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Recently an increasing amount of research focuses on improving agents believability by adding affective features to its traditional modeling. This is probably due to the demands of reaching ever more realistic behaviors on agents simulations which extends to several and diverse applications fields. The present work proposes O3A: an Open Affective Agent Architecture, which extends a traditional BDI agent architecture improving a practical reasoning with more "human" characteristics. This architecture tries to address disperse definitions combining the main elements of supporting psychological and neurological theories.

1 INTRODUCTION

Artificial intelligence constantly evolves. New methods, algorithms and techniques are created or improved in order to achieve more sophisticated solutions. The agents field is not far behind. With the vision of a computational agent as a reactive and proactive entity, with its own goals, desires, sensing and planning mechanisms, more steps are taken to simulate human behavior and human interactions. Nevertheless for a simulation that truly reflects how humans behave, it is necessary to model also its affective side. This new line of research has begun to grow in the last two decades, and several approaches have addressed the issue of modeling an agent that can not only "think" but also "feel". This feature allows to take decisions more aligned with human behavior.

Neuroscience methods have found significant evidence that emotions are associated to regions in the brain in charge of controlling the related functions. They also have demonstrated that these functions are necessary for the individual because they act as internal heuristics guiding decisions in uncertain situations. Authors like Joseph E. LeDoux [16] and António Damásio [6] investigated over the idea that emotions are the result of the evolution of ancient parts of the brain to generate appropriated responses to certain stimulus. Psychological and cognitive sciences have also made important contributions to further research on *emotional computing*, considered by R. W. Picard a "computing that relates to, arises from, or influences emotions" [33]. One of the challenges to deal with when addressing issues in emotional computing is to effectively combine results of several and varied sciences. Specifically cognitive science has received special interest by affective computing researchers due to its suitability for creating computational models. Among the psychological perspectives of personality and emotion, the cognitive is the most widely studied because, in some degree, it is contained in the other perspectives. Results of research in affective computing have been applied in fields like education, training, therapies or the simulation of disaster situations which often use virtual or robotic characters as interface for interaction. Structures that combine emotional models and expressive components are included on such simulations.

The aim of this work is to present O3A (**A**n Open **A**ffective **A**gent **A**rchitecture): general enough to consider aspects of rational agents as well as their affective nature and whose components can be customized or replaced according to the domain requirements. In this article it is shown how this emotion mechanism can be integrated into a practical reasoning architecture. We take the widely accepted BDI architecture of agents as starting point and we also endow the agent with the main affective concepts inherited from supporting sciences. We provide a summary of the main concepts extracted from psychological and neurological literature that had shed light over our work and briefly comment some significant related works. Then we present our architecture and its main components, pointing out how it is integrated with a traditional BDI algorithm. Final conclusions provide some annotations of the work performed.

1.1 Motivating ideas

The BDI agent architecture has been widely accepted in the agents community because it has important advantages compared to other agent architectures (logic based, reactive, or layered architectures [41]). It has been able to effectively reflect the human reasoning process having strong philosophical roots.

Besides, many logical and software frameworks based on the BDI architecture have been developed, what makes it to become a suitable alternative in order to represent the practical rational side of an agent. There are many approaches that have tried to improve the BDI architecture with the human emotional process, however these approaches result disperse and confusing on their definitions, and also sometimes they don't follow an incremental line where one reuses the others results [19]. However, some authors consider that maybe it is not useful to improve an architecture like BDI or any other with emotional issues since they are not present in the original theory [36]. Nevertheless we don't see this as a drawback; the BDI architecture offers cognitive processes and components, meaning the processing of perceptions, beliefs, and goals that are necessary and are directly affected by the emotional internal state [4], and those domains that need to simulate rationality as well as the emotional side of human behavior may fit well for BDI architectures with an emotional extension. According to Castelfranchi [4] the basic elements constituting emotions are: beliefs, evaluations, goals, arousal, and the "tendency towards action". *Beliefs* are individual representations of the world (which can be also endogenously generated) that activate emotions with a level of *arousal*, and motivate the conduct. Then emotions come from the interpretation of facts and sensations, which in other words can be called the "recognition" of emotions. On the other hand individuals tend to avoid or maybe to pursue some *goal* if this leads to a desirable emotional state; in this sense emotions itself can be considered as goals. But also they can monitor the goals in that emotions offer guidance about the possible consequences of goals, and they can activate new goals in order to face the triggering emotions. This function makes emotions to be closely related with planning and reasoning processes. Another important issue highlighted by Castelfranchi is the difference between the two kinds of appreciation of events' valence or *evaluations*: 1) adaptive and non rational, which are automatic, intuitive and unconscious orientations to what can be wrong or bad ("I feel fear because a snake has crossed the road") called also *primary* in the literature [30, 6, 1], and 2) declarative or explicit, which is an evaluation based on reasoning, can be explained and is closely related to goals (e.g. "I feel satisfied about my goal of getting good qualifications") called also *secondary*. These concepts together with some other ideas have laid the ground for structuring the O3A architecture.

