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Coping strategies in a BDI logic: How can agents do to drop their negative emotions

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Abstract

In the agent community, more and more researchers get interested in designing believable embodied agents with emotions. The focus is on the agent's external believability, *i.e*. the realism of their emotional expressions, neglecting the internal believability of the emotional processes. In this paper we ground on an existing formalization of emotions, that only accounts for appraisal (the psychological process leading to the triggering of emotions), and express in the same formalism (namely BDI logics) the process of coping (the individual's effort to manage a stressful situation). Indeed, following Lazarus, these two processes are indivisible for the description of human emotions. We thus consider coping strategies as particular actions with effects on the agent's mental attitudes. We formalize some strategies by expressing their preconditions and effects in a BDI logic, and then illustrate their functioning on an example from a training simulation application for firemen.

Keywords

Emotion, coping strategy, BDI logic, reasoning for embodied and believable agents.

Contents

1 Introduction

In the agent community, more and more researchers get interested in designing believable agents, aiming at applications in virtual worlds, simulations, video games, or Embodied Conversational Agents, for pedagogical (virtual tutor), assistance (interfaces agents) or entertainment (virtual companion) use. We believe that emotions should intervene in several aspects of such agents: to increase their **external believability**, *i.e.* the believability of their facial and bodily expression, which is a growing research area; but also to bring their reasoning closer to the human reasoning (a kind of **internal believability**). Many authors thus try to endow their agents with believable emotional expressions Pelachaud et al. (2002), formalizing their triggering by building essentially on Ortony and colleagues' typology of emotions Ortony et al. (1988) (*e.g.* Adam et al. (2006); Meyer (2004)). But in spite of the huge amount of psychological studies endorsing the role of emotions in behaviour (like the neurological studies from Damasio Damasio (1994), or the Affect Infusion Model of Forgas Forgas (1995)), very few agent designers give true emotional abilities to their agents. We can quote for example the EMA agent developed by Gratch and Marsella Gratch and Marsella (2004a); Marsella and Gratch (2003) for a virtual world simulating a war situation, who disposes of coping strategies, and Meyer's attempt Dastani and Meyer (2006) to formalize Frijda-like action tendencies Frijda (1986).

In this paper we build on the model proposed by Adam et al. in Adam et al. (2006) for the triggering of emotions, and propose to complete it with a model of the psychological concept of coping. In the sense of Lazarus Lazarus and Folkman (1984) this represents the conscious attempts of the individual to manage threatening stimuli pointed out by intense negative emotions. Actually, we ground on the COPE model Carver et al. (1989) that proposes a set of fifteen coping strategies, and we try to translate a part of these strategies into a logical language based on BDI logics (*Belief*, *Desire*, *Intention*). We thus consider coping strategies as actions with their preconditions, and effects on the agent's beliefs, desires, and intentions. Emotions thus modify the agent's subsequent behaviour through the choice and application of a coping strategy. In this paper we are not interested in the decision process leading to the choice of one particular coping strategy, but only in the effect of the chosen strategy on the agent's mental attitudes.

BDI logics Cohen and Levesque (1990); Rao and Georgeff (1991, 1992); Sadek (1992); Herzig and Longin (2004), that ground on the philosophy of language, mind, and action Bratman (1987), 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 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 from the formal logic point of view).

We begin by introducing the psychological concepts that we want to formalize. We then proceed with the description of the semantics and axiomatics of our logical framework. We will then propose a logical account of some coping strategies in this framework, and illustrate their actual use on an example from a training simulation for firemen. Finally we will discuss the other existing *internally believable* agents, namely Gratch and Marsella's EMA agent and Meyer's agent language.

2 The concept of coping

2.1 Psychological notion of coping

Lazarus and Folkman Lazarus and Folkman (1984) quote two origins of the concept of coping: the darwinian theory of stress and control in animals, defining coping as acts controlling aversive situations to lower psychological and physiological perturbations; and psychoanalytic ego psychology, defining coping as realist and flexible thoughts and acts that solve problems and reduce stress. But for Lazarus, what is important in coping is not the result but the efforts, that differentiate coping from automatic adaptive processes like action tendencies or reflexes. He thus gives a new definition of coping: "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" Lazarus and Folkman (1984). Coping thus has to do with the mastering or minimization of stressful situations. Lazarus 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.

2.2 Coping strategies

Carver and colleagues in their COPE model Carver et al. (1989) propose the following fifteen coping strategies: **active coping** consists in directly acting against the stressor; **planning** consists in thinking about the actions the individual could perform to actively cope, we consider it as a tool for active coping an thus we do not formalize it; **seeking instrumental social support** consists in asking assistance to other people, *e.g*. information or advice, we consider it as a subcase of active coping, where the action performed is a dialogic one, and thus we will not formalize it separately; **seeking emotional social support** consists in trying to get moral support (sympathy, understanding) from other people; **suppression of competing activities** consists in focusing on the problem by keeping other activities waiting for a while, we consider that it is a tool to free more resources for coping, but not a real strategy since it does not directly influence the emotion, thus we will not formalize it; **positive reinterpretation and growth** consists in reinterpreting the situation by finding some positive aspects in it; **restraint coping** consists in waiting a coping opportunity, it has no direct effect so we will not formalize this strategy; **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; **behavioral disengagement** consists in dropping the unsatisfiable intention; **religion**, **alcohol/drug use** and **humor** are particular types of mental disengagement that we will not formalize apart.

