A logical framework for an emotionally aware intelligent environment

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Abstract. In the agent community, emotional aspects receive more and more attention since they were proven to be essential for intelligent agents. Indeed, from a theoretical point of view, results from cognitive psychology and neuroscience have established the close links that exist in humans between emotions and reasoning or decision making. And from a practical point of view, numerous research findings show the interest of emotions in agents communicating with humans: interface agents, pedagogical agents... However, among the logical frameworks used to formalize these *rational agents*, very few integrate these emotional aspects. In this paper, we characterize some emotions, as defined in cognitive psychology, in a BDI (Belief, Desire, Intention) modal logic. We then validate our framework with a case study illustrating the problematic of Ambient Intelligence.

1 INTRODUCTION

Ambient Intelligence is the art of designing intelligent environments, *i.e.* environments that can adapt their behavior to their user, to his specific goals, needs... at every moment, in order to insure his well-being in a non-intrusive and nearly invisible way. At the same time, a great community is interested in agents and all their aspects. Recently, some researchers tried to integrate agents into Ambient Intelligence Systems (AmIS) [1, 3]. Our aim in this paper is to design such an agent. To be intelligent, it must have emotional abilities [6, 22], *i.e.* it must be able to feel emotions and to perceive the user's ones, for example to fulfil his expectancies. In this setting, we believe that an AmIS needs a computational model of emotion in the following cases: *(C1)* to compute the user's emotion triggered by an external event; *(C2)* to anticipate the effect of its actions on the user and then choose the best adapted one; *(C3)* to understand the causes of an emotion noticed in the user by observing his behavior, through inferring *(C3b)* or not *(C3a)* some hypothesis about the user's beliefs. To know the emotion felt by the user and the causes of this emotion is fundamental to act in a really adapted way.

In this paper, our aim is to propose a framework for rational agents able to manipulate some emotions (viz. *emotional agents*) intended to be integrated in an AmIS. This framework is based on modal BDI logics (*Belief*, *Desire*, *Intention*). These logics, that ground on the philosophy of language, thought, and action, propose to model agents *via* some key concepts such as action and *mental attitudes* (beliefs, goals, intentions, obligations, choices...). This framework is commonly used in the international agent community, and offers well-known interesting properties: great explanatory power of the agent's behavior, formal verifiability, rigorous and well-established theoretical frame (both from the philosophical and the formal logic point of view).

Our approach thus consists in extending a BDI logic in a minimal way in order to handle emotions. In Sect. 3, we show that this extension needs the definition of two operators representing what an agent likes or dislikes[2], and that from these two operators, traditional mental attitudes (belief, choice), action, and time, we can define some emotions (Sect. 4) that have been identified in psychology (Sect. 2). We illustrate the performance of our logic with a case study of an AmIS controlling an intelligent house, where the main agent $home$ takes care of its dweller by handling his emotions, possibly with help from other agents of the AmIS (Sect. 5).

2 ANALYSIS OF EMOTIONS

2.1 How to represent emotions?

Psychology proposes three types of explanatory models of emotions: *dimensional models* represent them with three dimensions, which generally are valence, arousal, and stance [25]; *discrete models* consider them as basic universal adaptive mechanisms designed during evolution to favor survival [7, 8]; *cognitive models* argue that emotions are triggered by a cognitive process appraising the relationship between the individual and its environment [17, 21]: the individual continuously evaluates, be it consciously or not, the impact of the stimulus on his internal needs (desires, goals...). While the two former models are mainly descriptive, the latter is normative and thus better adapted to our aim.

Ortony et al. [21] proposed a typology of emotions (the OCC typology, for short) that is based on the theory of cognitive appraisal. They consider three types of physical stimuli: events, actions of agents, and objects, that can be appraised following various criteria such as pleasantness, causal attribution, or probability, triggering twenty-two different emotions. This typology has been used very often in computer science to design virtual emotional agents [11].

