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Title: Designing an Affective Intelligent Agent on $GenIA^3$
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$GenIA^3$ is a General-purpose Intelligent Affective Agent Architecture, which can be committed with specific psychological theories to create the design of the final agent. Intelligent affective agents can be implemented by using the default design of $GenIA^3$. Also $GenIA^3$ helps experts on fields like psychology or behavioral computing, to provide more precise and refined ways of describing each particular affective process, facilitating the abstraction from irrelevant implementation or design details, and offering a default design for the main processes. Nevertheless an extensive set of domains need to be tested in order to properly validate and refine $GenIA^3$. In this work we describe the default design of $GenIA^3$, and we propose an alternative design which is based on a model of emotions previously proposed. This illustrates the flexibility of $GenIA^3$ and may inspire other alternative designs.

1 Introduction

Research on Multi-Agent Systems (MAS) has traditionally focused on the search for rational solutions that maximize the quality or utility of the result. However, when an agent needs to simulate human behavior, this kind of approach is not the most appropriate. Studies demonstrate that, when facing alternative choices, emotions guide decision making towards an advantageous direction, influencing the subjective utility of the choices [8]. Also studies show that, in human-machine applications, the human-machine interaction is improved when virtual agents express emotions, enhancing human satisfaction [20], and believability [7, 32], among others. These results highlight the importance of affective characteristics in social and cognitive functions, becoming required characteristics for believable intelligent agents. As it has been addressed by recent approaches, several applications can benefit from affective agents, for example video games, education, health care, and simulation of decision-making [6].

Many computational approaches that model affective agents are based on the cognitive perspective of emotions. These proposals may model interconnected phenomena such as the appraisal process, the emotions dynamics, and/or the influence of affect on the cognitive processes and agent behavior. For example, an embodied virtual character that reacts emotionally to some external stimulus requires, not only an emotion-reaction mechanism, but also a mechanism for "interpreting" the stimulus and generating emotions; or for example, an agent that imitates humans when playing a card game that involves gambling, needs mechanisms for making decisions about what play make next, possibly biased by the current affective state of the agent, and mechanism for emotionally react to what happens in the game[1]. Thus, when modeling a single affect-related phenomena, researchers often should deal with modeling all related processes (and hence making greater "unnecessary" efforts), or focusing on modeling the required phenomena, paying less attention to the rest of processes (and hence maybe missing important details). On the other hand, studies argue for the prevalence on each individual of either emotions or rationality on his behavior, and for the relation between these two aspects [11]. Nevertheless, computationally modeling this relation is difficult. One of the reasons may be probably because, to the best of our knowledge, current computational architectures do not allow to parametrize this relation thus allowing to create artificial entities that are more rational or more emotive.

In order to address these issues we have designed $GenIA^3$ [1], a General-purpose Intelligent Affective Agent Architecture. $GenIA^3$ is based on widely accepted psychological and neurological theories, and is built over a traditional BDI (Beliefs-Desires-Intentions) architecture, offering components to represent affective traits like personality, emotions and mood. $GenIA^3$ allows to implement various psychological theories relative to: individual differences, affect generation, affect dynamics, and affect influence on cognition and behavior, and comes with a default implementation that can be used in several domains. Besides $GenIA^3$ facilitates to set an equilibrium between the rational and the affective sides of an agent according to different psychological theories. Specifically it allows to establish this equilibrium by offering means for adjusting: the level of rationality of an individual, the frequency of rational and affective processes, the way the affective state influences decisions, the way the affective

[1]Literature argues for the influence of emotions on decisions in this kind of games [3, 9]

state influences individual's believes, and how changes on the affective state generate behaviors. An architecture like $GenIA^3$ facilitates "the creation of computational models of specific psychological phenomena of interest" [36], by relieving the modeler of irrelevant implementation choices or design specifications, and providing plausible default values.

Our aim is to illustrate the flexibility of $GenIA^3$ through two different designs of intelligent affective agents. One is the default design of $GenIA^3$ and the other is an alternative design based on the model of emotions for an empathic dialog agent proposed in [29]. This may help readers to get a better comprehension of how $GenIA^3$ works, and also, it may inspire researchers to perform alternative designs with other requirements and/or domain applications.

2 Background of $GenIA^3$

In order to improve the reader experience we informally define some terms that will be used throughout the text. Hereinafter we refer to *affective state* as a generalized representation of all agent attributes that characterize one or more aspects of the agent state in line with the definition of *core affect* in [38]: "A neurophysiological state that is consciously accessible as a simple, nonreflective feeling (...)"; *affective processes* as the new processes added to the original BDI processes in order to consider affective characteristics; *affective cycle* as the cycle which modifies or generates the *affective state*; and *reasoning cycle* as the cycle that represents the agent practical reasoning. Moreover we refer to the ranges of values for the variables that define the *affective state* as *affective categories*, and to a single emotion as an *emotion category* (e.g. joy, fear, or anger, in line with classifications like the one of OCC [31]).

2.1 Core Processes of $GenIA^3$

$GenIA^3$ includes the core processes that allow to implement different theories relative to: individual differences, affect generation, affect experience, and affect influence on cognition and behavior. First, individual differences are represented through personality traits that may influence the processes of the agent reasoning and affective cycles. Besides, affect generation is represented through the **appraisal** process, affect experience through the **affect generator** and **affect temporal dynamics** processes, affect influence on cognition though the **affective modulator of beliefs**, and affect influence on behavior is represented through the **coping** and **filter** processes. $GenIA^3$ also includes the processes of a traditional BDI agent architecture. Figure 1 shows the structure of $GenIA^3$. The reasoning cycle includes the main processes of a BDI agent (bottom side of Figure 1). The architecture has two other cycles: one has only one process that is executed continuously, the **affect temporal dynamic**, and the other (**affective cycle**) includes the rest of affective processes. In the implementation of the architecture, it is possible to set a synchronization between the reasoning and affective cycles. The theories that support this customization are the appraisal theories. Some of them such as Scherer's appraisal theory [40], state that the appraisal is performed at several levels and that several appraisal evaluation checks are performed sequentially. Next we describe the core processes of an affective BDI agent following the $GenIA^3$ structure [1].

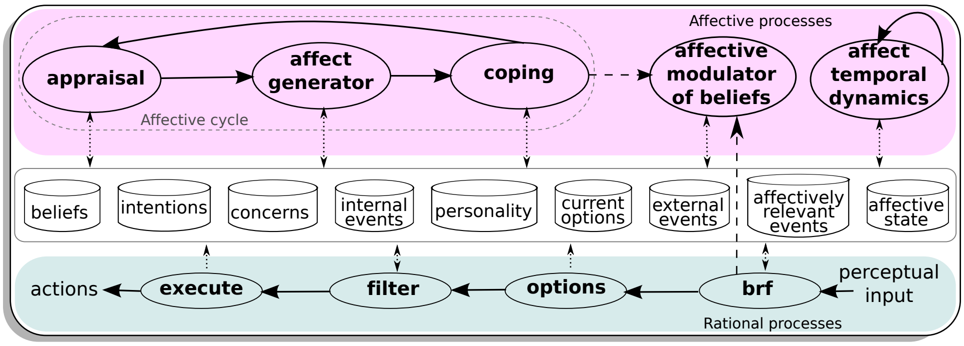


Figure 1: $GenIA^3$: a General-purpose Intelligent Affective Agent Architecture that integrates BDI and affective processes. Sequences are represented as solid line arrows, subprocess as dashed line arrows, and exchange of information as dotted line arrows.

