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## A FORMAL MODEL OF AN ARGUMENTATIVE DIALOGUE IN THE MANAGEMENT OF EMOTIONS

**Abstract.** In this research, we focus on designing an interactive tool which will be used as an aid in learning how to manage emotions during argumentative dialogues. To this end, a collection of examples illustrating the typical human's reactions was collated and used to explain mechanisms that appear in dialogues. We present a theoretical background of the project, i.e., a formal system to represent the change of intensity of emotions in argumentative dialogues. We rely here on persuasive dialogue games. A formal language for expressing properties of protocols for dialogues with emotional reasoning is proposed. We suggest that awareness of emotions improves communication between parents and children, and that it is an important element of both raising communication skills in adults and development of communication skills in children.

**Keywords:** argumentative dialogue; emotions; protocol; formal model

### 1. Introduction

Conversations with small children or teenagers are sometimes very difficult and arguments addressed to them are often ineffective. In such situations, we desperately ask ourselves why the arguments used don't bring the desired effects. The problem which we meet here is related to communication skills, i.e. expressing intentions in an effective and clear way as well as understanding what the interlocutor really wants to

convey. Anomalies in communication competence mean that a child is not able to meet expectations of adults and make it difficult to interact with peers. At school, they become a source of behavioral and learning problems. Very important for the social functioning of a child are skills such as: demonstrating reluctance, interest, sadness, disappointment, joy, satisfaction. Statements, reactions, but also the arguments of children are saturated with emotions. Emotions express the lack of consistency between the external and inner world. Whereas interpersonal communication is the exchange of emotional states. So we can talk about their mutual relationship and the huge role of emotions in communication with other people. We must be able to effectively express our emotions and recognize the feelings of others in order to communicate and build relationships effectively. For example, if we can tell others that we feel sad and helpless, we increase our chances of getting help. It has been suggested that each person has a set of skills that help him in laying a harmonious relationship with others. This collection is called emotional intelligence [12]. Intelligence is traditionally understood as a measure of an intellectually functioning human being, but does not decide success in life. This is determined by emotions, or more precisely, the ability to adapt to social situations. Children often act intuitively and can not understand their behavior or reasons for such behavior. The consequence of these actions can be pathological and undesirable activities. Therefore, the role of a parent is to teach the child how to manage his/her emotions. To do this, first, the parent himself must understand their emotions and be able to recognize the emotions of the child. It is therefore extremely important for the interpersonal development of the parent or teacher to raise communication competence and then be able to shape the communicative competence in children.

The goal of the authors here is to design and implement a software tool to train communication skills, especially in argumentative dialogues with children. This tool is intended to highlight to the most important elements of effective communication and identify possible causes of failures. It will teach how to choose effective arguments in conversation with a child. An effective argument cannot ignore the child's emotions. Parents should be aware of the fact that the change in the child's emotions imply the change in his/her behavior. Consequently, the goal of the parent as well as the child will be achieved. To give basis for the software tool we introduce a protocol for argumentative dialogue with emotional reasoning. We rely here on well-described literature in the field

of dialogue games. This research builds on the foundations of the well-known persuasion dialogue games [23, 24] and modify and adapt their protocols to represent parent-child dialogues about emotions. First of all, the set of the locutions (speech acts) is extended. Two new locutions are introduced: “*scold*” expressing disapproval, impatience and irritation, and “*nod*” expressing approval, understanding and interest (curiosity). In addition, our model describes the dynamics of participants’ emotions, i.e., how they change during the dialogue.

Within the scope of the research is argumentation aimed at a change in the emotional state of the interlocutor. The emotional state consists of many factors, e.g. a sense of security, self-agency, self-satisfaction, self-confidence and so on. An argument concurrently can increase one’s sense of self-agency, but decrease one’s sense of security (“*if you find a job, you could move out, but you would have to rent your own flat*”). We aim to design an application which would be of support for people who have to convince somebody in a social context, but a more important factor is the emotional well-being of the interlocutor. We see such an application as a trainer of good practices in argumentation. We consider possible reactions of potential interlocutor to specific arguments and monitor changes in the simplified representation of the emotional state. That is the rationale to investigate argumentative dialogue protocol, which is intended to take into account change an emotional state of interlocutor in order to obtain the desired result (e.g. some kind of decision).

