

Ambient Support for Group Emotion: an Agent-Based Model

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Abstract. This chapter introduces an agent-based support model for group emotion, used by ambient systems that support teams in their emotion dynamics. Using model-based reasoning, an ambient agent analyzes the team's emotion level for present and future time points. In case the team's emotion level is found to become deficient, the ambient agent provides support to the team, for example, by proposing the team leader to give a pep talk to certain team members. The support model has been formally designed and simulation experiments have been performed within a dedicated software environment.

Keywords. Ambient intelligence, agent model, group emotion, support

Introduction

Within psychology, emotion is often defined as a state or process that plays a role in various cognitive processes, amongst which are decision making and action preparation. In the multidisciplinary research of emotion, computational models of emotion can be found that are based on appraisal theory. Examples of models that have the goal to make virtual agents believable or human-like are: the Affective Reasoner [1] and the EMA model [2]. Examples of cognitive models of emotion are Frijda's model [3] and the OCC model [4]. In all of these models the focus lies on the individual, not on the group. Modelling emotions in a group based on appraisal models of emotion, can be problematic. In [5] the authors discuss the problem why appraisal models of emotion cannot enforce a consistent perspective on emotions in a group. Today, almost no literature on computational models of dynamics of emotions in groups exists. The model of emotion contagion introduced in [6] was a first exploration in the computational modelling of these dynamics. The current chapter introduces a support model which is based on this emotion absorption model and is therefore a first exploration in the modelling of support for dynamics of emotions in groups.

Another important area within emotion research is emotion recognition by machines, called affective sensing [7]. Many different applications of emotion recognition are in existence, for example speech recognition can be useful in call centers to either automate the system or to detect emotions, such as anger, in the voice of employees. The system give them real-time feedback on their intonation, so they do not sound/become angry in the conversation with clients. Also emotion recognition is

useful in real-time conversations with embodied agents in human computer interaction, for example in computer games, but also in (web)applications with virtual therapists.

Many approaches and techniques are available in emotion recognition research. In [7], the authors claim that affective sensing systems can recognize emotions in human voices and facial expressions better if semantic features are analysed, as well, besides the standard analysis of sound patterns (like prosody and energy levels), and pattern matching or statistical machine learning techniques in facial expressions. Besides adding semantics to the emotion recognition process, it seems that multimodal emotion recognition gains higher accuracy than uni-modal emotion recognition. For example in [8] it is shown how emotion recognition through the multiple modalities: facial expressions, body gesture and speech, produces higher accuracy than through any of the single modalities. There are still big steps to be made in research in uni-modal emotion recognition, for example in speech recognition. In [9] the main challenges in automatic emotion recognition from speech are discussed; how to segment audio files, how to extract the relevant features in these speech units and how to classify and train databases with emotional speech. The work described in [10] goes deeper into one of these issues: which features in speech are the most important for high accuracy in emotion recognition systems? All of these emotion recognition systems analyse individual uni- or multimodal emotional fragments of human speech, facial expressions or body gestures.

Besides analysis of individual emotion, research has been done in emotion recognition in groups. In [11] a system is proposed that measures emotions in people, through the collection and analysis of physiological data, like breathing and heart rate, collected through body sensors. Their research is conducted in the context of a European project, called e-SENSE, which envisions context aware, wireless applications, such as an application that can detect a dangerous person approaching another person in a public transport scenario, through the collection of the voice, breathing rate, heart rate, noise and position. A security staff member could then get a message showing which person is dangerous and escort this person to the exit, in order to protect the endangered person(s).

In psychological literature, emotional support models for grief and post-disaster counselors and doctors are proposed to treat victims, family of victims and patients. Imagine a situation where a software agent can provide emotional support to humans. For example, a virtual character on the Internet providing emotional support to humans that are depressed or a software agent providing emotional support on the work floor, such as during video-conferencing or during naval warfare. The goal of this chapter is to introduce a first agent-based support model for emotions in a group, which can be used by ambient systems to support humans within teams in their emotional responses. The idea here is that the ambient agent can analyze the levels of emotions in the team, both at present and future time points. In case these levels are found (to become) deficient, compared to a relevant norm, the ambient agent can provide support to the team. For instance, by proposing the team leader to give a pep talk to a team member whose emotional level causes the emotions in the group to become too low, or to intensify contacts between members that have a positive effect on the emotion levels of others.

In the description of the detailed model in the next sections, the temporal relation $a \rightarrow b$ denotes that when a state property a occurs, then after a certain time delay (which for each relation instance can be specified as any positive real number), state property b will occur. In this language (called LEADSTO) both logical and numerical

calculations can be specified, and a dedicated software environment is available to support specification and simulation; for more details see [12]. So far only one emotion at a time is analyzed in the ambient agent model, but this can easily be extended to take into account multiple emotions as long as they are considered as independent from each other.

Below, first a brief overview of the architecture and the models is presented. Thereafter, in Section 2, a detailed domain model of emotion contagion is explained and formalized. Subsequently, in Sections 3 to 5 a design of an ambient agent model is presented, which integrates the introduced domain model. More specifically, in Section 3 the domain model has been integrated within an analytical process, which could be used by the ambient agent to analyze the (expected) dynamics of emotion contagion processes. Section 4 introduces a support model which can be used by the ambient agent to generate supporting interventions for a team (based on results of the analysis) to keep the emotion level in the group optimal, given the purpose of the group; also in this support model the domain model is integrated. Section 5 points out how an adaptational model can be obtained to tune the parameters to a given group. In Section 6, simulation results are discussed of the analysis and the support processes of the ambient agent. Section 7 discusses neurological mechanisms that can be used to justify the domain model. Finally Section 8, concludes the chapter with a discussion.

1. Overall Architecture and Different Models Used

The integration of a *domain model* in an *ambient agent model* takes place by embedding the domain model in certain ways within the agent model. By incorporating a domain model within an agent model, the agent gets an understanding of the processes of its surrounding environment, which is a solid basis for knowledgeable human-aware intelligent behaviour. Three different ways to integrate domain models within an agent model are considered; see Figure 1. Here the solid arrows indicate information exchange between processes (data flow) and the dotted arrows the integration process of the domain models within an agent model.

- *analysis model*
To perform the analysis of humans' states and processes by reasoning based on observations (possibly using specific sensors) and the domain model.
- *support model*
To generate support for the humans, by reasoning based on the domain model.
- *adaptation model*
To tune parameters in the domain model better to the specific characteristics of the humans, by reasoning based on the domain model.

Note that here the *domain model* that is integrated refers to a group of agents, the humans considered, whereas the *ambient agent model* in which it is integrated refers to the ambient software agent. The *domain model* will be presented in detail in Section 2, the *analysis model* in Section 3, the *support model* in Section 4, and the *adaptation model* in Section 5.

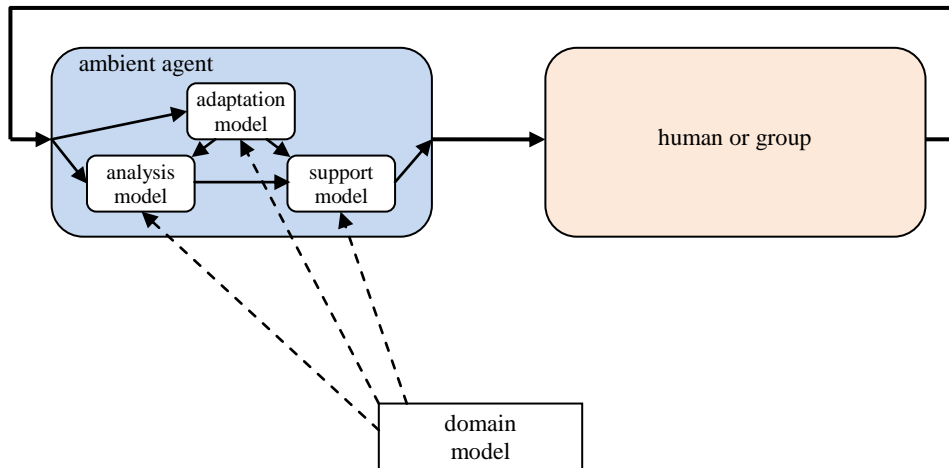


Figure 1. Ambient support agent architecture and models used

1.1. Analysis Model

A crucial element of ambient agents is that they collect and infer information about the humans' functioning. Some aspects of the states and processes related to the humans' functioning can be *directly observed*, but often many relevant aspects only can be indirectly derived from such observation information. For such derivations it is useful to have a domain model integrated within the analysis model, which can be used to estimate states of the human (for past, present and future time points). Given these estimated human states, an *assessment* is made to verify whether there is any reason to consider support. As an example, the level of positive emotions in the group may be assessed as too low.