We first note that behavioral disengagement is already built in the logical definition of intention so we will not formalize it.

3 Logical framework

As we stated before, we refer to Adam et al. (2006) for the modelling of the appraisal process. In order to use their formalization of the triggering of emotions, we use almost the same formal framework. However, we bring some modifications: since we do not need social ideals we do not use them, but we add a $Choice$ operator (realist preference) in order to define intention as in Herzig and Longin (2004). We also simplify the notion of desire by grounding on its proximity to the notion of ideality used in standard deontic logic to define obligation operators.

3.1 Semantics

Let AGT be the set of agents, $ATM = \{p, q...\}$ the set of atomic formulas and $ACT = \{\alpha, \beta...\}$ the set of actions. A possible-worlds semantics is used, and a model $\mathcal{M}$ is a triple $\langle W, V, \mathcal{R}\rangle$ where W is a set of possible worlds, V is a truth assignment which associates each world w with the set V_w of atomic propositions true in w, and $\mathcal{R}$ is a tuple of structures made up of:

– $\mathcal{A} : ACT \rightarrow (W \rightarrow 2^W)$ which associates each action $\alpha \in ACT$ and possible world $w \in W$ with the set $\mathcal{A}_\alpha(w)$ of possible worlds resulting from the execution of action α in w;

– $\mathcal{B} : AGT \rightarrow (W \rightarrow 2^W)$ which associates each agent $i \in AGT$ and possible world $w \in W$ with the set $\mathcal{B}_i(w)$ of possible worlds compatible with the beliefs of agent i in w. All these accessibility relations $\mathcal{B}_i$ are serial, transitive and euclidian;

– $\mathcal{C} : AGT \rightarrow (W \rightarrow 2^W)$ which associates each agent $i \in AGT$ and possible world $w \in W$ with the set $\mathcal{C}_i(w)$ of prefered worlds of agent i in w. All these accessibility relations $\mathcal{C}_i$ are serial, transitive and euclidian. $\mathcal{C}_i \subseteq \mathcal{B}_i$ for every $i \in AGT$ (strong realism constraint);

– $\mathcal{D} : AGT \rightarrow (W \rightarrow 2^W)$ which associates each agent $i \in AGT$ and possible world $w \in W$ with the set $\mathcal{D}_i(w)$ of ideal worlds compatible with what is desirable for the agent i in the world w. All these accessibility relations $\mathcal{D}_i$ are serial;

– $\mathcal{G} : W \rightarrow 2^W$ which associates each possible world $w \in W$ with the set $\mathcal{G}(w)$ of possible worlds in the future of w. This relation is a linear order (reflexive, transitive and antisymmetric). $\mathcal{G} \supseteq \mathcal{A}_\alpha$ for every α. w might be possible in the future without there being a particular sequence of actions leading to w: φ will be eventually true without necessarily having a sequence of actions which will achieve φ. This will be relevant when it comes to intentions, because an agent might believe w can be achieved without having a plan to reach w;

– $\mathcal{P} : AGT \rightarrow (W \rightarrow 2^{2^W})$ which associates each agent $i \in AGT$ and possible world $w \in W$ with a set of sets of possible worlds $\mathcal{P}_i(w)$. (See the neighborhoods semantics in Chellas (1980).) Intuitively for $U \in \mathcal{P}_i(w)$, U contains more elements than its complement $\mathcal{B}_i(w) \setminus U$.

We associate modal operators to these mappings: $After_\alpha\, \varphi$ 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".

$FORM = \{\varphi, \psi ...\}$ denotes the set of formulas.

The truth conditions are standard for almost all of our operators: $w \Vdash \Box\varphi$ iff $w' \Vdash \varphi$ for every $w' \in \mathcal{R}_\Box(w)$ where $\mathcal{R}_\Box \in \mathcal{A} \cup \mathcal{B} \cup \mathcal{C} \cup \mathcal{D} \cup \{\mathcal{G}\}$ and $\Box \in \{After_\alpha : \alpha \in ACT\} \cup \{Bel_i : i \in AGT\} \cup \{Choice_i : i \in AGT\} \cup \{Des_i : i \in AGT\} \cup \{G\}$ respectively. For the converse operators we have: $w \Vdash \boxminus\varphi$ iff $w' \Vdash \varphi$ for every w' such that $w \in \mathcal{R}_\boxminus(w')$ where $\mathcal{R}_\boxminus \in \mathcal{A} \cup \{\mathcal{G}\}$ and $\boxminus \in \{Before_\alpha : \alpha \in ACT\} \cup \{H\}$ respectively. Furthermore, $w \Vdash Prob_i\,\varphi$ iff there is $U \in \mathcal{P}_i(w)$ such that $w' \Vdash \varphi$ for every $w' \in U$.