2 State of the art and similar works

The psychological literature related to affective human characteristics talks about cognitive concepts like emotions, moods, feelings, and personality [3, 10, 7, 4, 35]. They generally agree in that *emotions* are reactions as a consequence of agents, other actions and/or objects[29, 11, 17, 38]. *Mood*, as emotions, is considered to be an experiential component too but it is not necessarily associated with a cause, lasts longer and has lesser intensity than emotions [22, 12, 11, 38, 39]. On the other hand, *personality* is seen as a set of individual characteristics which generally influence motivations and behaviors of the agent [15, 35, 37]. Personality and emotions have been addressed from different perspectives by important psychologists and scientists like Charles Darwin, William James, Sigmund Freud or Carl Jun [5, 35]. Among these theories, the cognitive perspective has special relevance for affective computing due to its suitability to be used in computational applications. Moreover, in the neurological field we found important works which have laid the foundations for future applications in artificial intelligence and human-computer interaction areas. LeDoux and Damásio made important contributions in this area [16, 7]. They found evidences of the relationship between emotions and the way in which the brain works.

Based on some interdisciplinary works [23, 34, 29], several approaches have tried to embody agents or virtual characters with affective traits and expressive functions [11, 31, 14, 1, 25]. Many of them are also based on the BDI agents architecture. For example Pereira et. al. [32] propose an architecture for emotional DBI agents that introduces a representation of the agent's *capabilities* and *resources* that helps the mechanism for updating the emotional state. This emotional state, together with the resources and capabilities influence the inner processes of the BDI architecture. Then the way the agent "feels" is directly and solely related with the *effective capabilities* and *effective resources* at a given point in time. Another interesting work is the one proposed in [31] where authors propose the DETT (Disposition, Emotion, Trigger, Tendency) model for situated agents. It is a domain specific approach that aims to model agents whose goal is to anticipate the actions of an enemy in a combat scenario. It proposes a not complex reasoning for the agents to perform fast actions, and it takes the features of the OCC model [29] for extending a BDI architecture. In this model emotions influence *perception* and *analysis*. The *disposition* element modulates the appraisal, and so, the way that emotions are triggered from beliefs. On the other hand, a *tendency* is imposed to intentions in that analysis is modulated by emotions. The analysis process together with the agent desires produce its intentions. The EBDI architecture for emotional agents [14] is another similar work. The author points out that the way that changes in the environment affect emotions and how they influence human behavior differs even individually so he separates the practical reasoning from the emotion mechanism. But he doesn't use any psychological concept to represent such individual differences. In this work a distinction between *primary* and *secondary* emotions is made. *Primary* emotions are considered reactive responses of the brain and *secondary* emotions appear later and can be caused by *primary* ones or by more complex chains of thinking. Similarly in [25] an architecture for emotional agents is presented. This architecture includes a *personality* and a *mood* component and it describes how affective characteristics influence perception, motivation, memory and the decision making of a BDI architecture. Its emotional component uses the results of the ALMA project [11], and therefore integrates personality, emotions and mood components which are modeled through the Five Factor Model (FFM) of personality [20, 13], the OCC model [29] and the PAD model [23] respectively. This approach focuses on the cognitive state. The coping actions[1] are linked to "filters" that select each time the percepts or facts that are aligned with the agent emotional state or plans that doesn't lead the agent to an undesirable emotional state. An approach that integrates the majority of issues of previous approaches is the one proposed in [1]. The authors propose an architecture to be implemented in virtual characters. They also include primary and secondary emotions where the former is directly linked to expressive capabilities like facial expressions and the latter come as the result of a reasoning about current events, and by considering expectations and past experiences. In this approach mood values are in a bipolar scale and move from positive to negative, and emotions mix theories from P.

