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Endowing emotional agents with coping strategies: from emotions to emotional behaviour

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Abstract

Emotion takes an increasingly important place in the design of intelligent virtual agents for various applications. To design such emotional agents it is important to build on psychological research that has already explored the functioning of emotions for a long time. Cognitive psychology agrees on a process of appraisal responsible for the triggering of emotions, complemented by a process of coping that modifies the behaviour to manage negative emotions. Nevertheless, among the existing emotional agents, a lot express their emotions but few have a real emotional behaviour impacted by their emotions. In previous work we have already formalized the appraisal process in a BDI framework. In this paper we thus want to extend this BDI framework to formalize the coping strategies that an emotional agent could use. Our aim here is not to propose an agent architecture or implementation, but rather to provide their theoretical basis.

Keywords

Modal logic, emotions, reasoning.

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1 Introduction

Emotion takes an increasingly important place in the design of intelligent virtual agents for various applications: Ambient Intelligence [Adam et al. \(2006a\)](#), believable agents for virtual worlds or video games [El Jed et al. \(2004\)](#); [Gratch and Marsella \(2004\)](#), emotionally aware pedagogical agents motivating students [Elliott et al. \(1999\)](#); [Jaques et al. \(2004\)](#)... To design such emotional agents it is important to build on psychological research that has already explored the functioning of emotions for a long time. Cognitive psychology agrees on a process of *appraisal* responsible for the triggering of emotions. According to [Lazarus Lazarus \(1991\)](#); [Lazarus and Folkman \(1984\)](#), a second process complements *appraisal* and is indivisible from it: *coping*. Actually *appraisal* triggers intense negative emotions to point out threatening stimuli, and *coping* modifies the behaviour to manage these stimuli.

Nevertheless, among the existing emotional agents, a lot express their emotions [Pelachaud et al. \(2002\)](#) but few have a real emotional behaviour impacted by their emotions [Meyer \(2006\)](#); [Gratch and Marsella \(2004\)](#); [Elliott \(1992\)](#). In previous work [Adam et al. \(2006a,b\)](#) we focused only on the triggering of emotions, *viz.* on the appraisal process. We provided a formalization of twenty emotions from the OCC typology [Ortony et al. \(1988\)](#), a well-known psychological theory of appraisal, in a BDI logic, *viz.* a logic of the agent's mental attitudes. Actually this was only a first step in modelling emotional agents: the next step is to formalize the impact of the triggered emotions on the agent's behaviour.

In this paper we thus want to formalize the coping strategies that an emotional agent could use. Our previous work has already shown that BDI logics allow to represent emotions, so we want to formalize coping strategies in the same framework. Due to the limited expressivity of BDI logics, such a model cannot account for all the subtleties of this complex emotional process, but it has undeniable assets to disambiguate its concepts and reason about its properties. Our aim here is not to propose an agent architecture or implementation, but rather to provide their theoretical basis.

We start off with an introduction of the psychological concept of *coping* and of the model of coping strategies on which we build (Section 2). We then proceed with a brief presentation of the axiomatic of our logical framework (Section 3). We then propose a logical account of some *coping* strategies in this framework (Section 4). We then illustrate on an example how an agent effectively chooses and applies a particular coping strategy in a given situation (Section 5). Finally we discuss some existing agents whose emotions impact their behaviour (Section 6).

2 The psychological concept of coping

Lazarus and Folkman [Lazarus and Folkman \(1984\)](#) define coping as “constantly changing cognitive and behavioral efforts to manage specific external and/or internal demands that are appraised as taxing or exceeding the resources of the person”. Coping thus has to do with the mastering or minimization of stressful situations. They then distinguishes two kinds of coping: *problem-focused coping* is oriented

toward the management of the problem creating the stress, and is more probable when appraisal indicates a possible solution to this problem; *emotion-focused coping* is oriented toward the regulation of the emotional response to the situation, and is more probable when appraisal indicates no solution to the problem. There are several strategies of each type of coping, and the individual has a personal coping style representing his preference order over strategies.

Carver et al. Carver et al. (1989) propose the COPE model, a set of fifteen coping strategies. We only present here the strategies that we judged the most useful for an agent and that we will formalize in the next section. **Active coping** consists in directly acting against the stressor. **Seeking emotional social support** consists in trying to get moral support (sympathy, understanding) from other people. **Positive reinterpretation and growth** consists in reinterpreting the situation by finding some positive aspects in it. **Resignation/acceptance** consists in accepting the reality and move forward. **Focus on and venting of emotions** consists in focusing on one's emotion and evacuate it. **Denial** is an immature strategy, trying to refuse the reality of the stressor. **Mental disengagement** consists in engaging in other activities in order to divert from the stressor.

3 Logical framework

Our account of coping strategies is built on a propositional modal logic. In this section we recall briefly the logical framework of Adam et al. (2006b) (except the social ideals operators that we do not use here) and bring some modifications: we simplify the notion of desire and add a *Choice* operator (realistic preference) in order to define intention as in Herzig and Longin (2004).