1.2. Support Model

For an ambient agent to have some beliefs and assessments about the humans' internal state is one thing, but to be of any help, actions are also needed to change or avoid undesirable states. To generate actions that fit to the results of the analysis, a support model is used by the ambient agent. In this model, based on the assessments and beliefs on the human's states, appropriate support actions are determined. For example, a group member with strong expressivity for positive emotions may be given a more central role in the group, so that more contagion will take place.

1.3. Adaptation Model

Domain models often include a number of *parameters* that represent certain characteristics of the processes modelled. In principle, for a given domain process such

characteristics are assumed constant; they allow the tuning of a domain model to specific situations, for example, specific types of human personalities. An ambient agent may have beliefs about these characteristics and use them in its reasoning processes. For a domain model the parameters involved are assumed fixed, but beliefs about them may change over time.

Beliefs on parameters used by an ambient agent in its analysis and support models need not (exactly) correspond to the actual parameters for the domain model that correspond to reality. Within an ambient agent the beliefs about such parameters may be questioned in the light of observations made. For example, if a certain growth factor for a population is believed, and it is observed that after some time the population is much smaller than predicted on the basis of the believed growth factor, the ambient agent may want to adapt its belief on the growth factor by replacing this belief by a belief in a lower value. When beliefs on parameters used by the ambient agent substantially differ from reality, the agent may make errors in its analysis and in its support actions. Often it is not easy to estimate such parameters beforehand (at design time). Therefore it is better to design an ambient agent in such a way that it can learn by identifying errors in parameter beliefs, and after discovering them, adapting these beliefs in order to obtain more correct beliefs on the parameters (at runtime). Two main questions to be addressed are:

- (1) How does the agent get information on the (extent of) *deviation* of the model from reality?
- (2) How can it relate such identified deviations to *adaptations* required in parameter beliefs to compensate for them?

For an answer to the first question, in this section it is assumed that at certain time points (but not necessarily always) information becomes available, as *observations* for the ambient agent. A deviation can be obtained as a difference between observation and prediction on the basis of a prediction model similar to the analysis model using the given beliefs on the parameters.

For the second question a deviation found has to be related to the beliefs on the parameters. Although it may be often assumed that in the numerical case the larger the deviation, the more the parameter value has to be adapted, still it is not clear in which direction (positive or negative) and to which extent such an adaptation of a parameter value is needed. In particular, when more than one parameter is involved this is a nontrivial challenge.

2. Domain Model for Emotion Contagion

The emotion contagion model used in this chapter was adopted from [6]. It has been designed as an interpretation of the bottom-up approach where group emotion can be seen as the sum of its parts [13]. It distinguishes multiple factors that influence emotion contagion processes. The model incorporates individual differences in two most relevant personality traits [14]: neuroticism and extraversion (BIS and BAS, [15]). A number of aspects of the proposed computational model are distinguished that play a role in the contagion, varying from aspects related to an agent *S* sending the emotion, an agent *R* receiving the emotion, and the channel between sender *S* and receiver *R*; see Table 1.

Table 1. Aspects related to a sender S, receiver R, or both

level of the sender's emotion	q_S
level of the receiver's emotion	q_R
sender's emotion expression	ε_S
openness for received emotion	δ_R
the strength of the channel from sender to receiver	α_{SR}
a person's relevance for the group's emotion state	ρ_A
the level of the group's emotion state	q

The aspect ε_S depends on how introvert or extravert, expressive, and/or active or energetic the person is. These aspects correspond to the personality trait extraversion and sensation seeking and the underlying neural system BAS. It represents how far a person transforms internal emotion into external expression. In this sense, an introvert person will induce a weaker contagion of an emotion than an extraverted person. The aspect α_{SR} depends on the type and intensity of the contact between the two persons (e.g., distance vs attachment). The aspect δ_R indicates the degree of susceptibility of the receiver. This represents in how far the receiver allows the emotions received from others to affect the own emotion, and how flexible/persistent the person is emotionally.

The parameter α_{SR} may be related to a combination of more specific aspects such as the directness of the emotion contagion, and the relations between sender and receiver. The stronger the channel, the higher α_{SR} and the more contagion will take place. Emotion contagion is direct if the persons infecting each other with emotions are together in the same room and pay attention to each other [16]. Indirect contagion can happen when for instance the contagion between others is observed. Direct contagion is propagated stronger than indirect emotion contagion.

The aspects shown in Table 1 have been formalized numerically by numbers in the interval $[0, 1]$. In addition, the parameter γ_{SR} is used to represent the strength by which an emotion is received by R from sender S , modelled as:

$$\gamma_{SR} = \varepsilon_S \alpha_{SR} \delta_R \quad (1)$$

The model works as follows: if γ_{SR} is 0, there will be no contagion, if it is 1, there will be a maximum strength of contagion. If γ_{SR} is not 0, there will be contagion and the higher the value, the more contagion will take place. In a way γ_{SR} expresses the energy level with which an emotion is being expressed, transferred and received. The overall strength by which emotions from all the other group members are received by R in a group G , indicated by γ_R , is defined as

$$\gamma_R = \sum_{S \in G \setminus \{R\}} \gamma_{SR} \quad (2)$$

Take weights proportional to $\varepsilon_S \alpha_{SR}$ defined by

$$w_{SR} = \varepsilon_S \alpha_{SR} / \sum_{C \in G \setminus \{R\}} \varepsilon_C \alpha_{CR} \quad (3)$$

and for any $R \in G$ let

$$q_R^* = \sum_{S \in G \setminus \{R\}} w_{SR} q_S \quad (4)$$

be the weighted combined emotion from the other agents. The set of differential equations for emotion contagion in group G is

$$dq_R/dt = \gamma_R (q_R^* - q_R) \quad (5)$$

for all $R \in G$. Here $\gamma_R = \sum_{S \in G \setminus \{R\}} \gamma_{SR}$ and $\gamma_{SR} = \varepsilon_S \alpha_{SR} \delta_R$, as defined by (1) and (2).

As an example to illustrate the introduced concepts, consider the group of three persons described in Table 2. The first three rows show example values for expressiveness, channel strengths and openness. The fourth row shows the contagion strengths resulting from these values by (1) above, the fifth row shows the overall incoming contagion strengths, by (2), and the sixth row the incoming contagion weights obtained by (3). Suppose at some point in time the emotion levels are: $q_A = 0.9$, $q_B = 0.1$, $q_C = 0.4$, then by (4) the following values for the aggregated incoming emotions q_A^* , q_B^* , q_C^* can be obtained:

$$\begin{aligned} q_A^* &= 0.667 * 0.1 + 0.333 * 0.4 = 0.2 \\ q_B^* &= 0.194 * 0.9 + 0.806 * 0.4 = 0.497 \\ q_C^* &= 0.667 * 0.9 + 0.333 * 0.1 = 0.634 \end{aligned}$$

By (5) it can be seen that for the next point in time, the emotion level of A will decrease as $q_A^* < q_A$, the emotion level of B will increase, as $q_B^* > q_B$, and the emotion level of C will increase as $q_C^* > q_C$.

Table 2. Example Settings

	<i>agent A</i>	<i>agent B</i>	<i>agent C</i>
expressiveness ε_S	0.6	0.5	1
outgoing channel strengths α_{SR}	0.2 to B 0.5 to C	0.8 to A 0.3 to C	0.2 to A 0.5 to B
openness δ_R	0.6	0.4	0.9
outgoing contagion strengths γ_{SR}	$\gamma_{AB} = 0.048$ $\gamma_{AC} = 0.27$	$\gamma_{BA} = 0.24$ $\gamma_{BC} = 0.135$	$\gamma_{CA} = 0.12$ $\gamma_{CB} = 0.2$
overall incoming contagion strengths γ_R	$\gamma_A = 0.36$	$\gamma_B = 0.248$	$\gamma_C = 0.405$
incoming contagion weights w_{SR}	$w_{BA} = 0.667$ $w_{CA} = 0.333$	$w_{AB} = 0.194$ $w_{CB} = 0.806$	$w_{AC} = 0.667$ $w_{BC} = 0.333$

Notice that, in contrast to a population- or group-based model that would use aggregate variables at the group level, the model used is an *agent-based model* with variables for individual group members. This conforms to the bottom-up approach to emotion contagion shown in the literature; e.g., [8].

Based on the emotion levels of the individual group members a level of the *group's emotion state* can be determined according to a certain measure. Within this measure the emotion levels of specific group members will contribute, but maybe not for each member in a comparable manner. Therefore for each group member A a

(relative) *relevance factor* (ρ_A) is considered indicating to which extent this member is relevant for the measure of the group's emotion level, i.e.,

$$q_G = \sum_{A \in G} q_A \rho_A$$

More details of this contagion model and an overview of simulation scenarios made based on the model can be found in [6]. In the current paper it is discussed how the model can be used as a basis to design an ambient agent model.