[1]The "coping" term is more detailed in [18]

Ekman [9] and OCC. This architecture also included a *memory* component which is used to generate the character expectations.

In [19] Marsella et. al. present a general computational appraisal model which (as our approach do) tries to cope with the main issues associated to emotions and their impact on the cognitive processes and state of the agent. This architecture is composed of three elements: the person-environment relationship, the appraisal variables, and the emotion or affect component. These components are linked in such a way that links have associated a transformation model and the component in the pointing side of the link needs elements from the previous component in the link. The *person-environment relationship* represents the relationship between the entities in the social environment, beliefs, desires or intentions, and the external events. The person-environment component is linked to the *appraisal variables* component, which contains the specific judgment of the agent that helps it to produce emotional responses. These variables are obtained as the result of the transformation of the representation of the person-environment relationship performed by the *appraisal derivation model*. The appraisal variables component is linked to the *emotion or affect* component which can be a discrete label, a set of discrete emotions, core affect or a combination of some of the previous possibilities. These *emotions* can keep a connection to the objects that initiated them. The *affect derivation model* maps the appraisal variables into this affective state, and the *affect intensity model* determines the strength of the emotional response. Finally the *affect consequent model* performs the mapping between *affect* and some behavioral (observable physical behavior) or cognitive (content of cognitive processes) change. The difference of our architecture with this model lies in that the link between cognitive processes and the affective component is made explicit through the use of the BDI architecture. On the other hand, individual traits are addressed throw the inclusion of the concept of *personality*, and also a differentiation between *primary* and *secondary* emotions is made explicit allowing to have different mechanisms (as argued by the supporting theories) for each kind of "evaluation". Moreover, this distinction allows to have different mechanisms for implementing a learning process on which past events and emotions experimented guide current actions. As Castelfranchi stated in this direction [4]: "A 'successful' (or ineffective or harmful) action or plan will subsequently be pursued (or avoided) not only in the light of memories, inferences and evaluations regarding outcome (. . .), but also (and in more direct fashion, without the mediation of reasoning) in order to experience (or avoid) the emotions associated with the outcome of the behaviour in question."

Other works like [24, 8, 27, 40] also propose the syntax and semantic of a logic-based agent-oriented agent language and the logical formulations of the OCC model of emotions respectively. They are remarkable works because they specify in a concrete way how external stimuli and the current sate of the agent beliefs and goal may derive in emotions. Specifically in [8], the authors also propose also transition rules for the execution of actions according the the current emotions, so emotion evaluation, as well as action tendency is described through programming constructs. These approaches do not contradict the architecture proposed. Conversely they could support some component of the architecture (it will be better detailed in section 3.1). Nevertheless in order to offer open structures for them to implement any model of emotions, distinguish between *primary* or *secondary* emotions, deal with a central core affect (or mood) if it necessary, or with individual differences like those determines be the

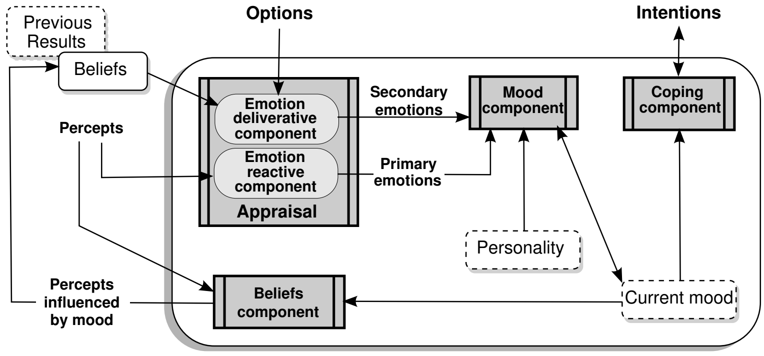

Figure 1: Main components of the O3A architecture.

personality, these approaches may not be suitable because they only describe specific emotions and their individual impact on cognitive processes.