Five core affective processes are included in $GenIA^3$: **appraisal**, **affect generator**, **coping**, **affective modulator of beliefs**, and **affect temporal dynamics**. In order to illustrate how each of these processes work, we will take up the example introduced in Section 1, of an gent that imitates humans when playing a card game that involves gambling. The evaluation of the current situation according to the current state of the world and the agent's *concerns* (i.e., interests, motivations, ideals, or standards) is performed in the **appraisal** process. In $GenIA^3$ this process can be committed to any particular appraisal theory (e.g., [43], [40], [37], [31]), and several parameters can be used in order to perform this appraisal (e.g., the agent's *beliefs*, *concerns*, *internal events*, *external events*, memories of *affectively relevant events*, *current options*). A set of "appraisal variables" result from this evaluation. Consider, for example, that our agent concerns involve to win every single hand, and he looses the current hand; an appraisal variable "desirability" may result from the evaluation of this event in the appraisal process, whose value will be negative. New relevant events (according to their impact on the affective state of the agent), are also stored in the memory of *affectively relevant events* during the **appraisal** process. These affectively relevant events may be used in a future appraisal.[2]. An example of affectively relevant event could be to loose a risky hand where a high bet was made. Although the appraisal process has several parameters, not all of them are necessarily used. For example, following the EMA model [23], the appraisal variable *desirability* is determined by assessing the value of a proposition. It may imply the use of the agent *concerns*, and the agent *beliefs* (in order to evaluate the agent concerns). The **affect generator** is in charge of generating the agent *affective state* by using the current *affective state* and the appraisal variables generated by the **appraisal** process. The **affect generator** process can be committed to any psychological theory and the agent *affective state* can be represented either as a set of emotion categories, appraisal variables, or mood dimensions. For example, when representing *affective state* through mood dimensions, the Pleasure-Arousal-Dominance or PAD model of mood [27], or the Russell's bipolar dimensions (hedonism and arousal[3]) [38] can be used. In our example, if out agent is very depressed,

[2]We allow this possibility on the base that past personally significant events (which are stored in the autobiographical memory), can have a significant impact on human life, shaping the perception of the upcoming tasks and modifying actual behavior [42, 41, 10].

[3]According to Russell's definition of affective state: "A neurophysiological state that is consciously acces-

and he wins a hand, he may feel more happy, but probably not as happy as if his previous affective state were happy already. Determining the way the agent affective state changes is what the **affect generator** does. The **coping** process is tightly linked to the agent personality, since this process determines whether some agent responses or reactive behavior should be generated, and what should be these responses or reactive behavior. These agent responses can represent "response tendencies" in line with [30], or can be oriented to take back the agent *affective state* to a desired state[4] (also called "coping strategies" [23]). Examples of possible reactive behaviors are facial expressions or body gestures that are involuntary and individual. The agent can have coping strategies like "shift responsibility" (e.g., to think that he received a bad hand because the dealer is cheating), or "wishful thinking" (e.g., to think that he will win all subsequent hands) [23]. These coping strategies may imply a modification on the beliefs of the agent, what involves the process **affective modulator of beliefs** (described bellow). The process for controlling the **affect temporal dynamics** is in charge of determining the temporal variation of the *affective state*, specifically its duration and decay. These dynamics vary from one individual to another, in such a way that some *personality* traits can determine the way that these variations are produced.

The **appraisal**, **affect generator**, and **coping** processes are part of the appraisal-reappraisal cycle (also called affective cycle) that is represented in most appraisal theories[5]. The **affective modulator of beliefs** is not executed as an independent process but as a subprocess of either the **coping** process or the **brf** process. The **brf** process corresponds to the "belief revision function" which is explained next. The **affect temporal dynamics**, on the other hand, is not included in this affective cycle, because it doesn't depend on any other process and no other process depends on it. Thus, the **affect temporal dynamics** is controlled in an independent cycle.

$GenIA^3$ also contains the cognitive processes that take place in a typical BDI agent reasoning cycle. These processes are summarized in **brf**, **options**, **filter**, and **execute** [45]. The **brf** process uses a perceptual input along with current *beliefs* in order to determine the agent's new *beliefs*. As a result of this process, new *external events* (one per percept) may be generated. In line with the idea that the agent *affective state* contributes to the maintenance of *beliefs* [22, 33, 18] (e.g., a negative affective state induces an individual to question more his or her beliefs, making him or her more susceptible to accept new information), the **brf** can use the **affective modulator of beliefs** to determine how the *beliefs* are maintained. In order to understand the function of the **affective modulator of beliefs** let's consider the agent perceived self-efficacy in the card game: the belief related to "the conviction that one can successfully execute the behavior required to produce the outcome" [2]. If he continuously losses several hands his perceived self-efficacy me be affected. See [33, 14] for a more detailed description of affective beliefs revision. The tasks for *options*

sible as a simple, nonreflective feeling that is an integral blend of hedonic (pleasure–displeasure) and arousal (sleepy–activated) values" [38].

[4]The specification of a "desired state" depends on the assumptions or psychological theories used in particular designs. For example according to [17], a desired state is that where emotional distress is reduced, and according to [21] a state where the negative emotional responses associated with stress are reduced.

[5]Appraisal-reappraisal is the term used in the Scherer's appraisal theory [40], which is considered one of the most complex and hence, the representation of other appraisal theories could be easily done through it [12].

generation are performed in the **options** process. These *options* (or desires) are generated on the base of the agent's current *beliefs*, *external events*, *internal events*, and *intentions*. These *options* represent the means whereby the agent can achieve its *intentions* (e.g., doubling the bet, standing, or hitting a card). The **filter** process determines what to do by generating the agent's *intentions* (e.g., rising the bet either by 5 or 10 points). To this end, a deliberation process is performed that considers previously-held *intentions*, current *beliefs*, and *options*. Also, as part of this deliberation process, the current agent *affective state*, and some aspect of the agent *personality*, are considered. Specifically, in relation to the agent personality, the extent to which the agent decisions are influenced by its *affective state* can be taken into account. We call it *rationality level*, which aims to facilitate setting an equilibrium between the rational and the affective sides. Including the affective state and personality aspects on the filter process relies on theories that argue for the need of considering the influence of emotions and individual differences for behaving either rationally or emotionally/intuitively/unconsciously, in order to properly model human behavior [19]. Experimental studies offer evidences that emotions drive deliberative decision making [9]. The **execute** process contains the "action selection function", so it uses the current *intentions* to determine the next action to be executed. The execution of actions can produce *internal events* that are related to, for example, the action failure or success. For example, if the action "rise bet" is execute, a possible reason for it to fail could be that the bet reached a top value.