3. The Emotion Analysis Model

The emotion contagion model described in Section 2 above can be used by an ambient agent to analyze the past, present and future (expected) dynamics of a team's emotion contagion processes. The main goal of the ambient agent designed is to estimate and predict the level of a given type of emotion in the group at present and future points in time and based on such an analysis, propose actions whenever considered needed. The emotion considered is assumed to be a positive emotion, so when the emotion level of the group is expected to become too low, this analysis process should detect this early enough to intervene.

Concepts needed in such a model for an ambient agent concern the ambient agent's estimations of the relevant human's states at different points in time; these estimations are described by the ambient agent's observations and beliefs; in addition an assessment of the (expected) group's emotion state is needed. An assessment is generated when the group emotion level at some (future) time point is expected to be too low, compared to some given norm (EN). Moreover, to model direct observation of individual emotion levels, the concept *expressed emotion level* ($\varepsilon_S q_A$) is used, as the emotion level that can be observed from someone's face, for example, by use of a face reader. This may differ from the emotion level in that the expressiveness factor also has effect on it.

To formalize the concepts introduced in this and the previous section, a number of logical atoms are introduced that incorporate numerical representations; see Table 3. Note that in order to generate and analyze possible temporal patterns for the future, some of the atoms have an additional time variable T . This is used to make predictions about future emotion states, as part of the analysis.

Table 3. Concepts to reason about emotion contagion and their formalization

<i>concept</i>	<i>formalisation</i>
observation that person A has expressed emotion level EV at time T	observed(agent, has_expressed_emotion_level_at(A:AGENT, EV:REAL, T:REAL))
belief that person A has expressed emotion level EV at time T	belief(agent, has_expressed_emotion_level_at(A:AGENT, EV:REAL, T:REAL))
belief that person B has expressiveness E	belief(agent, has_expressiveness(B:AGENT, E:REAL))
belief that person A has openness for received emotion D	belief(agent, has_openness(A:AGENT, D:REAL))

belief that the channel from B to A has strength C	belief(agent, has_channel_strength(B:AGENT, A:AGENT, C:REAL))
belief that the contagion strength from B to A is CS	belief(agent, has_contagion_strength(B:AGENT, A:AGENT, CS:REAL))
belief that the overall contagion strength to receiver A is CS	belief(agent, has_overall_contagion_strength(A:AGENT, CS:REAL))
belief that step size is DT	belief(agent, stepsize(DT:REAL))
belief that person A has relevance R	belief(agent, has_relevance(A:AGENT, R:REAL))
belief that person A has emotion level V at time T	belief(agent, has_emotion_level_at(A:AGENT, V:REAL, T:REAL))
belief that the group emotion level at T is GE	belief(agent, group_emotion_level_at(GE:REAL, T:REAL))
belief that the group emotion norm is EN	belief(agent, group_emotion_norm(EN:REAL))
assessment that the deficient of the group emotion at T is ED	assessment(agent, group_emotion_deficient_at(ED:REAL, T:REAL))

The dynamic relationships of the model to reason about emotion contagion are described and formalised as follows. Note that the beliefs on emotion expressiveness, openness, and channel strengths are assumed to be initially given and to persist (until they are changed). Moreover, a scenario is considered where at some (initial) point in time the current emotion levels of the members are estimated or observed, and from that point onwards, the beliefs on emotion levels for subsequent time points are determined, as a form of temporal projection (or prediction).

The full specification of the analysis model can be found in Box 1. First the role of observed expressed emotions is formalised in ADR1. The agent is assumed to possess observation equipment, for example, in the form of a face reader with software that detects emotion expressions from face images and possibly supplemented by other sensors and analysis methods. The model presented here is independent of the choice for these methods; it simply works together with them in a modular fashion.

As an example, the ambient agent may observe that at time T_0 agent A in the group has an expressed emotion level of 0.2 , and based on ADR1 generates a belief about this.

ADR1 Observing group members' expressed emotion levels

If the agent observes an expressed emotion level
 then the ambient agent will believe this.

observes(agent, has_expressed_emotion_level_at(A, V, T)) →
 belief(agent, has_expressed_emotion_level_at(A, V, T))

ADR2 Generating a belief on an emotion from a belief on an expressed emotion

If the agent believes that a group member has expressed emotion level EV
 and that this group member has expressiveness E

then it will generate a belief that this group member has emotion level EV/E
 belief(agent, has_expressed_emotion_level_at(A, EV, T)) & belief(agent, has_expressiveness(E))
 → belief(agent, has_emotion_level_at(A, EV/E, T))

ADR3 Generating beliefs on contagion strengths

If the ambient agent believes that B has expressiveness E
 and the ambient agent believes that the channel from B to A has strength C
 and the ambient agent believes that A has openness D

then the ambient agent will believe that the contagion strength from B to A will be $E*C*D$
 belief(agent, has_expressiveness(B, E)) & belief(agent, has_channel_strength(B, A, C)) &
 belief(agent, has_openness(A, D))
 → belief(agent, has_contagion_strength(B, A, E*C*D))

ADR4 Updating beliefs on emotion levels

If $A \neq B$ and $B \neq C$ and $C \neq A$
 the ambient agent believes that A has emotion level $V1$ at time T
 and the ambient agent believes that B has emotion level $V2$ at time T
 and the ambient agent believes that C has emotion level $V3$ at time T
 and the ambient agent believes that the contagion strength from B to A is $CS2$
 and the ambient agent believes that the contagion strength from C to A is $CS3$
 and the ambient agent believes that the step size is DT

then the ambient agent will believe that the emotion level of A will be
 $V1 + CS2*(V2 - V1)*DT + CS3*(V3 - V1)*DT$ at time $T + DT$
 $A \neq B$ & $B \neq C$ & $C \neq A$ & belief(agent, has_emotion_level_at(A, V1, T)) &
 belief(agent, has_emotion_level_at(B, V2, T)) & belief(agent, has_emotion_level_at(C, V3, T)) &
 belief(agent, has_contagion_strength(B, A, CS2)) & belief(agent, has_contagion_strength(C, A, CS3)) &
 belief(agent, step_size(DT))
 → belief(agent, has_emotion_level_at(A, V1 + CS2*(V2 - V1)*DT + CS3*(V3 - V1)*DT, T + DT))

ADR5 Determining beliefs on the group's emotion level

If the ambient agent believes that the group members have emotion levels $V1, V2, V3$
 and relevance $R1, R2, R3$ respectively

then it will believe that the group's emotion level is $R1*V1 + R2*V2 + R3*V3$.
 belief(agent, has_emotion_level_at(a1, V1, T)) & belief(agent, has_emotion_level_at(a2, V2, T)) &
 belief(agent, has_emotion_level_at(a3, V3, T)) &
 belief(agent, has_relevance(a1, R1)) & belief(agent, has_relevance(a2, R2)) &
 belief(agent, has_relevance(a3, R3))
 → belief(agent, group_emotion_level_at(R1*V1 + R2*V2 + R3*V3, T))

ADR6 Assessment of the group's emotion level

If the ambient agent believes that the group emotion level V at time T is lower than the emotion
 norm EN ,

then it will assess the situation as having a group emotion deficient $EN - V$ at T .
 belief(agent, group_emotion_level_at(V, T)) & belief(agent, group_emotion_norm(EN)) & $V < EN$
 → assessment(agent, group_emotion_deficient_at(EN - V, T))

Box 1. Specification of the Analysis Model

The expressed emotion EV results from the emotion level V and the expressiveness E by which the emotion is displayed on the face. In the model, it is assumed that the expressed emotion level is formalised as the product $V * E$. Note that this means that it is assumed that the expressiveness (being a number between 0 and 1) always reduces the level of the emotion: $EV \leq E$. In other words, this assumption excludes the situation

that an emotion level is expressed that is not there (no faking of emotions). Moreover, note that in ADR2 in Box 1 it is assumed that the expressiveness factor E is non-zero. Then under the assumptions discussed above, from an expressed emotion level EV the emotion level V itself can be determined as $V = EV/E$.

In the example, given the belief that at time T_0 the expressed emotion EV of agent A is 0.3 , and a belief that agent A 's expressiveness E is 0.5 , by ADR2, the ambient agent derives the belief that agent A has emotion level 0.4 at time T_0 .

In ADR3 and ADR4 in Box 1, the embedding of the domain model is shown. Using this, the ambient agent can predict the expected future emotion levels. By ADR5, a group emotion level can be determined.