Let AGT be the set of agents, $ATM = \{p, q, \dots\}$ the set of atomic formulas and $ACT = \{\alpha, \beta, \dots\}$ the set of actions. $FORM = \{\varphi, \psi, \dots\}$ denotes the set of formulas. We use a standard possible-worlds semantics that we do not recall here.

We use the following modal operators: $After_\alpha \varphi$ reads “ φ is true after every execution of action α ”. $Before_\alpha \varphi$ reads “ φ is true before every execution of action α ”. $Bel_i \varphi$ reads “agent i believes that φ ”. $Choice_i \varphi$ reads “agent i prefer worlds where φ is true”. $Des_i \varphi$ reads “ φ is desirable for i , viz. ideally, φ is true for agent i ”. $G\varphi$ reads “henceforth φ is true”. $H\varphi$ reads “ φ has always been true in the past”. $Prob_i \varphi$ reads “ φ is probable for i ”. We define an abbreviation $Expect_i \varphi \stackrel{def}{=} Prob_i \varphi \wedge \neg Bel_i \varphi$ reading “ i believes that φ is probably true, but envisages the possibility that it could be false”.

We then follow Herzig and Longin (2004) to define future directed intentions. Agent i intends that φ iff i does not believe that φ is currently true, not that he will believe φ some day, and in each of his preferred worlds i will believe φ some time. Thus:

$$Intend_i \varphi \stackrel{def}{=} Choice_i F Bel_i \varphi \wedge \neg Bel_i \varphi \wedge \neg Bel_i F Bel_i \varphi$$

3.1 Axiomatics

$After_\alpha$ and $Before_\alpha$ are defined in the standard tense logic K_t , *viz.* logic K with conversion axioms Burgess (2002). For every α and φ we have $G\varphi \rightarrow After_\alpha \varphi$. As we suppose that time is linear, $Happens_\alpha \varphi \stackrel{def}{=} \neg After_\alpha \neg \varphi$ reads “ α is about to happen, after which φ ” and $Done_\alpha \varphi \stackrel{def}{=} \neg Before_\alpha \neg \varphi$ reads “ α has just been done, and φ was true before”. In the following, $i:\alpha$ denotes an action α whose author is i . Bel_i and $Choice_i$ operators are defined in the standard KD45 logic Hintikka (1962); Chellas (1980); Herzig and Longin (2004). The axiom $Bel_i \varphi \rightarrow Choice_i \varphi$ ensures that choices are strongly realist. What is desirable represents possibly unrealistic preferences, *viz.* we impose no relationship between desire and belief¹. Desired propositions are true in ideal worlds, so the semantics of desire is that of the standard deontic logic (SDL), and the logic is the same as that of ideality (KD). Contrary to Adam et al. (2006b) we do not impose that desires persist. The logic of G and H is linear temporal logic with conversion axioms Burgess (2002). $F\varphi \stackrel{def}{=} \neg G\neg \varphi$ reads “ φ is true or will be true”. $P\varphi \stackrel{def}{=} \neg H\neg \varphi$ reads “ φ is or was true”. The probability operators match a notion of weak belief, built on the notion of subjective probability measure. The logic of $Prob$ is much weaker than the one of belief, in particular it is non-normal: the necessitation rule and the axiom K of belief operators do not have any counterpart in terms of $Prob$. They are related by the validity of the axiom $Bel_i \varphi \rightarrow Prob_i \varphi$. It follows that $Prob_i \varphi \rightarrow \neg Bel_i \neg \varphi$ is a theorem. For each operator $\Box \in \{Bel_i, Choice_i, Des_i, Prob_i\}$ we have the introspection principle $\Box \varphi \leftrightarrow Bel_i \Box \varphi$ ensuring that the agents are aware of their beliefs, choices, desires and probabilities. We can prove that this logic is sound and complete but we do not have enough room to provide this proof here.

3.2 Action laws and planning

Action laws are made up of executability laws, describing the preconditions of an action (*viz.* what must be true before its execution), and effect laws, describing the effect of the action (*viz.* what will be true after its execution).

Global axiom 1 (executability laws). *A coping action $i:\alpha$ is happening next iff all its preconditions are satisfied and i prefers that α be performed² Lorini et al. (2006). Thus:*

$$Happens_{i:\alpha} \top \leftrightarrow Precond(i:\alpha) \wedge Choice_i Happens_{i:\alpha} \top \quad (EXEC_\alpha)$$

Global axiom 2 (effect laws). *Effect laws are defined by instances of the following effect laws scheme:*

$$After_{i:\alpha} Effect(i:\alpha) \quad (EFFECT_{i:\alpha})$$

Finally we consider that we can build on a planning process that we do not detail here. Roughly speaking, if agent i intends that φ be true, and he considers probable

¹In particular $Bel_i \varphi \wedge Des_i \neg \varphi$ is consistent.