We have the following introspection constraints: if $w \in \mathcal{B}_i(w')$ then $\mathcal{B}_i(w) = \mathcal{B}_i(w')$, $\mathcal{C}_i(w) = \mathcal{C}_i(w')$, $\mathcal{D}_i(w) = \mathcal{D}_i(w')$ and $\mathcal{P}_i(w) = \mathcal{P}_i(w')$, ensuring that agents are aware of their beliefs, preferences, probabilities, and of what is desirable for them. We also require that $U \subseteq \mathcal{B}_i(w)$ for every $U \in \mathcal{P}_i(w)$, ensuring that belief implies probability, and that $\mathcal{C}_i(w) \subseteq \mathcal{B}_i(w)$ ensuring that belief implies preference (realistic choice).

3.2 Axiomatics

$After_\alpha$ and $Before_\alpha$ are defined in the standard tense logic K_t, *viz.* logic K with conversion axioms (see Burgess (2002) for more details). For every α and φ, as $\mathcal{G} \supseteq \mathcal{A}_\alpha$, we have that $G\varphi \rightarrow After_\alpha\,\varphi$. 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".

NOTATION 1 ($i{:}\alpha$). *In the following, the notation $i{:}\alpha$ denotes an action α of which i is the author.*

Bel_i and $Choice_i$ operators are defined in the standard KD45 logic that we do not develop here (see Hintikka (1962); Chellas (1980) and Herzig and Longin (2004) for more details). The only relationship between belief and choice is the axiom $Bel_i\,\varphi \rightarrow Choice_i\,\varphi$ (strong realism).

What is desirable represents possibly unrealistic preferences in the sense that we do not impose that $\mathcal{B}_i(w) \cap \mathcal{D}_i(w) \neq \emptyset$. In this sense, desired propositions are true in ideal worlds. Thus semantics is that of the semantics of standard deontic logic (SDL), and the logic is the same (KD). We define $Undes_i\,\varphi \stackrel{def}{=} Des_i\,\neg\varphi$. ($Des_i$ and $Undes_i$ are similar respectively to obligation Obl_i and forbidden $Forb_i$ of SDL.)

The logic of G and H is linear temporal logic with conversion axioms (see Burgess (2002) for more details). $F\varphi \stackrel{def}{=} \neg G\neg\varphi$ reads "φ is true or will be true at some future instant". $P\varphi \stackrel{def}{=} \neg H\neg\varphi$ reads "φ is or was true".

The probability operators correspond to a notion of weak belief. It is based 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 $\Box\varphi \leftrightarrow Bel_i\,\Box\varphi$.

DEFINITION 1 (EXPECTATION). *$Expect_i\,\varphi$ is true iff i believes that φ is probably true,*

but envisages the possibility that it could be false. Thus:

$$Expect_i\,\varphi \stackrel{def}{=} Prob_i\,\varphi \wedge \neg Bel_i\,\varphi \qquad (\text{Def}_{Expect_i})$$

DEFINITION 2 (ACHIEVEMENT GOAL). *Following Herzig and Longin (2004), agent i has φ as achievement goal iff i does not believe φ is currently true and in his every preferred worlds i will believe φ some time. Thus:*

$$AGoal_i\,\varphi \stackrel{def}{=} Choice_i\,FBel_i\,\varphi \wedge \neg Bel_i\,\varphi \qquad (\text{Def}_{AGoal_i})$$

DEFINITION 3 (FUTURE DIRECTED INTENTION). *Following Herzig and Longin (2004), agent i intends that φ iff φ is an achievement goal of i and i does not believe that he will believe φ some day. Thus:*

$$Intend_i\,\varphi \stackrel{def}{=} AGoal_i\,\varphi \wedge \neg Bel_i\,FBel_i\,\varphi \qquad (\text{Def}_{Intend_i})$$

We consider here we have a planification process that we do not detail here. Roughly speaking, if agent i intends that φ be true and he believes that after α, φ will be true, then he intends that α be performed. Thus:

$$Bel_i\,After_\alpha\,\varphi \wedge Intend_i\,\varphi \rightarrow Intend_i\,Done_\alpha\,\top \qquad (\text{PLAN}_{\alpha,\varphi})$$

4 Formalized coping strategies

In this paper, we restrain our account of coping strategies to event-based emotions. The definitions of these emotions, following Adam and colleagues Adam et al. (2006), all use weak or strong belief and a corresponding individual desire or undesire. Our coping strategies will modify these mental attitudes to drop the agent's emotion. We believe that action-based emotions may imply different specific coping strategies like "shifting responsibility" Gratch and Marsella (2004a). Moreover the social ideals underlying these emotions may not be as easy to change as individual preferences. We thus let the study of coping strategies against action-based emotions for future work.

