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APPROACHING ARGUMENTATIVE DIALOGUE WITH FORMAL MODELS

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1. *Introduction*

From the linguistic point of view, dialogue can be understood as an exchange of speech acts with its rules and constraints, with the main objective being communication. From pragmatic theory, dialogue could also be defined as a game where the participants try to maximize the possibilites of success in their argumentation in order to achieve their own goal.

Any contribution to the study of dialogue is in debt with the theory of speech acts, introduced by Austin (1962) and Searle (1969), that has become one of the central issues of pragmatics and human communication traditionally tackled by artificial intelligence.

The theory of dialogue acts has made it possible to establish units in dialogue and has allowed the start of the dialogue grammars approach (Sinclair & Coulthard 1975) as well as establishing several taxonomies of units (Sinclair & Coulthard 1975; Traum & Hinkelman 1992).

Computer science has been more interested in the structure and the interaction of agents in conversation (Litman & Allen 1990) rather than in single utterances. From that perspective, some authors (Sinclair & Coulthard 1975; Coulthard *et al*. 1981) have distinguished different levels inside the dialogue: *act*, *move*, *exchange* and *transaction*. Such classification has become classical, especially referring to moves (Kowto *et al*. 1993; Traum & Larsson 2003).

Traum and Hinkelman (1992) give a new perspective in the topic gathering different types of acts in four groups: *turn-taking*, *grounding*, *core speech acts* and *argumentation*. One of the novelties of this taxonomy consists in the inclusion of turn-taking into such categories.

A similar idea can be found in Bunt (2005), who defends the existence of *task-oriented acts* and *dialogue control acts*. Both types modify the linguistic and cognitive context. However, task-oriented acts only change the semantic context and dialogue control acts mainly affect the social or physical context. He considers turn taking to be included in *interaction management functions*, which belong to *dialogue control functions*.

By means of Grice's maxims, participants are required to be cooperative and they have to follow a behavior that is related more to politeness than to linguistics. But many times, contra to Grice's claims, participants have secret purposes that are not known by the other agents. In this sense, Reed and Long (1997) make an interesting

distinction between cooperation and collaboration. For a dialogue to be brought about, cooperation is necessary, but collaboration not always exists.

For us, a crucial and non-static element in dialogue is context, understood as the environmental and personal states and circumstances that can affect the development of the dialogue. This context is in constant evolution, not only because of external factors, but also because of the speech acts performed by the participants. Therefore, like Bunt (1995), we think that the configuration of the dialogue is directly related to the intentions of the speakers/hearers and to the context.

In what refers to the types of dialogues according to human argumentation, Walton and Krabbe (1995) introduced a taxonomy that has become classical. They distinguish between *information seeking*, *inquiry*, *persuasion*, *negotiation*, *deliberation* and *eristic* dialogues. Our work is mainly focused in deliberation, a kind of dialogue in which participants have to reach an agreement and make a decision.

We approach deliberation from the perspective of *dialogue games* following the research line started by Carlson (1983). Many authors have tackled dialogue as a game (Mcburney & Parsons 2002a, 2002b; Prakken 2006), although most of them have focused on persuasion (Hitchcock *et al.* 2001; Glazer & Rubinstein 2001, 2005). Glazer and Rubinstein introduce an interesting variant, which they name *debate*, based on game theory. In their model, two opponents have to convince a third person, which is the one deciding.

This paper is an attempt to start an approach for deliberation dialogue games accounting for argumentation, using some tools provided by mathematics, theoretical computer science and game theory. The definition of deliberation is derived from the general definition of dialogue, with the important restriction of the number of agents A, that in this case is given by A=2. In what refers to game theory, we use the extensive form of games representation because we assume the participation of the speakers is sequential and they alternate in turn. In this simple model, then, turn taking is already established, given by the number of agents.

In deliberation, agents interact to decide what action or course of actions should be adopted in some situation. Grice (1975) claims that cooperation is basic for the correct development of conversation from the pragmatic perspective. However, our work is based on the ignorance of agents' real attitude. We assume they could not follow Grice's principles. Therefore, participants in the system have one of the following configurations:

      a)   participants have secret intentions, and

      b)   participants are neutral.