For example, given the beliefs that at time T_0 the agents A, B, C have emotion levels $0.4, 0.8, 0.9$ respectively, by ADR3 and ADR4 the ambient agent derives the beliefs that at time $T_0 + 20$ the agents A, B, C have emotion levels $0.45, 0.5, 0.55$, respectively (as in Section 2). From these, by ADR5, the belief is derived that at time $T_0 + 20$ the group emotion level will be 0.5 .

An analysis also involves an assessment of the (expected) level of the group's emotion. To this end, the belief on the group's emotion level generated in ADR5, is used. An assessment is generated when the group emotion level at some (future) time point is expected to be too low, compared to a certain norm. In case of a negative outcome further action may be needed, to avoid this undesired situation. The assessment includes an estimation of how much the group emotion level is too low (the *group emotion deficient*); this is expressed in ADR6 in Box 1.

For example, given the beliefs that at time $T_0 + 20$ the group emotion level will be 0.5 , and the emotion norm is 0.7 , by ADR5 the assessment is derived that at time $T_0 + 20$ there will be a group emotion deficient of 0.2 .

4. The Group Emotion Support Model

In the previous sections, the emotion contagion model and the analysis process based on it have been discussed. In this section, the support model is introduced that uses these models to provide intelligent support to humans in cases where the group emotion level is expected to fall below a certain norm. The support model introduced here uses a heuristic approach. The idea here is that an ambient agent will reason about the proper actions that should be undertaken by the team leader to keep the group emotion level optimal. For example, it uses knowledge expressing that in case the group emotion level (e.g., relaxedness or happiness) is lower than a certain norm, certain members are to be detected that play a crucial role in a negative or positive sense and give them either a pep talk to or to increase or decrease their impact on the other group members.

When a negative assessment of the (future) group emotion state is made, then the ambient agent is assumed to propose actions to the team leader, in order to avoid such states. Some examples of possible actions are:

- giving a group member that negatively affects the emotion in the team a less central role (decreasing the emotion contagion strengths from this person)

- asking a person with a positive emotion level (for example the team leader) either to not be too open for other members (decrease the person’s openness; i.e., δ_R) or to be more expressive (increase the person’s expressiveness; i.e., ϵ_S)

Two heuristics that are applied are the following:

- *let the group members with lower emotion levels have less impact on the other members, and get more impact from the other members*
- *let the group members with higher emotion levels have more impact on the other members, and get less impact from the other members*

Here ‘higher’ and ‘lower’ can be defined as the members with highest or lowest emotion level, but also as above or under the group’s emotion level. In general, two (low and high) *emotion thresholds* are assumed for this, where a specific case is that these thresholds are both equal to the group’s emotion level.

For a group member under the low threshold, his or her impact on the other members can be decreased by (encouragement for) decreasing the person’s expressiveness, or by decreasing the channel strengths from this person to the other members. Moreover, the person’s impact from other members can be increased by increasing the person’s openness (which in general will be one of the less easy options), and by increasing the channel strengths from the other members. For an overview of the action options based on the two heuristics, see Table 4; in Table 5 the formalisation of the concepts used is shown.

Table 4. Overview of the action options

	<i>person under low threshold</i>	<i>person above high threshold</i>
<i>expressiveness</i>	decrease	increase
<i>openness</i>	increase	decrease
<i>channels to others</i>	decrease	increase
<i>channels from others</i>	increase	decrease

This approach does not give indications for the extent to which such adjustments have been applied. When such adjustment extents are chosen, the approach can also be combined with a feasibility ranking approach described next.

Table 5. Formalization of concepts in the support model

<i>concept</i>	<i>formalisation</i>
the agent believes that the low threshold for individual emotion levels is <i>LT</i>	belief(agent, low_threshold(LT:REAL))
the agent believes that the high threshold for individual emotion levels is <i>HT</i>	belief(agent, high_threshold(HT:REAL))
the agent believes that <i>A</i> is a low emotion member	belief(agent, low_emotion_member(A:AGENT))
the agent believes that <i>A</i> is a high emotion member	belief(agent, high_emotion_member(A:AGENT))
the agent believes that the adjustment extent is <i>AE</i>	belief(agent, adjustment_extent(AE:REAL))
the agent believes that an action option is to change the value <i>W1</i> for expressiveness of <i>A</i> to <i>W2</i>	belief(agent, action_option(adjust_to(expressiveness(A:AGENT), W1:REAL, W2:REAL)))

the agent believes that an action option is to change the value $W1$ for channel strength from A to B to $W2$	belief(agent, action_option(adjust_to(channel_strength(A:AGENT,B:AGENT), W1:REAL, W2:REAL)))
the agent believes that an action option is to change the value $W1$ for openness of A to $W2$	belief(agent, action_option(adjust_to(openness(A:AGENT), W1:REAL, W2:REAL)))
the agent believes that parameter P has adjustment infeasibility factor IF	belief(agent, has_infeasibility_factor(P: PARAMETER, IF:REAL))
the agent believes that the action option to adjust parameter P from $W1$ to $W2$ has infeasibility rank R	belief(agent, has_action_option_rank(adjust_to(P: PARAMETER, W1:REAL, W2:REAL), R:REAL))
the agent believes that the feasibility threshold is FT	belief(agent, feasibility_threshold(FT:REAL))
the agent proposes the action to adjust parameter P from $W1$ to $W2$	action_proposal(agent, adjust_to(P: PARAMETER, W1:REAL, W2:REAL))

The formalization of the dynamic relationships for the Support Model following the above explanation, is shown in Box 2 and Box 3.

<p>SDR1 Low emotion member identification If the ambient agent believes that A has emotion level V at $T0$ and that the low threshold is LT and $V \leq LT$ then the agent will believe that A is a low emotion member belief(agent, has_emotion_level_at(A, V, T0)) & belief(agent, low_threshold(LT)) & $V \leq LT$ → belief(agent, low_emotion_member(A))</p> <p>SDR2 High emotion member identification If the ambient agent believes that A has emotion level V at $T0$ and that the high threshold is HT and $V \geq HT$ then the agent will believe that A is a high emotion member belief(agent, has_emotion_level_at(A, V, T0)) & belief(agent, high_threshold(HT)) & $V \geq HT$ → belief(agent, high_emotion_member(A))</p> <p>SDR3 Heuristic generation of expressiveness action options for low emotion members If the ambient agent believes that A is a low emotion member and a group emotion deficient ED at T was identified and it believes that the adjustment extent is AE and the expressiveness of A is E then the agent will believe that an action option is to change the value E for expressiveness to $E - AE * ED * E$ belief(agent, low_emotion_member(A)) & assessment(agent, group_emotion_deficient_at(ED, T)) & belief(agent, adjustment_extent(AE)) & belief(agent, has_expressiveness(A, E)) → belief(agent, action_option(adjust_to(expressiveness(A), E, E - AE * ED * E)))</p> <p>SDR4 Heuristic generation of channel action options for low emotion members If the ambient agent believes that A is a low emotion member and that a group emotion deficient ED at T was identified and that the adjustment extent is AE and the channel from A to B has strength C then the agent will believe that an action option is to change the value C for channel strength to $C - AE * ED * C$ belief(agent, low_emotion_member(A)) & assessment(agent, group_emotion_deficient_at(ED, T)) & belief(agent, adjustment_extent(AE)) & belief(agent, has_channel_strength(A, B, C)) → belief(agent, action_option(adjust_to(channel_strength(A, B), C, C - AE * ED * C)))</p> <p>SDR5 Heuristic generation of openness action options for low emotion members If the ambient agent believes that A is a low emotion member and a group emotion deficient ED at T was identified and it believes that the adjustment extent is AE and the openness of A is D then the agent will believe that an action option is to change the value D for openness to $D + AE * ED * (1 - D)$ belief(agent, low_emotion_member(A)) & assessment(agent, group_emotion_deficient_at(ED, T)) & belief(agent, adjustment_extent(AE)) & belief(agent, has_openness(A, D)) → belief(agent, action_option(adjust_to(openness(A), D, D + AE * ED * (1 - D))))</p>
--

Box 2. Specification of the Support Model, Part I

The formalization of the concepts and relations given in Table 5 and Boxes 2 and 3, can be explained as follows. First, by SDR1 and SDR2, low and high emotion members are determined. After that, beliefs on action options are generated for the low emotion members by SDR3 to SDR5 in Box 2, and for the high emotion members by SDR6 to SDR 8 in Box 3.