3 Extension of the Jason Platform and Language to Include Affective processes

In order to offer a formalization of $GenIA^3$ we have extended the reasoning cycle and operational semantics used in Jason [4, 44], a well know agent-oriented programming language grounded in a logical computable language (AgentSpeak [35]). Jason is widely accepted on the agents community due to its versatility to be adapted to several kinds of agent applications, thus it becomes a suitable choice for building "customizable" affective agents able to represent a wide set of situations.

3.1 Extension of the Jason reasoning cycle

We have extended the reasoning cycle of a Jason agent [4], in order to build human-like agents whose execution and representation consider both affective and rational processes. Figure 2 shows the steps of the three cycles that are part of the agent execution, as well as the relationship between these steps. The colored steps are either new or modified, while the non-colored steps are the ones proposed in [44]. Similarly, the transitions with dashed lines are new or modified, and their corresponding transitions rules are presented in Section 3.2. There is a clear correspondence between these steps and the processes of $GenIA^3$. The affective processes **appraisal**, **affect generator**, **coping**, **affective modulator of beliefs**, and **affect temporal dynamics** of $GenIA^3$ are performed in the steps `Appr`, `UpAs`, `Cope`, `AffModB`, and `AsDecay` of Figure 2 respectively. The process `AffModB` has been integrated in the reasoning cycle, since it is closely linked to the addition and deletion of beliefs what takes place in the reasoning cycle. The process `SelCs` is part of the

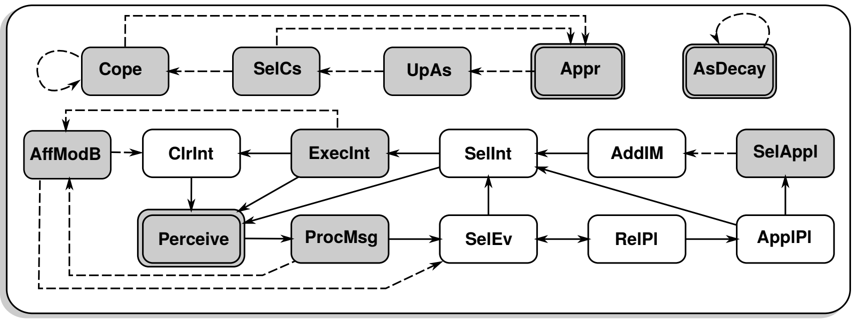
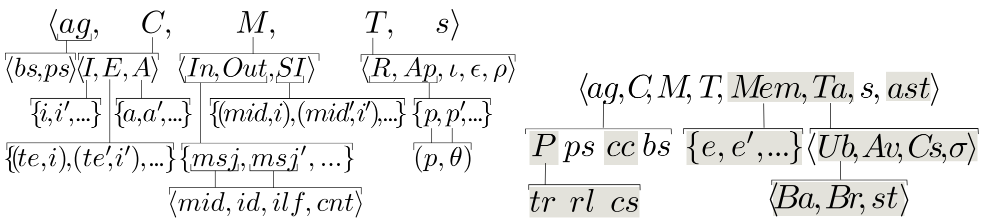


Figure 2: Extension of the reasoning cycle of AgentSpeak. New and modified steps are colored and new and modified transitions are dashed lines.

coping process of the $GenIA^3$ architecture, and it is in charge of determining the coping strategies that need to be executed in the current affective cycle. The **brf** process is performed through the `Perceive`[6] and `ProcMsg` steps; the steps `SelEv`, `RelPl`, and `ApplPl` perform the **options** process; the **filter** process is performed through the `SelAppl`, `AddIM`, and `SelInt` steps; and the `ExecInt` and `ClrInt` steps are in charge of the **execute** process.

Figure 2 also shows that three possible cycles can take place during the agent execution. These cycles control the affective processes (affective cycle), the rational processes (reasoning cycle) and the temporal dynamics of affect (affect temporal dynamics cycle). Next we describe the steps for each cycle. Before starting with the affective cycle it is worth mentioning that, in an initialization stage, the *affective state* has an initial value. This value is also the agent "equilibrium state", which is a neutral state where the agent doesn't experience any significant emotion. The affective cycle starts with the `Appr` step, where the **appraisal** process is performed on the base of several parameters including the agent *concerns*, *personality*, and the *probabilities* associated with agent *beliefs* (if prospect-based emotions are generated). The `Appr` also determines whether the event is relevant for the agent from an affective point of view (in case that the new *affective state* has an event associated). Then, in the `UpAs` step, the *affective state* is updated by using the appraisal variables generated in the `Appr` step. After the updating of the *affective state*, the `SelCs` step verifies whether it is necessary to generate new behaviors in the agent according to this change on the *affective state*, and also verifies which of the agent *coping strategies* are applicable. The `Cope` step performs the tasks required to execute the selected coping strategies. The intentions derived from the execution of coping strategies are added as intended means at the end of the base of intentions, which is shared by both reasoning and affective cycles. Both reasoning and affective cycles generate their own intentions independently which are included in this common base of intentions. Intentions generated by the affective cycle are added at the end of the current intentions, as well as the intentions generated by steps of the reasoning cycle. In the default design all intentions are executed by their insertion order in the `SelInt` step of the reasoning cycle. The default implementation of this step is explained in Section 4. The reasoning cycle contains two new steps (which are the steps `Perceive` and `AffModB`), and three modified steps (`ProcMsg`, `SelAppl`, and `ExecInt`). `Perceive` is

[6]Although the formalization of AgentSpeak considers that an agent can perceive new information from the environment, to the best of our knowledge, there is no explicit step in the reasoning cycle for this task. We have decided to make this step explicit with the initial step `Perceive`.



(a) Original configuration.

(b) New configuration. New components are highlighted.

Figure 3: Configuration of a Jason agent.

the initial step of the reasoning cycle. In this step the agent *beliefs* are modified according to what can be observed from the environment and/or according to external events. The `Perceive` step is followed by the `ProcMsg` step, which is in charge of processing the messages received from other agents. Next, the information coming from the received messages, and from the perception of the environment (on the `Perceive` step), can be modified in the step `AffModB`, which follows the `ProcMsg` step. In $GenIA^3$ the agent *affective state* also influences agent's decisions. The `SelAppl` step performs this task by selecting the next applicable plan; thus it has been modified to consider the agent current *affective state*, and also the agent *rationality level*. The step `ExecInt` may require to execute intentions that imply adding or removing beliefs. Thus it can also be followed by the step `AffModB` to this end. Finally the affect temporal dynamics cycle contains one step: `AsDecay`. This step determines the tendency of the *affective state* to return to its "equilibrium state". This task may use some trait of the agent *personality*.

