Towards a Model of Open and Reliable Cognitive Multiagent Systems: Dealing with Trust and Emotions

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KEYWORD	ABSTRACT
Agent; Trust; Emotions; Multi-Context System	*Open multiagent systems are those in which the agents can enter or leave the system freely. In these systems any entity with unknown intention can occupy the environment. For this scenario trust and reputation mechanisms should be used to choose partners in order to request services or delegate tasks. Trust and reputation models have been proposed in the Multiagent Systems area as a way to assist agents to select good partners in order to improve interactions between them. Most of the trust and reputation models proposed in the literature take into account their functional aspects, but not how they affect the reasoning cycle of the agent. That is, under the perspective of the agent, a trust model is usually just a "black box" and the agents usually does not take into account their emotional state to make decisions as well as humans often do. As well as trust, agent's emotions also have been studied with the aim of making the actions and reactions of the agents more like those of humans being in order to imitate their reasoning and decision making mechanisms. In this paper we analyse some proposed models found in the literature and propose a BDI and multi-context based agent model which includes emotional reasoning to lead trust and reputation in open multiagent systems.*

1. Introduction

Computer systems are becoming large, open, dynamic and distributed systems, containing a large number of agents who act in their own interests (Teacy et al., 2006). According to this context, open multiagent systems are those in which the agents can enter or leave the system freely. In these systems any human or software agent with unknown intentions can join the society of agents in the system and interact freely by asking each other to perform tasks or offering services. For this scenario trust and reputation mechanisms should be used to choose partners in order to request services or delegate tasks.

In an Open Multiagent System, it is very difficult for an agent to check whether other individuals who recently

entered the system are trustworthy, because usually there is not enough information about it. Trust and reputation models have been proposed in the Multiagent Systems area as a way to assist agents to select good partners, providing reliable information to help the decision making of the agent, in order to improve interactions between them (Teacy et al., 2006; Sabater and Sierra, 2001; Sabater and Sierra, 2005). Using trust and reputation in these systems is essential for effective interactions among agents (Dong-Huynha et al., 2004).

The study and modelling of trust have attracted the interest of researchers in various fields such as psychology, sociology, philosophy and economics. Trust has great importance in social and commercial relationships (Ostrom, 1998) and, for Computer Science, the interest is primarily in Multiagent Systems. However, most of the trust and reputation models for Multiagent Systems proposed in the literature take into account their functional aspects, but not how they can affect the reasoning cycle of the agent. For this approach, under the perspective of the agent, a trust model is usually just a "black box" and the agents usually does not take into account their emotional state to make decisions as well as humans often do. As well as trust, agent's emotions also have been studied with the aim of making the actions and reactions of the agents more like those of humans being in order to imitate their raisoning and decision making mechanisms.

Most models of trust and reputation adopt an essentially numerical approach (Lu et al., 2009), not taking into account the complexity of humans' reliance on each other. For humans, emotions directly influence the act of trust. This requires a subjective evaluation of trust. Furthermore, most of the models presented in the literature determine the relevance of the information through some metrics obtained from other agents to be used in the measurement of trust, becoming the action of trust dissociated from the personal history and from the context in which the agent is embedded.

Moreover, the BDI and E-BDI approaches have been consolidated in the multiagent system development methodologies as robust architectures of practical reasoning. According to the BDI model, *beliefs* represent the agent's knowledge about the world, *desires* are the agent's motivational state, and *intentions* constitute its deliberative component (Rao et al., 1995). The E-BDI model adds an emotional component to BDI, which can influence in several stages of the reasoning, since perceptions until internal states of the agents (Puică and Florea, 2013; Côrtes, 2013; Jiang et al., 2007).

In open BDI-multiagent systems, the success in achieving goals and fulfilling desires mainly depends on interaction with other agents. Therefore, communication and choosing partners are fundamental skills. The choice of partners is usually based on a measure of trust between agents but most of trust and reputation models ignore emotions when deciding which agent to interact.

In this paper we analyse some proposed models found in the literature and propose a trust model and a BDI and multi-context based agent model which includes emotional reasoning to lead trust and reputation in open multiagent systems. First we present a trust model named TrustE, which uses information of a symbolic nature directly related to the context in which the agent is embedded. Such information induces sensations or emotions that allow the agent to associate qualitative or subjective evaluations to the quantitative or rational evaluations, depending on the result of introspection on situations experienced by the agent. Further up we present an agent model as a multi-context system that integrates emotions and trust in a BDI model, in order to have trust as part of the reasoning cycle of the agent. Emotions also take a central role, composing impressions about events and interactions. These impressions become beliefs and are used in the trust processes. In this sense, emotions influence and are influenced by beliefs and consequently, all reasoning cycle of the agent is affected by them.

This paper is organised as follows. Section 2 presents an overview of BDI Agents, introduces the concept of emotions in agents and some models of emotions in agents and introduces trust and reputation models in the context of agents and presents some multi-context models found in the literature that are slightly related with our proposal. Section 3 presents the hybrid TrustE model which combine symbolic and numerical information to deal with emotions and trust. In Section 4 we present the proposed architecture of the multi-context based agent model, detailing its components and presenting the bridges rules that integrated them. In Section 5 we discusses

some evaluation scenarios of application and finally Section 6 presents some final remarks.

2. Background

In this section we bring some highlights about agents, multiagent systems, emotions and trust models in agents, and about multi-context systems, that will be useful to understand our approach.

Artificial Intelligence (AI) is the research field of Computer Science most akin to Social Sciences. The most pursued research goal of this field is create computer systems that play intelligent behaviour. However, it is not possible to ignore that this task requires the analysis of the phenomena related to human cognition and to human subjective experience or emotions. The approach carried out by Cognitive or Symbolic AI to handle this issue analyzes and proposes cognitive and social models that present viable computational interpretations, epistemological and psychological foundations, and formal specifications. The most current approaches to research in AI use the concept of Agent and Multiagent Systems (MAS) for modeling individual and social behavior. To this point of view, the design of intelligent systems starts from a strong notion of agency and deal with the problem of achieving the desired high-level properties as integral part of the modeling and design process.

2.1 Agents and Multiagents Systems

The Agents are basic autonomous elements of computation and Multiagent systems (MAS) are systems composed by a set of agents working together. There are several different definition of the notion of an agent found in the literature. Jennings (Jennings, 2001) for example, as well as Wooldridge (Wooldridge, 2009) assume, to the design purpose, that an agent is a computational process situated in an environment, which is designed to achieve a purpose in this environment through an autonomous and flexible behaviour. The environment is the application domain where the agent works to achieve its purposes. In a deeper and more comprehensive definition, a software agent is regarded as an entity that operates continuously and autonomously in a particular environment, usually inhabited by other agents, able to work in its environment, flexibly and intelligent, without requiring intervention or continuous human guidance. Ideally, an agent that works continuously for long periods of time, should be able to learn from its own experience and, if he shares the environment with other agents, should be able to communicate and cooperate with its partners, and, sometimes, moving from one location to another.

Franklin and Graesser (Franklin and Graesser, 1996) and Jenning and Wooldrige (Wooldridge and Jennings, 1995) point out some important features to an agent and theses features are important according to the context of the agent and its role in the system:

- Autonomy: an agent is capable to work without direct human intervention according to its own internal state and control;

- Social skill: an agent is capable to interact with other agent as partners aiming its own goals;

- Reactivity: an agent must perceive and react to any alteration in the environment

- Proactivity: an agent have not only react to external facts but also take control of the actions to achieve its goals

According to symbolic approach of Artificial Intelligence, the purpose of an agent can be fully specified by the definition of its beliefs and desires, and the behaviour of any agent is implied by its intentions. This is the BDI (Beliefs, Desires and Intentions) cognitive model (Bratman, 1987).

Beliefs represent provisional knowledge of the agent. The agent's knowledge can change any time to define what the agent knows about the world. Agents can update its beliefs to reflect changes detected in the environment. *Desires* specify the set of state of belief which the agent eventually wants to bring about. The cognitive model of agents supposes that the purpose of the agent is explicitly stated as the set of highest-priority desires of the agent. The action of the agent is driven by *intentions* that are characterized by a choice of a state of affairs to achieve, and a commitment to do this choice (Cohen and Levesque, 1990a) (Cohen and Levesque, 1990b) . The agent will choose those desires that are possible, according to its beliefs. The relationship of the agent with the world is performed by actions and perceptions. An action is change caused directly by the agent. Therefore, the agent should know (believe) the effects produced by its actions and what are the relations of these actions to their intentions.Changes in the environment occurs regardless of the agent or in response to some actions executed by the agent or by other agents. So, agent's perceptions produce updating in the base of beliefs of the agent. However, the exact update produced by a particular perception depends on the current state of beliefs of the agent.

Several architectures for building agents based on BDI model have been proposed. One of the main examples of BDI architecture is the PRS (Procedural Reasoning System) (Georgeff and Lansky, 1986). This pioneering architecture was the basis for others like A-PRS, C-PRS, AgentSpeak (L), dMARS and JAM. According to the PRS architecture, the agent has explicit representation of data structures that correspond slightly to beliefs, desires and intentions, as well as a precompiled library plans (Wooldridge, 2009).