According to Lazarus Lazarus and Folkman (1984), coping strategies only apply to stressful situations, so we are finally only interested in the negative (in the sense of Adam et al. (2006)) event-based emotions, that are: sadness, fear, fears-confirmed, disappointment, sorry for, and resentment. However, we do not assume a direct correspondance between one emotion and one fixed strategy (like it is the case in Dastani and Meyer (2006)). On the contrary we suppose that there is a complex decision process taking the emotion and the context into account to determine what is the most efficient strategy to drop this emotion. We consider this process is beyond the scope of this paper.

In the next subsections we will formalize some coping strategies as particular actions schemes, and describe their conditions and effects in our logical language.

4.1 Formal language

Let $STRA = \{\mathsf{ActiveCoping}, \mathsf{Denial}, \mathsf{SeekESupport}, \mathsf{Focus\&Venting}, \mathsf{Resign}, \mathsf{PosReinterp}, \mathsf{MentalDisengage}\}$ be a subset of action names from ACT corresponding to coping strategies.

Let $EMO^- = \{Distress, Disappointment, FearConfirmed, Fear, SorryFor, Resentment\}$ be the set of negative event-based emotions. Coping strategies can only apply to emotions $E_{i,k}\varphi$ where $E \in EMO^-$.

$E_{i,k}\varphi$ is the emotion felt by agent i about φ w.r.t. agent k[1]. As in the psychological literature φ is called the "stressor".

A coping action α is a 4-uple $\langle s, i, E_{i,k}\varphi, \psi\rangle$ where i is the agent applying the coping strategy $s \in STRA$ to the emotion $E_{i,k}\varphi$ thanks to the means ψ. The means is part of the specification of the strategy. When the means is not needed ψ is $\top$: we omit it and we write $\langle s, i, E_{i,k}\varphi\rangle$. In the next subsections we will write the preconditions and effects of each coping action.

4.2 Action laws

To be executable, a coping action must satisfy three conditions: a basic condition (BC) common to all strategies, a control condition (CC) determining which kind of strategy will be applied, and an additional condition (AC) specific to each strategy and constraining its means.

DEFINITION 4 (BASIC CONDITION). *An agent who feels a negative emotion can cope with it. Thus the basic condition of any strategy against an emotion $E_{i,k}\varphi$ where $E \in EMO^-$ is*

$$BC(\langle s, i, E_{i,k}\varphi, \psi\rangle) \stackrel{def}{=} Bel_i\, E_{i,k}\varphi \qquad (\text{Def}_{BC})$$

According to Lazarus Lazarus and Folkman (1984) there are two types of strategies: problem-focused ones, that he considers more likely against a controllable stressor, and emotion-focused ones, more likely otherwise. We capture this distinction in an all-or-none matter: if the stressor is controllable the agent will only use problem-focused strategies, whereas if it is not he will only use emotion-focused ones.

DEFINITION 5 (CONTROL CONDITION). *A problem 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 problem is not controllable iff agent i believes that φ is henceforth true. Thus:*

$$CC(\langle s, i, E_{i,k}\varphi, \psi\rangle) \stackrel{def}{=} \begin{cases} \neg Bel_i\, \neg F Bel_i\, \neg\varphi & \textit{if} \quad s = \mathsf{ActiveCoping} \\ Bel_i\, G Bel_i\, \varphi & \textit{else} \end{cases} \qquad (\text{Def}_{CC})$$

We can prove that both control conditions are mutually inconsistent.

To perform a particular coping action, the agent still has to validate some additional conditions that are specific to each coping strategy. These conditions are specified in the next section.

NOTATION 2. *We note $AC(\alpha)$ the additional condition of the coping action α and $Effect(\alpha)$ its effect.*

Action laws are made up of executability laws and effect laws. The former describe what must be true before the execution of an action (called the precondition of the action);

[1] k is not necessarily different from i. When i is k we will sometimes write $E_i\,\varphi$.

the latter describe what will be true after the execution of this action (called the effect of the action). In the case of coping actions, preconditions and effects are described in terms of mental attitudes.

GLOBAL AXIOM 1 (EXECUTABILITY LAWS). *A coping action α executed by agent i is happening next iff all its conditions are satisfied and i prefers that α be performed. Thus, for a coping action $i{:}\alpha = \langle s, i, E_{i,k}\varphi, \psi\rangle$ (*i.e.*:*

$$\begin{aligned} \mathit{Happens}_{i:\alpha}\top \leftrightarrow BC(i{:}\alpha) \wedge CC(i{:}\alpha) \wedge \\ AC(i{:}\alpha) \wedge \mathit{Choice}_i\, \mathit{Happens}_{i:\alpha}\top \end{aligned} \qquad (\text{EXEC}_\alpha)$$

GLOBAL AXIOM 2 (EFFECT LAWS). *Effect laws are defined by instances of the following effect laws scheme:*

$$\mathit{After}_\alpha\, \mathit{Effect}(\alpha) \qquad (\text{EFFECT}_\alpha)$$

where $\mathit{Effect}(\alpha)$ denotes the effect of the action α.

In the rest of this section, we describe the additional condition and the effect of each coping action we define. Thus, action laws will be defined for each coping action.