In section 3 we present our affective agent architecture called O3A (**A**n Open **A**ffective **A**gent **A**rchitecture).

3 Desription of the O3A architecture

The O3A architecture addresses mental, cognitive and motivational components of emotions, what, according to [4], makes them a complex, hybrid subjective state of mind. O3A is based on the appraisal theory that is currently the most accepted computational model of emotions. O3A is general because it tries to broadly cope with the main emotions-related issues. The components are integrated into a BDI agents architecture aiming to provide a model useful to build believable agents behaviors in several domains.

3.1 Main components

The O3A architecture, depicted in Figure1, consists of four main components in charge of controlling the agents emotional issues. These components have a well defined interface. This interface will allow us to easily re-implement any component if we need to use other emotional approach in the future.

The appraisal component is in charge of deriving emotions from perceptions and from the agent state. Two sub-components make this task. The ***Emotion reactive component*** takes what has been observed in the environment to obtain the *Primary emotions.* The function of this component is based on the idea of the non-rational, automatic, unconscious and adaptive evaluation of events stated in [4], what derives in primary emotions. In order to implement this component we have labeled each percept with a set of "more probable emotions" to be experimented by the agent after perceiving the event. Our taxonomy of emotions is based on the cognitive perspective of emotions proposed by Clore & Collins in 1988 [29], that was later improved by Ortony in 2003 [28]. This model of emotions, popularly know as OCC, consist of 22 emotions types with their specifications and attributes. These emotions are linked to eliciting conditions, and their intensity is affected by a set of variables. ***The emotion deliberative component*** is in charge of deriving *Secondary emotions*, and corresponds to the declarative and explicit evaluation of events that can be explained and argumented upon [4]. As these emotions are the result of more complex chains of thinking it is necessary to check current beliefs, options available, as well as information from previous results (e.g. how successful or ineffective has been an action or plan, or the emotional experience after a plan in previous executions). We use the ideas proposed in [18] for this component, where emotions emerge from evaluating appraisal variables of propositions. A work like [40] is also suitable to be used in this component of the architecture. The authors make logical formalizations to derive emotions starting from the agent mental attitudes.

The beliefs component determines how *Current Mood* influences the percepts before they become the agent's *Beliefs*. It starts from the idea that mood can intensify or blur perceptions and hence generate different perceptions for each agent [25, 26].

The mood component feeds on the agents *Personality* to establish the agent's initial mood and to update the *Current Mood*. This is based on the idea that individuals differentiate from each other in the way their mood changes depending on their personality traits. An explosive individual may reach a mood with high levels of arousal more easily than one that has a less neurotic personality. The Mood component updates the *Current Mood* also considering the *primary* and *secondary* emotions elicited. We use the dimensional representation of the core affect made by A. Mehrabian and A. Russell [23, 34] in order to describe mood. A three dimensional space whose dimensions are Pleassure, Arousal and Dominance (PAD) describes any emotional state of the agent. This component also deals with the concurrence of "evaluation and appraisal about the same entity/event", which can "give rise to convergence and enhancement of the valence, or to conflicts" [4]. Another issue that is addressed in this component is the duration and the return to an "equilibrium" state of the mood.

The coping component decides if the changes experimented in the current mood deserve to take actions in the cognitive processes of the agent, in this case determining the way intentions are selected to be achieved. As stated in [4] the responses of the agents to external events having the same knowledge, desires, and abilities will be different depending on each agent internal state. We use a plans prioritization strategy but also elements of previous works can be used, such as the programming constructs offered in [8], that offer transition rules for the execution of actions according the the current emotions[2].

Just as the mood can be modeled through a dimensional representation, there are models like the Five Factor Model of personality [20] that are useful to build *Personality* profiles. This model uses a set of five dimensions to describe each individual personality quite accurately.