For example, based on the beliefs that at time T_0 the agents A, B, C have emotion levels $0.4, 0.8, 0.9$ respectively, and the beliefs that the low and high emotion threshold is 0.5 and the high emotion threshold is 0.7 , by SDR1, the ambient agent derives the belief that agent A is a low emotion member, and by SDR2 it derives the beliefs that agent B and agent C are high emotion members. Then by SDR3, SDR4, and SDR5, three action options for agent A are generated: decrease A 's expressivity, outgoing channel strengths, and increase A 's openness, respectively. Similarly, by SDR6, SDR7, and SDR8 for agents B and C , action options are generated: increase their expressivity, outgoing channel strengths, and decrease their openness, respectively.

After the ambient agent has generated the actions options, they have to be ranked on their (in)feasibility expressing how difficult they are to achieve, because it may happen that some action options can be realized easily whereas others are difficult to realize. The action option with the lowest infeasibility will be chosen and proposed by the ambient agent to the team leader. A realistic ranking, from the most to the least infeasible parameter, can be: (1) openness (δ_A), because it seems that this personality characteristic is difficult to change over time; (2) expressiveness (ε_A) because this personality characteristic can be 'faked' (one can display emotions that are not experienced); (3) channel strength (α_{BA}) because it is easy, for example, to decrease the channel strengths between a person and every other group member, by simply separating this individual from the group.

For example, by SDR9, beliefs in the following infeasibility rankings may be derived:

Action option	Agent A	Agent B	Agent C
expressiveness	-0.9	0.8	0.7
channel strength	-0.15	0.1	0.05
openness	0.9	-0.85	-0.9

Based on these ranking beliefs, and a belief in a feasibility threshold of 0.85 ; by SDR10, it can be derived that the action proposals are: decrease agent A 's channel strength and increase the channel strengths of agent B and C .

SDR6 Heuristic generation of expressiveness action options for high emotion members
If the ambient agent believes that A is a high emotion member
and a group emotion deficient ED at T was identified
and it believes that the adjustment extent is AE
and that the expressiveness of A is E
then the agent will believe that an action option is to change the value E for
expressiveness to $E + AE*ED*(1-E)$
belief(agent, high_emotion_member(A)) & assessment(agent, group_emotion_deficient_at(ED, T)) &
belief(agent, adjustment_extent(AE)) & belief(agent, has_expressiveness(A, E))
→ belief(agent, action_option(adjust_to(expressiveness(A), E, E + AE*ED*(1-E))))

SDR7 Heuristic generation of channel action options for high emotion members
If the ambient agent believes that A is a high emotion member
and that a group emotion deficient ED at T was identified
and that the adjustment extent is AE
and that the channel from A to B has strength C
then the agent will believe that an action option is to change the value C for channel strength
to $C + AE*D*(1-C)$
belief(agent, high_emotion_member(A)) & assessment(agent, group_emotion_deficient_at(ED, T)) &
belief(agent, adjustment_extent(AE)) & belief(agent, has_channel_strength(A, B, C))
→ belief(agent, action_option(adjust_to(channel_strength(A, B), C, C + AE*ED*(1-C))))

SDR8 Heuristic generation of openness action options for high emotion members
If the ambient agent believes that A is a high emotion member
and a group emotion deficient ED at T was identified
and it believes that the adjustment extent is AE
and that the openness of A is D
then the agent will believe that an action option is to change the value D for
openness to $D - AE*ED*D$
belief(agent, high_emotion_member(A)) & assessment(agent, group_emotion_deficient_at(ED, T)) &
belief(agent, adjustment_extent(AE)) & belief(agent, has_openness(A, D))
→ belief(agent, action_option(adjust_to(openness(A), D, D - AE*ED*D))))

SDR9 Ranking action options
If the ambient agent believes that an action option is to change the value $W1$ for P to $W2$
and it believes that P has infeasibility factor IF
then the agent will believe that the action option has infeasibility rank $IF*(W2-W1)$
belief(agent, action_option(adjust_to(P, W1, W2))) & belief(agent, has_infeasibility_factor(P, IF))
→ belief(agent, has_action_option_rank(adjust_to(P, W1, W2), IF*(W2-W1)))

SDR10 Generation of action proposals
If the ambient agent believes that the action option has infeasibility rank R
and that the feasibility threshold is FT and $R \leq FT$ and $R \geq -FT$
then it will generate the action option as an action proposal.
belief(agent, has_action_option_rank(adjust_to(P, W1, W2), R)) &
belief(agent, feasibility_threshold(FT)) & $R \leq FT$ & $R \geq -FT$
→ action_proposal(agent, adjust_to(P, W1, W2))

Box 3. Specification of the Support Model, Part II

5. The Adaptation Model

When using a dynamic model to assess a human's states in the context of a task and environment, the software agent has to maintain beliefs about characteristics of the human, used as parameters in the model. As often it is not possible to determine accurate values beforehand, this section describes a method by which the agent adapts its beliefs concerning human characteristics to the real characteristics. The main idea is as follows. The agent initially receives rough estimations of the values for these human characteristics, and maintains them as beliefs. Using the dynamic model with parameter

values as represented by these initial beliefs, the agent predicts the human state, up to a certain time point. When at that time point, for example by observation, information is obtained that can be related to the real value of one or more state variables of the model, this can be used as input for the adaptation process. The agent then tries to minimize the difference between predicted and real value by adjusting the beliefs on the human characteristics (i.e., the parameter values which were initially assumed). This process of adaptation is kept going on until the difference is low enough, i.e., until the agent has a sufficiently accurate set of beliefs about the human's characteristics. To be able to make reasonable adjustments it is needed to obtain information on how a change in a parameter value affects the difference between the predicted and real value of the variable that is considered; this is called the sensitivity of the variable value for the parameter value. In more details, the adaptation process, which was adopted from [26], is described as follows.

5.1. Sensitivities: How They Can Be Determined

Within this adaptation process sensitivities of state variables for changes in parameter values for human characteristics play an important role. The *sensitivity* S of variable X for parameter P is the number such that a change ΔP in the value of P of parameter P will lead to a change ΔX in X which is (approximately) proportional to ΔP with proportion factor S :

$$\Delta X = S \Delta P$$

This is an approximation which is more accurate when the Δ 's are taken small; in fact the sensitivity is the partial derivative $\partial X/\partial P$. To determine a sensitivity S (so determining the partial derivative $\partial X/\partial P$) in principle, either both analytical and experimental/heuristic methods or a combination of them can be used. As systems of differential equations encountered usually cannot be solved analytically, a purely analytical approach to determine sensitivities is often not feasible. As an approximation method the following can be done. A small change ΔP in the parameter is tried to make an additional prediction for X , and based on the resulting change ΔX found in the two predicted values for X , by

$$S_{X,P} = \Delta X / \Delta P$$

the sensitivity S can be estimated. The idea is that this is done for each of the parameters, one by one.

5.2. Sensitivities: How They Can Be Used

Given that a sensitivity $S_{X,P}$ of variable X for parameter P is known it can be used in the following manner. First it can be noticed that sensitivities for some parameters P can be 0 or almost 0. Apparently, such parameters do not have any serious effect on the outcome of the value of variable X . Therefore, changing them based on available values for X does not make much sense: a deviation in value of X cannot be attributed to them, due to their low influence. Based on the estimation of a sensitivity which has distance at least τ_S to 0 (where τ_S is a small threshold value), in principle a better guess for the value of P can be determined by taking

$$\Delta P = -\lambda * \Delta X / S_{X,P}$$

where ΔX is the deviation found between observed and predicted value of X ; so, for example, when $\Delta X = 0.25$ and $\lambda = 0.3$, then for $S_{X,P} = 0.75$ this obtains $\Delta P = -0.3*0.25 / 0.75 = -0.1$. However, when the sensitivity $S_{X,P}$ is a bit smaller, it could be possible that the adjustment of the value of P based on the formula above would exceed the maximum or minimum value of its range. For example, when $\Delta X = 0.25$, $\lambda = 0.3$, and $S_{X,P} = 0.025$ it results in $\Delta P = -0.3*0.25 / 0.025 = -3$. To avoid such problems, a kind of threshold function can be applied that maps, for example: a parameter with values in the interval $[0, 1]$, the proposed adjustment on a $[0, 1]$ interval (which can still be multiplied by a factor for other intervals):

$$\begin{aligned} \Delta P &= \lambda * th(\sigma, \tau, \Delta X / S_{X,P}) * (I - W) && \text{when } \Delta X / S_{X,P} \geq 0 \\ \Delta P &= -\lambda * th(\sigma, \tau, -\Delta X / S_{X,P}) * W && \text{when } \Delta X / S_{X,P} < 0 \end{aligned}$$

Here the threshold function with steepness σ and threshold value τ is defined by

$$th(\sigma, \tau, V) = 1 / (1 + e^{-\sigma(V-\tau)})$$

or, to allow for lower steepness values by

$$\begin{aligned} th(\sigma, \tau, V) &= [1 / (1 + e^{-\sigma(V-\tau)}) - 1 / (1 + e^{\sigma\tau})] / [1 - 1 / (1 + e^{\sigma\tau})] \\ &= [1 / (1 + e^{-\sigma(V-\tau)}) - 1 / (1 + e^{\sigma\tau})] * [1 + e^{-\sigma\tau}] \end{aligned}$$

When for more than one variable X information about its real value is obtained, the adjustment ΔP for parameter P is taken as the average of all calculated adjustments based on the different variables X such that the sensitivity $S_{X,P}$ is not close to 0.