4.3 Qualification of coping actions

We have here selected seven strategies among those of the COPE model Carver et al. (1989). We recall that a coping action consists in a coping strategy associated with an optional constraint type of means, instantiated by the decision process depending on the specific context. It is important to understand that a coping strategy with a different type of means makes no sense in our formalism.

Active coping

For the agent to apply an ActiveCoping strategy, he must believe that there is at least one possibility to change (in the future) the fact that φ is true (this matches the control condition). Since the agent's goal when applying such a strategy is to make φ false, it is not necessary for him to apply it if he considers that φ could be false some time without acting for that. So the agent will use active coping only if he believes that there exists at least one possibility for him that henceforth he never believes φ to be false. This sets up the additional condition of this strategy. The effect of its application is that the agent adopts the realist preference that in the future he will believe φ to be false. Thus:

$$AC(\langle \mathsf{ActiveCoping}, i, E_{i,k}\varphi\rangle) \stackrel{def}{=} \neg Bel_i \neg G \neg Bel_i \neg\varphi$$
$$\mathit{Effect}(\langle \mathsf{ActiveCoping}, i, E_{i,k}\varphi\rangle) \stackrel{def}{=} \mathit{Choice}_i\, F\, Bel_i \neg\varphi$$

We can prove that $\mathit{After}_{\langle \mathsf{ActiveCoping}, i, E_{i,k}\varphi\rangle}\ \mathit{Intend}_i \neg\varphi$. (That is: i will act in order to make φ false.)

Denial

Denial operates by refusing the reality of the stressor, supporting this assumption by some proof; thus the means of denial is a formula ψ which is initially only probable for agent

i (*i.e.* $Prob_i\,\psi$) and believed to entail $\neg\varphi$ (*i.e.* $Bel_i\,(\psi \rightarrow \neg\varphi)$). These constraints on the formula ψ constitute the additional condition of denial. The effect of this strategy is to strengthen the belief that ψ is true (that is: believe it instead of considering it only probable) in the purpose of deducing $\neg\varphi$. Thus, formally:

$$AC(\langle \mathsf{Denial}, i, E_{i,k}\varphi, \psi\rangle) \stackrel{def}{=} Prob_i\,\psi \wedge Bel_i\,(\psi \rightarrow \neg\varphi)$$
$$After_{\langle \mathsf{Denial}, i, E_{i,k}\varphi, \psi\rangle}\; Bel_i\,\psi$$

We can easily prove that: $After_{\langle \mathsf{Denial}, i, E_{i,k}\varphi, \psi\rangle}\; Bel_i\,\neg\varphi$, so after the performance of the denial strategy agent i is not stressed anymore.

Seeking emotional support

SeekESupport (*viz*. seeking emotional support) operates by looking for the compassion of a friendly agent j who can see the situation; thus its means is $Bel_i\; Bel_j\,\varphi$, and its condition is that the agent j is believed to be friendly. By friendly we mean that agent j should dislike that his friend i believes something undesirable for him (*i.e.* $Bel_i\; Undes_j\; Bel_i\,\varphi$): this is the additional condition of this strategy. Its effect is that agent i, believing that j is friendly, will adopt the intention to obtain his compassion (*i.e.* $Intend_i\; SorryFor_{j,i}\varphi$)[2]. To achieve this intention he may have to communicate and explain his sadness to him.

$$AC(\langle \mathsf{SeekESupport}, i, Sadness_i\varphi, Bel_i\; Bel_j\,\varphi\rangle) \stackrel{def}{=}$$
$$Bel_i\; Undes_j\; Bel_i\,\varphi$$
$$After_{\langle \mathsf{SeekESupport}, i, Sadness_i\varphi, Bel_i\; Bel_j\,\varphi\rangle}\; Intend_i\; SorryFor_{j,i}\varphi$$

Focus on and venting

Focus&Venting operates by looking for the attention of any agent j attending the situation; thus its means is the same as for the previous strategy (*i.e.* $Bel_i\; Bel_j\,\varphi$). This strategy is similar to seeking emotional support, but it has no conditions and can be applied to any emotion. Its effect is that the agent i adopts the intention to communicate his emotion to j. This effect is a little weaker than the previous one since i is not sure to obtain compassion from an agent who is not believed to be friendly.

$$AC(\langle \mathsf{Focus\&Venting}, i, E_{i,k}\varphi, Bel_i\; Bel_j\,\varphi\rangle) \stackrel{def}{=} \top$$
$$After_{\langle \mathsf{Focus\&Venting}, i, E_{i,k}\varphi, Bel_i\; Bel_j\,\varphi\rangle}\; Intend_i\; Bel_j\; E_{i,k}\varphi$$

Resignation

Resign (*viz*. resignation) has no particular means, nor any condition. It is the simplest strategy, consisting in accepting the situation. Actually, to simulate how the agent can get used to the situation along time, we make him drop his contradicted desire immediately.