3.2 Extension of the AgentSpeak Operational Semantics

In order to build an extension of the Jason platform whose agents try to simulate a human-like behavior, with affect-related processes and characteristics, we extended the AgentSpeak operational semantics, considering that it is the base of the Jason operational semantics. The AgentSpeak agent configuration is defined by a tuple $\langle ag, C, M, T, s\rangle$, whose values can be modified after a transition among two steps. Figure 3(a) shows this configuration as well as the structure of each one of its components. The new Jason agent configuration has the form $\langle ag, C, M, T, Ta, Mem, s, ast\rangle$. The new components of this configuration are highlighted in Figure 3(b), and are described next.

- ag represents the agent program, which originally contains a set of beliefs (bs), and a set of plans (ps). Additionally a set of concerns (cc), and a personality (P) has been included in the agent program ag.
  - The agent concerns cc is an agent attribute which is in line with the concerns in $GenIA^3$, and reflects the agent's ideals, motivations, interests, and/or standards.
  - Personality P includes the personality traits tr. It contains a set of numerical values representing the agent personality traits (e.g., the Five Factor Model of personality [24] argues that the traits openness, conscientiousness, extraversion, agreeableness, and neuroticism can differentiate an individual from the rest). In line with the "rationality level" of $GenIA^3$ we propose rl, which is also part of the agent personality. The rationality level states the extent to which

agent decisions are influenced by its affective state[7]. cs represents the agent coping strategies, which relates a particular state (represented through a set of beliefs) and an affective state with a set of actions that generate intentions to be included in the agent current intentions.

- C, M, and T were originally part of AgentSpeak and represent the agent circumstance, communication parameters, and temporary information for a reasoning cycle.
- Mem contains a set on events $\{e, e', ...\}$ that have been relevant for the agent from an affective point of view. We consider this set as a kind of "autobiographic memory", where the meaningful experiences are stored as proposed by [28]. This events are determined and Mem is updated in the appraisal process.
- Ta is a tuple $\langle Ub, Av, Cs, \sigma \rangle$, which represents the temporary information used by the affective processes in a cycle. Its components are:
  - Ub is a tuple $\langle Ba, Br, st \rangle$ which contains those beliefs to be added to or removed from the agent belief base. Ba and Br represent the set of beliefs to be added and the set of beliefs to be removed respectively; st contains the label of the step that requires to add and/or to remove beliefs in Ba and Br[8].
  - Av contains the set of numerical values for the appraisal variables in the current affective cycle.
  - Cs contains the set of coping strategies to be executed in the current affective cycle.
  - σ represents the agent current affective state. It contains a set of variables $\{v, v', ...\}$ where each variable contains a numerical value representing the intensity or the presence or not (in the case a bivalent variable) of either an emotion category (e.g., sad, happy, angry), an appraisal variable (e.g., desirability, controllability), or a mood dimension (e.g., the dimensions of the PAD model [26]).
- s is a label annotating the current step in the reasoning cycle, where $s \in \{$*Perceive, ProcMsg, SelEv, RelPl, ApplPl, SelAppl, AddIM, SelInt, ExecInt, ClrInt, AffModB*$\}$. A new label *AffModB* has been included in s which corresponds to the new step `AffModB` in the reasoning cycle (see Figure 2).
- ast is a label annotating the current step in the affective cycle, where $ast \in \{$*Appr, UpAs, SelCs, Cope*$\}$ (see Figure 2).

Using a similar notation to that used in [44], we refer to attributes with a subindex. For example we refer to the appraisal variables Av that are part of the affective temporary information Ta, as Ta_{Av}. Similarly we refer to the traits tr of the agent personality ag_P as $ag_{P_{tr}}$. We have also defined the structure of new functions that are part of the agent configuration and whose content must be specified by the agent programmer[9]. By offering a way of customizing these function we fulfill our first requirement, where the possibility of implementing various psychological theories should be offered. An

[7]This personality aspect is inspired in psychological tests like the Cognitive Reflexion Test (CRT) [13]

[8]Ub is used by the step `AffModB`.

[9]The selection of the type and number of the parameters of these functions is based on those most commonly used in related computational approaches, and not all of them should be necessarily used in every case.

example of how these functions can be implemented is described in more detail in Section 4. One of these functions is $\texttt{AsDec}(\sigma, P_{tr})$, which controls how the affective state σ decays over time[10], and obtains new values for this affective state considering the personality traits P_{tr}. Appraisal variables are generated through the function $\texttt{Appraise}(\varepsilon, bs, cc, Mem, Ap)$, which considers the event to evaluate (ε)[11], a set of beliefs (bs), a set of concerns (cc), the affective relevant events for the agent (Mem), and options that the agent has available (Ap) [31, 22, 23]. The function $\texttt{AffRelEv}(\varepsilon, Av)$ evaluates if the event ε is relevant for the agent from an affective point of view, by using the appraisal variables in Av. The function $\texttt{UpAffSt}(\sigma, Av)$ determines a new affective state (which contains a set of variables), given the affective state σ and according to a set of appraisal variables Av [16, 23, 29]. Function $\texttt{modB}(AddB, DelB, \sigma)$ determines what beliefs, from the sets $AddB$ and $DelB$, need to be added or modified and which beliefs, from the set $DelB$, need to be removed, according to the affective state σ. We have also modified the AgentSpeak selection function S_{Ap} for selecting an applicable plan from the set of applicable plans Ap. It has the form $S_{Ap}(Ap, \sigma, P_{rl})$ where the affective state σ and an agent rationality level P_{rl} are new parameters. Besides, a new selection function $S_{cs}(Cs)$ has been created in order to select a coping strategy from a set of coping strategies Cs. The selection functions S_{Ap}, S_{cs}, and S_M, are defined at design time by the agent programmer, according to the desired behaviors for the agents. We do not include the selection functions in the configuration for a better readability. Nevertheless, Section 4 offers an informal description of them in our default design.

Additionally we have defined the $\texttt{EvalP}(PSet, bs)$, $\texttt{match}(\sigma, ac)$, and $\texttt{SelCopeSt}(P_{cs}, bs, \sigma)$ functions to determine changes on percepts in the environment; whether a particular affective state matches an affective category; and applicable coping strategies respectively. Definitions 2, 3, and 4 propose a formalization for these functions. The function $\texttt{agperc}(bs)$ of definition 1 is an auxiliary function that determines the agent current percepts.

Definition 1 *Given the set bs of agent beliefs, the set of beliefs that correspond to the agent percepts is defined as follows:*

$$\texttt{agperc}(bs) = \{b[annot] \mid b[annot] \in bs \text{ and } \texttt{source}(\texttt{percept}) \in annot\}$$

Definition 2 *Given the set bs of agent beliefs, and the set of percepts* $PSet = \{pc, pc', ...\}$ *observable in the environment (where each pc is a literal), the set of new percepts* $NewP$ *is calculated as the set difference* $PSet \backslash \texttt{agperc}(bs)$. *Also the set* $RemP$ *of percepts no longer existing in bs, is calculated as the set difference* $\texttt{agperc}(bs) \backslash PSet$. *The function* $\texttt{EvalP}(PSet, bs)$ *performs this task. It is defined as follows:*

$$\begin{aligned}\texttt{EvalP}(PSet, bs) = \{\langle NewP, RemP\rangle \mid\ & NewP = \{b \in PSet \mid b \notin \texttt{agperc}(bs)\} \text{ and} \\ & RemP = \{b \in \texttt{agperc}(bs) \mid b \notin PSet\}\}\end{aligned}$$

Definition 3 *Let be* $\sigma = \{a_1, a_2, ..., a_k\}$ *a set of* k *numerical values, each corresponding to an affective label, and let be* $ac = \{r_1, r_2, ..., r_k\}$ *a set of*

[10] By default it is considered that the affective state decays, because in general psychological theories argue for this decay when dealing with the affect temporal dynamic [15]. Nevertheless, the function $\texttt{AsDec}(\sigma, P_{tr})$ can be customized to include any other behavior.