²This entails that all actions are intentional, *viz.* they cannot happen unless the agent has chosen them to happen (otherwise they are not actions but events).

that henceforth after α , φ will be true, then he intends that α be performed³. Thus:

$$Prob_i GAfter_\alpha \varphi \wedge Intend_i \varphi \rightarrow Intend_i Done_\alpha \top \quad (PLAN_{\alpha, \varphi})$$

3.3 Formalization of emotions

Following [Adam et al. \(2006b\)](#), we consider emotions as mental states, defined as abbreviations of the language. According to Lazarus and Folkman (1984), *coping* strategies only apply to stressful situations, *viz.* to negative emotions. Moreover we restrain our account to strategies against event-based emotions⁴. We note $EMO^- = \{Distress, Disappointment, FearConfirmed, Fear, SorryFor, Resentment\}$ the set of these emotions and recall their definitions.

- $Distress_i \varphi \stackrel{def}{=} Bel_i \varphi \wedge Des_i \neg \varphi$
- $Fear_i \varphi \stackrel{def}{=} Expect_i \varphi \wedge Des_i \neg \varphi$
- $FearConfirmed_i \varphi \stackrel{def}{=} Bel_i PExpect_i \varphi \wedge Des_i \neg \varphi \wedge Bel_i \varphi$
- $Disappointment_i \varphi \stackrel{def}{=} Bel_i PExpect_i \neg \varphi \wedge Des_i \neg \varphi \wedge Bel_i \varphi$
- $SorryFor_{i,j} \varphi \stackrel{def}{=} Bel_i \varphi \wedge Prob_i FBel_j \varphi \wedge Bel_i Des_j \neg \varphi \wedge Des_i \neg Bel_j \varphi$
- $Resentment_{i,j} \varphi \stackrel{def}{=} Bel_i \varphi \wedge Prob_i FBel_j \varphi \wedge Bel_i Des_j \varphi \wedge Des_i \neg Bel_j \varphi$

In the following we note $E_{i,k} \varphi$ the emotion $E \in EMO^-$ felt by agent i about φ w.r.t. agent k ⁵. According to [Adam et al. \(2006b\)](#) we have an introspection axiom on emotions: $E_{i,k} \varphi \leftrightarrow Bel_i E_{i,k} \varphi$. Following the psychological literature we call φ the “stressor”. The desire term in the definition of the agent’s emotion is called the agent’s “contradicted desire”.

4 Formalization of some coping strategies

4.1 Intuitive description of the strategies

Our logical language is inevitably less expressive than natural language. Thus we explain here how we interpret and possibly simplify the functioning of the chosen strategies before formalizing them. The conditions and effects described here will then be translated into logical formulas in the following sections.

We consider an agent i feeling the negative event-based emotion $E_{i,k} \varphi$.

³Obviously this raises a number of problems, in particular i could adopt the intention to perform several actions leading to φ . Yet these considerations exceed the scope of this paper.

⁴Coping with action-based emotions may imply specific strategies to deal with the social ideals involved, so we let the study of these strategies for future work.

⁵ k is not necessarily different from i . When i is k we will sometimes write $E_i \varphi$.

- **ActiveCoping** consists in acting to make φ false. So i will use this strategy only if he does not believe that φ could become false later without acting for that. The effect is that i adopts the realistic preference that in the future he will believe $\neg\varphi$.
- **Denial(ψ)** operates by refusing the reality of the stressor. The condition is to support this assumption by some proof ψ entailing $\neg\varphi$. The effect is to add the belief that ψ is true, aiming at deducing $\neg\varphi$. (So this is a revision action.)
- **SeekESupport(j)** operates by looking for the emotional support of an agent j . The condition is that j is believed to be friendly⁶. The effect is that i adopts the intention to obtain j 's compassion.
- **Focus&Venting(j)** operates by looking for the attention of an agent j . The condition is that i believes j to trust him, in particular when he expresses his emotions. Its effect is that i adopts the intention to communicate his emotion to j ⁷.
- **Resign** has no condition. Logically we write that the condition is always true, by using the symbol \top . The effect is that i drops immediately⁸ his contradicted desire.
- **PosReinterp(ψ)** operates by looking for a positive aspect ψ of the stressor φ . The condition is that ψ is a non undesirable consequence of φ . The effect is to make ψ desirable. (So the negative emotion about φ is replaced by a positive one about ψ .)
- **MentalDisengage(ψ)** operates by focusing on another desire than the contradicted one. The condition is that i desires ψ and does not believe it. The effect is that i intends to realize this desire. (So after planning i will act to achieve ψ in order to trigger a positive emotion about ψ that divert him from the negative one about φ .)