[2]Given the definition of $SorryFor$ Adam et al. (2006) (that is: $SorryFor_{i,j}\varphi \stackrel{def}{=} Bel_i\,\varphi \wedge Bel_i\,F\,Bel_j\,\varphi \wedge Bel_i\; Undes_j\,\varphi \wedge Undes_i\; Bel_j\,\varphi$), this restrains the applicability of the strategy to sadness.

This is an approximation of a long-term process, which leads to the disappearance of the negative emotion.

$$AC(\langle \mathsf{Resign}, i, E_{i,k}\varphi\rangle) \stackrel{def}{=} \top$$
$$After_{\langle \mathsf{Resign}, i, E_{i,k}\varphi\rangle} \neg Undes_i\, \varphi$$

We can prove that after execution of this strategy, agent i no longer believes that he feels the negative emotion $E_{i,k}\varphi$. Formally, $After_{\langle \mathsf{Resign}, i, E_{i,k}\varphi\rangle} \neg Bel_i\, E_{i,k}\varphi$ is provable.

Positive reinterpretation

PosReinterp (*viz*. positive reinterpretation) operates by finding a positive aspect in the stressor; so its means is a formula ψ such that ψ is a not undesirable consequence of the stressor. This constraint on the formula ψ sets up the additional condition of positive reinterpretation (*i.e*. $\neg Undes_i\, \psi$). The effect of this strategy is that the formula ψ becomes desirable. Thus the negative emotion about φ will be replaced by a positive one about ψ.

$$AC(\langle \mathsf{PosReinterp}, i, E_{i,k}\varphi, \psi\rangle) \stackrel{def}{=} Bel_i\,(\varphi \rightarrow \psi) \wedge \neg Undes_i\, \psi$$
$$After_{\langle \mathsf{PosReinterp}, i, E_{i,k}\varphi, \psi\rangle}\, Des_i\, \psi$$

We can prove that $Bel_i\, \varphi \rightarrow After_{\langle \mathsf{PosReinterp}, i, E_{i,k}\varphi, \psi\rangle}\, Joy_i\, \psi$. In other words, if agent i believes φ then after the execution of this strategy he believes ψ and feels joy about it. We notice that we need the full belief about φ to make this strategy efficient, so it will not work on prospect-based emotions (*i.e*. fear).

Mental disengagement

MentalDisengage (*viz*. mental disengagement) operates by engaging in an action to take mind off stressor; thus its means is $Happens_{i:\alpha}\, \top$, and its condition is that the effect ψ of this action α is desirable for i. The effect of this strategy is that the agent adopts the intention to perform this disengaging action. As a consequence he will trigger in the future a positive emotion about the effect of this action.

$$AC(\langle \mathsf{MentalDisengage}, i, E_{i,k}\varphi, Done_{i:\alpha}\, \top\rangle) \stackrel{def}{=}$$
$$Bel_i\, After_\alpha\, \psi \wedge Des_i\, \psi$$
$$After_{\langle \mathsf{MentalDisengage}, i, E_{i,k}\varphi, Done_{i:\alpha}\, \top\rangle}\, Intend_i\, Happens_{i:\alpha}\, \top$$

We can prove that after this strategy the agent feels joy about ψ, *i.e*. formally $After_{\langle \mathsf{MentalDisengage}, i, E_{i,k}\varphi, Happens_{i:\alpha}\, \top\rangle}\, Joy_i\, \psi$.

In the next section we illustrate the functioning of this formalism on an example showing for each strategy how its means is instantiated, how its conditions are verified, and how it influences the agent's mental attitudes and emotions.

5 Case study

We consider the agent m, who is the manager of a hotel. We use the definitions proposed in Adam et al. (2006) to compute his emotions in a given situation, and then show how the strategies formalized in the previous section work against his negative emotions.

5.1 Initial situation 1

For the agent to use a problem-focused coping strategy, we need to place him in a situation where the stressor is believed to be controllable, *i.e.* not definitive. We thus consider the manager of the hotel discovering that a fire has started in his hotel ($Bel_m\ burning$), and we suppose that:

- his hotel could be destroyed

$$Prob_m\ destroyed \tag{H1}$$

- it is undesirable for him

$$Undes_m\ destroyed \tag{H2}$$

- he believes there is a possibility that his hotel will not be destroyed by the fire

$$\neg Bel_m\ \neg F\, Bel_i\ \neg destroyed \tag{H3}$$

Following Adam et al. (2006), (H1) and (H2) entail that the manager feels fear about the destruction of his hotel and he is conscious of this emotion.

$$Fear_m\ destroyed \tag{1}$$
$$Bel_m\ Fear_m\ destroyed \tag{2}$$

Since $Fear$ is a negative emotion (by definition of EMO^-), (2) and (Def$_{BC}$) entail $BC(\langle \mathsf{ActiveCoping}, m, Fear_m destroyed\rangle)$ holds: the agent can cope with this emotion. Moreover (H3) implies $AC(\langle \mathsf{ActiveCoping}, m, Fear_m destroyed\rangle)$ so he may use only problem-focused coping strategies. Among these strategies we only formalized active coping.