According to Baker (Baker, 1997), a multiagent system is a loosely coupled network troubleshooters working together to solve problems that go beyond their individual capacity. These troubleshooters are essentially autonomous, distributed and, often heterogeneous in nature.

The theoretical basis of multi-agent systems can be understood as a society of heterogeneous agents, based on a strong social interaction of individuals who live together and interact with each other to achieve common and individual goals. According to this view, an agent is seen as an autonomous individual, with capabilities that are inherent to the performance of its functions and the achievement of its objectives. An agent society shares a common world, and each member of this society has different goals and views, often creating some conflicts. These conflicts should be negotiated and resolved between agents, and should be committed to a joint plan. This plan is a set of commitments to actions and beliefs shared between actors at different levels of abstractions.

According to Torsun (Torsun, 1995), to achieve common goals, a society of agents, should be made by elements able to perform the following functions:

- Cooperation.

- Conflict resolution.

- Negotiation.

- Commitment.
- Interaction.

- Communication

It is very important to coordinate the behavior of agents and the manner in which they share their knowledge, goals, skills, and their plans to jointly take the necessary actions to solve a problem. So that different autonomous agents can cooperate with each other to achieve their goals it is necessary for society to have organization and communication. The organization refers to the nature and function of society and its constituent elements and communication is the main tool that agents use to develop the coordination of their actions.

When an agent joins in a society, two types of problems are identified for that this new agent can adapt to this society: the problem of language and interaction and the problem of knowledge and expertise. The first refers to the use of appropriate expressions and how interactions are organized in society, while the second refers to what role the agent should play and what role it should wait for the other agents, society members, play. In open Multiagent Systems, containing a large number of agents who act in their own interests (Teacy et al., 2006), it is very difficult for an agent to check whether other individuals are reliable or not. So, trust and reputation control needs to be used by the agents to select good partners (Teacy et al., 2006; Sabater and Sierra, 2001; Sabater and Sierra, 2005) and trust and reputation models are essential (Dong-Huynha et al., 2004).

2.2 Trust Models for Agents

Castelfranchi and Falcone (Castelfranchi and Falcone, 2010), claims that it is crucial to distinguish between trust as a psychological attitude and trust as the act and decision of relying on someone or something. The former is related with the desired behavior and the latter is related to dependency. Trust as an attitude can be thought of a part as the trust as a decision/action, i.e., it can be seen as an antecedent of the latter.

The literature presents several models of trust, addressing different aspects. These approaches can be grouped according to different criteria:

- use of cognitive or numeric approach;

- reasoning on different information sources: direct interaction, direct observation, witness information, sociological information, etc.;

- being context-sensitive or not: if it takes into account lying agents;

- acquisition and information sharing.

Besides that, we can consider several additional characteristics, like:

- memory and relevance - trust is built over time, over several interactions, and may emphasize more recent interactions;

- credibility - willingness to believe in an information source;

- reliability - analysis between information from direct interaction and information from other agents.

Emotional influence can, additionally be used in numerical and cognitive trust models. Emotional influences on the decision of an agent may determine that it take a different decision he could take if considering only rational decision about to trust or not some other agent

Among several trust and reputation models proposed in the literature (Lu et al., 2009), we can highlight the Marsh's model (Marsh, 1994), which considers only the trust dimension and the Spora model (Zacharia et al., 2000), which considers only the reputation dimension. Despite of the definition of trust and reputation remain unclear, some of them blend this two approaches: the Regret model (Sabater and Sierra, 2001), the Referral Network (Yu and Singh, 2003) and the Travos models (Teacy et al., 2006) take into account both trust and reputation, combining these values to get degree of trustness. Beside these proposed models, the Fire model introduces two additional concepts: role-based trust and certified reputation (Dong-Huynha et al., 2004).

Among these models, Regret was chosen as the base for the TrustE model (presented in Section 4), and the multi-context based agent model (presented in Section 5) because we found that it possesses some characteristics that allow us to easily incorporate symbolic evaluation to include emotions to the decision-making process of the agent about trust. In the sequence we present some details about the Regret model.

2.2.1 Regret

In this model, reputation is seen as the opinion or point of view of an agent about something, being formed and updated over time through interactions with other agents in the system. Interactions consequently provide *impressions* that are recorded by the agents and reflect how they evaluate their experiences with their partners. Reputation in this sense is more subjective, because each agent can possesses different opinion about the others (Sabater and Sierra, 2001).

The outcome o_b of an interaction related to a business transaction between two agents *a* and *b*, from the viewpoint of the agent buyer *b*, could be:

$$o_b = \quad (DeliveryDate =_c 10/02 \wedge Price =_c 2000 \wedge$$
$$Quality =_c A \wedge DeliveryDate = 15/02 \wedge Price$$
$$= 2000 \wedge Quality = C)$$

In this example, the variables with the subscript *c* represent the initial agreement, i.e, the contract between the two agents. Thus agent *b* expected a good quality product (A) but received a poor quality product (C), and received it five days late.

The model uses the term Individual Reputation (IR) to represent the direct trust between two agents, and Social Reputation (SR) to represent the reputation itself. The decentralised approach implemented by this model allows each agent to calculate the IR and SR from another agents, and to use both IR and SR, or just one of them to reach a final result.

Social Reputation takes into account three sources of information:

- the interaction of the agent *a* (trustor) with members of the group to which agent *b* (trustee) belongs, expressed by $R_{a!B}(')$, as presented in equation 1;

- what the members of group *A* (the group of the agent *a*) think about agent *b*, denoted by $R_{A \to b}(\varphi)$, as presented in equation 2;

- what the members of group *A* think about the other group *B*, denoted by $R_{A!B}(')$, as presented in equation 3.

$$R_{a \to B}(\varphi) = \sum_{b_i \in B} \omega^{ab_i}.R_{a \to b_i}(\varphi) \tag{1}$$

$$R_{A \to b}(\varphi) = \sum_{a_i \in A} \omega^{a_i b}.R_{a_i \to b}(\varphi) \tag{2}$$

$$R_{A!B}(') = \sum_{a_i 2A}^{a_i B} .R_{a_i!B}(') \tag{3}$$

where $'$ is the item from the outcome under consideration. These three values are combined with the agent's IR, denoted by $R_{a!b}(')$, to calculate the final value of trust, represented by, $SR_{a!b}(')$ as presented in equation 4.

$$SR_{a!b}(') = \breve{}_{ab}.R_{a!b}(') + \breve{}_{aB}.R_{a!B}(') + \breve{}_{Ab}.R_{A!b}(') +$$
$$\breve{}_{AB}.R_{A!B}(') \tag{4}$$

where $\breve{}_{ab} + \breve{}_{aB} + \breve{}_{Ab} + \breve{}_{AB} = 1$, representing the importance of each information's source to the trustor agent. These values are application dependent, i.e., they are chosen during the project of the system.

This characteristic allow us to incorporate the results of some symbolic evaluation, i.e. emotions. In this sense, we proposed that those values can be determined by the internal state of the agent, simulating an emotional state.

Next subsection presents concepts of emotions of agents which form the basis for the proposed models presented in Section 4), and Section 5)

2.3 Emotions

The study of emotions is part of various disciplines like Psychology, Economics, Cognitive Neuroscience, and, in recent years, Artificial Intelligence and Computer Science. These studies aims to establish systems for emotional interaction, such as robots with emotional behaviour and virtual agents for entertainment (Lorini, 2008). Nowadays more and more artificial agents integrate emotional skills to achieve expressiveness, adaptability and credibility (Adam et al., 2006). In psychological studies, the emotions that influence the deliberation and practical reasoning of an agent are considered as heuristics to prevent excessive deliberation (Steunebrink et al., 2007a).

Including emotions in computational systems is manyfold. the improvement of human-machine interaction, testing, refining and developing emotional hypothesis or even the improvement of artificial intelligence techniques, once it optimizes decision-making mechanisms (Marsella et al., 2010).

Appraisal theories (Scherer, 1999) are often used as computational models of emotions. Models as WASABI (Becker-Asano, 2008), FLAME (El-Nasr et al., 2000) and EMA (Marsella and Gratch, 2009) are examples of computational models of emotions that use appraisal theories. According to them, the elicitation and differentiation of emotions can happen through one's subjective appreciation from a situation, object or event. Besides the development of computational model of emotions, there is also research interest in integrating these models in agents. The aims of these works is to make emotions affect the agent's behavior; for example, affecting the beliefs and the agent's perception of the world.

The following section describes the OCC emotions model (Ortony et al., 1990). This model is widely used by Artificial Intelligence researchers who are developing systems for reasoning about emotions or that incorporate emotions in artificial agents (Adam et al., 2006; Steunebrink et al., 2009).