In this research, we are mainly interested in defining games where the participants in the deliberation have secret intentions. In the sequel, the term dialogue refers to "deliberation dialogue".

Summing up, we are interested in the formalization of deliberation with two agents that have secret goals, and in the analysis and optimization of their moves, tak-

ing some methods from game theory.

In Section 2 we introduce the main definitions of dialogue and deliberation. Section 3 shows an example. In Section 4 some strategies for improving the possibilities of success are discussed. Finally, Section 5 provides some discussion and future lines of work within this framework.

2. *Definitions*

2.1 Dialogue

First, we introduce a general definition for a formal dialogue, that must be adapted in order to account for deliberation. The main features of the definition below are: a) the number of agents A is, by default, A>2; b) the sets of stores are selected for approaching spontaneous, non task-oriented conversations; c) turn taking is not established; d) during the conversation, agents can become disconnected, participants can leave the scene, and new ones can enter.

The formal framework for dealing with this type of conversations would be the following:

Definition 1: Dialogue systems can be defined as a 4-tuple (A, Θ, Σ, G), where:

- $A = \{A_1, A_2, \ldots, A_n\}$ is the multi-agent structure, where every one of the agents has a configuration $A_i = (R_i, C_i)$, being:
  - R_i the set of rules. Every one has:
    - At the left side turn-taking for the rule to be applied.
    - At the right side:
      a) the rule of generation, and
      b) the agent whom the speech act is addressed to, if it exists.
  - C_i is the state of the communication channels. Every agent has bi-directional (input/output) channels with others, which can be set either as open or closed. For the communication to be possible between two given agents A_n and A_i, the channel has to be open in both directions. For the other combinations (open-closed, closed-open, closed-closed) communication is not possible.
- $\Theta = \{\kappa, \alpha, \gamma, \phi, \pi, \varepsilon, \sigma\}$ is the set of stores of core speech acts, being their configuration as follows: $\kappa = \{k_1, k_2, \ldots, k_n\}$, query; $\alpha = \{a_1, a_2, \ldots, a_n\}$, answer; $\gamma = \{g_1, g_2, \ldots, g_n\}$, agree; $\phi = \{f_1, f_2, \ldots, f_n\}$, reject; $\pi = \{p_1, p_2, \ldots, p_n\}$, prescription; $\varepsilon = \{e_1, e_2, \ldots, e_n\}$, clarify; $\sigma = \{s_1, s_2, \ldots, s_n\}$, assert.
- $\Sigma = \{K$ (Query), A (Answer), G (Agree), F (Reject), P (Prescription), E (Clarify), S (assert)$\}$ is the set of turn-taking dialogue acts.
- $G = \{G_1, G_2, \ldots, G_n\}$ is the set of registers of the system, the place where the dialogue games are stored. There is a different generation register for every conversation started by the system.

2.2 Deliberation

Bearing in mind the general formalization of dialogue, now a formal description of deliberation has to be given, by constraining and adapting some of the elements of the previous definition.

First of all, in order to approach deliberation, we establish the existence of only two agents A_1, A_2 which are the only participants. This is a methodological option to simplify the description of the system, but the formalization can be extended to *n* participants, only by adding the configuration of A in the definition we will introduce in this section.

The existence of only two agents implies that the turn taking is previously established as an alternance of A_1 and A_2, in a way that no other protocol is needed. Therefore, Σ and the transitions and rules it implies are not necessary for this simple case. When the number of agents is A>2, then Σ must be included again in the definition of deliberation.

Each one of the agents has a set of dialogue acts $\Theta(A_1)$, $\Theta(A_2)$. Each one of these sets is part of an acts store $\Theta = \{p, r, s, a, q, x\}$. Such a store is different from the one of the general case of dialogue, as the acts are especially selected to fit an argumentative exchange. In Θ, *p* and *s* are two different types of arguments, *r* is a counter-argument rejection, *a* is acceptance, *q* is a question and *x* indicates that an agent is quitting the dialogue. We also establish that *r* and *a*, cannot be initial productions of the dialogue because they are only valid as a counter-argument.