3.2 Integration in a BDI architecture

Figure 2 shows the interaction between the components and processes of the BDI and the O3A architectures. Dashed arrows represents a relation of the kind "A gets something from B" where A is in the pointing side of the arrow. Solid arrow represent the flow of actions, and what is on slashed borders boxes

[2]This is valid only if, according to the requirements of the domain, a centralized processing of a "mood" is not considered and the emotional internal state is represented directly by the emotions "evaluated"

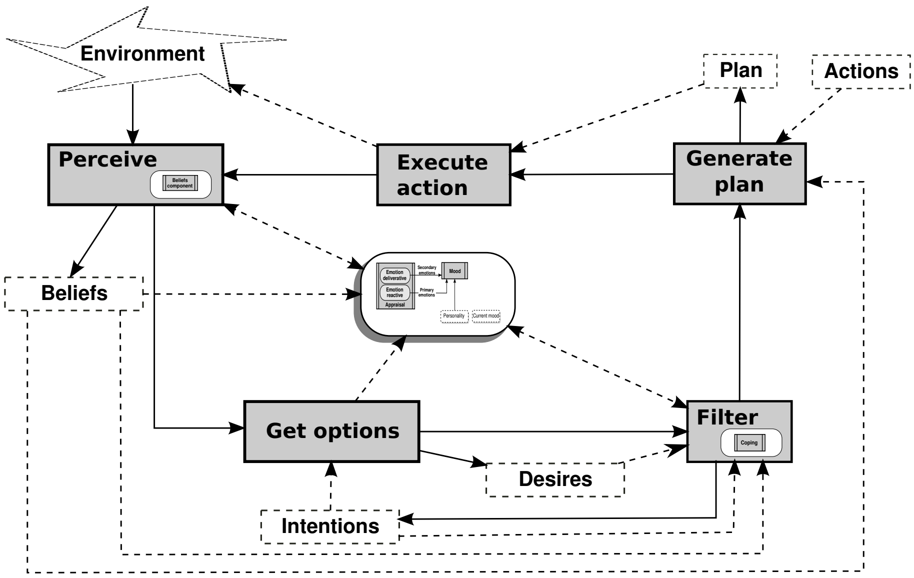

Figure 2: Main components of the O3A architecture.

represents elements that are produced or used depending if the arrow is pointing to them or not respectively. The rounded box in the center of the figure is the engine that responds to the O3A architecture; we"ll call it from now "emotion engine".

When the process of perceptions is performed trough the **perceive** component, what is observed in the environment is transformed into *Beliefs*. Functions corresponding to the **Beliefs component** of O3A are performed in this process; they modify the received perceptions according to the current emotional state. In the **perceive** component a request is done to the emotion engine in order to derive primary emotions that may come with the new perceptions. The **get options** component determines the current *desires* and also request the emotion engine to derive secondary emotions starting from the new *beliefs* and *desires*. In the **filter** process the *intentions* of the agent are updated starting from its *desires*. It determines the next intention to execute, what would be influenced by the current mood. The way the mood influences the intention selection is determined by the emotion engine. The plan to execute the selected intention is determined by the **generate plan** component and the whose actions are executed trough the **execute action** component. The execution of these actions modifies the environment on which the agent is situated.