2.3.1 OCC Model

The psychological model of emotions proposed by Ortony, Clore and Collins (OCC) (Ortony et al., 1990), classifies 22 types of emotions, both positive and negative. The quantitative aspects of emotions are described in terms of *potentials*, *thresholds* and *intensities*. For each of 22 emotions, the model provides a list of variables that affect the intensity of the emotion and if the condition which causes the emotion is guaranteed.

The OCC hierarchical model has three branches, each representing an evaluation of a different type of stimulus for certain actions and an evaluation of a determined variable. These branches are subdivided into groups of emotions caused by similar conditions, and are classified as:

- Event-based emotions (e.g. joy, pity)

- Agent-based emotions (e.g. pride, shame)

- Emotions Based on Aspects of Objects (e.g. love, hate).

The three branches of the model are described below. We pay greater attention to event-based emotions and agent-based emotions since they are essential in modelling emotions in agents and are strongly related to events and the agents' own actions. Object-based emotions are only mentioned in brief, since they are not as significant as other two types of emotions (Adam et al., 2006).

Event-based Emotions: The emotions in this branch are induced from the evaluation of an event with respect to the agent's goals. The *desirability* of the event occurring or not is the main variable of intensity of this kind of emotion. The agent will only want events to occur if they assist with its goals. Thus, if the event occurring is desirable for the agent it will feel positive emotions; otherwise it will feel negative emotions. This branch is subdivided into:

- Well-being emotions - triggered according to the desirability of the agent itself, that is, it is a feeling that only depends on the desire for a certain event to occur. Example: The agent felt joy about winning money.

- Prospect-based emotions - focused on the desirability of the agent itself in an expected event (uncertain) that could happen. This type of emotion uses a local variable of intensity- *likelihood* - which represents the probability of the event happening. Example: The agent hopes to make money.

- Fortunes-of-others emotions - derive from the supposed desire for another agent. These emotions utilise three local variables of intensity: *desirability for others*, *merit* and *liking*. The *desirability for others* is the evaluation of the desirability of the event to the other, *merit* represents how much agent *a* believes that agent *b* deserves what happened and *liking* represents the attitude of agent *a* relative to agent *b*. Example: Agent *a* became resentful because the agent *b* had lost its money.

Agent-based Emotions: These emotions are based on the judgment of the praiseworthiness of an action in relation to 'moral standards': that is, an action is praiseworthy when it follows the standards. The emotions of this group refer to both the agent's own action and the action of another agent.

- Attribution emotions - focused on the approval of the action of an agent. In this type of action there are two local variables of intensity, *strength of unit* and *expectation deviation*. The first applies the agent's own emotions to represent the degree to which the agent identifies with the author of the action. The second is the degree to which the action performed differs from what is normally expected, according to the social role. Example: The agent felt ashamed about stealing money.

Emotions Based on Aspects of Objects: The last branch considers mainly emotions related by the attraction that an agent feels by something or someone. This kind of emotion has only one local variable of intensity: *familiarity*. According to the OCC model, the more familiar a pleasing object is to the agent, the more the agent will love it, and in turn the more familiar is an unpleasant object, the more the agent will hate it. Example: Agent *a* loves agent *b*.

Additionally, some of these branches can be combined to form a group composed of emotions, based on the result of events and actions. Well-being emotions and attraction emotions can be combined, resulting in complex emotions. Example: Agent *a* felt gratitude to agent *b* because it returned its lost money.

2.3.2 Emotion Models for Agents

In Artificial Intelligence research, emotions have begun to receive more attention, and are more prominent in interactions between humans and machines focusing on expressing or feeling emotions. Recent works investigate the reasoning of common sense, but research on the application of emotions by decision making in agents is still very limited. The complexity of modelling the emotional behaviour of the human being in artificial agent is yet the biggest barrier (Jiang et al., 2007). To overcome this limitation, some researchers have worked on the development of logical structures for formal specification of emotions (Lorini, 2008; Adam et al., 2006; Steunebrink et al., 2007a; Dastani and Meyer, 2006; Meyer, 2006; Turrini et al., 2007).

In the great majority of these works, emotions are modeled in a qualitative way; however, some authors suggest a quantitative approach to emotions, that is, through the assignment of numerical values to emotions' intensity, e.g.,(Steunebrink et al., 2007b).

In this paper, we consider the introduction of numerical values representing the intensity of the emotions in the Regret Model. Despite of its qualitative nature, emotions are mapped to quantitative values that will compose the trust and reputation calculi. In the next section we present the Steunebrink's model that will be the basis for the TrustE model.

2.3.3 Steunebrink's Model

In order to formalise the 22 types of emotions present in the OCC model, Steunebrink at al. (Steunebrink et al., 2009; Steunebrink et al., 2007b) started by identifying ambiguities in the logical structure. These ambiguities were removed and some changes were consequently made to obtain a computational framework to emotion. This framework is based on inheritance and is present in Figure 1.

One of the major changes in the structure of the OCC model was the hierarchy had an explicit inheritance, with labels at each point of the hierarchy and each child node was a superset of its parent nodes. From this new structure were created new specifications of types of emotions. Analyzing the model hierarchy, we note that the feelings of begin pleased and displeased, approving, disapproving, liking and disliking are the basis for all other emotions.

Emotions Intensity   The intensity of an emotion is defined by subtracting the *threshold* of its *potentiality*. The *threshold* refers to the minimum value needed for the emotion to have some intensity and therefore interfere with an agent's behaviour. In turn, the *potentiality* of an emotion depends on the list of variables which affect it. The larger the *potentiality* of the emotion, the greater the chances of it occurring.

The OCC model does not specify how to calculate the *thresholds* of emotions, but it is believed that they depend on global variables indicating the mood of the agent (Steunebrink et al., 2007b). For example, if an agent is in a cheerful mood, the thresholds of negative emotions increase, causing a decrease in the intensity of this emotions. When the necessary condition to trigger an emotion is present, but its *potentiality* is below its *threshold*, an agent can recognize that the emotion was triggered but it will have no affect: for example, 'the mood of the seller agent was so good that even though it sold a shoddy product, it was not affected by shame'. The *intensity* of an emotion is calculated from the *intensity function*, which is composed of *function potentiality* and *function threshold*. The way these functions are calculated is application-dependent; however, in general, the *intensity function* can be expressed as:

$$I(P(E), L(E), t) \,!\, \mathbf{R}^+ \tag{5}$$

where $P(E)$ is the *function potentiality* of emotion E, $L(E)$ is the *function threshold* and t is the current time. As a result, the function returns a positive real, including 0 (zero), representing quantitatively the intensity of the emotion. Section 3.1.2 presents how these values could be calculated in the TrustE model.

2.3.4 Wasabi Model

In Appraisal theories the elicitation and differentiation of emotions are made through the evaluation or subjective individual assessment considering a situation, object or event (Scherer, 1999). In dimensional theories, emotions and other affective phenomena are viewed as points on a continuum dimensional space (Marsella et al., 2010). Although there are other, these two are the most common in computer models of emotions. While the OCC model proposed by Ortony, Clore and Collins (Ortony et al., 1990), used Appraisal Theories by ranking 22 emotions into
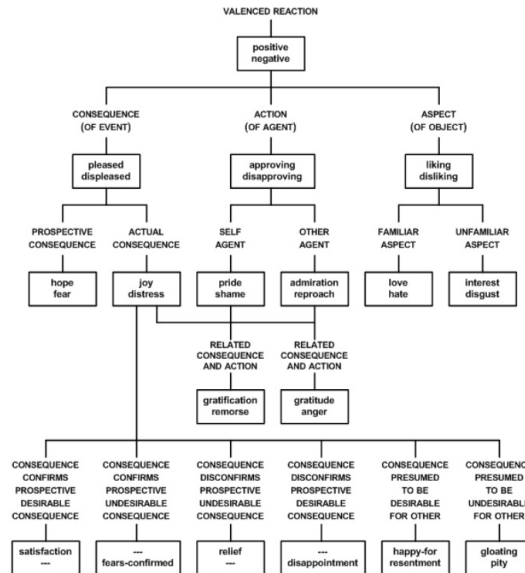
Figure 1: Hierarchy based on inheritance of emotions from Steunebrink et al (Steunebrink et al., 2009)

three groups: event-based, agent-based and based on aspects of objects (Ortony et al., 1990), the most significant representatives of Dimensional Theories, the model of emotional states PAD (Pleasure-Arousal-Dominance), is composed of three independent and bipolar axis representing Pleasure, Arousal (activation) and Dominance (Russell and Mehrabian, 1977) (Mehrabian, 1996). The first component, pleasure / non-pleasurable corresponds to the evaluation judgments, the higher the rating, the more pleasurable. The second component, activation /deactivation, is the level of activity. And the third component dominance / submissive is a measure of control, or power

   The WASABI model (Becker-Asano, 2008) (Becker-Asano, 2014), presents emotions as states with specific quality and intensity that are the result of a communication process. Emotions can be positive or negative valence and last significantly less than mood. Mood is modeled as a background state with an affective quality much simpler than emotions.Although they have different meanings, emotions, mood, and influence each other. According to this model, the agent has a homeostatic state. Whenever an emotional stimulus, internal or external, is detected, its valence serves as an impulse that disturbs this homeostatic state of emotional balance agent, causing certain levels of pleasure and emotional activation in the module. In addition, a dynamic process begins, in order to back the emotional balance of the agent.