Usually, the aim of argumentation is figuring the agreement, the conviction of someone for their own reasons or even reaching a compromise [15, 29]. Persuasive dialogues are dialogues aimed at resolving conflicts of opinion between at least two participants. There are many types of such dialogues, e.g. conflict resolution dialogue begins with a conflict of opinion and ends when one of the participants convinces the other one of their argument. By contrast, the argumentation under our consideration does not necessarily have to convince a child to do something, but it should help him become aware of his feelings. Certainly, we do not want to claim that there is an obvious argumentation that will convince everybody, but there are some argumentation strategies and mechanisms, which are known and considered as convincing ones.

This research is a continuation of our work on the mathematical model of dialogue founded on the tradition of dialogue games. Such an approach assumes very strict rules of communications, which for example, can prohibit moves representing argumentative mistakes [13, 17] or

help in validation and verification of some formulas [16, 30]. On one hand, the rules make dialogue little trivial, but on the other hand, we can focus on selected dialogue features. In this research, these are the emotions and the change of intensity of these emotions. Dialogue game is some kind of a two-player game. The principles of this game are determined by locution, effect and structural rules specifying legal moves, their outcomes, and legal answers. All of these define a protocol, which is the basis of which to construct a mathematical model of the dialogue system. This paper proposes a general framework for defining protocols for argumentations referring to emotions, and dialogues involving emotions.

Even though every protocol must meet some general requirement, each one can be unique and we are concerned with verifying characteristics and properties of the dialogue defined by the specific protocol. In order to do that, we used the model checking method applied in the verification of multi-agent systems (MAS). Main solutions in this matter combine bounded model checking (BMC) with symbolic verification using translations to either ordered binary decision diagrams (BDDs) [14] or propositional logic (SAT) [22]. Verified properties are expressed in logics which are combinations of the epistemic logic with branching [25] or linear time temporal logic [28]. Such logic can be interpreted either over interleaved interpreted systems (IIS) [19] or interpreted systems themselves [10]. In this paper we introduce an extension of Computation Tree Logic (CTL) with elements which make it possible to express a change in the intensity of emotions under the influence of executed actions.

The study of emotions is part of various disciplines like Psychology, Economics, Cognitive Neuroscience, and, in recent years, also Artificial Intelligence and Computer Science. These studies aim to establish systems for emotional interaction. Currently, more and more artificial agents integrate emotional skills to achieve expressiveness, adaptability, and credibility. Such multi-agent systems find application in the improvement of human-machine interaction, testing, refining and developing an emotional hypothesis or even the improvement of artificial intelligence techniques, once it optimizes decision-making mechanisms [26, 21, 7, 20, 6, 3, 1, 2].

## 2. What are emotions?

Every day each of us feel and experience emotions. There are a lot of theories and definition explaining how emotions are formed. The body of research shows different perspectives regarding this term. According to Frijda [11] emotion is the result of evaluation of the event. Usually, we experience emotions as a special mental state. Emotions may create somatic changes in our bodies such as increased heart rate, sweating or respiratory problems. They could also initiate behavioral reactions. For example, when you encounter the situation that you evaluate as a danger (snake, accident, storm) your limbic system activates resulting in behavioral actions (flee, freeze, act) [11]. Emotional patterns and triggers that induce specific reactions are biological but cannot be explained only from a biological perspective. We react in a certain way because of our past experiences. We decide of meaning from the situation we experience [11].

Ekman [5, 6] presented in his studies that there are emotions which are universal despite the cultural context. He discusses basic emotions such as: fear, anger, sadness, joy, disgust. These emotions are experienced and recognized in the same way all around the world. They are universal for all human beings. Other emotions are mixed and built from those basic emotions. The expression of emotion is independent from cultural factors. Joy, sadness or anger is perceived in the same way both by people from West or East culture [4].

It is important to develop skills to recognize emotions. Therefore we have a choice of what emotional response we choose, and we build knowledge about our emotional state. These skills are not given to us by nature but we can learn them. Knowledge about emotions increases our understanding of what emotions are and their effects on us, giving us awareness of what is happening to us when we experience them. We say that emotion is positive if the event is consistent with our objectives or negative if it is incompatible with them.

