A logic of emotions: from appraisal to coping

Mehdi Dastani[1] and Emiliano Lorini[2]

[1]Utrecht University, The Netherlands
[2]IRIT-CNRS, France

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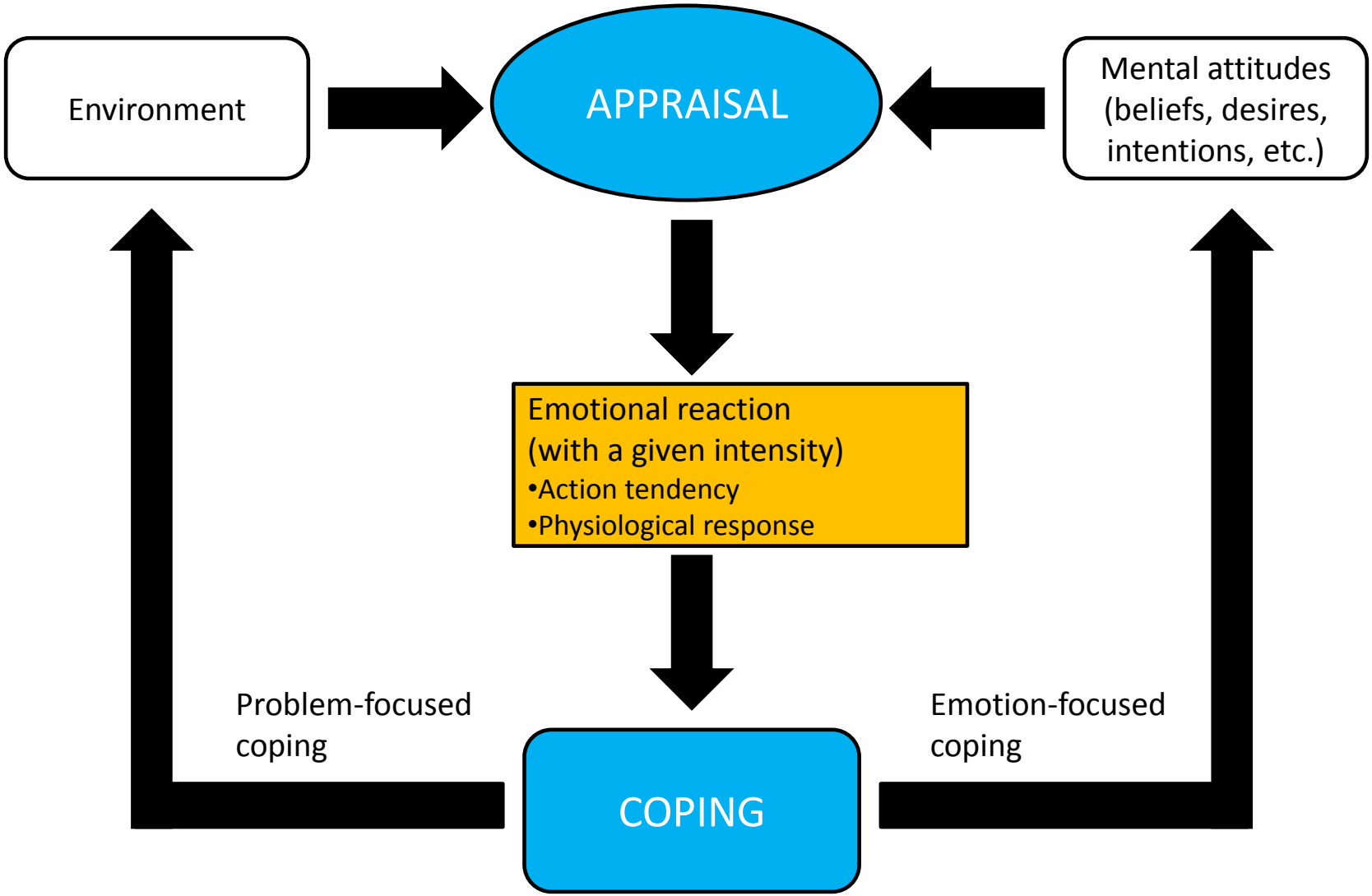
Appraisal and coping circuit

(Lazarus, 1991; Gratch & Marsella, 2004)



Appraisal and coping circuit (cont.)

Example

A robot has to transport some containers to their target positions. The robot can assess the state of its battery charge.