We note $EmoSTRA = \{\text{Denial}(\psi), \text{SeekESupport}(j), \text{Focus\&Venting}(j), \text{Resign}, \text{PosReinterp}(\psi), \text{MentalDisengage}(\psi)\}$ the set of emotion-focused coping strategies, and $PbSTRA = \{\text{ActiveCoping}\}$ the set of problem-focused coping strategies. We define $STRA = EmoSTRA \cup PbSTRA$, the set of coping strategies. Some strategies need a specific parameter (either a formula or an agent) as explained above.

4.2 Coping strategies as particular actions

We then define a coping action $i:\alpha = \langle i, s, E_{i,k}\varphi \rangle$ as the application by an agent i of a strategy $s \in STRA$ on a negative event-based emotion $E_{i,k}\varphi$. Coping actions

⁶Following Adam et al. (2006b), j is friendly if he dislikes that i believes something undesirable for him.

⁷This effect is weaker than the one of **SeekESupport(j)** since the condition does not impose that j is friendly, so i is not sure to obtain his compassion.

⁸This is an approximation of the long-term process leading to the disappearance of a negative emotion over time, by habituation.

are particular actions schemes obeying the action laws defined in Section 3.2. Their preconditions and effects are expressed in terms of the agent's mental attitudes, and depend on the possible parameter of the applied strategy.

The preconditions of the coping action $i:\alpha = \langle i, s, E_{i,k}\varphi \rangle$ are set up of the following conditions. First i must feel the negative event-based emotion $E_{i,k}\varphi$. Second the applied strategy s must match the adapted type of coping (defined by [Lazarus and Folkman \(1984\)](#), see Section 2): this is denoted by the abbreviation *TypeCond*. Third the strategy s must be applicable in the given context: this is denoted by the abbreviation *ApplyCond*.

Definition 1 (Preconditions of a coping action).

$$Precond(i:\alpha) \stackrel{def}{=} Bel_i E_{i,k}\varphi \wedge TypeCond(i:\alpha) \wedge ApplyCond(i:\alpha)$$

We consider that a stressor φ is controllable by agent i iff i believes that there is at least one possibility to change in the future the fact that φ is true. Conversely, the stressor is uncontrollable iff agent i believes that φ is henceforth true. This is expressed by the following formulas, and entails that a stressor cannot be both controllable and uncontrollable. Yet it can be neither fully controllable nor fully uncontrollable (*e.g.* if i only envisages that he could believe φ in the future, *viz.* $\neg Bel_i \neg F Bel_i \varphi$). According to [Lazarus and Folkman \(1984\)](#) problem-focused strategies are only more likely against a controllable stressor, and emotion-focused strategies only more likely otherwise, but we capture this distinction in an all-or-nothing way.

Definition 2 (Selection of a type of coping).

The stressor must be controllable to use problem-focused strategies, and it must be uncontrollable to use emotion-focused ones. So if the stressor is neither fully controllable nor fully uncontrollable i can use none of these types of coping.

$$\begin{cases} TypeCond(i:\alpha) \stackrel{def}{=} \neg Bel_i \neg F Bel_i \neg \varphi & \text{if } s \in PbSTRA \\ TypeCond(i:\alpha) \stackrel{def}{=} Bel_i G Prob_i \varphi & \text{if } s \in EmoSTRA \end{cases} \quad (DefTypeCond)$$

Definition 3 (Applicability preconditions).

These preconditions specify the context in which each coping action can be performed, depending on the possible parameter of the applied strategy. These conditions are not mutually exclusive so in some cases several strategies are applicable at the same time.

$$\begin{aligned} ApplyCond(\langle i, ActiveCoping, E_{i,k}\varphi \rangle) &\stackrel{def}{=} \neg Bel_i \neg G \neg Bel_i \neg \varphi \\ ApplyCond(\langle i, Denial(\psi), E_{i,k}\varphi \rangle) &\stackrel{def}{=} Bel_i G(\psi \rightarrow \neg \varphi) \\ ApplyCond(\langle i, SeekESupport(j), E_{i,k}\varphi \rangle) &\stackrel{def}{=} Bel_i G(Bel_j Des_i \neg \varphi \rightarrow Des_j \neg Bel_i \varphi) \\ ApplyCond(\langle i, Focus\&Venting(j), E_{i,k}\varphi \rangle) &\stackrel{def}{=} Prob_i After_{\langle i, Inform, j, E_{i,k}\varphi \rangle} Bel_j E_{i,k}\varphi \\ ApplyCond(\langle i, Resign, E_{i,k}\varphi \rangle) &\stackrel{def}{=} \top \\ ApplyCond(\langle i, PosReinterp(\psi), E_{i,k}\varphi \rangle) &\stackrel{def}{=} Bel_i G(\varphi \rightarrow \psi) \wedge \neg Des_i \neg \psi \\ ApplyCond(\langle i, MentalDisengage(\psi), E_{i,k}\varphi \rangle) &\stackrel{def}{=} \neg Bel_i \psi \wedge Des_i \psi \end{aligned}$$

We now translate the intuitive effects of the coping actions (described in Section 4.1) into logical formulas. This completes the specification of our coping actions.