[11] Events in AgentSpeak include the addition and deletion of beliefs (from the environment or own), addition of goals, and failure of goals.

k ranges of values for the same affective labels, where $r_i = [rmin_i, rmax_i]$. *The* `match` (σ, ac) *function determines whether a particular affective state* σ *matches an affective category ac or not, and it is defined as follows:*

$$\mathtt{match}\,(\sigma, ac) = \begin{cases} \mathit{TRUE} & \text{if } a_i \geq rmin_i \text{ and } a_i \leq rmax_i \quad \forall\, i \in \mathbb{Z} \mid 1 \leq i \leq k \\ \mathit{FALSE} & \text{otherwise} \end{cases}$$

A coping strategy has three components: *context*, *affective category*, and *body*. Both *context* and *body* have the same meaning and structure that a context and body of a plan, where *context* represents a set of conditions that must hold, and *body* contains a set of actions to be performed [44]. Also, for the *body*'s actions to be executed, the agent current affective state must match *affective category*. If a coping strategy cs has the form $(ct, ac) \rightarrow h$, where ct is the context, ac is the affective category, and h is the body, the function `SelCopeSt` (P_{cs}, bs, σ) is defined as follows:

Definition 4 *Given a set of coping strategies* P_{cs}*, a set of beliefs* bs *and a particular affective state* σ*, the set of applicable coping strategies is defined as follows:*

$$\mathtt{SelCopeSt}\,(P_{cs}, bs, \sigma) = \{(cs, \theta) \mid cs \in P_{cs} \text{ and } \theta \text{ is s.t. } bs \models ct\theta \text{ and } \mathtt{match}\,(\sigma, ac) \\ \text{where } ct = \mathtt{CsCtxt}\,(cs) \text{ and } ac = \mathtt{CsAc}\,(cs)\}$$

In the definition 4, the functions `CsCtxt` (cs) and `CsAc` (cs) return the context and the affective category of a given coping strategy cs, and θ is the most general unifier.

3.2.1 New Transition Rules

In this section we present the transition rules for the updated or new steps of the agent cycles (see Figure 2), with respect to [44] using the Structural Operational Semantics (SOS) [34]. Note that the initial state of the reasoning cycle is $\langle ag, C, M, T, Mem, Ta, \mathtt{Perceive}, \mathtt{Appr}\rangle$ now. At this point, the steps of the cycles are able to update one or more components of the agent configuration. Next we describe these transition rules individually. We start by the transition rules for the steps of the affective cycle.

Appraisal The process of appraisal takes place in this transition rules through the function `Appraise` $(T_\varepsilon, ag_{bs}, ag_{cc}, Mem, T_{Ap})$, which evaluates the current event T_ε. If the function `AffRelEv` (T_ε) returns `TRUE`, the current event T_ε is added to the set of affectively relevant events Mem (rule Appr$_1$). The next step in this transition is the `UpAs` step.

$$\frac{AppVar = \mathtt{Appraise}\,(T_\varepsilon, ag_{bs}, ag_{cc}, Mem, T_{Ap}) \quad \mathtt{AffRelEv}\,(T_\varepsilon, AppVar)}{\langle ag, C, M, T, Mem, Ta, s, \mathtt{Appr}\rangle \rightarrow \langle ag, C, M, T, Mem', Ta', s, \mathtt{UpAs}\rangle} \quad (\mathrm{Appr}_1)$$

$$\text{where: } Ta'_{Av} = AppVar \quad Mem' = Mem \cup T_\varepsilon$$

$$\frac{AppVar = \mathtt{Appraise}\,(ag_{bs}, ag_{cc}, T_\varepsilon, Mem, T_{Ap}) \quad \neg\mathtt{AffRelEv}\,(T_\varepsilon, AppVar)}{\langle ag, C, M, T, Mem, Ta, s, \mathtt{Appr}\rangle \rightarrow \langle ag, C, M, T, Mem, Ta', s, \mathtt{UpAs}\rangle} \quad (\mathrm{Appr}_2)$$

$$\text{where: } Ta'_{Av} = AppVar$$

Update Affective State In this transition the agent affective state is updated through the function $\texttt{UpAffSt}(Ta_\sigma, Ta_{Av})$. The next step after this transition is the $\texttt{SelCs}$ step.

$$\frac{}{\langle ag, C, M, T, Mem, Ta, s, \texttt{UpAs}\rangle \to \langle ag, C, M, T, Mem, Ta', P, s, \texttt{SelCs}\rangle} \quad \text{(UpAffState)}$$

$$\text{where: } Ta'_\sigma = \texttt{UpAffSt}(Ta_\sigma, Ta_{Av})$$

Select Coping Strategies In this transition the agent applicable coping strategies are determined through the function $\texttt{SelCopeSt}(ag_{P_{cs}}, ag_{bs}, Ta_\sigma)$. Ta_{Cs} is updated with the result of $\texttt{SelCopeSt}(ag_{P_{cs}}, ag_{bs}, Ta_\sigma)$ and the cycle goes on with the step $\texttt{Cope}$ (transition rule SelCs_2). If no coping strategy is applicable, the cycle returns to the step $\texttt{Appr}$ (transition rule SelCs_1).

$$\frac{\texttt{SelCopeSt}(ag_{P_{cs}}, ag_{bs}, Ta_\sigma) = \{\}}{\langle ag, C, M, T, Mem, Ta, s, \texttt{SelCs}\rangle \to \langle ag, C, M, T, Mem, Ta, s, \texttt{Appr}\rangle} \quad (\text{SelCs}_1)$$

$$\frac{\texttt{SelCopeSt}(ag_{P_{cs}}, ag_{bs}, Ta_\sigma) \neq \{\}}{\langle ag, C, M, T, Mem, Ta, s, \texttt{SelCs}\rangle \to \langle ag, C, M, T, Mem, Ta', s, \texttt{Cope}\rangle} \quad (\text{SelCs}_2)$$

$$\text{where: } Ta_{Cs} = \texttt{SelCopeSt}(ag_{P_{cs}}, ag_{bs}, Ta_\sigma)$$

Cope In the step $\texttt{Cope}$ the function S_{cs} selects a coping strategy from the current set Ta_{Cs} of applicable coping strategies. A plan p is created whose head is a $\texttt{TRUE}$ value and whose actions (which are the body h of the plan p) are those of the selected coping strategy. The plan p and the unifier θ are added as an intention to the set of current intentions C_I and the selected coping strategy is removed from the set of applicable coping strategies Ta_{Cs}. The intention added can lead to the addition or dropping of beliefs, goals, and to a variety of actions (in general all actions that Jason allows to perform in a plan body). This step is repeated until Ta_{Cs} is empty, and then, the cycles goes on with the step $\texttt{Appr}$.

