting process, taking into account both the state of the environment, the internal state and the agent's coping capabilities. The resulting emotional mechanisms play an important role in providing and managing information as well as influencing operating modes and processing strategies. Since the focus of this paper is on PSI, we will not dwell into details on these architectures.

3 FAtiMA-PSI

We have seen that despite having several advantages over FAtiMA, PSI model suffers from a lack of control. Thus, the ideal would be to integrate key components of both architectures to build a body-mind architecture that does not need as much authoring, and where goals are originated from drives, but at the same time provides authoring mechanism that give authors more control over the agent's learning and expected behaviour. The rational is to get a system between PSI and FAtiMA in the Physiological vs Cognitive dimension and Authored vs Learning-based dimension (see Figure 1).

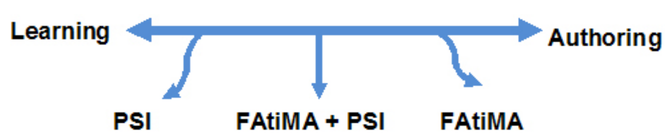

Fig. 1. Situating the integration of FAtiMA and PSI in the Authored vs Learned dimension

As mentioned above, in the new architecture shown in Figure 2, goals will be driven by needs. A motivational system as in PSI will provide the character with basis for selective attention, critical for learning and memory processes, hence increases its adaptive prowess. Five basic drives from PSI are modeled including Energy, Integrity, Affiliation, Certainty and Competence. Energy represents an overall need to preserve the existence of the agent (food + water). As the agent carries out actions, it consumes energy which means that eventually, it will have to rest or perform actions to regain energy. Integrity represents well being, i.e. the agent avoids pain or physical damage while affiliation is useful for social relationships. On the other hand, certainty and competence influence cognitive processes. Each agent has to maintain these needs by reducing a need's deviation from a fixed threshold as much as possible at all time in order to function properly.

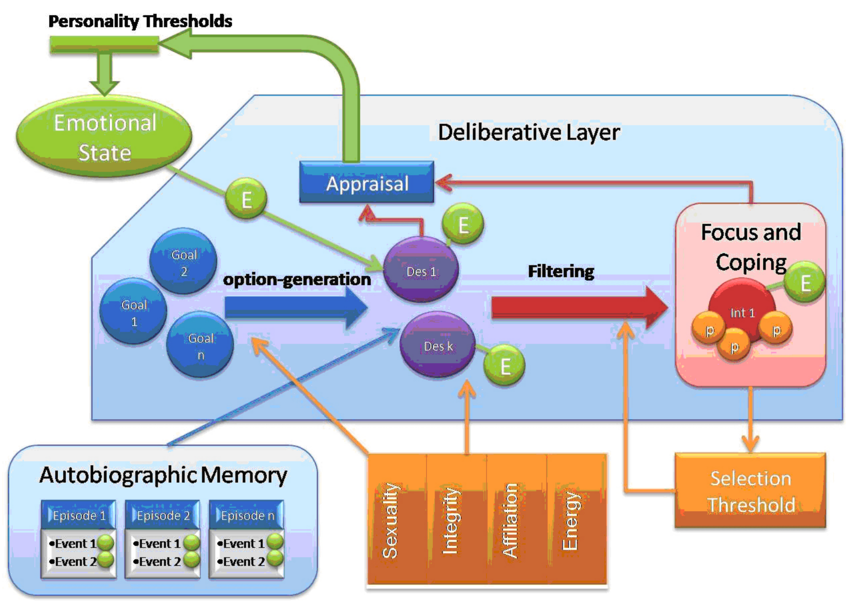

Fig. 2. FAtiMA-PSI architecture

Each need has a specific weight ranging from 0 to 1 that underlines its importance to an agent. The strength of a need depends on its current strength plus the amount of deviation from the set point and the specific weight of the need. For example, if agent A is a friendly character, affiliation would be an important factor in its social relations, say weight 0.7 while a hostile agent B would have a low importance for affiliation, say weight 0.3. Now, if both agents have a current affiliation value of 2 and if the deviation from set point is 4, agent A's need for affiliation would be 4.8 while agent B's need for affiliation would be 3.2 based on equation 1. This means that agent A will work harder to satisfy its need for affiliation than agent B. So, by assigning different weights for different needs to different agents, characters with different personalities can be produced.