Definition 4 (Effects of the coping actions).

$$\begin{aligned}
 \text{Effect}(\langle i, \text{ActiveCoping}, E_{i,k}\varphi \rangle) &\stackrel{\text{def}}{=} \text{Intend}_i \neg\varphi \\
 \text{Effect}(\langle i, \text{Denial}(\psi), E_{i,k}\varphi \rangle) &\stackrel{\text{def}}{=} \text{Bel}_i \psi \\
 \text{Effect}(\langle i, \text{SeekESupport}(j), E_{i,k}\varphi \rangle) &\stackrel{\text{def}}{=} \text{Intend}_i \text{SorryFor}_{j,i}\varphi \\
 \text{Effect}(\langle i, \text{Focus\&Venting}(j), E_{i,k}\varphi \rangle) &\stackrel{\text{def}}{=} \text{Intend}_i \text{Bel}_j E_{i,k}\varphi \\
 \text{Effect}(\langle i, \text{Resign}, E_{i,k}\varphi \rangle) &\stackrel{\text{def}}{=} \neg\text{Des}_i \neg\varphi \wedge \neg\text{Des}_i \neg\text{Bel}_k \varphi \\
 \text{Effect}(\langle i, \text{PosReinterp}(\psi), E_{i,k}\varphi \rangle) &\stackrel{\text{def}}{=} \text{Des}_i \psi \\
 \text{Effect}(\langle i, \text{MentalDisengage}(\psi), E_{i,k}\varphi \rangle) &\stackrel{\text{def}}{=} \text{Intend}_i \psi
 \end{aligned}$$

4.3 Choice of the preferred strategy

The agent i feeling an emotion $E_{i,k}\varphi$ now knows a list of coping actions whose preconditions are true. There is at least one applicable coping action (resignation whose condition is always true) but there can be several ones. Since the agent can only perform one coping action at a time, the final reasoning step is to select the one that he chooses to apply. To simplify we make the strong hypothesis that an agent who feels a negative event-based emotion always chooses to cope with it, *viz.* he always chooses to apply his preferred available strategy. We also suppose that there is only one coping action for each strategy, *viz.* there is only one possible instantiation of the parameter of each strategy that makes the preconditions true⁹. Thus we can number the n remaining coping actions $\alpha_1, \dots, \alpha_n$, in the order of preference over their applied strategy. The following global axioms express how the agent chooses to perform one coping action.

Global axiom 3 (Preference order among n coping actions for agent i).

The agent i always chooses to perform his preferred applicable coping action.

$$\begin{aligned}
 &\text{Bel}_i \text{Precond}(i:\alpha_1) \rightarrow \text{Choice}_i \text{Happens}_{i:\alpha_1} \top \\
 &\text{Bel}_i \text{Precond}(i:\alpha_2) \wedge \text{Bel}_i \neg\text{Precond}(i:\alpha_1) \rightarrow \text{Choice}_i \text{Happens}_{i:\alpha_2} \top \\
 &\dots \\
 &\text{Bel}_i \text{Precond}(i:\alpha_n) \wedge \text{Bel}_i (\neg\text{Precond}(i:\alpha_1) \wedge \dots \wedge \neg\text{Precond}(i:\alpha_{n-1})) \\
 &\quad \rightarrow \text{Choice}_i \text{Happens}_{i:\alpha_n} \top
 \end{aligned}$$

Then, action executability laws (Section 3.2) entail when a coping action is happening next. Thus our formalization allows to anticipate the agent's decisions and actions.

⁹Actually this is not always the case but we can suppose that else the agent randomly chooses one value of the parameter among the possible ones. In reality the agent would choose the most efficient value of the parameter but this involves a quantitative comparison that we cannot formalize in our current framework.

4.4 Some properties of coping strategies

We can now prove some indirect intuitive effects that the application of these strategies has on the agent's mental attitudes and behaviour.

Theorem 1 (Active coping). *After the active coping strategy, if i believes that after an action β , φ is false, he intends to perform this action¹⁰. (This comes from $(PLAN_{\alpha,\varphi})$.)*

$$After_{\langle i, \text{ActiveCoping}, E_{i,k}, \varphi \rangle} (Bel_i GAfter_{\beta} \neg\varphi \rightarrow Intend_i Done_{\beta} \top)$$

Theorem 2 (Denial). *After the performance of the denial strategy the agent believes that φ is false. (So after this strategy agent i does not feel $E_{i,k}\varphi$ anymore¹¹.)*

$$After_{\langle i, \text{Denial}(\psi), E_{i,k}, \varphi \rangle} Bel_i \neg\varphi$$