- **Appraisal**. *The robot notices that its low battery charge endangers the goal of having a container at its target position*.
- **Emotional reaction**. *The robot fears that it will fail to place a container at its target position*.
- **Coping**. *Fear leads the robot to reconsider its current intention to transport a container*.

Our proposal

A comprehensive logical model of emotion covering the following three aspects of emotion:

- Appraisal
- Emotion intensity
- Coping

We concentrate on *emotion-focused coping* (i.e., coping with the emotion by modifying one or more mental attitudes that triggered it):

- coping strategies affecting beliefs
- coping strategies affecting desires
- coping strategies affecting intentions

Outline

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- A set of propositional variables $Atm = \{p, q, \ldots\}$
- A finite integer scale $Num = \{0, \ldots, \max\}$ with $\max > 0$ for measuring strengths of beliefs and desires
- A finite set of physical actions $PAct = \{a, b, \ldots\}$
- $Num^{-} = \{-x : x \in Num \setminus \{0\}\}$

Operators for graded mental attitudes

$\mathsf{B}^{\mathsf{h}}\varphi$ = "the agent believes that φ is true with strength h" (with $\mathsf{h} \in \mathit{Num}$)

$\mathsf{SB}\varphi$ = "the agent strongly believes/is certain that φ is true"

$\mathsf{Des}^{\mathsf{k}}\mathsf{c}$ = "the consequence c has a degree of desirability k for the agent" (with $\mathsf{k} \in \mathit{Num} \cup \mathit{Num}^{-}$)

Achievement goal: $\mathsf{AchG}^{\mathsf{k}}\mathsf{c} \stackrel{\mathtt{def}}{=} \mathsf{Des}^{\mathsf{k}}\mathsf{c}$ for $\mathsf{k} > 0$

Avoidance goal: $\mathsf{AvdG}^{\mathsf{k}}\mathsf{c} \stackrel{\mathtt{def}}{=} \mathsf{Des}^{-\mathsf{k}}\mathsf{c}$ for $\mathsf{k} > 0$

Int_a = "the agent has the intention to perform the physical action a"

Two types of dynamic operators

$[a]\varphi$ = "after the agent has performed the physical action a, φ will be true"

$[*\psi]\varphi$ = "after the agent has learnt/sensed that ψ is true, φ will be true"

$*\psi$ is an operator of belief revision in the sense of Spohn (1992)

Physical action description

As in Situation Calculus (Reiter, 2001)

$$\begin{aligned}
\textbf{Executability preconditions}: &\quad Pre : PAct \longrightarrow Prop \\
\textbf{Positive effect preconditions}: &\quad \gamma^{+} : PAct \times Atm \longrightarrow Prop \\
\textbf{Negative effect preconditions}: &\quad \gamma^{-} : PAct \times Atm \longrightarrow Prop
\end{aligned}$$

where *Prop* is the set of propositional formulas

$$\langle\langle a \rangle\rangle \varphi \stackrel{\texttt{def}}{=} Pre(a) \wedge [a]\varphi$$

$\langle\langle a \rangle\rangle \varphi$ = "the physical action a is executable and, φ will be true after its execution"

Outline

Intensity of hope and fear

According to several emotion models (Gratch & Marsella, 2004; Reisenzein, 2009; Ortony et al., 1988; Lazarus, 1991):

- **intensity of hope** with respect to a given event is a *monotonically increasing function* of:
  - the degree to which the event is **desirable**
  - the **(subjective) probability** of the event (the strength of belief)
- **intensity of fear** with respect to a given event is a *monotonically increasing function* of:
  - the degree to which the event is **undesirable**
  - the **(subjective) probability** of the event (the strength of belief)

Several possible merging functions *merge* for calculating emotion intensity which satisfy these properties. E.g.,

- arithmetic mean
- product (Gratch & Marsella, 2004; Reisenzein, 2009)

Formalization of hope and fear

$$\mathrm{Hope}^{\mathrm{i}}(a,\mathrm{c}) \stackrel{\mathtt{def}}{=} \bigvee_{\mathrm{h},\mathrm{k}\in \mathit{Num}\setminus\{0\}:\mathrm{h}<\max \text{ and } \mathit{merge}(\mathrm{h},\mathrm{k})=\mathrm{i}} (\mathrm{B}^{\mathrm{h}}\langle\langle a\rangle\rangle \mathrm{c} \wedge \mathrm{AchG}^{\mathrm{k}}\mathrm{c} \wedge \mathrm{Int}_a)$$