2.4 Multi-Context Systems and Agents

A Multi-context system (MCS) provide a framework to allow several distinct theoretical components to be specified together, with a mechanism to relate these components (Giunchiglia and Serafini, 1994).

Definition 1 (Agent as a Multi-Context System (Casali et al., 2005)) *In a multi-context approach, an* agent *is an ordered pair*

$$h\{C_1, C_2, \ldots C_n\}, \Delta_{br}i$$

where $\{C_1, C_2, \ldots C_n\}$ is a set of contexts, indexed by natural numbers and Δ_{br} is a set of bridge rules. Each context C_i is a tuple

$$\langle L_i, A_i, \Delta_i \rangle$$

where L_i is a language, A_i is the axioms set and Δ_i are the inference rules.

To illustrate the MCS dynamics, let C_1 (Beliefs), C_2 (Desires) and C_3 (Planner) be contexts, and ′ and formulae deductible from C_1 and C_2, respectively. With the bridge rule 6, the formula is added to the context C_3 (Casali et al., 2005).

$$\frac{C_1 : \varphi, C_2 : \psi}{C_3 : \theta} \tag{6}$$

As noted by Sabater, Sierra and Parsons (Sabater et al., 2000), the use of MCS in agents is advantageous in terms of both software engineering and logical modeling. From the software engineering perspective, it helps in encapsulation and modular decomposition. Every architectural component — functional component or data structures — may be represented as a data context that may be reused by another context. From the logical modeling perspective, the division in contexts simplifies the conceptual definition of the agents and increases the representation power of logical agents. Looking BDI agents as MCSs means that beliefs, desires and intentions as well as communication interface are contexts. In the proposed approach, the BDI-*like* agent is a MCS.

2.5 Related Work

In this section we describe some interesting works that either relate trust and reputation with MCS, or relate emotions and trust.

Pinyol and Sabater (Pinyol and Sabater-Mir, 2009) integrate the reputation model Repage (Sabater et al., 2006) in a BDI agent through a MCS. Repage is based on a cognitive theory of reputation and makes distinction between *image* and *reputation*. Image is an own evaluative belief that tells whether the target is *good* or *bad* according to a context (or role). Reputation is a meta-belief about the existence of an *told* evaluation. A social evaluation is composed by: the target, the role of the target, and a probability distribution over a set of labels. In the BDI+Repage agent, each attitude (belief, desire, intention) is represented as a context and one context is used for the Repage model. Additionally there are two functional contexts, namely communication and planner.

The work proposed by Koster, Schorlemmer and Sabater (Koster et al., 2012) also uses a MCS and the BDI agent is capable to reason about its trust model, and proactively adapt it. The use of BDI in this context is justified by the clear definitions of the agent's beliefs and goals. Thus, the trust role can be explicitly incorporated into the logical framework. The authors consider two properties for trust models: trust is a computational process with a functional nature; and a trust model must have at least one parameter whose change predictably alters the output of the trust model. These parameters are used by the agent to adapt its trust model. They add three reputation models to BDI agents: BRS (Commerce et al., 2002), ReGreT (Sabater-Mir, 2002) and ForTrust (Herzig et al., 2010), but others trust models can be incorporated in the agent. In this work, they define contexts to represent beliefs, desires, intentions, interaction and planner. Beside these, two contexts are add: one for priority rule, where the agent adapt its priorities; and one with the set of priorities for each parameter of the trust model.

In the work of Bosse and Höhle (Bosse and Höhle, 2011), trust and emotions are mental states added to a BDI agent. The model is described in a modeling language based on LEADSTO (Bosse et al., 2005). Emotions are generated according to appraisal theories; that is, based on analysis of events related to the agent's goals or desires. The intensity of emotions is represented in the interval [0, 1]. The work also models mood; it lasts longer than emotions and its triggering is not necessarily linked to a specific event. Mood is also represented in the interval [0, 1]. The impact of emotions in beliefs, desires and intentions is based on rules. rust is based on beliefs on the agent's capabilities.

3. TrustE: An Emotional Trust Model for Agents

3.1 TrustE Model

The TrustE model proposed in this work adds emotions to calculation of trust and reputation for agents. All models found in the literature make use of algebraic analysis to determine the act of trust, which makes such models essentially mathematical and disconnected from the agent's history. The proposed TrustE model permeates the trust model with estimates derived from symbolic reasoning, making the act of trust more dynamic and dependent on the agent's history.

The incorporation of emotions in trust models can be done in several ways; however, we chose to incorporate emotional factors in the Regret model (section 2.2.1), once (i) this model mixes both Individual Reputation and Social Reputation to obtain a final measure of trust; and (ii) this model uses weights noted by ˇ and !(see equations 1 - 4) that are defined by the programmer and are application dependent. These values are good candidates to represent *emotions' intensities* of the agent, going to be updated in run time.

By its nature, the process of trust should result in a numerical value. Therefore, emotions intensities are aggregated to the model as numerical values representing the strength of emotions at a given time *t*. This allows the model to accept each of the 22 existing emotions in OCC model (section 2.3.1), requiring only the qualitative and quantitative aspects of each of the emotions to be modelled. The qualitative aspects can follow the same ideas as the models proposed by (Lorini, 2008; Adam et al., 2006; Steunebrink et al., 2007a; Dastani and Meyer, 2006; Meyer, 2006; Turrini et al., 2007) or be adapted according to the needs of each system. Quantitative aspects are obtained from each emotion, which is calculated from an *intensity function* (see equation 5), and can follow the concept presented in (Steunebrink et al., 2007b) or be reformulated according to the application's needs. This flexibility is a key feature of the proposed model.

Figure 2 shows the TrustE Model. Two blocks compose the coalition between trust and emotions. The *trust model* (*TM*) is responsible for calculating the Individual Reputation (*IR*) and Social Reputation (*SR*), which together will result in the trust final value (TV). The *emotions model* (*EM*) contains the emotion's intensity functions, denoted by *I*(*E*), and agents' emotion memory (*AEM*). Each agent has its own *AEM* where all current emotion intensities of the agent are stored.
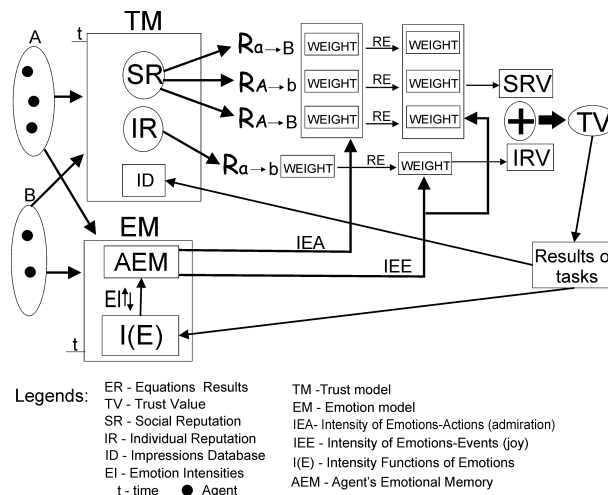

Figure 2: The TrustE Model

As presented in section 2.2.1, the Regret model has four values which form the final trust, represented in Figure 2 by $R_{a!b}$, $R_{a!B}$, $R_{A!b}$ and $R_{A!B}$. The first weight used in the calculation of RI, i.e.$R_{a!b}$, is the same as that used in Regret, which assigns higher values to the ratings given recently by trustor agent. Already the first weights in SR $R_{a!B}$, $R_{A!b}$ and $R_{A!B}$, are calculated from the *Intensity of Emotions triggered by Actions* (*IEA*). This group of emotions involve the emotions that are based on the judgment of an action's praiseworthiness, i.e, *agent-based emotions* in OCC model. So it is possible that each agent can evaluate the other taking into account the emotions related to each of them. After calculation of these four R values, they are combined to form the *Trust Value* (*T V*). The weights used in this part of the computation take into account the *Intensity of Emotions triggered by Events* (*IEE*), that are related with the evaluation of an event with respect to the agent's goals, i.e. *event-based emotions* in OCC model. This group of emotions is not directly related to any specific agent but are the events that change the emotional state of the agent.

3.1.1 Formalisation of Emotions

As introduces above, emotions in the TrustE model are divided in two groups: *Emotions triggered by Events* and *Emotions triggered by Actions*. For each one of these groups we choose a set of four kinds of emotions from the OCC model. They are:

- Emotions triggered by Events: *hope*, *fear*, *joy* and *distress*.

- Emotions triggered by Actions: *pride*, *shame*, *admiration* and *reproach*.

