Emotion in Intelligent Agents

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Overview

1. Motivation

EMOTION THEORY

2. What is emotion?
3. Why should machines experience emotion?
4. (How) can machines experience emotion?

TOWARD AI MODELS OF EMOTION

5. The antecedents of emotion
6. The behaviors of emotion

7. Conclusion
1. Motivation

- Overcome: Emotion would interfere rationality
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- Evolution of the brain suggests differently

Doyle (1991): “AI is the discipline aimed at understanding intelligent beings by constructing intelligent systems.”
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- Evolution of the brain suggests differently
- Neurological research too
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Emotion in intelligent agents – p.4
Motivation

- Overcome: Emotion would interfere rationality
- Evolution of the brain suggests differently
- Neurological research too

★ Doyle (1991):
  “AI is the discipline aimed at understanding intelligent beings by constructing intelligent systems”.

⇒ So construct emotionally intelligent systems
EMOTION THEORY
2. What is emotion?

- Unclear: as many as 92 different definitions in literature (Kleinginna & Kleinginna 1981)
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- LeDoux (1994):
  “Emotions are [...] conscious states”.

Damasio (1994):
“[.. .] designate a collection of responses triggered from parts of the brain to the body, and from parts of the brain to other parts of the brain”. What LeDoux calls emotion is what Damasio calls feeling.
2. What is emotion?

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★ LeDoux (1994):
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  “[...] designate a collection of responses triggered from parts of the brain to the body, and from parts of the brain to other parts of the brain”.

⇒ What LeDoux calls emotion is what Damasio calls feeling.
Two kinds of emotion: Primary

- Primary emotions are innate emotional reactions to bodily stimuli.
Two kinds of emotion: Primary

- **PRIMARY EMOTIONS** are innate emotional reactions to bodily stimuli.

- Sometimes acquired, but mostly pre-wired.
Two kinds of emotion: Secondary

- Secondary emotions are subconsciously created connections between cognitive constructs and primary emotions.
Two kinds of emotion: Secondary

- **Secondary emotions** are subconsciously created connections between cognitive constructs and primary emotions.
- Probably always acquired.
Feeling

- **Feeling** is becoming conscious of what is happening in the body
Feeling

- Feeling is becoming conscious of what is happening in the body

? Body-based, why don’t emotions trigger feeling directly?
Feeling

- **FEELING** is becoming conscious of what is happening in the body

**:question:** Body-based, why don’t emotions trigger feeling directly?

**:arrow:** Emotions felt like this constitute the ‘**AS IF’** LOOP
Feeling: body vs ‘as if’
Definitions for agents

**Definition 1 (Emotion).** Emotion is a collection of physical or mental unconscious responses unconsciously triggered by the mind.

**Definition 2 (Feeling).** Feeling is a collection of mental conscious responses unconsciously triggered by the body or the mind.
Definitions for agents: Diagram

Brain

Feeling

Emotion

Body
3. Why should machines experience emotion?

Emotion important for natural agents, why for artificial agents?
3. Why should machines experience emotion?

? Emotion important for natural agents, why for artificial agents?

⇒ Maybe there are problems that can only be solved by emotion-like processes
Why should machines experience emotion?: Examples

- Reality is very detailed and constitutes many properties
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Problem: How does an agent image the relevant part of reality?

Example: Recalling this room after we went to the corridor

Example: Do you want to marry me?
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Problem: How does an agent reason with limited information of reality?
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Problem: How does an agent reason with limited information of reality?

Example: Do you want to marry me?
Say \( \varphi \equiv \text{‘marry Peter-Paul’}, \ \psi \equiv \text{‘like my life’}, \) and a goal-generation rule (Castelfranchi et al. 2000):

\[
G_i \varphi \land B_i \left( \text{GOODFOR}_i \varphi \psi \right) \Rightarrow G_i \varphi
\]
Why should machines experience emotion?: Examples

- Say $\varphi \equiv \text{‘marry Peter-Paul’}$, $\psi \equiv \text{‘like my life’}$, and a goal-generation rule (Castelfranchi et al. 2000):

$$G_i \varphi \land B_i (\text{GOODFOR}_i \varphi \psi) \Rightarrow G_i \varphi$$