Theorem 3 (Seek Emotional Support). *After application of this strategy, agent i adopts the intention to inform j about the emotion he is feeling.*

$$After_{\langle i, \text{SeekESupport}(j), E_{i,k}, \varphi \rangle} Intend_i Done_{\langle i, \text{Inform}, j, E_{i,k}, \varphi \rangle} \top$$

Sketch of proof. Under sincerity and competence hypothesis (plausible for friends) i believes that after being informed, his friend j believes that i feels the emotion $E_{i,k}\varphi$. Agent i then deduces that after being informed, j will be sorry for him about φ , so: $Bel_i GAfter_{\langle i, \text{Inform}, j, E_{i,k}, \varphi \rangle} Bel_i \text{SorryFor}_{j,i}\varphi$ (since j is friendly all the terms of the definition of this emotion will hold). Thus $(PLAN_{\alpha,\varphi})$ allows to prove the theorem.

Theorem 4 (Focus and Venting). *After the performance of this strategy, agent i intends to inform j that he feels the emotion $E_{i,k}\varphi$.*

$$After_{\langle i, \text{Focus\&Venting}(j), E_{i,k}, \varphi \rangle} Intend_i Done_{\langle i, \text{inform}, j, E_{i,k}, \varphi \rangle} \top$$

Theorem 5 (Resignation). *After the execution of this strategy, agent i no longer feels the negative emotion $E_{i,k}\varphi$.*

$$After_{\langle i, \text{Resign}, E_{i,k}, \varphi \rangle} \neg E_{i,k}\varphi$$

Theorem 6 (Positive Reinterpretation). *After the execution of $\text{PosReinterp}(\psi)$, we envisage two cases. If agent i believes ψ (or deduces it from the belief that φ) the definitions¹² immediately entail that he feels joy about it:*

$$After_{\langle i, \text{PosReinterp}(\psi), E_{i,k}, \varphi \rangle} ((Bel_i \varphi \vee Bel_i \psi) \rightarrow Joy_i \psi)$$

If agent i only considers φ probable (in the case of fear), and under the additional condition that i does not believe ψ , he expects ψ and then feels hope about it:

$$After_{\langle i, \text{PosReinterp}(\psi), E_{i,k}, \varphi \rangle} ((Prob_i \varphi \wedge \neg Bel_i \psi) \rightarrow Hope_i \psi)$$

¹⁰In the case where i cannot perform the action β himself he has to ask material support to another agent: this is another problem-focused coping strategy. Yet our logic does not allow to express ability so we do not distinguish these two strategies.

¹¹Indeed each of the negative event-based emotions entails either $Bel_i \varphi$ or $Expect_i \varphi$ and both formulas are inconsistent with $Bel_i \neg\varphi$.

¹²According to Adam et al. (2006b) $Joy_i \varphi \stackrel{\text{def}}{=} Bel_i \varphi \wedge Des_i \varphi$ and $Hope_i \varphi \stackrel{\text{def}}{=} Expect_i \varphi \wedge Des_i \varphi$.

Theorem 7 (Mental Disengagement). *Axiom $(PLAN_{\alpha,\varphi})$ entails that after this strategy, if i knows an action that will probably establish ψ , he intends to perform it. (Then the performance of β will trigger a positive emotion that may divert him from $E_{i,k}\varphi$).*

$$After_{\langle i, \text{MentalDisengage}(\psi), E_{i,k}\varphi \rangle} (Bel_i G After_{\beta} \psi \rightarrow Intend_i Done_{\beta} \top)$$

5 Application on some examples

We consider the agent m who is the manager of a hotel. This case study describes how this agent (for example in the context of a virtual world) chooses actions to perform depending on his current emotion, by using the coping strategies formalized above. The first example illustrates the whole coping process, from the feeling of an emotion to the selection and application of a coping strategy. The second example illustrates in which kinds of situations an agent can use some strategies formalized in this paper¹³.

5.1 Example 1: process of selection of a coping action

Step 1: awareness of a negative emotion to cope with. We consider the manager of the hotel discovering that a fire has started in his hotel ($Bel_m \text{ burning}$), and considering probable that his hotel will be destroyed ($Prob_m \text{ destroyed}$), what is undesirable for him ($Des_m \neg \text{destroyed}$). This entails that the manager feels fear about the future destruction of his hotel ($Bel_m \text{ Fear}_m \text{ destroyed}$). Fear is a negative event-based emotion so m can use a coping strategy against it.

Step 2: choice of a type of coping. We also suppose that the manager still envisages a possibility that his hotel will not be destroyed by the fire ($\neg Bel_m \neg F Bel_i \neg \text{destroyed}$). This entails that $TypeCond(\langle m, s, \text{Fear}_m \text{ destroyed} \rangle)$ is true for any problem-focused strategy s . So m may only use problem-focused strategies. Then m has to check the applicability preconditions of the available problem-focused strategies.