2.2 How to know about a human's emotions?

Agents designers have investigated different methods to know about the user's emotion when he does not express it directly. Prendinger and Ishizuka [23] deduce[3] an emotion label from monitoring his physiological signals and gaze direction. This method allows to detect in real-time the least changes in the subject's emotions, but it is

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[2] We use two operators instead of only one because these notions are bipolar rather than complementary or dual (Sect. 3).

[3] Existing works [22] allow to do this deduction

quite intrusive, disobeying an important principle of ambient intelligence.

Other researchers use fuzzy inference rules [18] to deduce the user's emotion from prosody or other physiological cues. But such models can not explain the causes of the emotion and so do not allow the agent to adapt to it.

Another method is explored by Jaques et al. [16]. Their pedagogical agent deduces its pupil's emotion by construing events from his point of view (thanks to a model of user), via an appraisal function based on the OCC typology. This method only gives a speculation on the user's emotional state, but is quite efficient when associated with a good model of his mental attitudes, and most important, it is not intrusive at all. Moreover, it also allows the agent to anticipate the user's emotional reaction to its actions, and thereof to try to induce a particular emotion in the user by choosing the adapted action. This is a very important feature, because emotions were proven to influence all aspects of human reasoning [6]. Finally this third method is better adapted to the problematic of ambient intelligence.

In the next section we present our framework that is an extension of standard BDI logics, and that will allow to represent the user's mental attitudes and emotions.

3 LOGICAL FRAMEWORK

The agent's initial knowledge base T_0 is made up of: initial knowledge that can change over time depending on observation actions of the agent or informative actions of other agents of the AmIS; and of non-logical global axioms *i.e.* axioms true in every possible state (alias world). Initial knowledge includes Factual Knowledge (FK), *i.e.* knowledge of world facts (e.g.: the weather is fine); and epistemic knowledge (EK), *i.e.* knowledge of mental attitudes of others agents, who could be human or not (e.g.: the user does not know that it is raining outside). Global axioms contain some world law knowledge (WLK) (e.g.: if a glass falls over, then it breaks), and some behavioral knowledge (BK) (e.g.: if the user slams the door then he may be angry).

In this section, we define our formal framework, based on the modal logic of belief, choice, time, and action of Herzig and Longin [15] which is a reformulation of Cohen and Levesque's works [5]. In particular, we enhance it with the probability operator defined by Herzig [12].

Let AGT be the set of agents, ACT the set of actions and $ATM = \{p, q...\}$ the set of atomic formulae. Complex formulae are noted A, B... The following paragraphs present a set of axioms characterizing our operators.[4]

Full belief. Full belief represents what the agent privately thinks to be true. (Note that contrarily to knowledge, belief is not truth-related.) We use the operator Bel to represent it: $Bel_i\, A$ reads "agent i believes that A".

The logic of belief operator is a standard normal modal logic (KD45) [4]. Normal modal logics can be characterized by the following axiom and inference rule, under which the set of beliefs is closed:

$$\text{if } A \text{ then } Bel_i\, A \qquad (\text{RN}_{Bel_i})$$

$$Bel_i\, A \wedge Bel_i\,(A \rightarrow B) \rightarrow Bel_i\, B \qquad (\text{K}_{Bel_i})$$

[4] Only the axiomatics will be presented; we use a standard possible worlds semantics, for details see [15, 12].