- We should add consistency:

$$G_i \chi \rightarrow \neg B_i (\text{BADFOR}_i (\varphi \land \chi) \psi)$$

where we assume that

$$(G \varphi \land G \psi) \rightarrow G (\varphi \land \psi).$$
Why should machines experience emotion?: Examples

- We can now specify the operator \( \text{GOODFOR}_i \varphi \psi \):

\[
(B_i \varphi \rightarrow \Diamond^n B_i \psi) \land (\Diamond^m B_i \psi) \land n > m
\]

where \( \Diamond^p \chi \) means that eventually \( \chi \) is true with probability \( p \).
Why should machines experience emotion?: Examples

- We can now specify the operator $\text{GOODFOR}_i \varphi \psi$:

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- We should add the following rule to select the best:

$$ (B_i \xi \rightarrow \Diamond^k B_i \psi) \rightarrow k \leq n $$
Why should machines experience emotion?: Examples

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$\Rightarrow$ To much effort!
Why should machines experience emotion?: Examples

⇒ Hence emotional appraisals would be advantageous if they would:

1. drastically reduce the amount of possible goals to evaluate for acceptance, by means of precognitive filtering

2. drastically shorten the cognitive chain in evaluations, by means of providing a threshold when to stop
Why should machines experience emotion?: Examples

⇒ Hence emotional appraisals would be advantageous if they would:

1. drastically reduce the amount of possible goals to evaluate for acceptance, by means of precognitive filtering

2. drastically shorten the cognitive chain in evaluations, by means of providing a threshold when to stop

⇒ The same can be said of DERIVABLEFROM ϕ ψ
Advantages of the emotional way

⇒ Body and mind are pre-cognitively tuned to cope with the current situation either by interrupt or heuristic with limited resources and time:
Advantages of the emotional way

⇒ Body and mind are pre-cognitively tuned to cope with the current situation either by interrupt or heuristic with limited resources and time:

1. Introduces new urgent goals or alter the priorities of existing goals

2. Attention is demanded to important or relevant information

3. Keeps track of the higher goals, i.e. desires
Advantages of the emotional way: Diagram

⇒ Emotional processes thus ideally relate to artificial reasoning in terms of beliefs and goals:
4. (How) can machines experience emotion?

Would a machine built like us experience emotion like us?
4. (How) can machines experience emotion?

? Would a machine built like us experience emotion like us?

★ First step:

“Why don’t we just build an embodied agent, able to have emotions and to react to those? This is not so hard” (Castelfranchi, 2003).
4. (How) can machines experience emotion?

Would a machine built like us *experience* emotion like us?

★ First step:

“Why don’t we just build an embodied agent, able to have emotions and to react to those? This is not so hard” (Castelfranchi, 2003).

⇒ For this we can propose agent-architectures, describing both having emotion and feeling.
Proposed agent-architecture requirements

1. Rich enough body signals (primary input)
2. Rich enough mental constructs (secondary input)
3. *if–then-like rules* that identify typical structures (emotion/feeling triggers)
4. These *if–then-like rules* need to be learned (emotional adaptivity)
5. Check each rule on the agent’s input in each deliberation cycle
6. If rules match then resulting typical behavior
TOWARD AI MODELS OF EMOTION
4. The antecedents of emotion

⇒ To describe emotion artificially we need to look at it from the engineering point of view:
4. The antecedents of emotion

⇒ To describe emotion artificially we need to look at it from the engineering point of view:

- Research is needed in the area of the development of programs for machines that have rules like:

\[
\text{IF antecedent } \varphi_0, \ldots, \varphi_n \text{ of emotion } E \text{ hold} \\
\text{THEN (at a later timepoint) trigger behavior of } E(\varphi_0, \ldots, \varphi_n) \\
\text{AND learn to connect } \varphi_0, \ldots, \varphi_n \text{ to } E.
\]
The antecedents of emotion: Example

★ Frijda (1986):  

“Fear [...] is uncertain expectation of the presence of negative valence, or absence of positive valence, over which there is insufficient control, but which event is modifiable, its degree corresponds to the measure of closure, and urgency of the situation”.
4. The antecedents of emotion

⇒ Emotions can thus be uniquely categorized by means of component profiles:

<table>
<thead>
<tr>
<th></th>
<th>Positive character</th>
<th>Negative character</th>
<th>Desire</th>
<th>Interest</th>
<th>Positive valence</th>
<th>Negative valence</th>
<th>Presence</th>
<th>Absence</th>
<th>Certainty</th>
<th>Uncertainty</th>
<th>Change</th>
<th>Open</th>
<th>Closed</th>
<th>Intentionality of other</th>
<th>Intentionality of self</th>
<th>Controllability</th>
<th>Uncontrollability</th>
<th>Modifiability</th>
<th>Finality</th>
<th>Object</th>
<th>Event</th>
<th>Focality</th>
<th>Globality</th>
<th>Strangeness</th>
<th>Familiarity</th>
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<tr>
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If the agent evaluates $\text{GOODFOR}(\varphi, \psi)$ for a situation $\varphi$ and active goal $\psi$, then positive demand character holds for $\varphi$, and if $\text{BADFOR}(\varphi, \psi)$, then negative demand character holds for $\varphi$.

If the agent believes the eliciting situation $\varphi$ from moment $t$, then change of $\varphi$ holds if $t$ is close to the current moment.
Profiling: Eliciting rule of *fear*

IF antecedent

\[
\text{negative\_demand\_character}(\varphi, \psi) \quad \text{AND} \quad \text{uncertainty}(\varphi) \quad \text{AND} \quad \text{closed}(\varphi) \\
\text{AND} \quad \text{uncontrollability}(\varphi) \quad \text{AND} \\
\text{modifiability}(\varphi) \quad \text{AND} \quad \text{event}(\varphi) \quad \text{AND} \\
\text{focality}(\varphi) \quad \text{AND} \\
((\text{positive\_valence}(\varphi) \quad \text{AND} \\
\text{absence}(\varphi)) \quad \text{XOR} \\
(\text{negative\_valence}(\varphi) \quad \text{AND} \\
\text{presence}(\varphi))) \quad \text{holds} \\
\text{THEN} \quad \text{trigger behavior of} \quad \text{fear}(\varphi, \psi) \\
\text{AND learn} \ldots
6. The behaviors of emotion: BDI example

- Eliciting rule for DISLIKING:

\[ B_i(\neg B_j \rightarrow \text{Sad}_i(\varphi) \rightarrow I_j(\text{Sad}_i(\varphi))) \rightarrow \text{Dislike}_i(j) \]
6. The behaviors of emotion: BDI example

- Eliciting rule for **DISLIKING**:

\[ B_i(B_j \neg \text{Sad}_i(\varphi) \rightarrow I_j(\text{Sad}_i(\varphi))) \rightarrow \text{Dislike}_i(j) \]

- Consequentive behavior rule:

\[ \text{Dislike}_i(j) \rightarrow (B_i \neg \text{Sad}_j(\varphi) \rightarrow I_i(\text{Sad}_j(\varphi))) \]
The behaviors of emotion: KARO example

Agent $i$ is \textsc{ RESPONSIBLE} for performing $\pi$ resulting in $\varphi$:

$$Res_i(\pi, \varphi) \leftrightarrow I_i(\pi, \varphi) \land Com_i(\pi) \land [\pi]_i(\varphi \land B_\pi)$$

for some non-empty sequence actions $\pi$. 
The behaviors of emotion: KARO example

- Agent $i$ is **RESPONSIBLE** for performing $\pi$ resulting in $\varphi$:

$$\text{Res}_i(\pi, \varphi) \leftrightarrow I_i(\pi, \varphi) \land \text{Com}_i(\pi) \land [\pi]_i(\varphi \land B_i \varphi)$$

for some non-empty sequence actions $\pi$.