R is a set of combinations of argumentation-counter argumentation that relates elements from the set $\Theta(A_1)$ to acts belonging to the set $\Theta(A_2)$, or vice versa. These rules are different for each one of the agents or participants, and they have the form p → q. Every agent has its own set of rules, R_1 for A_1, R_2 for A_2, R_n for A_n. If single elements are found in the sets of rules of the agents, they can be used only as a "starting production". They are, then, the starting symbols of the system. If both agents have starting acts, only A_1 will be able to use them, since this is the agent, which, by definition, starts the debate, if it has arguments to do that. The participant that starts the dialogue is A_1, if it has some argument that is not generated by another argument, i.e. some single symbol in R_1.

We denote a production w of an agent A_n in a given state as $A_n(w)$, and the set of possible productions for an agent A_n in a given state as $\theta(A_1)$.

The possible outcomes of the deliberation are represented with upper-case roman letters. They are part of the set O, such that O = {A, B, C...}.

Some of the elements of Θ are associated to elements of O by an application F. Such elements are named terminal acts.

Definition 2: Having two speakers A_1 and A_2, a deliberation game G between them is defined as a 4-tuple:

G = (Θ, R, O, F)

where:

- Θ is an acts store;
- R = $R_1 \cup R_2, ... \cup ..., R_n$ is the set of argumentation rules for each agent;
- O is the set of possible outcomes of the deliberation;
- F is an application relating elements of Θ to elements of O. Such application is denoted by the symbol '$\rightarrow$'. If there is not an O element for a sign belonging to Θ, then the result is *Ind*, which means that the outcome is undecidable and the deliberation has to go on.

The graphic representation of the deliberation game can be seen by means of a tree-diagram. For this we follow the regular elements and terminology. Using the tree graphic and the concepts that have been defined, we introduce several statements for the description and study of the properties of a deliberation dialogue.

Description 1: Tree-Diagram

The tree-diagram will show all the possible productions of the game, where the nodes are the agents speaking and the edges denote dialogue acts. Every different branch in the tree determines a possible trajectory.

Description 2: Terminal nodes

Terminal refers to the nodes that cannot be developed any more at the end of the debate, which corresponds to the classical definition of "terminal".

Description 3: Final nodes

Final nodes are terminal nodes after a given move, that is, the nodes that, after the application of F are not labelled wit *Ind*. Nodes *Ind* are final but non terminal nodes.

Description 4: Trajectories

A trajectory of dialogue is every lineal path of the tree starting at the initial node. A complete trajectory is every path from the starting utterance to a terminal symbol. There are as many trajectories in a dialogue as the final nodes it has. There are as many complete trajectories in a dialogue as terminal nodes it has. There are as many possible trajectories in a given move as the new nodes it produces.

Description 5: Trajectories in deliberation

Being G a deliberation game for agents A_1 and A_2, and $\Theta = \{w\}$ the acts store, we denote a trajectory of this game with the form $G(w_1, w_2, ..., w_n)$, being $w_1, w_2, ... ,w_n$ the utterances generated to reach the final agreement in order of generation. Since a dialogue has as many trajectories as final results, then we say that a G = $\{G_1, G_2, ... ,G_n\}$.

Description 6: Width

The width of a dialogue $w(G)$ is the maximal number of trajectories it has. The trajectories are ordered starting with the leftmost and finishing by the rightmost.

Description 7: Paired trajectories

We call paired trajectories those that have an even number of edges and unpaired trajectories those that have an odd number of edges.

Description 8: Move

We define a move M as an adjacency pair that consists of argument and counterargument. A sequence is a set of moves M_m, M_n, ...,M_i. A debate can have one or more moves. As in real life, some debates stop after a number of productions that has been determined before, and others can be calculated after all possibilities have been explored.