The formal modelling of these emotions has been simplified to suit the model and make calculating of the *intensity* of each of these emotions easy. The following will be presented qualitative formalisation of these emotions taking into account certain adjustments made in OCC model 2.3.3. Let *a* and *b* be agents, *X* an event, *Y* an action, *positive* a positive reaction in relation to something, and *negative* a negative reaction in relation to something.

- $Action_a(Y)$: an action *Y* performed by *a*.

- $Prospective(X)$: an event *X* which is prospective.

- $Actual(X)$: an event *X* which is actual.

- $Pleased_a(X)$: *a* is *positive* about a consequence of *X*.

- $Displeased_a(X)$: *a* is *negative* about a consequence of *X*.

- $Approving_a(Y)$: *a* is *positive* about an action *Y* of some agent.

- $Disapproving_a(Y)$: *a* is *negative* about an action *Y* of some agent.

Emotions triggered by Events: These emotions are felt by the agents depending on the occurrence of a certain event and are independent of the actions of other agents. For this reason they were introduced in the TrustE model (see Figure 2) from the functions' values *IEE*.

The emotions in this set are defined as (where the syntax has the usual meaning):

$$Hope_a(X) \ \$ \ Pleased_a(X) \ ^\wedge \ Prospective(X) \tag{7}$$

An agent feels hope if it is pleased about the expected event. Example: *The agent expects that the product purchased will be of good quality*.

$$Fear_a(X) \ \$ \ Displeased_a(X) \wedge Prospective(X) \tag{8}$$

An agent feels fear if it is displeased about an expected event. Example: *The agent was afraid of not receiving the purchased product*.

$$Joy_a(X) \ \$ \ Pleased_a(X) \wedge Actual(X) \tag{9}$$

An agent feels joy when it is pleased about an actual event. Example: *The agent was happy to have received the product before the stipulated time*.

$$Distress_a(X) \ \$ \ Displeased_a(X) \wedge Actual(X) \tag{10}$$

An agent feels distress when it is displeased about an actual event. Example: *The agent was distressed by the poor quality of the product received*.

Emotions triggered by Actions: These emotions are felt by agents as a result of actions taken by other agents. For this reason they were introduced in the TrustE model (see Figure 2) from the functions' values *IEA*. The emotions in this set are defined as:

$$Pride_a(Y, a) \ \$ \ Approving_a(Y) \wedge Action_a(Y) \tag{11}$$

An agent feels pride if it approves of its own action. Example: *The agent was proud of having sold a high-quality product*.

$$Shame_a(Y, a) \ \$ \ Disapproving_a(Y) \wedge Action_a(Y) \tag{12}$$ An

agent feels shame if it disapproves of its own action. Example: *The agent felt ashamed of having delivered the product late*.

$$Admiration_a(Y, b) \ \$ \ Approving_a(Y) \wedge Action_b(Y) \tag{13}$$ An

agent feels admiration towards another agent if it approves of this agent's action. Example: *The agent was stuck by the honesty of the seller*.

$$Reproach_a(Y, b) \ \$ \ Disapproving_a(Y) \wedge Action_b(Y) \tag{14}$$

An agent feels reproach towards another agent if it disapproves of this agent's action. Example: *The agent deplored the fact that the seller agent did not answer your questions*.

The following section explains the *intensity function* used in the TrustE model.

3.1.2 Emotion Intensity in TrustE

To model the emotion intensities in TrustE, we chose a simple e effective equation as follows:

$$I_a(E, t) = max(0, P_a(E, t) - L_a(E, t)) \tag{15}$$

Where $I_a(E, t)$ is the *intensity function* of emotion E of the agent a at time t; E could be one of the eight emotions as presented before (however any of the 22 emotions of the OCC model could be used); $P_a(E, t)$ is the *potentiality* of E; $L_a(E, t)$ the *thresholds* of E and t the current time.

The value of intensity of emotions triggered by events of agent a at the current time will be denoted by $I_a(E)$ and the value of intensity of emotions triggered by actions of agent a in relation to agent b will be denoted by $I_a(E_b)$.

The values of $P_a(E, t)$ and $L_a(E, t)$ are recalculated each time E is triggered again, so these values does not persist over time. The value of $I_a(E, t)$ persists over time and tends to decrease or increase over it, until to stabilise in the default value. To support the temporality of the value of $I_a(E, t)$, each agent must have a memory (*AEM*) that stores the values of each of the emotions felt by it.

The *function potentiality $P_a(E, t)$* is calculated using the formula:

$$P_a(E, t) = \frac{\sum_{i=1}^{N} V I_i}{N} \qquad (16)$$

where $V I \in [0, 1]$ are the values of the variables that affect the *intensity* of emotion E and N is the number of variables.

To fit the model we assigned the function $L_a(E, t)$ values in the range $[0, 1]$ representing the 'emotional profile' of agent a. Agents in a 'cheerful mood' have a lower *threshold* value for positive emotions and a higher one for negative emotions, and an agent in a 'bad mood' will have a higher value for positive emotions and a lower one for negative emotions. Thus, an agent in a 'cheerful mood' will feel positive emotions with greater ease than an agent in a 'bad mood'.

Since the values of $P_a(E, t)$ and $L_a(E, t)$ are in the range $[0, 1]$, the function $I_a(E, t)$ also has values in the range $[0, 1]$.

3.1.3 Conceptual View

Figure 3 shows a conceptual view of TrustE model where the flow of actions of agents is presented. To explain the model let us create a scenario in which agent a wants to buy a good quality (A) product from agent b, taking into account the characteristics presented in Table 1. To simplify the example, the values of *threshold* and *potentiality* are fixed.

Table 1: Characteristics of agents.

Characteristics	Agent a	Agent b
mood	bad	cheerful
time t	0	0
potential-positive emotions	0.5	0.7
potential-negative emotions	0.8	0.4
threshold-positive emotions	0.8	0.1
threshold-negative emotions	0.2	0.9
good quality product	A	A or B
I(*joy*)	0.5	0.5
I(*reproach*)	0.5_b	0.5_a
I(*fear*)	0.5	0.5

Agent a chooses a sales agent from all existing sellers (step 1). To decide whether or not to buy the product from b, it will calculate the trust in b (step 2). If the trust value is low, a will look for another sales agent; if
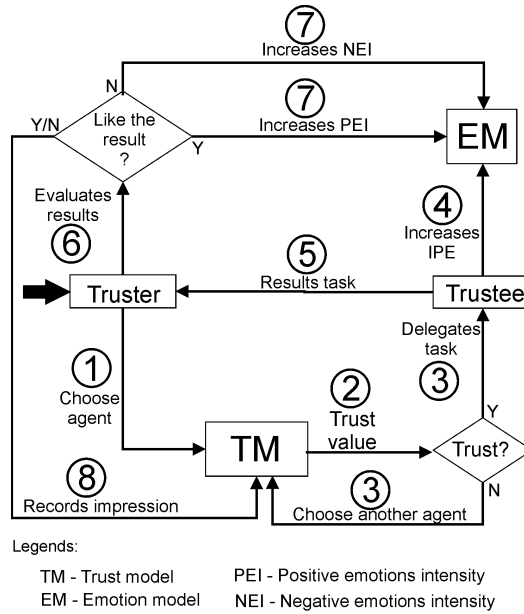
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http://adcaij.usal.es

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Figure 3: TrustE conceptual view

it is high, *a* will buy the product from *b* (step 3). Upon receiving the trust of *a*, agent *b* will increase positive emotions (step 4). For example, *b* was happy to have sold a product and felt joy. If $I_b(joy, 1) > I_b(joy, 0)$ then the emotion intensity will change in agent's *AEM*. As $I_b(joy, 1) = max(0, (0.7 − 0.1)) = 0.6$ e $0.6 > 0.5$, the value of $I_b(joy)$ is changed to 0.6.

After some time, *b* will deliver the product to agent *a* (step 5), and *a* in turn will evaluate the quality of the product (step 6). As agent *b* delivered a quality product *B* from the point of view of agent *a*, and *a* expected a quality product *A*, it will feel *reproach* in relation to the attitude of *b*. Now $I_a(reproach_b, 2) = max(0, (0.8 − 0.2)) = 0.6$ and $0.6 > 0.5$ the $I_a(reproach_b)$ is changed to 0.6 (step 7) and their evaluation with respect to *b* will be negative (step 8). If the product was quality *A*, the positive emotions (e.g. admiration) of agent *a* would increase and their evaluation with respect to *b* would be positive.

At the beginning of the transaction agent *a* could feel *fear* about not receiving the product. As soon as $I_a(fear, 1) = max(0, (0.8 − 0.2)) = 0.6$ and $0.6 > 0.5$ the $I_a(fear)$ is changed to 0.6.

When agent *a* calculated the trust in *b* (step 2), the value of *IEA* was 0.5, since $I_a(reproach_b, 0) = 0.5$. The value of *IEE* was the function value $I_a(fear, 0) = 0.5$. As these values changed after the transaction with *b*, if immediately afterwards agent *a* were to purchase another product from *b*, the values of *IEA* and *IEE* would both be 0.6.