$\mathrm{Hope}^{\mathrm{i}}(a,\mathrm{c})$ = "the agent hopes with intensity i that its current intention to do a will lead to the desirable consequence c"

$$\mathrm{Fear}^{\mathrm{i}}(a,\mathrm{c}) \stackrel{\mathtt{def}}{=} \bigvee_{\mathrm{h},\mathrm{k}\in \mathit{Num}\setminus\{0\}:\mathrm{h}<\max \text{ and } \mathit{merge}(\mathrm{h},\mathrm{k})=\mathrm{i}} (\mathrm{B}^{\mathrm{h}}\langle\langle a\rangle\rangle \mathrm{c} \wedge \mathrm{AvdG}^{\mathrm{k}}\mathrm{c} \wedge \mathrm{Int}_a)$$

$\mathrm{Fear}^{\mathrm{i}}(a,\mathrm{c})$ = "the agent fears with intensity i that its current intention to do a will lead to the undesirable consequence c"

Remark

We assume $\mathrm{h} < \max$ *in the preceding definitions because hope and fear require some level of uncertainty.*

Formalization of joy and distress

$$\mathrm{Joy}^{\mathsf{i}}(a,\mathsf{c}) \stackrel{\mathtt{def}}{=} \bigvee_{\mathsf{k}\in \mathit{Num}\setminus\{0\}:\mathit{merge}(\max,\mathsf{k})=\mathsf{i}} (\mathrm{SB}\langle\langle a\rangle\rangle \mathsf{c} \wedge \mathrm{AchG}^{\mathsf{k}}\mathsf{c} \wedge \mathrm{Int}_a)$$

$\mathrm{Joy}^{\mathsf{i}}(a,\mathsf{c})$ = "the agent is joyful with intensity i that its current intention to do a will lead to the desirable consequence c"

$$\mathrm{Distress}^{\mathsf{i}}(a,\mathsf{c}) \stackrel{\mathtt{def}}{=} \bigvee_{\mathsf{k}\in \mathit{Num}\setminus\{0\}:\mathit{merge}(\max,\mathsf{k})=\mathsf{i}} (\mathrm{SB}\langle\langle a\rangle\rangle \mathsf{c} \wedge \mathrm{AvdG}^{\mathsf{k}}\mathsf{c} \wedge \mathrm{Int}_a)$$

$\mathrm{Distress}^{\mathsf{i}}(a,\mathsf{c})$ = "the agent is distressed with intensity i that its current intention to do a will lead to the undesirable consequence c"

Example

Example

A robot has to transport either container 1 or container 2 to its target positions (pos). The robot can assess the state of its battery charge.

Physical action description:
$\gamma^+(transport_1, pos) = \{fullCharge\}$
$\gamma^-(transport_1, pos) = \{\neg fullCharge \wedge \neg pos\}$
$\gamma^+(transport_2, pos) = \{fullCharge \vee halfCharge\}$
$\gamma^-(transport_2, pos) = \{\neg halfCharge \wedge \neg fullCharge \wedge \neg pos\}$
$Pre(tranport_1) = Pre(tranport_2) = \top$

Robot's initial mental state:
$M, w \models \mathsf{AvdG}^{\mathsf{k}} \neg pos \wedge \mathsf{Int}_{transport_1} \wedge \mathsf{SB} \neg pos$

Effects of the sensing action on the robot's emotions:
$M, w \models [*halfCharge \wedge \neg fullCharge]\mathsf{Distress}^{\mathsf{i}}(transport_1, \neg pos)$

Outline

Extension with coping strategies

$$\mathit{CStr} \quad : \quad \beta \quad ::= \quad \varphi{\uparrow}^{\mathsf{B}} \mid \varphi{\downarrow}^{\mathsf{B}} \mid \mathsf{c}{\uparrow}^{\mathsf{D}} \mid \mathsf{c}{\downarrow}^{\mathsf{D}} \mid +a \mid -a$$

- increase ($\varphi{\uparrow}^{\mathsf{B}}$) or decrease ($\varphi{\downarrow}^{\mathsf{B}}$) the strength of the belief that φ
- increase ($\mathsf{c}{\uparrow}^{\mathsf{D}}$) or decrease ($\mathsf{c}{\downarrow}^{\mathsf{D}}$) the desirability of c
- generate ($+a$) or remove ($-a$) the intention Int_a