5.3. Specification of the Adaptation Model

Determination of parameters to be adjusted is based on the sensitivities of the (future) group emotion level for the different parameter values. For the moment these sensitivities are assumed to be available. Below it will be discussed in more detail how they can be obtained (dynamic relationships CDR7 and further). But first it is shown how adaptation options for parameters can be generated, by using given sensitivities, when deviations of the beliefs based on the emotion contagion model from observed emotion levels are detected. Note that the process of parameter adaptation as described can address all of the parameters in turn.

CDR1 Determining deviations

If the agent believes that the emotion level for A at T is $V1$
 and the agent observes that the emotion level for A at T is $V2$
 then the agent will believe that the emotion level $V1$ for A at T has a deviation of $V2-V1$
 $\text{belief}(\text{agent}, \text{has_emotion_level_at}(A, V1, T)) \ \& \ \text{observed}(\text{agent}, \text{has_emotion_level_at}(A, V2, T))$
 $\rightarrow \text{belief}(\text{agent}, \text{has_deviation}(\text{has_emotion_level_at}(A, V1, T), V2-V1))$

CDR2 Generating adaptation options: upward

If the agent believes that the emotion level V for A has sensitivity S for parameter P
 with value W
 and that a deviation D for emotion level V for A at T was identified and $D/S \geq 0$
 and the agent believes that the adaptation speed is U
 then the agent will believe that an adaptation option is to change the value W for P
 to $W + U * D * (1 - W) / S$
 $\text{belief}(\text{agent}, \text{has_sensitivity_for}(\text{has_emotion_level_at}(A, V, T), S, P, W))$
 $\text{belief}(\text{agent}, \text{has_deviation}(\text{has_emotion_level_at}(A, V, T), D)) \ \& \ D/S \geq 0 \ \&$
 $\text{belief}(\text{agent}, \text{adaptation_speed}(U))$
 $\rightarrow \text{belief}(\text{agent}, \text{adaptation_option}(\text{adapt_to}(P, W, W + U * D * (1 - W) / S)))$

CDR3 Generating adaptation options: downward

If the agent believes that the emotion level V for A has sensitivity S for parameter P
 with value W
 and that a deviation D for emotion level V for A at T was identified and $D/S \leq 0$
 and the agent believes that the adaptation speed is U
 then the agent will believe that an adaptation option is to change the value W for P
 to $W + U * D * W / S$
 $\text{belief}(\text{agent}, \text{has_sensitivity_for}(\text{has_emotion_level_at}(A, V, T), S, P, W))$
 $\text{belief}(\text{agent}, \text{has_deviation}(\text{has_emotion_level_at}(A, V, T), D)) \ \& \ D/S \leq 0 \ \&$
 $\text{belief}(\text{agent}, \text{adaptation_speed}(U))$
 $\rightarrow \text{belief}(\text{agent}, \text{adaptation_option}(\text{adapt_to}(P, W, W + U * D * W / S)))$

CDR4 Performing an expressiveness parameter adaptation

If the agent believes that an adaptation option is to change the value $E1$ for expressiveness of A to
 $E2$
 then the agent will believe that the expressiveness of A is $E2$
 and it will not believe that the expressiveness of A is $E1$
 $\text{belief}(\text{agent}, \text{adaptation_option}(\text{adapt_to}(\text{expressiveness}(A), E1, E2)))$
 $\rightarrow \text{belief}(\text{agent}, \text{has_expressiveness}(A, E2)) \ \& \ \text{not belief}(\text{agent}, \text{has_expressiveness}(A, E1))$

CDR5 Performing a channel strength parameter adaptation

If the agent believes that an adaptation option is to change the value $C1$ for channel strength from A
 to B to $C2$
 then the agent will believe that the channel strength from A to B is $C2$
 and it will not believe that the channel strength from A to B is $C1$
 $\text{belief}(\text{agent}, \text{adaptation_option}(\text{adapt_to}(\text{channel_strength}(A, B), C1, C2)))$
 $\rightarrow \text{belief}(\text{agent}, \text{has_channel_strength}(A, C2)) \ \& \ \text{not belief}(\text{agent}, \text{has_channel_strength}(A, C1))$

CDR6 Performing an openness parameter adaptation

If the agent believes that an adaptation option is to change the value $D1$ for openness of A to $D2$
 then the agent will believe that the openness of A is $D2$
 and it will not believe that the openness of A is $D1$
 $\text{belief}(\text{agent}, \text{adaptation_option}(\text{adapt_to}(\text{openness}(A), D1, D2)))$
 $\rightarrow \text{belief}(\text{agent}, \text{has_openness}(A, D2)) \ \& \ \text{not belief}(\text{agent}, \text{has_openness}(A, D1))$

Box 4. Specification of the Adaptation Model, Part I

Next it is discussed how sensitivities can be determined; see Box 5. First the dynamic relationship in CDR7 shows how from multiple predictions with different values $W1$ and $W2$ for the same parameter P , sensitivities can be found. To obtain predictions based on an assumed value for a specific parameter, in principle the approach described in Section 3 can be used. However, as it is important to keep track of for which parameter and value the prediction is made, it is needed to add this to the representations. As a starting point time point 0 is considered; see CDR8 in Box 5.

Updating the predicted emotion levels over time is similar to dynamic relationship ADR4; a difference is that assumed parameter values are used, and that the parameter P

and value V for which the predictions are made are included in the representations; see CDR9.

CDR7 Sensitivity estimation from multiple predictions

If the ambient agent predicts by parameter P with value $W1$ that the emotion level $V1$ for A occurs at T ,
 and it predicts by parameter P with value $W2$ that emotion level $V2$ for A occurs at T ,
 then it will believe that the sensitivity of the emotion level $V1$ of A for P and value $W1$ is $(V2-V1)/(W2-W1)$
 $\text{prediction_for}(\text{agent}, \text{has_emotion_level_at}(A, V1, T), P, W1)$ &
 $\text{prediction_for}(\text{agent}, \text{has_emotion_level_at}(A, V2, T), P, W2)$
 $\rightarrow \text{belief}(\text{agent}, \text{has_sensitivity_for}(\text{has_emotion_level_at}(A, V1, T), (V2-V1) / (W2-W1), P, W1)$

CDR8 Initial assumption-based prediction

If the ambient agent is predicting for parameter P with value W
 and it observes that emotion level V for A occurs at time point 0
 then it will predict for parameter P with value W that emotion level V for A occurs at time point 0
 $\text{is_predicting_for}(\text{agent}, P, V)$ & $\text{observed}(\text{agent}, \text{has_emotion_level_at}(A, V, 0))$
 $\rightarrow \text{prediction_for}(\text{agent}, \text{has_emotion_level_at}(A, V, 0), P, W)$

CDR9 Updating assumption-based predictions on emotion levels

If $A \neq B$ and $B \neq C$ and $C \neq A$
 and the ambient agent predicts for parameter P with value W that A has emotion level $V1$ at time T
 and the ambient agent predicts for parameter P with value W that B has emotion level $V2$ at time T
 and the ambient agent predicts for parameter P with value W that C has emotion level $V3$ at time T
 and the ambient agent assumes that the contagion strength from B to A is $CS2$
 and the ambient agent assumes that the contagion strength from C to A is $CS3$
 and the ambient agent believes that the step size is DT
 then the ambient agent will predict for parameter P with value W that the emotion level of A will be $V1 + CS2 * (V2 - V1) * DT + CS3 * (V3 - V1) * DT$ at time $T + DT$
 $A \neq B$ & $B \neq C$ & $C \neq A$ &
 $\text{prediction_for}(\text{agent}, \text{has_emotion_level_at}(A, V1, T), P, W)$ &
 $\text{prediction_for}(\text{agent}, \text{has_emotion_level_at}(B, V2, T), P, W)$ &
 $\text{prediction_for}(\text{agent}, \text{has_emotion_level_at}(C, V3, T), P, W)$ &
 $\text{assumption}(\text{agent}, \text{has_contagion_strength}(B, A, CS2))$ &
 $\text{assumption}(\text{agent}, \text{has_contagion_strength}(C, A, CS3))$ & $\text{belief}(\text{agent}, \text{step_size}(DT))$
 $\rightarrow \text{prediction_for}(\text{agent}, \text{has_emotion_level_at}(A, V1 + CS2 * (V2 - V1) * DT + CS3 * (V3 - V1) * DT, T + DT), P, W)$

Box 5. Specification of the Adaptation Model, Part II

To obtain the assumptions on the different parameters and their values that are needed, the relationships are used shown in Box 6. First, in CDR10 it is shown how assumptions on contagion strengths are determined. Next, in CDR11, CDR12 and CDR13 it is shown how an assumption for a parameter for which a prediction is made is generated. Finally, for parameters for which no predictions are made, assumptions are just based on the beliefs about them, as shown in CDR14 and further in Box 5.