- Example of an eliciting rule of **ANGER**:

$$B_i \text{Res}_j(\pi, \text{Dislike}_i(j)) \rightarrow \text{Angry}_i(\pi, \varphi, j)$$
6. Conclusion

- 1. Distinguished processes of primary and secondary emotion, feeling, and gave general definitions
6. Conclusion

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- 2. The experience of emotion as interrupt, and heuristical tool
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- 3. As a result: Possible architecture for having emotion and feeling
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- 1. Distinguished processes of primary and secondary emotion, feeling, and gave general definitions
- 2. The experience of emotion as interrupt, and heuristical tool
- 3. As a result: Possible architecture for having emotion and feeling
- 4. Specified eliciting rules for emotions by antecedents, and a proposal general eliciting rule
- 5. Current AI languages can be tailored for expressing emotional behavior
Questions?
EXTENSION
Fig. 1: A diagram representing the set of regions whose damage compromises both aspects of reasoning and processing of emotion (Damasio 1994).
Secondary emotion

Fig. 2: Diagram of evolutionary development and dependency of cognitive processes. We probably inherited primary emotions, and merely the *ability* of the others.
Fig. 3: The neural machinery for the true smile is different from that of the voluntary (Damasio 1994).
Feeling

- On the moment feelings become cognitive, we probably have images of them within our minds (from the somatosensory to the cerebral cortices) (Shepard)
Feeling

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- Images are multi-media and -dimensional conscious representations (Damasio 2004)
On the moment feelings become cognitive, we probably have images of them within our minds (from the somatosensory to the cerebral cortices) (Shepard)

Images are multi-media and -dimensional conscious representations (Damasio 2004):

“Thoughts are based directly on those neural representations, and only those, which are organised topographically and which occur in early sensory cortices”.
Feeling

- On the moment feelings become cognitive, we probably have images of them within our minds (from the somatosensory to the cerebral cortices) (Shepard)

- Images are multi-media and -dimensional conscious representations (Damasio 2004):
  "Thoughts are based directly on those neural representations, and only those, which are organised topographically and which occur in early sensory cortices".

- So even abstract thoughts would be imaged
Fig. 4: Images are literally to be detected in brains (vision in macaques) (Tootell et al.).
The position of emotion

- Beliefs
- Goals
- Emotion
- Reason
- Intentions
- Action
- Body
Profiling by antecedents

Fig. 5: Proposal of basic emotions seems not sufficient to emotional subtleties (Plutchik).
**KARO-based behavior: Explanation**

- $I_i(\pi, \varphi)$: agent $i$ has intention to do $\pi$ for achieving $\varphi$
- $Com_i(\pi)$: $i$ is committed to $\pi$, i.e. $\pi$ is in $i$’s agenda
- $B_i(\pi)$: $i$ believes $\varphi$
- $\alpha \preceq \pi$: $\alpha$ is first action of sequence actions $\pi$
- $\pi \setminus \alpha = \pi'$ iff $\pi = \alpha; \pi'$
- $[\alpha]_i \varphi$: $\varphi$ true after $i$ performs action $\alpha$
KARO-based behavior: Explanation 2

- $P_i(\pi, \varphi)$: $i$ has practical possibility to perform \(\pi\) for achieving \(\varphi\)

- $\textit{angry}_{i}(\pi, \varphi, j)$: $i$ is angry with $j$ with respect to remainder $\pi$ of $i$’s plan to achieve $\varphi$

- $\textit{Res}_{i}(\pi, \varphi)$: $i$ is responsible for doing $\pi$ in order to achieve $\varphi$

- $\textit{Res}_{i}(\pi, \varphi) \equiv I_i(\pi, \varphi) \land \textit{Com}_{i}(\pi) \land [\pi]_i(\varphi \land B_i \varphi)$, for some non-empty sequence actions $\pi$ and equals
## Grouping by antecedents: Scheme

<table>
<thead>
<tr>
<th>group</th>
<th>specification</th>
<th>intensity variables</th>
<th>some emotion types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well-Being</td>
<td>appraisal of a situation as an event</td>
<td>desirability</td>
<td>joy: pleased about an event</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>distress: displeased about an event</td>
</tr>
<tr>
<td>Fortunes-of-Others</td>
<td>presumed value of a situation as an event affecting another</td>
<td>desirability-for-other, liking, deservingness</td>
<td>happy-for: pleased about an event desirable for another</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>gloating: pleased about an event undesirable for another</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>resentment: displeased about an event desirable for another</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>jealousy: resentment over a desired mutually exclusive goal</td>
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<td></td>
<td></td>
<td></td>
<td>envy: resentment over a desired non-exclusive goal</td>
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<td></td>
<td></td>
<td></td>
<td>sorry-for: displeased about an event undesirable for another</td>
</tr>
<tr>
<td>Prospect-based</td>
<td>appraisal of a situation as a prospective event</td>
<td>likelihood, effort, realization, desirability</td>
<td>hope: pleased about a prospective desirable event</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>fear: displeased about a prospective undesirable event</td>
</tr>
</tbody>
</table>
## Grouping by antecedents: Scheme 2