Description 9: Move productions

The productions generated after a move Mn are $\theta(M_n)$. In $\theta(M_n)$ two types of acts can be distinguished: final $f(M_n)$ and terminal $t(M_n)$. The state of the dialogue after M_n, denoted $\Theta(M_n)$, includes $\theta(M_n)$ and all the terminal acts before Mn, denoted by $T(M_n)$. Being Mm, Mn the first and second moves in a debate, it is clear that in Mm, $\Theta(M_m) = \theta(M_m)$, while in M_n, $\Theta(M_n) = t(M_m) \cup \theta(M_n)$. Being $M = \{M_m, M_n, ... , M_i\}$, $\Theta(M_i) = t(M_m) \cup t(M_n)... \cup ...\theta(M_i)$. If in a given move M_n, $\theta(M_n) = t(M_n)$, then the debate is complete.

The results of the productions in a move Mn are designed by $g(M_n)$, and they are obtained by applying $F(\theta (Mn) => O)$. The results of the debate after the move Mn are denoted by $G(M_n)$, and they are obtained by applying $F(\Theta (M_n) => O)$.

Description 10: Final Generation

A generation is a final generation if it is the last generation that has been stipulated for a debate. A generation is a terminal generation if it produces an agreement between agents. Terminal generations produce complete nodes because, after the agreement, the dialogue does not develop any more.

Description 11: Finished and complete dialogues

We say a dialogue is finished, when the number of moves that have been assigned to it, have been performed. We consider a dialogue to be complete when every one of the acts generated in a production has an outcome in O.

Description 12: Finite and infinite deliberation games

We name finite dialogues those, which can be completed in *n* number of moves. For example a finite 2-complete dialogue is the one that can be completed performing two moves. An infinite dialogue is the one that cannot be completed. For debates that last until they have found an agreement for every possibility, a finished debate is a complete debate. This is only possible for finite dialogues.

Description 13: Degree of a deliberation game

Degree of a dialogue deg(G) is the length of the shortest trajectory to reach an agreement.

Description 14: Depth of a deliberation game

Depth of a dialogue depth(G) is the length of the largest trajectory to reach an agreement. For infinite dialogues the depth of the dialogue is ∞.

Description 15: Monotonous / non-monotonous / undecidable deliberation dialogues

If there is a debate where the deg(G) = depth(G) then such debate is called monotonous. When deg(G) ≠ depth(G) then the debate is non-monotonous. A debate where deg(G) = depth(G) = ∞ is an undecidable debate.

3. *Example*

In this section, we introduce an example of debate. We do not establish a number of moves to compute, in a way that the dialogue will continue if there is any undefined result after every move.

We will study the basic features of the dialogue taking into account the concepts introduced above.

Example 1: Let's take $G = (\Theta, R, O, F)$, with:

- $\Theta \ (= \Theta(A_1) = \Theta(A_2)) = \{p, s, r, a, x\}$;

- $O = \{A, B, C\}$;

- $F = \{A_1 (x) \Rightarrow A, A_2 (x) \Rightarrow B, a \Rightarrow C\}$;

- $R = R_1 \cup R_2$ being:
    - $R(A_1) = \{p, s, r \to s, r \to x, p \to x\}$,
    - $R(A_2) = \{p \to x, p \to r, p \to a, s \to a, s \to p\}$.