5.2 Initial situation 2

For the agent to use emotion focused strategies, we now have to send him a stressor that he cannot control. We thus consider that:

- his hotel is destroyed by the fire and this is undesirable for him

$$Bel_m\ G\, Bel_m\ destroyed \tag{H4}$$
$$Undes_m\ G\, destroyed \tag{H5}$$

Following emotions definitions of Adam et al. (2006), the manager feels sadness about this destruction and he is aware about that:

$$Sadness_m\ destroyed \tag{3}$$
$$Bel_m\ Sadness_m\ destroyed \tag{4}$$

Since $Sadness$ is a negative emotion, it follows from (4) that the basic condition $BC(\langle s, m, Sadness_m destroyed, \psi\rangle)$ holds, where $s \in STRAT$ and where ψ is the means of s.

(H4) entails that the control condition Def_{CC} is true. The manager may thus apply emotion-focused coping strategies. We will discuss the context in which each strategy can be applied, and its effects on the manager's sadness.

5.2.1 Denial

Since the firemen came, the manager considers it probable that they extinguished the fire in time to save his hotel (*i.e.* $Prob_m\ extingInTime$). Moreover, he believes that if the firemen extinguish the fire in time, his hotel is not destroyed (*i.e.* $Bel_m\ (extingInTime \rightarrow \neg destroyed)$. The additional condition for the manager to deny the destruction of his hotel through the hypothesis $extingInTime$ thus holds, and the manager may apply this strategy.

If the manager executes this coping action, the effect will be that he reinforces his weak belief that the fire was extinguished in time (*i.e.* now $Bel_m\ extingInTime$), and can then deduce that his hotel is not destroyed ($Bel_m \neg destroyed$). He is thus denying the reality, trying to convince himself that the firemen must have extinguished the fire in time and saved his hotel. As an immediate effect, his sadness will disappear since he no longer believes that the stressor is real. Then he will probably have to use some strategies to prevent himself from seeing the reality, like avoiding talking to people and looking at his hotel for a while.

5.2.2 Seeking emotional support

In the same initial situation, we suppose that one of the manager's friends j passes by the hotel. Since he is friendly, he is believed to dislike that something undesirable occurs to the manager, in particular the destruction of his hotel (*i.e.* $Bel_m\ Undes_j\ Bel_m\ destroyed$). The additional condition for m to seek emotional support from agent j seeing the scene (the means of the strategy is $Bel_m\ Bel_j\ destroyed$) thus holds. So the manager can apply this strategy, and as an effect he adopts the intention to receive compassion from agent j ($Intend_m\ SorryFor_{j,m} destroyed$). To realize this intention he will probably engage in a dialogue with j and use expressive dialog acts, but to receive compassion he must explain the cause of his sadness to his interlocutor.

We can notice that this strategy only applies to sadness, since an agent can only be sorry for a sad agent (following the definitions given in Adam et al. (2006)).

5.2.3 Focus on and venting

This strategy is weaker than the previous one, since it has no additional condition, but it applies to all negative emotions. In any case, the manager can always use this strategy on an agent j attending his situation. The effect is that m adopts the intention to let j know about his emotion ($Intend_m\ Bel_j\ Sadness_m\ destroyed$). As for SeekESupport he can communicate his sadness verbally (engaging in dialogue to tell that he is sad and to explain his problem). However since he is not looking for compassion, he does not need

to explain the cause of his emotion, so non-verbal venting of emotion (crying) would be sufficient.

5.2.4 Acceptation and resignation

The manager can also accept the situation and resign himself, through abandoning his contradicted desire. This strategy has no additional condition. As a result of its application, the manager drops his contradicted desire, *i.e*. he tries to get used to the destruction of his hotel in order not to consider it undesirable anymore ($\neg Undes_m\ destroyed$). By this way, his sadness disappears.

Actually, it can take some time to abandon a desire and detach oneself from the situation, but as a simplification we formalize the effect of this strategy as being immediate. This strategy is difficult to apply in a situation where the threatened desire is quite an important one, and the manager would probably not choose such a strategy in this case. But as we said before, the effective choice of a strategy by the decision process is out of the scope of this paper.

5.2.5 Positive reinterpretation

In the same initial situation, we consider that the manager believes that the destruction of his hotel is an opportunity to rebuild it ($Bel_m\,(destroyed \rightarrow canRebuild)$), and that this is not undesirable for him ($\neg Undes_m\ canRebuild$). The additional condition for the manager to positively reinterpret the destruction of his hotel thus holds with $canRebuild$ as the means of the strategy. As an effect of the execution of this coping action, the manager now considers it desirable to rebuild his hotel ($Des_m\ canRebuild$), for example because it will be more beautiful than before. He then reinterprets the event through the light of this positive consequence and abandon his contradicted desire ($\neg Undes_m\ destroyed$)[3]. Actually, the positive emotion triggered by the possibility to rebuild a better hotel makes him forget his sadness about the destruction. As a consequence he will probably engage in actions to rebuild his hotel.