This project is designed to increase knowledge and awareness of emotions that may be present during dialogue. Emotion gives information and allows us to choose the adequate response. This response may be cognitive (appraisal) or behavioral (fight or flee) or both. We base our study on a cognitive approach. Lazarus' two-factor theory [18] claims that the quality and intensity of emotions are controlled through cognitive processes. These processes underline coping strategies that form the emotional reaction by altering the relationship between the person

and the environment. Cognitive appraisal of the event triggers biological changes such as increased heart rate or pituitary adrenal response [27]. The individual feels given emotion and chooses how to react. The main objective of our project is to show that by recognizing interlocutors' emotions during the conversation we are teaching children to identify them. Naming emotions and being aware of them help to focus on finding a solution to the problem. In our study, we show which emotions accompany given statements (locutions and their contents) and how the way we talk can affect their intensity. This mechanism is shown on five Ekman's basic emotions: fear, disgust, joy, sadness, and anger [6].

### 3. Illustration

The problem that most commonly appears in the argumentative dialogue between a parent and a kid is illustrated in an example from Fig. 1. In this dialogue 15-year-old boy John and his mother are involved. John states that he is not going to school. Mother asks for reasons. John replies that as a 15-year-old can decide for themselves, and today decides to stay home and play computer games. Further discussion ensues in an attempt to convince him to change his mind, but it does not bring the expected effect. On the contrary, it only worsens the conflict. Why? In this example, John saying that he is not going to school signals a problem that he faces and cannot solve. Behind this statement lies fear and anxiety. John feels the helplessness with which he does not know what to do. The only thing that comes to his mind is not to go to school. The parent, who tries to blackmail him, accuses him of laziness and selfishness, and triggers the boy's aggression. The parent's argument is not effective because the child is focused on defending against attack. He is filled with pain, disappointment, and sadness caused by misunderstanding and lack of acceptance of his feelings and problems. The dialogue ends in failure. The parent unintentionally and unconsciously denies the child's feelings and can't hear his call for help. John understands why he should go to school and how absence can affect his future life. The parent has no reason to argue that school is important. Instead, the mother should talk about the emotions of the child, get to know them and finally understand the reasons for the behavior of John.

After each statement, we present an intensity of five emotions: *fear*, *disgust*, *joy*, *sadness*, and *anger* (respectively for the parent and the

child). We assume some initial state of interlocutors' emotions. The intensity of single emotion is represented by natural number from the set  $\{1, 2, \dots, 10\}$  and can change after each statement.

Before this dialogue, the mother is rather joyful, but the child feels fear (of confrontation with the mother or of some situation in school), sadness (a child cannot cope alone with some problems) and some anger. In the first statement, the child informs the mother that he does not want to go to school. We can see that this utterance made by the child resulted in an increase of his fear (of mother's reaction). In the same time, mother's fear also increased because he is keeping her waiting. She is also feeling some anger because she suspects that it has something to do with the truancy of her son. She asks about the reason, and this question increases not only the fear of the teenager but also the anger about that he has to tell everything about his problems at school. He shouts that he is old enough to decide for himself. As we can suspect, this statement causes the increase in the fear and the anger in the mother's emotions (and decrease in intensity of joy). She starts to feel a disgust about the way her son talks to her.

She responds (statement 4) with the rhetorical question, which arouses her anger even further. This question causes also the increase in the disgust and anger in the teenager's emotions. He answers that he prefers to stay home and play games, which slightly increase the anger of his mother. In statement 6 she scolds his son and tells him to go to school. After that, he is more angry, a little sadder and more disgusted about the way his mother treats him. He still claims that he is not going to school today, which makes his mother more disgusted and angry. She threatens his son that she will not give him money for the concert and tries to blackmail him (she also feels sad about the means she just used). The teenager feels increasing disgust and anger and he repays her by stating, that from now on she will have to mow the lawn by herself. Such a statement increases his fear about the reaction of the mother. It also causes the slight increase in the fear, the anger and the sadness in the mother's emotions. She concludes her son's behavior (statement 10), reproaches him and makes him sadder and angrier. He shouts about his hate and makes her sadder.