Step 3: checkout of applicability preconditions. We finally suppose that m is not sure that the fire will be extinguished, so he still envisages that henceforth he will believe his hotel to be destroyed ($\neg Bel_m \neg G Bel_m \text{ destroyed}$). This entails that $ApplyCond(m;\beta)$ is true (where we note $m;\beta = \langle m, \text{ActiveCoping}, \text{Fear}_m \text{ destroyed} \rangle$), so m can use the active coping strategy. At this point $Precond(m;\beta)$ holds (Def 1). The agent knows no other problem-focused strategy so he has no more conditions to check.

Step 4: choice of the preferred strategy. At this step m already has only one applicable coping action. Whatever his preference order (*cf.* Global axiom 3) he then chooses to perform this action: $Choice_m Happens_{m;\beta} \top$. So finally the executability law (Global axiom 1) entails that m will perform this action next: $Happens_{m;\beta} \top$.

¹³Actually we describe all emotion-focused strategies except *Resign* that is trivial since its condition is always true.

Effects of the strategy. The direct effect of this coping action is that m adopts the intention that his hotel is not destroyed: $Intend_m \neg destroyed$. So $(PLAN_{\alpha,\varphi})$ allows to deduce that he will select an action that may result in this effect. For example we can suppose that he will call the firemen.

5.2 Example 2: contexts of application of some strategies

We now place at a later moment, after the departure of firemen. We consider that m believes that his hotel has been definitely destroyed by the fire ($Bel_m G Bel_m destroyed$), what is undesirable for him ($Des_m \neg destroyed$). This entails that the manager feels sadness about this destruction ($Bel_m Sadness_m destroyed$), and that $ApplyCond(\langle m, s, Sadness_m destroyed \rangle)$ is true for any emotion-focused strategy s . The manager may thus apply only emotion-focused coping strategies.

Denial We suppose that the manager believes that in general, if the firemen extinguish the fire in time, then his hotel is not destroyed ($Bel_m G(extInTime \rightarrow \neg destroyed)$). This validates $ApplyCond(\langle m, Denial(extInTime), Sadness_m destroyed \rangle)$, viz. the manager can use $extInTime$ as an argument to deny $destroyed$. Then the effect of this strategy is that the manager convinces himself that $extInTime$ is true (for example he conduces some reasoning like “the firemen always extinguish fires in time”) and begins to believe it ($Bel_m extInTime$). As a consequence he revises his beliefs by deducing that $\neg destroyed$, so he is not sad anymore.

Seeking emotional support and focus and venting. We now suppose that one of the manager’s friends j passes by the hotel. We adopt a simplified notion of friendship represented by particular global axioms. For instance in this case we have $Bel_m G(Bel_j Des_m \neg destroyed \rightarrow Des_j \neg Bel_m destroyed)$, reading “ m believes that anytime j believes $destroyed$ to be undesirable for m , it is undesirable for j that m believes $destroyed$ ”. This entails that $ApplyCond(\langle m, SeekESupport(j), Sadness_m destroyed \rangle)$ holds, thus m can use this strategy. Moreover, since j is considered to be a friend, we can also suppose that m believes j to trust what he says, in particular about his emotions, so: $Bel_m GAfter_{\langle m, Inform, j, Sadness_m destroyed \rangle} Bel_j Sadness_m destroyed$. This entails that $ApplyCond(\langle m, Focus\&Venting(j), Sadness_m destroyed \rangle)$ holds. Thus m can also use this second strategy.

To allow m to choose between these two strategies we suppose that m prefers expressing his emotion ($\alpha_1 = \langle m, Focus\&Venting(j), Sadness_m destroyed \rangle$) rather than getting compassion ($\alpha_2 = \langle m, SeekESupport(j), Sadness_m destroyed \rangle$). So we have the two following axioms (cf. Global axioms 3): $Bel_m Precond(\alpha_1) \rightarrow Choice_m Happens_{m:\alpha_1} \top$ and $(Bel_m Precond(\alpha_2) \wedge Bel_m \neg Precond(\alpha_2)) \rightarrow Choice_m Happens_{m:\alpha_2} \top$. Since the preconditions of α_1 and α_2 are both true this entails that $Choice_m Happens_{m:\alpha_1} \top$. So the manager will apply this strategy next, what will make him inform j about his emotion.

Positive reinterpretation We now consider that the manager believes that the destruction of his hotel is an opportunity to rebuild it ($Bel_m G(destroyed \rightarrow canRebuild)$),

and that this is not undesirable for him ($\neg Des_m \neg canRebuild$). Then $ApplyCond(\langle m, PosReinterp(canRebuild), Sadness_m destroyed \rangle)$ holds. The effect of this coping action is that m desires to rebuild his hotel ($Des_m canRebuild$), for example because it will be more beautiful. Since in this case m believes $canRebuild$ to be true (as a consequence of *destroyed*) he feels joy about it ($Joy_m canRebuild$), and this new emotion makes him forget his sadness about the destruction. Actually he reinterprets the event through the light of this positive consequence.