For a KD45 logic, the following axioms, expressing that the agent's beliefs are consistent (D_{Bel_i}), and that the agent is aware of what he believes (4_{Bel_i}) and of what he does not (5_{Bel_i}), hold too:

$$Bel_i\, A \rightarrow \neg Bel_i\, \neg A \qquad (\text{D}_{Bel_i})$$

$$Bel_i\, A \rightarrow Bel_i\, Bel_i\, A \qquad (4_{Bel_i})$$

$$\neg Bel_i\, A \rightarrow Bel_i\, \neg Bel_i\, A \qquad (5_{Bel_i})$$

Probability. To model emotions we will need a notion of weak belief. Thereby, we will use the modal operator P defined by Herzig in [12], and based on the notion of subjective probability measure. $P_i\, A$ means that "for agent i A is probable". The logic of P is much weaker than the one of belief, in particular it is non-normal: the inference rule (RN_{Bel_i}) and the axiom (K_{Bel_i}) do not have any counterpart in terms of P. We still have the following inference rule and axioms:

$$\text{if } A \rightarrow B \text{ then } P_i\, A \rightarrow P_i\, B \qquad (\text{RM}_P)$$

$$P_i\, \top \qquad (\text{N}_P)$$

$$P_i\, A \rightarrow \neg P_i\, \neg A \qquad (\text{D}_P)$$

Belief and Probability are deeply linked. We only expose here the main axioms from [12]:

$$Bel_i\, A \rightarrow P_i\, A \qquad (\text{BPR}_1)$$

$$P_i\, A \rightarrow Bel_i\, P_i\, A \qquad (\text{BPR}_2)$$

$$\neg P_i\, A \rightarrow Bel_i\, \neg P_i\, A \qquad (\text{BPR}_3)$$

Choice. Choice refers to what the agent prefers: $Choice_i\, A$ reads "i prefers that A is true". As for the belief operator, choice is defined in a KD45 logic. Thus we have the following axioms, expressing that an agent's choices are consistent (D_{Choice_i}), and that an agent must be in agreement with what he chooses (4_{Choice_i}) and what he does not (5_{Choice_i}):

$$Choice_i\, A \rightarrow \neg Choice_i\, \neg A \qquad (\text{D}_{Choice_i})$$

$$Choice_i\, A \rightarrow Choice_i\, Choice_i\, A \qquad (4_{Choice_i})$$

$$\neg Choice_i\, A \rightarrow Choice_i\, \neg Choice_i\, A \qquad (5_{Choice_i})$$

Following Cohen & Levesque [5] and Rao & Georgeff [24] works, we here consider the choice as realistic, in the sense that an agent cannot choose something false for him, *i.e.*:

$$Bel_i\, A \rightarrow Choice_i\, A \qquad (\text{BCR}_1)$$

An agent is aware of his choices (as of his beliefs):

$$Choice_i\, A \rightarrow Bel_i\, Choice_i\, A \qquad (\text{BCR}_2)$$

$$\neg Choice_i\, A \rightarrow Bel_i\, \neg Choice_i\, A \qquad (\text{BCR}_3)$$

Like/Dislike. $Like$ represents a preference disconnected from reality. $Like_i\, A$ (resp. $Dislike_i\, A$) reads "agent i likes (resp. hates) that A". These operators are close to the notions of choice (as defined above) and desire. They differ from choice because they are disconnected from the real world: $Like_i\, A \wedge Bel_i\, \neg A$ is satisfiable contrarily to $Choice_i\, A \wedge Bel_i\, \neg A$. We cannot view them as a desire either because they are bipolar: agent i can like A ($Like_i\, A$), hate A ($Dislike_i\, A$), or be indifferent to A. On the contrary, the desire has no symmetrical notion.

For the sake of simplicity, we use a standard KD-logic for $Like$ and $Dislike$ [5]. Note that there is no strong link between $Like$ and $Dislike$ so **neither** $Like_i\, A \rightarrow Dislike_i \neg A$ **nor** the converse $Dislike_i\, A \rightarrow Like_i \neg A$ is valid. As for other mental attitudes we make the negative (NP_{Like_i}) and positive (IP_{Like_i}) introspection hypotheses:

$$Like_i\, A \rightarrow Bel_i\, Like_i\, A \qquad (IP_{Like_i})$$

$$\neg Like_i\, A \rightarrow Bel_i\, \neg Like_i\, A \qquad (NP_{Like_i})$$

Action. Dynamic operators $After_\alpha$ and $Before_\alpha$ mean that "after (resp. before) every execution of the action α A holds". They are defined in the standard tense logic K^t, *i.e.* in a normal modal logic with conversion axioms:

$$A \rightarrow After_\alpha \neg Before_\alpha \neg A \qquad (CA_1)$$

$$A \rightarrow Before_\alpha \neg After_\alpha \neg A \qquad (CA_2)$$

Time. We do not use exactly the temporal logic defined in [15], but we keep a linear temporal logic LTL with operators G (GA means that "henceforth A is true") and H (HA means that "until now A was true") operators. These operators are defined in a S4 logic with confluence and conversion axioms (in particular, axiom (T_G) means that future includes present):

$$GA \rightarrow A \qquad (T_G)$$

$$GA \rightarrow GGA \qquad (4_G)$$

$$\neg G \neg GA \rightarrow G \neg G \neg A \qquad (G_G)$$

$$A \rightarrow G \neg H \neg A \qquad (GHR_1)$$

$$A \rightarrow H \neg G \neg A \qquad (GHR_2)$$

We add to the Herzig & Longin's framework the operator "next" X (XA means that A will hold at the next instant) and its converse X^{-1} ($X^{-1}A$ means that A held at the previous instant). These operators are defined in a KD logic with the corresponding conversion axioms.

4 EMOTIONS FORMALIZATION

4.1 Appraisal criteria

The agreement criterion. It characterizes stimuli providing a kind of well-being to the agent, for various reasons; non exhaustively: because he likes it, or because it takes part in the satisfaction of one of his choices. We define $Pleasant_i\, A$ and $Unpleasant_i\, A$ as follows:

$$Pleasant_i\, A \stackrel{def}{=} (Like_i\, A \wedge \neg Dislike_i\, A) \vee (\neg Dislike_i\, A \wedge X^{-1} Choice_i\, XA \wedge X^{-1} \neg Bel_i\, XA)$$

$$Unpleasant_i\, A \stackrel{def}{=} (Dislike_i\, A \wedge \neg Like_i\, A) \vee (\neg Like_i\, A \wedge X^{-1} Choice_i\, X \neg A \wedge X^{-1} \neg Bel_i\, X \neg A)$$

A can thus be pleasant either if the agent likes A (and does not dislike it at the same time), or if he does not dislike A and just before preferred that A occurred ($X^{-1} Choice_i\, XA$) without being sure ($X^{-1} \neg Bel_i\, XA$).

Given these definitions we deduce the following properties:

$$\neg Pleasant_i \top \wedge \neg Unpleasant_i \top \qquad (1)$$

$$\neg Pleasant_i \bot \wedge \neg Unpleasant_i \bot \qquad (2)$$

$$Pleasant_i\, A \rightarrow \neg Unpleasant_i\, A \qquad (3)$$

(1) and (2) mean that we are indifferent to tautologies and contradictions: we do not like them and we do not dislike them. (3) means that what is pleasant cannot be unpleasant, and conversely (which is quite intuitive). But these definitions allow to deduce neither $(Pleasant_i\, A \wedge Pleasant_i\, A') \rightarrow Pleasant_i\, (A \wedge A')$ nor $Pleasant_i\, (A \wedge A') \rightarrow (Pleasant_i\, A \wedge Pleasant_i\, A')$: A and A' can be both pleasant but not when associated; the classical example is that it can be pleasant to marry Ann, be pleasant to marry Betty, but not be pleasant to be polygamous.

The probability criterion. It characterizes stimuli that the agent considers to be probable. $Expect_i\, A$ means "the agent i believes that A is probable".

$$Expect_i\, A \stackrel{def}{=} P_i\, A \qquad (Def_{Expect_i})$$

We also define $Envisage_i\, A$ ("the agent i is not sure that A is false") as follows:

$$Envisage_i\, A \stackrel{def}{=} \neg Bel_i\, \neg A \qquad (Def_{Envisage_i})$$

We notice that $Expect_i\, A \rightarrow Envisage_i\, A$, which is intuitive.