$$Strength(d) = Strength(d) + (Deviation(d) * Weight(d)) \quad (1)$$

From the equation, it can be observed that the inclusion of needs requires a change to FAtiMA's existing goal structure that consists of precondition, success condition, failure condition, importance of success and importance of failure. Besides goal, needs are also affected by events taking place in the environment and actions the agent performs. These effects of needs are useful in the appraisal phase to create emotional impact that will be stored in the autobiographic memory and guide the agent's further actions. Since each agent has different personality, the effect of an event may differ from an agent to another, which in turn affects their emotional and behavioural responses. Thus, needs can be considered both the source of behaviour and feedback from the effect of behaviour, a fundamental aspect necessary for learning agents.

Each goal will contain additional information about expected contributions of the goal to energy, integrity and affiliation needs, that is, how much the needs may be deviated or satisfied if the goal is performed. But then, importance of success and failure of goals become irrelevant as this information can be readily generated from needs. Likewise, existing structure of events in FAtiMA has to be extended to include its contributions on needs. As for certainty and competence, no explicit specification of contributions is necessary because they are cognitive needs and their values can be calculated automatically as described below.

Whenever an expected event fails to turn up or an unknown object appears, the agent's certainty drops. Certainty is achieved by exploration of new strategies or actions (trial and error), which leads to the construction of more complete hypotheses. If trial and error is too dangerous, developments in the environment are observed in order to collect more information. Since certainty depends on the amount of information unknown about the goal, the more an agent encounter the same situation, the higher its certainty is regarding the situation.

Competence represents the efficiency of an agent in reaching its goals and fulfilling its demands. Success increases competence while failure decreases it. The agent's autobiographic memory provides a history of previous interactions, which records the agent's experience in a task (the number of success in performing a goal) useful for calculation of goal competence (likelihood of success in performing a goal, Equation 2). Since there is no distinction in competence in terms of achieving an important goal and a less important one, one can assume that all goals have the same contribution to the success rate. If the agent cannot remember previous activations of the goal, then it ignores the likelihood of success and increases the goal's contribution to certainty.

$$Comp(goal) = NoOfSuccess(goal)/NoOfTries(goal) \tag{2}$$

$$OverallComp = NoOfSuccess/NoOfGoalsPerformed \tag{3}$$

The autobiographic memory also stores information about the agent's overall performance (the number of success so far taking into consideration all goals performed) useful for calculation of overall competence (Equation 3). The expected competence (Equation 4) of the agent will then be a sum of its overall competence and its competence in performing a current goal. A low competence level indicates that the agent should avoid taking risks and choose options that have worked well in the past. A high competence means that the agent can actively seek difficulties by experimenting new courses of action less likely to succeed. Together, competence and certainty direct the agent towards explorative behavior; depending on its abilities and the difficulty of mastering the environment, it will actively seek novelty or avoid complexity.

$$ExpComp(goal) = OverallComp + Comp(goal) \tag{4}$$

During the start of an interaction, each agent will have a set of initial values for needs. It is assumed that the scales for all needs are comparable, ranging from 0 to 10 where 0 means complete deprivation while 10 means complete satisfaction. Based on the level of its current needs, the agent generates intentions, that is, it activates goal(s) that are relevant to the perceived circumstances. A need may have several goals that satisfy it (e.g. I can gain energy by eating, or by resting) and a goal can also affect more than one need (e.g. eating food offered by another agent satisfies the need for energy as well as affiliation). So, when determining a goal's strength (Equation 5), all drives that it satisfies are taken into account. A goal that satisfies more drives will have a higher strength than those that satisfy less.

$$Strength(goal) = \sum Strength(d) \tag{5}$$

In terms of a particular need, the more a goal reduces its deviation, the more important is the goal (e.g. eating a full carbohydrate meal when you're starving satisfies you better than eating a vegetarian salad). By looking at the contribution of the goal to overall needs and to a particular need, goals that satisfy the same need can be compared so that success rate in tackling the current circumstances can be maximised. So, the utility value of a goal can be determined taking into consideration overall goal strength on needs, contribution of the goal to a particular need (*ExpCont(goal, d)*) and the expected competence of the agent. Please note that the urgency component in PSI is ignored because there is no easy way to determine the urgency of a given goal.

$$EU(goal) = ExpComp(goal) * Strength(goal) * ExpCont(goal, d) \tag{6}$$

The integration of goals and needs brings important advantages. The degree of desirability (or undesirability) of an action or event is proportionate to the degree of positive (or negative) changes that an action or event brings to the agent's drives. This desirability value can then be used to automatically generate emotions according to OCC model, removing part of the necessity of writing predefined domain-specific emotional reaction rules which means that the reactive layer in FAtiMA may be omitted.