(Bitencourt, 2014) presented a preliminary proposal of a hybrid model, TrustE, which is a trust model based on the Regret model and the OCC model. TrustE considers emotions in the trust calculation. The incorporation of emotions aims to capture, in a simple way, the complexity of human reasoning. Our idea is to introduce some qualitative elements into the quantitative evaluations performed by the trust model. The inclusion of emotions and their intensities makes the model more realistic because the decision-making process of the agent will be directly linked to its emotional state. We illustrate this process by a scenario of negotiation between agents.

As an evolution of this work, (Gelaim et al., 2015) presented a complete architecture for a multi-context

based agent model which includes emotional reasoning to lead trust and reputation in open multiagent systems.

4. Integrating Emotion on Trust within BDI Agents

In the great majority of the works, trust and reputations have been seen as black boxes, that receive information and return a degree of trustworthiness. As pointed out by Sabater and Sierra (Sabater-Mir and Sierra, 2012), the efforts to design better reputation and trust models (better aggregation forms, use of new information sources, use of different mathematical tools, etc.) are being directed toward the integration of these components to other processes of the agent.

The work presented by Gelaim (Gelaim, 2015) (Gelaim et al., 2015) intends walk in this direction, putting together all the aspects of the agent's reasoning. As in the works of Pinyol and Sabater (Pinyol and Sabater-Mir, 2009) and Koster, Schorlemmer and Sabater (Koster et al., 2012), we propose to integrate trust and reputation in a BDI agent using a multi-context system. The proposed agent's model is inspired in these works and also in the multi-context system defined by Casali, Godo and Sierra (Casali et al., 2005) (Casali et al., 2008) (Casali et al., 2011). However none of them add an emotion context, so we focus on that context as well as the bridge rules that link it to the other contexts.

In the work of Bosse and Höhle (Bosse and Höhle, 2011), emotions and trust may both affect beliefs, desires and intentions directly. In our model, we intend to explore the influence of emotions in determining trust. Differently of Bitencourt, Silveira and Marchi (Bitencourt et al., 2013) that propose a trust and reputation model with emotions, our research focus on an agent capable of reasoning about trust and reputation using a computational model of emotions.

In this proposal we define contexts to represent emotions and trust. Despite emotions can affect all beliefs, we focus on their impact on trust related ones. We use the model of emotions proposed by Steunebrink, Dastani and Meyer (Steunebrink et al., 2007b; Steunebrink et al., 2009) and improved by Bitencourt, Silveira and Marchi (Bitencourt et al., 2013), but other models can be used.

The relationship between emotions and trust contexts is mediated by the belief context. In that context emotions can be explicitly represented as annotations in beliefs about impressions. Impressions are annotated beliefs defined as evaluations about interactions between the agent and the environment (including other agents). The trust context uses these impressions in order to define trust evaluation.

4.1 Agent's Definition

In this work the agent is defined as a Multi-Context System according to definition (1). The following definition states our proposal:

Definition 2 *The proposed multi-context agent is defined as*

$$AG = \text{h}\{BC, DC, IC, P\,C, T\,C, EC, CC\}, \Delta_{br}\text{i}, \tag{17}$$

where BC, DC, IC, $P\,C$, $T\,C$, EC, CC are the contexts of belief, desire, intention, planner, trust, emotions and communication, respectively; and Δ_{br} are the bridge rules.

Figure 4 presents the agent's model with its contexts and where the bridge rules are enumerated from 14 to 22. We detail each component in the following.

Figure 4: Proposed agent model. Each edge (or group of edges) represents a bridge rule; the numbering refers to the corresponding formal rule, listed in subsections below
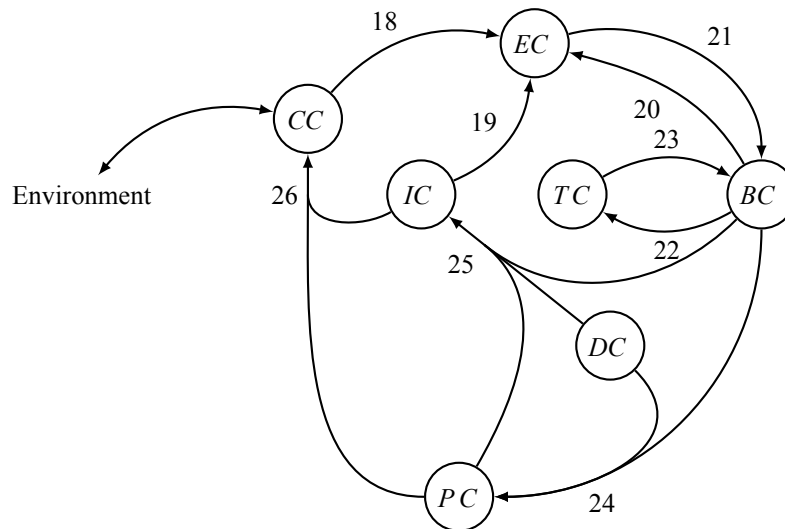
4.2 Emotional Context (*EC*)

This context keeps track of the agent's emotions. As was shown in 2, the literature on emotions in agents has several models. Thus, instead of proposing a new model Thiago proposal uses an existing template. Among the models refered in Section 2, the WASABI was chosen (Becker-Asano, 2008) to manage the emotional state of the agent. The choice of this model is due to the flexibility of integration with cognitive agents *frameworks* (Becker-Asano, 2014), and also the fact that this model separates the primary emotions and secondary emotions, allowing both reactive actions as actions cognitive are taken with emotional influence and emote. Therefore, integration with confidence does not need complex manipulations.

The intention to integrate emotions in the agent is to allow the agent affective experiences are part of the subjective factor in the definition of trust. As a direct impact of emotions affects the agent's beliefs, the emotional factor linked to these beliefs is added to the algorithms for the calculation of trust. In agents E-BDI, emotions can influence on various components of reasoning, but in this work, only the aspect described above is focused. According to the model, every time a belief judgment type is created, the current emotional state of the agent is updated to integrate this belief.

According to the WASABI model, the context of emotions is organized into two components: the *emotional dynamics*, in which the positive and negative stimuli are used to define the emotions, mood and personality and *PAD space* in which the result of the emotional dynamics is mapped to this component that evaluates what emotions were involved with each stimulus, according to its intensity. Although the original model also consider the secondary emotions, they are not used in this study.

4.2.1 Update Emotional State

The emotional stimuli perceived by the agent comes from the communication context, the beliefs context and from the intentions context. From the communication context comes the comments, messages and results of actions performed by the agent. In the emotions context, comments on an environmental entity can result in emotional impulses that are integrated in the trial of beliefs about the evaluated agent. Messages communicated may represent trials, and if pulses are positive, according to the knowledge of the agent, and negative otherwise. The actions that the agent performs generate emotional impulses that can also cause changes in the agent's beliefs and affect the appreciation in the context of emotions. The intentions context, in turn, is strongly linked to the desires of the agent, and generates impulses according to its graduation. The value of emotional stimuli caused by each source is set according to the environment in which the agent is inserted.

Emotional dynamics: The emotional dynamics describes the interaction between affective phenomena of emotions and mood. The first step of deployment is an orthogonal arrangement of the two components, where the valence of emotions corresponding to x axis, and the valence of humor to the axis y. Following the work of Becker-Asano (Becker-Asano, 2008) a *reference point* is defined, and as it is moved from the original point, two independent forces are created F_x and F_y to bring its axis back to origin. The greater the distance between the reference point and the axis of emotion or mood, the greater the valence component. Emotions and mood are updated in each cycle separately. Moreover, emotions influence the agent humor. In addition to the emotional dynamics, Becker-Asano (Becker-Asano, 2008) add the concept of *boredom*. Boredom is represented as a third axis, z. It emerges in the absence of stimuli.

Mapping to the PAD Space : The component of the emotional dynamics are able to provide at any time t a 3-tuple of the form

$$D(t) = (x_t, y_t, z_t), com\ x_t = [-1, 1], y_t = [-1, 1], z_t = [-1, 0]$$

where x_t is the emotional valence, y_t is the valence of humor, and z is the degree of boredom. According to this aspect, the closer to -1, the agent will be more bored. These three values are used for mapping space PAD. The new value of P is

$$P(x_t,\ y_t) = \frac{1}{2} \cdot (x_t + y_t)$$

A é atualizado para

$$A(x_t,\ z_t) = |x_t| + z_t$$

D is not updated from the emotional dynamic, he is an agent of the component, that defines whether it is dominant or submissive according to external circumstances (Becker-Asano, 2008).

4.3 Trust Context (TC)

This context determines the agent's trust in their partners. This is done by using a trust model, considering the information of the context itself, as well as information provided by the beliefs context. The trust model used is an adaptation of Regret model described in 2. The information that is contained in TC are: biases, rules, descriptions of fields, etc. The beliefs context provides the own agent's judgments or third parties' judgment and may suffer emotional influence.