This example shows how important is the role of emotions in the argumentative discourse. Choosing the arguments, it is necessary to consider how they affect the emotions of the child. It is extremely important to help your child manage his emotions. This means that the

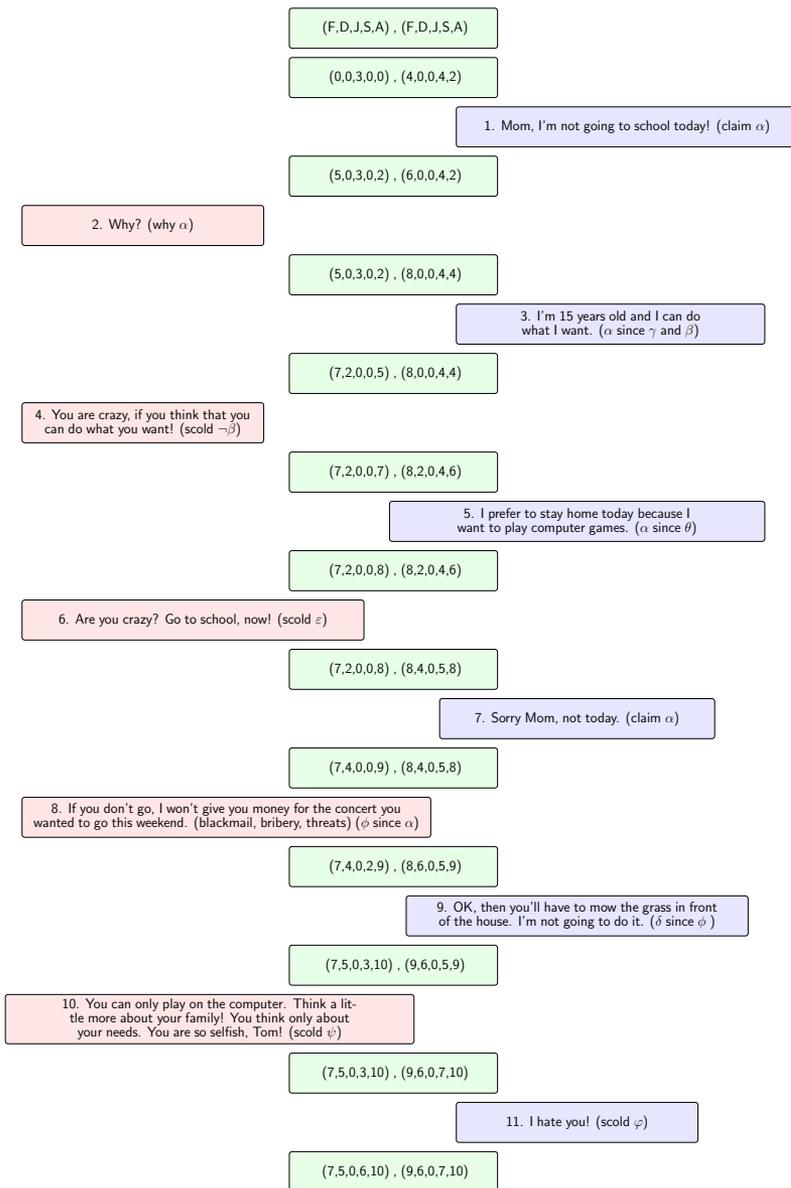


Figure 1. Dialogue between 15-year-old John and his mom.

adult should attempt to identify the child's emotions and get to the real, often hidden motivation of the child's behavior. At the same time, the role of the tutor is to help to solve problem, including assistance in coping with emotions and feelings. An argument referring only to the rational premises that ignore feelings and emotions of a child, will not bring satisfactory results. Conversely, changing the child's emotions can cause a change in the attitude of the child and his behavior to one that is desired by the parent. If the mom discovered that the real cause of John's behavior is the fear of test in mathematics and the conflict with the teacher, it would be easier to convince him to go to school. The real reason for the failure of the argument was different objectives of mom and child. Mom was focused on convincing John, that he must not stay at home, while John waited for her understanding and support in solving a difficult problem.

#### 4. Model for parent-child argumentative dialogue

In this section, we introduce a formal framework for argumentative dialogue and, more specifically, we define the dialogue protocol modeling conversation between a parent and a child. We start by defining a mathematical model which uses the concept of interpreted systems and Kripke structures. In the model, we assume that the set of players of a dialogue game consists of two players: *Parent* ( $P$ ) and *Child* ( $CH$ ),

$$Pl = \{P, CH\}.$$

To each player  $p \in Pl$ , we assign a set of actions  $Act_p$  and a set of possible local states  $L_p$ . We assume that the set  $Act_p$  contains also the special empty (null) action  $\varepsilon$ . Every action (except null action) is synonymous with locution expressed by the specific player. In argumentation systems the most commonly used locutions are: *claim* – some statement, *concede* – confirmation, *since* – justification, *why* – the request for justification, *retract* – revocation, and *question* about some fact. Thus, in argumentation dialogues, a player can *claim* some facts, *concede* with the opponent or change his mind performing action *retract*. To challenge the opponent's statement, he may ask *why*, or ask whether the opponent commits to something, i.e., perform action *question*. For defense he can use the action *since*. It is the kind of reasoning and argumentation.