In the rest of this section, we specify the existence conditions of the eight emotions that we want to characterize.

4.2 Emotional existence conditions

In the OCC typology, emotions result from the occurrence of three types of stimuli (events, actions, and objects; herein we only consider events) which may change the agent's mental attitudes and make some particular conditions true. The emotions are thus abbreviations of the language, equivalent to their existence conditions.

Joy/Sadness. Joy (resp. sadness) is the emotion that an agent feels when an event occurs that is pleasant (resp. unpleasant) for him.

- $Joy_i A \stackrel{def}{=} Bel_i\, A \wedge Pleasant_i\, A$
- $Sadness_i A \stackrel{def}{=} Bel_i\, A \wedge Unpleasant_i\, A$

Hope/Fear. An agent feels hope (resp. fear) when he expects an event to occur in the future, but envisages that the contrary event could occur instead, and this second event is pleasant (resp. unpleasant) for him.

- $Hope_i A \stackrel{def}{=} Expect_i \neg A \wedge Pleasant_i\, A \wedge Envisage_i\, A$
- $Fear_i A \stackrel{def}{=} Expect_i \neg A \wedge Unpleasant_i\, A \wedge Envisage_i\, A$

Satisfaction/Fear-confirmed/Relief/Disappointment. These four emotions are triggered when an event occurs that confirms or disconfirms a past emotion of hope or fear.

- $Satisfaction_i A \stackrel{def}{=} Bel_i\, A \wedge X^{-1} Hope_i A$
- $Disappointment_i \neg A \stackrel{def}{=} Bel_i \neg A \wedge X^{-1} Hope_i A$
- $Relief_i \neg A \stackrel{def}{=} Bel_i \neg A \wedge X^{-1} Fear_i A$

[5] This implies that $Like_i\, A$ holds for every tautology A. This property seems to be quite counterintuitive, but this does not prevent us from handling emotion in this simple logic: indeed, by defining $Like'_i A \stackrel{def}{=} Like_i\, A \wedge \neg Dislike_i\, A$, we get that $Like'_i \top$ is not a tautology, and we will use this $Like'_i$ in the emotion definitions.

• $FearConfirmed_i A \stackrel{def}{=} Bel_i\, A \wedge X^{-1} Fear_i A$

We notice that satisfaction implies joy, and fear-confirmed implies sadness, what seem to be intuitively correct.

5 CASE STUDY

We now want to apply our framework to four different scenarios corresponding to the four cases identified in the introduction where the agent needs emotions. In every case, we consider a home managing AmIS, administrated by agent m. Let h be a human dweller of this house.

Case (C1): appraisal of an external event from the user's point of view. By definition, as soon as the agent m believes that h's mental state validates the conditions composing a given emotion, m believes that h feels this emotion. Thus, if m believes that h believes that the sun is shining (*i.e.* $Bel_m\, Bel_h\, sunny$) and m also believes that this is pleasant for h ($Bel_m\, Pleasant_h\, sunny$) then by definition m believes that h is joyful about this (*i.e.* $Bel_h\, Joy_m sunny$)[6].

Case (C2): pre-evaluation of the emotional effect of an agent's action on the user. In some cases, emotional impact can be part of a plan. For example, when the production or removal of some emotion of the addressee of the action accounts for the aimed effect (commonly named *Rational Effect* in the agent community [9]), or when various actions with the same informative or physical effect have different emotional effects (these effects are a selection criterion of the action among the other possible ones).