CDR10 Generating assumptions on contagion strengths

If the ambient agent assumes that B has expressiveness E
 and the ambient agent assumes that the channel from B to A has strength C
 and the ambient agent assumes that A has openness D
 then the ambient agent will assume that the contagion strength from B to A will be $E * C * D$
 $\text{assumption}(\text{agent}, \text{has_expressiveness}(B, E)) \ \& \ \text{assumption}(\text{agent}, \text{has_channel_strength}(B, A, C)) \ \& \ \text{assumption}(\text{agent}, \text{has_openness}(A, D))$
 $\rightarrow \text{assumption}(\text{agent}, \text{has_contagion_strength}(B, A, E * C * D))$

CDR11 Generating assumptions for prediction based on expressiveness

If the ambient agent is predicting for expressiveness of A with value E
 then the ambient agent will assume that A has expressiveness E
 $\text{is_predicting_for}(\text{agent}, \text{expressiveness}(A), E)$
 $\rightarrow \text{assumption}(\text{agent}, \text{has_expressiveness}(A, E))$

CDR12 Generating assumptions for prediction based on channel strengths

If the ambient agent is predicting for channel strength from A to B with value C
 then the ambient agent will assume that the channel from A to B has strength C
 $\text{is_predicting_for}(\text{agent}, \text{channel_strength}(A, B), C)$
 $\rightarrow \text{assumption}(\text{agent}, \text{has_channel_strength}(A, B, C))$

CDR13 Generating assumptions for prediction based on openness

If the ambient agent is predicting for openness of A with value D
 then the ambient agent will assume that A has openness D
 $\text{is_predicting_for}(\text{agent}, \text{openness}(A), D)$
 $\rightarrow \text{assumption}(\text{agent}, \text{has_openness}(A, D))$

CDR14 Prediction parameter exclusiveness

If the ambient agent is predicting for parameter P with value W
 and parameter Q is not equal to P
 then the agent is not predicting for Q
 $\text{is_predicting_for}(\text{agent}, P, W) \ \& \ Q \neq P$
 $\rightarrow \text{not is_predicting_for}(\text{agent}, Q)$

CDR15 Generating assumptions for prediction not based on expressiveness

If the ambient agent is not predicting for expressiveness of A
 and the ambient agent believes that A has expressiveness E
 then the ambient agent will assume that A has expressiveness E
 $\text{not is_predicting_for}(\text{agent}, \text{expressiveness}(A)) \ \& \ \text{belief}(\text{agent}, \text{has_expressiveness}(A, E))$
 $\rightarrow \text{assumption}(\text{agent}, \text{has_expressiveness}(A, E))$

CDR16 Generating assumptions for prediction not based on channel strengths

If the ambient agent is not predicting for channel strength from A to B
 and the ambient agent believes that the channel from A to B has strength C
 then the ambient agent will assume that the channel from A to B has strength C
 $\text{not is_predicting_for}(\text{agent}, \text{channel_strength}(A, B)) \ \& \ \text{belief}(\text{agent}, \text{has_channel_strength}(A, C))$
 $\rightarrow \text{assumption}(\text{agent}, \text{has_channel_strength}(A, B, C))$

CDR17 Generating assumptions for prediction not based on openness

If the ambient agent is not predicting for openness of A
 and the ambient agent believes that A has openness D
 then the ambient agent will assume that A has openness D
 $\text{not is_predicting_for}(\text{agent}, \text{openness}(A)) \ \& \ \text{belief}(\text{agent}, \text{has_openness}(A, D))$
 $\rightarrow \text{assumption}(\text{agent}, \text{has_openness}(A, D))$

Box 6. Specification of the Adaptation Model, Part III**6. Example Simulation Results**

To illustrate the group emotion support model described in previous sections, by a specific example, a specific scenario is addressed. Section 6.1 discusses the analysis process and Section 6.2 the support process. For more explanation and experiments with the adaptation approach, see [26].

6.1. The Analysis Process

In this section the simulation results of the analysis process are shown in an example scenario that represents a situation where the group emotion is happiness and is analyzed by the ambient agent. The LEADSTO software environment [12] has been used to perform a number of simulation experiments. In this example, the ambient agent generates beliefs on the individual emotion levels of three group members, named Arnie, Bernie and Charlie (see ADR2), and of the group emotion level at different points in time (see ADR5). The agent also assesses the (expected) group's emotion deficient at a future time point based on its belief of the group emotion level and the norm for the group emotion level. The norm of the group emotion can be set by the modeller and represents in this example an optimal level of happiness, at which the team can perform as optimal as possible. The norm was set to 0.62 in this example.

In this example scenario, Arnie is very happy (initial emotion level = 0.9), he cannot receive other emotions (because his δ and receiving α 's are zero), however, he is able to send emotions (his ε is non-zero). Bernie is not happy (initial emotion level is 0.05), he cannot receive emotions (his δ is zero), but he can send emotions (his ε is non-zero). The contagion strengths toward Arnie and Bernie are zero. If these strengths stay zero, Arnie and Bernie will stay on the same emotion level. Finally, Charlie is also not happy (initial emotion level = 0.3), but he can receive and send emotions quite strongly (because his δ is 0.9 and his ε is 1). For an overview of the settings, see Table 6.

Table 6. Parameter Settings in Example Scenario

	<i>Arnie</i>	<i>Bernie</i>	<i>Charlie</i>
Initial emotion level q	0.9	0.05	0.3
expressiveness ε	0.6	0.5	1
outgoing channel strengths α	0	0.6	0.6
openness δ	0	0	0.9
relevance ρ	0.34	0.33	0.33

In Figure 1 a simulation trace is shown in which the horizontal axis represents time, and the vertical axis represents quantitative information about generation of ambient agent's beliefs on the individual and group emotion levels at different (future) time points. In this situation the total group emotion level goes from 0.64 to 0.59 in 500 time steps. This means that the group emotion level is above the norm of 0.62 at first, but will get below this norm later. The idea of the analysis model is that the ambient agent predicts this downward development early in time (long before it actually happens), so it can propose appropriate actions to the team leader early, to prevent this from happening. The simulations are based on step size $\Delta t = 0.1$.

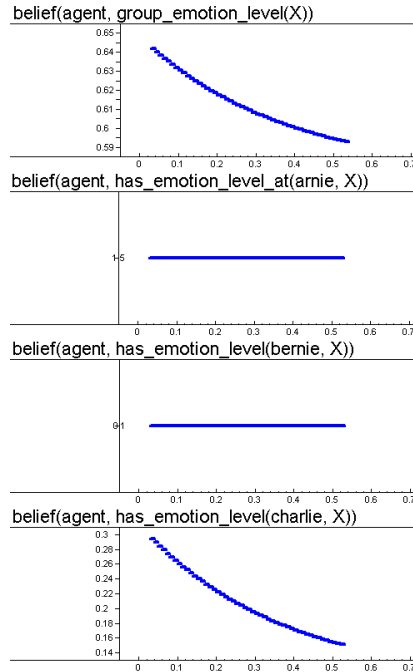


Figure 2. Simulation trace of the analysis processes

In Figure 1, on the x-axis time goes from 0 to 0.7. This is the processing time of the ambient agent. The idea is that the agent reads the emotions of the persons at time point 0 and from that time point, ambient agent starts to generate beliefs on the development of the emotion levels of the group members and the group as a whole. This simulation can be found in all the graphs of the individual and group emotion. The developments of the emotion levels (simulated by the ambient agent from time point 0 to 0.5) are estimated for the future time points 0 to 5. Figure 2 shows the assessment of the expected emotion deficient by the ambient agent (see ADR6). For the sake of presentation, only that part is shown where assessment is generated. At time point 0.55 on the x-axis the ambient agent makes an assessment of the future group emotion level deficient for time point 5. The ambient agent assesses that on future time point 5 indeed there is a group emotion deficient to be expected (of about 0.027).