We observed that in dialogues aimed at children, there are two additional very important locutions: *scold* and *nod*. Actions *scold* and *nod*

express reprimand and approval, respectively. For example, the mother saying “*You think only about your needs. You are so selfish, Tom!*” (see Fig. 1), in fact, is focused on her emotions like grief, disappointment, frustration and helplessness. We call this *scolding*. Much more effective would be to show acceptance and understanding. For example, “*I see that you’re angry.*” or “*I understand that mowing bothers you.*”. Such a reaction is cold “*nodding*”. Both locutions demonstrate large emotional charge. The first usually increases the anger, the other its decline.

Players’ local states  $l_p \in L_p$  consist of the players’ *commitments*, *emotions*, and *goals*

$$l_p = (C_p, E_p, GO_p).$$

Commitments are public declarations that can be compatible with knowledge or belief of a player or otherwise. While, a goal is understood as an expression that the player wants to be publicly declared by his/her opponent. For example John shouts “*I hate you!*” but in fact he loves his mother but do not know how to express his anger. John’s goal is to receive help and support from his mom “*I understand, you do not want to go to school, because you are concerned math test*”. Mother’s goal is to receive John’s assurance: “*I’ll go to school*”.

Players’ commitments and goals are elements of a fixed topic language, which allows expression of the content of locutions. Thus,  $C_p$  and  $GO_p$  are sets of such expressions. These sets may be subject to change after players’ actions. More specifically, the player can add or delete the selected expression. Formally we assume a finite set *FORM* of expressions which can be used as a content of a locution and thereby express some commitment or goal of a player.

Emotions which we consider are

*fear, disgust, joy, sadness, and anger.*

Their strength (intensity) is represented by natural numbers from the set  $\{1, 2, \dots, 10\}$ . Therefore,  $E_p$  is a 5-tuple consisting of five values, which may also change after a certain action. It is worth highlighting here that a change in the intensity of the emotions is dependent on the type of locution and, perhaps even more, on its content.

Let  $\alpha, \beta, \varphi, \psi_1, \dots, \psi_n, \gamma_1, \dots, \gamma_n \in FORM$ . Locutions used in players’ actions are the same for both players:

$$Act_P = Act_{CH} = \{\varepsilon, \textit{claim } \varphi, \textit{concede } \varphi, \textit{why } \varphi, \\ \textit{scold } \varphi, \textit{nod } \varphi, \varphi \textit{ since } \{\psi_1, \dots, \psi_n\}, \textit{retract } \varphi, \textit{question } \varphi\}.$$

Next,  $Act$  denotes a subset of the Cartesian product of the players' actions such that:

$$Act = \{(a, \varepsilon) : a \in Act_P\} \cup \{(\varepsilon, a) : a \in Act_{CH}\}.$$

The global action  $a \in Act$  is a pair of actions

$$a = (a_P, a_{CH}),$$

where  $a_P \in Act_P$ ,  $a_{CH} \in Act_{CH}$  and at least one of these actions is the empty action. This means that players cannot speak at the same time. Moreover, a player cannot reply to his own moves. Thus, the empty action is performed alternately by players  $P$  and  $CH$ .

During the dialogue, we assign to each performed global action  $a \in Act$  two numbers: the first one  $n_1 \in \mathbb{N}$  (ascending) indicates order (starting from the value 1). The second one  $n_2 \in \mathbb{N}$  points out to which earlier action this action is referring (0 at the beginning of the dialogue means that we are not referring to any move). Therefore, we define *double-numbered global actions* set

$$Num_2Act = \{(n_1, n_2, a) : n_1, n_2 \in \mathbb{N}, a \in Act\}.$$

Furthermore, we define *numbered global actions* set

$$Num_1Act = \{(n_2, a) : n_2 \in \mathbb{N}, a \in Act\}.$$

Each element of this set is a pair  $(n_2, a)$  consisting of an action  $a \in Act$  and the identifier of the action it refers to,  $n_2 \in \mathbb{N}$ . If we want to find out whether we can use some global action one more time, we should check if the possible move containing the same global action refers to the different earlier move. We also need the function

$$\begin{aligned} Denum: Num_2Act &\rightarrow Num_1Act, \\ Denum(n_1, n_2, a) &= (n_2, a), \end{aligned}$$

which maps double-numbered global action to the numbered global action.