5.2.6 Mental disengagement

In the same initial situation, we consider that the manager likes running because it makes him feel good ($Bel_m\ After_{m:run}\ feelsGood \wedge Des_m\ feelsGood$). The additional condition for mental disengagement of the destruction of the hotel through running thus holds. Actually, mental disengagement is an attempt to perform another satisfying action, with the aim that they trigger positive emotions that divert the individual from the negative one.

As a result of the strategy, the manager will adopt the intention to run, and he will probably perform this action if all its conditions are true.

[3]Thus this strategy is a special kind of acceptation.

6 Discussion

6.1 Meyer

Meyer proposes a programming language to implement emotional agents. In previous work Meyer (2004) he described the triggering of four emotions relative to the agent's plans and goals. In his latest paper Dastani and Meyer (2006) he explores the influence of the agent's emotions on its actions, following Oatley and Jenkins' theory of emotions Oatley and Jenkins (1996). He makes a correspondence between each emotion and one kind of action tendency (in the sense of Frijda Frijda (1986)). Our approach differs from Meyer's one in several points. First, we do not represent the same phenomena. Following Lazarus, action tendencies are innately programmed reflexes, and thus unconscious, whereas coping strategies are conscious efforts to adapt to one's emotion. Moreover, each emotion corresponds to exactly one action tendency, while coping strategies can apply to several emotions, depending on the particular context. Second, our approach is different, since Meyer provides the syntax and semantics of a programming language, aiming at immediately implementing these agents, whereas we are first interested in axiomatizing these agents' coping strategies in a BDI logic.

6.2 Agent EMA - Gratch et Marsella

Gratch and Marsella do not propose a logical account of psychological emotional processes but an implementation in the EMA agent. The current mental state is represented with a Causal Interpretation (CI) structured in three parts : the causal history (the past), the current world (the present), and the task network (the future). These three are causally interrelated. It is a classical planning representation enriched with decision theory concepts like probability and utility, intending to unify all the needs of an emotional agent in a single architecture. The appraisal process works on this CI to elicit various emotions, and the strongest one provides a coping opportunity. The different strategies are then assessed w.r.t. their coping potential, and the agent chooses and applies his preferred one. The formalized strategies are also inspired from the COPE model Carver et al. (1989): planning, positive reinterpretation, acceptance, denial, mental disengagement, shift blame. Their effect on the CI is mainly expressed in terms of intention dropping or modification of utility or probability values.

This is actually a functional implementation Gratch and Marsella (2004b), but we believe that our logic of belief, intention, desire, probability, action and time also allows to represent all the concepts that Gratch and Marsella identify as essential to talk about appraisal and coping. However, we lack graduality in mental attitudes.

7 Conclusions

We started this paper by noticing that the close relationship between appraisal and coping, the two parts of the human emotional process, while being endorsed by the psychological literature, is something neglected in virtual agents. Indeed, many researchers are interested in the triggering of emotions by an appraisal process, but very few manage their

subsequent influence on their agent's behaviour. For example Meyer considers this influence through a formalization of the action tendencies, which is quite different from the coping process. Gratch and Marsella may have been the first ones to integrate appraisal and coping in an agent. To do so, they introduced a complex representation of the agent's mental state, that they believe to be necessary to express all the concepts needed to describe the emotional process. On the contrary in this paper we showed that BDI logics are expressive enough to describe the this process. Actually, given the huge amount of work already existing on the appraisal process, we did not try to present a formalization it but only grounded on an existing one in a BDI logic, and thus focused on the coping process.

We proposed to represent coping strategies as actions, whose conditions and effects are expressed in terms of the agent's mental attitudes, and written in a BDI logic. We believe that this well-known framework offers interesting properties, mainly its reusability in a large amount of existing BDI agents. The application domain for such agents mainly consists in designing human-like characters for virtual worlds: a plausible emotional model can increase their believability and thus improve the user's immersion in the virtual world.

Our short-term prospects consist in extending this model to account for agent-based emotions of the OCC typology. In a longer-term prospect, we envisage to implement this model in an embodied conversational agent, in order to simulate some dialogic behaviours that are often observed in human-human interactions, but are not captured by actual models of dialogue (for example, why do people change subject suddenly, or refuse to answer a question or to believe obviousness). Indeed, we believe that such kinds of irrational behaviours follow from the use of coping strategies.

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Abstract

In the agent community, more and more researchers get interested in designing believable embodied agents with emotions. The focus is on the agent's external believability, *i.e.* the realism of their emotional expressions, neglecting the internal believability of the emotional processes. In this paper we ground on an existing formalization of emotions, that only accounts for appraisal (the psychological process leading to the triggering of emotions), and express in the same formalism (namely BDI logics) the process of coping (the individual's effort to manage a stressful situation). Indeed, following Lazarus, these two processes are indivisible for the description of human emotions. We thus consider coping strategies as particular actions with effects on the agent's mental attitudes. We formalize some strategies by expressing their preconditions and effects in a BDI logic, and then illustrate their functioning on an example from a training simulation application for firemen.

Keywords

Emotion, coping strategy, BDI logic, reasoning for embodied and believable agents.

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