The deliberation game resulting from this formalization is shown in Figure 1.
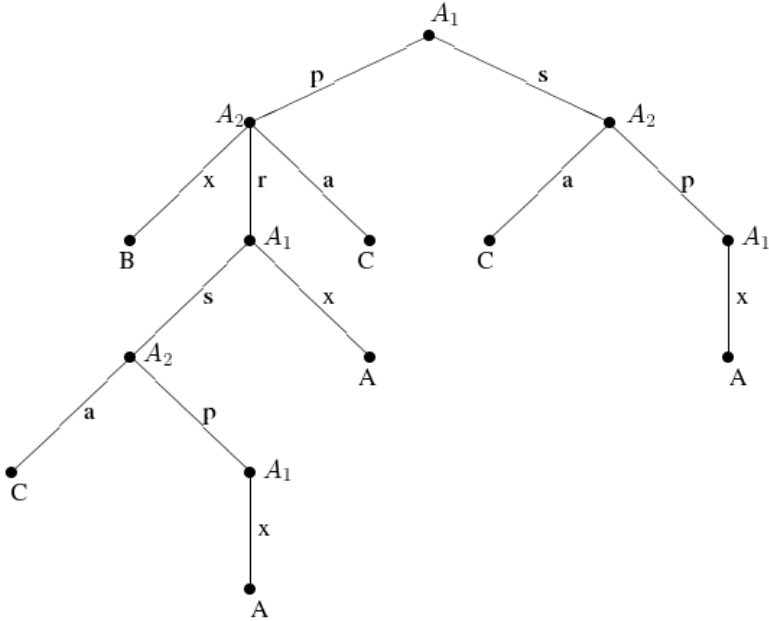
Figure 1: *Tree-diagram*

It is easy to see, observing the rules, that for A_1, the secret goal is B, and for A_2, the secret goal is A, since when A_1 quits the deliberation the result is A, and when A_2 quits the game the outcome is B.

Looking at the diagram we can say that this is a finite 3-complete dialogue. The debate consists of two paired moves and one unpaired move: $deg(G) = 2$ and $depth(G) = 5$. This is, then, a non-monotonous debate. The width of the dialogue, $width(G)$, is 7, being the trajectories G_1 (px), G_2 (prsa), G_3 (prspx), G_4 (prx), G_5 (pa), G_6 (sa), G_7 (spx). G_1, G_2, G_5, G_6 are paired trajectories, whereas G_3, G_4, G_7 are unpaired trajectories.

The productions generated after the first move are $\theta(M_1) = \{x, r, a, a, p\}$. $\Theta(M_1) = \theta(M_1)$. Applying F to this outcome we obtain the result of the deliberation after the first move, which is $g(M_1) = \{B, Ind, C, C, Ind\}$.

By means of the second move we obtain $\theta(M_2) = \{a, p, x, x\}$. $\Theta(M_2) = t(M_1) \cup \theta(M_2)$, being $g(M_2) = \{C, Ind, A, A\}$ and $G(M_2) = \{B, C, Ind, A, C, C, A\}$.

The third move is an unpaired one, because there is only one *Ind* node, and it is complete after one generation. Therefore $\theta(M_3) = \{x\}$. $\Theta(M_3) = t(M_1) \cup t(M_2) \cup \theta(M_3)$, being $g(M_3) = \{A\}$ and $G(M_3) = \{B, C, A, A, C, C, A\}$.

4. *Optimization Strategies*

The analysis of the formal properties of a dialogue must help the agents to calculate their possibilities to reach a good agreement. The example introduced in the last section can be a tool for introducing simple calculus of the probabilities of success.

As it has been already said, the secret goal of A_1 is B and the secret goal of A_2 is A. Even if both of the agents want to reach an agreement, they both have a clear order of preferences. For both agents, the first option is their preference, and the second the neutral agreement C. Finally, the last option is the preference of the opponent. Since the debate is complete, there is not the possibility of leaving the dialogue without a result. There are three possible results, O = {A, B, C}. Let's give a score for each one of them: 3 for the best option, 2 for the second, 1 for the worst. Table I shows the scores for agents A_1 and A_2.

	A	B	C
A_1	1	3	2
A_2	3	1	2

Table I: Scores

Formally, it can be said that $O(A_1)$={B, C, A}, $O(A_2)$={A, C, B}

With these scores for every result, two techniques can be implemented: horizontal scoring and branching scoring.

Description 16: Horizontal scoring

Horizontal scoring is the calculation of the possibilities of success for every agent by uttering each one of the possible speech acts in a given move.

Description 17: Branching scoring

Branching scoring is the calculation of the possibilities of final success in a trajectory of a deliberation game for every agent.