In the first case, suppose that m knows that h feels a negative emotion (for example, sadness) because it is raining (and thus he cannot take a walk), *i.e.* $Bel_m\, Sadness_h raining$. Some behavioral laws can motivate m to help h to cope with his emotions[7] either by informing h that it is not raining anymore as soon as m learns it, or by focusing h's attention on something else[8]. In the first case such a law could be: $Bel_m\, (Sadness_h \varphi \wedge \neg\varphi) \rightarrow Intend_m\, Bel_h\, \neg\varphi$ (*i.e.*: if m believes that h feels sad about φ whereas himself knows that φ is wrong, then he will intend to inform h about this).

Concerning the second case, let's suppose that m believes that the time just before h hoped to play chess with John (*i.e.* $Bel_m\, X^{-1} Hope_h\, JohnPlaysChess$), but finally John does not come anymore ($Bel_m\, \neg JohnComesHome$). We also suppose that m and the other agents have world laws knowledge like $XPlaysChess \rightarrow XComesHome$ where $X \in \{John, Peter, Paul\}$ meaning that if X plays chess with h then necessarily X comes at h's home. Under these conditions, if m informs h that John does not come home, m can logically deduce that h will know that he will not play chess with him (*i.e.* $Bel_m\, Bel_h\, \neg JohnPlaysChess$) which will disappoint him, by definition (*i.e.* $Disappointment_h \neg JeanPlaysChess$). m then hears that Peter and Paul propose to play chess with h, and must choose the partner that will best fit h's likings. m believes that h likes that Paul visit him ($Bel_m\, Pleasant_h\, PaulComesHome$), but is indifferent to Peter visiting him ($Bel_m\, \neg Pleasant_h\, PaulComesHome$). We can then prove that if m informs h that Paul plays chess with him then m will believe that h is joyful about Paul visiting him ($Bel_m\, Joy_h\, PaulComesHome$) (and not joyful about playing chess with Paul, which is indifferent to him; what was pleasant to him was to play chess with John in particular). We can also prove that if m informs h that Peter will play chess with him, h will feel no emotion. Thus m will rather ask Paul to come than Peter.

Case (C3a): observation and explanation of behavior. In the morning, h is visibly stressed but m does not know why. We suppose that m believes that h has a meeting in the morning and must present his work here. Moreover, his world knowledge tells m that when one is well-prepared, one expects one's meeting to go well but envisage it could go wrong (*i.e.* $Bel_m\, (Bel_h\, prepared \rightarrow Expect_h\, meetingOk \wedge Envisage_h\, \neg meetingOk)$)[9]. Moreover m knows that a good performance is pleasant for h ($Bel_m\, Pleasant_h\, meetingOk$), and that a bad performance is unpleasant for h ($Bel_m\, Unpleasant_h\, \neg smeetingOk$). m deduces that if h believes that he is not well-prepared then h hopes that his meeting could go well anyway ($Bel_m\, (Bel_h\, \neg prepared \rightarrow Hope_h meetingOk)$), and if h believes that he is well-prepared then h fears that his meeting could go wrong anyway (*i.e.* $Bel_m\, (Bel_h\, prepared \rightarrow Fear_h \neg meetingOk)$). Note: if m did not know about h's likings he could deduce no emotion from the same information.

Case (C3b): observation, and explanation hypothesis. h comes home in the evening and m observes that he looks sad (*i.e.* after his observation[10], m believes that h is sad about a certain φ: $Bel_m\, Sadness_h \varphi$). However, m does not know the object of this emotion, *i.e.* there exists in his knowledge base no formula φ verifying the definition of sadness (*i.e.* verifying $Bel_m\, Bel_h\, \varphi \wedge Bel_m\, Unpleasant_h\, \varphi$). If we suppose that, following his factual knowledge, the agent m knows that h had a meeting, and we would like that m could deduce that h believes his meeting has gone wrong (*i.e.* $Bel_m\, Bel_h\, \neg meetingOk$), and that he is sad about this[11]. Thereby he could try to cheer him up or propose him some relaxation services.