$$\frac{Ta_{Cs} \neq \{\} \quad S_{cs}(Ta_{Cs}) = (cs, \theta) \quad cs = (ct, ac) \to h}{\langle ag, C, M, T, Mem, Ta, s, \texttt{Cope}\rangle \to \langle ag, C', M, T, Mem, Ta', s, \texttt{Cope}\rangle} \quad (\text{Cope}_1)$$

$$\text{where: } p = \texttt{true} \leftarrow h \quad C'_I = C_I \cup \{[p\theta]\} \quad Ta'_{Cs} = Ta_{Cs} \backslash \{(cs, \theta)\}$$

$$\frac{Ta_{Cs} = \{\}}{\langle ag, C, M, T, Mem, Ta, s, \texttt{Cope}\rangle \to \langle ag, C, M, T, Mem, Ta, s, \texttt{Appr}\rangle} \quad (\text{Cope}_2)$$

Perceive This is the initial step of the reasoning cycle. The agent checks the environment for determining changes on percepts ($PSet$) through the function $\texttt{EvalP}(PSet, ag_{bs})$. $NewP$ contains new percepts to be included in, and $RemP$ contains percepts to be removed from the agent belief base ag_{bs} The next step in the cycle is $\texttt{ProcMsg}$, and both $NewP$ and $RemP$ are stored in the affective temporal information of the agent configuration as Ta_{Ub} for them to be processed later in the step $\texttt{AffModB}$.

$$\frac{\texttt{EvalP}(PSet, ag_{bs}) = \langle NewP, RemP\rangle}{\langle ag, C, M, T, Mem, Ta, \texttt{Perceive}, ast\rangle \to \langle ag, C, M, T, Mem, Ta', \texttt{ProcMsg}, ast\rangle} \quad \text{(Perc)}$$

$$Ta'_{Ub} = \langle NewP, RemP, \texttt{Perceive} \rangle$$

The next four rules are related to the processing of received messages. In these rules the functions $S_M(M_{In})$ and $\texttt{SocAcc}(id, ilf, at)$ are used. The first selects a message from the messages set M_{In}, and the second determines if a message is "socially acceptable", where id is the message identifier, ilf is the illocutionary force of the message, and at is the propositional content of the message. More details of these functions can be found in [44].

Receiving a Tell message This transition has been modified in the same way as other transitions in which beliefs were added to the agent belief base. Thus, instead of adding them directly to the agent belief base, they are added to the affective temporal information of the agent configuration Ta_{Ub}, for them to be processed in the step `AffModB`.

$$\frac{S_M(M_{In}) = \langle mid, id, Tell, Bs \rangle \quad (mid, i) \notin M_{SI} (\text{for any intention } i) \qquad \texttt{SocAcc}(id, Tell, Bs) \quad Ta_{Ub} = \langle NewP, RemP, \texttt{Perceive} \rangle}{\langle ag, C, M, T, Mem, Ta, \texttt{ProcMsg}, ast \rangle \rightarrow \langle ag, C, M', T, Mem, Ta', \texttt{AffModB}, ast \rangle} \quad (\text{Tell'})$$

$$\begin{aligned} \text{where: } & M'_{In} = M_{In} \setminus \{\langle mid, id, Tell, Bs \rangle\} \quad Bs' = NewP \\ \text{and for each } b \in Bs\text{: } & Bs' = Bs' \cup \{b[\texttt{source}(id)]\} \\ & Ta'_{Ub} = \langle Bs', RemP, \texttt{ProcMsg} \rangle \end{aligned}$$

Receiving a Tell message as Reply Similarly, in this transition, beliefs sent by another agent as reply, are added to Ta_{Ub} for them to be processed in the step `AffModB`. Also, the required actions to resume the required intention are performed.

$$\frac{S_M(M_{In}) = \langle mid, id, Tell, Bs \rangle \quad (mid, i) \in M_{SI} (\text{for any intention } i) \qquad \texttt{SocAcc}(id, Tell, Bs) \quad Ta_{Ub} = \langle NewP, RemP, \texttt{Perceive} \rangle}{\langle ag, C, M, T, Mem, Ta, \texttt{ProcMsg}, ast \rangle \rightarrow \langle ag, C', M', T, Mem, Ta', \texttt{AffModB}, ast \rangle} \quad (\text{TellRepl'})$$

$$\begin{aligned} \text{where: } & M'_{In} = M_{In} \setminus \{\langle mid, id, Tell, Bs \rangle\} \quad M'_{SI} = M_{SI} \setminus \{(mid, i)\} \\ & C'_I = C_I \cup \{i\} \quad Bs' = NewP \\ \text{and for each } b \in Bs\text{: } & Bs' = Bs' \cup \{b[\texttt{source}(id)]\} \\ & Ta'_{Ub} = \langle Bs', RemP, \texttt{ProcMsg} \rangle \end{aligned}$$

Receiving an Untell message In this transition, beliefs that need to be removed as the result of a message of other agent, are added to Ta_{Ub} for them to be processed in the step `AffModB`.

$$\frac{S_M(M_{In}) = \langle mid, id, Untell, ATs \rangle \quad (mid, i) \notin M_{SI} (\text{for any intention } i) \qquad \texttt{SocAcc}(id, Untell, ATs) \quad Ta_{Ub} = \langle NewP, RemP, \texttt{Perceive} \rangle}{\langle ag, C, M, T, Mem, Ta, \texttt{ProcMsg}, ast \rangle \rightarrow \langle ag, C, M', T, Mem, Ta', \texttt{AffModB}, ast \rangle} \quad (\text{Untell'})$$

$$\text{where: } M'_{In} = M_{In} \backslash \{\langle mid, id, Untell, ATs \rangle\}$$
$$DelB = \{at\theta | \theta \in \texttt{Test}(ag_{bs}, at) \wedge at \in ATs\}$$
$$DelB' = RemP$$
$$\text{and for each } b \in DelB\text{: } DelB' = DelB' \cup \{b[\texttt{source}(id)]\}$$
$$Ta'_{Ub} = \langle NewP, DelB', \texttt{ProcMsg} \rangle$$

Receiving an Untell message as Reply This rule is similar to the previous one where beliefs that need to be removed as the result of a reply message of another agent, are added to Ta_{Ub} for them to be processed in the step AffModB. Also, the required actions to resume the required intention are performed.