The main cycle for agents under O3A starts from the control cycle of a BDI practical reasoning agent offered in [2]. The algorithm of Figure 3 integrates a traditional BDI agent architecture with the emotional components proposed in O3A. Note that this architecture is independent of the internal implementation of these emotional components that can be substituted in the future. In lines 1-3 the initial values for Beliefs (B_0), Intentions (I_0) and Current Mood (M_0) are respectively set. In particular, Current Mood is initialized according to the Personality profile (P). We use the proposal made in [21] to establish the correlation between the PAD space [23] and the Five Factor Model [20]. Lines 4-31 represent the basic control loop. The main actions performed in this loop are: observe, execute, and update options. In line 5 the next percept (ρ) is observed from the environment. This percept may have associated a set of the "more probable emotions" to experiment with this percept. In line 6 Beliefs are updated considering the agent's current Beliefs (B), the new percept (ρ), and the Current Mood (M). In this algorithm, Desires are considered "candidate options", and are determined in line 7 on the basis of the current Beliefs and Intentions. In lines 8 and 9 Primary and Secondary emotions are obtained. Secondary Emotions also consider Desires and Beliefs because they are the product of a more complex deliberative process that may emerge from evaluating the agent options, current Beliefs (including past experiences and/or expectations) and current Mood. As it has been posed in section 3.1, some previous approaches may be used in this last two steps such as [8, 27, 40]. In particular we derive PEm directly from percepts and SEm according to [18]. Current Mood is updated taking into account Primary and Secondary Emotions as well as the previous Mood and the agent's personality in line 10. The main goal of this step is to perform a transformation from a set of emotions to a mood in a coherent way. Intentions are updated in the same way in line 11 on the basis of the selected Desires and the Current Mood. Then in line 12 the *plan* function generates a plan for achieving the selected intentions. The actions of the loop in lines 13-30 will be executed as soon as the plan is not empty, succeeded or impossible. In lines 14-16 the first action of the plan is selected and executed, and the plan is updated with the remaining actions. Lines 18-21 represent a pause that the agent makes to detect changes in the environment (which is verified in line 17), and reconsider its Intentions, deriving again Primary Emotions, Secondary Emotions and Mood as previously in lines 8-10. If it's worth to reconsider and to deliberate (Intentions may suffer changes according to the current state and Mood) the Desires and Intentions are reevaluated (lines 23-24). In lines 26-28 a replanning is made in case the current plan doesn't fit well any more with the current Intentions and Beliefs[3]. Finally, in line 29 a measure of the relation between the times the plan has successfully fulfilled the committed Intentions and the times it has been executed is saved. This indicator is used for future deliberations[4].

4 CONCLUSIONS

The O3A architecture is inspired on the most prominent results of psychological and neurological areas. It offers a general agents structure, with an open component implementation in order to be applied in a wide range of domains. It's integration into a typical BDI architecture allows to combine practical rational elements with more "human" features what results in believable behaviors for the agents. This approach has practical uses in human-computer interaction applications like education, pathologies treatments, training, entertainment and human simulation behavior in general. Nevertheless, the main challenge after roughly define how the agent reasoning processes are integrated into the architecture, is the detailed specification of each one of the particular components and how to achieve a coherent behavior aligned with real situations.

[3]Note that lines 22-28 are kept from the original algorithm in [2] where the authors point out that reconsideration is performed only if this leads to a change of intentions and a replanning is performed if the plan is not sound any more according to what it wants to achieve (intentions) and what it thinks it is the current state of the world (beliefs).

[4]The intention in this step is above all to keep the necessary records associated to the results of current results of plans executed and/or achievement of goals in order to reuse this information as a "memory" for further deliberations.

```
B ← B_0; /*B_0 are initial beliefs*/
I ← I_0; /*I_0 are initial beliefs*/
M_0 = M = initialize_mood(P); /*P: the agent personality*/
while (true) do
    get next percept ρ via sensors;
    B ← get_new_beliefs(B, ρ, M);
    D ← get_options(B, I);
    PEm ← get_primary_Em(ρ);
    SEm ← get_secondary_Em(B, M, D);
    M ← update_M(PEm, SEm, M, P);
    I ← filter(B, D, I, M);
    π ← plan(B, I, Ac); /*Ac: set of actions*/
    while not (empty(π) or succeeded(I, B) or impossible(I, B)) do
        α ← first element of π;
        execute(α);
        π ← tail of π;
        observe environment to get next percept ρ
        B ← get_new_beliefs(B, ρ, M);
        PEm ← get_primary_Em(ρ);
        SEm ← get_secondary_Em(B, M, D);
        M ← update_M(PEm, SEm, M, P);
        if (reconsider(I, B, M)) then
            D ← get_options(B, I);
            I ← filter(B, D, I, M);
        end if
        if not (sound(π, I, B)) then
            π ← plan(B, I, Ac);
        end if
        SuccRate_π ← get_succ_rate(SuccRate_π, π);
    end while
end while
```

Figure 3: Control loop for an emotional BDI agent.

This approach is a work in progress. We are currently engaged on implementing a practical application in order to tests the strength of the proposal as well as to identify improvements and/or necessary modifications.

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