Mental disengagement Finally we consider that the manager desires to feel good ($Des_m feelsGood$) and does not believe that it is the case now ($\neg Bel_m feelsGood$). This entails $ApplyCond(\langle m, MentalDisengage(feelsGood), Sadness_m destroyed \rangle)$. As a consequence m adopts the intention to realize this desire ($Intend_m feelsGood$). His planning process will then select an action that he believes to reach this effect, and m will adopt the intention to perform this action. For example we suppose that m believes that running makes him feel good ($Bel_m After_{m:run} feelsGood$). Thus m adopts the intention to run, what will trigger a positive emotion diverting him from his sadness.

Actually, mental disengagement is an attempt to perform another satisfying action, with the aim that it triggers positive emotions to divert the individual from the current negative one. Each individual has his own favourite diverting actions: eating chocolate, taking alcohol or drugs, doing sport, sleeping...

6 Discussion of other formalizations of coping

Meyer Meyer (2006) describes the triggering of four emotions relative to the agent's plans and goals (following Oatley and Jenkins' theory of emotions Oatley and Jenkins (1996)). He then represents the influence of the agent's emotions on its actions through action tendencies (in the sense of Frijda (1986), for example anger induces aggression). Following Lazarus, action tendencies are innately programmed unconscious reflexes whereas coping strategies are conscious efforts to adapt to one's emotion, so we do not represent the same phenomena. Moreover Meyer makes a direct correspondence between each emotion and one kind of action tendency, while our coping strategies can apply to several emotions, depending on the particular context. Thus our approach is more flexible.

Gratch and Marsella Gratch and Marsella (2004) implement some coping strategies from the COPE model in the EMA agent. The most intense triggered emotion provides a coping opportunity. The available strategies are then compared and the agent chooses and applies his preferred one. Its effect is mainly expressed in terms of intention dropping or modification of utility or probability values. Moreover our model is built on BDI logics, a standard language used in many rational agents architectures, while EMA's mental state is represented by a complex structure inspired from planning. Though this complex structure is more expressive and allow to compute quantitative degrees of intensity.

Elliott's Affective Reasoner Elliott (1992) simulates the emotional behaviour of humans. The agent's emotions are computed according to the OCC typology Ortony

et al. (1988), and matched with an action depending on the agent's personality. The action database mixes coping strategies with other types of reactions like unconscious physiological changes, action tendencies, or reappraisals. However, psychological theories support the distinction between these reactions Lazarus and Folkman (1984). In our work we only account for coping actions and try to be more faithful to psychology than Elliott's implementation. Yet our logic may be very complex (due to revision actions in particular) and difficult to implement.

7 Conclusion

In this paper we proposed to represent coping strategies as actions, whose conditions and effects are expressed in terms of the agent's mental attitudes, and represented in a BDI logic. This language suffers some lacks of expressivity, for example we do not manage the intensity of emotions. As a consequence we assume that the execution of a coping strategy simply makes the emotion disappear, instead of making its intensity decrease. Nevertheless we believe that BDI logics also offer interesting properties and most of all they are widely used, what offers a great potential of agents compatible with our approach. Our account is limited for now, since we only formalize half coping strategies of the COPE model, and only against event-based emotions. The extension of this first account will be subject to later work.

Yet this work already offers interesting application prospects. First, it could make embodied conversational agents once more realist and believable. Indeed we believe that some kinds of dialogic behaviours often observed in human-human interaction, and that are not captured by standard models of dialogue (for example changing subject suddenly, or refusing to answer a question or to believe obviousness), actually result from the use of specific coping strategies. Second, an agent who knows some coping strategies could help the user to cope with his own emotions, either during his interaction with the system (intelligent interfaces, pedagogical agents) or during his everyday life (design of Ambient Intelligence Systems Adam et al. (2006a)). Third, such an emotional model could increase the believability of human-like characters for virtual worlds or video games, and thus improves the user's immersion in the virtual world. The use of context-dependent coping strategies also makes these virtual characters more unpredictable and enhance the pleasure of the human player.

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Abstract

Emotion takes an increasingly important place in the design of intelligent virtual agents for various applications. To design such emotional agents it is important to build on psychological research that has already explored the functioning of emotions for a long time. Cognitive psychology agrees on a process of appraisal responsible for the triggering of emotions, complemented by a process of coping that modifies the behaviour to manage negative emotions. Nevertheless, among the existing emotional agents, a lot express their emotions but few have a real emotional behaviour impacted by their emotions. In previous work we have already formalized the appraisal process in a BDI framework. In this paper we thus want to extend this BDI framework to formalize the coping strategies that an emotional agent could use. Our aim here is not to propose an agent architecture or implementation, but rather to provide their theoretical basis.

Keywords

Modal logic, emotions, reasoning.