$$\frac{S_M(M_{In}) = \langle mid, id, Untell, ATs \rangle \quad (mid, i) \in M_{SI}(\text{for any intention } i) \quad \texttt{SocAcc}(id, Untell, ATs) \quad Ta_{Ub} = \langle NewP, RemP, \texttt{Perceive} \rangle}{\langle ag, C, M, T, Mem, Ta, \texttt{ProcMsg}, ast \rangle \rightarrow \langle ag, C', M', T, Mem, Ta', \texttt{AffModB}, ast \rangle} \quad \text{(UntellRepl')}$$

$$\text{where: } M'_{In} = M_{In} \backslash \{\langle mid, id, Untell, ATs \rangle\} \quad M'_{SI} = M_{SI} \backslash \{(mid, i)\}$$
$$C'_I = C_I \cup \{i\} \quad DelB = \{at\theta | \theta \in \texttt{Test}(ag_{bs}, at) \wedge at \in ATs\} \quad DelB' = RemP$$
$$\text{and for each } b \in DelB\text{: } DelB' = DelB' \cup \{b[\texttt{source}(id)]\}$$
$$Ta'_{Ub} = \langle NewP, DelB', \texttt{ProcMsg} \rangle$$

Selection of an Applicable Plan This transition rule has been modified so that the S_{Ap} function has two additional parameters: the agent current affective state Ta_σ, and the agent rationality level $ag_{P_{rl}}$. Thus the plan that the agent selects to execute, will be influenced by this two parameters. This is another function that can be customized by the programmer, nevertheless its default implemented mechanism is described in Section 4.

$$\frac{S_{Ap}(T_{Ap}, Ta_\sigma, ag_{P_{rl}}) = (p, \theta)}{\langle ag, C, M, T, Mem, Ta, \texttt{SelAppl}, ast \rangle \rightarrow \langle ag, C, M, T', Mem, Ta, \texttt{AddIM}, ast \rangle} \quad \text{(SelAppl')}$$

$$\text{where: } T'_\rho = (p, \theta)$$

Executing an Intention Following with the notation used in [44], $i[p]$ denotes an intention i with the plan p on top of it. Similarly to other transition rules above, in the next two rules, if the intention to be executed implies adding or removing a belief, these beliefs are stored in Ta_{Ub} for them to be processed in the step AffModB.

$$\frac{T_\iota = i[head \leftarrow +b; h]}{\langle ag, C, M, T, Mem, Ta, \texttt{ExecInt}, ast \rangle \rightarrow \langle ag, C', M, T, Mem, Ta', \texttt{AffModB}, ast \rangle} \quad \text{(AddBel')}$$

$$\text{where: } Ta'_{Ub} = \langle \{b[\texttt{source(self)}]\}, \{\}, \texttt{ExecInt} \rangle \quad C'_I = (C_I \backslash \{T_\iota\}) \cup \{i[head \leftarrow h]\}$$

$$\frac{T_\iota = i[head \leftarrow -at; h]}{\langle ag, C, M, T, Mem, Ta, \texttt{ExecInt}, ast \rangle \rightarrow \langle ag, C', M, T', Mem, Ta', \texttt{AffModB}, ast \rangle} \quad \text{(DelBel')}$$

$$\text{where: } Ta'_{Ub} = \langle \{\}, \{at[\texttt{source(self)}]\}, \texttt{ExecInt} \rangle \quad C'_I = (C_I \backslash \{T_\iota\}) \cup \{i[head \leftarrow h]\}$$

Affective modulator of beliefs In this transition beliefs to be added and beliefs to be removed in tuple Ta_{Ub} are modulated according to the agent current affective state Ta_σ (by the function $\texttt{modB(}AddB, DelB, Ta_\sigma\texttt{)}$), where a new set of beliefs to be added ($MAddB$) and a new set of beliefs to be removed ($MDelB$) are obtained. The third component of Ta_{Ub} indicates the step that requires the addition or deletion of beliefs, helping to determine the next step in the cycle (i.e., `SelEv` or `ClrInt`). The corresponding additions and deletions are performed, and the corresponding events of belief addition or deletion are created.

$$\frac{Ta_{Ub} = \langle AddB, DelB, \texttt{ProcMsg}\rangle \quad \texttt{modB(}AddB, DelB, Ta_\sigma\texttt{)} = (MAddB, MDelB)}{\langle ag, C, M, T, Mem, Ta, \texttt{AffModB}, ast\rangle \rightarrow \langle ag', C', M, T, Mem, Ta, \texttt{SelEv}, ast\rangle} \quad (\text{ModB}_1)$$

where for each $mdb \in MDelB$: $ag'_{bs} = ag_{bs} \setminus \{mdb\} \quad C'_E = C_E \cup \{\langle -mdb, \top\rangle\}$
and for each $mab \in MAddB$: $ag'_{bs} = ag_{bs} \cup \{mab\} \quad C'_E = C_E \cup \{\langle +mab, \top\rangle\}$

$$\frac{Ta_{Ub} = \langle AddB, DelB, \texttt{ExecInt}\rangle \quad \texttt{modB(}AddB, DelB, Ta_\sigma\texttt{)} = (MAddB, MDelB)}{\langle ag, C, M, T, Mem, Ta, \texttt{AffModB}, ast\rangle \rightarrow \langle ag', C', M, T, Mem, Ta, \texttt{ClrInt}, ast\rangle} \quad (\text{ModB}_2)$$

where for each $mdb \in MDelB$: $ag'_{bs} = ag_{bs} \setminus \{mdb\} \quad C'_E = C_E \cup \{\langle -mdb, \top\rangle\}$
and for each $mab \in MAddB$: $ag'_{bs} = ag_{bs} \cup \{mab\} \quad C'_E = C_E \cup \{\langle +mab, \top\rangle\}$

Mood temporal dynamic A single cycle controls how the affective state decays over time. It contains the single step `AsDecay`, which is continuously executed. This task is performed by the $\texttt{AsDec(}Ta_\sigma, ag_{P_{tr}}\texttt{)}$ function.

$$\frac{}{\langle ag, C, M, T, Mem, Ta, s, ast\rangle \rightarrow \langle ag, C, M, T, Mem, Ta', s, ast\rangle} \quad (\text{DecAffState})$$

where: $Ta'_\sigma = \texttt{AsDec(}Ta_\sigma, ag_{P_{tr}}\texttt{)}$

The transition rules that correspond to the steps not previously addressed, have also been modified so that the structure of the agent configuration has been adapted to the new configuration. They are not presented for simplicity.

4 Default design

In Section 3.2 we introduced a set of functions that are used in the agent execution cycles, and that can be customized by the programmer. The existence of this set of functions adds flexibility to the agent programmer to adapt the agents behavior to several psychological theories and application domains. We have implemented these functions on the base of widely used psychological theories. This default implementation has been used in several scenarios, and can be extended if required. Next we perform a general description of these functions in order to offer a global understanding of the default implementation, avoiding specific details for simplicity.

In our default design, the affective state Ta_{σ} is represented as the agent mood in a dimensional way, where three values describe the agent mood in a particular moment: pleasure, arousal, and dominance (or PAD, according to Mehrabian's model [26]). Appraisal variables Ta_{Av} can take three possible values (`desirability`, `likelihood`, or `causal attribution`), which were selected from the EMA model proposed in [23]. The traits of the agent personality follow the Five Factor Model [24], which describes individual traits through five dimensions (openness, conscientiousness, extraversion, agreeableness, and neuroticism).