A *dialogue*  $d$  is a sequence of double-numbered global actions. We denote

$$d_{1\dots n} = d_1, \dots, d_n,$$

where  $d_i \in Num_2Act$ ,  $d_i = (i, j, a)$ ,  $i, j \in \mathbb{N}$ ,  $j < i$ ,  $a \in Act$ .

A *global state*  $g$  is a triple consisting of dialogue history and players' local states corresponding to a snapshot of the system at a given time point

$$g = (d(g), l_P(g), l_{CH}(g)),$$

$g \in G$ , where  $G$  is the set of global states. Given a global state  $g$ , we denote by  $d(g)$  a sequence of moves executed on a way to state  $g$  and by  $l_p(g)$  – the local state of player  $p$  in  $g$ .

An *interpreted system* for a dialogue game is a tuple

$$IS = (I, \{L_p, Act_p\}_{p \in Pl}),$$

where  $I \subseteq G$  is the set of initial global states.

Now we define *legal answer function*

$$F_{LA}: Num_2Act \rightarrow 2^{Num_1Act},$$

which maps a double-numbered action to the set of possible numbered actions. This function is symmetrical for both players and determines for every action a set of legal actions which can be performed next. It also defines the locution which can start a dialogue. A precise definition depends on a specific application but the function must comply with the following condition:

$$\text{if } (j, a') \in F_{LA}(n_1, n_2, a) \text{ then } j = n_2.$$

The actions executed by players are selected according to a *protocol function*

$$Pr: G \rightarrow 2^{Num_2Act},$$

which maps a global state  $g$  to the set of possible double-numbered global actions.

The protocol is a crucial element of the model since it gives strict rules which determine the behavior of players. In other words, it formally describes who, when and which action can perform.

To show how locutions and their contents affect players' emotions and goals we define two functions. The first one determines the change of intensity of emotions:

$$EMOT_p: Act_w \times Emotion_p \rightarrow Emotion_p$$

where  $p \in Pl$  and  $Emotion_p$  is a set of all possible 5-tuples for emotions, i.e.,

$$Emotion_p = \{(n_1, \dots, n_5) : n_i \in \{1, \dots, 10\} \wedge i \in \{1, \dots, 5\}\}.$$

The second one determines the change of goals:

$$GOAL_p : Act_w \times Goal_p \rightarrow Goal_p,$$

where  $p \in Pl$  and  $Goal_p$  is a set of possible goals represented by expressions from the topic language, i.e.,

$$Goal_p \subset FORM.$$

Finally, we define *global (partial) evolution function*

$$t: G \times Num_2Act \rightarrow G,$$

which determines results of actions. This function is also symmetrical for both players.

With the interpreted system we associate a *Kripke structure*, which gives an interpretation for formulas expressing properties of dialogue protocols. A Kripke structure is defined as a tuple

$$M = (G, Act, T, I)$$

consisting of a set of global states  $G$ , a set of actions  $Act$  (in our approach  $Num_2Act$ ), a set of initial states  $I \subseteq G$ , a transition relation  $T \subseteq G \times Act \times G$  such that  $T$  is left-total. Relation  $T$  is defined as follows

$$(g, a, g') \in T \text{ iff } g' \in t(g, a).$$

By  $T^*$  we will denote the reflexive and transitive closure of  $T$ .

## 5. Formal language to express the change of emotions

Interpreted systems are traditionally used to give semantics to an epistemic language enriched with temporal connectives based on linear time [10]. Here we use *Computation Tree Logic* (CTL) by Emerson and Clarke [8] as our basic temporal language and add *commitment*, *emotion*, and *goal* components to it.

DEFINITION 5.1 (Syntax). Let  $Pl = \{P, CH\}$  be a set of players. The set of formulas is defined inductively as follows:

- *true* is a formula,
- if  $\varphi \in FORM$  and  $p \in Pl$  then  $COM_p(\varphi)$  and  $GOA_p(\varphi)$  are formulas,
- $EMO_p(e)$  is a formula for  $p \in Pl$  and  $e \in \{\text{fear, disgust, joy, sadness, anger}\}$ ,

- if  $\alpha$  and  $\beta$  are formulas, then so are  $\neg\alpha$ ,  $\alpha \wedge \beta$  and  $\alpha \vee \beta$ ,
- if  $\alpha$  and  $\beta$  are formulas, then so are  $AX\alpha$ ,  $AG\alpha$ ,  $AF\alpha$  and  $A(\alpha U\beta)$ .