Each coping strategy β has a corresponding dynamic operator $[\beta]$:

$[\beta]\psi \quad = \quad$ "after the occurrence of β, ψ will be true"

Some theorems

1. $\models \mathsf{B}^{\geq \mathsf{h}}\varphi \rightarrow [\varphi\uparrow^{\mathsf{B}}]\mathsf{B}^{\geq Cut_{\mathsf{B}}(\mathsf{h}+\omega)}\varphi$
2. $\models \mathsf{B}^{\geq \mathsf{h}}\varphi \rightarrow [\varphi\downarrow^{\mathsf{B}}]\mathsf{B}^{\geq Cut_{\mathsf{B}}(\mathsf{h}-\omega)}\varphi$ if $Cut_{\mathsf{B}}(\mathsf{h}-\omega) > 0$
3. $\models \mathsf{B}^{\geq \mathsf{h}}\varphi \rightarrow [\varphi\downarrow^{\mathsf{B}}]\neg\mathsf{B}\varphi$ if $Cut_{\mathsf{B}}(\mathsf{h}-\omega) = 0$
4. $\models \mathsf{Des}^{\mathsf{h}}\mathsf{c} \rightarrow [\varphi\uparrow^{\mathsf{D}}]\mathsf{Des}^{Cut_{\mathsf{D}}(\mathsf{h}+\omega)}\mathsf{c}$
5. $\models \mathsf{Des}^{\mathsf{h}}\mathsf{c} \rightarrow [\varphi\downarrow^{\mathsf{D}}]\mathsf{Des}^{Cut_{\mathsf{D}}(\mathsf{h}-\omega)}\mathsf{c}$
6. $\models [+a]\mathsf{Int}_a$
7. $\models [-a]\neg\mathsf{Int}_a$

Triggering conditions of coping strategies

$$Trg : CStr \longrightarrow Fml$$

Inspired by Marsella & Gratch (2009)

Triggering conditions of intention-focused coping (Resignation)

$$Trg(-a) = \bigvee_{\mathrm{c} \in Lit, \mathrm{i} \in EmoInt : \mathrm{i} \geq \theta} ((\mathrm{Fear}^{\mathrm{i}}(a, \mathrm{c}) \vee \mathrm{Distress}^{\mathrm{i}}(a, \mathrm{c})) \wedge \mathrm{B}\ \mathrm{Control}\ \mathrm{c})$$

$$\textit{where}\ \mathrm{Control}\ \mathrm{c} \stackrel{\mathtt{def}}{=} \bigvee_{b \in PAct} \langle\langle b \rangle\rangle \neg \mathrm{c}$$

Triggering conditions of belief-focused coping (Wishful thinking)

$$Trg(\langle\langle a \rangle\rangle \mathrm{c}{\downarrow^{\mathrm{B}}}) = \bigvee_{\mathrm{i} \in EmoInt : \mathrm{i} \geq \theta} ((\mathrm{Fear}^{\mathrm{i}}(a, \mathrm{c}) \vee \mathrm{Distress}^{\mathrm{i}}(a, \mathrm{c})) \wedge \neg \mathrm{B}\ \mathrm{Control}\ \mathrm{c})$$

Triggering conditions of goal-focused coping (Positive reinterpretation)

$$Trg(\mathrm{c}{\uparrow^{\mathrm{D}}}) = \bigvee_{\mathrm{i} \in EmoInt : \mathrm{i} \geq \theta} ((\mathrm{Fear}^{\mathrm{i}}(a, \mathrm{c}) \vee \mathrm{Distress}^{\mathrm{i}}(a, \mathrm{c})) \wedge \neg \mathrm{B}\ \mathrm{Control}\ \mathrm{c})$$

In the paper

- Model-theoretic semantics for our logic (base logic+extension with coping strategies)
- Complete axiomatization
- Decidability result

Future work

- **Logical analysis of problem-focused coping**
- **Extension with awareness** (Halpern & Rego, 2009)
  - implicit vs. explicit belief
  - attentional shift as a coping strategy
- **Reasoning module for practical applications**: implementation of the logic in the theorem prover LOTREC (available at http://www.irit.fr/Lotrec/)
  - artificial agent capable of reasoning about the user's mental states and emotions (with their intensities) and of predicting the user's coping strategies
  - a robot acting in the real world