We propose a design for the affective cycle steps inspired by the Gebhard's ALMA model [16][12]. The initial (and also equilibrium affective state) of the agent is calculated following Mehrabian's work [25], which proposes a mapping of the agent five dimensions of personality to the three dimensions of the PAD space. The function `Appraise`$(\varepsilon, bs, cc, Mem, Ap)$ evaluates the event ε when this event implies the addition or deletion of a belief. This function determines the `desirability`, `likelihood`, and `causal attribution` of the resulting state after the addition or deletion of the belief. `Desirability` is determined according to the agent concerns (by using its numerical value), `likelihood` is determined according to the probabilities of the agent beliefs (taking the probability value), and the `causal attribution` can be the `environment` (if the belief to be added or removed is a percept) `other agent` (if the belief to be added or removed is a message), or `self` (if the belief to be added removed is a mental note). For example, consider an agent that represents a student who wants to pass an exam, and whose concerns value can be calculated as $V = Note/MaxNote$, where $Note$ is the exam result and $MaxNote$ is the maximum possible result (lets say 5). If he is told by the *teacher* that he passed with 4, `desirability` will be $\frac{4}{5}$, `likelihood` will be 1, and the `causal attribution` will be `other agent`. Also, in our default implementation, the function `AffRelEv`(ε, Av) determines that the event ε is relevant when the `desirability` in Av is not in a range of "average desirabilities" (i.e., when it is extremely undesirable or extremely desirable). Besides the affective state is updated through the function `UpAffSt`(σ, Av) in three steps. First, five possible emotion categories can be derived (`hope`, `joy`, `fear`, `sadness`, and `guilt`), starting from the appraisal variables Av following [23]. Secondly, each emotion is mapped into the three PAD dimensions following [16]. Thirdly, mapped emotions are averaged in a single value for each dimension according to [16][13]. The function $S_{Ap}(Ap, \sigma, P_{rl})$ uses the affective state σ and the rationality level of the agent personality P_{rl} in order to select the next actions to be performed (by selecting the next applicable plan). It selects an applicable plan by ranking applicable plans with and without considering the affective state; then a general ranking is assigned to each plan by weighing up the two first rankings (the weight for the rank with affect is $1 - P_{rl}$ and the weight for the rank without affect is P_{rl}). The applicable plan with the minimum value in the general ranking is selected.

The function $S_{Cs}(Cs)$ always selects by default the first coping strategy from the set of coping strategies to be executed. Also by default the function `modB`$(AddB, DelB, \sigma)$ adds beliefs to $AddB$ and removes beliefs from $DelB$. Offering additional mechanisms to determine the way beliefs may be modu-

[12] In the implementation of the steps we avoided to introduce too much execution complexity selecting as default mechanisms, those most commonly implemented in computational approaches.

[13] Considering that the set of emotions in [16] doesn't contain all emotions in [23] we carefully looked for a similarity assuming `sadness` as `distress` and `guilt` as `remorse`.

lated would make this approach too complex for being included as a default implementation. The default design for the rest of the functions that haven't been described (such as $S_M(M_{In})$ or SocAcc(id, ilf, at)), follows the default design of a Jason agent, which can be found in [5]. Some of these function of the original Jason agent (such as the function $S_I(C_I)$ for selecting the next intention to be executed), could also be customized by using the tools offered by the Jason original platform.

5 An Alternative Design

In order to illustrate the flexibility of our approach, in this section we describe an alternative design based on the model of emotions for an empathic dialog agent proposed in [29]. This model starts from BDI-like agents and it is focused on the improvement of the human-machine interaction by endowing an agent with facial expressions related to empathic emotions. This alternative model proposes an appraisal process based on known appraisal theories [39, 31, 37]. In this model the agent personality traits, coping strategies, and emotional memory are not represented. Neither do the related processes or a process for modulating the agent beliefs. On the other hand the action selection is focused on the generation of dialogs and facial expressions. We will focus on the appraisal process. In to this model the agent affective state σ can be represented as a set of five emotion intensities[14] corresponding to satisfaction, frustration, irritation, sadness, or anger. The set Ta_{Av} would include four appraisal variables, (called intensity variables in [29]), which are computed from an event characteristics with respect to an intention. This event corresponds to T_ϵ in our approach, and we represent the intention achievement with a particular belief b[15]. The affective cycle is executed twice the reasoning cycle, after the step `SelEv` and after the step `ClrInt`, in such a way that it is possible to evaluate the mental state at the beginning and at the end of the reasoning cycle by updating different appraisal variables. The appraisal variables are calculated by the function Appraise($T_\epsilon, bs, cc, Mem, Ap$) as follows. *Potential to cope in case of an intention failure (potential_cope):* if a plan in Ap with triggering event $+b$ contains an action $-b$, and there is an action $+b$ in another plan of Ap then $potential\_cope = 1$, if there isn't an action $+b$ in another plan then $potential\_cope = 0$; *importance of achieving the intention (imp_s)*: it can be calculated by subtracting the value of concerns cc when the agent doesn't believe b from the value of concerns cc when the agent believes b; *importance not to have the intention blocked (imp_e)*: according to [29] the value of imp_e may be equal or negatively correlated with imp_s according to the nature of the intention; *effort invested to try to complete the intention ($effort$)*: if the agent believes b, then $effort = 0$, otherwise $effort = 1$; *degree of certainty before the event concerning the intention achievement (deg_cert)*: it can be evaluated according to the probability of the belief b[16]. With this design, emotions can be derived according to the formalization in [29], and facial expressions can be integrated, but we mainly wanted to focus on the integration of a different appraisal model.

[14] The authors point out that one or more emotions may be active at the same time.

[15] If the agent believes b after the event T_ϵ (which has the form $+b$), we consider that the intention has been achieved.

[16] These calculations can be improved for example by increasing the search depth for determining whether some action leads the agent to believe b, nevertheless our aim is just to illustrate a possible way to apply other alternatives to implement affective processes through our approach.

6 Conclusions

In this work we have described the core processes of $GenIA^3$, a General-purpose Intelligent Affective Agent Architecture which is based on the BDI agent architecture. We have also presented its formalization and its customizable components. This formalization includes an extension of the AgentSpeak reasoning cycle, and the definition of its operational semantics. With this kind of formalization, comparisons of different psychological theories can easily be performed (thus approaches can be adapted to specific application domains requirements and psycho- logical theories). $GenIA^3$ is grounded on widely studied psychological and neurological theories and offers an integral vision of the agent and its behavior considering both rational and affective attributes and processes. In order to offer this integral vision we have not only modeled emotions. We also address the agent affective state in a more generic way allowing to use different psychological theories for its representation. Also different psychological theories can be used in other affect-related processes, since our formalization allows customizing several steps in the reasoning and affective cycles. In order to illustrate this we have described two different designs: the default design of $GenIA^3$ and an alternative design based on a previously proposed model of emotions.

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