Additionally, needs generate modulating parameters - *arousal, resolution level* and *selection threshold*. *Arousal* is the sum of all needs, *resolution level* co-varies inversely to *arousal* while *selection threshold* co-varies directly to *arousal*.

There may be more than one intention that is activated at any time instance. One of these intentions will be selected for execution based on the *selection threshold* value as in PSI. The current active intention is selected based on winner takes all approach, that is, the goal with the higher expected utility value is chosen. An unselected goal can be activated if its strength plus the selection threshold exceeds the strength of the current active intention. After an intention is selected, the agent proceeds to generate plan(s) to achieve it.

Each event may affect the character's needs level and hence modulate its planning behaviour. The *resolution level* can influence the number of alternative plans generated (comprehensiveness in terms of number of plans considered) or comprehensiveness of plan (in terms of the details and number of actions). For example, if an event leads to a drop in the character's certainty, then its *arousal* level increases causing a decrease in the *resolution level*. In such situation, quick reaction is required hence forbidding time consuming search. The character will concentrate on the task to recover the deviated need(s) and hence may choose to carry out the first action that it found feasible. On the other hand, if an event causes satisfaction of the character's needs, its *arousal* level drops and its *resolution level* increases. Now, the character may spend time to consider more than one action to achieve the task at hand. The level of deliberation that the character allocates to actions selection will be proportional to its *resolution level*.

4 Possible Application

An ideal example for the application of the FAtiMA-PSI architecture is in ORIENT (Overcoming Refugee Integration with Empathic Novel Technology), a part of the EU-FP6 project called eCircus[3] (Education through Characters with emotional Intelligence and Role-playing Capabilities that Understand Social interaction). ORIENT is designed as an interactive computer assisted role-playing game where the players act as visitors to a foreign planet that is inhabited by several alien cultures. In order to save the planet from an imminent catastrophe, the users have to cooperate with the alien inhabitants, which can only be achieved by integrating themselves into the culture. The inhabitants are represented as autonomous agents with autobiographical memory, individual personalities, attributes and improvisational capabilities. The project aims at creating an innovative architecture to enable educational role-play for social and emotional learning in virtual environments, focusing on evoking inter-cultural empathy with the virtual characters through conflict resolution and narrative interaction.

The FAtiMA-PSI architecture includes a variety of aspects that are crucial to modelling ORIENT agents. The motivational system from PSI allows creation of agents with personality. It also serves as quick adaptation mechanism of the agent to a specific situation and may lead to a change of belief about other agent as shown in [25], important for conflict resolution. This permits more flexibility

[3] http://www.e-circus.org/

both in authoring and the character's behaviour that FAtiMA alone lack. On the other hand, the OCC model from FAtiMA allows appraisal process that takes into consideration the cultural and social aspects to generate emotions which are later used for intention selection. Since former experiences is important in social relationship and provides information about a character's competence, the existence of autobiographic memory is inevitable. By being able to retrieve from the autobiographic memory its previous experiences, a character will be able to know how to react sensibly to a similar future situation. Hence, the resulting characters will be more variable, adaptive and intelligent.

5 Conclusion and Future Work

This paper proposes a new emotion model that balance Physiological vs Cognitive and Authored vs Learning-based dimensions to create autonomous characters that are self-regulating and able to perform life-like improvisational actions without the requirement for complete authoring of the charcters' behaviour. The author has the liberty to how much information he wants to provide the characters to start with and leave the rest for the characters to learn. Currently, the motivational system has been integrated into FAtiMA and the next step is to apply the modulating parameters in the deliberative processes such as intention selection and planning. Besides using the information in autobiographic memory solely to determine the need for certainty and competence, it would be desirable to utilise the information to further drive the action of the characters.

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