<table>
<thead>
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<th>group</th>
<th>specification</th>
<th>intensity variables</th>
<th>some emotion types</th>
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</thead>
<tbody>
<tr>
<td>Confirmation</td>
<td>appraisal of a situation as confirming or disconfirming an expectation</td>
<td>likelihood, effort, desirability</td>
<td>satisfaction: pleased about a confirmed desirable event</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>relief: pleased about a disconfirmed undesirable event</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>fears-confirmed: displeased about a confirmed undesirable event</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>disappointment: displeased about a disconfirmed desirable event</td>
</tr>
<tr>
<td>Attribution</td>
<td>appraisal of a situation as an accountable act of some agent</td>
<td>praiseworthiness, strength of cognitive unit, expectation-deviation</td>
<td>pride: approving of one's own act</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>admiration: approving of another's act</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>shame: disapproving of one's own act</td>
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<td></td>
<td></td>
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<td>reproach: disapproving of another's act</td>
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</tbody>
</table>
### Grouping by antecedents: Scheme 3

<table>
<thead>
<tr>
<th>group</th>
<th>specification</th>
<th>intensity variables</th>
<th>some emotion types</th>
</tr>
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<tbody>
<tr>
<td>Attraction</td>
<td>appraisal of a situation as containing an attractive or unattractive object</td>
<td>familiarity appealingness</td>
<td>liking: finding an object appealing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>disliking: finding an object unappealing</td>
</tr>
<tr>
<td>Well-being/ Attribution</td>
<td>compound emotions</td>
<td></td>
<td>gratitude: admiration + joy</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>anger: reproach + distress</td>
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<td></td>
<td></td>
<td></td>
<td>gratification: pride + joy</td>
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<td></td>
<td>remorse: shame + distress</td>
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<tr>
<td>Attraction/ Attribution</td>
<td>compound emotion extensions</td>
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<td>love: admiration + liking</td>
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<td></td>
<td></td>
<td>hate: reproach + disliking</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>grief: disappointment + liking</td>
</tr>
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## Profiling by antecedents: Scheme

<table>
<thead>
<tr>
<th></th>
<th>Positive character</th>
<th>Negative character</th>
<th>Desire</th>
<th>Interest</th>
<th>Positive valence</th>
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Belief-based behavior

- Belief-based
  - Non-monotonicy
  - Possibility
  - Gradability
  - Non-logical omniscience
- Further extensions
  - Desirability
  - Interestingness
  - ...
Belief-based behavior: KD45

(A1) All propositional tautologies.

(A2) \( (B\varphi \land B(\varphi \rightarrow \psi)) \rightarrow B\psi \)

(D) \( \neg B \bot \)

(A4) \( B\varphi \rightarrow BB\varphi \)

(A5) \( \neg B\varphi \rightarrow B\neg B\varphi \)

(R1) \( \varphi, \varphi \rightarrow \psi \vdash \psi \)

(R2) \( \varphi \vdash B\varphi \)

Not inconsistent.

+ Introspection.

– Introspection.

Modus ponens.

Necessitation.
Belief-based behavior: Logical omniscience

- Not all valid formulas are believed:

\[ B\varphi \rightarrow \neg B\neg\varphi \] (A1, A2, D, R1)

- Belief of possibility to be wrong:

\[ B(B\varphi \rightarrow \varphi) \] (A1, A2, D, A5, R1, R2)

- Possible solution:

\[ B_E\varphi \leftrightarrow ((B\varphi \lor P\varphi) \land A\varphi) \]
KARO-based behavior: Eliciting rule

- The eliciting rule of *anger*

\[ I_i(\pi, \varphi) \land Com_i(\pi) \land B_res_j(\alpha, \neg P_i(\pi, \varphi)) \rightarrow \]

\[ [\alpha]_j(B_i(\neg \varphi \land \neg P_i(\pi, \varphi)) \rightarrow \text{angry}_i(\pi, \varphi, j)) \]

when \( j \neq i \).