 Hoelz and Ralha (Hoelz and Ralha, 2014) created a model for trust which is defined as

$$m_{conf} = \{id,\ v,\ n,\ dc,\ ac,\ td\}$$

representing, respectively, direct interaction, use of biases, standards, dimensions and contexts, reliable evaluation and decision-making. On this basis, the information used in the context of trust are:

1. *Direct interaction*: result of an interaction of the agent with another entity of the environment. This result generates one or more judgments, which can undergo emotional influence.

2. *Direct observation*: observation of the target entity to evaluate their behavior. It also generates one or more judgments with emotional influence.

3. *Witness information*: judgment made by another entity of the target entity's environment. This does not suffer emotional influence, but when receiving the information, the agent can generate a trial with emotional influence over the entity that provided the information. This judgment has high cost in having to interact with the environment (Hoelz and Ralha, 2014).

4. *Bias*: an internal preference agent, positive or negative. For example, an emotional bias may allow the agent to give more attention to negative judgments than positive (Smith et al., 2006).

5. *Standard*: Description of obligations, permissions and prohibitions that influence the behavior of an agent within a society (Kollingbaum, 2005).

6. *Dimensions and context*: dimensions can be combined to generate a more global confidence. For example, trust in an agent about his/her teaching skills and knowledge about automata can be combined to generate a confidence in being professor of automata. Contexts describe more precisely a scenario involved in the definition of trust.

7. *Trust evaluation*: in the presence of more than one trust model, the agent could make use of information that has to decide which model to use. In this study it was used ReGreT thus the evaluation is restricted to handling of regret parameters.

8. *Result in decision making*: once you have the confidence beliefs were created, the context of planning and intentions decide with whom to interact.

Items 1, 2, 3 are stored in the belief context. They are obtained through interactions with the external environment. The items 4, 5, 6 are represented in the trust context using descriptive logic. The choice of descriptive logic is because of the clear view of these items such as domains. Also, the description in the descriptive logic can be configured from shared descriptions. Item 7 is accomplished by means of Regret model. This model was chosen because it is a numerical model, which allows the emotions influence on trust, both based and not based on beliefs. The influence based on beliefs, according to the proposed model, is made by the affective appraisal of judgments in the definition of individual reputation. Item 8 is not done in the context of trust and is the final step of the process.

4.4 Belief Context (*BC*)

Beliefs represent the knowledge that the agent has on the world. They may have graduations representing the degree of certainty of its credibility. The predicate *J* is set to represent the judgments made by the agent on interactions with other agents, institutions or groups. Beliefs about the confidence that the agent has in environmental entities are defined with the predicate *C*. The beliefs' language presented by Casali, Godo and Sierra (Casali et al., 2005) is extended to contemplate judgments and confidence. Predicates *J* and *C* are added to represent, respectively, judgment and confidence. The predicate *J* has arity 7, and its form is

$$J(X,\ Y,\ C_j, P_c, A_r, \{E\}, T),$$

where X is the agent that created the judgment, Y is the evaluated entity, C_j is the judgment context, P_c is the property of this context being evaluated, $A_r\ 2\ [-1,\ 1]$ is the rational assessment on this property, $\{E\}$ It is the set of emotions involved at the time the trial was performed, and T is the time when the judgment was set.

A judgment can be read as " the agent X evaluated the entity Y considering the property P_c of context of the judgment C_J in time T, making rational assessment A_r and feeling the emotions $\{E\}$. The number of judgments that the agent stores in their belief context is dependent on the domain. For example, in a dynamic environment where the agent creates judgments in short periods of time, can be very costly to keep all of them. Thus, the agent needs plans that remove old judgments, or judgments that are not related to its goals.

The predicate C has arity 5, and its form is:

$$C(Y,\ C_c,\ Obj,\ V,\ T),$$

where Y It is the trusted entity, C_c is the trust context, Obj is the goal dependent of Y, $V\ 2\ [-1,\ 1]$ is the value that represents how much the agent trust in Y, and T is the time when the trust was set.

The confidence of belief can be read as: " In time T, the agent relies on entity Y with value V considering the context ç aiming accomplish the goal Obj, " The agent decide the number of new trials needed to update their belief C.

This definition of trust is very close to Castelfranchi and Falcone (Castelfranchi and Falcone, 2010) where trust is a relationship of at least five parts:

(i) an agent who trusts X; (ii) a trusted entity Y ; (iii) an action performed by Y an the result p; (iv) a goal g; e (v) a context C. These can be summarized as: the agent X relies on Y entity in the context C to perform the action and get the result p, aiming to achieve, at least partially, the goal g.

4.5 Desire Context (DC)

We also follow (Casali et al., 2011) leaving this context charged of the agent's desires. Desires can be positive —things the agent wishes were true — or negative — things the agent reject or wishes were not true. The language of this context, L_{DC}, is defined over a classic propositional logic using two fuzzy modal operators to represent positive and negative desires, together with the degree of liking/disliking the desire to become real.

4.6 Intention Context (IC)

This context is composed by the agent's intentions base, this context is built upon beliefs and desires. As in (Casali et al., 2011; Casali et al., 2005; Pinyol et al., 2012) the intentions are graded, aiming to evaluate the cost-benefit of an action.

4.7 Planner Context (PC)

This context creates plans to fulfill the agent's desires. The used language is based on first order logic restricted to Horn clauses. There are defined three special predicates: *basic action* - representing the basic atomic action; *plan* - representing composite actions; and *best plan* - representing best composite actions. This context follows (Koster et al., 2012) (Casali et al., 2011).

4.8 Communication Context (*CC*)

This context interfaces with the environment and is defined following the proposals of (Casali et al., 2011; Koster et al., 2012; Pinyol et al., 2012). The received information are restricted to Horn clauses in first-order logic. There are defined three special predicates: *does*, representing an action performed by the agent; *receive message*, for the messages received by the agent; and *observe*, representing observations made by the agent.

4.9 Bridge Rules

Communication between contexts is done using bridge rules. The edges shown in figure 4 represent the bridge rules that are described in this section. Two contexts can only exchange information if there is a rule that mediates between them. When a formula of a unit is added in another, she is surrounded by d·e. This means that this formula is converted in first order terms. This approach was proposed by Giunchiglia and Serafini (Giunchiglia and Serafini, 1994) for modeling modal logic as first-order theories.

Perception ′, obtained from environment through sensors by the communication context (CC), is directed to the emotions context (EC), which generates a belief that is used to assess the emotional agent component. The message , received when an assessment is done, is added to EC as a judgment *J*.

$$\frac{CC : observe(\varphi)}{EC : (B\varphi,\ r)},\ \frac{CC : receive\,message(\psi)}{EC : J\psi} \tag{18}$$

The intention *I* that is executed with the plan or action
to the desire ′, and cost-effective *r*, is informed by the intention context (IC) to EC aiming to generate emotional stimulus.

$$\frac{IC : (I_\alpha\varphi,\ r)}{EC : (I_\alpha\varphi,\ r)} \tag{19}$$

Changing the agent's knowledge about the world can generate emotional stimuli. Therefore, the belief ′ with *r* degree of belief context (BC), representing the previous knowledge, is sent to EC in order to compare with the new perception.

$$\frac{BC : (B\varphi,\ r)}{EC : (B\varphi,\ r)} \tag{20}$$

beliefs with certainty *r*, obtained by DC perceptions, and notified the EC, are transferred to BC, which makes a belief review. Although all perceptions are transferred from CC to EC and after EC to BC, not all suffer emotional influence. Only judgments suffer emotional influence, they are created in EC and transferred to BC.

$$\frac{EC : (B\varphi,\ r)}{BC : (B\varphi,\ r)},\ \frac{EC : J\psi}{BC : J\psi} \tag{21}$$

Confidence in an entity is defined by the context of trust (TC) from judgments that are in BC. This needs a bridge rule to transfer this knowledge and convert it to first order terms to the calculation of confidence.

$$\frac{BC : J\varphi}{TC : julgamento(\lceil J\varphi \rceil)} \tag{22}$$

Belief *E* of confidence created by TC from the judgments is transferred to BC, where it is stored.

$$\frac{TC : C\varphi}{BC : C\varphi} \tag{23}$$

Plans are created by the planning context (PC) considering positive $D^{+\prime}$ and negative $D^{-\prime}$ desires and its degree d, beliefs $B\Phi$ with its degree of sureness r and, when is a plan on interacting with an entity, belief C of confidence is also used. This rule is defined by Casali, Godo and Sierra (Casali et al., 2011), together with the possibility of transferring trust predicates. This bridge rule also becomes modal formulas in to first-order terms, since PC is implemented in this type of logic.

$$\frac{DC : (D^+\varphi,\ d)}{PC : pos\,desire(\lceil (D^+\varphi,\ d)\rceil)}$$
$$\frac{DC : (D^-\psi,\ d)}{PC : neg\,desire(\lceil (D^-\psi,\ d)\rceil)}$$
$$\frac{BC : (B\Phi,\ r)}{PC : belief(\lceil (B\Phi,\ r)\rceil)}$$
$$\frac{BC : C\theta}{PC : confianca(\lceil C\theta\rceil)}$$