The remaining basic modalities are defined by derivation:  $EX\alpha \stackrel{\text{df}}{=} \neg AX\neg\alpha$ ,  $EG\alpha \stackrel{\text{df}}{=} \neg AF\neg\alpha$ ,  $EF\alpha \stackrel{\text{df}}{=} \neg AG\neg\alpha$ . Moreover,  $\alpha \Rightarrow \beta \stackrel{\text{df}}{=} \neg\alpha \vee \beta$ ,  $\alpha \Leftrightarrow \beta \stackrel{\text{df}}{=} (\alpha \Rightarrow \beta) \wedge (\beta \Rightarrow \alpha)$ , and *false*  $\stackrel{\text{df}}{=} \neg \text{true}$ .

The formula *true* is used for technical reasons and helps to express that some action is possible to execute, i.e., an action can lead to a state in which *true* holds. Of course, *true* is satisfied in every state. Formula  $COM_p(\varphi)$  describes the actual set of commitments of player  $p$ , more precisely, it expresses that  $\varphi$  is in this set. We should emphasize that  $\varphi$  is not a formula of the language defined herein, but a part of a separate structure in which it is possible to express the spoken sentences. In dialogue system, all actions are aimed at influencing the players' commitments. Therefore, the modality  $COM$  is very important and often used in the protocol specification. Modalities  $EMO_p$  and  $GOA_p$  allow for expressing properties concerning emotions and goals of player  $p$ . The temporal modalities X, G stand for "at the next step", and "forever in the future", respectively. The modality A is the universal quantifier - "for all". Thus, AX means "for all next states", while AG means "for all states on all paths". AF expresses "for a state on all paths". The operator U stands for *Until*; the formula  $\alpha U\beta$ , expresses the fact that  $\beta$  eventually occurs and that  $\alpha$  holds continuously until then.

First, in order to give the semantics for the above formulas, we need to give a formal definition of a computation. A *computation* in a Kripke structure  $M = (G, Act, T, I)$  is a possibly infinite sequence of states  $\pi = (g_0, g_1, \dots)$  such that there exists an action  $a_m$  for which  $(g_m, a_m, g_{m+1}) \in T$  for each  $m \in \mathbb{N}$ , i.e.,  $g_{m+1}$  is the result of applying the transition relation  $T$  to the global state  $g_m$ , and the action  $a_m$ .

Below we abstract from the transition relation, the actions, and the protocols, and simply use  $T$ , but it should be clear that this is uniquely determined by the interpreted system under consideration. In interpreted systems terminology, a computation is a part of a run. A  $k$ -computation is a computation of length  $k$ . For a computation  $\pi = (g_0, g_1, \dots)$ , let  $\pi(k) = g_k$ , and  $\pi_k = (g_0, \dots, g_k)$ , for each  $k \in \mathbb{N}$ . By  $\Pi(g)$  we denote the set of all the infinite computations starting at  $g$  in  $M$ , whereas by  $\Pi_k(g)$  the set of all the  $k$ -computations starting at  $g$ .

DEFINITION 5.2 (Semantics – Interpretation). Let  $M$  be a model (Kripke structure),  $g \in G$  be a state,  $\pi$  be a computation, and  $\alpha, \beta$  be formulas,  $\varphi \in FORM$ .  $M, g \models \alpha$  denotes that  $\alpha$  is true at the state  $g$  in the model  $M$ .  $M$  is omitted, if it is implicitly understood. The relation  $\models$  is defined inductively as follows:

$$\begin{array}{ll}
g \models true & \text{for all } g \in G, \\
g \models COM_p(\varphi) & \text{iff } \varphi \in C_p(g), \\
g \models EMO_p(e) & \text{iff } n_i > 5 \text{ in } E_p(g) = (n_1, \dots, n_5), \text{ where } e \text{ is fear,} \\
& \text{disgust, joy, sadness, or anger and } i = 1, 2, 3, \\
& 4, 5, \text{ respectively,} \\
g \models GOA_p(\varphi) & \text{iff } \varphi \in GO_p(g), \\
g \models \neg\alpha & \text{iff } g \not\models \alpha, \\
g \models \alpha \wedge \beta & \text{iff } g \models \alpha \text{ and } g \models \beta, \\
g \models AX\alpha & \text{iff } \forall g' \in G \forall a \in Num_2 Act \\
& \text{(if } (g, a, g') \in T, \text{ then } g' \models \alpha), \\
g \models AG\alpha & \text{iff } \forall \pi \in \Pi(g) (\forall_{m \geq 0} \pi(m) \models \alpha), \\
g \models AF\alpha & \text{iff } \forall \pi \in \Pi(g) (\exists_{m \geq 0} [\pi(m) \models \alpha]), \\
g \models A(\alpha U \beta) & \text{iff } \forall \pi \in \Pi(g) (\exists_{m \geq 0} [\pi(m) \models \beta \text{ and} \\
& \forall_{j < m} \pi(j) \models \alpha]).
\end{array}$$

After extending CTL logic by adding these new operators, we get an adequate language to express the change of emotions in argumentative dialogues. As a result, we can conduct semantic verification of protocols for dialogue games in which emotions play an important role. Selected properties, that are within the scope of our interests, are described below.

In dialogue systems, we often assume that the end of a dialogue means the fulfillment of a certain condition. This condition may express that one of the players, e.g. the child, is happy:

$$EF(EMO_{CH}(joy)).$$

If any dialogue should end with the *termination* condition and this condition means that the child does not feel fear, then we can express this fact as follows:

$$AF(\neg EMO_{CH}(fear)).$$

This formula claims that every computation contains a state in which the required condition holds.

An important feature of an argumentative dialogue is that it can lead to an agreement, i.e., resolve the conflict:

$$EF(COM_{CH}(I'll \text{ go to school}) \wedge \neg EMO_{CH}(fear))$$

This formula expresses that it is possible to get to a state where the child declares that he/she will go to school and he/she does not feel fear.

The next formula says that if the child expects understanding and acceptance, then he/she will be eventually understood:

$$AG(COM_{CH}(I'm\ afraid\ of\ the\ math\ test)\wedge GOA_{CH}( Mom\ understands\ me ) \rightarrow AF(COM_P( I\ understand\ you ))).$$

Let us finish giving an optimistic formula which expresses that it is possible to get from any state to a state in which the child feels joy:

$$AG(AF(EMO_{CH}(joy))).$$

## 6. Conclusion

The objective of our research was to develop a tool which will be a support in improving communication and argumentation skills and shows the role of emotions in an argumentative discourse. To this end, we have analyzed real parent-child dialogues and we have selected these aspects of dialogues, which lead to an agreement, and those that cause lack of success. The accuracy of our choices is supported by scientific and experimental research. Now our main challenge is a task involving the modeling of a dialogue with emotional reasoning as an argumentative game. Therefore, we developed a general framework for defining and specifying protocols for dialogues under consideration. Next, we defined a mathematical model resulting from these protocols and propose an extension of branching time modal logic. Using this method, we provide a language for expressing properties concerning emotions.

It is a common knowledge that emotions are important in interpersonal contact. Some of the artificial intelligence systems are also equipped with modules which allow for the exploration of the role of emotions in e.g. decision making (see [21]). We use our model to show that a very important, if not the most important thing in successful argumentation carried out between an adult and a child is the ability to manage emotions. This is particularly important for training teachers, educators, psychologists, and parents. This process can take place between a human, which plays a role of a student, and a software agent, which plays a role of a teacher. As a case study, we consider real dialogues between parents and children. In these dialogues, parents learn how to manage emotions to achieve the intended behavior, e.g., the

child does homework, tidies the room, doesn't use offensive language, etc. Every statement (of a child, but also an adult) contains content (usually formulated explicitly) and emotions (often hidden). It is possible we understand the content but we are not able to properly interpret the accompanying emotions. We should also be aware how our own emotions are perceived by the interlocutor. Understanding our emotions and interlocutor's emotions especially in difficult situations enables effective communication. Emotions are important guideposts, which allow us to decide how to handle a conversation [9]. The main task of the project is to show that through recognizing child's emotions we are teaching him to identify them. Naming emotions and being aware of them help to focus on finding a solution to the problem. In our study, we show what emotions accompany given statements and how the way we talk can effect their intensity. This mechanism is shown using five emotions: fear, disgust, joy, sadness, and anger [6].

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