Let's take the perspective of A_1. After M_1, $g(M_1)$ = {B, Ind, C, C, Ind}. Applying the scores of Table 1, we obtain $g(M_1)$ = {3, 2, 2}. After M2 $g(M_2)$ = {C, Ind, A, A}, therefore $g(M_2)$ = {2, 1, 1}. Finally, after M_3 we obtain $g(M_3)$ = {A} and $g(M_3)$ = {1}. From these scores, and in a scale from 1 to 3, the average score for A1 if the dialogue finishes in the first move is 2,3. The average score if the dialogue does not finish in the first move and a second move is necessary, 1,3. Finally, if the debate does not finish with two moves and a third move is necessary, the score for A_2 will be just 1, this is, the minimal.

Let's take the perspective of A_2. If the debate finishes in the first move, then the average score for this agent will be $g(M_1)$ = {1, 2, 2}, which is 1.6. However, if the debate goes on, then we get $g(M_2)$ = {C, Ind, A, A}, which is $g(M_2)$ = {2, 3, 3}, this is an average of 2,6. Finally, if the game needs a third move, then the average for A_2 is the

best, because $g(M_3) = \{A\}$, and the score for A is 3 in A_2.

The outcome obtained by scoring the results in each move is shown in Table II.

	M_1	M_2	M_3
A_1	2,3	1,3	1
A_2	1,6	2,6	3

Table II: *Scores by moves*

Table II shows how, for A_1 the best option is to try to finish as soon as possible. However, the possibilities of obtaining a good agreement increase for A_2 when the debate lasts for more than one move.

It seems, then, that its first act should be s, because the shortest trajectories come from the right. However, this is not accurate. In the first move, A_1 has the possibility of finishing with a good result 2/3 on the left and 1/2 on the right. On the other hand, the only possibility to reach its secret goal is playing on the left.

In general A_1 has a 50% possibility of getting a good result starting on the right and 60% if starting on the left. A_1 has to try to start on the left and finish at the first move.

A_2 cannot choose the starting symbol, and it has to wait for A_1 in order to give its counter-arguments. If A_1 starts on the right, A_2 has an 83% possibility of success, whereas the percentage is 73% if A_1 starts with p.

Broadly speaking, A_1 prefers trajectories starting with p and A_2 prefers trajectories starting with s. But in all cases, it seems A_2 has more possibilities to "win" the debate.

The best trajectory for an agent is the shortest one with score 3. For A_1 the best trajectory is G_1. For A_2 the best ones are G_4 and G_7, but it has to prefer G_7 because starting with s it always achieves a good score.

But if we examine the trajectories and their possible accomplishments, we have the following: $G_1 = 1/6$, $G_2 = 1/24$, $G_3 = 1/24$, $G_4 = 1/12$, $G_5 = 1/6$, $G_6 = 1/4$, $G_7 = 1/4$.

5. *Discussion*

By means of the method introduced in this paper we intend to explore some mathematical properties of deliberation dialogues, and the possibilities that the agents have to achieve a good agreement.

By introducing this approach, we try to tackle dialogue, and especially deliberation, from a perspective that can help to:

- simulate argumentative processes in/with computers,
- explore some mathematical properties of argumentation and,
- introduce a method for the formalization of some problems in pragmatics of dialogue.

The system we present in this paper allows us to relate the behavior of the participants to pragmatics, especially to the context, to the behavior of the other agents, to the content of the utterances and to the secret intentions of the speakers. We think this method can be very useful to achieve an optimization of the arguments and counter-arguments produced in deliberation dialogues.

Since this is a first approach to the topic from the formal-computational perspective, the method is not very realistic, mainly because of three reasons: a) agents know everything about the other agents, they see all the time the general acts store, b) agents can change the strategy, but they cannot add new arguments to their stores, c) the final result of the dialogue can be calculated from the first move; it is deterministic. Therefore, in order to research this area more, we suggest performing the following improvements: a) the number of agents can be A>2, b) the agents can change strategies, add new acts to the stores and make new rules, c) agents can be blind, this is, they do not see the other agents' stores. With these new features, the method can make a small contribution to achieving real micro spaces of artificial intelligence, being more realistic and human inspired.

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