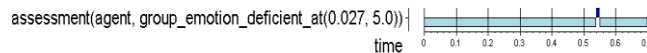


Figure 3. Simulation trace for assessment of emotion deficient

In general, when all α 's and δ 's are non-zero, the pattern is that the emotion levels converge to each other and reach a value which is a weighted average of the initial emotion values. In this weighted average, the values of the agents with higher ε and outgoing α values have higher weights.

6.2. The Support Process

In this section the example scenario of the previous section is extended with the support of the ambient agent. The assumption is made that Arnie is working separately from Bernie and Charlie; i.e., he works in a different office than Bernie and Charlie. Therefore, Arnie's channels to Bernie and Charlie have strength 0. Previously, the ambient agent assessed that there is a non-zero emotion deficient expected: the group emotion level slowly gets below the group emotion level norm of 0.62. Therefore, based on its heuristics, the ambient agent detects which group members are high or low emotion members, and generates action options that decrease or increase parameters related to these members: expressiveness, openness or channel strength. After ranking these options, the agent proposes to the group leader those options, which do not exceed a certain feasibility threshold. An example of (a part of) such a trace is shown in Figure 3. Here, time is on the horizontal axis, and state properties are on the vertical axis. A dark box indicates that a state property is true. Figure 3 shows that the ambient agent detects the high and/or low emotion members (Arnie is detected as a high emotion member and Bernie as a low emotion member; see SDR1 and SDR2), the action-options are ranked (see SDR9) and the ambient agent proposes the actions that do not exceed the feasibility threshold to the group leader (see SDR10).



Figure 4. Simulation trace of heuristics and action proposals

Given that agents with high ε and outgoing α values have the strongest impact on the covering value for the emotions, the general pattern in the support process is to increase the ε and outgoing α values of the agents with the higher emotion levels and decrease these values for agents with the lower emotion levels.

7. Discussion and Neurological Justification

In this section it is briefly discussed how the plausibility of the domain model for emotion contagion can be justified on the basis of neurological literature, in particular Damasio's theory, cf.[17], [18].

7.1. Emotion as a Response and Feeling an Emotion

First Damasio's notion of *emotion* triggered by some stimulus s is addressed. According to his description ([17], p.79), the substrate for the representation of an emotional state is a collection of neural dispositions in the brain, which are activated as a reaction on a certain stimulus s with sensory representation of s . Once this occurs, it entails modification of both the body state and the state of other brain regions. By these events, an emotional state is created which is accessible for external observation; this state may have multiple facets or dimensions, for example, represented as a combination of preparation state properties for the activation of the body responses b_1, b_2, \dots . Note that the state properties are abstract in the sense that a state property refers to a specific neural activation pattern, or neural activation basin of attraction. From a more abstract perspective, the conjunction of all body state properties b_1, b_2, \dots responding to stimulus s can be denoted by (composite) state property b . In [17], the neurological mechanisms and substrates under these states and causal relationships are discussed in more detail; e.g., ([17], pp. 47-53, pp. 59-62, pp. 79-81). Moreover, for different types of emotions these sites are involved to varying degrees

Next, Damasio's notion of *feeling* is considered. A central role is played by the proto-self that provides a map of the state of the organism's body ([17], pp. 153-154). Based on this proto-self he expresses the emergence of feeling (e.g., [17], p. 79). He describes how the neural patterns which constitute the substrate of feeling arise in two classes of biological changes: changes related to body state and changes related to cognitive state ([17], pp. 79-80). Thus, a feeling emerges when the collection of neural patterns contributing to the emotion lead to mental images. In other words, the organism senses the consequences of the emotional response state. In a generic manner, abstracting from the more specific and detailed biological states as described above, the two mechanisms by which a feeling can be achieved as distinguished by Damasio have been incorporated in the model:

1. Via the *body loop*, the internal emotional state leads to a changed state of the body, which subsequently, after sensing, is represented in somatosensory structures of the central nervous system.
2. Via the *as if body loop*, the state of the body is not changed. Instead, on the basis of the internal emotional state, a changed representation of the body is created directly in sensory body maps for b . Consequently, the organism experiences the same feeling as via the body loop: it is 'as if' the body had really been changed but it was not.

The body loop (or as if body loop) is extended to a recursive body loop (or recursive as if body loop) by assuming that the preparation of the bodily response is also affected by the state of feeling the emotion as an additional causal relation. Such recursiveness is also assumed by Damasio ([18],pp. 91-92) as he notices that what is felt by sensing is

actually a body state which is an internal object, under control of the person. Thus reciprocal causation relations between emotion felt and body states occur.

7.2. Mirror Neurons as a Basis for the Emergence of a Shared Feeling

In Section 7.1 the cycle was discussed underlying the generation of emotions upon a stimulus. In social contagion as addressed in the current paper, the stimuli considered are the other agents' expressions. The effect of such stimuli on the own preparation of emotional responses and feelings is based on the notion of mirror neuron (e.g., [19], [20], [21]). Here the stimulus s is observing somebody's body state, for example, a face expression. Mirror neurons are neurons which, in the context of the neural circuits in which they are embedded, are active not only when a person intends to perform a specific action or body change, but also when the person observes somebody else performing this action or body change. This includes expressing emotions in body states, such as facial expressions. For example, there is strong evidence that (already from an age of just 1 hour) sensing somebody else's face expression leads (within about 300 milliseconds) to preparing for and showing the same face expression ([22], pp. 129-130). The idea is that these neurons and the neural circuits in which they are embedded play an important role in social functioning and in (empathic) understanding of others; (e.g., [19], [20], [21]). When internal states and processes of other persons are mirrored by the person's own (similar) states and processes (as a way of internal simulation), and at the same time these processes are crucial for the person's own feelings and actions, then this provides an effective basic mechanism for how in a social context persons fundamentally affect each other's feelings and actions. In [23] it is discussed in more detail how such a neurological mechanism can account for the emergence of sharing, both in affective and cognitive respect, and of collective action.

7.3. How the Contagion Model Relates to the Neurological Principles

Within the emotion contagion model presented in this paper, in the first place the other agents' expressions are used as stimuli upon which emotional responses occur, as described in Section 7.2. This process in principle occurs according to the cycle described in Section 7.1. However, in the presented contagion model the cyclic structure behind the generation of emotions has been given a more abstracted form by assuming that this cyclic process will reach an equilibrium, and taking this equilibrium value for the preparation state as the resulting value for the emotion upon incoming stimuli. Different methods to work out this idea of abstraction formally, can be found in [24], [25].

8. Conclusion

Complex and critical tasks are often allocated to teams. An important task of a team leader in particular, is to maintain a good spirit in the team. As circumstances may be stressful and subject to high pressure, the performance of the tasks may be disappointing from time to time. Emotions within the team may easily become more and more negative. The team leader has as a special responsibility to regulate such patterns.

The literature on emotion contagion addresses how emotions of group members can affect each other. Based on such literature, in [6] a computational model is presented for emotion contagion based on the idea of mutual absorption of emotions. This emotion contagion model was taken as a point of departure for the work reported in the current chapter. An ambient agent model was presented that uses the computational model to analyze the expected group emotion levels at future time points, and to propose actions to the team leader to regulate the group emotion. The approach is modular in that it is easy to replace the emotion contagion model used as a point of departure by a different one. The adaptability of the model is similar to what is introduced in [26] in the context of attention; more details can be found there.

One of the possible applications of this ambient agent model could be analyzing and supporting group emotion in virtual meetings. For example, when two groups at two locations in the world are video-conferencing, a software agent could measure the group emotion of both groups and could show the emotion level of the other group to the group leaders. The software agent could then, if necessary, provide support to the group leaders, e.g. when is the best time to let the other group make a decision, or how to calm the other group down after their anger level got too high during decision making.

So far only one emotion at a time is analyzed in the ambient agent model, but in future work this can easily be extended to take into account multiple emotions as long as they are considered independent from each other. For specific types of emotions, specific values may have to be estimated. However, if also the interaction between different emotions is to be addressed (for example, anger in one person affecting fear in another person), more specific work is needed, which is planned for the future. The emotion contagion model used as a point of departure is based on a principle of mutual absorption. This may be well applicable to a certain type of group members. However, also group members may exist, that by their personality amplify the emotions observed in others beyond the boundaries of emotion levels that already exist in the group. To cover such extreme cases a different domain model for emotion contagion is needed, an example of which can be found in [27].

Other further work may address specific ways in which emotion levels can be detected to obtain input for the presented models. For example by analysing recorded speech and/or text utterances or face expressions (e.g., [7-10], [28], [29], [30]). Once such techniques have been incorporated, an important next step is to conduct experiments in order to validate the approach put forward. An interesting issue here is to investigate in how far group members may feel that the offered approach is violating their privacy norms.

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