By now, we have no reason to suppose that m knows if the meeting has gone wrong (*i.e.* $\neg BelIf_m\, meetingOk$), even though he knows *a priori* from his epistemic knowledge that this would be unpleasant for h (*i.e.* $Bel_m\, Unpleasant_h\, \neg meetingOk$), and he believes that h knows if his meeting has gone wrong or well (*i.e.* $Bel_m\, BelIf_h\, meetingOk$).

In addition, following the emotional definitions he disposes of, m knows that if h believes that his meeting has gone well then he will be happy about it (*i.e.* $Bel_m\, (Bel_h\, meetingOk \rightarrow Joy_h meetingOk)$ and if he believes that it has gone wrong he will be sad (*i.e.* $Bel_m\, (Bel_h\, \neg meetingOk \rightarrow Sadness_h meetingOk)$. Given that m believes that h is sad, m infers that h believes his meeting has gone wrong ($Bel_m\, Bel_h\, \neg meetingOk$) : what we wanted to prove[12].

[6] Here, the considered emotion is positive. m can then aim at maintaining it, or considering it in particular situations (for example if he has bad news to tell to h).

[7] In psychology, the coping is the agent's choice of a strategy aiming at suppressing or decreasing a negative emotion that he feels (for example by downplaying or totally suppressing its causes). We consider here that the AmIS can help the user in this task.

[8] This (yet uncovered here) case needs a handling of *activation degrees* accounting for the accessibility of the belief to the conscious. See John Anderson's works in cognitive psychology [2].

[9] m also disposes of a law accounting for the consequences of an unprepared performance, *i.e.* $Bel_m\, (Bel_h\, \neg prepared \rightarrow Expect_h\, \neg meetingOk \wedge Envisage_h\, meetingOk)$

[10] In previous work we studied the perception actions (called *sensing* or *knowledge gathering actions* in the literature cf. [13, 14]).

[11] This requires the integration of some abductive reasoning

[12] We can notice that we have here an example using non trivial epistemic logic inferences.

We have sketched how the four example cases of the introduction can be handled in our framework. We did not show details on the domain modeling, and have omitted the proofs. These will be elaborated in future work.

6 RELATED WORKS & CONCLUSION

Some other researchers recently took an interest in logical formalization of emotions. We analyze below the originality of our work in relation to two other contributions to this growing field.

Meyer's work [19] is mainly oriented towards the link between emotions and the satisfaction of a plan. He designs KARO, a specific logic of action, belief, and choice, and uses it to express a generation rule for each of his four emotions (happiness, sadness, anger and fear). These rules are quite complex and do not for now associate an intensity degree to the generated emotions. Moreover, only four emotions are described. However, Meyer investigates the influence that emotions then have on action, a very important point that we do not handle at all for now.

Ochs et al. [20] focus on emotional facial expression for embodied agents. They yet provide a formalization based on Sadek's rational interaction theory [26], a logic of belief, intention and uncertainty. They stay very close to the OCC typology, but restrict it to only four emotions (joy, sadness, hope and fear), that they associate with intensity degrees depending on their uncertainty degrees. Moreover, they investigate the essential problem of emotional blending. Their results are not very formal, since they propose a kind of spatial mixing of emotional facial expressions.

To conclude, we argue that our model, based on definitions of emotions stemming from psychology, is quite simple to manipulate. Of course, we will need to make it more complex to express more emotions, but we believe that its modular construction allows to extend it quite easily. Moreover, it is already useable as is, as illustrated by our case study. In later work, we envisage to explore several directions, like the integration of intensity degrees for emotions, allowing a sharper adaptation, or the study of adaptation strategies from psychological theories of coping.

For now, we have designed a logic able to deal with emotions. Because of the lack of place, neither semantics nor completeness result have been presented. The next step is to implement this framework in a theorem prover. First, we aim at using the generic prover developed in our team, Lotrec [10], to prove the feasibility of an implementation. Then a specialized prover could be developed and optimized for this logic, although this is not our field of research. All these enhancements aim at designing agents more and more useful for human beings.

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