(24)

plans, desires and beliefs are used to generate intentions. $(B[\alpha]\varphi, r)$. This means that, after the implementation of the action α, φ is true, with degree r for sureness. The function $f(d, r, c_\alpha) = \frac{d+r+c_\alpha}{3}$ is used to evaluate the cost/benefit of an intention. Intuitively, the more the agent want, trust and believe, the higher the priority of intention. This rule is strongly influenced the work of (Casali et al., 2011). The function f is changed to contemplate confidence.

$$\frac{\begin{array}{c} DC : (D^+\varphi,\ d), \\ BC : (B[\alpha]\varphi,\ r), \\ PC : best\,plan(\varphi, \alpha, pre\,condition, post\,condition, c_\alpha) \end{array}}{IC : (I_\alpha\varphi, f(d,\ r,\ c_\alpha))}$$

(25)

Once the intention is defined, it is communicated to the CC that is responsible for the action. This rule is defined in (Casali et al., 2011).

$$\frac{\begin{array}{c} PC : best\,plan(\varphi, \alpha, pre\,condition, post\,condition, c_\alpha), \\ IC : (I_\alpha\varphi, i_\varphi), IC : (I\varphi, i_\varphi) \end{array}}{CC : does(\alpha, I_\alpha)}$$

(26)

In order to illustrate our proposal, the next section presents a hypothetical scenario using the described model to deal with trust considering some emotional states.

5. Evaluation Scenarios

Lets assume a scenario where Bob is an agent and he believes his car is broken.

$$(B(\neg carro(funcionando)),\ 1)$$

A positive desire to Bob is that your car is always working.

$$(D^+(carro(funcionando)), 0.7)$$

Assuming that Bob does not know how to fix his car, he must delegate this task in order to have his goal realized. Suppose Bob has a *confidence* belief about the mechanic named Steve. According to this belief, in time 29/06/2015, Bob fully trust (1) in Steve as a mechanic, so that his desire to have the car running will be satisfied if it delegates this task to Steve.

$$C(steve, \: mecânico, carro(funcionando), \: 1, \: 29/06/2015)$$

Bob has a belief saying that after interacting with Steve, he will have your car running with credibility 1.

$$(B([interactWithSteve]carro(funcionando)), \: 1)$$

So when faced with her broken car, Bob selects his plan to interact with Steve.

$$
\begin{aligned}
&Action(\\
&\quad interactWithSteve, \neg carro(funcionando) \wedge disponível(steve), \\
&\quad carro(funcionando), \: 1) \\
&plan(\\
&\quad carro(funcionando), interactWithSteve, \\
&\quad \neg carro(funcionando) \wedge disponível(steve), carro(funcionando), \: 1)
\end{aligned}
$$

But Steve is out of town and can not repair the car of Bob. This event fires in Bob creating judgments about the unavailability of Steve, and also cause the decrease of credibility in car-related belief be working whenever interacting with Steve.

$$
\begin{aligned}
&(B([interactWithSteve]carro(funcionando)), \: 9) \\
&J(bob, \: steve, \: mecânico, \: disponibilidade, \: -1, \\
&\quad \{raiva \: = \: 0.75\}, \: 30/06/2015) \\
&J(bob, \: steve, \: mecânico, \: ServiceQuality, -1, \\
&\quad \{raiva \: = \: 0.75\}, \: 30/06/2015)
\end{aligned}
$$

At this point, Bob looks for another mechanic in his belief context, but unfortunately he has no beliefs or judgments about other mechanics. So Bob demands for mechanical information asking other agents by means of the predicate *does* in the communication context and making observations with the predicate *observe*. Messages received from other entities with judgments reach the context of communication by means of the predicate , and are sent to the emotions of context. These are not affected by Agent emotions, since they are not acquired by direct interaction. On the other hand, to make observations about mechanics, new emotions are linked to the agent.

$J(alice, john, mecânico, disponibilidade, 0.9, 20/06/2015)$

$J(alice, john, mecânico, ServiceQuality, 1, 20/06/2015)$

$J(alice, john, mecânico, preço, 0.8, 20/06/2015)$

$J(alice, aaron, mecânico, disponibilidade, 1, 15/02/2015)$

$J(alice, aaron, mecânico, ServiceQuality, 0.5, 15/02/2015)$

$J(alice, aaron, mecânico, preço, -0.4, 15/02/2015)$

$J(daniel, edward, mecânico, disponibilidade, 1, 23/03/2014)$

$J(daniel, edward, mecânico, ServiceQuality, -0.5, 23/03/2014)$

$J(daniel, edward, mecânico, preço, -0.4, 23/03/2014)$

$J(bob, john, mecânico, disponibilidade, 1,$
$\{concentrado = 0.59\}, 30/06/2015)$

$J(bob, aaron, mecânico, disponibilidade, -1,$
$\{concentrado = 0.6, irritado = 0.34\}, 30/06/2015)$

$J(bob, edward, mecânico, disponibilidade, 1,$
$\{concentrado = 0.19\}, 30/06/2015)$

After this, these beliefs are sent as judgments for the beliefs context. Now Bob has a set of judgments about other mechanics, that are sent to the trust context where the trust level for each agent is calculated. Emotions only influence the direct trust, and in this case, this is defined considering only the judgment on agent availability. trust beliefs are generated and sent to the beliefs context. At this time, Bob can select other agent according to his new trust beliefs that have the best evaluation. The belief about John is the best evaluated, and thus, it is the mechanical chosen.

$$C(john, mecânico, carro(funcionando), 0.94, 30/06/2015)$$

After receiving your car repaired, Bob generates a new positive judgment.

$J(bob, john, mecânico,$
$disponibilidade, 1, \{feliz = 0.41\}, 01/07/2015)$
$J(bob, john, mecânico,$
$ServiceQuality, 0.8, \{feliz = 0.41\}, 01/07/2015)$
$J(bob, john, mecânico,$
$preço, 0.8, \{feliz = 0.41\}, 01/07/2015)$

Again Bob's car is broken. Bob chooses not to update their trust beliefs about mechanics. Bob's belief about Steve is best, however, Steve, once again, can not meet it. So Bob chooses the second best choice to fix your car: John. After new experiences, there comes a moment before deciding which mechanical pick, Bob updates its trust beliefs, and realizes that John is more reliable than Steve.

The objectives of this example are: (I) describe the dynamics of the agent; (Ii) show that recent failures can undermine confidence; (Iii) the agent does not need to update their trust beliefs after a retrial; and (Iv) depending on the quantity and quality of judgments, the agent can give greater weight to their experiences or to third party information through the final reputation function.

6. Final Remarks

This paper presented a small survey and highlighted some important issues regarding the problem of trust in large and open multiagent systems as well as the problem of considering emotional states of the agents to deliberate and make decisions instead of considering only rational aspects.

First, in Section 2 we presented an overview of Agents and Multiagent Systems, introduced trust and reputation models in the context of agents, discussed the concept of emotions in agents, presented some well known models of emotions used in agents architecture, and finally we presented the idea of using multi-context models to design agents, because we think this very useful to join emotions and trust to BDI agents architecture.

Further, in Section 3 we presented the hybrid TrustE model which combine symbolic and numerical information to deal with emotions and trust. TrustE is a trust model based on the Regret model and the OCC model wish considers emotions in the trust calculation. In this model, the incorporation of emotions aims to capture, in a simple way, the complexity of human reasoning. The main idea of this model is to introduce some qualitative elements into the quantitative evaluations performed by the trust model. The inclusion of emotions and their intensities makes the model more realistic because the decision-making process of the agent is directly linked to its emotional state.

In Section 4 we presented a model that integrates trust and emotions into a multi-context BDI agent, described its components and the bridge rules that integrated these components. In this model, the agents can deliberate on trust through the use of beliefs based on the impression of events, actions or observations and also based on the emotions that come from these impressions. These components and the ontological information can be used by trust models to create trust beliefs. The purpose in adding emotions is to increase the accuracy of the agent rational part in situations where it can not have enough information, or when it can not realize any sudden change in the environment. As in (Pinyol and Sabater-Mir, 2009) and (Koster et al., 2012) we defined an agent as multi-context systems and integrated trust into it. We add emotions to trust beliefs, what differs from these works.

In the TrustE model (Bitencourt et al., 2013) presented in Section 3, trust and emotions are analyzed, but not are integrated to agent reasoning cycle as it is done on the in the multi-context based model (Gelaim et al., 2015) described in Section 4, although the same model of emotions as (Bitencourt et al., 2013) is used. The multi-context based model (Gelaim et al., 2015) evaluates the relationship between trust and emotions, while in (Bosse and Höhle, 2011) trust and emotions are present in others agent components.

In Section 5 we discussed some evaluation scenarios of application. As future work we intend to integrate cognitive trust models in our agent and include the implementation and the validation of this model. We also intend to explore other possibilities to include emotions in trust/reputation models, as well as to expand the present model to include a greater number of emotions.

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